2009 BFRL Project Description

Project Title: Advanced Tools for Simulating Performance of Vapor Compression Systems

August 25, 2008

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BFRL Program: Healthy and Sustainable Buildings

Objective: To develop the measurement science needed for the design of high-efficiency vapor-compression cooling and heating systems.

Problem:

What is the problem? Residential energy usage for space cooling and heating accounted for 28.6 % of total electrical energy consumption by residential buildings in 2005[1]. We can conserve energy and reduce operational costs by improving the efficiency of vapor-compression cooling and heating equipment. In recent years, increasing concerns about climate change put additional emphasis on the importance of equipment efficiency because the greenhouse effect from CO_2 that is released upon burning fossil fuels to power the air-conditioning system is greater than that of the refrigerant. Greenhouse gas (GHG) emission reductions due to efficiency improvements offer the least expensive and highest impact path[2].

The coefficient of performance (COP) of a vapor-compression system is limited by the Carnot cycle's COP, and practical efficiency improvements are increasingly more difficult to obtain. To generate new, more energy-efficient systems, industry needs new, effective simulation tools to evaluate merits of different refrigerants and design options[3].

Why is it hard to solve? To effectively and correctly evaluate new designs, simulation models must be based on physical principles, and must use the best analytical representations of the fluid properties and processes involved. The simulation tools must account for all influential phenomena affecting the performance of refrigerants and equipment. Computational robustness is also required for these tools, particularly when considering optimization opportunities provided by computational-intelligence methods, where a simulation model can be called several thousand times within a single optimization run.

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[1] 2007 DOE Buildings Energy Data Book, http://buildingsdatabook.eren.doe.gov/
[2] Reducing U. S. Greenhouse Gas Emissions: How Much at What Cost?, http://www.mckinsey.com/clientservice/ccsi/pdf/US_ghg_final_report.pdf
[3] ASHRAE Research Strategic Plan 2005-2010: Navigation for Sustainable Future, http://www.ashrae.org/docLib/200641713376_347.pdf

How is it solved today, and by whom? The measurement science (physics-based modeling tools) needed for automated optimization of vapor-compression cooling and heating equipment using computation-intelligence methods is not currently available. The heat pump simulation developed by Oak Ridge National Laboratory, Mark V[4], is suitable for general system design and rating development, but it does not allow optimizing refrigerant circuitry architectures in the heat exchangers. Also, public domain does not include a model for simulating a composition shift of the zeotropic refrigerant mixture during a leak/recharge event.

Why NIST? This project is aligned with the BFRL mission and vision by providing industry with performance prediction tools for refrigerants and vapor-compression systems. This project also directly supports the BFRL Strategic Priority of Measurement Science for Net Zero Energy, High-Performance Buildings because the knowledge and simulation tools developed under this project will help in reducing the amount of energy used for cooling and heating in buildings. The proposed work will utilized NIST's unique capabilities to optimize refrigerant circuitry to investigate the impact of various real-world air velocity distributions across the heat exchangers and evaluate alternative refrigerants.

Approach:

What is the new technical idea? We will equip BFRL's EVAP-COND design tool for evaporators and condensers with the capability of accounting for a two-dimensional inlet air distribution. This will enhance the opportunity to optimize heat exchangers and to improve the system performance. The internal logical structure of the program will be revamped to allow for assigning air mass flow rate, temperature, and humidity to individual sub-elements of the heat exchangers. Both refrigerant and air parameters will have to be traced within the heat transfer process in the heat exchanger, and the mixing of air will have to be accounted for while air flows through the heat exchanger and is redirected by heat exchanger tubes. The modeling task will be more involved for the evaporator than the condenser because the water vapor contained in the air stream may condense on the evaporator surface. This process will have to be accounted for to enforce the mass conservation principle for water and properly model the heat transfer between the wet heat exchanger surface and air.

The evaporator (EVAP) and condenser (COND) simulation modules from EVAP-COND will be employed in HPSIM, which will provide the user with the heat exchanger simulation capability and the detailed analysis available in EVAP-COND. The designer will be able to use HPSIM to verify and tune up the heat exchanger design in complete system simulations after a preliminary design effort using EVAP-COND. Future expansion to the EVAP-COND and HPSIM models will include implementation of novel microchannel heat exchangers, which industry is beginning to examine because of their better heat transfer characteristics than traditional finned-tube designs.

Why can we succeed now? Increased computer capabilities facilitated the acceptance of computationally intensive, fundamental simulation models. Breakthrough improvements in CPU speed allow us to introduce additional levels of analysis to our simulation models that improve

[4] http://www.ornl.gov/sci/btc/apps/hpdm.html

the accuracy of their predictions without significantly increasing simulation time. Equipment manufactures are increasingly relying on simulation models in their R/D efforts.

