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STUDY OF COMPONENT TECHNOLOGIES FOR FUEL CELL ON-SITE INTEGRATED ENERGY SYSTEMS

Volume II-Appendices

W. David Lee, Siegfried Mathias
Arthur D. Little, Inc.

December 1980

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Under Contract DEN 3-121

for
U.S. DEPARTMENT OF ENERGY
Fossil Energy
Office of Coal Utilization
STUDY OF
COMPONENT TECHNOLOGIES FOR
FULL CELL ON-SITE
INTEGRATED ENERGY SYSTEMS

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INTRODUCTION

This data base catalogue was compiled in order to facilitate the analysis of various on-site integrated energy systems with fuel cell power plants. The catalogue is divided into two sections. The first characterizes individual components in terms of their performance profiles as a function of design parameters. The second characterizes total heating and cooling systems in terms of energy output as a function of input and control variables.

In the first section, data for each component are organized as follows:

1) Component Description

   This sheet contains the following information:

   a) Component Name
   b) Range of standard nominal sizes
   c) Average useful lifetime
   d) Physical dimensions of a representative size
   e) Standard operation conditions
   f) Parameter constraints limiting component operation

2) Component Cost

   Installed cost including overhead and profit are summarized for various component sizes. Component sizes considered are determined by the energy use profiles and design parameters for the two buildings studied.
Some components, such as terminal units, are fixed by building design loads. In such instances only the appropriate units are costed. In other instances, component size is a function of the total system configuration (e.g., compression chiller size is a function of chilled water storage and concurrent use of absorption machines). In such cases, a range of equipment size is costed. All costs are in 1978 dollars.

3) Performance Profiles

Variation of component capacity or efficiency is profiled against design and control parameters such as part load, fluid temperatures, flow rates, etc.

The second section analyzes energy systems used for heating, cooling and domestic hot water. Each system includes source of heating or cooling energy distribution components and terminal units. Design conditions are specified for the system, and energy demand for each component is specified as a function of the total system output. In addition, a control sheet is provided for each system to describe the intended energy flow control. Analysis of system input at other than design conditions can be accomplished as follows:

1) determine component energy demand under design conditions. 2) change individual component variables according to the control strategies given on the system control sheet. 3) alter component energy demand according to the profiles established in Section 1 of the catalogue.
1. Component Name: FUEL CELL

2. Available nominal size: 20 to 30KW

3. Useful life: 25

4. Physical Dimensions for 703KW (200 ton) component size:
   \[1.1 \text{ to } 1.3 \text{ ft}^2/\text{KW}\]

5. Standard Rating Conditions:

   Fuel Cell A  
   \[80 \text{ to } 140^\circ\text{F Return } 210^\circ\text{F delivery}\]

   Fuel Cell B  
   \[80 \text{ to } 140^\circ\text{F Return } 60 \text{ psig and } 160^\circ\text{F delivery}\]

   Fuel Cell C  
   \[120 \text{ to } 200^\circ\text{F Return } 60 \text{ psig delivery}\]

6. Parameter Constraints:

   Fuel Cell A  20 KW minimum size module

   Fuel Cell B  20 KW minimum size module

   Fuel Cell C  100 KW minimum size module

7. Unit Cost in 1978 Dollars:

   Fuel Cell A  = 420 $/KW^{.93}

   Fuel Cell B  = 615 $/KW^{.93}

   Fuel Cell C  = 463 $/KW^{.93}

   and $50 per KW for installation.
FIGURE 1A
POWERPLANT A ELECTRICAL EFFICIENCY

Percent of rated power

Percent of Fuel Lower Heating Value

Net AC power to bus

0 10 20 30 40

0 25 50 75 100
FIGURE 1B

POWER PLANT A HEAT RECOVERY EFFICIENCY

Percent of Fuel Lower Heating Value

0 - 10 - 20 - 30 - 40 - 50 -

0 - 25 - 50 - 75 - 100 -

80°F Return

Hot Water 210°F

140°F Return

Percent of Rated Power

Revised 8-22-79
FIGURE 2A
POWERPLANT B ELECTRICAL EFFICIENCY

Percent of Fuel Lower Heating Value

Percent of rated electric power

Net AC power to bus
FIGURE 2B
POWERPLANT B HIGH TEMPERATURE HEAT EFFICIENCY

Net Steam at 60 psig max

FIGURE 2C
POWERPLANT B LOW TEMPERATURE HEAT EFFICIENCY

Water at 160°F
80°F return
140°F return

Percent of rated power
FIGURE 3A
POWERPLANT C ELECTRICAL EFFICIENCY

Percent of Fuel Lower Heating Value vs. Percent of rated power

Net AC power to bus
FIGURE 1B
POWERPLANT C HEAT RECOVERY EFFICIENCY

Percent of rated power

Percent of fuel lower heating value

120°F Return

Net steam at 60 psig max

200°F Return
1. Component Name: CENTRIFUGAL CHILLERS

2. Available nominal size: 281KW to 7032KW (80 tons to 2000 tons)

3. Useful life: 20 years

4. Physical Dimensions for 703KW (200 ton) component size:
   8.8M x 2.8M x 2M (29' x 9' x 7') space required

5. Standard Rating Conditions:

   **Evaporator:**
   
   \[0.043 \text{ l/s per KW (2.4 gpm/ton) flow rate}\]
   
   6.7°C (44°F) Leaving water temperature
   
   12.2°C (54°F) Entering water temperature

   **Condenser:**
   
   \[0.054 \text{ l/s per KW (3 gpm/ton) flow rate}\]
   
   35°C (95°F) Leaving water temperature
   
   29.4°C (85°F) Entering water temperature
   
   Fouling Factor \[0.00009 \text{ M}^3\cdot\text{K}/\text{W} \ (0.0005 \text{ h} \cdot \text{ft}^2\cdot\text{F}/\text{BTU}\]

6. Parameter Constraints:

   A. Water flow rates between 1 M/s and 3.66 M/s
      (3 1/3 fps and 12 fps)
   
   B. Minimum load 10% full load
   
   C. Condenser water temperature range between
      1.7°C and 11.1°C (3°F and 20°F)
   
   D. Leaving evaporator water temperature between
      4.4°C and 10°C (40°F and 50°F)
## CENTRIFUGAL CHILLERS

### COST DATA

<table>
<thead>
<tr>
<th>Component Size in rated KW (tons)</th>
<th>Installed Cost*</th>
<th>Unit Cost in $/KW (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>352 (100)</td>
<td>$41,000</td>
<td>$117 ($470)</td>
</tr>
<tr>
<td>527 (150)</td>
<td>49,300</td>
<td>94 (330)</td>
</tr>
<tr>
<td>703 (200)</td>
<td>56,500</td>
<td>80 (282)</td>
</tr>
<tr>
<td>721 (250)</td>
<td>63,600</td>
<td>72 (214)</td>
</tr>
<tr>
<td>1054 (300)</td>
<td>67,300</td>
<td>64 (214)</td>
</tr>
<tr>
<td>1406 (400)</td>
<td>82,225</td>
<td>58 (205)</td>
</tr>
</tbody>
</table>

O&M as % installed cost = 7.5%

* Including overhead and profit.
### CENTRIFUGAL CHILLER

**INCREMENTAL INSTALLED COST VS. COP**

<table>
<thead>
<tr>
<th>Capital Cost</th>
<th>COP</th>
<th>KW/ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>$43,000</td>
<td>5.5</td>
<td>.64</td>
</tr>
<tr>
<td>37,500</td>
<td>4.6</td>
<td>.77</td>
</tr>
</tbody>
</table>

Incremental Capital Cost:

- $6000 increase per COP increase of 1
- ($4200 increase per .1 KW/ton power decrease)

Incremental Installed Cost:

- $8400 increase per COP increase of 1
- ($6000 increase per .1 KW/ton power decrease)

* These are representative numbers for a 700 KW (200 ton) unit.

† Applicable for range of COP from 4.2 to 5.6
CENTRIFUGAL CHILLER

CAPACITY AS A FUNCTION OF CONDENSER WATER FLOW

PERCENT BASE CONDENSER GPM

CORRECTION FACTOR

Base flow = 360PM/TON
# CENTRIFUGAL CHILLER

## CAPACITY VS. LEAVING CHILLED WATER TEMP. (LCWT)

(Leaving condenser water temperature 35°C (95°F))

<table>
<thead>
<tr>
<th>LCWT °C</th>
<th>LF °F</th>
<th>Average % Capacity increase over base*</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4</td>
<td>40°</td>
<td>-7</td>
</tr>
<tr>
<td>5.5</td>
<td>42°</td>
<td>-3</td>
</tr>
<tr>
<td>6.7</td>
<td>44°</td>
<td>0</td>
</tr>
<tr>
<td>7.8</td>
<td>46°</td>
<td>4</td>
</tr>
<tr>
<td>8.9</td>
<td>48°</td>
<td>7</td>
</tr>
<tr>
<td>10.0</td>
<td>50°</td>
<td>11</td>
</tr>
</tbody>
</table>

* Average values taken for 3 units of nominal capacity 200, 350 and 650 tons
COP VS. FOULING FACTOR
OF CONDENSER OR EVAPORATOR

![Graph showing COP vs. Fouling Factor](image)

FOULING FACTOR $\text{m}^2\cdot\text{kW} \ (\text{HR} \cdot \text{FT}^2 \cdot ^\circ\text{F}/\text{BTU})$

COP (% of Nominal)
1. Component Name: RECIPROCATING CHILLERS

2. Available nominal size: 35KW to 843KW (10 tons to 240 tons)

3. Useful life: 20 years

4. Physical Dimensions for 352KW (100 ton) component size:
   \(5M \times 2M \times 1.5M\) (17' x 6' x 5') space required

5. Standard Rating Conditions:

   **Evaporator:**
   - \(0.043 \text{ l/s per KW (2.4 gpm/ton) flow rate}\)
   - 6.7°C (44°F) Leaving water temperature
   - 12.2°C (54°F) Entering water temperature

   **Condenser:**
   - \(0.054 \text{ l/s per KW (3 gpm/ton) flow rate}\)
   - 35°C (95°F) Leaving water temperature
   - 29.4°C (85°F) Entering water temperature
   - Fouling Factor \(0.0009 \text{ M}^3\cdot\text{K/W (0.0005 h\cdot ft}^2\cdot\text{F/BTU)}\)

