HVAC Energy Efficiency

Maintenance Study

Appendices

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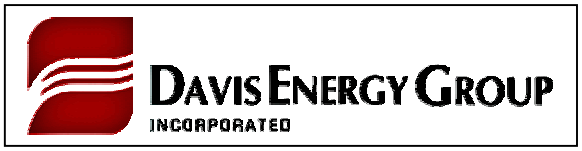

HVAC Energy Efficiency Maintenance Study

Appendix A:

Bibliography

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Preface

This document compiles existing literature on factors that impact HVAC maintenance measures, policy, program design, evaluation, and end-user behavior. Findings are categorized by the most influential elements of HVAC programs; Laboratory Testing, Field Testing, Diagnostic Methods, Standards, Human Factors, Policy, and Evaluation, Verification, and Measurement. There is a wealth of existing research and independent findings but few places where this information is brought together to provide a broader examination of possibilities and limitations for the development of future HVAC programs. In bringing these documents together, we hope to facilitate the examination of them in the context of each other rather than as independent findings. Our goal is to be comprehensive thereby providing a valuable tool to the reader. References incorporated in the documents can be followed as needed by the reader. Summaries of important documents are selectively included and contain material taken from the document abstract, executive summary, or elsewhere as needed; and are to be understood as being attributed to those documents without having to include reference footnotes. In support of making this document as useful as possible, we welcome additions, modifications and corrections. Please make submittals to: Dr. Kristin Heinemeier, kheinemeier@ucdavis.edu .

Laboratory Testing

Since the beginning of the manufacturing of direct expansion (DX), unitary HVAC equipment extensive testing has been performed by researchers, government laboratories, manufacturers and private laboratories. With the development of national energy efficiency standards laboratory testing has been done in support of certified equipment efficiency programs. The Air-conditioning, Heating and Refrigeration Institute (AHRI) Standards 210/240 (up to 65,000 Btuh) and 340/360 (above 65,000 Btuh) establish the testing required for developing EER and SEER efficiency ratings. Two chambers, indoors and outdoors, are used each being able to maintain prescribed temperature and humidity conditions while the equipment being tested is run for testing. "Off rating" conditions testing are when the chambers are operated at setpoints that are not those specified by the AHRI standards and/or faults are introduced in the system being tested. While the standards specify the measurements and calculations to be made laboratories, especially ones like Herrick Laboratory at Purdue University, take additional data. This type of detailed data is used to develop and calibrate mathematical, computer simulations of the system. The "off rating" data is the most accurate source of data for assessing the potential of energy efficiency maintenance measures by producing efficiency with and without faults.

Refrigerant Charge and Airflow

Aaron, A. A. and Domanski, P A., "An experimental investigation and modeling of the flow rate of refrigerant through the short tube restrictor: NISTIR 89-4120," 1989.

Bullock, Charles, D. Schuster, and R. Lambert. July, 16, 2004. "Heat Pump Heating Performance Comparison Between Short-tube Orifice and TXV". Prepared by Carrier Residential Engineering in response to questions from Bob Davis, Ecotope.

Chen, Bo, Echard A. Groll, James E. Braun, "Improvement and Validation of Unitary Air Conditioner and Heat Pump Simulation Models at Off-Design Conditions", Final Report – 1173 RP, ASHRAE Inc., HL 2006-2, Report 6304-2, June 2006.

This is one of key reports for understanding the performance of unitary equipment. Simulation models generate the majority of data used for rating equipment and thus it is critical that they be accurate. Exisitng models do not work well at "off-design" conditions and manufacturers seldom perfrom tests at these conditions. Herrick Laboratories at Purdue University have extensive experience in modeling and testing air sourse vapor compression systems. The report builds on that experience and the work of Rossi, Leroy, Harms, and Braun. In the appendices of the report is an extensive data set of tests performed on four different systems. A varietyof faults such as low air flow or low charge are tested.

Choi, J., Payne, W., et. al, "Effects of Non-Uniform Refrigerant and Air Flow Distributions on Finned-Tube Evaporator Performance," NIST, International Congress of Refrigeration 2003.

An experimental investigation was implemented to determine the capacity degradation due to non-uniform refrigerant and airflow distributions, and to assess the potential to recover the lost capacity via controlling refrigerant distribution between individual refrigerant circuits. The tests were performed on a three-circuit, three-depth- row, finned-tube evaporator. Refrigerant inlet quality, exit saturation temperature, and exit superheats for the individual circuits were controlled.

The study showed that capacity degradation due to refrigerant misdistribution can be as much as 30 %, even when the overall evaporator superheat is kept at the target 5.6 ºC. Experimental data indicate that part of this capacity degradation was caused by the internal heat transfer within the evaporator assembly. For the coil and air misdistributions studied, the maximum capacity degradation was found to be 8.7 %. A 4.0% capacity recovery was obtained by controlling refrigerant distribution to obtain the target 5.6 ºC at each circuit exit.

Chwalowski, M., Didion, D. A., and Domanski, P. A., 1989, Verification of Evaporator Computer Models and Analysis of Performance of an Evaporator Coil, ASHRAE Trans., Vol. 95, no. 1.

Davis, R., "Influence of the Expansion Device on the Performance of a Residential Split-System Air Conditioner," Report No. 491-01.4, PG&E, Technical Application Services, January 2001.

In support of energy efficiency programs, Robert Davis conducted testing of a three ton system in which both a TXV and a fixed orifice expansion are installed so that either one can be chosen for a particular test. R-22 is used in this system.

Davis, R. 2001b. Influence of Expansion Device and Refrigerant Charge on the Performance of a Residential Split-System Air Conditioner using R-410a Refrigerant. Report No.: 491-01.7. San Francisco, Calif.: Pacific Gas and Electric.

This is a companion report to 491-01.4. The refrigerant is different and additional test are perfromed. Both reports are primary support documents for estimating the impact of low and high charge conditions with different expansion devices.

Davis, R., Experimental Analysis of Tube Surface Temperature Measurements, Laboratory Test Report # 491-07.6, Applied Technology Services, PG&E, San Ramon, December 6, 2007.

This is a first step in the development of the information that is missing about the uncertainty inherent in different temperature sensors installed in different manners.

Faramarzi, R., Coburn, B., Sarhadian, R., Mitchell, S. and Pierce, R.A., “Performance Evaluation of Rooftop Air Conditioning Units at High Ambient Temperatures. In Proceedings of the ACEEE 2004 Summer Study on Energy Efficiency in Buildings, 2004.

Faramarzi, R., Rauss, D., "An Experimental Approach to Quantify Effects of Common Maintenance Strategies for 5-Ton Rooftop Units," ASHRAE 2010 Annual Meeting – Orlando Seminar 6 (Sponsored by TC-8.11) January 24, 2010, Technology Test Centers (TTC) Southern California Edison www.sce.com/rttc

Farzad, M., and D.L. O’Neal. 1988. An evaluation of improper refrigerant charge on the performance of a split system air conditioner with capillary tube expansion. Texas A&M University, Energy Systems Laboratory Report ESL-TR-88/07-01. July.

Farzad, M., O’Neal, D. 1993. “Influence of the Expansion Device on Air Conditioner System Performance Characteristics Under a Range of Charging Conditions.” Paper 3622. ASHRAE 2004 ACEEE Summer Study Proceedings I-226 Transactions. Atlanta, Ga.: American Society of Heating Refrigerating and Air-Conditioning Engineers.

Harms, T.M., 2002. Charge Inventory System Modeling and Validation for Unitary Air Conditioners, Ph.D. Thesis, Herrick Labs 2002-13, Report No. 5288-2, Purdue University, West Lafayette, IN.

Henderson, H., Rengarajan, K., "A Model to Predict the Latent Capacity of Air Conditioners and Heat Pumps at Part Load Conditions with the Constant Fan Mode. ASHRAE Transactions. 102 (1)," January 1996.

Henderson, H.I., 1990. 'An Experimental Investigation of the Effects of Wet and Dry Coil Conditions on Cyclic Performance in the SEER Procedure,' Proceedings of USNC/IIR Refrigeration Conference at Purdue University, July, West Lafayette, IN

Henderson, H., Parker, D., et. al, "Improving DOE-2's RESYS routine: User Defined Functions to Provide More Accurate Part Load Energy Use and Humidity Predictions," August 2000.

> In hourly energy simulations, it is important to properly predict the performance of air conditioning systems over a range of full and part load operating conditions. An important component of these calculations is to properly consider the performance of the cycling air conditioner and how it interacts with the building. This paper presents improved approaches to properly account for the part load performance of residential and light commercial air conditioning systems in DOE-2.

Henderson, H., Sachs, H., "The Efficacy of SEER as a Seasonal Performance Measure for Different Climates," July 2006.

> In the United States, the energy efficiency of single-phase, central air conditioners and heat pumps up to 65,000 Btu/h is measured by the Seasonal Energy Efficiency Ratio (SEER) test and rating procedure. Over the years the test and rating procedure has been revised several times to account for multi-speed air conditioning systems and other product improvements. In 1992, a SEER of 10 Btu/Wh was set by the federal law to be the minimum allowable efficiency for products sold in the US. On January 2006, the minimum efficiency increased to 13 Btu/Wh. SEER is a single national standard, intended to provide a representative ranking or measure of seasonal performance for typical US climate conditions. This paper evaluates ways that the SEER rating procedure could be modified to provide better and more meaningful predictions of seasonal efficiency and performance in the key US regions. The overall goal is to determine how the calculation procedures could be modified to use the current set of laboratory test data to meet the needs of different US regions. The premise is that climate-specific SEER values could be calculated for each region, while still retaining the current typical SEER for compatibility and compliance with current federal minimum efficiency standards.

Kim, M., Payne, W., et. al, "Performance of a residential heat pump operating in the cooling mode with single faults imposed," Journal of Applied Thermal Engineering, Volume 29, No. 4, March 2009.

> The system behavior of a R410A residential unitary split heat pump operating in the cooling mode was investigated. Seven artificial faults were implemented: compressor/reversing valve leakage, improper outdoor air flow, improper indoor air flow, liquid line restriction, refrigerant undercharge, refrigerant overcharge, and presence of non-condensable gas in the refrigerant. This study monitored eight fault detection features and identified the most sensitive features for each fault. The effect of the various fault levels on energy efficiency ratio (EER) was also estimated. Since the studied system employed a thermostatic expansion valve (TXV) as an expansion device, it could adapt to some faults making the fault less detectable. The distinctiveness of the fault depended on the TXV status (fully open or not). EER is relatively insensitive to evaporator

fouling or refrigerant overcharge faults. Since this is a heat pump system, the evaporator is larger than would be seen in a comparable cooling-only air conditioner; this makes the heat pump system less susceptible to EER degradation due to improper indoor airflow. For refrigerant overcharge, the fault is the most distinctive at the highest temperature lift (indoor and outdoor temperature difference) test #8 showing the low capacity. All faults, except the compressor leakage fault, must have a fault level greater than 10% to produce a 5% decrease in EER. The highest EER degradation occurs with a 20% refrigerant undercharge, especially at the lowest temperature lift occurring for test #5. EER degradation due to overcharge is much smaller.

Kim, M., Payne, W.V., Hermes, C.J.L., and Domanski, P.A., 2006, "Performance of a Residential Air Conditioner at Single-Fault and Multiple-Fault Conditions," NISTIR 7350, National Institute of Standards and Technology, Gaithersburg, MD.

Kim, M., Yoon, S., et. al, "Cooling Mode Fault Detection and Diagnosis Method for a Residential Heat Pump," October 2008.

This research addresses the need for fault detection and diagnosis (FDD) in residential-style, air conditioner, and heat pump systems in an attempt to make these systems more trouble free and energy efficient over their entire lifetime. This work is one of the first to apply FDD techniques to a residential system with the added control element of a thermostatic expansion valve (TXV). Any control element actively seeks to perform its duties and thus obscures any faults occurring by making adjustments. This research work takes this into account and shows how FDD techniques may be applied to this type of system operating in the cooling mode.
Performance characteristics of an R410A residential unitary split heat pump equipped with a TXV were investigated in the cooling mode under no-fault and faulty conditions. Six artificial faults were imposed: compressor/reversing valve leakage, improper outdoor air flow, improper indoor air flow, liquid-line restriction, refrigerant undercharge/overcharge, and presence of non-condensable gas.

Lee, J., Domanski, P. A., 1997, Impact of Air and Refrigerant Misdistributions on the Performance of Finned-Tube Evaporators with R22 and R407C, Report DOE/CE/23810-81 for ARI, National Institute of Standards and Technology, Gaithersburg, MD.

Lee, W.S., Grosh, D.L., Tillman, F.A., and Lie, C.H., 1985, "Fault Tree Analysis, Methods, and Applications – A Review," IEEE Transactions on Reliability, Vol. R-34, No. 3, pp. 194-203.

Lee, W.Y., House, J.M., Park, C., and Kelly, G.E., 1996b, "Fault Diagnosis of Air-Handling Unit Using Artificial Neural Networks," ASHRAE Transactions, Vol. 102, Part. 1, pp. 540-549.

Lee, W.Y., Park, C., and Kelly, G.E., 1996a, "Fault Detection in an Air-Handling Unit Using Residual and Recursive Parameter Identification Methods," ASHRAE Transactions, Vol. 102, Part 1, pp. 528-539.

Levins, W., K. Rice and V. Baxter. 1996. Modeled and Measured Effects of Compressor Downsizing in an Existing Air Conditioner/Heat Pump in Cooling Mode. Prepared for ASHRAE by Oak Ridge National Laboratory, Oak Ridge, TN.

Li, Haorong. A Decoupling-based Unified Fault Detection and Diagnosis Approach for Packaged Air Conditioners, Ph.D. Thesis, West Lafayette, IN: Purdue University, 2004.

This is an important document explicating the mathematics behind fault detection and diagnosis with an emphasis on the importance of uncertainty. Included in the dissertation are helpful charts and graphics some of which are used in the report. Dr. Li is now at the University of Nebraska, Ohama, where he is continuing his work.

Li, H. and Braun, J.E. An Overall Performance Index for Characterizing the Economic Impact of Faults in Direct Expansion Cooling Equipment," International Journal of Refrigeration, Vol. 30, No. 2, Pages 299-310, 2007.

Li, H., Braun, J.E. and Groll, E.A., "The Impact of Fouling on the Performance of Filter-Evaporator Combinations," International Journal of Refrigeration, Vol. 30, No. 3, Pages 489-498, 2007.

Li, Y., Braun, J.E. and Groll, E.A., "The Impact of Filter Type on the Performance of Packaged Air Conditioners," International Journal of Refrigeration, Vol. 30, No. 3, Pages 506-514, 2007.

Mulroy, W., "The Effect of Short Cycling and Fan Delay on the Efficiency of a Modified Residential Heat Pump," ASHRAE Transactions, 1986, V. 92.

The object of this study was to determine if the use of a cycling controller would improve the efficiency of a residential air conditioner or heat pump. It was concluded that any control strategy that resulted in shortened on-cycle runtimes would reduce the cyclic efficiency for all designs tested. It was further concluded, based in part on the work of others, that fan delay is an undesirable control strategy for units that have an indoor air handler and coil installed within the conditioned space.

O'Neal, D.L., C.J. Ramsey, and M. Farzad. 1989. An evaluation of the effects of refrigerant charge on a residential central air conditioner with orifice expansion. Texas A&M Energy Systems Laboratory, ESL-PA-89/03-01.

One of original studies that is widely referenced.

O'Neal, D., Farzad, M. 1990. "The Effect of Improper Refrigerant Charging on Performance of an Air Conditioner with Capillary Tube Expansion." Energy and Buildings 14: 363-371.

Palani, M., O'Neal, D. and Haberl, J. 1992. Monitoring the Performance of a Residential Central Air Conditioner under Degraded Conditions on a Test Bench, ESL-TR-92/05-05, Energy Systems Laboratory.

Palani, M., O'Neal, D., and Haberl, J. 1992. The Effect of Reduced Evaporator Air Flow on the Performance of a Residential Central Air Conditioner, The Eighth Symposium on Improving Building Systems in Hot and Humid Climates.

Pape, F.L.F., Mitchell, J.W., and Beckman, W.A., 1991, "Optimal Control and Fault Detection in Heating, Ventilating, and Air-Conditioning System," ASHRAE Transactions, Vol. 97, Part 1, pp. 729-745.

Rodriguez, A., "Effect of Refrigerant Charge, Duct Leakage, and Evaporator Air Flow on the High Temperature Performance of Air Conditioners and Heat Pumps, Master's Thesis," August 1995.

An experimental study was conducted to quantify the effect of several installation items on the high outdoor ambient temperature performance of air conditioners. These installation items were: improper amount of refrigerant charge, reduced evaporator airflow, and return air leakage from hot attic spaces. Selected results: The performance of the orifice unit was more sensitive to charge than it was for the TXV unit. For the TXV unit on the -27% to +27% charging range, the capacity and EER changed little with charge. A TXV unit and a short-tube orifice unit were also tested for reduced evaporator airflow. As evaporator airflow decreased, the capacity and EER both decreased as expected. However, the drop was not as significant as with the charging tests. For the extreme case of 50% reduced evaporator airflow, neither unit's capacity or EER dropped more than 25%.

Return air leakage from hot attic spaces was simulated by assuming adiabatic mixing of the indoor air at normal conditions with the attic air at high temperatures. Effective capacity and EER both decreased with increased return air leakage. However, power consumption was relatively constant for all variables except outdoor temperature, which meant that for the same power consumption, the unit delivered much lower performance when there was return air leakage. The increase in sensible heat ratio (SHR) with increasing leakage showed perhaps the most detrimental effect of return air leakage on performance, which was the inability of the unit to absorb moisture from the environment.

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.

Schein, J. and Bushby, S., 2005, “A Simulation Study of a Hierarchical, Rule-Based Method for System-Level Fault Detection and Diagnostics in HVAC Systems,” NISTIR 7216, National Institute of Standards and Technology, Gaithersburg, MD.

Shen, B., Groll, E., et. al, "Improvement and Validation of Unitary Air Conditioner and Heat Pump Simulation Models at Off-Design Conditions," June 2006.

Summary: This report discusses sources of simulation inaccuracies under off-design conditions (e.g.,, high ambient temperatures, off-design charges, off-design air flow rates). It evaluates approaches for improving simulation accuracy under off-design conditions.

Shirey, D. and H.I. Henderson. 2004. “Dehumidification at Part Load,” ASHRAE Journal. Vol. 46, No. 4. April.

Siegel, J., and Wray, C., "An Evaluation of Superheat-Based Refrigerant Charge Diagnostics for Residential Cooling Systems," ASHRAE TRANSACTIONS 2002, V. 108, Pt. 2.

Verified, Inc., “Evaluation, Measurement and Verification of Air Conditioner Quality Maintenance Measures: Draft Project Report,” March 2010.

A draft report by VERIFIED, Incorporated with all measurements performed by Intertek Testing Services. The information from this study contributes to Western HVAC Performance Alliance Quality Maintenance Program initiated by California Investor-Owned Utilities under the auspices of the California Public Utilities Commission (CPUC). The study answers the following questions: 1. What are the specific cooling capacity, run time, energy and peak demand savings and energy efficiency ratio (EER) improvements achieved by HVAC QM measures?; 2. What is the baseline for each measure and what parameters need to be measured accurately and precisely to achieve the energy efficiency improvement?; 3. How can the study provide information to inform DEER updates to ex-ante energy and peak demand savings estimates for QM measures?;

4. How can QM measures or procedures be modified to improve performance, persistence, reliability, precision (repeatability), and energy savings?

Watt, J., Haberly, J., O'Neal, D., "Development of Temperature and Humidity-Based Indicators for Diagnosis Problems in Low Tonnage Split System Air Conditioners," 1998.

Presents the results of the literature and indentifies the most common degraded conditions associated with low-tonnage air conditioners. Other laboratory studies as well as marketed diagnostic systems are also summarized. A procedure for identification of useful, low-cost temperature-based indicators of degraded conditions has been developed at the Energy Systems Laboratory, Texas A&M under contract to Honeywell. This paper presents the methodology used to identify the temperature-based indicators for the most common degraded conditions gleaned from the literature.

Ducts

Andrews, J.W., (1997), "Error Analysis for Duct Leakage Tests in ASHRAE Standard 152P", Brookhaven National Laboratory Report 64679.

Andrews, J.W., Pierce, B.L., Hedrick, R., Lubliner, M., Reid, B., and Saum, D., (1997), "Repeatability of ASHAE Standard 152P: results of a round robin test", Draft of paper for ASHRAE TC6.3 symposium.

Boe, A.B., "Review of Literature 1989-1997: Impacts of Forced Air Distribution Systems on Homes and Potential for Improvements," January 1998.

Literature review that examines the effect of forced air systems on home energy loss. Key losses caused by forced air systems include losses due to leakage to/from ducts (particularly if they are located in unconditioned space); losses due to increased building envelope leaks due to addition of forced air (and associated pressure differentials); and thermal siphon effect when system is off. Typical energy losses are 30-40% (without improvement). Study finds that duct repairs can reduce leakage by 40-70%, depending on specifics of system. This translates to 5-20% reduction in annual energy use.

Hammarlund, J., Proctor, J., Kast, G., and Ward, T. 1992. "Enhancing the Performance of HVAC and Distribution Systems in Residential New Construction." In Proceedings of 1992 ACEEE Summer Study on Energy Efficiency in Buildings, 2: 85-87. Washington, D.C.: American Council for an Energy-Efficient Economy.