What is the research plan?

The project is divided into three tasks with separate deliverables and milestones.

Task 1. Expansion of EVAP-COND. We will develop a new version of EVAP-COND that will account for two-dimensional, non-uniform air distribution. The main parts of EVAP-COND are the evaporator model, condenser model, and Graphical User Interface (GUI); each of them will undergo substantial modifications. The technical nature of changes in the evaporator and condenser model is defined by the modeling approach stated above. The effort required to implement these changes is large because the nature of the changes and the large size of evaporator and condenser simulation modules, since some changes will propagate through the source code (e.g., the evaporator code consists of 157 subroutines without counting the refrigerant property routines imported from REFPROP[5]). We expect that the new detailed modeling approach will create stability problems which we will address.

We will modify the GUI to facilitate input of a two-dimensional air distribution. All changes in the program will be reflected in the modified Help Menu. An EVAP-COND installation module will be prepared and placed on BFRL website for download.

Task 2. HPSIM Heat Pump Simulation Model. We will complete our physics-based simulation model of a heat pump, HPSIM, equipped with a thermostatic expansion device. This model will include the FY08 version of EVAP-COND heat exchanger modules. The effort will include debugging of the system model, completion and debugging of the GUI, implementing comments received from industry reviewers, developing the Help Menu, developing HPSIM installation module, and placing it on the BFRL website.

Task 3. Standard Reference Data Databases. The HVAC&R Equipment Performance Group developed and maintains two programs/databases distributed by the Standard Reference Data Program of NIST, CYCLE_D and REFLEAK. REFLEAK is used by companies that apply to ASHRAE for classification and listing of their new zeotropic refrigerant mixtures in ASHRAE Standard 34[6]. In FY09, we will complete the harmonization of REFLEAK with this standard. When harmonized, REFLEAK will include a new simulation path tailored to match the ASHRAE submittal requirements (refined by ASHRAE in interactions with NIST). The REFLEAK GUI and simulator will require modifications.

Recent Results:

Output: Domanski, P.A., 2008. EVAP-COND, Version 2.3; finned-tube simulation model, placed on BFRL website, May 2008.

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[5] Lemmon, E. W., Huber, M. L., McLinden, M. O., 2007, NIST Reference Fluid Thermodynamic and Transport Properties Database (REFPROP): Version 8.0. NIST Standard Reference Database 23, National Institute of Standards and Technology, Gaithersburg, Maryland, U.S.A.

[6] ANSI/ASHRAE Standard 34, Designation and Safety Classification of Refrigerants

Outcome: Over 3000 downloads of EVAP-COND since January 2003 by manufacturers, consultants and academia.
Impact: Manufacturers use EVAP-COND to design high-efficiency systems.

Output: Domanski, P.A., Hermes, C.J.L., 2008. An improved correlation for two-phase pressure drop of R-22 and R-410A in 180° return bends, Applied Thermal Engineering, Vol. 28, pp. 793-800.

Output: Gebbie, J. G., Jensen, M. K., Domanski, P.A., 2007, Experimental Transient Performance of a Heat Pump Equipped With a Distillation Column", Int. J. Refrig., Vol. 30, No. 3. pp. 499-505.

Output: Standard Reference Database 73, *REFLEAK: NIST Leak/Recharge Simulation Program for Refrigerant Mixtures*, Version 3.1, Nov. 2007. (Didion, D.A., Kim, M.S., Domanski, P.A.

Output: Domanski, P.A., Choi, J. M., Payne, W. V., 2007. Longitudinal Heat Conduction in Finned-Tube Evaporators", Int. Congress of Refrigeration, Beijing, August 20-26.

Outcome: *Sixth translation* of the paper "*Status of R22 Replacements*", *ASHRAE Journal*, 46(8):29-39, 08/2004, by Calm, J. and Domanski, P.A. Статус-kbo с Заменой Хладагента R-22 (in Russian), ИЗВЕСТИЯ СПбГУНиПТ 1', 2008, pp. 28-36. The previous translations were in Chinese, Portuguese, Polish, Italian and Spanish. The paper was also re-published in English in Australia.

Standards and Codes: ASHRAE Standard 34; the new version of REFLEAK will be synchronized with the submittal requirements for a zeotropic mixture to ASHRAE Standard Project Committee 34; it will simplify preparing the submittals by industry and evaluating these submittals by the ASHRAE committee.