HVAC Roundtable Summary and Notes

The HVAC Roundtable was convened by Architectural Energy Corporation and New Buildings Institute with sponsorship by the California Energy Commission Public Interest Energy Research Program. The purpose of the meeting was to stimulate a dialogue on critical technical and research issues for current and emerging utility HVAC energy efficiency programs. The meeting was held on November 28 and 29, 2006 in Oakland, California.

Background

Existing studies as well as field work completed (and ongoing) through utility air conditioning service programs, have clearly demonstrated a wide range of problems with the installation and ongoing maintenance of residential central HVAC systems as well as larger-sized commercial rooftop HVAC units. This field reality along with a need to dramatically improvement electricity end-use efficiency has led electric utilities in California to implement through a variety of program implementers, large scale HVAC service programs especially focused on, but not limited to, refrigeration charge and air flow correction. A number of utilities in the Pacific Northwest and Northeast are contemplating the appropriate design of HVAC service programs and related field service protocols and approaches.

There appear to be several fundamental technical questions and issues that have been raised by experienced HVAC industry professionals that remain unresolved related to the methods and protocols appropriate for utility program designers/implementers as well as field technicians. These issues have a direct relationship to the potential for achieving more substantial, cost-effective, and persistent energy and demand savings from the operation of utility-sponsored residential and commercial HVAC service programs in California, as well as nationally.

In considering these issues, there was no obvious national-level venue for a discussion of the merits of the topics proposed (see Appendix E for details) and for resolution of the issues raised that were both technical in nature and directly related to utility energy efficiency program design and implementation effectiveness. It seemed that it might be useful to convene a group of knowledgeable individuals from inside and outside California to look at these issues and perhaps agree on actions to resolve them.

A number of individuals representing a wide range of experience in the HVAC field were invited although ultimately, participation had to be limited in order to assure that discussion was manageable and productive.

The following individuals participated in the Roundtable:

Name	Affiliation
Bob Davis	Ecotope
Buck Taylor	Roltay Inc.
Christopher Ganimian	Conservation Services Group
Dale Gustavson	Better Buildings Interactive
Dick Lord	Carrier Corporation
Greg Risko	Architectural Energy Corporation
Howard Reichmuth	New Buildings Institute
Jim Braun	Purdue-Herrick Lab
Jim Hussey	Marina Mechanical
John Proctor	Proctor Engineering Group
Karim Amrane	Air-Conditioning and Refrigeration Institute
Keith Temple	Field Diagnostic Services, Inc.
Kim Olsen	AAON, Inc.
Kristen Frey	Architectural Energy Corporation
Kurt Pulvermacher	Wisconsin Energy Conservation Corp
Mark Cherniack	New Buildings Institute
Rick Diamond	Facilitator
Robert Mowris	Robert Mowris & Assoc.
Tav Commins	California Energy Commission
Todd Rossi	Field Diagnostic Services, Inc.
Vern Smith	Architectural Energy Corporation
Randall Higa	Southern California Edison
Mark Hardin	Engineered Equipment Sales, Inc.

Introduction

This summary of the 1.5 day Roundtable is in two parts plus Appendices. Part I notes the priority action items that were generally and specifically agreed to by the participants. Part II covers significant follow up activities since the meeting October 28-29, 2006 up to the date of this report. The Appendix includes: notes provided by Kristen Frey and Vern Smith, Buck Taylor and Iain Walker; the invitation to participants with the proposed meeting topics; and the starting agenda: and two brief presentations by Jim Braun and Keith Temple. It is highly recommended that the notes be reviewed since they provide some flavor of the discussion, as well as additional thoughtful comments and issue descriptions.

It was uncertain as to the direction the discussion would take, but what quickly emerged was a lot of interest in a wide ranging discussion of not only the topics that were suggested by the organizers, but a number of fundamental technical and field issues that need attention by the HVAC manufacturers as quickly as possible.

Keith Temple presented an alternative method for charge checking that needs to be further refined and validated for potential use nationally. Jim Braun presented some new ideas on temperature-only diagnostic approaches and virtual sensors that are in development and field testing stages.

Mark Cherniack noted that there are a number of "significant coincidences" related to research, development and demonstration projects on residential and small commercial cooling around the country. They include not only the topics that were discussed by the Roundtable participants, but also climate-optimized units (hot dry and hot humid), new evaporative cooling approaches, field install/maintenance quality issues, embedded diagnostics, Advanced Rooftop Unit, ASHRAE activities, whole house design, and much more. Mark also noted that there is no national strategy or process for bringing the pieces together, determining the priorities and directing more resources to the most promising activities. It's a free for all with limited effectiveness toward meeting local, national and global energy efficiency and global warming mitigation goals with any sense of urgency.

The group agreed that a letter representing the outcomes of the consensus be sent to the CEC, as well as to ARI for a formal industry response. It is hoped that a positive response might quickly lead to an even greater level of active cooperation among the field practitioners, electric utility program implementers, and the HVAC industry.

One of the last exercises that the group went through was directed at the need to press for more comprehensive, integrated design strategies to optimize the selection of appropriate cooling strategies for commercial (and residential) buildings. The graphic presented in Figure 1 Appendix A represents at least a start on mapping the entire framework that affects cooling in commercial buildings. It was noted that current utility programs generally do not have a comprehensive approach. Typically, the programs provide financial incentives for higher efficiency equipment, but not on integrated design for new small commercial buildings.