Lambert, L. and Robison, D., 1989. "Effects of Ducted Forced-Air Heating Systems on Residential Air Leakage and Heating Energy Use." ASHRAE Transactions, v95.2, 534-41.

Palmiter, L. and P. Francisco. July 1997. Development of a Practical Method for Estimating the Thermal Efficiency of Residential Forced-Air Distribution Systems. Prepared for the Electric Power Research Institute. Prepared by Ecotope, Inc. Seattle, WA.

Siegel, J., McWilliams, J., Walker, I., "Comparison Between Predicted Duct Effectiveness from Proposed ASHRAE Standard 152P and Measured Field Data for Residential Forced Air Cooling Systems," April 2002.

The proposed ASHRAE Standard 152P "Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems" (ASHRAE 2002) has recently completed its second public review. As part of the standard development process, this

study compares the forced air distribution system ratings provided by the public review draft of Standard 152P to measured field results. 58 field tests were performed on cooling systems in 11 homes in the summers of 1998 and 1999. Seven of these houses had standard attics with insulation on the attic floor and a well-vented attic space. The other four houses had unvented attics where the insulation is placed directly under the roof deck and the attic space is not deliberately vented. Each house was tested under a range of summer weather conditions at each particular site, and in some cases the amount of duct leakage was intentionally varied. The comparison between 152P predicted efficiencies and the measured results includes evaluation of the effects of weather, duct location, thermal conditions, duct leakage, and system capacity. The results showed that the difference between measured delivery effectiveness and that calculated using proposed Standard 152P is about 5 percentage points if weather data, duct leakage and air handler flow are well known. However, the accuracy of the standard is strongly dependent on having good measurements of duct leakage and system airflow. Given that the uncertainty in the measured delivery effectiveness is typically also about 5 percentage points, the Standard 152P results are acceptably close to the measured data.

Sherman, M., Walker, I., "Residential HVAC and Distribution Research Implementation: CIEE/PG&E Final Report," 2002.

This report provides information to support energy efficiency and peak demand reduction in residential thermal distribution systems.

Key Results:

- There are significant energy savings (25%-30%), peak demand reduction (25%-30%) and comfort improvements to be realized from combining good duct systems with correctly sized HVAC systems.
- Cloth duct tapes are the only sealants to fail longevity testing under both cycling and steady temperatures.
- Testing of splitter boxes has shown that splitter box leakage can be a significant source of duct leakage (up to 3 cfm per box).
- The round-to-round connections have not shown the extremely rapid failure we found with previously tested collars. However, the same tape samples that failed in previous testing have shown considerable visual degradation and their measured leakage is slowly increasing.
- Field tests showed that failure of plastic flex duct is usually limited to the exterior layer. Although this does not lead to duct leakage, there is significant insulation degradation, due to insulation falling off the duct systems.
- Evaluation of a new flow-plate air-handler flow measurement technique has shown that this device under predicts air handler flows by about 10% compared to our standard pressure matching method. For systems with central air handler filter slots, this method can be quick and easy to perform, however, in typical new California systems with filters at the return grille, significant air flow adjustments are required to account for return duct leakage that introduce additional flow errors and additional measurements that increase the time required for the test.
- Laboratory and field tests of flow hoods has shown that commercially available devices are poor at measuring residential register flows. Typical errors are in the range of 20% to 30%, mostly due to non-uniformity of flow entering the flow hoods and backpressure issues.
- Powered flow hoods were found to be much more accurate, with uncertainties of about 2% to 3%.
- Over one hundred houses (mostly between 5 and 15 years old) were tested by CSUC staff for duct leakage. The average duct leakage for these houses was typical of other surveys at 10% supply and 12% return leakage.
- The DeltaQ test was performed in all these houses and small changes to the measurement procedure resulted from these field experiences. In particular a method of eliminating the

measurement of plenum pressures (thus making the test simpler and faster) has been developed. The DeltaQ test is now being used by many field practitioners (including researchers, building science experts and Building America partners) and is being evaluated by ASHRAE and DOE sponsored research programs.

- The DeltaQ test was found to take about 30 minutes on average – this time should be reduced by removing the requirement to measure plenum pressures.
- Considerable differences (typically half of the measured flows) were found between DeltaQ and fan pressurization results. This result is expected because the DeltaQ test measures leakage flows at operating conditions and the pressurization tests measures the size of the holes in the duct system. However, if we look at screening, compliance or quality control tests where a low leakage limit is imposed, then better agreement was found between the two test methods, with the pressurization test tending to over predict leakage (i.e., it is a conservative test of leakage).
- Potential users of the DeltaQ test like its straightforward procedure (no registers to be covered), the fact that it uses existing blower door equipment, the short time requirements and the fact that the test includes envelope leakage.
- Repeatability testing of the DeltaQ test has indicated that the repeatability is excellent for this test method over a range of duct leakage and supply/return leakage imbalance. The results show the repeatability uncertainty is less than 1% of fan flow.
- Laboratory tests have produced new duct fitting loss coefficients for use in duct design calculations. The new coefficients are for fittings not currently found in design guides.
- Laboratory tests have shown how compression of flexible plastic duct significantly increases the pressure losses for duct systems – with typically compressed duct having about five times the flow resistance and pressure drop of fully stretched duct. A simple calculation procedure for compressibility effects has been developed that is suitable for use in standard calculation procedures, e.g., ASHRAE or ACCA.
- A full scale “typical” California duct system test facility has been built at LBNL. This facility has been used in the duct fitting and flow hood development testing. We are planning to use this facility in future residential HVAC research projects for developing diagnostic techniques and evaluation of potential residential HVAC performance and comfort improvements.

Walker, I., Dickeroff, D., Delp, W. "Residential Forced Air System Cabinet Leakage and Blower Performance," LBNL 3383E, PIER Final Project Report, CEC-500-07-006, December 2008.

Walker, I., M. Sherman, Modera, M., and J. Siegel 1998. “Leakage Diagnostics, Sealant Longevity, Sizing and Technology Transfer in Residential Thermal Distribution Systems." Lawrence Berkeley National Laboratory. LBNL-41118.

Field Testing

The following section collects documents that report on the results of field testing in new residential units and in the context of refrigerant charge and airflow and ducts. This data demonstrates practical application of proven lab technologies and indicates the wide variance between lab and field efficiency/performance of HVAC measures.

New Residential

Blasnik, M., Downey, T., Proctor, J. and Peterson, G. 1996. Assessment of HVAC installations in New Homes in APS Service Territory. Proctor Engineering Group Report for Arizona Public Service Company.

Blasnik, M., Proctor, J., Downey, T., Sundal, J., and Peterson, G.1995. Assessment of HVAC Installations in New Air Conditioners in SCE's Service Territory. Rosemead, Calif.: Southern California Edison.

Blasnik, Michael et al. 1995a, "Assessment of HVAC Installations in New Homes in Nevada Power Company's Service Territory", Final Report, Electric Power Research Institute, Palo Alto, CA.

Davis Energy Group, "Residential Construction Quality Assessment Report- Phase II Final Report", California Energy Commission, 400-98-004, 2002.

Hammon, R.W. and Modera, M.P., "Improving the Energy Efficiency of Air Distribution Systems in New California Homes." Proceedings of ACEEE Summer Study, Pacific Grove, CA, August 1996.

Refrigerant Charge and Airflow

ADM Associates, Inc., "Field Performance Assessment of Package Equipment to Quantify Benefits of Proper Service," June 2008.

In this docuemnt, ADM Associates, Inc. has undertaken to conduct a field performance assessment of HVAC packaged equipment to quantify the benefits of proper service. This involved making detailed baseline measurements pertaining to the performance of a sample of HVAC packaged units, performing servicing on a subset of this sample, and then making a new set of performance measurements on the serviced units. Using paired pre- and post-servicing values for EER measured at standard conditions, it was determined that the average EER for the serviced units increased from 7.37 before servicing to 7.92 after servicing, an increase of about 7.4%. Further examination indicated that there was no strong relationship between the percentage changes in the EERs and either the sizes or the ages of the units.

Architectural Energy Corporation, “Integrated Energy Systems: Productivity & Building Science Program, Element Four—Integrated Design of Small Commercial HVAC Systems, Summary of Problems Observed in Field Studies of Small HVAC Units. (P500-03-082-A-25),” 2003.

The Cadmus Group, "Rooftop Unit Pilot Servicing Program," January 2010.

In the Summer 2009 pilot, the Bonneville Power Administration (BPA) sought to determine: which measures have the lowest cost and generate the greatest paybacks; which screening methods will identify units with the greatest potential for savings; and which methodology to use to create a provisionally deemed energy savings number. BPA conducted a packaged RTU servicing pilot project and monitored 150 of the serviced units at 41 sites in the Seattle City Light and Snohomish PUD territories. Cadmus conducted all RTU monitoring, and measured electric cooling and fan energy savings from the monitored units, analyzed savings per RTU and per measure category, reported the results, and recommended improvements for future programs.

Energy Center of Wisconsin, "Central Air Conditioning in Wisconsin: A compilation of recent field research," May 2008.

The report summarizes the results of several field studies involving residential central air conditioners in Wisconsin. The studies include: A 2007 study involving field measurements before and after making airflow and refrigerant charge corrections—and in some cases cleaning condenser coils; A 2005 field assessment of refrigerant charge, airflow and other parameters of new SEER 13+ systems; Field monitoring and experimental control of two-stage systems over the course of the 2004 – 2005 cooling seasons; Detailed monitoring at two sites where over-sized 3-ton systems where replaced with identical 2- ton systems to assess the impact of sizing on energy and indoor comfort; and, A large-sample 2003 telephone survey of air conditioning use the previous day.

Selected results: Experiments at two homes in which otherwise identical 2- and 3-ton systems were installed and monitored yielded inconclusive results as to whether down-sizing saves energy or affects humidity control. One of the sites showed no difference in weather-normalized energy consumption: reduced power requirements were almost exactly offset by increased run time. The other site showed some energy savings, but the difference was not statistically significant. The latter site also had higher indoor humidity with the smaller system, likely due to the fact that airflow provided by a 100kBtu/hr furnace could not be adjusted downward sufficiently to match the 2-ton system. In contrast, the smaller system at the first site produced lower indoor humidity (relative to outdoor humidity levels) in hot weather.

Henderson, H.I., K. Rengarajan, D.B. Shirey, 1992. ‘The Impact of Comfort Control on Air Conditioner Energy Use in Humid Climates,’ ASHRAE Transactions Vol. 98 Part 2, June.

Henderson, H.I., Rengarajan, K., Raustad, R. 1991. Measuring Thermostat and Air Conditioner Performance in Florida Homes. Research Report #FSEC-RR-24-91. Florida Solar Energy Center, Cape Canaveral, FL. May.

Koran, W. (PECI), Kaplan, M. (Kaplan Engineering), and Streele, T. (BPA), “DOE-2.1C Model Calibration with Short-Term Tests versus Calibration with Long-Term Monitored Data,” ACEEE Summer Session, 1992.

Lucas, Robert G., “Analysis of Residential Air Conditioning Equipment Using Monitored Data”, Proceedings of 1992 ACEEE Summer Study on Energy Efficiency in Buildings, Volume 2, pp. 157-165.

Mowris, R., Blankenship, A., et. al, "Field Measurements of Air Conditioners With and Without TXVs," ACEEE Summer Study Proceedings 2004.

This paper summarizes field measurements of 4,168 air conditioners with and without TXVs. Approximately 72 percent of the air conditioners had improper refrigerant charge and 44 percent had improper airflow. Average energy savings for correcting RCA are 12.6 ± 2.3 percent. The paper provides detailed EER measurements and the relative efficiency improvement for sixteen TXV and forty-nine non-TXV air conditioners. EER measurements of air conditioners with improper RCA indicate a relative efficiency gain of 21 ± 7 percent for TXV and a gain of 17.1 ± 2.8 percent for non-TXV air conditioners. The difference in efficiency gain between TXV and non-TXV air conditioners is 3.9 ± 0.3 percent at the 90 percent confidence level. The uncertainty associated with field measurements of capacity and EER was evaluated using the propagation of error technique and the overall uncertainty error is ± 4.4 percent. The paper indicates proper RCA is much more effective than a TXV in terms of delivering rated efficiency performance, especially if TXV sensing bulbs are improperly attached to the vapor line or are not insulated.

Neal, Leon and Dennis O'Neal, 1994, "The Impact of Residential Air Conditioner Charging and Sizing on Peak Demand," ACEEE 1994 Summer Study on Energy Efficiency in Buildings, Vol. 2, pp. 189-200.

Neal, Leon, "Field Adjusted SEER (SEERFA), Residential Buildings: Technologies, Design and Performance Analysis", Proceedings of 1998 ACEEE Summer Study on Energy Efficiency in Buildings, Neme, Chris et al., “Southern Maryland Electric Cooperative Power Saver Home Program Impact Evaluation”, December 9, 1997.

New Buildings Institute, “Review of Recent Commercial Roof Top Unit Field Studies in the Pacific Northwest and California,” 2004.

Orans, R., Woo, C., Swisher J., B. Wiersma, B., and Horit, B., “Targeting DSM for T&D Benefits: A Case Study of PG&E’s Delta District,” 1991.

Palimiter, L., Francisco, P.W., “Development of a Simple Device for Field Air Flow Measurement of Residential Air Handling Equipment: Phase II,” 2000.

Summary: Proper airflow is crucial to efficient operation of HVAC systems and it is desirable to obtain quick, easy, and accurate measurement of airflow using inexpensive instrumentation in diagnosis. This report presents the results of the development of a new calibrated plate device for measuring the airflow through a residential air handler. The project was completed in two Phases; the Phase II prototype is proven to be a reproducible and reliable design as demonstrated through field testing in 81 homes using the Duct Blaster method.

Parken, W.H., Beausoliel, R.W., and Kelly, G.E. 1977. Factors Affecting the Performance of a Residential Air-to-Air Heat Pump. ASHRAE Transactions. 83(1) No. 4269. pp. 839-849.

Parken, W.H., Didion, D.A., Wojciechowshi, P.H., and Chern, L. 1985. Field Performance of Three Residential Heat Pumps in the Cooling Mode. NBSIR 85-3107, report by National Bureau

of Standards, sponsored by U.S. Department of Energy for U.S. Department of Commerce, March.

Parker, D. 1997. Impact of Evaporator Coil Air Flow in Residential Air Conditioning Systems, FSEC-PF-321-97. Cocoa, Fla.: Florida Solar Energy Center.

The performance of conventional split system residential air conditioners is highly dependent on adequate air flow across the evaporator coil. Sufficient air flow is necessary to achieve a proper balance between sensible and latent cooling capacity. Typical target air flow rates are approximately 350 - 450 cubic feet per minute per ton (47.0 - 60.5 L/S per kW) of cooling capacity. The authors have measured the air flow across the coil in 27 installations in Florida. Both flow hood and strip heat resistance methods were used to measure air flow with an established protocol. The installations measured ranged in capacity from 2 to 4 tons (7 - 14 kW). Measured air flows ranged from 130 to 510 cfm per ton (17.5 - 68.5 L/S per kW) with an mean of 320 cfm/ton (43.0 L/S per kW). Reasons for inadequate flows included undersized return ducts and grills, improper fan speed settings, fouled filters and cooling coils. High distribution system static pressures were due to long, circuitous runs and pinched or constricted ducts. Recommendations are made to improve current practice.

Peterson, G. and J. Proctor. 10/18/1998. Negative Technical Degradation Factors Supplement to Persistence Studies, Final Report. CADMAC Report #2031P San Francisco, CA: Persistence Subcommittee, California DSM Measurement Advisory Committee, (PEG 1998 Neg-TDF Supplement)

Peterson, G. and J. Proctor. 2/22/1999. Persistence 3A: An Assessment of Technical Degradation Factors for Commercial Air Conditioners and Energy Management Systems, Final Report. San Francisco, CA: Persistence Subcommittee, California DSM Measurement Advisory Committee (CADMAC Report #2028P), (PEG 1999 Persistence 3A)

Peterson, G., Proctor, J.. 5/14/1998. Statewide Measure Performance Study #2: An Assessment of Relative Technical Degradation Rates, Final Report. CADMAC Report #2027P San Francisco, CA: Persistence Subcommittee, California DSM Measurement Advisory Committee, (PEG 1998 Persistence 2)

Peterson, George and John Proctor, "Effects of Occupant Control, System Parameters, and Program Measures on Residential Air Conditioner Peak Demands", Proceedings of 1998 ACEEE Summer Study on Energy Efficiency in Buildings, Volume 1, pp. 253-264.

Pigg, S., “Central Air Conditioning in Wisconsin: A Compilation of Recent Field Research”, Energy Center of Wisconsin, ECW Report Number 241-1, May 2008.

Summary: Central air conditioning is an important and fast-growing electrical load among Wisconsin households. This report compiles the key findings from several recent research efforts to better understand the nature of central air conditioning electricity use in Wisconsin and explore the opportunities for improving the efficiency of this end-use.

Price, S., Rosenow, L., "BPA RTU Puget Sound Pilot," November 2009.

Summary: In the summer of 2009, Bonneville Power Administration (BPA) and a number of partner organizations engaged in a Puget Sound area pilot to evaluate the energy savings potential of a select package of optimization services. These services are above and beyond what is normally provided as standard preventative maintenance. The field pilot included pre- and post-

service power consumption data logging, and tracking of as-found conditions and most common modifications and repairs. Although the energy saving potential of this service protocol is promising, the challenge is balancing the level of service technician effort with the expected savings.

Proctor Engineering Group, "Air Conditioner Service Light Project, Final Report," December 2006.

Summary: This project designed, built, and tested a device that continuously monitors the performance of an A/C to ensure efficient operation using real-time diagnostics to detect incorrect refrigerant charge and insufficient evaporator airflow. When faults are detected, the service light turns on, and the unit can be serviced. The device was lab tested and one prototype was field-tested. The majority of units performed well in the field, detecting faults that reduced efficiency by more than 5%.

Proctor, J. 1991. Pacific Gas and Electric Appliance Doctor Pilot Project: Final Report. Pacific Gas and Electric Company, San Francisco, California.

Proctor, J. 1997. Field measurements of new residential air conditioners in Phoenix, Arizona. ASHRAE Transactions 103(1): 406-415. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Proctor, J. 1998. Monitored in-situ performance of residential air-conditioning systems. ASHRAE Transactions, 104(1): 1833-1840. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Proctor, J., CheckMe!TM Expert Analysis System Developed by Proctor Engineering Group, 418 Mission Avenue, San Rafael, CA 94901, <http://www.proctoreng.com/checkme/checkme.html>, 2006.

Proctor, J., Downey, T., Conant, A., and Wright, D. et al., “Innovative Peak Load Reduction Program, CheckMe! Commercial and Residential AC Tune-up Project,” November 2003.

Selected by the California Energy Commission, Proctor Engineering Group was tasked with reducing peak demand from residential and commercial air conditioners via the statewide CheckMe!® program from August 2001 to June 2003. CheckMe! examines the critical airflow and refrigerant charge parameters of air conditioners and determines if they are correct. When diagnosis shows one of these problems, the system directs the service technician to correct refrigerant levels and address airflow. It verifies the validity of the tests and reinforces proper procedures with the technician. When the technician leaves the jobsite the air conditioner is tuned to manufacturer’s standards. The customer is integral to the system, becomes informed about the process, and becomes knowledgeable about the results.

During this program PEG collected CheckMe!® data from 36,940 air conditioners. 15,014 of those were residential air conditioners and 21,926 were commercial. The deemed savings from the program was 30.3 MW, which was 118% of the goal. The cost was $171 per kW. One of the constant challenges for residential and small commercial energy efficiency and peak reduction programs is the diffuse nature of the energy

consumption. While the total consumption and peak load are substantial, these loads are spread over many buildings and relatively small units.

Proctor, John and Ronald Pernick, 1992a, “Getting It Right the Second Time: Measured Savings and Peak Reduction from Duct and Appliance Repairs”, Proceedings of 1992 ACEEE Summer Study on Energy Efficiency in Buildings, Volume 2, pp. 217-224.

Proctor, John et al. 1995, “Southern California Edison Coachella Valley Duct and HVAC Retrofit Efficiency Improvement Pilot Project”, Draft Report, July 3, 1995.

Proctor, John et al. 1997a, "Assessment of Energy Savings and kW Reduction Potential from Air Conditioner and Duct Improvements for New Homes in PSE&G Service Territory", Summary, March 31, 1997.

Proctor, John et al. 1997b, "Residential New Construction Pilot in Nevada Power Company Service Territory", Final Report, Prepared for Electric Power Research Institute, TR-108445, July 1997.

Proctor, John et al., "Bigger is Not Better: Sizing Air Conditioners Properly", Home Energy, May/June 1995, pp. 19-26.

Proctor, John, "Performance of a Reduced Peak kW Air Conditioner at High Temperatures and Typical Field Conditions", Proceedings of 1998 ACEEE Summer Study on Energy Efficiency in Buildings, Volume 1, pp. 265-274.

Rodriguez, A., "Effect of Refrigerant Charge, Duct Leakage, and Evaporator Air Flow on the High Temperature Performance of Air Conditioners and Heat Pumps, Master's Thesis," August 1995.

Results of an experimental study conducted to quantify the effect of several installations on the high outdoor ambient temperature performance of air conditioners. These installation items were: improper amount of refrigerant charge, reduced evaporator airflow, and return air leakage from hot attic spaces. There were five sets of tests used for this research: two for the charging tests, two for the reduced evaporator airflow, and one for the return air leakage tests.

