2009 BFRL Project Description

Project Title: Novel Methods for Optimization of HVAC&R Equipment

August 25, 2008

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BFRL Program: Healthy and Sustainable Buildings

Objective: To provide the measurement science needed to reduce the energy consumption associated with HVAC&R equipment through the development of computational intelligence based design tools for heat exchangers.

Problem:

What is the problem?

In 2005, the US energy usage for refrigeration and space cooling in residential and commercial building accounted for 25.8 % of total electrical energy use in buildings[1]. The efficiency of the heat exchangers used in these applications are strongly influenced by (1) the inlet distribution of the air that passes through them, which dictates the amount of air available for heat exchange at any given location within the heat exchanger, and (2) the refrigerant circuitry, the sequence in which tubes are connected to form the refrigerant flow path, which dictates the amount and thermodynamic state of the refrigerant at any given location within the heat exchanger. An optimized finned-tube heat exchanger is one in which these two factors are best matched. This can only be accomplished when the measurement science exists to accurately measure the air flow distribution, and to correspondingly distribute refrigerant flow in the heat exchanger.

The ASHRAE Strategic Research Plan[2] targets design tools that improve the energy efficiency of installed HVAC systems and components as a major goal towards achieving net zero energy buildings. It is reasonable to assume that the current practice of disregarding air distribution results in a minimum of 2% reduction in overall system efficiency, but may be as

[1] 2007 DOE Buildings Energy Data Book, http://buildingsdatabook.eren.doe.gov/
[2] ASHRAE Strategic Research Plan 2005-2015, Navigation for a Sustainable Future, http://www.ashrae.org/docLib/200641713376_347.pdf

much as 10% under certain conditions[3]. This loss can be substantially avoided by optimizing refrigerant circuitry design[4].

Why is it hard to solve?

Optimizing the performance of finned tube heat exchangers is a complicated problem that requires a large effort on two fronts. The key to optimization is designing the refrigerant circuitry to accommodate the existing air distribution. Accurate knowledge of in-situ air flow distribution is critical, which is difficult to obtain by traditional methods. Once this information is obtained, the next step is to determine the best way to design the refrigerant circuitry for it. The number of possible circuitry architectures is extraordinarily large; e.g., a small heat exchanger consisting of 36 tubes has approximately $2 \cdot 10^{45}$ possible architectures. The large number of possible designs makes it difficult to find the optimal refrigerant circuitry, particularly if the air flow is not uniformly distributed over the coil surface.

How is it solved today, and by whom?

The current state-of-the-art is to either measure air-side velocity distribution with hot wire anemometers, which are cumbersome and inaccurate; use Computational Fluid Dynamics (CFD) simulations without proper validation, or simply to assume a distribution for the purpose of heat exchanger design. To our knowledge there is no public domain information, domestic or international, providing air flow distribution information for finned-tube heat exchangers with the accuracy and detail that Particle Image Velocimetry (PIV) can provide, outside of this project. Furthermore, our industry contacts have indicated that proprietary information might not exist at all. The use of computational intelligence algorithms to assist with refrigerant circuitry design is a novel concept, and is unique.

Why NIST?

This project directly promotes US innovation and competitiveness by providing the measurement science necessary to determine the air velocity profile through finned-tube heat exchangers and developing the computational intelligence software package that enables equipment manufacturers to design products with superior performance over those currently in production. This project is firmly aligned with the Measurement Science for Building Energy Technology BFRL competency since the measurements and models produced here will result in reduction of energy use on a national scale.

Approach:

What is the new technical idea?

There are two new technical ideas involved in this project, each task emphasizes one. PIV will be applied to accurately measure the air velocity distribution through a finned-tube heat exchanger. PIV is a technique for measuring flow velocity which uses a high-speed, high-

[3] M. Chwalowski, D.A. Didion, P.A. Domanski, Verification of evaporator computer models and analysis of performance of an evaporator coil, ASHRAE Transactions 95 (1) (1989) (Paper No. CH-89-23-1).
[4] Domanski, P. A., Yashar, D. A. and Kim, M. Performance of a finned-tube evaporator optimized for different refrigerants and its effect on system efficiency, Int. J. of Ref. Vol 28 (2005), May 2005.

resolution camera to track the motion of illuminated dust particles entrained in a flow field. A preliminary FY08 study demonstrated that this highly accurate measurement technique can uncover detailed air flow patterns that cannot be registered by traditional measurement methods. The preliminary study will be extended to heat exchangers operating at controlled air conditions. The overall goal is to make high-accuracy measurements of air distributions for representative heat exchangers, develop understanding of prevailing flow patterns in typical HVAC heat exchanger installations, and validate CFD-based models for accurate predictions of air velocity.