6. Parameter Constraints:

   A. Water flow rates between 1 M/s and 3.66 M/s (3 1/3 fps and 12 fps)

   B. Minimum load 10% full load

   C. Condenser water temperature range between 1.7°C and 11.1°C (3°F and 20°F)

   D. Leaving evaporator water temperature between 4.4°C and 10°C (40°F and 50°F)
## RECIPROCATING MILLER

### COST DATA

<table>
<thead>
<tr>
<th>Component Size in rated KW (tons)</th>
<th>Installed Cost*</th>
<th>Unit Cost In $/KW (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>88 (25)</td>
<td>$11,500</td>
<td>$131 ($460)</td>
</tr>
<tr>
<td>176 (50)</td>
<td>16,950</td>
<td>96 (339)</td>
</tr>
<tr>
<td>264 (75)</td>
<td>26,650</td>
<td>101 (355)</td>
</tr>
<tr>
<td>352 (100)</td>
<td>28,250</td>
<td>80 (282)</td>
</tr>
<tr>
<td>527 (150)</td>
<td>45,200</td>
<td>85 (300)</td>
</tr>
<tr>
<td>703 (200)</td>
<td>63,000</td>
<td>90 (315)</td>
</tr>
</tbody>
</table>

O&M as % installed cost = 6%

* Including overhead and profit
RECIPROCATING CHILLER

COP AND CAPACITY AT VARIOUS LEAVING CONDENSER AND LEAVING CHILLEd WATER TEMPERATURES

![Graph showing COP and capacity at various leaving condenser and leaving chilled water temperatures.](image-url)
RECIPIENT CHILLER

COP AT PART LOAD
FOR VARYING CAPACITY CONTROL

1. HOT GAS BYPASS
2. BACKPRESSURE VALVE
3. SUCTION VALVE-LIFT UNLOADING SINGLE COMPRESSOR
4. SUCTION VALVE-LIFT UNLOADING TWO COMPRESSORS
5. SUCTION VALVE-LIFT UNLOADING THREE COMPRESSORS
6. SUCTION VALVE-LIFT UNLOADING FOUR COMPRESSORS

ORIGINAL PAGE IS OF POOR QUALITY
**RECIPROCATING CHILLERS**

**COP AT PART LOAD**

Y = A + BX + CX^2 + DX^3

<table>
<thead>
<tr>
<th>Capacity Control</th>
<th>Range of (X)</th>
<th>Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>1. Hot Gas Bypass</td>
<td>20 &lt; x &lt; 100</td>
<td>-2.83</td>
</tr>
<tr>
<td>2. Back Pressure Valve</td>
<td>20 &lt; x &lt; 100</td>
<td>20.56</td>
</tr>
<tr>
<td>3. Cylinder-head Bypass, Single Compressor</td>
<td>25 &lt; x &lt; 100</td>
<td>56.14</td>
</tr>
<tr>
<td>4. Cylinder-Head Bypass, Two Compressors</td>
<td>15 &lt; x &lt; 100</td>
<td>37.5</td>
</tr>
<tr>
<td>5. Cylinder-Head Bypass, Three Compressors</td>
<td>10 &lt; x &lt; 100</td>
<td>92.28</td>
</tr>
<tr>
<td>6. Cylinder-Head Bypass, Four Compressors</td>
<td>10 &lt; x &lt; 100</td>
<td>105.72</td>
</tr>
</tbody>
</table>
## RECIPROCATING CHILLERS

### PART LOAD PERFORMANCE

<table>
<thead>
<tr>
<th>% Load</th>
<th>% COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>90</td>
<td>98</td>
</tr>
<tr>
<td>80</td>
<td>94</td>
</tr>
<tr>
<td>70</td>
<td>91</td>
</tr>
<tr>
<td>60</td>
<td>87</td>
</tr>
<tr>
<td>50</td>
<td>82</td>
</tr>
<tr>
<td>40</td>
<td>74</td>
</tr>
<tr>
<td>30</td>
<td>65</td>
</tr>
<tr>
<td>20</td>
<td>53</td>
</tr>
<tr>
<td>10</td>
<td>33</td>
</tr>
</tbody>
</table>
COP VS. FOULING FACTOR
OF CONDENSER OR EVAPORATOR

COP (% OF NOMINAL)

FOULING FACTOR km².K/W (H2 Ft² °F/BTU)
1. Component Name: ABSORPTION CHILLERS

2. Available nominal size: 10KW to 5837KW (3 tons to 1660 tons)

3. Useful life: 20 years

4. Physical Dimensions for 703KW (200 ton) component size:
   $8.5 \text{M} \times 3 \text{M} \times 2.5 \text{M}$ (28' x 10' x 8') space required

5. Standard Rating Conditions:
   A. $83 \text{ KPa (12 psig)}$ steam or 115.6°C (240°F) hot water at .050 1/s per KW (2.8 gpm/ton)
   B. 29.4°C (85°F) entering condenser water temperature
   C. .064 1/s per KW (3.6 gpm/ton) condenser water flow
   D. 6.7°C (44°F) leaving evaporator water temperature
   E. .043 1/s per KW (2.4 gpm/ton) evaporator water flow rate

6. Parameter Constraints:
   A. Leaving evaporator water temperature between 4.4°C and 10°C (40°F and 50°F)
   B. Entering condenser water temperature greater than 12.8°C (55°F)
   C. Maximum design load - 113% nominal
   D. Maximum operating capacity 140% nominal
   E. Maximum steam temperature 171.1°C (340°F)
   F. Maximum hot water temperature 132.2°C (270°F)
   G. Maximum evaporator flow 3 M/s (10 fps)
# Absorption Chillers

## Cost Data

Single Effect (18.7# Steam Per Ton-Hour)

<table>
<thead>
<tr>
<th>Component Size in rated KW (tons)</th>
<th>Installed Cost*</th>
<th>Unit Cost in $/KW (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>355 (101)</td>
<td>$60,000</td>
<td>$171 ($600)</td>
</tr>
<tr>
<td>454 (129)</td>
<td>59,500</td>
<td>131 (460)</td>
</tr>
<tr>
<td>612 (174)</td>
<td>67,500</td>
<td>110 (388)</td>
</tr>
<tr>
<td>802 (228)</td>
<td>76,280</td>
<td>95 (334)</td>
</tr>
<tr>
<td>1034 (294)</td>
<td>89,300</td>
<td>85 (300)</td>
</tr>
<tr>
<td>1353 (385)</td>
<td>106,500</td>
<td>78 (276)</td>
</tr>
<tr>
<td>88+ (25+)</td>
<td>22,125</td>
<td>252 (885)</td>
</tr>
</tbody>
</table>

Double Effect (12.0# Steam Per Ton-Hour)

<table>
<thead>
<tr>
<th>Component Size in rated KW (tons)</th>
<th>Installed Cost*</th>
<th>Unit Cost in $/KW (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1353 (385)</td>
<td>148,208</td>
<td>109 (385)</td>
</tr>
<tr>
<td>3730 (1060)</td>
<td>301,136</td>
<td>80 (284)</td>
</tr>
</tbody>
</table>

O&M as % installed cost = 4%

* Including overhead and profit (32%)

+ Arkla, Steam
COP VS. CONDENSER WATER TEMPERATURE

\[ \text{COP (\% of Nominal)} \]

\[ T_{\text{CHILLED WATER}} = 6.7^\circ \text{C (44^\circ \text{F})} \]

\[ T_{\text{CONDENSER WATER TEMPERATURE}} ^\circ \text{C} \]

\[ 10.5 \quad 8.8 \quad 8.4 \quad 9.5 \]
CAPACITY VS. CONDENSER WATER TEMPERATURE

(Same for Double/Single Effect)

INLET COOLING TOWER WATER TEMPERATURE

CHILLED WATER OUTLET TEMPERATURE

10°C (50°F)

6.7°C (44°F)

4.4°C (40°F)

70 90 110 120 130

CAPACITY (% OF NOMINAL)

(15) (30) (60) (90) °F

29.9°C 32.2°C
ABSORPTION CHILLER

performance at part load

COP (% of nominal)

90 80 70 60 50 40 30 20 10 0

% of design load

60 70 80 90 100

cooling water temperature

(°C)

150 (10.8)

75°C (20.5)

65°C (18.3)
ABSORPTION CHILLER

CAPACITY VS. STEAM SUPPLY PRESSURE

CHILLED WATER OUTLET TEMPERATURE

CAPACITY (% OF NOMINAL)

30 40 50 60 70 80 90 100 110 120

EQUIVALENT STEAM SUPPLY PRESSURE (% OF NOMINAL)

10°C (50°F)
6.7°C (44°F)
4.4°C (40°F)
ABSORPTION CHILLER

CAPACITY AND COP
VS. HOT WATER TEMPERATURE

ENTERING HOT WATER TEMPERATURE

[Graph showing capacity and COP vs. hot water temperature]
## CAPACITY vs. CHILLED WATER AND COOLING TOWER WATER TEMPERATURES

**Capacity as % of Nominal**

<table>
<thead>
<tr>
<th>Entering Cooling Water (Tower) Temperature (°F)</th>
<th>LEAVING CHILLED WATER TEMPERATURE °C (40)</th>
<th>(42)</th>
<th>(44)</th>
<th>(45)</th>
<th>(46)</th>
<th>(48)</th>
<th>(50)</th>
<th>(52)</th>
<th>(54)</th>
<th>(55)</th>
<th>(56)</th>
<th>(58)</th>
<th>(60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>4.4</td>
<td>5.5</td>
<td>6.7</td>
<td>7.2</td>
<td>7.8</td>
<td>8.9</td>
<td>10</td>
<td>11.1</td>
<td>12.2</td>
<td>12.8</td>
<td>13.3</td>
<td>14.4</td>
<td>15.6</td>
</tr>
<tr>
<td>18.3°C (65)</td>
<td>1.28</td>
<td>1.32</td>
<td>1.37</td>
<td>1.40</td>
<td>1.42</td>
<td>1.46</td>
<td>1.50</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>23.9°C (75)</td>
<td>1.13</td>
<td>1.19</td>
<td>1.26</td>
<td>1.29</td>
<td>1.32</td>
<td>1.38</td>
<td>1.44</td>
<td>1.47</td>
<td>1.50</td>
<td>1.52</td>
<td>1.53</td>
<td>1.56</td>
<td>1.59</td>
</tr>
<tr>
<td>26.7°C (80)</td>
<td>1.03</td>
<td>1.09</td>
<td>1.13</td>
<td>1.15</td>
<td>1.18</td>
<td>1.23</td>
<td>1.27</td>
<td>1.32</td>
<td>1.37</td>
<td>1.39</td>
<td>1.40</td>
<td>1.43</td>
<td>1.46</td>
</tr>
<tr>
<td>29.4°C (85)</td>
<td>0.90</td>
<td>0.95</td>
<td>1.00</td>
<td>1.02</td>
<td>1.05</td>
<td>1.10</td>
<td>1.14</td>
<td>1.19</td>
<td>1.23</td>
<td>1.25</td>
<td>1.26</td>
<td>1.30</td>
<td>1.33</td>
</tr>
<tr>
<td>32.2°C (90)</td>
<td>0.77</td>
<td>0.82</td>
<td>0.87</td>
<td>0.89</td>
<td>0.92</td>
<td>0.96</td>
<td>1.01</td>
<td>1.06</td>
<td>1.11</td>
<td>1.13</td>
<td>1.15</td>
<td>1.18</td>
<td>1.21</td>
</tr>
<tr>
<td>35.0°C (95)</td>
<td>0.60</td>
<td>0.61</td>
<td>0.71</td>
<td>0.74</td>
<td>0.76</td>
<td>0.81</td>
<td>0.86</td>
<td>0.90</td>
<td>0.94</td>
<td>0.96</td>
<td>0.98</td>
<td>1.01</td>
<td>1.04</td>
</tr>
</tbody>
</table>
## ABSORPTION CHILLER