Rossi, T. 2004. Unitary Air Conditioner Field Performance. International Refrigeration and Air Conditioning Conference at Purdue. July 2004. Breuker, M.S. and Braun, J. E. 1997.

Units at least five years old showed greater average savings than those less than five years old, which showed not only lower, but negative, average savings. All-electric units had the highest savings. Heat pumps showed slightly negative average savings, although most were smaller than 7 tons, and thus expected to generate smaller savings. (Further research into actual heat pump performance is necessary to understand winter operation.) Savings were slightly higher in units that did not have a servicing contract with this project’s servicing company. Thermostat measures had the greatest correlation with positive savings; economizer measures were difficult to isolate, and did not show strong negative or positive savings. Reduction in fan operating hours was found to have a significant influence on energy savings.

Siegel, J., Carey, V., “Fouling of HVAC Fin and Tube Heat Exchangers,” 2001.

Fin and tube heat exchangers are used widely in residential, commercial and industrial HVAC applications. Invariably, indoor and outdoor air contaminants foul these heat exchangers. This fouling can cause decreased capacity and efficiency of the HVAC equipment as well as indoor air quality problems related to microbiological growth. This paper describes laboratory studies to investigate the mechanisms that cause fouling. The laboratory experiments involve subjecting a 4.7 fins/cm (12 fins/inch) fin and tube heat exchanger to an air stream that contains monodisperse particles. Air velocities ranging from 1.5 - 5.2 m/s (295 ft/min - 1024 ft/min) and particle sizes from 1 ñ 8.6 µm are used. The measured fraction of particles that deposit as well as information about the location of the deposited material indicate that particles greater than about 1 µm contribute to fouling. These experimental results are used to validate a model that describes the relative importance of several deposition mechanisms including impaction, Brownian diffusion, turbophoresis and gravitational settling. The analysis is extended to apply to different fin spacings and particle sizes typical of those found in indoor air.

Siegel, J., Wray, C., "An Evaluation of Superheat-Based Refrigerant Charge Diagnostics for Residential Cooling Systems," 2001.

Although refrigerant charge has an important influence on the performance of residential cooling systems with fixed orifice metering devices, there has been little research to quantify the effects of incorrect charge or design new diagnostics for evaluating charge level. The most common diagnostic for charge level in these systems is the superheat test. In this paper, we examine three superheat technologies/techniques. Two of the diagnostics are appropriate for detecting incorrect charge, one is not. Additionally, measurements at four houses indicate that it is important to measure the condenser air entering temperature with a high degree of accuracy. Measurement of the wet-bulb temperature in the return plenum and the suction line temperature are equally important but seemingly easier than measuring the condenser air temperature, as several measurement technologies yielded similar results for these quantities. The importance of refrigerant charge to energy use and capacity of residential cooling systems, the limitations of the superheat test, and the variations in the test method results and interfaces necessitate the development of a standard method or methods to determine refrigerant charge level.

Temple, K, “A Performance Based Method to Determine Refrigerant Charge Level for Commissioning Unitary AC and HP Systems,” Proceedings of the ACEEE 2004 Summer Study on Energy Efficiency in Buildings, 2004.

Wilcox, B., Chitwood, R., Proctor, J., “2010 California New Home Energy Study Survey: Presentation at ACI Austin,” April 2010.

Ducts

Coito, F., Syphers, G., and A. Lekov, “Are Your Ducts All in a Row? Duct Efficiency Testing and Analysis for 150 New Homes in Northern California,” ACEEE Summer Study Proceedings 1998.

Duct leakage measurements were completed on 158 homes participating in PG&E’s new construction program impact evaluation. Key information on the 158 duct systems were input in into a 152P model to develop distribution system efficiency estimates. The average duct leakage of the 158 homes was found to be 144 cfm (0.081 cfm/ft2 of

conditioned floor area) vs. 187 cfm (0.100 cfm/ft2) for a sample of "non-program" homes. The 19% duct leakage reduction was less than originally projected, resulting in about ½ the expected energy savings. Seasonal duct efficiencies calculated using the 152P algorithms resulted in seasonal cooling and heating duct efficiencies were considerably lower than CEC default assumptions (e.g. program home cooling average duct efficiency of 0.768 was determined vs. the Title 24 assumption of 0.860).

Cummings, J. B., J. J. Tooley, N. Moyer, and R. Dunsmore. 1990. "Impacts of Duct Leakage on Infiltration Rates, Space Conditioning Energy Use, and Peak Electrical Demand in Florida Houses." Pp. 9.65–9.76 in Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings, vol. 9. Washington, D.C.: American Council for an Energy-Efficient Economy.

Cummings, J., and Tooley, J., ``Infiltration and Pressure Differences Induced By Forced Air Systems in Florida Residences." ASHRAE Transactions, v95.2,551 -60. 1989.

Cummings, J., Withers, C., et. al, "Field Testing and Computer Modeling to Characterize the Energy Impacts of Air Handler Leakage," 2003.

This report presents the results of air duct leakage tests conducted on 69 residential AC systems in Florida. Selected results: One of the interesting and disturbing findings of this project was the high correlation between number of supply grills and amount of supply side duct leakage. This strongly suggests that there are one or more duct installation practices which are being systematically implemented and which are creating duct leakage. The good news is that these practices have been identified as ones that can be corrected by proper training.

Cummings, J., Withers, C., et. al, "Field Testing and Computer Modeling to Characterize the Energy Impacts of Air Handler Leakage," Florida Solar Energy Center (FSEC). 2003.

Cummings, James B., Tooley, John J., Jr., Moyer, Neil, 1991, Investigation of Air Distribution System Leakage and Its Impact in Central Florida Homes, Florida Solar Energy Center, FSEC-CR-397-91, Cape Canaveral, FL, 1991.

Davis, B. E., and M. Robinson. 1993. "Using the Pressure Pan Technique to Prioritize Duct Sealing Efforts: A Study of 18 Arkansas Homes." Energy and Buildings 20:57–63.

Davis, B., 1991. "Impact of Air Distribution System Leakage on Heating Energy Consumption in Arkansas Homes." Home Comfort, Fayatteville, AR. 9:91.

Davis, B., David Baylon, and Aaron Houseknecht. 1998. "Developing a Market-Based Utility Duct Sealing Program." Pp. 2.21–2.31 in Proceedings of the ACEEE 1998 Summer Study on Energy Efficiency in Buildings, vol. 2. Washington, D.C.: American Council for an Energy-Efficient Economy.

Delp, W., Matson, N., Modera, M.P., "Exterior Exposed Ductwork: Delivery Effectiveness and Efficiency" LBL-39083

Jump, D., l. S. Walker, and Modera M., ”Field Measurements of Efficiency and Duct Retrofit Effectiveness in Residential Forced Air Distribution Systems. “ ACEEE Summer Study Proceedings, 1996.

Forced air distribution systems can have a significant impact on the energy consumed in residences. It is common practice in U.S. residential buildings to place such duct systems outside the conditioned space. This results in the loss of energy by leakage and conduction to the surroundings. In order to estimate the magnitudes of these losses, 24 houses in the Sacramento area of California were tested before and after duct retrofitting. The systems in these houses included conventional air conditioning, gas furnaces, electric furnaces and heat pumps. The retrofits consisted of sealing and insulating the duct systems.

The field testing consisted of the following measurements: leakage of the house envelopes and their ductwork, flow through individual registers, duct air temperatures, ambient temperatures, surface areas of ducts, and HVAC equipment energy consumption. These data were used to calculate distribution system delivery efficiency as well as the overall efficiency of the distribution system including all interactions with building load and HVAC equipment. Combined supply and return duct leakage was reduced from 35% of system fan flow to 18% after remediation. Analysis of the test results indicate an average increase in delivery efficiency from 64% to 76% and a corresponding average decrease in HVAC energy use of 18%. The average cost of the remediation effort was $635, ranging from $335 to $1069.

Jump, D., Modera, M., 1994. “Energy Impact of Attic Duct Retrofits in Sacramento Houses.” In Proceedings of ACEEE Summer Study on Energy Efficiency in Buildings, 9.195-203.

Kallett, R. et al, SMUD’S New Residential Duct-Improvement Program Using an Aeroseal-Based Sealant. ACEEE Summer Study Proceedings, 2000.

The Sacramento Municipal Utility District was interested in evaluating the performance and cost effectiveness of the Aeroseal duct sealing system. Aeroseal results from 121 SMUD customers showed an average 81% reduction in duct leakage from a baseline level of 220 cfm (ranging from 53 to 564 cfm25). The average cost for the Aeroseal procedure of $1,009 was higher than the $635 average manual duct sealing cost reported by Jump, Walker, and Modera (1996 ACEEE), but the savings were more significant.

Karins, N., Tuluca, A., Modera, M., 1997. “Effectiveness of Duct Sealing and Duct Insulation in Multifamily Buildings, Final Report.” For NYSERDA, Albany, NY, NYSERDA-97- 11.

Kinert, R. et al, “The PG&E Model Energy Communities Program: Offsetting Localized T&D Expenditures with Targeted DSM,” ACEEE Summer Study Proceedings 1992.

The paper discusses a three year pilot project run in PG&E territory directed towards implementing aggressive demand side management strategies to alleviate localized strain on the transmission and distribution system infrastructure. Over the three year period, a total of 5,000 existing air conditioned homes will be targeted for HVAC and insulation improvements. The paper summarizes results from the first 1000 homes where duct leakage remediation was completed and 175 homes where AC charge modifications were implemented. Duct leakage measurements for the 1000 homes showed initial Duct Blaster readings of 374 cfm, which were reduced after remediation to 157 cfm. Of the 175 AC systems that were tested, 44% were found to have evaporator airflows below 350 cfm/ton, 23% were found to be undercharged, and 33% were found to be overcharged.

Kolb, James O., and Mark P. Ternes. 1995. “Investigation of Air Distribution System Deficiencies and Repair Benefits in Phoenix, Arizona.” Pp. 379–87 in Proceedings of the

Thermal Performance of the Exterior Envelopes of Buildings VI, Clearwater Beach, Fla., December 4–8. Atlanta: ASHRAE Special Publication.

Lerman, D., "Getting Our Ducts in a Row: Evaluation of the Tacoma Duct Sealing Program. ACEEE Summer Study Proceedings, 1998.

In 1995 Tacoma Power initiated a test of residential duct sealing to determine the feasibility of a full-scale program to improve the duct system in customer homes with central electric heat. The Residential Duct Sealing Pilot Program featured several main goals including determining the typical reduction in heating energy use attributable to reducing duct leakage and determining the cost-effectiveness of the program.

A PRISM analysis was completed for the 181 participating homes. Comparing results to baseline homes, annual heating energy savings of 1,507 kWh/year were projected. Contractors charged an average of $451 to perform all tests and seal the ducts for all of the houses that participated in the program. Costs ranged from a low of $42 to a high of $1,264. The higher cost jobs, those more than double the average cost of $450, either had significant repair costs included in the total cost of the work done on the house, were very large homes with extensive duct systems, or were participants relatively early in the program when staff cost-control oversight was less stringent. Interestingly, there does not appear to be any correlation between the cost of duct sealing on a particular house and the energy savings.

Manclark, Bruce, Delta-T, Inc. and Bob Davis, Ecotope, "Report on Delta Q Field Testing", Puget Sound Energy, January 22, 2009. See also http://www.pse.com/solutions/foryourhome/pages/

Modera, M. and F. Carrie. 1995. "Aerosol-Based Duct Sealing Technology." Center for Building Science Newsletter, #5. Winter. Berkeley, CA: Environmental Energy Technologies Div., Lawrence Berkeley National Laboratory.

Modera, M., D. Dickerhoff, and D. Wang. 1997. Field Testing of Aerosol-Based Sealing Technology. LBL-39521. Berkeley, CA: Lawrence Berkeley National Laboratory.

Modera, M., Dickerhoff, D., Jansky, R., and Smith, B., 1992. "Improving the Efficiency of Residential Air Distribution Systems in California Phase I." For Cailfornia Institute for Energy Efficiency, 6:92.

Modera, M., et al. 1996. "Residential Field Testing of an Aerosol-Based Technology for Sealing Ductwork." In Proceedings ofthe ACEEE 1996 Summer Study on Energy Efficiency in Buildings,

Modera, M.P. 1993. ''Characterizing the Performance of Residential Air Distribution Systems''. Energy and Buildings. 20:65–75.

Modera, M.P., and Wilcox, B., (1995), "Treatment of residential duct leakage in Title 24 energy efficiency standards", California Energy Commission Contract Report.

Modera, Mark and David Jump, "Field Measurement of the Interactions between Heat Pumps and Attic Duct Systems in Residential Buildings", presented at ASME International Solar Energy Conference (March 19-24, 1995), LBL-36047 (UC 1600).

Modera, Mark et al., "Residential Field Testing of an Aeroseal-Based Technology for Sealing Ductwork", Proceedings of 1996 ACEEE Summer Study on Energy Efficiency in Buildings, Volume 1, pp. 169-175.

Palmiter, Larry and Paul W. Francisco, "Measured Efficiency of Forced-Air Distribution Systems in 24 Homes", Proceedings of 1994 ACEEE Summer Study on Energy Efficiency in Buildings, Volume 3, pp. 177-187.

Sonne, Jeffrey K., Danny S. Parker, and Don B. Shirey III. 2006. "Measured Impacts of Proper Air Conditioner Sizing in Four Florida Case Study Homes," Florida Solar Energy Center Report FSEC-CR-1641-06, October 25, 2006. Available from www.fsec.ucf.edu.

Ternes, M.P., and Hwang H., "Field Test of Aerosol-Spray and Best Practice Duct-Sealing Approaches " ACEEE Summer Study Proceedings, 2002.

A field test of an aerosol-spray duct-sealing technology and a conventional, best-practice approach was performed in 80 homes and five states to determine the efficacy and programmatic needs of the duct-sealing technologies as applied in the U.S. Department of Energy Weatherization Assistance Program. The study found that, compared with the best-practice approach, the aerosol-spray technology is 16–60% more effective at sealing duct leaks and can potentially reduce total labor time and repair costs for duct sealing by 30%. A pilot test of full production weatherization programs using the aerosol-spray technology is recommended to develop approaches for integrating this technology with other energy conservation measures and minimizing impacts on weatherization agency logistics. Application testing of the aerosol-spray technology in mobile homes is also recommended.

Ternes, Mark P., and Ho-Ling Hwang. 2001. Field Test of Advanced Duct Sealing Technologies within the Weatherization Assistance Program, ORNL/CON-480, Oak Ridge National Laboratory, November.

Vieira, R.K., J.F. Klongerbo, J.K. Sonne, and J.E. Cummings, 1995, "Florida Air-Conditioning Sizing Survey Results," ASHRAE Transactions, V. 101, Pt. 2.

Vieira, R., Parker, D., et. al, "How Contractors Really Size Air Conditioning Units,"

This paper presents results from 489 of the 5559 Florida air conditioning contractors surveyed (an 8.5% response rate) regarding equipment sizing methods in new residences. Air conditioning sizing is accomplished by using ACCA's Manual-J procedure by 33% of the respondents, software by 34.4% of the respondents, square-footage by 24.2% and other estimate procedures by about 8.4%. Those using square-footage estimates varied from 350 square-feet- per-ton to 700 square-feet-per-ton. Over a third of respondents indicated oversizing intentionally on some jobs, in order to avoid complaints, accommodate future expansions, enable quicker cooling down of homes, and to allow for lower cooling set points by homeowners.

Walker, I., M. Sherman, Modera, M., and J. Siegel, "Leakage Diagnostics, Sealant Longevity, Sizing and Technology Transfer in Residential Thermal Distribution Systems. Lawrence Berkeley National Laboratory. LBNL-41118," 1998.

This paper reports on field testing of duct leakage diagnostic tests using standard duct pressurization techniques, house pressure test, the nulling pressure test, the Delta Q test, and tracer gas methods. The paper looks at uncertainties for different techniques, finding that standard duct pressurization tests have an instrument precision of 5 cfm and a repeatability

accuracy of 15 cfm. The repeatability was determined by completing multiple tests with the same crew under different conditions, as well as testing differences from one crew to another. Nine houses in the San Francisco Bay Area had duct leakage measurements and system fan flow measurements completed before and after duct leakage remediation. Average system fan flow reduced from 880 cfm to 870 cfm after remediation efforts.

Walker, I., Modera, M., Tuluca, A., Graham, I., 1996. “Energy Effectiveness of Duct Sealing and Insulation in Two Multifamily Homes.” In Proceedings of ACEEE Summer Study on Energy Efficiency in Buildings, 1.247-54.

Walker, I., Sherman, M., et. al, "Leakage Diagnostics, Sealant Longevity, Sizing and Technology Transfer in Residential Thermal Distribution Systems," January 1998.

This field study concentrated on measurement of duct leakage to outside the conditioned space because this is most useful in energy calculations, e.g., proposed ASHRAE Standard 152P (ASHRAE 1997). The objective of this field study is to help to identify major sources of uncertainty and to quantify the trade-offs between different test methods. The identification of the areas requiring significant improvement will aid in future development of duct leakage test methods. For example, during the course of this study a new method for correcting house pressure tests to account for the presence of duct leakage in measured envelope leakage was developed.

Diagnostic Methods

Architectural Energy Corporation, Final Report Compilation for Fault Detection and Diagnostics for Rooftop Air Conditioners, CEC # 500-03-096-A1, October 2003

Architectural Energy Corporation, "Final Report: Describing the Development of Refrigeration Cycle, Temperature-Only Refrigeration Cycle Diagnostics," June 2005.

Summary: In a first phase of this CEC sponsored project, a decoupling-based FDD technique was developed, which handles multiple-simultaneous faults and eliminates a cost-prohibitive system model to do FDD. In this previous work, the decoupling features were verified using laboratory data for a fixed-orifice system. Then the complete decoupling-based FDD technique was demonstrated using a prototype in which four types of faults were artificially introduced one by one and removed one by one. In the current project, FDD performance was evaluated further. This report presents a detailed evaluation of the sensitivity and robustness, which was tested using data from the prototype under a range of conditions. The report also provides a method, which uses only one temperature sensor for each heat exchanger coil to obtain pressures. With the virtual pressure sensors combined with the decoupling-based FDD, a temperature only FDD technique is developed. The whole technique has been validated using extensive experimental data. Simple indices are provided to evaluate the performance of the monitored system. These indices should be determined from low-cost measurements and measure impact on comfort, indoor air quality, efficiency, reliability, control performance, etc.

Architectural Energy Corporation, "Final Report: Energy Efficient and Affordable Commercial and Residential Buildings," November 2003.

Summary: Provides findings of the Energy Efficient and Affordable Small Commercial and Residential Buildings Program, summarizing each of the 17 technical projects within the research program and serving as a preliminary information source for manufacturers, service providers, researchers, and the general public regarding the energy savings potential within California of each technology. The Research Program had 17 technical projects organized into one administrative element and five technical elements.

Element 2, Automated Commissioning and Diagnostics, had seven projects focused on finding ways to detect subtle, energy-wasting problems, or faults, within heating and cooling equipment and control systems. Finding a problem begs the question of what caused it, and much of the effort in these seven projects was devoted to isolating the causes of faults and estimating their impact on the energy and comfort performance of the heating, ventilating, and air-conditioning (HVAC) systems.

Element 3, Advanced Load Management and Control, had five projects covering a wide range of strategies to reduce peak loads. Two projects focused on optimizing strategies that would reduce energy consumption as well as peak demand (demand controlled ventilation, optimizing night cooling controls that used outside air or mechanical cooling to remove heat from the building's thermal mass). Two others investigated ways to reduce peak demand at periods of very high grid use (smart load controls built into appliances, and aggregated load shedding for buildings under a common utility meter). Finally one project explored options for extending the HVAC BACnet controls standard to include lighting controls and interfacing with the utility.

Breuker, M., Rossi, T., and Braun, J., "Smart Maintenance for Rooftop Units. ASHRAE Journal 42 (11): 41-46," 2000.

Breuker, M.S. and Braun, J. E. 1997. Evaluation of a Statistical, Rule-based Detection and Diagnosis Method for Vapor Compression Air Conditioners, MS Thesis, HL 98-9, Report #1796-7a, School of Mechanical Engineering, Purdue University.

Breuker, M.S. and Braun, J.E., 1998 a, "Common faults and their impacts for rooftop air conditioners," International Journal of Heating, Ventilating, Air-Conditioning and Refrigerating Research, Vol. 4, No. 3, pp. 303-318.

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

California Energy Commission, 2008 Building Energy Efficiency Standards Residential Compliance Manual, CEC-400-2008-016-CMF-Rev1, March 2010.

California Energy Commission, Reference Appendices for the 2008 Building Energy Efficiency Standards for Residential and Nonresidential Buildings, CEC-400-2008-004-CMF, December 2008.

California Energy Commission, Appendix RD, Residential Alternative Calculation Method (ACM) Approval Manual for the 2005 Building Energy Efficiency Standards, CEC 400-003-003F, October 2004

Carrier Corporation, 1994, Charging procedures for residential condensing units, No. 020-122, Syracuse, N. Y.: Carrier Corporation.

Chen, B. and Braun, J.E., 2001, "Simple Rule-Based Methods for Fault Detection and Diagnostics Applied to Packaged Air Conditioners," ASHRAE Transactions, Vol. 107, Pt. 1, pp. 847-857.

Field Diagnostic Services, Inc., "Advanced Automated HVAC Fault Detection and Diagnostics Commercialization Program: Final Report Describing VM Implementation, Emulation/Bench Testing and Laboratory Testing, and Field Installation," 2006.

