64-bit Server Cooling Requirements

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Fujitsu Laboratories of America
64-bit Server Cooling Requirements

- Power Dissipation and Distribution
- Temperature Dependence of Power
- Power Reduction by Refrigeration
- Air- to Water Cooling Migration
High Performance Processor Power Trend

Year of Production

Power Dissipation, W


1999 2000 2001 2002 2003 2004
Chip Power Map
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Fujitsu Laboratories of America

Kang, ITherm 2000

Air - Enhanced
PA-8700 Power Distribution
Power Distribution of the Microprocessor Design
Temperature Distribution on Junction Surface
Copper Heat Spreader
Center Core Location
Middle Core Location
Corner Core Location
## Power Multiple Core Location Results

<table>
<thead>
<tr>
<th></th>
<th>Center</th>
<th>Middle</th>
<th>Corner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Temperature</td>
<td>97.0 C</td>
<td>73.6 C</td>
<td>79.0 C</td>
</tr>
<tr>
<td>Silicon heat spreading</td>
<td>2 sides</td>
<td>4 sides</td>
<td>2 sides</td>
</tr>
<tr>
<td>Copper heat spreading</td>
<td>2 sides</td>
<td>4 sides</td>
<td>4 sides</td>
</tr>
</tbody>
</table>
Nonuniform Power Map on the Die

- 100W/cm²
- Other area: 38.8W/cm²

Dimensions: 20 mm x 20 mm

Sun: Xu et al., ITherm 2004
Effect of Power Distribution on the Thermal Resistance

Xu et al., ITherm 2004
Case to Ambient Resistance

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AMD Opteron  194 mm²
Intel Itanium 2  409 mm²
IBM Power5 389 mm²
Sun UltraSPARC 4 356 mm²
Sun Niagara ~340mm²
Total Chip Dynamic and Static Power Dissipation Trends Based on the ITRS
Variation of Leakage Current Components with Temperature
Leakage Current Growth with Temperature

```
0.1 μm, 15mm² die, 0.7V
Leakage
Active
```

**Power (W)**

**Temperature (°C)**

- 30: 6%
- 40: 9%
- 50: 14%
- 60: 26%
- 70: 33%
- 80: 41%
- 90: 49%
- 100: 56%
- 110: 66%
Leakage Current Growth of One Transistor

Temperature (°C)

$I_{off} (\text{nA/µm})$

10,000

1,000

100

10

1

30 40 50 60 70 80 90 100 110

0.10 µm

0.13 µm

0.18 µm

0.25 µm
Effect of Thermal Resistance on Junction Temperature

Junction Temperature, C

Ambient Temperature, C

- 0.30 C/W
- 0.25 C/W
- 0.20 C/W
- 0.15 C/W
Effect of Thermal Resistance on Power Supply Output
Effect of Junction and Ambient Temperatures on Power ($\Theta = 0.30 \, \text{C/W}$)
Effect of Junction and Ambient Temperatures on Power ($\Theta = 0.15 \text{ C/W}$)
Intel: Mahajan, IEPS 2004

5x to 20 Reduction in Transistor Leakage Power

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International Technology Roadmap for Semiconductors
64-bit microprocessors (2002 update)

<table>
<thead>
<tr>
<th>Technology</th>
<th>2003</th>
<th>2005</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Node (nm)</td>
<td>100</td>
<td>80</td>
<td>65</td>
</tr>
<tr>
<td>Die size (mm)</td>
<td>17.6</td>
<td>17.6</td>
<td>17.6</td>
</tr>
<tr>
<td>Power (W)</td>
<td>150</td>
<td>170</td>
<td>190</td>
</tr>
</tbody>
</table>
Estimated Subthreshold Leakage Over the Near Term
Ratio of Leakage Current Relative to 85 C
<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>15</th>
<th>20</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure MPa</td>
<td>0.488</td>
<td>0.572</td>
<td>0.665</td>
</tr>
<tr>
<td>Heat kJ/kg</td>
<td>105.6</td>
<td>108.3</td>
<td>110.9</td>
</tr>
<tr>
<td>Work kJ/kg</td>
<td>28.7</td>
<td>25.3</td>
<td>22.2</td>
</tr>
<tr>
<td>COP ideal</td>
<td>3.68</td>
<td>4.28</td>
<td>5.00</td>
</tr>
<tr>
<td>COP actual</td>
<td>2.21</td>
<td>2.57</td>
<td>3.00</td>
</tr>
</tbody>
</table>
Total Power for 30% and 50% Static Leakage Loss

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Intel: Sauciuc et al., ITS 2004

SM Heat Sink 80 mm x 90 mm x 27.53 mm + (2) Delta Fans 12 V
\( \Delta P_{\text{system}} = 100\% \text{ of } \Delta P_{\text{HS}} \)
\( T_{\text{ambient}} = 39 \degree \text{C}; \ ZT = 0.90; \ \text{TIM A&B} = 0.4 \text{ } \degree \text{Ccm}^2/\text{W}; \)

1U Thermal Performance–Using Solid Metal Spreader and Several TECs

Acceptable Solutions

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Refrigeration Cooled Module utilizing Refrigerant Cooled Heat Sinks and Remote Condensing Devices
Increase in Power per Rack with Technology Advancements
New ASHRAE Updated and Expanded Power Trend Chart
Raised Floor Implementation Most Commonly Found in Data Centers Today Using CRACs
Raised Floor Implementation Using Inlet and Outlet Plenums / Ducts Integral to the Rack
Internal Liquid Cooling Loop Restricted to Within Rack Extents
Internal Liquid Cooling Loop Extended To Liquid Cooled External Modular Cooling Unit
64-bit Server Cooling Requirements

• **Power Dissipation and Distribution**
  • Multiple core processors

• **Temperature Dependence of Power**
  • Increasing leakage power

• **Power Reduction by Refrigeration**
  • Lower total power consumption

• **Air- to Water Cooling Migration**
  • More direct path to building water