### AUXILIARY ELECTRIC REQUIREMENTS FOR SINGLE EFFECT MACHINES

<table>
<thead>
<tr>
<th>KW out (Tonnage)</th>
<th>KW Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>355 (101)</td>
<td>3.8</td>
</tr>
<tr>
<td>394 (112)</td>
<td>3.8</td>
</tr>
<tr>
<td>454 (129)</td>
<td>4.2</td>
</tr>
<tr>
<td>520 (148)</td>
<td>4.2</td>
</tr>
<tr>
<td>612 (174)</td>
<td>5.1</td>
</tr>
<tr>
<td>802 (228)</td>
<td>5.8</td>
</tr>
<tr>
<td>1034 (294)</td>
<td>7.2</td>
</tr>
<tr>
<td>1245 (354)</td>
<td>7.5</td>
</tr>
<tr>
<td>1635 (465)</td>
<td>8.0</td>
</tr>
</tbody>
</table>

![Chart showing the relationship between KW output (Tonnage) and KW input.](chart.png)

32
AUXILIARY ELECTRIC REQUIREMENTS
FOR DOUBLE EFFECT MACHINES

POWER INPUT (KW)

NOMINAL CHILLER CAPACITY IN KW (TONS)
1. Component Name: COOLING TOWERS

2. Available nominal size: 10KW to 5625KW (3 tons to 1600 tons)

3. Useful life: Steel - 15 years

4. Physical Dimensions for 703KW (200 tons) component size:

   2M x 4.3M x 2.4M (7' x 14' x 8' high) space required

5. Standard Rating Conditions:

   0.54 l/s per KW* (3 gpm/ton) cooled from 35°C to 29.4°C at 25.6°C C.W.B. (95°F to 85°F at 78°F W.B.)

   * Cooling tower heat rejection = 1.25 KW per KW refrigeration (15,000 BTUH/ton)

6. Parameter Conditions:

   Freeze protection needed to operate below 0°C W.B. (32°F W.B.)
**COOLING TOWERS**

**COST DATA**

<table>
<thead>
<tr>
<th>Component Size in rated KW (tons)</th>
<th>Installed Cost*</th>
<th>Unit Cost in $/KW (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>440 (125)</td>
<td>$ 9,900</td>
<td>$ 23 ($79)</td>
</tr>
<tr>
<td>703 (200)</td>
<td>13,900</td>
<td>20 (70)</td>
</tr>
<tr>
<td>1143 (325)</td>
<td>21,300</td>
<td>19 (66)</td>
</tr>
<tr>
<td>1406 (400)</td>
<td>25,000</td>
<td>18 (62)</td>
</tr>
<tr>
<td>1582 (450)</td>
<td>27,000</td>
<td>17 (60)</td>
</tr>
<tr>
<td>2110 (600)</td>
<td>39,300</td>
<td>18 (65)</td>
</tr>
</tbody>
</table>

O&M as % installed cost = 15%

* Including overhead and profit
## COOLING TOWERS

### POWER CONSUMPTION vs. RATED FLOW

**Rated size in l/s (gpm) for 35°C/29.4°C (95°F/85°F) condenser water and 25.6°C CWB (78°F FWB)**

<table>
<thead>
<tr>
<th>Fan KW (hp)</th>
<th>Rated size in l/s (gpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.7 (5)</td>
<td>18.9 (300)</td>
</tr>
<tr>
<td>5.6 (7.5)</td>
<td>23.7 (375)</td>
</tr>
<tr>
<td>5.6 (7.5)</td>
<td>28.4 (450)</td>
</tr>
<tr>
<td>5.6 (7.5)</td>
<td>33.1 (525)</td>
</tr>
<tr>
<td>7.5 (10)</td>
<td>37.9 (600)</td>
</tr>
<tr>
<td>7.5 (10)</td>
<td>47.3 (750)</td>
</tr>
<tr>
<td>11.2 (15)</td>
<td>52.1 (825)</td>
</tr>
<tr>
<td>11.2 (15)</td>
<td>56.8 (900)</td>
</tr>
<tr>
<td>11.2 (15)</td>
<td>61.5 (975)</td>
</tr>
<tr>
<td>11.2 (15)</td>
<td>66.3 (1050)</td>
</tr>
<tr>
<td>14.9 (20)</td>
<td>71.0 (1125)</td>
</tr>
<tr>
<td>14.9 (20)</td>
<td>75.7 (1200)</td>
</tr>
<tr>
<td>14.9 (20)</td>
<td>80.5 (1275)</td>
</tr>
<tr>
<td>14.9 (20)</td>
<td>85.2 (1350)</td>
</tr>
<tr>
<td>18.6 (25)</td>
<td>89.9 (1490)</td>
</tr>
<tr>
<td>18.6 (25)</td>
<td>94.7 (1500)</td>
</tr>
</tbody>
</table>

**Summary Power Consumption:**

1. At rated conditions average KW/l/s = 11.8) (Avg. hp/gpm = .017)

2. At 23.3°C WB (74°F WB) and 35°C/29.4°C (95°F/85°F) Average KW/l/s = 8.7 (Avg. hp/gpm = .013)

3. At 23.3°C WB (74°F WB) and 39.4°C/29.4°C (103°F/85°F) Average kw/l/s = 9.5 (Avg. hp/gpm = .014)
COOLING TOWERS

LEAVING COOLING TOWER WATER AS A FUNCTION OF LOAD AND AMBIENT WET BULB TEMPERATURE

1. Part Load:
   A. Percent decrease in load = Percent decrease in approach.
   B. Leaving cooling tower water temperature = design cooling tower water temperature minus (percent decrease in load x design approach).

2. Reduced ambient temperature:
   A. .56°F.W.B (1°F.W.B) decrease in wet bulb temperature results in .37°C (.67°F) leaving cooling tower water temperature.
   B. Leaving cooling tower water temperature = design cooling tower water temperature minus \[ (.37 \times \text{ambient wet bulb temperature reduction}) \].
1. Component Name: HOT WATER BOILERS - PACKAGED
2. Available nominal size: 10KW to 20,000KW
3. Useful life: 20 years
4. Physical Dimensions for 980KW (100Bhp) component size: 4.3M x 1.8M x 2M (14' x 6' x 7') space required
5. Standard Rating Conditions:
   I = B = R for cast iron oil fired
   1) 10% CO₂ in the flue gas
   2) Not more than No. 2 Shell Smoke Scale Reading
   3) Flue gas temperature at Gross Output less than 316°C (600°F)
   4) Draft loss through boiler must not exceed specified values
   5) Minimum overall efficiency not less than 70%
6. Parameter Constraints:
   121.1°C (250°F) maximum water temperature
## HOT WATER BOILERS

### COST DATA

<table>
<thead>
<tr>
<th>Component Size in rated KW (MBH) out</th>
<th>Installed Cost*</th>
<th>Unit Cost in $/KW (MBH) out</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 (240)</td>
<td>$2000</td>
<td>$28.70 ($8.40)</td>
</tr>
<tr>
<td>117 (400)</td>
<td>3340</td>
<td>28.70 (8.40)</td>
</tr>
<tr>
<td>176 (600)</td>
<td>4650</td>
<td>26.60 (7.80)</td>
</tr>
<tr>
<td>234 (800)</td>
<td>5730</td>
<td>24.40 (7.16)</td>
</tr>
<tr>
<td>352 (1200)</td>
<td>8456</td>
<td>23.90 (7.0)</td>
</tr>
<tr>
<td>469 (1600)</td>
<td>10,600</td>
<td>22.50 (6.6)</td>
</tr>
</tbody>
</table>

O&M as % installed cost = 5%

* Including overhead and profit
Efficiency VS. Load
BOILER - ELECTRIC (HIGH VOLTAGE)

EFFICIENCY AT PART LOAD

*DEPENDENT UPON INSTALLATION HEAT LOSSES
BOILER - GAS/OIL

AUXILIARY ELECTRIC INPUTS*

* AUXILIARY ELECTRIC POWER REQUIRED BY PUMP, FUEL PUMP, AND AIR PUMP FOR FIRE TUBE BOILERS
1. Component Name: WATER-WATER HEAT PUMP (TEHLIFIER)

2. Available nominal size: 15KW to 220KW (50MBH to 750MBH)

3. Useful life: 15 years

4. Physical Dimensions for 73KW (250MBH) component size:
   2.7M x .9M x 1.2M (9' x 3' x 4') space required

5. Standard Rating Conditions:
   None

6. Parameter Constraints:
   Maximum leaving hot water temperature 104.4°C (220°F)
### WATER-WATER HEAT PUMP (TEMPLIFIER)

#### COST DATA

<table>
<thead>
<tr>
<th>Component Size in rated KW (MBH)</th>
<th>Installed Cost</th>
<th>O&amp;M as % installed cost = 5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>66 (224)</td>
<td>$14,500</td>
<td></td>
</tr>
<tr>
<td>86 (294)</td>
<td>15,600</td>
<td></td>
</tr>
<tr>
<td>110 (374)</td>
<td>17,200</td>
<td></td>
</tr>
<tr>
<td>164 (561)</td>
<td>20,520</td>
<td></td>
</tr>
<tr>
<td>196 (668)</td>
<td>24,300</td>
<td></td>
</tr>
<tr>
<td>219 (748)</td>
<td>25,200</td>
<td></td>
</tr>
</tbody>
</table>