Kim, M. and Kim, M.S., 2005, "Performance Investigation of a Variable Speed Vapor Compression System for Fault Detection and Diagnosis," International Journal of Refrigeration, Vol. 28, No. 4, pp. 481-488. 80.

Kim, M., Yoon, S. H., Payne, W. V., and Domanski, P. A., 2008, "Design of a steady-state detector for fault detection and diagnosis of a residential air conditioner," International Journal of Refrigeration 31(5), 790-99.

Kim, M., Yoon, S., et. al, "Cooling Mode Fault Detection and Diagnosis Method for a Residential Heat Pump," October 2008.

Summary: This research addresses the need for fault detection and diagnosis (FDD) in residential-style, air conditioner, and heat pump systems in an attempt to make these systems more trouble free and energy efficient over their entire lifetime. This work is one of the first to

apply FDD techniques to a residential system with the added control element of a thermostatic expansion valve (TXV). Any control element actively seeks to perform its duties and thus obscures any faults occurring by making adjustments. This research work takes this into account and shows how FDD techniques may be applied to this type of system operating in the cooling mode.

Li, H. and Braun, J.E. "A Methodology for Diagnosing Multiple-Simultaneous Faults in Vapor Compression Air Conditioners,"HVAC&R Research, Vol. 13, No. 2, Pages 369-395, 2007

Li, H. and Braun, J.E. "Decoupling Features and Virtual Sensors forDiagnosis of Faults in Vapor Compression Air Conditioners," International Journal of Refrigeration, Vol. 30, No. 3, Pages 546-564, 2007.

Li, H. and Braun, J.E., "Economic Evaluation of the Benefits Associated with Application of Automated Fault Detection and Diagnosis in Rooftop Air Conditioners," ASHRAE Transactions, Vol. 113, Pt. 2, Pages 200-210, 2007.

Li, H. and Braun, J.E. "Development, Evaluation and Demonstration of a Virtual Refrigerant Charge Sensor," HVAC&R Research, Vol. 15, No. 1, Pages 117-136, 2009.

Li, H. and Braun, J.E. "Decoupling Features for Diagnosis of Reversing and Check Valve Faults in Heat Pumps," International Journal of Refrigeration, Vol. 32, No. 2, Pages 316-326, 2009.

Li, H. and Braun, J.E. "Virtual Refrigerant Pressure Sensors for Use in Monitoring and Fault Diagnosis of Vapor Compression Equipment," HVAC&R Research, Vol. 15, No. 3, Pages 597-616, 2009.

Li, H., “A decoupling-based unified fault detection and diagnosis approach for packaged air conditioners. Ph.D. Thesis, West Lafayette, IN: Purdue University,” 2004.

Summary: Existing methods addressing automated FDD for vapor compression air conditioning systems 1) require measurements over a wide range of conditions for training reference models, development of which can be time consuming and costly, and 2) can not deal with multiple faults that occur simultaneously. This thesis presents new methods that reduce engineering and installed costs for FDD, improve overall sensitivity for detecting and diagnosing faults, and handle multiple-simultaneous faults.

Li, H. and Braun, J.E., 2003, “An Improved Method for Fault Detection and Diagnosis Applied to Packaged Air Conditioners,” ASHRAE Transactions, Vol. 109, Pt. 2, pp. 683-692.

Mei, V.C., F.C. Chen, and Z. Gao Development of Refrigerant Charge Indicator and Dirty Air Filter Sensor, ORNL/CON-489, Oakridge National Laboratory. February 2003.

Parker, D., P. Fairey, and L. Gu. 1993. ‘‘Simulation of the Effects of Duct Leakage and Heat Transfer on Residential Space-Cooling Energy Use’’. Energy and Buildings. 20 (2):97–114.

Rossi, M.T, Temple, K.A. and Sun, C., 2008, Method for determining evaporator airflow verification, Patent No.: US 2008/0196421 A1.

Rossi, M.T., Douglas, D.J., Bianchi, V.A.M. 2004, Estimating operating parameters of vapor compression cycle equipment, Patent No.: US 6,701,725.

Rossi, M.T., Rossi, D., Douglas, D.J., Stockman, P.T., 2006, Apparatus and method for detecting faults and providing diagnostics in vapor compression cycle equipment, Patent No.: US 7,079,967.

Rossi, T.M., 1995, Detection, diagnosis, and evaluation of faults in vapor compression cycle equipment, Ph.D. Thesis, Purdue University, West Lafayette, IN, USA.

Rossi, T.M., J.E. Braun, A statistical rule-based fault detection and diagnostic method for vapor compression air conditioners, HVAC&R Research 3 (1) (1997) 19–37.

Temple, 2004. A Performance Based Method to Determine Refrigerant Charge Level for Commissioning Unitary AC and HP Systems. In Proceedings of the ACEEE 2004 Summer Study on Energy Efficiency in Buildings, 1:306-317. Washington, D.C.: American Council for an Energy-Efficient Economy.

Temple, K., Rossi, T., "Enhanced Refrigeration Diagnostics for an Improved Air Conditioning Tune-Up Program," ACEEE Summer Study 2006.

> An enhanced refrigeration diagnostics method is presented that has the opportunity for improving the results of air conditioning tune-up programs. An existing tune-up protocol focused on refrigerant charge and indoor airflow was evaluated based on data collected for 350 small commercial HVAC units, and an enhanced protocol is proposed that addresses identified limitations of the evaluated protocol. The study found several problems that contribute to reduced efficiency in the post data – those causing low evaporating temperature (22% of units) and high condensing temperature over ambient (28% of units), and specifically incorrect charge (71% of units). The tune-up actually increased the number of units with high condensing temperature over ambient and high charge. Furthermore, the study found that use of the existing protocol can result in overestimating energy savings associated with tune-ups since calculations based only on charge adjustment typically assume the final unit charge state is the nominal charge (desired charge), not the actual charge, and that there are no other faults. The proposed protocol is designed to address these problems.

Temple, K.A., Rossi, T.M., Sun, C., 2008, Method for evaluating refrigeration cycle performance, Patent No.: US 2008/0196425 A1.

Temple, K.A., “Expanded Test Protocols for Low Ambient Testing of Unitary Air Conditioning Systems, Final Report: Building Energy Research Grant (BERG) Program,” 2008.

> Unitary air-conditioner and heat pump system cooling performance at low ambient conditions was studied with the intent to expand existing test protocols to address testing at these conditions. Experimental data and simulation results were used to characterize performance at low outdoor ambient air temperature and low indoor (return) air wet-bulb temperature conditions. A number of existing test protocols were reviewed in order to form the basis for expanded test protocols. Proposed enhancements to the existing protocols, focusing on refrigerant charge and indoor airflow verification, were developed. The enhancements include (i) superheat verification for TxV systems, (ii) the use of both superheat and subcooling to evaluate refrigerant charge for non-TxV systems, addressing cases when superheat alone is not adequate, (iii) new performance expectations for superheat (expanded) and subcooling (new) for non-TxV system, and (iv)

expanded performance expectations for the Temperature Split airflow evaluation method. The protocols were demonstrated using the available low ambient fault data (experimental and simulation data) based on identification of faults at three operating conditions – nominal rating condition, low outdoor ambient and dry coil condition. Based on the available data, the expanded protocols were successful at identifying refrigerant charge (low and high) and indoor airflow faults (low and high).

Temple, K.A., Rossi, T.M., "Enhanced Refrigeration Diagnostics for an Improved Air Conditioning Tune-up Program," ACEEE Summer Study, 2006.

Paper presents an enhanced refrigeration diagnostics method that has the opportunity for improving the results of air conditioning tune-up programs. An existing tune-up protocol focused on refrigerant charge and indoor airflow was evaluated based on data collected for 350 small commercial HVAC units. All of the units met the requirements of the tune-up protocol and the data indicate that the number of units with low charge was reduced. Detailed analysis of the test data identified three indicators of reduced operating efficiency – low evaporating temperature (35% of units pre and 22% post), high condensing temperature over ambient (22% pre and 28% post), and incorrect charge (72% pre and 71% post). The pre test results indicate a need for unit repairs in the field and an enhanced protocol is proposed that addresses identified limitations of the evaluated protocol. The enhanced refrigeration diagnostic approach requires the following six measurements: suction pressure, suction temperature, liquid pressure, liquid temperature, ambient temperature, and return air wet-bulb temperature, in addition to an evaluation of indoor airflow. These measurements are used to calculate superheat, subcooling, evaporating temperature, and condensing temperature over ambient, which are then used to assess the performance of the unit. The application of this enhanced protocol would result in improved (collective) unit performance. In particular, the enhanced protocol would benefit units with problems other than charge and indoor airflow and help avoid incorrect charge adjustments.

Tomczyk, J. 1995. Troubleshooting and Servicing Modern Air Conditioning and Refrigeration Systems. ESCO Press. Mt. Prospect, Ill.: Educational Standards Corporation.

Wu, S., Sun, J., "Multilevel Fault Detection and Diagnosis on Office Building HVAC Systems," 2010 ACEEE Summer Study on Buildings, 2010.

This paper presents a multilevel fault detection method. Two key features of the proposed method are 1) an energy description of all the units in a HVAC system and 2) a spatial-temporal partition approach, which allows us to apply the FDD strategy to the entire building in a uniform manner. Energy flow models for HVAC units at all levels are presented. The concept of absolute and relative references for monitoring the energy performance is introduced. A numerical example of cross-level fault detection involving an upper level AHU and lower level VAVs is presented where a fault from the AHU is detected. With the limited real time data, we discuss the threshold for detecting this AHU fault. More measurements and extensive studies are needed to establish thresholds for various faults at different levels.

Standards and other Foundational Documents

An assessment of current standards provides a contextual framework for existing HVAC maintenance and installation practices. This section examines industry-accepted standards, regulatory standards for the state of California, and procedures for the implementation of RCA programs by Verified Service Providers.

General

ACCA, "ANSI/ACCA 4, Maintenance of Residential HVAC Systems," 2008.

Describes minimum inspection requirements for the maintenance of residential heating, ventilating, and air conditioning (HVAC) applications for one- and two-family dwellings of three stories or less. Includes checklist tasks for inspecting, testing, and measuring electrical controls, mechanical venting, air distribution, and piping systems of residential HVAC system. Also provides recommended corrective actions which the contractor shall present to the homeowner to remedy identified faults. The standard excludes steam distribution heating systems and presumes that the HVAC system was designed, installed, and tested in accordance with OEM instructions, applicable codes, and other industry standards.

ACCA, "ANSI/ACCA 5, HVAC Quality Installation Specification (QI-2007)," 2007.

Establishes minimum criteria for the proper installation, maintenance, and servicing of residential and commercial HVAC systems to meet occupant demands for energy efficiency, comfort, and IAQ in residential and commercial applications.

ACCA, "ANSI/ACCA 6, Restoring the Cleanliness of HVAC Systems (HVAC System Cleanliness-2007)," 2007.

Establishes minimum requirements to restore the cleanliness of residential and commercial HVAC systems in accordance with manufacturer or customer specified criteria. Defines minimum procedures and practices to: determine when airside surfaces should be cleaned (and when they require repair or replacement), clean the airside surfaces within HVAC systems, control the spread of contaminants which may be released as a result of the HVAC cleaning process, verify the cleanliness of HVAC systems.

ACCA, "ANSI/ACCA 9, HVAC Quality Installation Verification Protocols (QIVP-2009)," 2009.

Establishes minimum requirements for verifying that residential and light commercial HVAC systems meet the ANSI/ACCA 5 QI-2007 standard. Provides guidance to Contractors, Verifiers, and Administrators who participate in verification efforts which use independent, objective, and qualified third parties to ensure that HVAC installations meet requirements established by the QI-2007 standard.

AHRI, ANSI/AHRI Standard 210/240-2008, Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment, Air Conditioning and Refrigeration Institute, Fairfax, VA.

AHRI, ANSI/AHRI Standard 340/360 -2007, Performance Rating of Commercial and Industrial Unitary Air-Conditioning and Heat Pump Equipment, Air Conditioning and Refrigeration Institute, Fairfax, VA.

Amrane, K., Sachs, H., Nadel, S., "The Regional Standards Agreement for Residential Furnaces, Air Conditioners, and Heat Pumps: Process, Results, and Implications," 2010 ACEEE Summer Study on Buildings, 2010.

On October 13, 2009, HVAC equipment manufacturers and efficiency advocates signed an agreement on regional standards for residential furnaces, central air conditioners, and heat pumps. The agreement is without precedent. If accepted by Congress and the Department of Energy, it will profoundly change strategies for achieving greater energy efficiency. First, the agreement will avoid the long, expensive, and unpredictable process of a DOE rule-making, giving manufacturers predictable standards to meet with cost-effective, innovative, products. Second, the agreement will ultimately shift some enforcement responsibility from manufacturers to distributors, contractors, and local officials, because efficiency levels will vary regionally. In addition, the agreement reaches out to call for changes to building codes that will lead to more efficient structures by allowing states to increase the standards for reference buildings in new homes.

Work on the potential of regional standards began early in the decade, in a USDOE- NASEO State Technology Advancement Collaborative (STAC)-funded project sponsored by California, New York, Wisconsin, and Florida. Its results, guided by an advisory panel, led to language in the Energy Independence and Security Act (EISA) 2007 requiring DOE to evaluate the potential of regional HVAC standards. Frank, intensive, negotiations among all stakeholders accelerated in early 2009. Assuming legislative acceptance and/or a DOE implementation of the agreement in a direct final rule, the new furnace standards will take effect in 2013 and air conditioner-heat pump standards in 2015. We estimate that the proposed standards would save 3 quads of primary energy by 2030, with another 0.7 quad from the building code provisions.

ASHRAE, "ANSI/ASHRAE Standard 116-1995 (RA 2005) Methods of Testing for Rating Seasonal Efficiency of Unitary Air Conditioners and Heat Pumps," 2005.

Provides standard test methods and calculation procedures for determining the capacities and cooling seasonal efficiency ratios for unitary air-conditioning and heat pump equipment and heating seasonal performance factors for heat pump equipment. Covers electrically driven, air-cooled air conditioners and heat pumps used in residential applications in the contiguous continental USA. Includes test methods for standard-state, cyclic, and part-load performance and methods for establishing seasonal performance. Also includes equipment with single-speed, multiple-speed, variable-speed, uploading, or multiple compressors for ducted and ductless systems; excludes room air conditioners.

ASHRAE, "ANSI/ASHRAE Standard 152-2004, Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems," 2004.

The objective of this method of test is to provide efficiency of thermal distribution systems that may be used in energy consumption or system capacity estimates and does not address the effectiveness of tested systems to provide comfort in the conditioned space or to deliver the designed or required airflow to individual rooms within the conditioned space. The standard prescribes a method of test to determine the efficiency of space heating and/or cooling thermal

distribution systems under seasonal design conditions in single-family detached and attached residences with independent thermal systems.

ASHRAE, "ANSI/ASHRAE/ACCA Standard 180-2008, Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems," 2008.

This standard establishes minimum HVAC inspection and maintenance requirements that preserve a system's ability to achieve acceptable thermal comfort, energy efficiency, and indoor air quality in commercial buildings.

ASHRAE, "ASHRAE Guideline 2-2005, Engineering Analysis of Experimental Data," 2005.

Provides guidelines for planning, analyzing data, and reporting the uncertainty of experimental data related to heating, ventilating, air-conditioning, and refrigeration (HVAC&R); expanded to include guidelines on both data collection ***and*** analysis.

E3, "E3 Energy Efficiency Cost Effectiveness", ghttp://www.ethree.com/public_projects/cpuc4.html

ARI, 2004, "Performance rating of positive displacement refrigerant compressors and compressor units," ARI Standard 540, Air Conditioning and Refrigeration Institute, Arlington, VA, USA

ARI. 2003. 2003 Standard for Unitary Air Conditioning and Air-Source Heat Pump Equipment. ARI 210/240-2003. Arlington, Va.: American Refrigeration Institute.

ARI. 2004. ARI Statistical Release of Unitary Heating and Cooling Section's Reports of U.S. Manufacturers Shipments. Arlington, Va.: American Refrigeration Institute. Available online: http://www.ari.org/sr/2003.

ASHRAE, 1993, 1993 Handbook of Fundamentals, Atlanta, GA.

ASHRAE. 2002. ASHRAE Guideline 14-2002 – Measurement of Energy and Demand Savings. Atlanta, Ga.: American Society of Heating Refrigerating and Air-Conditioning Engineers.

ASTM. 1992. ASTM E779. Standard test Method for Determining Air Leakage Rate by Fan Pressurization. American Society for Testing and Materials. Philadelphia, P.A. 69

Brandemuehl, M., S. Gabel and I. Anderson. 1993. HVAC 2 Toolkit - A Toolkit for Secondary HVAC System Energy Calculations. Prepared for TC 4.7 Energy Calculations. ASHRAE. Atlanta.

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Hall, N., Barata, S., Chernick, P., Jacobs, P., Keating, K., Kushler, M., Migdal, L., Nadel, S., Prahl, R., Reed, J., Vine, E., Waterbury, S., Wright, R. 2004. The California Evaluation Framework, Appendix to Chapter 7: 191-195. Uncertainty Calculation. San Francisco, Calif.: California Public Utilities Commission.

Hirsch, J. J. 2002. eQuest and DOE-2.2 Building Energy Simulation Program. Version 3.37, Copyright J.J. Hirsch. Camarillo, California.

Keating, K. 1991. "Persistence of Energy Savings." Handbook of Evaluation of Utility DSM Programs. E. Hirst and J. Reed, eds., pp. 89-99. Oak Ridge National Laboratory, Oak Ridge, TN.

Sachs, H. , Henderson, H., Shirey, D., De Forest, W., "A Robust Feature Set for Residential Air Conditioners, ACEEE Report Number A081" 2009.

Summary: Robust central air conditioners and heat pumps are units with special features and specifications that are designed to remain very efficient, require minimum maintenance over their lifetimes, and to automatically signal problems that require service. This report stresses the specifications required to identify the differentiated product, and the parameters that were varied in a simulation to study the benefits of the specification.

Key results: The following features can define a Robust Central Air Conditioner that has the potential to improve customer satisfaction and provide a platform for marketing premium, differentiated products. It will save energy, but all of the savings are from characteristics that are not reflected in the federal test procedure: SEER 14, EER 11.5; Resistant to refrigerant charge errors; Resistant to refrigerant leaks and other degradation; adaptive air handler; Air handler integrity; Alarms; and Quality. From simulations of the features selected for inclusion, conservative estimates dictate that the robust unit would save approximately 10%, which is more than the change from 14 SEER to 15 SEER.

TecMarket Works, "The California Evaluation Framework," June 2004.

Summary: The California Evaluation Framework provides a consistent, systemized, cyclic approach for planning and conducting evaluations of California's energy efficiency and resource acquisition programs. This document presents that Framework and provides valuable information concerning when evaluations should be conducted, the types of evaluation that can be conducted, and a discussion of approaches for conducting those studies.

The TecMarket Works Team, "California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals", Prepared for the California Public Utilities Commission , April 2006.

Verification Service Providers

Architectural Energy Corporation, "[1]Residential Air Conditioner Charge and Air Flow Verification Study, Task 4 Report, Technical Specifications and Best Practices for Charge and Air Flow Verification Services", Contract # 4600010737, Revision 2, PG&E, August 19, 2004.

Summary: This report summarizes the results of the Residential Air Conditioner Charge and Air Flow Verification Study. This study identified a number of verification service providers, and

performed interviews with each of these providers to determine which ones were most likely to provide refrigerant charge and airflow verification services in a PG&E rebate program. A series of field observations of contractors trained to work with each of these verification service providers were conducted, as well as field observations of non-verification contractors as a comparison. These reports are proprietary and are for PG&E internal use only.A best practices specification was developed from a variety of sources to be used as the basis of the PG&E Residential Air Conditioner Charge and Air Flow program. The project was originally planned to proceed in the order described above. However, due to delays in project startup, it was necessary to rearrange the task order such that the best practices specification was developed prior to performing the field observations. Therefore, the field observation information was obtained after the specification was developed, and could not be used as input. The best practices specification included in this report includes some modifications, based on the field observations as well as other data gathered subsequent to its original release.

Architectural Energy Corporation (AEC), Commercial HVAC Refrigerant Charge & Airflow and Economizer Verification Study, Contract #4600016485, Job I.D. #06 CEE-T-3589, Task 3: Conduct Additional Research, Draft, December 15, 2006.

Enalasys, "Calibration Documentation," 2002.

Summary: This document describes the calibration processes and equipment used to establish reliable reference sources for accurate calibration of the eScan Diagnostic System sensors and measurements.

Enalasys, "PG&E 2010-2012 Quality Maintenance Contractor Incentive Program Field Manual," February 2010.

Summary: Describes program requirements and incentives for PG&E's 2010 QI-QM Program managed by Enalasys.

Pacific Gas and Electric, "PG&E 2010-2012 Quality Installation Contractor Incentive Program: Field Policies and Procedures Manual for Residential and Commercial Customers," December 2009.

Summary: Pacific Gas and Electric Company has created the 2010 Quality Installation Contractor Incentive Program. This Quality Installation Contractor Incentive Program Field Policies and Procedures Manual establishes policies and procedures for Program.

Pacific Gas and Electric, "PG&E 2010-2012 Quality Maintenance Contractor Incentive Program: Field Polices and Procedures Manual for Residential and Commercial Customers," December 2009.

