Summary of Research Activities

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Main Driving Factors for Research are Energy and Environment

- Energy Conversion/Distribution
  - power generation
  - electrical transmission
  - oil refining

- Fossil Fuel Resources
  - oil
  - natural gas
  - coal

- Commercial Residential
  - buildings
  - refrigeration

- Industry
  - manufacturing
  - food processing
  - chemical processing

- Transportation
  - automobiles, trucks, buses
  - planes, ships

- Global Warming
- Acid Rain
- Ozone Depletion
Thermal System Research Area

Fundamentals
- thermodynamics
- heat transfer
- fluids dynamics
- mechanics
- controls
- sensors

Applications
- vapor compression systems & components
- alternative ref. cycles
- thermal storage
- buildings
- furnaces
- appliances
- automotive
- power plants

Analysis Tools
- modeling
- numerical methods
- experimental techniques
- optimization methods
- Information technology

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Thermal Systems Strategic Plan

International Reputation
- Papers, short courses, conferences
- ASHRAE, ARI, IIR participation

Critical Mass of Faculty Expertise

Attract Government Funding
- Research support
- Equipment grants

Recruit High Quality Graduate Students
- Solve fundamental problems

Heat Transfer
- Fluids
- Thermodynamics
- Machinery
- Controls
- Modeling
- Experiments
- Optimization

Solutions
- Knowledge
- Engineers & researchers

Serve the HVAC&R Industry
- Resources
- Problems
- Gifts
- Testing contracts

High Quality Research Facilities
Main Research Thrusts

- **Alternative Technologies** for heat pumping, air conditioning, refrigeration, drying, etc.:
  - Analysis of transcritical CO\textsubscript{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\textsubscript{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 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 compressors for electronics cooling
  – Evaluation of miniature-scale diaphragm compressors for electronics cooling
Test Facilities

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
Alternative Refrigeration Technologies: Transcritical CO$_2$ Cycle

**CO$_2$ Compressor Load Stand:**

**Performance of CO$_2$ Prototype Compressor:**

The diagram shows the overall isentropic efficiency as a function of pressure ratio $p_2/p_1$.

The equation for overall isentropic efficiency is:

$$\text{ov.Is.eff} = -2.78259157 \times 10^{-1} + 8.95484761 \times 10^{-3} \cdot p_1 - 2.69714368 \times 10^{-2} \cdot p_1^2 + 9.76968361 \times 10^{-4} \cdot p_1^3 + 2.55739111 \times 10^{-1} \cdot p_2 - 2.83526791 \times 10^{-2} \cdot p_2^2 + 9.86399651 \times 10^{-4} \cdot p_2^3 + 2.58389357 \times 10^{-2} \cdot p_1 \cdot p_2 - 9.84810719 \times 10^{-4} \cdot p_1 \cdot p_2^2 - 1.70586490 \times 10^{-4} \cdot p_1^2 \cdot p_2$$

where $p_1 = \text{suction pressure [MPa]}$ and $p_2 = \text{discharge pressure [MPa]}$.

$DT_{sh} = 14.6 \text{ K}$, $\text{stdev} = 2.3 \text{ K}$

Approx. $p_1$: 1.76 [MPa]
Approx. $p_1$: 2.47 [MPa]
Approx. $p_1$: 3.12 [MPa]
Approx. $p_1$: 4.19 [MPa]
Approx. $p_1$: 4.81 [MPa]

Measured $p_1$: 1.76 [MPa]
Measured $p_1$: 2.47 [MPa]
Measured $p_1$: 3.12 [MPa]
Measured $p_1$: 4.19 [MPa]
Measured $p_1$: 4.81 [MPa]
Alternative Refrigeration Technologies: Transcritical CO₂ Cycle

Expansion Work Output Machine:
Improved Components: Scroll Compressor Analysis

Experimental Setup:

Model Validation:

![Image of experimental setup and graph]

- Pressure transducers
- Thermocouples
- Photo-electric sensor

Graph showing orbiting angle [degree] vs. pressure [kPa] for Chamber 2, Chamber 4, Chamber 6, and Chamber 7, with model prediction and measurements compared.
Improved Components:
Beard-Pennock Variable-Stroke Compressor (1988)

Concept:

Predicted Performance:

\[ T_{\text{cond}} = 40^\circ\text{C} \quad \text{and} \quad T_{\text{evap}} = -15^\circ\text{C} \]
Improved Components: Refrigerant Flow Distributor Analysis

CFD Modeling of Refrigerant Flow Distribution

Refrigerant Mal-distribution:

- Type 2
- Type 3
- Type 4
- Type 5

\[ \varepsilon_{\text{m}, \text{ix}} \times 100 \% \]
Improved Components: Air-Side Heat Exchanger Fouling Analysis

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

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

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</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>
Miniature-Scale Refrigeration System (MSRS)

Target Operating Conditions

- Cooling capacity: \(\geq 200\text{W}\)
- 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

DC rotary compressor; \(\phi\) 85 mm & 166 mm height & 2.8 kg weight

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## Future Research Opportunities

<table>
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<tr>
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<th>Research Directions</th>
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<td>Global warming</td>
<td>Energy efficiency improvements</td>
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<tr>
<td>Utility deregulation</td>
<td>Alternative technologies</td>
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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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<tr>
<td>Population Growth</td>
<td>Improved food production, preservation, transportation, and storage</td>
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<tr>
<td>Food Quality Demands</td>
<td>Small-scale refrigeration systems</td>
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<tr>
<td>Electronic cooling needs</td>
<td>Low temperature system / cryogenics</td>
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<tr>
<td>Medical needs</td>
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