* Including overhead and profit
### COP vs. INLET AND OUTLET WATER TEMPERATURES

<table>
<thead>
<tr>
<th>Leaving Source Water Temp. °C (°F)</th>
<th>LEAVING HOT WATER TEMP. °C (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>43.3</td>
</tr>
<tr>
<td>51.7 (125)</td>
<td>--</td>
</tr>
<tr>
<td>48.9 (120)</td>
<td>--</td>
</tr>
<tr>
<td>46.1 (115)</td>
<td>--</td>
</tr>
<tr>
<td>43.3 (110)</td>
<td>--</td>
</tr>
<tr>
<td>40.6 (105)</td>
<td>--</td>
</tr>
<tr>
<td>37.8 (100)</td>
<td>--</td>
</tr>
<tr>
<td>35.0 (95)</td>
<td>--</td>
</tr>
<tr>
<td>32.2 (90)</td>
<td>--</td>
</tr>
<tr>
<td>29.4 (85)</td>
<td>5.67</td>
</tr>
<tr>
<td>26.7 (80)</td>
<td>5.43</td>
</tr>
</tbody>
</table>
1. Component Name: DOMESTIC HOT WATER BOILERS - PACKAGED

2. Available nominal size: 114 to 379 (30 gal to 100 gal)

3. Useful life: 7 years

4. Physical Dimensions for 303 (80 gal) component size:
   
   .74M diameter x 1.6M high (29" diameter x 63" high)
   space required

5. Standard Rating Conditions:
   AGA

6. Parameter Constraints:
   
   121.1°C (250°F) Maximum water temperature
DOMESTIC HOT WATER BOILER

COST DATA

<table>
<thead>
<tr>
<th>Component Size in rated (gal)</th>
<th>Installed Cost*</th>
</tr>
</thead>
<tbody>
<tr>
<td>284 (75)</td>
<td>$ 650</td>
</tr>
<tr>
<td>3786 (1000)</td>
<td>15,000</td>
</tr>
<tr>
<td>7572 (2000)</td>
<td>16,500</td>
</tr>
</tbody>
</table>

O&M as % installed cost = 5%

* Including overhead and profit
DOMESTIC HOT WATER - GAS BOILER

EFFICIENCY VS. CONSUMPTION AND TEMPERATURE

* THROUGH 90°F TEMPERATURE
** INSULATION THICKNESS 3/8"
DOMESTIC HOT WATER - ELECTRIC BOILER

EFFICIENCY AS A FUNCTION OF CONSUMPTION AND TEMPERATURE

![Graph showing efficiency as a function of hot water consumption and temperature.]

Example labels on the graph:
- Hot water consumption (GAL./DAY)
- Appliance efficiency (%)
- Hot water temperatures:
  - 45.0°C (110°F)
  - 65.0°C (150°F)
  - 77.6°C (170°F)
  - 85.6°C (185°F)

Legend:
- As-received
- Extra insulation
- Pre-received
1. Component Name: WATER TO WATER HEAT EXCHANGER

2. Nominal sizes: 91.7 W/°C to 4745 W/°C (174 BTU/HR °F) to 9000 BTU/HR °F

3. Useful life: 20 years

4. Physical Dimensions for 2025W/°C:
   \[0.34\text{M} \times 0.064\text{M} \times 0.087\text{M}\]
   \[(13.4 \text{ IN} \times 2.5 \text{ IN} \times 3.44 \text{ IN)}\]

5. Standard Rating Conditions
   
   A. 60°C (140°F) outlet cold water temperature
   B. 21°C (70°F) inlet cold water temperature
   C. 60°C (140°F) outlet hot water temperature
   D. 82°C (180°F) inlet hot water temperature

6. Parameter Constraints
   
   A. Entering hot water temperature must be between 0°C and lower than 100°C (32°F to 212°F)
   B. Entering cold water temperature must be between 0°C and 100°C

7. Performance Rating:

   Known Parameters:

   UA - The overall heat transfer-area product of the heat exchanger.

   \(T_{CIN}\) - Inlet cold side temperature.

   \(T_{COUT}\) - Outlet cold side temperature.

   \(T_{HIN}\) - Inlet hot side temperature.

   \(T_{HOMIN}\) - Maximum outlet hot side temperature.

   \(M_{UMAX}\) - Maximum mass flow rate on the cold side.
Unknown Parameters:

\( M_{\text{COLD}} \) - Mass flow rate on the cold side.

\( M_{\text{HOT}} \) - Mass flow rate on the hot side.

\( Q \) - Heat transferred by the heat exchanger.

\( T_{\text{HOUT}} \) - Outlet hot side temperature.

The following equations are solved simultaneously to calculate the unknown parameters:

Equation for a heat exchanger:

\[
Q = UA \Delta T_{LM}
\]

Where:

\[
\Delta T_{LM} = \frac{(T_{\text{HOUT}} - T_{\text{CIN}}) - (T_{\text{HIN}} - T_{\text{COUT}})}{\ln\left[\left(T_{\text{HOUT}} - T_{\text{CIN}}\right)/\left(T_{\text{HIN}} - T_{\text{COUT}}\right)\right]}
\]

Energy Balance:

\[
Q = M_{\text{COLD}} (T_{\text{COUT}} - T_{\text{CIN}})
\]

\[
Q = M_{\text{HOT}} (T_{\text{HIN}} - T_{\text{HOUT}})
\]

User Constraints:

The user sets the cold side mass flow rate equal to the maximum mass flow rate on the cold side, i.e.,

\[
M_{\text{COLD}} = M_{\text{CMAX}}
\]

There are now 3 equations and 3 unknowns. The user solves for the unknown parameters and if:

\[
T_{\text{HOUT}} < T_{\text{HOMAX}}
\]

The user is finished.

If \( T_{\text{HOUT}} > T_{\text{HOMAX}} \), which implies the heat exchanger is too small to handle the maximum mass flow rate on the cold side, the user sets:

\[
T_{\text{HOUT}} = T_{\text{HOMAX}}
\]

and solves for \( M_{\text{COLD}} \), \( M_{\text{HOT}} \) and \( Q \) with the 3 equations.
### WATER TO WATER HEAT EXCHANGER

#### COST DATA

Component Size in Overall Heat Transfer Coefficient

<table>
<thead>
<tr>
<th>W/°C</th>
<th>Times Area</th>
<th>(BTU/HR-°F)</th>
<th>Installed Cost*</th>
</tr>
</thead>
<tbody>
<tr>
<td>91.7</td>
<td>174</td>
<td></td>
<td>131</td>
</tr>
<tr>
<td>633</td>
<td>1200</td>
<td></td>
<td>374</td>
</tr>
<tr>
<td>2025</td>
<td>3840</td>
<td></td>
<td>749</td>
</tr>
<tr>
<td>4745</td>
<td>9000</td>
<td></td>
<td>1324</td>
</tr>
</tbody>
</table>

*O&M as % installed cost = %

*Including overhead and profit
1. Component Name: STEAM/WATER HEAT EXCHANGE

2. Nominal Sizes: 1500W/K to 6500W/K (2888 BTU/HR °F to 12300 BTU/HR°F)

3. Useful Life: 20 years

4. Physical Dimensions for 1500W/°C:
   
   0.9M x 0.17M x 0.138M
   
   (35.5 IN x 6.72 IN x 5.44 IN)

5. Standard Rating Conditions:
   
   A. 446KPA (50PSIG) steam
   B. 10°C (50°F) entering cold water temperature
   C. 44°C (80°F) cold water temperature rise

6. Parameter Constraints:
   
   A. Entering steam between 100 and 110KPA (0 and 150 PSIG)
   B. Entering water temperature between 0 and 100°C (32 and 212°F)

7. Performance Rating:

   Known Parameters:
   
   UA - The overall heat transfer-area product of the heat exchanger.
   TSTM - The temperature of the steam.
   TCOUT - Outlet cold side temperature.
   TCIN - Inlet cold side temperature.
   HFGSTM - Heat of condensation of the steam.

   Unknown Parameters:
   
   M_COLD - Mass flow rate on the cold side.
   M_HOT - Mass flow rate on the hot side.
Q - Maximum heat transfer possible by the heat exchanger.

The following equations are solved simultaneously to calculate the unknown parameters:

Equation for a heat exchanger:

\[ Q = UA \Delta T_{LM} \]

Where:

\[ \Delta T_{LM} = \frac{T_{COUT} - T_{CIN}}{\ln\left(\frac{T_{STM} - T_{CIN}}{T_{STM} - T_{COUT}}\right)} \]

\[ Q = M_{COLD} (T_{COUT} - T_{CIN}) \]

\[ Q = M_{HOT} \times H_{FGSTM} \]

The user will find that if the steam condensate is not allowed to subcool, the heat exchanger can only be operated at full capacity. In practice, we allow the condensate to subcool (but do not calculate the subcooling since the additional heat is negligible compared to the heat of vaporization) which permits operation of the heat exchanger from zero to full capacity. Given the rate of cold water heating required, the mass of steam needed is:

\[ M_{HOT} = \frac{M_{COLD} (T_{COUT} - T_{CIN})}{H_{FGSTM}} \]

Provided we do not exceed the heat exchanger's maximum rate as calculated previously.
### STEAM/WATER HEAT EXCHANGER

#### COST DATA

<table>
<thead>
<tr>
<th>Component Size in Overall Heat Transfer Coefficient</th>
<th>Installed Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Times Area</td>
<td></td>
</tr>
<tr>
<td><strong>W/°C</strong> (BTU/HR°F)</td>
<td></td>
</tr>
<tr>
<td>1522 (2888)</td>
<td>1025</td>
</tr>
<tr>
<td>3696 (7010)</td>
<td>1070</td>
</tr>
<tr>
<td>6462 (12260)</td>
<td>1196</td>
</tr>
</tbody>
</table>

O&M Costs as a % of installed costs =

* Including overhead and profit.*
1. Component Name:  FAN COIL UNITS

2. Available nominal size:  1.76KW to 10.5KW (.5 tons to 3 tons)

3. Useful life:  20 years

4. Physical Dimensions for .15 M³/s (300 CFM) component size:
   1.5M x .3M x .76M (5' x 1' x (2.5' high)) space required