Summary: Pacific Gas and Electric Company has created the 2010 Quality Maintenance Contractor Incentive Program. This Quality Maintenance Contractor Incentive Program Field Policies and Procedures Manual establishes policies and procedures for Program. All incentive payments made under the Program must meet all requirements described herein.

Verified, Inc., "Verified PDA Training Manual: Duct Test and Seal" 2010.

Human Factors

As one of the most crucial but understudied aspects of the HVAC spectrum, human factors influence everything from program design and product installation to end-user behavior. This section compiles existing findings on technician training and certification, barriers to program acceptance, operator training, and how end-users use energy and efficiency technology. Many entries are from the 2010 ACEEE Summer Study because they are the most recent information on the topic, and because they contain references that allow the reader to go deeper into the topic of interest.

End-User Behavior

Barry, J., Prigo, N., Muldoon, R., "Elevating the Role of the Multifamily Building Operator: How Operators Can Save Energy, Minimize Waste, and Improve the Bottom Line," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2010

> Summary: Recent reports have highlighted disappointing energy performance from green buildings, automated systems that are never fully utilized and major capital improvements that do not result in expected energy savings. All of these factors have one thing in common. In the quest to improve building performance, human behavior is the wild card. This paper will examine how the behavior of one particular person -- the building operator -- can positively influence the performance of a multifamily building. This paper describes a collaborative effort between labor, multifamily building owners and property managers in a major metropolitan city to empower 2,000 operators to increase the energy efficiency of large multifamily buildings. We think this is the first large-scale comprehensive program to both educate superintendents and building operators, and then document the best practices and upgrades these operators make in their buildings.
>
> The paper describes innovative teaching techniques, identify barriers that prohibit greater operator involvement in energy management, share student perceptions of the training and review a preliminary list of changes superintendents made in their buildings. After the architects and engineers leave the building it is in the hands of the staff. This paper makes the case that investing in the building operator is perhaps the single most important efficiency investment an owner can make.

Bobker, M., Joseph, V., Aslanian-Persico, A., "Addressing the Operator as a Driver of Building Performance," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2010

> Summary: A handful of programs emerging in the United States attempt to address operational improvements in buildings and the need for building operators to attain a more sophisticated level of knowledge, understanding and practice. Program results are considered at two levels. The first is change in the industry's expectations of operating engineers. These new expectations are seen as the basis of skills sets and learning objectives. The second level is based on training evaluation, conducted through pre/post surveys in 2009, that assesses participating operators' perceptions of their job functions and specific skills. Preliminary findings suggest that properly structured training can contribute to changes in operator functions as required by the industry but that further specification of training instruments is still necessary.

Dougherty, A., Mitchell-Jackson, J., Wellner, P., "Ethnographic Inquiry in Energy: Exploring Meaning-Making and Sociality in Language Use, Program Participation, and Behavioral Choice," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2010

Summary: Ethnographic research provides unique insights into the everyday lives of individual households that other research methods cannot. Focusing on the living, day-to-day culture of individuals, ethnography provides a window into the ways language use, belief systems, family and social networks, and one's geography inform and guide energy-saving (or wasting) practices. Opinion Dynamics conducted one of the largest ethnographic research studies in the energy industry, conducting in-home visits throughout the state of California to understand how households make day-to-day decisions on their energy use, and what specific cultural factors promote and detract from smart energy choices. Here, we discuss how our observations of and conversations with households have generated new knowledge for the energy industry that can inform and enhance program implementation, communication, and upfront market and evaluation research design. In particular, we focus on the insights gained in listening to everyday language use and meaning-making around energy, household and social dynamics, what households say versus what they do and mean, and the cultural particularities that emerged in our research. We highlight how these insights add depth of understanding to more traditional research techniques, such as surveys and in-depth interviews. Further, we discuss how our ethnographic research can be taken off the shelf and incorporated into multiple program and evaluation efforts implemented throughout the US.

Harris, J., Hummer, J., "Behavior Change Interventions; What Works, What Doesn't, and Why," 2010 ACEEE Summer Study on Buildings, 2010

Summary: Recent studies have identified significant energy efficiency savings potential resulting from behavioral interventions. These interventions are beginning to gain traction, acceptance, and credit from regulatory entities for the energy and demand savings they produce as well as their market transformation effects. Early interventions have been launched and much research is underway in this field. This paper summarizes a meta-analysis of existing research on energy- related consumer behavior and initiatives. In this analysis, leading thinkers in the field were interviewed and current studies, initiatives, and evaluations were identified and analyzed. The research, evaluations and pilot programs reviewed were categorized by their approach, and best practices and key lessons learned were teased out and summarized.

A thorough understanding of successful behavior change approaches and consumers' energy-related behaviors and attitudes is essential not only to launching successful behavior change interventions, but also to maximizing participation in traditional energy efficiency programs. This paper provides an overview of recent research and outlines strengths and weaknesses of the approaches analyzed.

Lopes, J., Agnew, P., "FPL Residential Thermostat Load Control Pilot Project Evaluation, " 2010 ACEEE Summer Study on Buildings, 2010.

In a 2008-2009 pilot study of 400 participants, Florida Power & Light (FPL) and Applied Energy Group, inc. (AEG) evaluated the technical and economic benefits of a new generation of two-way communicating programmable thermostat technology to enhance FPL's existing switch-based direct load control program. This new technology provided FPL with enhanced capability to monitor and control heating and cooling during system-critical periods. A typical barrier to customer acceptance of utility load control programs is the reluctance of customers to surrender control of heating and air conditioning appliances. Consequently, FPL proposed to evaluate whether the benefits of the On Call Program could be expanded through a new generation of

communication and control technologies that put residential customers in charge of decisions that could lower energy costs, while allowing customers to override FPL interruption of their heating and air conditioning appliance curtailments. Pilot participants also had the option of overriding FPL's interruption of their central AC and heat via phone or Internet. Participants' accessibility to the Internet also provided them the option of remote access to their thermostat for programming to save energy and to monitor the temperature of their homes.

McRae, M., Van Clock, J., Levy, M., "Engaging Nonresidential Customers in Whole Organization, Whole Building Efficiency," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2010

Summary: Programmatic approaches that target attitude and behavior changes to support whole organization, whole building efficiencies can achieve greater savings than programs promoting individual measures and activities, even if the latter programs offer a broad array of incentives and technical assistance. Although recent nonresidential programs have moved away from single end-use measures toward multiple building measures and services, these oft-called "comprehensive" programs still rely mostly on devices to achieve energy efficiency. By contrast, this paper examines programs working with businesses to not only increase the up-take of utility-offered measures and services, but also to affect attitudes and behaviors of the people who operate the buildings. We dub these programs "Whole Organization" programs; ones that truly address energy use *comprehensively* by including the human element to reap maximum efficiencies.

Meir, A., et. al., "How People Actually Use Thermostats," 2010 ACEEE Summer Study on Buildings, 2010.

Summary: Residential thermostats have been a key element in controlling heating and cooling systems for over sixty years. However, today's modern programmable thermostats (PTs) are complicated and difficult for users to understand, leading to errors in operation and wasted energy. Four separate tests of usability were conducted in preparation for a larger study. These tests included personal interviews, an on-line survey, photographing actual thermostat settings, and measurements of ability to accomplish four tasks related to effective use of a PT. The interviews revealed that many occupants used the PT as an on-off switch and most demonstrated little knowledge of how to operate it. The on-line survey found that 89% of the respondents rarely or never used the PT to set a weekday or weekend program. The photographic survey (in low income homes) found that only 30% of the PTs were actually programmed. In the usability test, we found that we could quantify the difference in usability of two PTs as measured in time to accomplish tasks. Users accomplished the tasks in consistently shorter times with the touchscreen unit than with buttons. None of these studies are representative of the entire population of users but, together, they illustrate the importance of improving user interfaces in PTs.

Moezzi, M., Lutzenhiser, L., "What's Missing in Theories of the Residential Energy User," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2010

Summary: Residential energy use has been envisioned in varied ways, each highlighting different factors and capturing a partial truth. This paper outlines assumptions of core theories about household energy use. It gives an abbreviated list of major empirical findings framed by these theories. It then identifies a new set of "blind spots" created by overly-simple reliance on models and by data shortcomings that in combination may block development of a more sophisticated understanding of energy use. Policies and program strategies, in turn, can become oriented toward simplistic approaches to change. We point to the need for improved interpretation and elaboration of existing theories, and accordingly toward richer comprehension of energy users

and the dynamics of energy use, suitable to the wider policy world of climate change and sustainability that the energy use research field now faces.

This paper examines some principal assumptions and theories of household energy use, and asks how the simplifications in these theories may mislead in the energy efficiency field's everyday modes of thinking and strategizing about how to reduce energy use. As the formerly relatively confined world of energy efficiency research, which spoke in restricted terms and within a limited number of institutions, confronts the wider world of climate change and sustainability science and policy, developing capacity to recognize and transcend conventional boundaries of these theories becomes critical to the development and application of "good ideas" to reasonably vetted strategies.

Sanquist, T., Schneider, K., Meier, A., "Human-Centered Technology Design for Energy Efficiency and Conservation," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2010

Summary: Human-centered design (HCD) is the practice of designing systems for human use. This paper describes the discipline of human factors engineering, which has traditionally been applied to energy intensive complex systems such as automobiles and aircraft, and will look ahead to applications in sustainable systems design. The focus of HCD has been ensuring efficient and effective human-system performance, through application of design principles such as understanding the user, providing feedback, and minimizing cognitive load. These principles also apply to the design of sustainable socio-technical systems, both through specific device user interfaces and broader developments such as transportation systems and urban design. HCD design principles need to be embedded within a social-systems engineering model that considers the overall *constraints* of physical and institutional processes, the *cultural* aspects of designs and interventions, various *comfort* and *convenience* factors at the level of individual users, and the *cognitive* impacts of designs – the 5C model. Application of HCD will involve a more holistic view of human-systems than is traditionally adopted by government and industry. HCD methods can be useful in disaggregating the energy intensive aspects of lifestyle and work, as well as applying design principles to address the 5 C's.

Ventura Ashby, K., Nevius M., Walton, M., et. al., "Behaving Ourselves: How Behavior Changes Insights Are Being Applied to Energy Efficiency Programs," 2010 ACEEE Summer Study on Buildings, 2010

Summary: While there is growing interest in applying behavior change to the energy efficiency context, there is often a great deal of uncertainty about how behavior strategies are incorporated, or could be incorporated, into efficiency programs and what tools may be useful in this work. The Consortium for Energy Efficiency (CEE) membership recognized the potential benefit of gathering information on behavior change in the context of ratepayer-funded energy efficiency. To this end, CEE and its members have developed an overview of behavior insights from across the social sciences that could be incorporated into efficiency efforts, with examples of programs applying those insights. A goal of this effort was to facilitate information exchange between program administrators and provide the necessary resources to those incorporating behavior approaches into their programs.

This paper will describe a wide variety of behavior insights potentially applicable to the energy efficiency program context, provide examples of efficiency programs that have already begun to apply these insights, and explore some untapped opportunities to achieve energy savings through behavior change. CEE members have already incorporated numerous behavior insights into their programs, such as social norms, feedback, public commitment, and goal setting. Yet other key insights, such as self-efficacy, cognitive dissonance, and loss aversion, have gone largely

underutilized in energy efficiency up to this point. Future participation in and effectiveness of energy efficiency efforts would likely benefit from the application of these additional insights.

Training and Certification

Anderson, M., Cowan, C., Sayen, N., "If We Ramp Up, Will They Come? Assessing Employer and Workforce Readiness to Accelerate Energy Efficiency in Three Midwestern States," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2010

Summary: The American Recovery and Reinvestment Act invested millions in support of "green job" development and training – much of it targeted at the transition to clean energy. Across the country, energy efficiency programs are at various stages of an unprecedented ramp-up. How aligned are these two efforts? Will employers and appropriately skilled human capital be available for energy efficiency programs – or do we face skill and other workforce barriers to accelerating energy efficiency? Are there gaps we can address now to support energy efficiency and robust economic development? This research will examine exactly what skills we need to support specific energy efficiency programs, where investment may not be necessary, and workforce market barriers that neither ARRA nor current energy efficiency programs are currently addressing.

These research projects focus on three Midwestern states seeking a post-manufacturing workforce transition. Wisconsin, Michigan and Illinois are in various stages of energy efficiency program delivery, ranging from new and modest programs to mature and accelerating programs. This paper will share the results of the first research project, which includes perspectives from thought leaders from a broad spectrum of workforce, economic development, and energy efficiency perspectives. The paper will also map ARRA investments and energy efficiency programs to assess opportunities to better leverage ARRA investments to support job creation in energy efficiency.

Buhr, T., Wellner, P., "California Energy Centers and Workforce Development: What Other States Can Learn," 2010 ACEEE Summer Study on Buildings, 2010.

Summary: The California Statewide Energy Efficiency Education and Training Program is one of the largest training programs of its kind in the country. California's Investor-Owned Utilities (PG&E, SCE, SCG, and SDG&E) operate nine Energy Centers that provide a wide variety of educational programs for both market actors and end-users. In this paper, we present the results from a three-year evaluation of this program. The purpose of the evaluation was to assess the indirect energy efficiency impacts of the Statewide Energy Efficiency Education and Training Program. The evaluation had two main charges: identify changes in attitudes, awareness, and knowledge of energy efficiency, and quantify net energy savings for key components of the programs. In addition, we examined the role the Energy Centers play in the continuing education marketplace in California, which is the focus of this paper. The results of the evaluation indicate that the Centers provide training that increases the knowledge of training participants and causes them to change their behaviors. Participants apply what they learn in the workplace, which results in measurable energy savings. The Centers play a vital role in providing workforce training. Similar training is either not as easily accessible or affordable. Given the success of this program, future programs could look to the California Statewide Education and Training Program as a model.

Marver, J., Benningfield, L., et. al., "Workforce Training that Changes Behavior and Improves Outcome," 2010 ACEEE Summer Study on Buildings, 2010.

Summary: Energy codes are complex. Workforce turnover happens. Time constrains effectiveness. Motivation is a major driver for competency. These barriers and others create a

situation where the energy savings delivered from building energy codes often fall short of expectations. The most ambitious code accomplishes little if the process undermines its implementation. Implementation strategies rely on each market actor playing their role effectively. Any weak link in the compliance chain diminishes or eliminates the energy savings at the meter. The California Investor Owned Utilities' (IOUs) Statewide Codes and Standards (C&S) Program is moving away from the traditional energy code training approach and replacing it with a fully integrated system that moves toward measurable outcomes.

Peters, J., Albers, N., Goldman, C., et. al., "Energy Efficiency Services Sector: Workforce Education and Training Needs," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2010

Summary: This study provides an initial assessment of the current state of workforce development in energy efficiency and identifies high-priority training needs for this sector. We focus specifically on the energy efficiency services sector (EESS), which includes those service-oriented jobs that target improving the energy efficiency of residential and nonresidential buildings.

Walther, R., "California's Workforce Education and Training Needs Assessment: An Interim Update," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2010

Summary: In September 2008, workforce education and training was identified as a cross-cutting issue in California's Energy Efficiency Strategic Plan adopted by the California Public Utilities Commission. One of the near-term strategies identified for the workforce issue was a needs assessment to be conducted by a third-party consultant and jointly managed by the CPUC and California's major investor-owned utilities. Following stakeholder discussions regarding the scope of work and a competitive solicitation, a consultant was selected and the project got underway in December 2009. The schedule calls for completion of the project by the end of 2010. This paper reviews the design and implementation of the on-going project and shares some preliminary results and general observations. The paper is intended for those interested in the objectives and findings of the on-going needs assessment being conducted in California as well as those considering a workforce needs assessment of their own.

Whitehurst, D., "The Trade Ally Approach to Growing the Green Workforce," 2010 ACEEE Summer Study on Buildings, 2010

Summary: "Green jobs!" is the rallying cry for economic growth, but where will they come from and how will they be created? Training existing trade allies in new and improved energy efficiency technologies is a core component of increasing the market's capacity to deliver energy savings. This education can expand a trade ally's service offerings, leading to increased opportunities for business growth and revenues. This presentation reviews in more detail the three trade ally training approaches (tell, show, and get to know), with a specific emphasis on the trade show approach. We review key concepts for hosting trade shows and provide suggestions for future enhancements. We also highlight how two trade allies facing the economic downturn increased their offerings and revenue to play a tangible role in growing the green economy.

Policy

Regulatory policy, specific to RCA and general to HVAC program, guides all actions of HVAC program design and implementation. This section compiles existing policies and regulations that influence current HVAC programs and dictate future savings goals and program structure. Recommendations for re-structuring policy and regulatory framework are also included.

Refrigerant Charge and Airflow

California Energy Commission, "Strategic Plan to Reduce the Energy Impact of Air Conditioners," June 2008.

Summary: The California Energy Commission is providing a strategic plan designed to improve the energy efficiency and reduce the peak energy use of central air□conditioning systems in California. The plan was developed through a working group process to define a vision or new business model for the heating, ventilating and air□conditioning (HVAC) industry, investigate options to meet the vision, and recommend specific actions to be taken by public and private organizations to achieve the Legislature's goal of reduced peak energy use.

California Energy Commission, 2008 Building Energy Efficiency Standards Residential Compliance Manual, CEC-400-2008-016-CMF-Rev1, March 2010.

Energy Market Innovations, "Small Commercial HVAC Pilot Program, Market Progress Evaluation Report #1," November 2004.

Summary: This report documents the experiences of a research, development, and implementation effort involving a multi-year Small Commercial HVAC Pilot program undertaken by the Northwest Energy Efficiency Alliance. The goal of the proposed project was to create a market for energy-efficiency tune-up services for packaged rooftop units (RTUs) in smaller commercial buildings. The pilot targeted 5-15 ton RTUs on commercial buildings.

The pilot was largely unsuccessful in part because customers were unwilling to spend the money needed to tune up the units. Two conclusions from the program were that the observed energy savings were not reliable (because they were due to a variety of factors, not just the retrofits) and that the addition (or reconfiguration) of programmable thermostats could yield significant energy savings.

This file also includes the following appendix: Small HVA Decision-Maker Market Research Draft Report, prepared by Energy Market Innovations, April 2002.

Energy Market Innovations, "Process Evaluation: CPACS Program 2007-2008," March 2009.

Summary: This document represent the results and recommendations of a review of Southern California Edison's (SCE) Comprehensive Packaged Air Conditioning System (CPACS) Program for the period 2006-2008. SCE launched the CPACS Program in 2006 to reduce electricity consumption through the promotion of high efficiency packaged air conditioning systems and high quality installation and service of commercial and residential air conditioning equipment.

The evaluation applied standard process evaluation methodologies but was unique in its timing and approach. SCE's EM&V staff requested Energy Market Innovations, Inc. (EMI) to perform a Rapid- Feedback evaluation of the CPACS Program in the second year of the program implementation period (2007). As the project title states, the intent of this evaluation was to identify and assess program performance issues and feed them back to the Program for addressing

in a manner that the Program could make informed decisions. This report provides a number of recommendations for making the program more effective.

Proctor Engineering Group, "Summary Report of Persistence Studies: Assessments of Technical Degradation Factors, Final Report," February 1999.

Summary: This report is a summary of previously published persistence studies. This summary report is designed to be suitable for utility consultants who may need to use the results of the Persistence Studies but do not need the background information, source documentation, or analysis and logic contained in the full reports. This document defines the study measures in some detail, discusses the boundary between persistence and retention, and presents TDF summary tables that incorporate final results from all the Persistence Studies.

Southern California Edison, "2009 – 2011 Energy Efficiency Plans: HVAC: Residential Quality Maintenance and Commercial Quality Maintenance," March 2009.

Summary: Describes requirements and incentives for 2009-2011 HVAC Residential Quality Maintenance and Commercial Quality Maintenance HVAC sub-programs.

Vine, E., "Strategies and Policies for Improving Energy Efficiency Programs: Closing the Loop Between Evaluation and Implementation," 2008.

Summary: Discusses reasons why energy efficiency program implementers may be disinclined to use program evaluation data to improve implementation approaches, including a lack of incentives, hostility between implementers and evaluators, and unclear evaluator recommendations.

Vine, E., "The Human Dimension of Program Evaluation," Lawrence Berkeley Labs, May 1993.

Summary: Discusses human behaviors that influence expected versus realized energy savings, particularly for demand-side management programs. Describes key issues that should be considered in evaluating DSM program efficacy.

General

Auffhammer, M., Aroonruengasawat, A., "Uncertainty over Population, Prices or Climate? Identifying the Drivers of California's Future Residential Electricity Demand," Energy Institute at Haas, WP 208, August 2010.

Bertoldi, P., Rezessy, S., Boza-Kiss, B., et. al., "Rewarding Energy Savings Rather than Energy Efficiency," 2010 ACEEE Summer Study on Buildings, 2010.

Summary: Financial incentives are important for overcoming certain market barriers to improved energy efficiency and for the adoption of energy efficient technologies. Such incentives are mainly focused on the introduction of specific technologies, rather than behavioral change.

