Objectives
Demonstrate new sensing techniques to improve performance of CA refrigeration systems.

Significant Findings
• A new sensing method for detection of frost/ice on evaporators was evaluated for use on CA refrigeration systems. The method was found to be unsuitable for large steel evaporator units used in CA rooms.

• A new sensing technique for monitoring pressures in closed-loop CA refrigeration systems was demonstrated.

Methods
Frost/Ice Sensor for Defrost Control
The sensing principle utilized for both the defrost sensor and the pressure sensor requires that ultrasonic energy (frequency range 30 kHz) be transmitted through the evaporator tubing. A schematic of the measurement scheme appears in Figure 1. This project initiated with a field experiment at Stemilt facilities in Pasco, Washington, to determine the vibration power spectra arising from an operating CA evaporator unit (Figure 2). These power spectra enabled us to choose suitable excitation frequencies for the defrost control sensor. Prior to defrost, ice on the evaporator serves as a bridge to increase mechanical coupling between the tubing and fins. During ice buildup, ultrasonic energy introduced by the transmit transducer will be shunted to the fins resulting in a decrease in signal level observed by the receive transducer. In our prior work on commercial air conditioning units, this effect is very pronounced (Figure 3). For the current experiments, an out-of-service evaporator unit was borrowed from Doubl Kold, Yakima, Washington. Piezoelectric transducers were affixed in pairs (one transmitter, one receiver) at a variety of locations on the unit (Figure 4). Ice was formed on the evaporator by discharging a large carbon dioxide cylinder through the fins. Output signal level was monitored with an oscilloscope and AC voltmeter. Initial measurements indicated that the transmit/receive piezoelectric transducers exhibited high temperature sensitivity during the simulated freeze-up (Figure 5), necessitating their mounting in temperature-controlled enclosures (Figure 6).

Non-Invasive Pressure Sensor
Further experiments were performed to assess the suitability of the ultrasonic sensing method to non-invasively monitor pressures in refrigeration lines (to monitor refrigerant levels, compressor operation, etc.). The attraction of this scheme is that the pressure measurements are made outside the piping eliminating the need for penetrations into the sealed system. Our hypothesis is that
Strains/stresses induced in the piping by internal pressures will manifest as changes in ultrasonic propagation properties (velocity, attenuation, dispersion) through the piping. The system used for these experiments is depicted schematically in Figure 7. A photograph of the laboratory setup appears in Figure 8. The transmitting piezoelectric transducer was excited with a constant amplitude sine wave over a frequency range of 100 Hz to 100 KHz. Output of the receiving transducer was measured as a function of excitation frequency with a lock-in amplifier to determine amplitude and phase. Measurements were performed for several internal pipe pressures while the pipe was held at constant temperature. Sample data appear in Figure 9 for a narrow frequency range between 30.1-30.2 kHz. These data indicate that both phase and amplitude of the detected signal are functions of internal pipe pressure suggesting that this method may be useful for non-invasive pressure measurements.

Results and Discussion

- With constant amplitude transmitter excitation and ice on the evaporator, no signal fluctuation was observed at the receiver that could not be attributed to temperature sensitivity of the piezoelectric transducers. This result is in marked contrast to our previous measurements on a commercial HVAC evaporator coil. We suspect the negative result to be due to the much larger mass and better mechanical coupling of the CA evaporator unit. The CA unit fins were made of heavy galvanized steel (compared to light aluminum in the HVAC unit). Also, a number of welded plates on the CA unit mechanically coupled the evaporator tubing lines making it difficult to predictably propagate ultrasound along any given evaporator tube. Consequently, this scheme for frost/ice detection (and defrost control) appears to be unsuitable for large, steel evaporator units.

- Experiments to demonstrate the non-invasive pressure sensor concept have been successful. We have observed frequency-dependent variations in transmitted ultrasound amplitude and phase for varying internal pipe pressure. These results suggest that, if transducer temperature dependence can be minimized, this method may be useful for monitoring internal pressures in sealed refrigeration systems (without introducing new penetrations).

Budget

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<td>Staff Labor</td>
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Measurements indicated no significant vibration components above 15 KHz.

Figure 1. Defrost Sensor Measurement System

Figure 2. Vibration Power Spectra Obtained at Stemilt Facilities in Pasco, Washington
Figure 3. Ice Sensor Demonstrated on Commercial HVAC Unit
**Figure 4.** Transducer Placement on Doubl Kold Evaporator

**Figure 5.** Temperature Sensitivity of Piezoelectric Transducers
Figure 6. Temperature-Controlled Transducer Enclosure

Figure 7. Non-Invasive Pressure Sensor
Figure 8. Laboratory Setup for Evaluation of Non-Invasive Pressure Sensor
Figure 9. Amplitude and Phase Variations with Internal Pipe Pressure