5. Standard Rating Conditions at nominal CFM

   Cooling:
   (25.6° C.D.B./18.3° C.W.B. or 26.7° C.D.B./19.4° C.W.B.)
   (78° F.D.B./ 65° F.W.B. or 80° F.D.B./67° F.W.B.) entering air temperature
   7.2°C (45°F) entering chilled water temperature
   5.5°C (10°F) chilled water temperature rise

   Heating:
   21.1°C.D.B. (70° F.D.B.) entering air temperature
   82.2°C (180°F) entering water temperature
   Water flow rate as specified by cooling

6. Parameter Constraints

   Minimum chilled water flow = .032 l/s (.5gpm)
FAN COIL UNITS

COST DATA

<table>
<thead>
<tr>
<th>Component Size in rated M³/s (CFM)</th>
<th>Installed Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>.14 (300)</td>
<td>$340</td>
</tr>
<tr>
<td>.28 (600)</td>
<td>430</td>
</tr>
</tbody>
</table>

O&M as % installed cost = 10%

* Including overhead and profit
FAN COIL UNITS

HEATING CAPACITY vs. ENTERING WATER TEMPERATURE AND ENTERING AIR TEMPERATURE

\[ H = 0.00972 \frac{H_o (9 \times \text{ITD})^*}{5} \times 0.98571 \]

<table>
<thead>
<tr>
<th>Ent. Air °C (°F)</th>
<th>37.8 (100°F)</th>
<th>43.3 (110°F)</th>
<th>48.8 (120°F)</th>
<th>54.4 (130°F)</th>
<th>60 (140°F)</th>
<th>65.6 (150°F)</th>
<th>71.1 (160°F)</th>
<th>76.7 (170°F)</th>
<th>82.2 (180°F)</th>
<th>87.8 (190°F)</th>
<th>93.3 (200°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 (50)</td>
<td>0.46</td>
<td>0.55</td>
<td>0.64</td>
<td>0.73</td>
<td>0.82</td>
<td>0.91</td>
<td>1.00</td>
<td>1.09</td>
<td>1.18</td>
<td>1.27</td>
<td>1.16</td>
</tr>
<tr>
<td>12.8 (55)</td>
<td>0.41</td>
<td>0.50</td>
<td>0.59</td>
<td>0.68</td>
<td>0.77</td>
<td>0.86</td>
<td>0.96</td>
<td>1.05</td>
<td>1.14</td>
<td>1.23</td>
<td>1.32</td>
</tr>
<tr>
<td>15.6 (60)</td>
<td>0.36</td>
<td>0.46</td>
<td>0.55</td>
<td>0.64</td>
<td>0.73</td>
<td>0.82</td>
<td>0.91</td>
<td>1.00</td>
<td>1.09</td>
<td>1.18</td>
<td>1.27</td>
</tr>
<tr>
<td>18.3 (65)</td>
<td>0.32</td>
<td>0.41</td>
<td>0.50</td>
<td>0.59</td>
<td>0.68</td>
<td>0.77</td>
<td>0.86</td>
<td>0.96</td>
<td>1.05</td>
<td>1.14</td>
<td>1.23</td>
</tr>
<tr>
<td>21.1 (70)</td>
<td>0.27</td>
<td>0.36</td>
<td>0.46</td>
<td>0.55</td>
<td>0.64</td>
<td>0.73</td>
<td>0.82</td>
<td>0.91</td>
<td>1.00</td>
<td>1.09</td>
<td>1.18</td>
</tr>
<tr>
<td>23.9 (75)</td>
<td>0.23</td>
<td>0.32</td>
<td>0.41</td>
<td>0.50</td>
<td>0.59</td>
<td>0.68</td>
<td>0.77</td>
<td>0.86</td>
<td>0.96</td>
<td>1.05</td>
<td>1.14</td>
</tr>
<tr>
<td>26.7 (80)</td>
<td>0.18</td>
<td>0.27</td>
<td>0.36</td>
<td>0.46</td>
<td>0.55</td>
<td>0.64</td>
<td>0.73</td>
<td>0.82</td>
<td>0.91</td>
<td>1.00</td>
<td>1.09</td>
</tr>
</tbody>
</table>

\[ H = \text{capacity at given conditions} \]

\[ H_o = \text{rated capacity at } 82.2^\circ \text{C} (180^\circ \text{F}) \text{ EWT} \]
\[ 21.1^\circ \text{C} (70^\circ \text{F}) \text{ EAT} \]

\[ \text{ITD} = \text{EWT} - \text{EAT} \text{ in degree C} \]
1. Component Name: AIR HANDLING UNIT

2. Available nominal size: 0.3 m$^3$/s to 31 m$^3$/s (600 CFM to 65,000 CFM)

3. Useful life: 20 years

4. Physical Dimensions for 19 m$^3$/s (40,000 CFM) component size:

   3.7 m x 4.9 m x 3.7 m (12' x 16' x 12') space required

5. Standard Rating Conditions:

   **Cooling**:

   (25.6°C D.B./18.3°C W.B. or 26.7°C D.B./19.4°C W.B.)
   (78°F D.B./65°F W.B. or 80°F D.B./67°F W.B.) entering air temperature

   7.2°C (45°F) entering chilled water temperature

   5.5°C (10°F) chilled water temperature rise

   **Heating**

   21.1°C W.B./70°F D.B. entering air temperature

   82.2°C (180°F) entering water temperature

   Water flow rate as specified by cooling

6. Parameter Constraints

   Maximum water velocity in coils 2.3 m/s (7.5 fps)

   Maximum face velocity across coils 3.6 m/s (700 fps)

   outlet velocity
## COST DATA

<table>
<thead>
<tr>
<th>Component Size</th>
<th>40,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>in rated CFM</td>
<td></td>
</tr>
<tr>
<td>a) Fan &amp; Housing</td>
<td>$20,240</td>
</tr>
<tr>
<td>b) heating coils</td>
<td>3,900</td>
</tr>
<tr>
<td>c) cooling coils</td>
<td>10,250</td>
</tr>
</tbody>
</table>

O&M as % installed cost = 5%

* Including overhead and profit*
AIR HANDLING UNIT

FAN POWER REQUIREMENT vs. ENTERING WATER TEMPERATURE AND FLOW RATE

1. Power correction factor for various water temperatures at a flow rate of 8.52 l/s (135 gpm).

<table>
<thead>
<tr>
<th>°C</th>
<th>°F</th>
<th>% FAN ON TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>140</td>
<td>3/31 = 0.097</td>
</tr>
<tr>
<td>54.4</td>
<td>130</td>
<td>3/27 = 0.111</td>
</tr>
<tr>
<td>48.9</td>
<td>120</td>
<td>3/22 = 0.136</td>
</tr>
<tr>
<td>43.3</td>
<td>110</td>
<td>3/19 = 0.158</td>
</tr>
<tr>
<td>37.8</td>
<td>100</td>
<td>3/15 = 0.20</td>
</tr>
</tbody>
</table>

2. Power correction factor for various flow rates.

<table>
<thead>
<tr>
<th>M/S (fps)</th>
<th>1/s (GPM)</th>
<th>C.F.</th>
<th>Nominalized to .9M/s (3 fps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3 (7½)</td>
<td>8.5 (135)</td>
<td>1</td>
<td>.88</td>
</tr>
<tr>
<td>2.1 (7)</td>
<td>8.0 (127)</td>
<td>1</td>
<td>.88</td>
</tr>
<tr>
<td>1.8 (6)</td>
<td>6.8 (108)</td>
<td>1.025</td>
<td>.90</td>
</tr>
<tr>
<td>1.5 (5)</td>
<td>5.7 (90)</td>
<td>1.05</td>
<td>.92</td>
</tr>
<tr>
<td>1.2 (4)</td>
<td>4.5 (72)</td>
<td>1.09</td>
<td>.96</td>
</tr>
<tr>
<td>.9 (3)</td>
<td>3.4 (54)</td>
<td>1.14</td>
<td>1</td>
</tr>
<tr>
<td>.6 (2)</td>
<td>2.3 (36)</td>
<td>1.26</td>
<td>1.11</td>
</tr>
<tr>
<td>.3 (1)</td>
<td>1.1 (18)</td>
<td>1.64</td>
<td>1.40</td>
</tr>
</tbody>
</table>

+ Fan is on 100% time for cooling mode.
1. Component Name: CABINET UNIT HEATERS

2. Available nominal size: 3KW to 73KW (10MBH to 250MBH)

3. Useful life: 20 years

4. Physical Dimensions for 29.3KW (100MBH) component size:
   \(1.5\text{M} \times 0.3\text{M} \times 0.76\text{M} \ (5' \times 1' \times (2.5' \text{ high}))\) space required

5. Standard Conditions:
   - 93.3°C (200°F) entering water temperature
   - 11.1°C (20°F) water temperature drop
   - 15.6°C or 21.1°C (60°F or 70°F) entering air temperature

6. Parameter Constraints:
   - Minimum flow rate = 0.15 M/s (0.5 ft/sec)
## COST DATA

<table>
<thead>
<tr>
<th>Component Size in rated KW (MBH)</th>
<th>Installed Cost*</th>
<th>Unit Cost in $/KW (MBH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.9 (20)</td>
<td>$400</td>
<td>$68 ($20)</td>
</tr>
<tr>
<td>11.7 (40)</td>
<td>520</td>
<td>44 (13)</td>
</tr>
<tr>
<td>17.6 (60)</td>
<td>640</td>
<td>38 (11)</td>
</tr>
<tr>
<td>23.4 (80)</td>
<td>760</td>
<td>32 (9.5)</td>
</tr>
<tr>
<td>29.3 (100)</td>
<td>950</td>
<td>32 (9.5)</td>
</tr>
</tbody>
</table>

O&M as % installed cost = 2%

* Including overhead and profit
UNIT HEATERS/CABINET

CAPACITY AS A FUNCTION OF ENTERING AIR TEMPERATURE AND ENTERING WATER TEMPERATURE

\[ H = H_o \times 0.00835^* \times (\frac{9}{5} \Delta t) \]