While the declared goal of financial support schemes is to save energy or reduce harmful emissions rather than to foster new technologies *per se*, it is very often encountered that such financial support for energy efficient technologies may not ensure real energy savings due to the rebound effect and remaining barriers. In the area of renewable energies it is common for financial support to be given to power producers for the verified production of renewable electricity, in the form of a guaranteed financial incentive (feed-in tariff). In the energy efficiency policy research little attention has been paid to the possible use of a "feed-in tariff" (FIT), in the form of a financial incentive based on the kWh saved by the end-user. This paper discusses the

possible setup of a FIT designed to reward real energy savings (ES FIT). The paper first explores the rationale behind and the possible functionality of an ES FIT, giving examples of similar policy tools implemented or planned. The paper looks into additionality and persistency of energy savings thus supported. Finally, key advantages and complexities related to a FIT scheme for energy savings are discussed, intending to open a discussion and foster further research on the topic.

Brown, K., Daly, A., Elliot, J., et. al., "Hitting the Whole Target: Setting and Achieving Goals for Deep Efficiency Buildings," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2010.

Summary: Zero net energy or carbon neutrality goals have emerged as a defining theme for building energy efficiency. This has been accompanied by interest in greenhouse gas emission accounting in anticipation of either carbon trading schemes or regulation of such emissions. These trends have spurred an increased interest in the actual measured energy performance of buildings. Yet, due to the need for early analysis relative to code and rating system requirements, energy modeling during design has become decoupled from actual measured performance of new buildings.

Deep efficiency and zero net energy goals require two profound shifts in thinking about evaluation of building performance. First, performance targets must expand from a limited set of building systems addressed by traditional codes and standards, to an all-systems accounting of energy use. Second, there must be intent to assess performance relative to targets as-operated (measured) in addition to as-designed (modeled). These two shifts need to be accompanied by availability of more measured performance data to support goal setting and modeling.

Friedman, H., Sreedharan, P., "Wiring the Smart Grid for Energy Savings: Mechanisms and Policy Considerations," 2010 ACEEE Energy Efficiency in Buildings, 2010.

Summary: The smart grid is often promoted as a pathway to save energy and reduce greenhouse gas (GHG) emissions. However, smart grid data, communications, and controls infrastructure only "enables" energy savings and renewable energy opportunities. This paper discusses energy savings opportunities through four key mechanisms: improved energy use information, dynamic pricing programs, automated diagnostics, and improved program delivery. We discuss technical challenges to achieving energy savings using the smart grid infrastructure across building types, such as the need for commercial buildings to have properly functioning controls. Against a backdrop of current smart grid policies, we discuss the relationship between smart grid and GHG emissions reductions from a policy perspective. These include understanding the GHG emissions reduction potential from smart grid, barriers to using smart grid to enable energy savings, and policies that might address these barriers. We conclude with a discussion of energy savings opportunities through smart grid. We aim to expand the dialogue on the intersection of smart grid and energy savings and to highlight opportunities for engagement by the efficiency community.

Gidding, D., Gage, L., "Oh, Behave! Fitting Multi-Sector Behavioral Programs into Utility Frameworks," 2010 ACEEE Summer Study on Buildings, 2010.

Summary: The development of behavior-based programs in the context of traditional energy efficiency programs, which are based on single-transaction incentives, has posed numerous challenges for planners, implementers and evaluators. For planning, challenges arise in predicting and reporting the stream of savings over time. Within program design, implementers must construct a program that provides incentives for persistent and permanent savings, requiring a multi-year effort of program resources and communication channels between implementer and end user. For evaluation, questions include the correct evaluation approach, the timing and length of the evaluation, and the reliability of savings over time achieved through behavior. In addition to programmatic challenges, overarching issues arise in regards to the framework of cost

effectiveness, measure life and persistence, and uncertainty in performance and supply side impacts.

Lutzenhiser, L, Hungerford, D., Friedmann, R., "Sticky Points in Modeling Household Energy Consumption," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2010.

Summary: A variety of approaches have been proposed to explaining individual household energy consumption, its variation, and its potential reduction. Some focus on technology, some on costs, and some on a combination of behaviors, attitudes, intentions, and norms. All try to make sense of a problem that, from a modeling perspective, involves hundreds of potentially important factors, yet is supported by highly inadequate or at best selective data. While there is value in "doing the best one can" with the resources at hand, building a defensible science requires a cold hard look at the quality of theory, research and data. This paper draws upon the authors' assessment of data and critical literature review to examine the implications of common "sticky points" in modeling residential energy consumption. These include: variability in consumption within and across households, data quality issues, conflicts among various modeling approaches and underlying theoretical constructs, and tacit beliefs about causal relationships. The combination of uncertainties in these areas can lead to adoption of cautious (and sometimes misleading) assumptions, and to conservative policy approaches that hedge against behavioral failures in efforts to secure energy savings.

This paper is occasioned by the convergence of two energy efficiency policy imperatives. The first is an interest in "behavioral" approaches to accelerating efficiency hardware adoption, along with behavior change as a source of energy conservation. The second is the increased use of models and modeling to inform efficiency policy development, implementation and evaluation. As participants in both movements, our aim is to explore how well behavioral understandings can translate into better models and, as a result, into better policies.

Murphy, W. C., "Comprehensive Existing Home Retrofit Programs: Designing Programs in a Stakeholder Rich Environment," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2010.

Summary: In past years, utilities often bore the full burden of designing, creating, and implementing comprehensive (i.e., whole house) energy efficiency programs for the existing home marketplace. These responsibilities included 1) building a supply of contractors through recruitment, training, certification, mentoring, and retention; 2) creating market demand through advertising, rebates, financing, and other marketing efforts; and, 3) providing quality assurance and control. The public and private demand for energy efficiency services has dramatically altered that environment. Federal, state and local funding for a variety of programs are combining with rapidly growing customer and contractor knowledge to become both a threat and an opportunity for utilities. Workforce development programs, property tax financing, and community rebate programs are new variables for which utilities must account. Without proper coordination, customers (and contractors) may face conflicting programmatic requirements and/or messaging.

This paper highlights the key programmatic areas in which utilities and other stakeholders may intentionally or unintentionally compete and/or cooperate. Particular focus is paid to 1) how local efforts have often lacked the full range of support needed to successfully deliver home performance services, 2) the roles and responsibilities of different groups during implementation, and 3) how different state-centric and utility-centric implementation models appear to be emerging.

Schwartz, L., "Smart Policies Before Smart Grids: How State Regulators Can Steer Investments Toward Customer-Side Solutions," 2010 ACEEE Energy Efficiency in Buildings, 2010.

Summary: The Smart Grid holds promise as an enabler of customer-side resources – energy efficiency, demand response, and distributed generation and storage. Together with utility measures to more precisely control electricity on the grid, improve integration of renewable resources and support electrification of the transportation sector, the Smart Grid can help reduce carbon dioxide to levels that significantly lower the risk of dangerous threats to the climate. But without the right policies, the Smart Grid will simply divert attention and funds from carbon reductions achievable today with clean energy resources. State regulators are key. They have broad authority to establish the requirements that are needed to tap the full potential of Smart Grid technologies that consumers will be paying for. And they can ask tough questions about whether proposed investments will, in fact, save energy, increase development of clean supply-side resources and reduce greenhouse gas emissions.

Star, A., et. al., "The Dynamic Pricing Mousetrap: Why Isn't the World Beating Down Our Door?, 2010 ACEEE Summer Study on Buildings, 2010.

Summary: In the smart grid debate, a key consumer oriented benefit has been the potential of dynamic rates. Properly implemented dynamic rates can reduce costs for consumers and provide them with valuable information about their energy usage in ways that enable them to reduce consumption, particularly at peak times when the electric gird is most stressed. Seven years of experience with thousands of residential real-time pricing customers in Illinois has supported this theory. Participants in the Ameren Illinois Utilities' Power Smart Pricing and ComEd's Energy-Smart Pricing PlanSM and the later Residential Real-Time Pricing programs have been successful in reducing peak demand in the 15% range and achieving bill savings that averaged in the 10 to 15% range. Recent evaluations have shown a conservation effect of reduced kWh at the level of 6% in the summer and 1.5% annually. Surveys have found that participants find it easy to manage their energy use and have high levels of satisfaction. These findings span race, income, usage and community demographics. But if it's such a great idea, why have only a small percentage of customers signed up? This paper will explore the challenges and learnings from marketing a new voluntary rate that tries to undo 100 years of public policy that separated consumer electric rates from the real costs of generation.

Van de Grift, S., Schauer, L., "A Hand to Hold: A Holistic Approach to Addressing Barriers in the Home Retrofit Market," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2010.

Summary: Policy makers and program implementers agree that we need more comprehensive residential retrofit programs. Getting more households to implement holistic measures will yield the deeper energy savings needed to address climate change while creating green jobs and reducing household energy costs. There is also increased recognition that programs need to address behavior as well as equipment. The only question is how to make this happen. After decades of efforts that have yielded relatively low participation rates, inconsistent measure implementation rates, and other lost opportunities, we launched a pilot in two Milwaukee neighborhoods in 2008. Our aim was to test a more aggressive approach to barrier reduction. As part of this pilot we substantially increased incentives and financing (to reduce first-cost barriers), integrated behavioral savings opportunities with shell measures and equipment, and hired "case managers" to help households overcome the various hassle barriers associated with efficiency improvements. The results were substantial; nearly 100% of households that initiated activities completed comprehensive measures despite the fact that many households in the program had substantial income restraints. Initial estimates suggest that household savings will exceed 25% for both gas and electric usage.

This paper provides an overview of the program, documents program evaluation results, and discusses the lessons learned from the first year pilot program. Specific to the program evaluation, this paper focuses on the findings related to the differentiating components of the program: the energy advocate, the turnkey service offering, and the co-payment (or incentive) assistance.

Wigington, L., "Staged Approaches for Deep Energy Reductions in Existing Homes," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2010.

Summary: It is possible to achieve substantially deeper reductions of energy use in existing homes than was previously assumed practical or possible. However, a comprehensive "all at once" deep energy retrofit may be overwhelming for many homeowners, either in terms of complexity or expense. However well-intended or cost-effective, fragmented improvements have the potential to create barriers to deep reductions as a result of suboptimal levels of investment in efficiency or the need to undo or redo work to achieve a higher level of performance. This paper addresses the need for and challenge of steering our investments in home improvements and energy investment so that they lay the foundation for substantial reductions in the immediate future. Staging deep retrofits pose opportunities and challenges. This paper will explore bundles of measures that can be deployed in a staged manner to achieve the following objectives: 1) create, rather than block, opportunities and options for further reductions; 2) minimize negative unintended consequences such as indoor air quality or combustion safety problems; and 3) build the knowledge and institutional and human capacity to achieve deeper savings. Bundles of measures that form a defined package have the possibility of simplifying an array of options and making it easier to communicate choices to occupants and owners as well as designers and contractors. This paper will examine potential strategies and implications for energy efficiency initiatives. The confounding issue of uncertainty, particularly related to the cost and performance of emerging technology, will be acknowledged.

Evaluation, Verification, and Measurement

As the largest portion of this document, the Evaluation, Verification, and Measurement, section compiles assessments of existing and completed programs. This section provides not only valuable information on best practices and lessons learned but demonstrates the wide extent of existing HVAC programs and their varying success.

General

The Cadmus Group, "Northwest Commercial Building Stock Assessment," Final Report, December 2009.

Summary: The report summarizes the research findings characterizing the commercial building stock in the Pacific Northwest. The research was intended to update and augment the 2003 Commercial Building Stock Assessment (CBSA) study, a unique effort to characterize the physical and energy-use characteristics of commercial facilities in the Pacific Northwest by integrating and updating information from several previous regional data collection efforts. The study's resulting database has served as a valuable resource for regional energy planners and researchers. Extensive technical data were compiled, providing reasonably detailed information on key structural characteristics, energy systems, and components existing at the time of the study.

Consortium for Energy Efficiency, "Residential HVAC Programs National Summary," September 2005

Summary: Provides a summary of National residential HVAC programs. Includes details on program background, program components, and program marketing and evaluation.

De Kleine, R., Keoleian, G., Kelly, J., "Life Cycle Optimization Of Residential Air Conditioner Replacement (Draft)," 2009.

Summary: Using life cycle optimization, this research determines when a residential air conditioning unit should be replaced with three separate objectives of minimizing life cycle (1) energy consumption, (2) greenhouse gas (GHG) emissions and (3) cost to the consumer over a fixed time horizon. Optimal replacement was explored over two periods, 1985 thru 2025, and 2009 thru 2005.

Key findings: Energy minimization requires frequent replacement compared to GHG or cost minimization. In many cases, following the GHG minimization replacement schedule yields an energy savings that is nearly as large as the energy minimization case at a lower cost to the homeowner. Practicing optimal replacement while introducing higher efficiency replacement paths either through increasing the federal minimum efficiency standards, creating a higher regional standard in the south, or by deciding to replace with Energy Star units can reduce energy consumption and greenhouse gas emissions even further.

Delahay, B., Ware, W., Lee, L. et. al., "Running Hot and Cold: Predictable HVAC Programs with Unpredictable Results," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2010

With a multitude of factors influencing the residential HVAC market, why are some programs smashing their goals while other programs struggle to succeed? And how are program managers, utilities, and regulators reacting to the unexpected results? This is

particularly perplexing when programs have similar program designs. Consumers Energy (Michigan) and National Grid (New York State) are providing HVAC programs to their customers for the first time in many years. The programs, first implemented in 2009, have evolved quickly. These utilities have had significant (and surprising) program uptake in some territories while struggling in others. As a result of program progress (or lack thereof), program managers are faced with the need to make early program design changes. The programmatic changes being proposed and/or implemented may have ramifications for the programs' uptake and portfolio of offerings in future years. This paper presents these utilities' early experiences and reactions to their 2009 performance. Program evaluators supplement their story with data captured through trade ally and program staff interviews.

Energy and Environmental Analysis, Inc., "Light Commercial HVAC: Market Research Report, Final Report 05-561-02B", July 2005.

Summary: Presents results of a light commercial heating, ventilating, and air-conditioning (HVAC) market characterization study covering the four-state region of Oregon, Washington, Idaho, and Montana (collectively referred to as the Pacific Northwest). The analysis is focused on the supply-side of the market for packaged HVAC products up to 25 tons capacity that are installed in non-residential buildings.

Gamson, D., "Decision determining Evaluation, Measurement, and Verification process for the 2010 through 2012 Energy Efficiency portfolios," March 2010.

Summary: This decision sets out the roles and relationships among the Commission's Energy Division (ED), California's investor-owned utilities (utilities or IOUs), and stakeholders regarding Evaluation, Measurement and Verification (EM&V) of energy efficiency programs for 2010 through 2012. The roles and responsibilities previously laid out in Decision (D.) 05-01-055 are clarified to improve transparency of EM&V activities, minimize conflicts of interest, and reduce duplication of effort and undue expenditure of ratepayer funds for the 2010 through 2012 time period.

Credible and effective EM&V requires a clear separation between "those who do" (the program administrators and implementers) and "those who evaluate" the program performance. Accordingly, we do not alter the fundamental division of responsibilities struck in D.05-01-055, under which the ED maintains management and contracting responsibilities for all EM&V studies used to measure and verify energy, peak load savings and cost-effectiveness for individual programs, groups of programs and at the portfolio level, while the utilities retain a limited EM&V budget to carry out studies that inform portfolio implementation and process evaluation. On the basis of experience over the past several years of EM&V activity, however, we make several process changes to improve oversight and accountability of EM&V activities carried out by both ED and the utilities.

All parties agree that we need to codify more collaborative and transparent processes as an important step towards improving the effectiveness of our EM&V efforts. In this decision we set forth new standards for transparency, coordination, and stakeholder engagement relating to EM&V projects carried out by both the utilities and ED. We believe that this more collaborative process will result in greater cost-efficiencies, more reliable results, broader stakeholder buy-in, and fewer disputed issues. In particular, we: clarify process for ED review of all IOU EM&V contracting decisions; grant IOU authority to develop ex ante values under limited circumstances; grant ED authority to conduct process evaluations; clarify process for stakeholder input on all EM&V projects; and provide a new resolution process for disputes over EM&V processes and findings.

This decision finalizes the $125 million budget for EM&V activity over 2010-2012. We also approve a Joint Plan submitted by the utilities and ED, which lays out a roadmap for the EM&V studies to be performed on the 2010-2012 energy efficiency portfolios approved in D.09-09-047. Finally, we address certain carryover policy issues, including the treatment of savings estimates from behavioral programs and codes & standards.

Hall, N., Roth, J., Best, C., "California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals", April 2006

Summary: Guide to evaluation protocol of California's energy efficiency programs and program portfolios launched after December 31,2005. The Protocols are the primary guidance tools policy makers will use to plan and structure evaluation efforts and that staff of the California Public Utilities Commission's Energy Division (CPUC-ED) and the California Energy Commission (CEC), and the portfolio (or program) administrators (Administrators) will use to plan and oversee the completion of evaluation efforts. The Protocols are also the primary guidance documents evaluation contractors will use to design and conduct evaluations for programs implemented after December 31, 2005.

Hart, R. et al., "Expected Value Prescriptive Savings Method," in *ACEEE Summer Study 2010; Poster Presentation Handout* (presented at the ACEEE Summer Study 2010, Portland Energy Conservation, Inc. (PECI) and Energy Trust of Oregon (ETO), 2010), www.peci.org/resources/commercial-retail.html. http://www.peci.org/documents/ACEEE_EV_Handout.pdf; also, http://www.peci.org/documents/rtuPremVent_ShortTermRpt09.pdf

Heschong Mahone Group; Evaluation, Measurement and Verification of the Davis Energy Efficiency Program, HMG Project #0307, September 22, 2004.

IPMV, "International Performance Measurement & Verification Protocol Concepts and Options for Determining Energy and Water Savings Volume I", DOE/GO-102002-1554, March 2002.

Norford, L., Tabors, R. (MIT), Byrd, J., Philadelphia Electric Company, "Non-Intrusive Electrical Load Monitoring, a Technique for Reduced-Cost Load Research and Energy Management," ACEEE Summer Session 1992.

Pacific Gas and Electric Company, Southern California Edison, Southern California Gas Company, and San Diego Gas and Electric Company, "Responses to EM&V Impact, Process, and Market Assessment recommendations," May 2010

Summary: Summarizes the Investor Owned Utility (IOU) responses to the recommendations from the 2006-2008 process and impact evaluations. Reflecting additional guidance from the CPUC's Energy Division (ED) (email correspondence between the IOUs and Jeanne Clinton, April 7, 2010), this report contains two major sections: A narrative section stating actions the IOUs are taking in the 2010-2012 programs to respond positively to recommendations from the 2006-2008 process and impact evaluations, including citations of the section of the relevant PIP that incorporates or could incorporate the recommendation, and an appendix that summarizes all IOU responses (both negative and positive) to the major findings and recommendations from each of the process and evaluation studies.

Van Buskirk, B., Pearce, E., "Yes You Can! Achieving Quantity and Quality with Commercial HVAC Programs," 2010 ACEEE Energy Efficiency in Buildings, 2010

Summary: There are over nine million commercial packaged rooftop units (RTUs) in the United States. It is estimated that 75 percent of these units are not running efficiently. Although the savings per unit are small, they represent a large energy savings potential when aggregated. The challenge in capturing savings from the small commercial HVAC market is cost-effectively combining programmatic quality control, advanced technical diagnostics, and a multi-dimensional market penetration approach. This paper discusses the critical program components of an established HVAC initiative that has grown from a small regional pilot in 2002, to today achieving over 46 million kWh in savings and servicing over 20,000 rooftop units. Realizing this level of program success requires designing quality controls into every program component, as well as establishing a sustainable model for long term contractor involvement. This paper further outlines the importance of effective enrollment, comprehensive training, and automated diagnostic tools.

Vine, E., "Behavior and Energy White Papers: Use of Papers and Next Steps," November 2009.

Summary: The California Institute for Energy and Environment (CIEE) conducted a survey in the Fall of 2009 to assess the value of nine papers on behavior and energy funded by the California Public Utilities Commission (CPUC), to see how these papers have been used and are planning to be used, and determine what additional activities should be conducted in the area of behavior and energy (e.g., more white papers or other activities)

Vine, E., "Energy Efficiency Evaluation Training Opportunities," November 2009

Summary: Prepared for the California Institute for Energy and Environment and the California Public Utilities Commission's Energy Division, provides a list of the types of programs/ services offered for improving the capabilities of individuals in the field of energy efficiency evaluation.

Refrigerant Charge and Airflow

ADM Associates, "2009 Residential High Efficiency AC Program NV Energy – Southern Nevada Program Year 2009," February 2010.

Summary: The Residential High Efficiency Air Conditioning (AC) Program, implemented by Enalysis for NV Energy, is a demand side management (DSM) program that offered contractors incentives for performing AC tune ups, installing high efficiency AC units, properly commissioning newly installed units, and sealing AC ducts for residential customers during the January to December 2009 program year. This report provides final estimates of energy impacts achieved by electric measures implemented by the program in Southern Nevada.

ADM Associates, Inc., "Field Performance Assessment of Package Equipment to Quantify Benefits of Proper Service," June 2008.

Summary: Under contract with the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE), ADM Associates, Inc. (ADM) performed Research Project 1274-TRP to conduct a field performance assessment of HVAC package equipment to quantify the benefits of proper service. Working with the project advisory committee, ADM developed a set of diagnostic procedures for making in-field measurements of HVAC units' performance, and for using these measurements to diagnose and detect faults in the operation of the units. The procedures developed were used to assess the performance of a total of 184 commercial HVAC rooftop units distributed across five cities, and located primarily in retail buildings. Baseline measurements were made on all 184 units, with the most prevalent faults detected being: (1) high refrigerant charge, and (2) high CFM. Servicing

was provided for 35 of the units for which defaults were detected, and these units were re-tested after the servicing. Using paired pre- and post-servicing values for EER measured at standard conditions, it was determined that the average EER for the serviced units about 7.4% after servicing. Further examination indicated that there was no strong relationship between the percentage changes in the EERs and either the sizes or the ages of the units. Of the units for which ADM conducted performance testing, 66% were identified as having economizers; of the units with economizers, 36% were determined to have non-functioning economizers. The units with non-working economizers were on average smaller (7.4 tons versus 8.5 tons) and older (10.3 years versus 7.3 years) than the units with working economizers. The average EER (measured at standard conditions) for units with non-working economizers was lower than for units with operating economizers (i.e., 7.57 versus 9.29).

