Summary of Research Activities

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Main Driving Factors for Research are Energy and Environment
Main Research Thrusts

• **Alternative Technologies** for heat pumping, air conditioning, refrigeration, drying, etc.:
  – Analysis of transcritical CO$_2$-cycle technology (some details later on)
  – Evaluation of thermoelectric refrigeration and air conditioning
  – Stirling cycle coolers
  – Ericsson cycle coolers
  – Air-cycle technology (reversed Brayton cycle) for transport air conditioning and drying applications.
  – Combined absorption/compression cycle (vapor compression cycle with solution circuit) utilizing working pairs such as ammonia/water, CO$_2$/Acetone, and HFC-23/DEGDME.

Main Research Thrusts, cont’d

• **Improved Components**, such as compressors, heat exchangers, expansion devices, distributors, etc.:
  – Modeling, analysis, and testing of positive displacement compressors (some details later on)
  – Evaluation of scroll or screw compressors for the combined compression of refrigerant vapor and solution in absorption/compression cycles
  – Modeling, analysis, and testing of two-phase work output expansion machines
  – Development of an improved method for refrigerant flow distribution
  – Analysis and design of heat exchangers
  – Heat transfer and pressure drop characteristics during in-tube gas-cooling, condensation, and evaporation of new/substitute refrigerants
  – Performance evaluation and investigation of the fouling behavior of air-to-refrigerant heat exchangers
Main Research Thrusts, cont’d

- **Improved Systems**, (Air Conditioners and Heat Pumps, Chillers, Refrigerators, Furnaces, etc.) through modeling optimization, reliability studies:
  - Improved steady-state design models for air conditioners and heat pumps (some details later on)
  - Transient models of unitary systems and chillers
  - HFCs and HFC mixtures as a replacement for R-22 in unitary air conditioning and heat pumping equipment
  - Hydrocarbons and their mixtures as a replacement for HCFC-22 in unitary equipment and as a replacement for R-134a in domestic refrigerator/freezers
  - Secondary loop refrigeration systems using ammonia or hydrocarbons for commercial and unitary applications
  - A cost-based methodology for determining optimal refrigerants
  - Impact of heat exchanger fouling on system performance

Main Research Thrusts, cont’d

- **Miniature-Scale Refrigeration Systems (MSRS)** for electronics cooling:
  - Performance evaluation of miniature-scale refrigeration systems for electronics cooling (some details later on)
  - Modeling, analysis, design and testing of miniature-scale rotary and linear compressors for electronics cooling
  - Evaluation of miniature-scale diaphragm compressors for electronics cooling
**Two Large Environmental Chambers**
- Testing of AC, HP and Refrig. Systems
- -20°C to +50°C, < 5-ton equipment
- Steady-state and cyclic testing of existing, modified, or new equipment designs

**90-ton Centrifugal Chiller**
- Automated control of boundary conditions

**Heat Exchanger Test Facility**
- Testing of coiling coils, heating coils, evaporators, condensers
- Capable of controlled heat exchanger fouling

**Compressor Load Stands**
- CO₂, R-22, R-410a

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**Alternative Refrigeration Technologies: Transcritical CO₂ Cycle**

**CO₂ Compressor Load Stand:**

**Performance of CO₂ Prototype Compressor:**

\[\text{ov.Is.eff} = -2.78259157 \times 10^{-01} + 8.95484761 \times 10^{-03} \times p_1 - 2.69714368 \times 10^{-02} \times p_1^2 + 9.76968361 \times 10^{-04} \times p_1^3 + 2.55739111 \times 10^{-01} \times p_2 - 2.83526791 \times 10^{-02} \times p_2^2 + 9.86399651 \times 10^{-04} \times p_2^3 + 2.58389357 \times 10^{-02} \times p_1 \times p_2 - 9.84810719 \times 10^{-04} \times p_1^2 \times p_2 - 1.70586490 \times 10^{-04} \times p_1 \times p_2^2\]

\[
\text{DTsh} = 14.6 \text{ K}; \text{ stdev} = 2.3 \text{ K}
\]
Alternative Refrigeration Technologies: Transcritical CO₂ Cycle

Expansion Work Output Machine:

[Diagram showing pressure and enthalpy for different cases]

Improved Components: Scroll Compressor Analysis

Experimental Setup:

Model Validation:

[Graph comparing model predictions with measurements]

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Improved Components:
Beard-Pennock Variable-Stroke Compressor (1988)

Concept:

![Diagram of Beard-Pennock Compressor](image)

Predicted Performance:

![Graph showing predicted performance](image)

- Cooling Capacity
- EER

Swept Volume (cm$^3$)

- 3.5
- 4.0
- 4.5
- 5.0
- 5.5

T$_{cond}$ = 40°C & T$_{evap}$ = -15°C

Improved Components:
Refrigerant Flow Distributor Analysis

CFD Modeling of Refrigerant Flow Distribution

Refrigerant Mal-distribution:

![Diagram showing refrigerant mal-distribution](image)
Improved Components:
Air-Side Heat Exchanger Fouling Analysis

Air-side Effective Heat Transfer Coefficient Fouling Factor (Measured):

\[ f_h = \frac{100(h_i - h_c)}{h_c} \%
\]

Air-side Pressure Drop Fouling Factors (Measured):

\[ f_{dp} = \frac{100(\Delta P_{c,f} - \Delta P_{c,c})}{\Delta P_{c,c}} \%
\]

Improved Systems:
Secondary-Loop Refrigeration Systems

Supermarket Case Study:

<table>
<thead>
<tr>
<th>System Description</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium Temperature DX (R-22)</td>
<td>2.01</td>
</tr>
<tr>
<td>Low Temperature DX (R-404A)</td>
<td>1.19</td>
</tr>
<tr>
<td>Medium Temperature SL (R-717/HFE)</td>
<td>2.31</td>
</tr>
<tr>
<td>Low Temperature SL (R-717/HFE)</td>
<td>1.56</td>
</tr>
</tbody>
</table>
Target Operating Conditions

- Cooling capacity: ≥ 200W
- Evaporating temperature: 10 to 25°C
- Condensing temperature: 40 to 55°C
- Superheat: 3 to 8°C
- Subcooling: 3 to 10°C
- Ambient temperature: 25 to 45°C

Future Research Opportunities

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<tr>
<td>Limited generating capacity</td>
<td>Performance monitoring &amp; diagnostics</td>
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<td>Information technologies</td>
<td>Intelligent controls</td>
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<td>Consolidation of service providers</td>
<td>Integrated facility management</td>
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<td>Worker Productivity</td>
<td>Human perception and productivity</td>
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<td>Low-cost sensors &amp; computers</td>
<td>Distributed power generation</td>
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<td>Population Growth</td>
<td>Improved food production, preservation, transportation, and storage</td>
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<td>Food Quality Demands</td>
<td>Small-scale refrigeration systems</td>
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<td>Electronic cooling needs</td>
<td>Low temperature system / cryogenics</td>
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<td>Medical needs</td>
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