\( H_o \) normalized to 15.6°C (60°F) EAT, and 82.2°C (180°F) EWT

\[
\begin{array}{cccccccccccccccc}
\text{ENTERING WATER TEMPERATURE} & & & & & & & & & & & & & & & & \\
& ^{\circ}C & (^{\circ}F) & & & & & & & & & & & & & & \\
\text{Ent.} & \text{Air Temp.} & 35 & 37.8 & 43.3 & 48.9 & 54.4 & 60.0 & 65.6 & 71.1 & 76.7 & 82.2 & 87.8 & 93.3 & 98.9 & 104.4 \\
\hline
\text{Temp.} & ^{\circ}C (^{\circ}F) & (95) & (100) & (110) & (120) & (130) & (140) & (150) & (160) & (170) & (180) & (190) & (200) & (210) & (220) \\
\hline
4.4 & (40) & .458 & .500 & .583 & .666 & .75 & .833 & .917 & 1.00 & 1.08 & 1.16 & 1.25 & 1.33 & 1.42 & 1.50 \\
10.0 & (50) & .375 & .417 & .500 & .583 & .666 & .75 & .835 & .917 & 1.00 & 1.08 & 1.16 & 1.25 & 1.33 & 1.42 \\
15.6 & (60) & .292 & .333 & .417 & .500 & .583 & .666 & .750 & .835 & .917 & 1.00 & 1.08 & 1.16 & 1.25 & 1.33 \\
21.1 & (70) & .208 & .250 & .333 & .417 & .500 & .583 & .666 & .750 & .835 & .917 & 1.00 & 1.08 & 1.16 & 1.25 \\
26.7 & (80) & .125 & .167 & .250 & .333 & .417 & .500 & .583 & .666 & .750 & .835 & .917 & 1.00 & 1.08 & 1.16 \\
\end{array}
\]

\* \( H = H_o \times 0.0092 \times \frac{9}{5} \times \Delta T \) if rated at 21.1°C (70°F) EAT, and 82.2°C (180°F) EWT
UNIT HEATERS/CABINET

CAPACITY AND FRICTION HEAD vs. FLOW RATE

PRESSURE LOSS AND HEATING CAPACITY FACTORS FOR VARIOUS RATES OF WATER FLOW

<table>
<thead>
<tr>
<th>% OF RATED WATER FLOW</th>
<th>25</th>
<th>50</th>
<th>75</th>
<th>100</th>
<th>125</th>
<th>150</th>
<th>175</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friction Head Factor</td>
<td>.085</td>
<td>.254</td>
<td>.575</td>
<td>1.00</td>
<td>2.18</td>
<td>2.32</td>
<td>3.85</td>
</tr>
<tr>
<td>Heating Capacity Factor</td>
<td>.80</td>
<td>.89</td>
<td>.96</td>
<td>1.00</td>
<td>1.04</td>
<td>1.07</td>
<td>1.10</td>
</tr>
</tbody>
</table>

CAP = CAP_o \left( \frac{\% \text{ rated flow}}{100} \right)^{.17}

where \ CAP_o = \text{Capacity at rated flow}
UNIT HEATERS/CABINET

CAPACITY VS. AIR FLOW

CAPACITY VARIATION WITH AIRFLOW
0.94 - 2.0 M/s (200-600 CFM)

% OF FREE FLOW CAPACITY

UNIT SIZES 02-06

% OF RATED FREE FLOW

CAPACITY VARIATION WITH AIRFLOW
0.98 - 8.0 M/s (800-1800 CFM)

UNIT SIZES 08-10
1. Component Name: **THERMAL STORAGE TANK**

2. Available Nominal Sizes: 379 l to 190,000 l
   (100 gal to 50,000 gal)

3. Useful life: **20 years**

   
   **1.63 M diameter x 3.68 M high** (64" diameter x 145" high)

5. Standard Rating Conditions:
   
   A. The Stored water must be between 0 and 100°C
      (32 and 212°F)

   B. The tank is above ground.

6. Jacket Loss:

   The user specifies the overall heat transfer coefficient area product (UA). The percent loss is calculated by:

   \[
   \% \text{loss} = \frac{Q_{\text{Loss}}}{Q_{\text{Total}}} \times 100
   \]

   where \( Q_{\text{Total}} = M \cdot C_p \cdot \Delta T \)

   and \( M \) = Mass of water in the tank

   \( C_p \) = Water heat capacity

   \( \Delta T \) = Temperature difference between the tank contents and the room.

   \( Q_{\text{Loss}} = UA \cdot \Delta T \)

   thus: \( \% \text{loss} = \frac{UA}{M \cdot C_p} \times 100 \)

   To obtain the tank cost the user interpolates the cost versus % loss numbers.
### THERMAL STORAGE TANK

#### COST DATA

<table>
<thead>
<tr>
<th>Component Size</th>
<th>% loss/day 52°C (125°F)</th>
<th>Tank Temp. 1%</th>
<th>2%</th>
<th>5%</th>
<th>5%/Liter</th>
</tr>
</thead>
<tbody>
<tr>
<td>liters (gal)</td>
<td>Installed Cost*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>379 (100)</td>
<td>$264</td>
<td>191</td>
<td>148</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1893 (500)</td>
<td>447</td>
<td>323</td>
<td>248</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2271 (600)</td>
<td>1481</td>
<td>1347</td>
<td>1273</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3785 (1000)</td>
<td>1699</td>
<td>1538</td>
<td>1451</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18927 (5000)</td>
<td>3597</td>
<td>3287</td>
<td>3101</td>
<td></td>
<td></td>
</tr>
<tr>
<td>37854 (10000)</td>
<td>5830</td>
<td>5582</td>
<td>5334</td>
<td>.140</td>
<td></td>
</tr>
<tr>
<td>189271 (50000)</td>
<td>23569</td>
<td>22948</td>
<td>22948</td>
<td>.121</td>
<td></td>
</tr>
</tbody>
</table>

O&M Costs as a % of installed costs =

*Including overhead and profit
SUBSYSTEM ELEMENTS

To assure accurate system modelling several common subsystem designs (combinations of components) were developed to identify interconnection components such as pumps and controls. Also, interconnection flow rates were identified so that proper component sizing could be maintained. The following section is a summary of the subsystem elements.
**System Description:** VAPOR COMPRESSION CHILLER WITH CENTRAL STATION AIR HANDLING UNITS

**System Output:**
- Design KW output = DKWO
- Design tonnage = DT

**Design Conditions:**
1. \(0.043 \text{ l/s per KW (2.4 gpm/ton)}\) evaporator
2. \(0.054 \text{ l/s per KW (3 gpm/ton)}\) condenser
3. \(7.2^\circ C (45^\circ F)\) leaving evaporator water temperature
4. \(29.4^\circ C (85^\circ F)\) entering condenser water temperature
5. 210 KPa (70 ft) evaporator side pressure drop
6. 150 KPa (50 ft) condenser side pressure drop
7. \(0.034 \text{ m}^3/\text{s per KW (400 CFM/ton)}\) at AHU

**Component**

1. **Centrifugal Chiller**
   - Design KW Input
   - \(\text{DKWO/Design COP}\)
   - \(\text{DT x Design KW/Ton}^*\)

2. **Cooling Tower Fan**
   - \(0.00924 \text{ DKWO}\)
   - \(\text{DTx.013hp/gpmx3gpm/ton x .75KW/hp}\)
   - \(.9 \text{ eff}\)

3. **Evaporator Water Pumps**
   - \(0.0134 \text{ DKWO}\)
   - \(\text{DTx2.4gpm/tonx70' x .75KW/hp}\)
   - \(3960 \times .75 \text{ eff} x .9 \text{ eff}\)
(cont'd)

<table>
<thead>
<tr>
<th>Component</th>
<th>Design KW Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Condenser water pumps</td>
<td>.0120 DKWO</td>
</tr>
<tr>
<td></td>
<td>$\text{DT} \times \text{3gpm/ton} \times 50' \times .75\text{KW/hp}$</td>
</tr>
<tr>
<td></td>
<td>$3960 \times .75 \text{ eff} \quad .9 \text{ eff}$</td>
</tr>
<tr>
<td>5. AHU</td>
<td>.0622 DKWO</td>
</tr>
<tr>
<td></td>
<td>$\text{DT} \times \text{400CFM/ton} \times 2.5'' \times .75\text{KW/hp}$</td>
</tr>
<tr>
<td></td>
<td>$6346 \times .6 \text{ eff} \quad .9 \text{ eff}$</td>
</tr>
</tbody>
</table>

* .78KW/ton Centrifugal
  .95KW/ton Reciprocating
1. **Centrifugal Chiller**
   a) Water flow rates constant
   b) Cop (KW/ton) corrected for part load
   c) Leaving evaporator water temperature constant
   d) Entering condenser water temperature constant

2. **Cooling Tower Fan**
   Cycle to maintain constant entering condenser water temperature with a given reduction in wet bulb temperature and part load.

3. **Evaporator water pumps**
   Water flow rate constant

4. **Condenser water pumps**
   Water flow rate constant

5. **AHU fans**
   Cycle during heating only
System Description: ABSORPTION CHILLER WITH CENTRAL STATION AIR HANDLING UNIT

System Output:
Design KW output = DKWO
Design tonnage = DT

Design Conditions:
1. .043 l/s per KW (2.4 gpm/ton) evaporator
2. .064 l/s per KW (3.6 gpm/ton) condenser
3. 7.2°C (45°F) Leaving evaporator water temperature
4. 29.4°C (85°F) Entering condenser water temperature
5. 210 KPa (70') Evaporator side pressure drop
6. 150 KPa (50') Condenser side pressure drop
7. .051 m³/s per KW (400 CFM/ton) at AHU

Component Design KW Input
1. Absorption Chiller
   DKWO x f(DKWO)
   DT x f(DT) *

2. Cooling Tower Fan
   DT x .014hp/gpm x 3.6gpm/ton x .75KW/hp x .9 eff

3. Evaporator Water Pumps
   DT x 2.4gpm/ton x 70' x .75KW/hp
   3,360 x .75 eff x .9 eff
Component | Design KW Input
---|---
4. Condenser Water Pumps | .0144 DKWO
| DTx3.6gpm/tonx50' x .75KW/hp
| 3960 x .75 eff
| .9 eff
5. AHU fans | .0622 DKWO
| DTx400CFM/tonx2.5" x .75KW/hp
| 6346 x .6 eff
| .9 eff

* See Absorption Chiller section for power consumption
Absorption Chiller with AHU Control Sheet

1. Absorption Chiller
   a) Electric input constant
   b) Steam or hot water input varies with part load. (LEWT and ECWT are constant)

2. Cooling Tower Fan
   Cycle to maintain constant entering condenser water temperature with a given reduction in wet bulb temperature and part load.

