2009 BFRL Project Description

Project Title: Fully Automated Fault Detection and Diagnostic Methods for Residential Heat Pumps

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BFRL Program: Healthy and Sustainable Buildings

Objective: BFRL will develop and validate Fault Detection and Diagnosis (FDD) methods for residential heat pump systems and system components and validate these methods, as installed, to ensure these heat pumps perform as designed throughout their lifetime, thus saving energy, reducing refrigerant emissions, and providing reliable comfort for home owners.

Problem:

What is the problem? Energy consumption for residential heating and cooling accounted for 28.6 % of total electrical energy consumption by residential buildings in 2005[1]. In order to move the nation toward Net Zero Energy Buildings[2], it is imperative that this equipment operate at its optimum efficiency throughout its lifecycle[3]. Faulty heat pumps waste energy, and the occurrence of faults is common. Proctor performed a field survey of 55,000 air conditioning units and found that 95 % failed a diagnostic test due to improper refrigerant charge, duct leakage, improper airflow, non-condensable gas contamination, or oversizing[4]. Another independent survey of 1500 rooftop units showed that the average efficiency was only 80 % of the expected value, primarily due to improper refrigerant charge[5]. Heating efficiency degradation will waste even more electrical energy because any shortfall in heating capacity must be met by using lower efficiency electrical resistance heaters.

Timely detection and elimination of faults can result in substantial energy savings on a national scale. FDD has the potential of reducing energy use and directly contributing to GHG emission reductions by monitoring the heat pump and warning of any performance degradation.

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[1] DOE Buildings Energy Data Book, http://buildingsdatabook.eren.doe.gov/docs/1.2.3.pdf
[2] http://www.eere.energy.gov/buildings/highperformance/zero_energy_buildings.html
[3] HUD/PATH, Technology Roadmap, Volume 2: Strategies Defined, http://www.pathnet.org/sp.asp?id=10155
[4] Proctor, J., 2004. "Residential and Small Commercial Air Conditioning – Rated Efficiency Isn't Automatic," ASHRAE Public Session, Anaheim CA, Meeting.
[5] Rossi, T.M., 2004, "Unitary Air Conditioner Field Performance," International Refrigeration and Air Conditioning Conference at Purdue, Paper No. R146, July 12-15, West Lafayette, IN.

Why is it hard to solve? Residential heat pumps are field-assembled, and their characteristics are affected by the specifics of each installation. The FDD method must have "learning" capabilities to account for these varied installations and still have rigorous diagnostic methods. Additional difficulty is added by the active refrigerant flow control used in most heat pumps and by extended periods of transient operation in the heating mode due to frost formation on the outdoor heat exchanger. To be applied, the FDD method must be economically viable; the use of expensive sensors must be justified on a life cycle basis.

How is it solved today, and by whom? The measurement science for FDD application in field-assembled heat pumps has not been solved. In a limited scope, fault detection is implemented within the basic control unit of large water chillers where the cost of the system is large in comparison to the cost of sensors that indicate selected faults. Prior research includes studies on water chillers[6], factory-assembled roof top units[7], and NIST testing of a cooling mode field-assembled system[8]. Yet, no one has directly investigated adaptable FDD for field-assembled systems with active refrigerant flow control in the heating mode.

Why NIST? The project is aligned with the BFRL mission and vision by developing the measurement science of FDD methods for residential field-assembled heat pumps, anticipating the needs of the U.S. HVAC&R industry. The project also supports the BFRL strategic priority of Measurement Science for Net Zero Energy, High-Performance Buildings[9] to reduce energy use and energy demand in buildings.

Approach:

What is the new technical idea? The application of adaptable, "*learning*" FDD methods to a residential heat pump in the cooling and heating mode has not been investigated. Heat pump heating performance under fault conditions has not been documented in the literature. BFRL will advance measurement science and facilitate implementation of residential FDD by examining heating mode faulty operation and developing new adaptable FDD algorithms. The developed FDD techniques will not only be applicable to heat pumps, but also to other vapor compression systems that can experience similar faults. Generalization of these techniques and application of the statistical methods engrained within the FDD algorithms will give U.S. industry seeds for innovation and will promote faster introduction of this technology into the marketplace.