ADM Associates, Inc., "Market Assessment and Field M&V Study for Comprehensive Packaged A/C Systems Program", Final Report, July 2009.

Summary: This report presents and discusses the results of a market assessment and field measurement and verification study that was conducted for the Comprehensive Packaged Air Conditioning (A/C) Systems Program that Southern California Edison Company has been implementing. Sample results: There were 43 units that received refrigerant charge servicing from an HVAC contractor for which ADM field staff took pre-servicing and post-servicing measurements. Conditions for the pre and post measurements were different and often made months apart. These pre- and post-servicing measurements were used to analyze changes in the EERs for the units at standard conditions before and after the servicing. The average EER for the units increased from 6.64 before servicing to 7.05 after servicing, an increase of about 6.1%. Baseline measurements of total duct leakage and of duct leakage to unconditioned space were made for the sample of 109 sites for which air conditioning measurements were made. The improved airflow that resulted from reducing duct leakage implies an annual kWh savings of 82.1 kWh per HVAC unit.

Aloha Systems, "Evaluation, Measurement, and Verification Final Report: RCA Verification Program for New and Existing Residential and Commercial Air Conditioners," 2006.

Summary: The Refrigerant Charge and Airflow Verification Program (RCAVP) was implemented by Robert Mowris & Associates. Its purpose was to verify the refrigerant charge and airflow in 12,000 air conditioners located within the three major investor-owned electric utilities' service territories and to adjust the charge and airflow as needed to optimize system performance and energy efficiency. In doing so, the program estimated a net annual energy savings of 5,037,027 kWh and a peak demand reduction of 4,348 kW.

The program met its goals. It fully documented the RCA verification of 12,453 units. The participating contractors also reported an additional 1,059 units verified that were not fully documented because incentive funds had run out. Therefore a total of 13,512 air conditioners were verified as a result of the program. The net energy savings achieved by the statewide program were 5,700,679 kWh per year, with a peak demand reduction of 5,925 kilowatts. This is 113% of the energy savings goal of 5,037,027 kWh/yr and 136% of the demand reduction goal of 4,348 kW.

Baylon, D., Strand S., et. al. "Analysis of Heat Pump Installation Practices and Performance: Final Report", December 2005. http://neea.org/research/reports/169.pdf

Summary: This study used a variety of analytical methods to assess the overall performance of heat pumps in Northwest climates and to identify the factors that have the most impact on the efficiency achieved. Goals were to assess energy use/savings from heat pumps; assess installation practices; assess heat pump performance under lab

conditions; and assess installer's approach to sizing and performance. The study included billing analysis, field review, lab testing, and distributor/installer interviews.
Key results: Billing analysis indicates heat pumps performing as expected, at about 85% of expected savings. An interesting note: "Installers generally understand the trade-offs inherent with heat pumps (more comfort compromises efficiency) and usually come down on the side of more comfort. This should be of concern to regional policymakers and utilities that expect rated efficiency from new heat pumps.

Downey, T., of Proctor Engineering Group, to Conservation Services Group, "Comments on EMI and ADM Evaluation of the SCE CPACS Program," June 2009.

Summary: This letter disputes the findings of the EMI evaluation of the CPACS RCA Billing Analysis Report. On behalf of Proctor Engineering Group (PEG), Downey states that PEG does not believe that whole building energy analysis is a suitable methodology for trying to discern energy savings for RCA measures; the only reliable way to determine energy savings is through direct pre/post sub-metering of treated systems. Proctor Engineering Group has reviewed comments by Robert Mowris, dated June 24, 2009 and agrees that the EMI evaluation does not follow the evaluation guidelines established by the California Public Utilities Commission (CPUC).
The letter also finds fault with the Market Assessment and Field M&V Study for Comprehensive Packaged A/C Systems Program conducted by ADM Associates. While this study shows savings for both RCA and ducts, Downey assesses that the quality of the overall analysis and reporting is not good. There are numerous issues with this study and PEG recommends not taking any action based on the results of this study. Because there are too many issues with this study to address all of them in this memo, only the most serious problems related to two issues are discussed, calculated EER and associated energy savings and duct leakage savings.

Downey, T., Proctor, J., "What can 13,000 Air Conditioners Tell Us?," Proceedings of the 2002 American Council for an Energy Efficient Economy Summer Study on Energy Efficiency in Buildings.

Summary: Performance data on more than 13,000 air conditioners on residential and commercial buildings in California have been gathered over the last two years. These measurements were collected via a computer expert system used by HVAC field technicians during routine installation, repair, and maintenance visits. The data provide an extensive picture of the condition of air conditioning (AC) units, their operating and performance parameters, the indoor conditions of the buildings they cool, and many other factors. This paper presents an analysis of these data. The purpose of this analysis was to extract valuable information about residential and commercial AC systems in California, including refrigerant charge and airflow problems, system performance, and return air characteristics of the buildings in which the systems are installed.
Selected conclusions: Contractors are willing to put forth the effort necessary to make sure air conditioning systems are operating within manufacturers' refrigerant charge specifications, once they are taught to do it correctly and are held to an easy means of checking their work. 65% of the residential systems tested required repairs. 71% of the light commercial systems tested required repairs. 57% of the systems were outside specification for refrigerant level Above 76 degrees outdoor temperature, residential humidity ratios average above 0.01 lbs. per lb. of dry air. The current temperature split method of identifying units with low airflow is flawed and should be revised to eliminate biases associated with the conditions at the time the measurements are made.

Energy Market Innovations, Inc., "CPACS RCA Billing Analysis Report," April 2009.

Summary: Southern California Edison (SCE), other utilities, and professionals studying air conditioning efficiency have identified concerns with savings claimed for residential and

commercial air conditioning maintenance programs typically known as Refrigerant Charge Adjustment (RCA) or AC tune up, and functionally similar programs targeting efficiency improvement to package air conditioning systems through routine maintenance procedures. SCE tasked EMI to discover and evaluate measureable electric billing impacts associated with its RCA/tune-up measures that were implemented as a part of the utility's Comprehensive Packaged Air Conditioning Systems (CPACS) program. Michael Blasnik & Associates (Blasnik) was contracted by EMI to prepare a quantitative billing-based savings assessment of the RCA program element using program data of RCA measures implemented in 2006 and 2007 matched with program participants' electric bills before and after the measure was installed. The goal of this analysis was to see if energy reduction could be identified based on participant electric usage billing data.

The billing analysis-based assessment of SCE's RCA measure showed no statistically significant energy savings for the general populations of participants studied (26±28 kWh/yr). The great difference between the confidence interval of expected savings found from this statistical analysis of participants' bills and the 2005 DEER calculated savings (233 kWh/yr) provides a high degree of certainty that the DEER calculation requires re-calibration.

The notable exceptions where RCA measure savings may have been identified were residential customers located in climate zone 15, where savings of about 7% of pre-treatment summer/cooling loads were observed. The savings for these participants were generally consistent with ex-ante savings estimates produced by DEER 2005 protocols. However, this cohort represents less than 10% of the single-family residential participants and a much smaller fraction of all program participants. Savings also appear to have been identified among single-family residential customers outside of zone 15 if their usage was high– above 4,000 kWh. Again, this cohort is only a small fraction of the customers served – slightly more than 10%. The only other factor to be associated with significant positive savings was air conditioner systems with a reported initial supply air temperature split of less than 15°F.

Energy Market Innovations, Inc., "Market Progress Evaluation of the Small Commercial HVAC Pilot Program, #E04-135," November, 2004.

Summary: Documents the experiences of a research, development, and implementation effort involving a multi-year Small Commercial Heating Ventilating and Air Conditioning (HVAC) Pilot program undertaken by the Northwest Energy Efficiency Alliance (Alliance). The goal of the pilot was create a market for energy efficiency tune-up services for 5-15 ton packaged rooftop units (RTUs) in smaller commercial buildings.

Important technical findings include the following: Significant opportunities for energy savings in existing RTUs definitely exist – The pilot implementation confirmed the magnitude of the opportunity for energy savings. Time required to deliver ACP service was longer than anticipated – The development of the protocol proved quite challenging and took more time to refine than anticipated. Moreover, the resulting protocol proved to take longer to complete in the field than most service providers considered acceptable. Savings are unreliable – While the metering results from sites with participating RTUs document reductions in energy use, the observed savings are not all directly attributable to the ACP protocol. Savings came from a wide variety of changes made to the units. The installation and set-up of programmable thermostats may yield significant savings – Based upon the facilities addressed, it appears that the installation of programmable thermostats, and the set-up of existing thermostats, may yield significant savings as a focused program opportunity.

Important market-related findings include the following: The proposed service poses potential conflicts with the existing service industry infrastructure – One issue identified during the pilot was the challenge of introducing a new service when, in some cases, customers have assumed that such work was already being undertaken as part of already-existing maintenance contracts.

Service providers were enthusiastic about the concept of ACP, but did not actively market the service – Service providers are definitely interested, at a conceptual level, in having a premium service to differentiate their services and increase revenue. Yet, during the pilot market, test, very few actively marketed the service. Customers are not willing to pay the cost currently required to cover the time required for ACP service delivery – The market cost of the service is approximately $300-$500, a cost which is not acceptable in a market where maintenance needs are perceived as being minimal. The best opportunity for this service may lie as a utility-sponsored program – With utility rebates or other mechanisms to offset the cost of the service to the customer, both contractors and customers are more likely to be interested in this service.

Energy Market Innovations, Inc., "Process Evaluation: CPACS Program 2007-2008, #SCE0265.01", March 2009.

Southern California Edison (SCE) launched the Comprehensive Packaged Air Conditioning System (CPACS) Program in 2006 to reduce electricity consumption through the promotion of high efficiency packaged air conditioning systems and high quality installation and service of commercial and residential air conditioning equipment. This evaluation study applied standard process and evaluation methodologies to assess the CPACS Program for the period of 2006-2008 but was unique in it's timing and approach. Energy Market Innovations, Inc. (EMI) performed a Rapid-Feedback evaluation of the CPACS Program in the second year of the program implementation period (2007). The intent of this evaluation was to identify and assess program performance issues and feed them back to the Program for addressing in a manner that the Program could make informed decisions.

Eto, J. Prahl, R., Schlegel, J. 1996. A Scoping Study on Energy Efficiency Market Transformation by California Utility DSM Programs. LBNL-39058. Berkeley, Calif.: Lawrence Berkeley National Laboratory.

Field Diagnostics Services Inc. ," Impact Analysis of A/C Tune-up Protocols on Energy Savings," Review Draft, February 2010.

Summary: The correlation between two A/C refrigeration cycle testing protocols and energy efficiency was studied. Pre-test measurement data collected during three major utility-incentivized A/C tune-up protocols were analyzed for the results. The study covers approximately 10,000 units over 5,000sites in California. It was found that examining only one performance indicator (SH or SC) to predict tune-up requirements (as per protocol in the RCA Charge Test) does not provide a sufficient correlation between unit tune-up and energy efficiency. Furthermore, the data indicate that using the RCA Charge Test for A/C tune-up can lead to faulty equipment not being serviced, or being serviced incorrectly, which can result in additional unit inefficiencies. A diagnostic method that examines four performance indicators (SH, SC, COA, and ET) to predict tune-up requirements (as per Field Diagnostics' protocol) demonstrates a high degree of correlation between unit tune-up and energy efficiency. Possible explanations for the results were provided.

Henderson, H. 1992. Simulating Combined Thermostat, Air Conditioning and Building Performance in a House. Transactions of the American Society of Heating, Refrigeration, and Air-Conditioning Engineers, 98(1): 370-386.

tron, Inc. 2007. 2004-2005 Statewide Residential Retrofit Single-Family Energy Efficiency Rebate Evaluation. prepared for Pacific Gas & Electric Company, Study I.D. PGE0214.01; 1115-04. Oakland, Calif: Itron, Inc. Available online: www.calmac.org

KEMA, "2005 Smart Thermostat Program Impact Evaluation Final Report," April 2006.

Summary: SDG&E implemented the Smart Thermostat Program beginning in the spring of 2002. The equipment deployed allows SDG&E to remotely raise the cooling setpoints on participating customers' thermostats during Stage 2 Alerts. Participating customers may override the re-set, but forfeit a portion of their incentive each time they do so.

This report provides the findings from an impact evaluation of the fourth summer of the program in 2005, when the program was invoked 12 times. (The program had previously been evaluated in 2003 and 2004.) This report estimates impacts per unit for the re-set days as well as projected savings under alternate conditions. The report finds that the program yielded significantly lower energy savings than projected, due to several factors. These include non-responding units, user over-ride rates, and zero users (i.e., people who were not using their A/C units at the time the re-set was activated, and thus had no effect on savings.) "The findings from this year's analysis provide another sobering piece of evidence that the future performance of the Smart Thermostat program, as a mechanism to respond to statewide emergencies, is not fully reliable."

KEMA, "Evaluation Measurement and Verification of the California Public Utilities Commission HVAC High Impact Measures and Specialized Commercial Contract Group Programs," February 2010.

Abstract: The California Public Utilities Commission Energy Division (CPUC) created a grouping of programs and measure evaluations consisting of three heating, ventilation and air conditioning high-impact measures (HVAC HIMs), including residential and small commercial applications. The HIMs are defined as those efficiency measures that contribute 1% or more to the entire IOU savings portfolio for reductions in electrical energy consumption (kWh), electrical demand (kW), or natural gas (therm) consumption. The IOUs filed gross energy and demand savings estimates with the CPUC based on the Database for Energy Efficiency Resources (DEER) and workpaper estimates of unit energy savings (UES) for multiple categories of measures, building types, building vintages, and locations.

This evaluation estimated the unit energy savings (UES), installation rate, and net-to-gross ratio (NTGR), an estimate of the percentage of measures that would not be installed without the incentive programs, for each program and measure combination using a CPUC approved consistent methodology. HIMs addressed by this evaluation include refrigerant charge and airflow (RCA), AC replacement, and duct sealing. The final HVAC HIM evaluated savings yielded lower gross savings than the ex-ante estimates for most program-HIM combinations.

KEMA, California Residential Appliance Saturation Study, Executive Summary, CEC-200-2010-004-ES, KEMA, October 2010

Kinert, B., D. Engel, J. Proctor, and R. Pernick. 1992." The PG&E Model Energy Communities Program: Offsetting Localized T&D Expenditures with Targeted DSM." Proceedings of the ACEEE 1992 Summer Study on Energy Efficiency in Buildings, Washington, D.C.: American Council for an Energy-Efficient Economy.

McClain, H. and D. Goldberg, "Benefits of Replacing Residential Central Air Conditioning Systems", Proceedings of 1984 ACEEE Summer Study on Energy Efficiency in Buildings, Volume E, pp. E-226 to E-237.

Metoyer, J., Swan, E., McWilliams, J. "HVAC Airflow Measurement Issues for Programs and Evaluators," KEMA, 2010.

Mowris, R., Bacchus, R., Jones, E., Field Report, Interek News, March 2010.

Summary: Several short status reports on status of testing 3-ton split-system A/C units with three TXV technologies, SEER impacts. Discusses shortcomings of evaluation protocols.

Mowris, R., Jones, E., et. al, "Evaluation, Measurement, and Verification Report for the Moderate Income Comprehensive Attic Insulation Program," Final Report, June 2008.

Summary: This report describes the results of the EM&V of the attic insulation program. It describes the evaluation methodology and provides ex post first-year electricity and gas savings figures. It also provides recommendations for improving the program's services and procedures.
Selected results: Differences between the ex ante estimates and ex post accomplishments are due to the 16-year effective useful life (EUL) assumed for the CFL torchieres. The EUL value for this measure was reduced to 11 years based on light logger data. The 15W, 20W, and 24W CFL EUL values were reduced from 8 years to 6 years based on light logger data. The average ex post operating hours are 1,624 ± 298 hours/yr based on light logger data for 1,173 fixtures at 66 sites. The net ex post first-year gas savings are 572,704 ± 31,956 therms and this is 16% lower than the ex ante estimate. The difference is largely due to lower ex post gas savings for attic insulation based on unavailability of R-0 to R-30 attic insulation measures (i.e., lack of attics without any insulation). The program assumed it would install 802,226 ft2 of R-0 to R-30 attic insulation and 2,716,175 ft2 of R-5 to R-30 insulation. The program actually installed 295,130 ft2 of R-0 to R-30 (63.2% less than assumed) and 3,210,619 ft2 of R-5 to R-30 insulation (18.2% more than assumed). The program also installed 56,095 ft2 of R-15 to R-30 attic insulation. The program actually installed 3,561,844 ft2 of attic insulation and exceeded its attic insulation goal by 1.2%.

Mowris, R., of Verified Inc., to Samiullah, S., in response to Energy Market Innovations report "CPACS RCA Billing Analysis Report", June 2009.

Summary: This letter disputes the findings of the EMI study above. Mowris states that using billing analysis to evaluate energy savings is an approach that is unreliable and does not adhere to EM&V standards published by the CPUC, AHSRAE, and others.

Neme, C., Proctor, J., Nadel, S., "National Energy Savings Potential from Addressing Residential HVAC Installation Problems," February 1999.

Summary: There is a growing body of evidence that suggests that most equipment -- both standard efficiency and high efficiency -- is improperly installed, with significant adverse effects

on how efficiently equipment actually works in the home. Indeed, recent studies suggest that the manner in which equipment is installed may have much greater impact on actual operating efficiency than whether or not it has a high efficiency rating.

The purpose of this paper is to summarize what is known about key installation problems and, based on studies that have already been conducted, quantify the potential benefits of addressing these problems. The paper addresses four key installation issues -- equipment sizing, refrigerant charging, air flow rates, and duct leakage. It should be noted that the principal focus is on cooling energy savings. To calculate national savings potential, we have simplistically assumed that the heating energy savings from improved installation and maintenance of heat pumps are comparable, in percentage terms, to cooling energy savings.

Neme, Chris et al., "Promoting High Efficiency Residential HVAC Equipment: Lessons Learned from Leading Utility Programs", Proceedings of 1998 ACEEE Summer Study on Energy Efficiency in Buildings, Volume 2, pp. 2.153-2.164.

Parker, D.S., S.F. Barkaszi, Jr.,., J.R. Sherwin,., and C.S. Richardson, 1996, "The Influence of Central AC Conditioner Usage Patterns in a Hot and Humid Climate," Submitted to the American Council for an Energy Efficient Economy, Washington, DC.

Peterson, G. and Proctor, J. 1998. "Effects of Occupant Control, System Parameters, and Program Measures on Residential Air Conditioner Peak Demands", Proceedings of 1998 ACEEE Summer Study on Energy Efficiency in Buildings

Proctor Engineering Group, “Statewide Measure Performance Study, Final Report: An Assessment of Relative Technical Degradation Rates. CADMAC Report #2023P,” 1996.

Summary: The Statewide Measure Performance Study is a project, sponsored by the CADMAC subcommittee on persistence, which examined the relative technical degradation or thirteen major DSM measures compared to the standard efficiency equipment which they replace The project did not involve collecting new data, but instead focused on assessing existing information. There were two primary stages of work. The first stage involved performing an exhaustive search for existing information from published and unpublished sources and synthesizing this information into an engineering analysis of technical degradation rates. The second stage of the project involved developing research plans for assessing relative technical degradation for those measures where substantial uncertainty was found in stage one. This report provides the findings from both stages of the project.

Reddy, T.A. and Claridge, D.E. 1993. Effect of Air Conditioner Oversizing and Control on Electric Peak Loads in Residences. Energy, 11:1139-1152.

Residential/Small Commercial Joint Single NTG (Self Report Committee), et. al., “Response to Overarching Comments Regarding the Use of Self-Reported Net-to-Gross (NTG) and the Residential and Small Commercial Self-Report Approach NTG Method: Draft,” January 2010.

Summary: There are a significant number of comments that are repeated or overlapping that are broad enough to be considered overarching comments regarding the use of the self-report approach (SRA) for net-to-gross ratio (NTGR) estimation.This document is the response developed to efficiently respond to these overarching comments on the consistent SRA for NTGR estimation for the residential and small commercial programs. Identification of topics/issues brought up in comments are referenced in this document as end-notes. This allows evaluation

contractors to reference particular areas in this document in their specific responses to particular comments through the end-notes.

RLW Analytics, "Sacramento Municipal Utility District Residential HVAC Program Evaluation," March 2008.

Summary: RLW Analytics, in partnership with The Benningfield Group (The Evaluators) completed an evaluation of Sacramento Municipal Utility District's (The District's) Residential HVAC program (Program). This program offers monetary incentives for installation of above code efficiency units combined with performance testing.

Key results: The realization rate is 1.17-1.20 for total energy savings (kWh). This means the evaluation found the per unit savings to be approximately 18.5% higher than the utility's estimates. The result is likely due to the higher efficiency savings than estimated, significant duct leakage in the non participant sample and the higher percentage of TXV installed on participant systems. However, the realization rate for the peak demand (kW) savings is 0.67-0.69, meaning the evaluated savings are lower than the ex-ante estimates. This result may be attributable to over sizing in both participant and non-participant systems and shows the duct system deficiencies had little impact on peak.