3. Evaporator Water Pumps
   Water flow rate constant

4. Condenser Water Pumps
   Water flow rate constant

5. AHU Fans
   Cycle during heating only
System Description: VAPOR COMPRESSION CHILLER WITH FAN COIL UNIT

System Output:
Design KW output = DKWO  
Design Tonnage = DT

Design Conditions:
1. .034 l/s per KW (2.4 gpm/ton) evaporator
2. .054 l/s per KW (3 gpm/ton) condenser
3. 7.2°C (45°F) leaving evaporator water temperature
4. 29.4°C (85°F) entering condenser water temperature
5. 210 KPa evaporator side pressure drop
6. 150 KPa condenser side pressure drop
7. .142 M³/s (300 CFM) for (1.76KW) 1/2 ton unit; .284 M³/s (600 CFM) for 3.5 KW (1 ton) unit

Component | Design KW Input
--- | ---
1. Centrifugal Chiller | Design KW Input
2. Cooling Tower fan | .00924 DKWO
3. Evaporator water pumps | .0134 DKWO

<table>
<thead>
<tr>
<th>Component</th>
<th>Design KW Input</th>
</tr>
</thead>
</table>
| | DKWO  
| | Design Cop  
| | DT x Design KW/ton  
| | DT x .013 hp/gpm x 3 gpm/ton x .75 KW/hp  
| | .9 eff  
| | DT x 2.4 gpm/ton x 70' x .75 KW/hp  
| | 3960 x .75 eff .9 eff
<table>
<thead>
<tr>
<th>Component</th>
<th>Design KW Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Condenser Water pumps</td>
<td>0.0120 DKWO&lt;br&gt;DTx3gpm/tonx50' x 0.75KW/hp&lt;br&gt;3960 x 0.75 eff 0.9 eff</td>
</tr>
<tr>
<td>5. Fan Coil Unit</td>
<td>19.2KW&lt;br&gt;100 watts per 1.76KW(½ ton) unit times 192 units</td>
</tr>
<tr>
<td></td>
<td>16.8KW&lt;br&gt;175 watts per 3.516KW(1 ton) unit times 96 units</td>
</tr>
</tbody>
</table>
Vapor Compression Chiller with FCU
Control Sheet

1. Centrifugal Chiller
   a) Water flow rates constant
   b) COP (KW/ton) corrected for part load
   c) Leaving evaporator water temperature constant
   d) Entering condenser water temperature constant

2. Cooling tower fan
   Cycle to maintain constant entering condenser water temperature with a given reduction in wet bulb temperature and part load.

3. Evaporator water pumps
   Water flow rate constant

4. Condenser water pumps
   Water flow with constant

5. FCU
   Cycle during heating only
System Description: ABSORPTION CHILLER WITH FCU

System Output: Design KW output = DKWO
Design ton = DT

Design Conditions:
1. 0.043 l/s per KW (2.4 gpm/ton) evaporator
2. 0.064 l/s per KW (3.6 gpm/ton) condenser
3. 7.2°C (45°F) leaving evaporator water temperature
4. 29.4°C (85°F) entering condenser water temperature
5. 210 KPa (70’) evaporator side pressure drop
6. 150 KPa (50’) condenser side pressure drop

Component | Design KW Input
--- | ---
1. Absorption Chiller | DKWO x f(DKWO)*
2. | Dt x f(DT)*
| Cooling Tower fan | 0.012 DKWO
| Evaporator Water pumps | 0.0134 DKWO
| | DT x 0.14 hp/gpm x 3.6 gpm/ton x 0.75 kW/hp
| | 0.9 eff
| | DT x 2.4 gpm/ton x 70’ x 0.75 kW/hp
| | 3960 x 0.75 eff
| | 0.9 eff
(cont'd)

<table>
<thead>
<tr>
<th>Component</th>
<th>Design KW Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Condenser Water Pumps</td>
<td>.0144 DKW0</td>
</tr>
<tr>
<td></td>
<td>$DT \times 3.6\text{gpm/ton} \times 50' \times \frac{.75\text{KW/\text{hp}}}{3960} \times .9\text{eff}$</td>
</tr>
<tr>
<td>5. Fan Coil Units</td>
<td>.01622 DKW0</td>
</tr>
<tr>
<td></td>
<td>100 Watts per 1.75KW(1 ton) unit times 192 units</td>
</tr>
<tr>
<td></td>
<td>175 watts per 3.516KW(1 ton) unit times 96 units</td>
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</tbody>
</table>

* See absorption chiller section for power consumption
Absorption Chiller with FCU
Control Sheet

1. **Absorption Chiller**
   
   a) Electric input constant
   
   b) Steam or hot water input varies with part load (LEWT and ECWT are constant)

2. **Cooling Tower Fan**
   
   Cycle to maintain constant entering condenser water temperature with a given reduction on wet bulb temperature and part load.

3. **Evaporator Water Pump**
   
   Water flow rate constant

4. **Condenser Water Pumps**
   
   Water flow rate constant

5. **FCU Fans**
   
   Cycle during heating only
System Description: GAS/OIL BOILER WITH FCU

System Output: Design KW output = DKWO
Design MBH = DMBH

Design Conditions:
1. Select Hot Water Temperature
2. 75 KPa (25'') pressure drop
3. .054 l/s per KW (3 gpm/ton) hot water flow rate established by cooling

Component | Design KW Input
--- | ---
1. Circulating Pump | .048 DKWO
| | $(DT \times 2.4 \text{ gpm/ton} \times 25' \times 0.75\text{KW/hp})$
| | $3960 \times 0.75 \text{ eff}$

2. FCU fans | 9.6 KW
| | .5x100W per 1.70KW(.1 ton) unit
| | times 192 units

| 8.4 KW |
| .5x175W per 3.516KW(1 ton) unit |
| times 96 units |
Gas/Oil Boiler with FCU

Control Sheet

1. Water flow rate constant

2. Cycle fans
### System Description:
GAS/OIL BOILER WITH CUH

### System Output:
Design KW output = DKWO  
Design MBH = DMBH

### Design Conditions:
1. Select Hot water temperature  
2. 75 KPa (25') pressure drop  
3. 11.1°C (20°F) Hot water temperature drop  
4. (.0215 DKWO) 1/s (.1 DMBH)gpm) Hot water flow rate

<table>
<thead>
<tr>
<th>Component</th>
<th>Design KW Input</th>
</tr>
</thead>
</table>
| 1. Circulating Pump | [.0024 DKWO  
\[
\frac{\text{DMBH}}{10} \times 25' \times .75\text{KW/hp} \\
3960 \times .75 \text{ eff} \times .9 \text{ eff}
\]  |
| 2. CUH fans        | CUH rated watts* x No. of CUH .5 eff |

* Use largest units available (≈.35KW) and select hot water temperature and no. of units to meet DMBH
Gas/Oil Boiler with CUH
Control Sheet

1. Circulating Pump
   Water flow rate constant

2. CUH fans
   Fans constant on
**System Description:**
GAS/OIL BOILER WITH AHU

**System Output:**
Design KW output = DKWO  
Design MBH = DMBH

**Design Conditions:**
1. Select hot water temperature
2. 75 KPa 25' potential drop
3. 0.3048 M/s (3 fps ≈ 55 gpm/ft) water flow rate

<table>
<thead>
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<th>Component</th>
<th>Design KW Input</th>
</tr>
</thead>
</table>
| 1. Circulating pump | 4.6 KW  
                   | (55 gpm/ft x 3 ft/ton x 1 unit/ton)  
                   | x 25' x .75 KW/ton  
                   | +  
                   | (3960) x (.75 eff) x (.9 eff)                                                |
| 2. AHU fans     | .0622 DKWO  
                   |  
                   | DT x 400 CFM/ton x 2.5' x .75 KW/ton  
                   | .6346 x .8 eff x .9 eff

86
1. Water flow rate constant

2. Cycle fans
GLOSSARY OF HEATING, VENTILATING AND AIR CONDITIONING (HVAC) TERMS

Absorption Chiller: An absorption chiller is a heat (steam, hot water, or gas fired) driven machine for providing chiller water to a building. A relatively small amount of electric power for pumps and fans is needed while the major source of input power is thermal.

Air Handling Unit: A central air handling unit conditions the air and supplies either a mixture of outdoor and return air or 100 percent outdoor air to the room unit. The apparatus contains fan(s), filters to clean the air, preheat coils (if required) to temper cold winter air, and a dehumidifier to cool and remove excess moisture from warm humid air or to add winter humidification.

Boiler Efficiency: This is the ratio of BTU output divided by BTU input. It includes allowance for stack, radiation, convection and other losses.

Boiler Horsepower: A boiler horsepower (BHP) is defined as the evaporation of 34.5 lb. of water per hour from a temperature of 212°F into dry saturated steam at the same temperature.

Boiler, Packaged: A boiler equipped and shipped complete with fuel burning equipment, mechanical draft equipment, automatic controls and accessories. Usually shipped in one or more major sections.

British Thermal Unit (BTU): The amount of energy required to raise one pound of water 1 degree Fahrenheit.

Centrifugal Chiller: A centrifugal refrigeration machine consists basically of a centrifugal compressor, a cooler and a condenser. It may be driven by an electric motor, steam turbine or internal combustion engine.

Cooling Tower: A device that cools water directly by evaporation.

Fan Coil Terminal Unit: This is a room type terminal unit of the factory-fabricated, cabinet style package with fan, filters, chilled water and hot water coils.

Fouling Factor: Fouling factors represent the thermal resistance to heat flow introduced by scale and other water impurities in a heat exchanger. Normally, manufacturers rate a water-cooled condenser for various values of water side fouling.

Heat Exchanger: A device specifically designed to transfer heat between two physically separated fluids.

Heat Pump: A refrigerating system designed to utilize alternately the heat extracted at a low temperature and the heat rejected at a higher temperature for cooling and heating functions respectively.
Split System: Unitary equipment, incorporating the following possible arrangements:

1. Air handling unit with coil and compressor and remote condenser.

2. Air handling unit with coil and remote condensing unit.

Ton of Refrigeration: A refrigerating unit equal to 3,516 watts (12,000 BTU/hr), the rate at which it is necessary to freeze water in order to produce a ton of ice in 24 hours. The size of refrigeration and air conditioning systems is usually indicated in terms of "tons".

Two Pipe/Four-Pipe Systems: A two-pipe system contains a single piping system used to circulate chilled or hot water to a single air handling unit coil. A four-pipe system completely isolates the chilled and hot water systems so that the piping for each system may be designed independently.