Additionally the project will experimentally verify the performance enhancements that are possible through the use of our computational intelligence-based optimization program ISHED (Intelligent System for Heat Exchange Design)[5]. The concept and beta version of ISHED were developed in recent years through a cooperative effort between BFRL and George Mason University. Until now, ISHED has only been evaluated analytically. In every case examined, ISHED proved capable of generating refrigerant circuitry architectures for finned-tube heat exchangers that resulted in the same or higher capacities than those of the heat exchangers generated by humans[6].

Why can we succeed now?

Advances in measurement techniques, PIV, allow us to accurately measure the air distribution. Advances in computational intelligence that will allow the optimization of refrigerant circuitry for in-situ air flow distribution is a recent advancement. The overall project can succeed because the increasing need to improve efficiency generates demand for optimization tools that help us save energy; therefore these tools will be employed by industry as a result of this project.

What is the research plan?

The research plan is described by the following two tasks:

Task 1 started in FY08 and is concerned with the determination of the heat exchanger inlet air distribution via PIV measurements and CFD simulations. The Air Conditioning and Refrigeration Technology Institute (ARTI) co-funded this portion of the project with some significant suggestions that structured the focus of the research.

<u>1a) Laboratory Phase:</u> PIV measurements will be taken to characterize the air flow distribution for a common residential air conditioning heat exchanger coil in the horizontal flow configuration. We will use PIV to examine the air flow distribution at the heat exchanger inlet and outlet, under two different air flow rates, and under dry and dehumidification conditions.

<u>1b) Modeling Phase:</u> The ultimate goal of this effort is to determine the steps and assumptions necessary to formulate CFD models that provide accurate predictions of real world air flow distributions, including the effects of moisture removal and the variation of air flow rate. We will use a commercial software package to construct a CFD model that predicts the air flow

[5] Domanski, P. A., Yashar, D. A., Kaufman, K. A. and Michalski, RK. SA. An Optimized Design of Finned-Tube Evaporators Using the Learnable Evolution Model HVAC&R Research April 01, 2004.
[6] Domanski, P. A.; Yashar, D. A., Optimization of Finned-Tube Condensers Using an Intelligent System, International Journal of Refrigeration, Vol. 30, No. 3, 482-488, May 2007.

distribution for the configurations tested during the laboratory phase and we will use the results of the PIV measurements to validate these simulations.

Task 2 is concerned with practical demonstration of intelligent heat exchanger design software tool for optimization of refrigerant circuitry.

2a). Laboratory Phase 1: Two major equipment manufactures will each provide us with two conventional evaporators for testing at NIST. We will measure the inlet air velocity profiles through either PIV or hot wire anemometry; PIV will be used for any installation where the necessary line-of-sight can be established. We will also measure each evaporator's capacity in cooling mode operation.

2b) Optimization Phase: We will perform ISHED optimization runs for each heat exchanger using the measured air flow data from Sub-task 2a as input. Therefore, we will determine a unique circuitry configuration for each heat exchanger based on its specific air flow distribution. Through this effort, we will also determine an analytical prediction of the capacity improvement that will result from each optimized circuitry configuration.

2c) Laboratory Phase 2: Each equipment manufacturer will assemble new heat exchangers, similar to the original test subjects but with the ISHED-generated circuitry configurations. We will measure the capacity of the optimized evaporators in our laboratory to demonstrate the performance improvement resulting from the optimized circuitries.

Recent Results:

Output: Yashar, D., Cho, H., and Domanski, P., 2008, Measurement of Air velocity Profiles for Finned-Tube Heat Exchangers Using Particle Image Velocimetry, Int. Ref. and AC Conf. at Purdue University.
Outcome: Demonstrated use of PIV for detailed characterization of air flow distribution in air-to-refrigerant heat exchangers.

Output: NIST Tech Beat article, January 23, 2008, NIST Helps Heat Pumps 'Go With the Flow' to Boost Output. (At least twelve media outlets rebroadcast January TechBeat article)

Output: Domanski, P. A., Yashar, D., 2007, Optimization of Finned-Tube Condensers Using an Intelligent System, Int. J. Refrig., 30(3) 482-488.
Outcome: **Spanish** translation published in Frio Calor Aire Acondicionado, February 2008;

Output: David Yashar and Hong Hyun Cho, 2007, Air-Side Velocity Distribution in Finned-Tube Heat Exchangers, NISTIR 7474.

Output: Domanski, P. A., 2007, Application of Evolutionary Algorithms for Refrigerant Circuitry Optimization, Technical Presentation at the ASHRAE Winter Meeting, Dallas, TX, January 28.

Output: Established Cooperative Research and Development Agreement with ARTI, 2007

Standards and Codes:

None