Robert Mowris and Associates, "Evaluation Measurement and Verification Report for the Time-of-Sale Home Inspection Program #180-02," November 2004.

Summary: This report provides the Evaluation, Measurement, and Verification (EM&V) findings for the GeoPraxis Time-of-Sale (TOS) Home Inspection Local Program #180. The GeoPraxis program trained and equipped home inspectors to integrate a streamlined energy audit into the traditional Time-of-Sale home inspection. The program provided Northern California ratepayers with timely access to key information to help them improve the energy efficiency, comfort, and resale value of their homes. This program offered an integrated approach to achieving cost-effective energy savings.

Key results: Program energy savings accomplishments are 95 percent less than the ex ante goals. This is due to: 1) lack of homebuyer and realtor awareness about the benefits of EnergyCheckup™ inspections at time of sale; and 2) inability of participating home inspectors to sell EnergyCheckup™ inspections to home buyers at time of sale. The 2002-2003 program was originally designed to market EnergyCheckup™ audits directly though GeoPraxis' certified EnergyCheckup™ inspectors. According to GeoPraxis many inspectors were enthusiastic about the service and made efforts to promote EnergyCheckup™ audits directly to homebuyers and real estate agents in their local areas. GeoPraxis also made an effort to coordinate with statewide marketing and outreach programs, utility rebate and information programs, and other local non-utility programs. Unfortunately, these marketing efforts did not generate significant homebuyer or real estate agent awareness about the program. Without significant awareness, most inspectors were ineffective in their efforts to sell EnergyCheckup™ inspections to home buyers.

Robison, D. 2000. "Use of a Billing Simulation Tool for Performance Measurement and Verification." In Proceedings of the 2000 ACEEE Summer Study on Energy Efficiency in Buildings. 4:283-293. Washington, D.C.: American Council for an Energy-Efficient Economy.

Southern California Edison, "Impacts of PCTs on Demand Response, Phase II," April 2007.

Summary: "This project analyzes the potential electricity demand response of small commercial HVAC systems and residential split air-conditioners due to the use of programmable communicating thermostats (PCTs). Phase I of this project looked at three of the most common applications: small office buildings, small retail buildings and single-family residential buildings. This phase (Phase II) of the project expands the original analysis with the addition of seventeen

additional building types." Selected results: The choice of a particular HVAC unit is shown to impact the demand response by approximately ±15%. Analysis conducted for this project shows the potential for 10 – 30% increased demand savings over constant volume systems due to the use of staged volume systems.

The AC tune-up program component achieved a lower than expected realization rate. As discussed in the previous section, this is due to three main reasons: 1. The relative savings for RCA, as determined from field measurements, is about 18% lower than the ex-ante estimations. 2. Some of the measures were entered in the data store prior to a major downward revision of ex-ante energy savings that occurred in April 2009. 3. The baseline cooling energy usage, in kWh/ton, is approximately 2% lower in the 2009 data than in the 2008 data.

The main issue that affected the program realization rate was the discrepancy between ex-ante and ex-post estimations of the relative efficiency improvements attributable to tune ups. One possible explanation for the lower than expected savings is that the average charge correction in 2009 is lower than the average reported in 2008. This trend also manifest in our field measurements – our sample had an average charge correction that was similar to the program wide average. ADM has developed, and presented to Enalasys an ex-ante savings formulation that uses charge correction as a parameter that informs the energy savings calculation.

Vieira, R., Parker, D., et. al, "How Contractors Really Size Air Conditioning Units," available at http://www.fsec.ucf.edu/en/publications/html/FSEC-PF-289-95/index.htm

Summary: This paper presents results from 489 of the 5559 Florida air conditioning contractors surveyed (an 8.5% response rate) regarding equipment sizing methods in new residences. Air conditioning sizing is accomplished by using ACCA's Manual-J procedure by 33% of the respondents, software by 34.4% of the respondents, square-footage by 24.2% and other estimate procedures by about 8.4%. Those using square-footage estimates varied from 350 square-feet-per-ton to 700 square-feet-per-ton. Over a third of respondents indicated oversizing intentionally on some jobs, in order to avoid complaints, accommodate future expansions, enable quicker cooling down of homes, and to allow for lower cooling set points by homeowners.

Proctor, J., and Pernick R., "Getting it Right the Second Time: Measured Savings and Peak Reduction from Duct and Appliance Repairs "ACEEE Summer Study Proceedings, 1992.

Summary: This paper reports on potential energy and peak savings in residential air conditioners, heat pumps, and gas forced air furnaces. In four different pilot projects, the state of the space conditioning systems of over one thousand homes was documented. Duct leakage, air flow through the appliances and refrigerant charge on compressor systems were measured before and after repairs were made. Intensive monitoring was utilized in one project to determine the actual behavior of the system and the human occupants. In two of the pilots, sixty-one air conditioners were submetered to record use at 15 minute intervals. The pre-/post metering took place on homes divided into three groups: random customers, high-use customers, and high-use customers that complained of high utility bills. Submetering results are compared to similar recorded peak and kWh use of a group on non-participants.

Based on monitored pre- and post-data and using Fresno TMY weather data, overall program cooling kWh savings (refrigerant charge, airflow, and duct leakage remediation) of about 24% were projected. Individual savings estimates of 8% for airflow, 12% of correcting refrigerant overcharge, 12% for correcting refrigerant undercharge, and 18% for duct leakage remediation were projected.

West, Anne and Mike Logsdon (The Cadmus Group, LLC), Howard Reichmuth, PE, and Jarred Metoyer (KEMA), "The Field Hand and the California Model: An Example of Blending

Operational Measurements with Performance Models," 2010 ACEEE Summer Study on Energy Efficiency in Buildings.

Summary: This paper describes the analytical process and results of a metering study of more than 150 residential participants in utility programs focused on early replacement of air conditioning (AC) with high efficiency systems. This metering study is one of the largest performance measurement efforts to date to monitor efficiency in addition to energy consumption. The study employs new data analysis methods supporting examination of site metered data for large samples in a cost effective manner. This work was particularly challenged because the measurement process began after the replacement event; only the post-replacement performance could be monitored. Savings were calculated as the difference between the actual monitored post-replacement performance and a hypothetical baseline developed from monitoring other units. The differences were applied to samples of residential stock that were considered similar to the pre-retrofit stock.

A fortunate finding in this work has been that the empirical efficiency measurements are readily comparable to the detailed efficiency employed in the eQuest energy simulation models used to develop results for the Database for Energy Efficient Resources database. In this work the DEER models' derived efficiencies can be used as estimators of upper bound performance. Results of this work show that units meeting the code requirement of SEER 13 do not meet expected efficiency performance levels, and prior estimates of the cooling load for mild regions are too high. This work demonstrates a methodology that can develop detailed site monitoring data into annual energy and demand savings estimates, which is also compatible to, and consistent with, the existing DEER energy simulation modeling approach.

World Wide Web URL

http://www.deeresources.com/deer0911planning/downloads/EUL_Summary_10-1-08.xls

http://www.energyconservatory.com/download/trueflow.pdf

http://www.energy.ca.gov/2008publications/CEC-400-2008-002/CEC-400-2008-002-CMF.PDF

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http://www.google.com/powermeter/about/about.html

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http://www.theenergydetective.com/store/ted-5000

Acronym Guide

ACCA	Air Conditioning Contractors of America
ACEEE	American Council for an Energy-Efficient Economy
AEO	Annual Energy Outlook
AER	Annual Energy Review
AHRI	Air-Conditioning, Heating and Refrigeration Institute [formerly American
AHU	Air Handling Unit
ARI	Refrigerant Institute (ARI)]
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BTU	British Thermal Unit
BPA	Bonneville Power Administration
CAC	Central Air Conditioner
CBSA	Commercial Building Stock Assessment
CEC	California Energy Commission
CDD	Cooling Degree Days (base 65 F)
CIEE	California Instituted for Energy and Environment
CLH	Cooling Load Hours
CPACS	Comprehensive Packaged Air Conditioning System Program
CPUC	California Public Utilities Commission
CPUC-ED	California Public Utilities Commission Energy Division
DEER	Database for Energy Efficient Resources
DOE	Department of Energy
DSM	Demand Side Management
DTS	Duct Test and Seal
EER	Energy Efficiency Ratio
EIO-LCA	Economic Input-Output Life Cycle Assessment
EMI	Energy Market Innovations
EPA	Environmental Protection Agency
EUL	Effective Useful Life
FDD	Fault Detection and Diagnosis
GHG	Greenhouse Gas
HCD	Human-centered Design
HIMs	High Impact Measures
HFC	Hydrofluorocarbon
HP	Heat Pump
HVAC	Heating, Ventilation and Air Conditioning
IOU	Investor Owned Utility
ISO	International Organization for Standardization
LCI	Life Cycle Inventory
LCO	Life Cycle Optimization
MECS	Manufacturing Energy Consumptions Survey
NAICS	North American Industry Classification System
NERC	North American Electricity Reliability Corporation
NYSERDA	New York State Energy Research and Development Authority
PCT	Programmable Communicating Thermostat

PIP	Program Implementation Plan
PEG	Proctor Engineering Group
PT	Programmable Thermostat
QI	Quality Installation
QM	Quality Maintenance
RCA	Refrigerant Charge and Airflow
RCAVP	Refrigerant Charge and Airflow Program
RTU	Rooftop Units
SCE	Southern California Edison
SEER	Seasonal Energy Efficiency Ratio
SRB	Statistical Rule Based
TEWI	Total Environmental Warming Impact
TMY3	Typical Meteorological Year 3 Database
TXV	Thermostatic Expansion Valve
UES	Unit Energy Savings
VSP	Verification Service Providers

HVAC Energy Efficiency Maintenance Study

Appendix B:

Potential Retrofit, Repair, and Refurbishment Activities

Appendix B: Potential Retrofit, Repair, and Refurbishment Activities

- **Advanced Maintenance Opportunities.** Advanced maintenance measures take more time and expertise than simple tune-up measures. The list that follows is a list of the possible advanced maintenance measures that can save considerable energy.

  - *Replace Capacitors and Contactors.* Both contactors and capacitors can fail over a long period of use. A simple preventive maintenance measure would be to replace both of these components if they are showing signs of wear or reduced resistance (in the case of a capacitor). While replacing these components will not directly contribute to energy savings, it will extend the life of the equipment, thereby extending the estimated useful life of other QM measures.

  - *Evaporator Coil Cleaning.* A diagnostic protocol will detect inadequate heat transfer on the low pressure side of the refrigeration system. Packaged units have accessible coils, but split system coils are hard to access. An access port must be made by cutting a large opening in the side of the coil casing.

  - *Refrigerant Evacuation.* There are several faults that require the technician to evacuate the refrigerant within the system in order to correct the problem. These faults include refrigerant leakage, the presence of non-condensables (such as nitrogen, water, debris, or acid) in the system, compressor degradation or failure, refrigerant flow restriction, and clogged filter dryer. While system evacuation is a time consuming process, it represents an opportunity for the technician to do other work on the system. If the evacuation allows the technician to accomplish several repairs, this can be a cost-effective measure.

- **Repair Opportunities.** Many systems are in need of a repair rather than a simple adjustment. This has traditionally been beyond the scope of a maintenance program, although meeting Big-Bold goals will require not walking away from significant savings opportunities. There are several types of repairs that can be done.

  - *Duct Renovation.* During the initial visual inspection, the existing duct system may clearly need to be replaced in part or in total. Field research has found consistent failure of the outer wrap on flex ducts and some failures in the inner duct. Flex ducts often lack adequate supports and strapping allowing them to sag and collapse, obstructing air flow. These ducts must be repaired.

  - *Leakage.* Ducts must be tested for leakage, and if the leakage is too high then they must be sealed before the technician begins work on the refrigeration system. Revised protocols need to require more effective sealing work (focus on the high pressure parts of

the system) with the goal of getting close to the Title 24 desired leakage level of 6% of total system airflow.

- *Sizing.* Almost all duct systems are undersized. The static pressure difference between the return plenum and supply plenum should not be more than 0.5 IWC or 125 Pa. Duct runs will need to be enlarged using R8 ducts with a UV resistant outer wrap to achieve the 0.5 IWC goal, and blower controls set to achieve a minimum of 350 cfm/ton airflow. Inadequate system airflow is often largely due to undersized return air systems. Future Title 24 initiatives are proposing a prescriptive requirement for return air duct sizing in new homes[1], indicating a persistent problem in this area.

- *Insulation.* Ducts in attics need to have at least R8 insulation. One approach is to retrofit accessible ducts with FSK[2] insulation; even better is to reroute the ducts to lie on the bottom cord of the trusses and use baffles to hold blown-in insulation. This technique not only achieves average duct R-values much greater than R8, but also improves the home's overall thermal performance.

- **Refurbishment Opportunities.** Many systems may be working adequately, but due to their age or condition they do not operate efficiently. These systems should be replaced. However, many homeowners are not financially able to replace their entire system. Financing mechanisms need to be in place so that technicians can address these situations.

- *Compressor replacement.* Replacing a failing compressor with a newer, more efficient model can yield significant energy saving. Compressor replacement may be an effective strategy even when the compressor hasn't failed; Mowris has demonstrated that the savings from such a retrofit can be quite significant--potentially over 50% (Mowris, personal communication, 2010). It may also be possible to downsize the compressor for systems that are currently oversized[3], resulting in additional energy savings and peak demand reductions. More research is needed in this area to determine viability and whether there are any warranty issues that come into play.

[1] Personal communication with Bruce Wilcox (September 2010)

[2] FSK – a fiberglass, scrim or mess, and silver colored kraft paper blanket insulation commonly used for insulating ducts.

[3] Many homes have had window replacements or ceiling insulation added since the original air conditioner was installed. Completing a Manual J calculation would be informative in determining if compressor capacity could be reduced.

- *Condenser fan replacement.* An older condenser fan can also be very inefficient both in terms of airflow and Watts/cfm. A fan replacement often provides two benefits: increased airflow and improved airflow efficiency.

- *Blower replacement.* Similarly, blowers can be inefficient, and newer blowers with larger blade sizes can be more efficient and can increase evaporator airflow rates, providing an efficiency boost. This replacement also saves energy in two ways: by improving the operating efficiency, and by reducing fan heat addition to the supply airstream.

- *Motor Replacement*. Most furnace or heat pump blowers and condenser fans are driven by small permanent split capacitor motors. Variable-speed, constant-volume motors are used in many new furnaces and other air handlers, and can be 50% more efficient (in terms of Watts/cfm delivered), provided that the duct system is not too restrictive. A blower motor replacement program must be integrated with a duct screening to ensure that the duct system is adequately sized.

- **Retrofit Opportunities.** It is estimated that there are over 13 million unitary HVAC systems in California. With a typical service life of 15 to 20 years, 5 to 7% of the existing stock are being replaced annually, making retrofits of existing systems important. Systems that are at least (?) 10 years old can be good candidates for retrofit improvements, including the following:

Residential:

- *Night Ventilation Cooling*. There are significant areas of the state that experience summer daytime temperatures above 100 °F, but cool nights with lows below 60° F. Night ventilation cooling, the concept of using a fan system to deliver cooler outdoor air indoors, can be an effective strategy for homes with adequately insulated envelopes so that cooling can be effectively stored. Whole house fans represent a highly efficient solution for many, but issues of noise, window operation, temperature control, air filtration, and security have limited the widespread application of whole house fans. A potential retrofit technology is to promote integrate night ventilation cooling systems[4] that are tied in to the central HVAC system. These strategies rely on an outside air duct, dampers, and attic relief to automate the night ventilation strategy.
- *Supply Fan Control.* The Hot Dry Air Conditioner (HDAC) project[5] has shown that in California's hot and dry climate zones the air handler fan should run longer than the typical 90 seconds after the cooling thermostat is satisfied. Longer fan run times would

[4] See https://www.beutler.com/heating_prod_smartvent.asp and http://www.davisenergy.com/technologies/nightbreeze.php

[5] http://www.energy.ca.gov/2008publications/CEC-500-2008-056/CEC-500-2008-056.PDF

allow the condensed moisture on the evaporator coil to be fully re-evaporated (free cooling).

- *Evaporative Condensers.* Evaporative condensers[6] replace the existing air-cooled condensing unit with an outdoor "cooling tower" which allows typical dry climate peak condensing temperatures to be reduced by up to 30°F. This improves the capacity and efficiency of the system by 25% or more while reducing peak demand. But, as with other evaporative technologies, there have been problems with pre-coolers, primarily related to water quality issues, maintenance, and component reliability. Further testing and longer term reliability monitoring is needed.
- *Air Balance and Zoning.* Few duct systems have ACCA Manual D[7] prescribed dampers installed to enable room-by-room airflow adjustment, and fewer still include air balance commissioning so that the design airflow is delivered. Wihout proper duct design and air balancing, many occupants set lower thermostat setpoints to cool a single problem room, which wastes energy[8]. Controls and in-line duct dampers can be used to create zoning for central forced air systems, and when done properly can save energy and reduce peak demand. Increased installation of variable-speed blower motors and two-stage compressors provide the opportunity for greater savings. To be successful a retrofit zoning program must be tightly specified.

Commercial:

- *Controls.* Wireless controls and low cost energy management systems for small commercial application open a wide range of possibilities that should be explored.
- *Economizer Retrofit.* Much of California's climate is characterized by significant number of hours during the work day that are cool and dry, making economizers a logical choice as the first stage of cooling delivery. Over the years, Title 24 and ASHRAE 90.1 have required the application of economizers to increasingly smaller equipment capacities. Yet it is not uncommon to find suitable applications that have no economizer. An analysis tool using inputs from the site is needed to determine whether or not to install an economizer and what savings can be achieved.
- *Economizer Renovation.* Recent advances in controls and dampers have demonstrated the technologies to renovate existing economizers. Field research and pilot programs are needed to establish savings, technician protocols, and verification methods.
- *Demand Control Ventilation.* Demand control ventilation (DCV) relies on a carbon dioxide sensor to control the rate of outdoor air ventilation, rather than providing a constant outdoor air rate regardless of occupancy. The RTU fan can be operated during occupancy only when CO_2 levels exceed the setpoint or it can be run during occupancy, but the outdor air damper activates only when CO_2 levels are too high. Various strategies can be implemented including a two-speed fan and mixed air temperature controls to

[6] http://www.etcc-ca.com/images/stories/pdf/ETCC_Report_464.pdf

[7] ACCA, Manual D, Duct Design.

[8] Duct leakage is another variable affecting where conditioned air is delivered.

minimize fan power and energy consumption. Field research and pilot programs are needed to establish savings, technician protocols and verification methods. For larger buildings, dedicated outside air systems may be a good solution by substituting a small number of continuously operating makeup air systems, instead of having each RTU operate independently.

- *Desuperheaters*. For typical air-cooled RTU's, hot refrigerant gas leaves the compressor and rejects all of the heat at the air cooled condenser. A desuperheater is a refrigerant-to-water heat exchanger that heats water using the hot gas leaving the compressor, reducing the heat rejection load on the condenser. This results in improved cooling efficiency and "free" hot water. In applications with significant cooling and hot water loads (such as a restaurant or health club), the economics can be very favorable.
- *Subcoolers*. A subcooler is a refrigerant-to-water heat exchanger installed downstream of the condenser to further cool liquid refrigerant. Although less effective in water heating than a desuperheater, both technologies boost the refrigeration system efficiency. Field demonstration and pilots are needed to establish the appropriate applications.
- *Condenser Pre-cooler*. Condenser air pre-coolers generate energy and demand savings by using direct evaporative cooling to reduce condenser inlet air temperatures 50-75% of the way from the outdoor dry to wet bulb temperature. The higher the dry bulb to wet bulb "delta", the greater the benefit, indicating that demand savings with such a system represent the primary value. More advanced pre-coolers such as the DualCool[9], circulate chilled sump water to an coil covering the outdoor air inlet, to pre-cool outdoor makeup air, further reducing the peak load on the system. Similar to the residential evaporative condenser, this technology has experienced ups and downs over the past 20 years, as the implementation struggles with water quality and maintenance issues. Field demonstration and pilots are needed to better document performance and reliability issues. Key to success will be the understanding of water chemistry and water quality maintenance (this is one of the research thrusts of the UC Davis Western Cooling Efficiency Center (WCEC)).
- *Indirect Evaporative Cooling*. Indirect cooling involves sensible cooling from moist evaporatively cooled air to supply through heat exchange passages, resulting in cooler air with no moisture addition. By making multiple passes, supply air can be cool below the outdoor wet bulb temperature. In most hot dry climate conditions, supply air from the indirect cooler will be below 70°F. In the economizer mode, outdoor air up to 70° F can be used when controls allow the compressor to operate in tandem. At least two indirect evaporative cooling technologies are available[10] and have been tested by PG&E's test lab.
- *Air Balance,Zoning* – Commercial spaces commonly have dampers that allow air balancing, but modifications to the space to meet the tenant needs often do not include rebalancing the system. Also, a newly created enclosed area will not have the same loads as the space where the thermostat is located. Zoning for comfort control can increase occupant satisfaction but will use more energy if it is not done correctly. A program

[9] http://icidualcool.com/

[10] http://www.climatewizard.com.au/ and http://www.coolerado.com/

designed to intervene on behalf of increased efficiency could forestall problems of increased energy usage while supporting increased comfort.