Why can we succeed now? The lower costs of sensors, computer technology, and controls make FDD more economical, especially in light of increased energy costs. The need for increased energy efficiency to achieve Net Zero Energy Buildings and GHG reduction is pushing all levels of the U.S. HVAC&R industry to produce better products. Organizations such as the

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[6] Navarro-Esbri J, Torrella E, Cabello R., 2007, "A vapour compression chiller fault detection technique based on adaptive algorithms. Application to on-line refrigerant leakage detection," International Journal of Refrigeration, Vol. 29, pp. 716-723.

[7] Breuker, M.S. and Braun, J.E., 1998, "Evaluating the performance of a fault detection and diagnostic system for vapor compression equipment," HVAC&R Research, Vol. 4, No. 4, pp. 401-425.

[8] Kim M, Payne WV, Domanski PA, Hermes CJL. 2006. Performance of a residential heat pump operating in the cooling mode with single faults imposed. NISTIR 7350, Gaithersburg, MD: National Institute of Standards and Technology.

[9] Zero Energy Buildings: A Critical Look at the Definition, http://www.nrel.gov/docs/fy06osti/39833.pdf

U.S. Green Building Council[10], the DOE Building Technologies Program[11], the National Science and Technology Council's (NSTC) subcommittee on Buildings Technology Research[12], along with industry organizations, see the need for energy efficient HVAC systems.

What is the research plan? The proposed FY09 project involves completing the heating mode FDD algorithm begun in FY08 and experimentally validating the cooling and heating mode algorithms within our environmental chamber test facility. We will verify the FDD algorithms by processing previously taken fault-imposed test data with the new algorithms and testing the algorithms on an operating heat pump.

In FY09, we will begin developing a "self training" method within our FDD module, which is the key for deploying FDD in field-assembled systems. FDD systems will be implemented on residential field-assembled heat pumps, thus the system reference model and important fault threshold values must "adapt" to these widely varying, as-installed configurations. The FDD system must be able to store data during steady-state and fault-free operation, refine its fault-free reference model, and adjust statistically determined fault thresholds. The FDD system must also account for heat pump aging.

Our experimental results and analytical developments will be published within internal reports and archival journal papers. Developmental versions of the FDD techniques will be made available to the HVAC&R industry for their inspection, implementation, and feedback. We expect that these interactions will lead to FDD field testing by manufacturers involved.

BFRL will begin work on an automated Commissioning Tool that takes advantage of the capabilities installed with the heat pump FDD system. Improper installation of a heat pump results in degraded efficiency. Based upon discussions with manufacturers, the majority of warranty issues and equipment failures are caused by improper installation. The Commissioning Tool will guide the installer in setting proper refrigerant charge, establishing proper indoor unit airflow rates, and verifying the overall health of the system within its measurement capabilities. The main advantage of this Commissioning Tool will be the verified, standardized installation of heat pumps that perform as-designed from the first day.

BFRL work will focus upon component level FDD that may be applied to individual subsystems within a complete heat pump system. For example, a particular outdoor unit (consisting of the compressor, outdoor heat exchanger, and outdoor fan) is installed with various indoor air movers, such as furnaces or air handlers. Manufacturers see the benefit in having a FDD system that can at least diagnose faults with the outdoor unit components, and ideally operate in a "plug-n-play" fashion with multiple indoor unit components.

Recent Results:

Output: Kim M, Payne WV, Domanski PA, Hermes CJL, Yoon SH., 2008. Performance of a residential heat pump operating in the cooling mode with single faults imposed. Accepted by *Applied Thermal Engineering*, http://dx.doi.org/10.1016/j.applthermaleng.2008.04.009

[10] http://www.usgbc.org/
[11] http://www.eere.energy.gov/buildings/
[12] http://www.ostp.gov/cs/nstc

Output: Kim M, Yoon SH, Payne WV, Domanski PA., 2008. Development of the reference model for a residential heat pump system for cooling mode fault detection and diagnosis. Submitted to *HVAC&R Research Journal*, ASHRAE, May.

Output: Kim M, Yoon SH, Payne WV, Domanski PA., 2007. Design of a steady-state detector for fault detection and diagnosis of a residential air conditioner. *Int. J. of Refrigeration*. Vol. 31(5), pp. 790-799.

Standards and Codes: There are no standards or codes that apply directly to this work.