Unitary Equipment: A unitary air conditioning unit, sometimes referred to as packaged equipment, consists of one or more factory-fabricated assemblies designed to provide the functions of air moving, air cleaning, cooling and dehumidification. The functions of heating and humidifying are also usually possible with such equipment. Unitary equipment includes a direct expansion cooling coil and a compressor condenser combination in addition to fans, auxiliaries and internal wiring and piping.

Unit Heater: The term unit heater denotes an assembly of elements, the principal function of which is to heat a space. The essential elements are a fan and motor, a heating element, an an enclosure. Filters, dampers, directional outlets, duct collars, combustion chambers, and flues may also be included.
1. Centrifugal Chillers - Trane Centravac DS CTV1
   Carrier
   York Turbopak

2. Reciprocating Chillers - Trane
   Carrier
   York

3. Absorption Chillers - Trane Absorption Cold Generator
   Arkla
   York Absorption Liquid Chillers
   Model ES
   Carrier Hemetic Absorption
   Liquid Chillers

4. Hot Water Packaged Boilers - Hydrotherm - Mult-Temp
   Burnham
   Kewanee

5. Cooling Towers - Baltimore Air Coil Engineering
   Manual

6. Fan Coil Units - Trane Fan-Coil Unitrane

7. Cabinet Unit Heaters - Trane

8. Water - Water Heat Pump - Templifier

9. Air Handling Units - Trane Catalog
   Aerofin Catalog
2. INTEGRATED FUEL CELL SYSTEMS DIAGRAMS

The following pages illustrate the final baseline system diagrams for the system identified in Tables 19 and 20 of Volume I and follow the System Master List convention code.
3. COMPUTER ANALYSIS OF SYSTEMS

All systems analyzed in this project are summarized on the following Master List of Tables. This list is repeated in Section 4 of Volume I for completeness. The first set of tables provides the component size and brief description for the key components of each system. Each system is assigned a system number or computer run number and these are used throughout the report.

The second set of data summarizes the performance and cost results of the analysis. All costs are in 1978 dollars.
<table>
<thead>
<tr>
<th>RUN</th>
<th>FUEL CELL NUMBER</th>
<th>MODULE SIZE KW</th>
<th>BOILER ABSORPTION KW</th>
<th>CHILLER ELECTRIC KW</th>
<th>DISCHARGE DUR. HRS.</th>
<th>THERMAL STORAGE LITERS</th>
<th>DOMESTIC HOT WATR. LITERS</th>
<th>NOTES</th>
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</table>

1 - Water to Water Heat Exchanger Used Throughout - 8098 Watts/°C
2 - High Efficiency Modulated Boiler
3 - Battery Storage 1000 KWH
4 - Battery Storage 500 KWH
5 - The Absorption Chiller Attempts to Limit the Fuel Cell to 200KW
6 - Water-fired Absorption Unit
3. COMPUTER ANALYSIS OF SYSTEMS

All systems analyzed in this project are summarized on the following Master List of Tables. This list is repeated in Section 4 of Volume I for completeness. The first set of tables provides the component size and brief description for the key components of each system. Each system is assigned a system number or computer run number and these are used throughout the report.

The second set of data summarizes the performance and cost results of the analysis. All costs are in 1978 dollars.
<table>
<thead>
<tr>
<th>RUN</th>
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<th>MODULE</th>
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</table>

1 - Water to Water Heat Exchanger Used Throughout - 3098 Watts/°C
2 - High Efficiency Modulated Boiler
3 - Battery Storage 1000 KWH
4 - Battery Storage 500 KWH
5 - The Absorption Chiller Attempts to Limit the Fuel Cell to 300KW
6 - Water-fired Absorption Unit
### Table 4B

**MASTER SYSTEM LIST**

**FUEL CELL B - APARTMENT**

<table>
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<th>RUN</th>
<th>FUEL CELL NUMBER</th>
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1. A 7812 Watts/°C steam to water heat exchanger
2. A 8097 Watts/°C water to water heat exchanger
3. A 3182 liter hot water storage tank
4. 8000 KWH battery limiting the load to 250 KW
5. 4000 KWH battery limiting the load to 150 KW
6. 2000 KWH battery limiting the load to 150 KW
7. 1000 KWH battery limiting the load to 200 KW
8. 500 KWH battery limiting the load to 200 KW
9. High efficiency modulating boiler trying to limit the load to 200 KW
10. 1000 KWH battery limiting the load to 200 KW
11. 500 KWH battery limiting the load to 200 KW
12. A 16365 liter hot water storage tank
### TABLE 4C
**FUEL CELL C - APARTMENT**

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<th>RUN</th>
<th>FUEL CELL MODULE</th>
<th>BOILER</th>
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1 - A steam to water heat exchanger 7832 watt/°C is used.
2 - High efficiency modulating boiler.
**TABLE 4D**

**RETAIL STORE**

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<th>CHILLER</th>
<th>THERMAL STORAGE</th>
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1 - H₂O to H₂O heat exchanger only 2024/watts/°C for all Fuel Cell C cases.
2 - Steam H₂O heat exchanger 1957 watts/°C and 3163 watts/°C H₂O to H₂O.
3 - 1957 watts/°C steam to H₂O heat exchanger only.
4 - This run represented 36 days of data. Otherwise it is exactly the same as 4CS.
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1 - Eliminate 507 Watts/°C H₂O to H₂O Heat Exchanger, Use Steam to H₂O Heat Exchanger 1957 Watts/°C only.
2 - High Efficiency (Custom) Absorption Chiller 12# Steam Ton-HR
3 - Relax Fuel Cell Reliability to 30 Hours per 10,000
4 - Relax Fuel Cell Reliability to 10 Hours per 10,000
5 - High Efficiency Absorption Chiller 10# Steam/Ton-HR
6 - High Efficiency Modulating Boiler
TABLE 4F
RETAIL STORE ANALYSIS
(Continued)

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<th>RUN</th>
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<th>CHILLER</th>
<th>THERMAL STORAGE</th>
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7 - 350KW Peak Limiting by Absorption Unit
8 - 400KW Peak Limiting by Absorption Unit
9 - 500KW Peak Limiting by Absorption Unit
10 - 600KW Peak Limiting by Absorption Unit
11 - 700KW Peak Limiting by Absorption Unit
12 - 3000KWH Battery Trying to Hold the Load at 350KW
13 - Adiabatic Thermal Storage Tank
14 - High Efficiency Absorption Chiller 12# Steam/Ton-Hour
15 - Higher Efficiency Absorption Chiller 6# Steam/Ton-Hour
16 - 380KW Boiler
17 - 350KW Boiler
### Fuel Cell A

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<td>$/KW BTU original gas cost</td>
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For the Levelized Annual Cost the following constants are defined:

- Fixed change rate
- Fuel energy costs in $/million BTU
- Escalation in fuel energy costs (decimal)
- Weighted cost of capital (%)
- System life (years)
- Electric utility electricity costs ($/kwh)
- Escalation in electricity costs (decimal)

### Run F.C. Size (kw) HVAC Kwh Capital Cost except Fuel Cells Operation and Maintenance except Taxes + Insurance Gas Costs $ No of Fuel Cells Correction to lights Kwh

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<th>HVAC Kwh</th>
<th>Capital Cost except Fuel Cells</th>
<th>Operation and Maintenance except Taxes + Insurance</th>
<th>Gas Costs $</th>
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### FUEL CELL 9 STORE

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### FOR THE LEVELIZED ANNUAL COST, THE FOLLOWING CONSTANTS ARE DEFINED

| FIXED CHARGE RATE | 0.0444 |
| FUEL ENERGY COSTS IN B/MILLION BTU | 3.0300 |
| ESCALATION IN FUEL ENERGY COSTS (DECIMAL) | 0.0240 |
| WEIGHTED COST OF CAPITAL (T) | 0.0000 |
| SYSTEM LIFE (YEAR) | 25.00 |
| ELECTRIC UTILITY ELECTRICITY COSTS (S/KWH) | 0.0423 |
| ESCALATION IN ELECTRICITY COSTS (DECIMAL) | 0.0060 |

### RUN P.C. SIZE (KW) HVAC KWH CAPITAL COST EXCEPT FUEL CELLS OPERATION AND MAINTENANCE EXCEPT TAXES & INSURANCE GAS COSTS & NO OF FUEL CORRECTION TO LIGHTS KWH CELLS

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For the Levelized Annual Cost the Following Constants are Defined:

- **Fixed Charge Rate**: 0.14440
- **Fuel Energy Costs In $/Million Btu**: 3.03000
- **Escalation in Fuel Energy Costs (Decimal)**: 0.02400
- **Weighted Cost of Capital (R)**: 0.10000
- **System Life (Years)**: 25.000
- **Electric Utility Electricity Costs ($/kWh)**: 0.04230
- **Escalation in Electricity Costs (Decimal)**: 0.06890

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# FUEL CELL A

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| EXTRA # OF FUEL CELLS | 0.0 |
| HVAC FOR THE LIGHTS/CON HVAC EQUIPMENT | 11133.00 |
| FUEL CELL INSTALLATION COST ($/KW) | 50.00 |
| TYPE OF FUEL CELL (1 + A, 2 = B, 3 = C) | 1.00 |
| $/MILLION BTU ORIGINAL GAS COST | 3.03 |

For the levelized annual cost the following constants are defined:

| FIXED CHARGE RATE | 0.144400 |
| FUEL ENERGY COSTS IN $/MILLION BTU | 3.030000 |
| ESCALATION IN FUEL ENERGY COSTS (DECIMAL) | 0.024000 |
| WEIGHTED COST OF CAPITAL (R) | 0.100000 |
| SYSTEM LIFE (YEARS) | 25.00 |
| ELECTRIC UTILITY ELECTRICITY COSTS ($/KWH) | 0.042300 |
| ESCALATION IN ELECTRICITY COSTS (DECIMAL) | 0.000000 |

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### Fuel Cell C Apartments

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For the levelized annual cost the following constants are defined:

- **Fixed Charge Rate**: 0.11244
- **Fuel Energy Costs in $/Million BTU**: 3.03000
- **Escalation in Fuel Energy Costs (Decimal)**: 0.02300
- **Weighted Cost of Capital (R)**: 0.10000
- **System Life (Years)**: 25.000
- **Electric Utility Electricity Costs ($/kWh)**: 0.04230
- **Escalation in Electricity Costs (Decimal)**: 0.00600

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4. CASH FLOWS FOR BASELINE SYSTEMS

Cash flows following the format of Section 4.2 are given in the following pages.

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