At the conclusion of the meeting, Mark Cherniack and Vern Smith took on the responsibility of compiling the meeting summary, distributing it to participants and other interested parties, sending it to CEC-PIER, sending a letter to ARI (a draft will be circulated for signatures), and staying in touch with participants and others interested parties as events unfold. There was some talk about another meeting, but until there is a compelling reason to reconvene, communications will continue electronically.

The real thanks for the success of this Roundtable goes to the participants, who actively and occasionally, without restraint, shared the common voice of their experience, all under the guiding hand of our most excellent facilitator, Rick Diamond.

Part I: HVAC Roundtable Consensus Recommendations

The group decision process relied on vocal agreement and a sense of the group rather than operating through a voting procedure. As topics were discussed and concluded, several items emerged for follow up that were noted as important by nearly everyone. They are not in a specific order of importance as listed. They are all important to improving the operating efficiency and field performance of air conditioning systems and for the most part, they require action by the HVAC manufacturers and/or the Air-Conditioning Refrigeration Institute (ARI).

More topics were raised than could be addressed effectively in the time allotted. There still remains an open question as to how all of this information on research needs, results, and field experience can be made available to interested parties in California and nationally. In some sense, ARI would be the natural host for the information and research items discussed in the Roundtable. The question to be posed to manufacturers and ARI is whether or not ARI should be considered as a repository for the results of the recommended work, especially since the results apply to not only the industry as a whole, but also specifically to the priorities and needs of the electric utility industry nationwide.

1. There is an immediate need for the manufacturers to update and expand the range of in-field unit refrigeration charge diagnostic protocols down to 50°F outside temperature, 40°F degree wet-bulb (basically a dry coil), with an upper limit of 115°F outside. The Carrier representative noted that for a fixed metering device, the lower limit has probably already been reached. Most current equipment with TXV’s could probably not go much lower (60°F), however with better (wider range/extended range) TXV valves, a lower range might be possible.

2. There is an immediate need for manufacturers to review and revise as needed, the current superheat/subcooling tables along with evaporator and condenser performance charts in relation in part to the item noted above, but also for other reasons including differences in operating pressures in newer higher efficiency vs. older lower efficiency units.

3. There is a critical need for manufacturers to provide data labeling via stickers, plates, or potentially an RFID tag, with enhanced data sets such as superheat/subcooling charts for a wide range of conditions (indoor & outdoor dry bulb/ wet bulb temperatures), permanently affixed to each unit. This will help field technicians perform field diagnosis and correction. Depending on the approach chosen, a standard mounting location should be established industry-wide.

4. The industry should develop a minimum standard for onboard diagnostics functionality for all units. It could take the form of a universal plug point for all manufacturers with a universal protocol for data requirements and data analysis.

5. Manufacturers should look into creating a standard for specification of designated sensor mount locations for field testing. Manufacturers should mark appropriate locations for technicians to attach sensors. At least one manufacturer has a product with sensor mounting locations marked.

6. There is a need to prioritize in-field diagnostic approaches based on benefit-cost of the energy savings, cost to diagnose/repair, and the

frequency of occurrence of faults. This might be determined by review and analysis of existing field experience.

7. There is an immediate need for benchmarking existing diagnostic and repair protocols. While there are a number of commercially available diagnostic tools, there are no underlying benchmarks from which to gauge the consistency of the tools currently used in the field. There is a need to create a national standard. The research for this standard could be undertaken by ASHRAE and/or ARI.

8. There is a critical need to gather protocols and data, and post them to a common place. The collection of data should allow researchers and practitioners to examine the quality of the data including sensor and instrument types, accuracies, measurement uncertainties, and testing methods. ARI could provide this information hosting service.

9. There is a critical need to define a clean coil and how to measure it, including as noted in #6, quantification of ROI for coil cleaning, equipment life, energy performance and reliability.

10. There is a need to revise DOE/ASHRAE/ARI test pressures for furnaces and air handlers, and require measured blower power. Fan power should be included as a required measurement to help determine the impact of airflow on overall energy savings. Fan power, especially with ECM motors, has a bigger percentage impact on total system efficiency moving forward, especially in commercial systems with integrated ventilation or economizers.

PART II Roundtable Followup

Since the Roundtable ended, several notable followup events have occurred:

1. At least two proposals dealing with the expanded ambient test condition issue were submitted to the CEC-PIER Building Energy Research Grant Program from Roundtable participants.
2. Jim Braun at Herrick Laboratories, Purdue University, agreed to develop a proposal to establish a set of benchmarks for field test protocols that would represent an industry standard. The proposal will be submitted to ARI and CEC.
3. As a result of a manufacturer meeting that followed the Roundtable, the following information has come from industry sources. Ongoing discussions will be held with HVAC industry representatives on the resolution of the issues raised and on the suggested actions by manufacturers to clarify the situation.
    - Each manufacturer is going to do some further evaluations of their charge checking tables. After initial discussion, manufacturers

believe the current charge checking tools/protocols are not properly checking the charge and in fact are most likely causing over charging of many of the new high efficiency systems.

From what is understood by the manufacturers, some of the tools use a generic model for superheat and subcooling. This can work if all the units are designed to operate at the same saturated suction and saturated condensing temperature, but that is not the case. As unit efficiencies are increased, both indoor and outdoor coil areas are increased. This results in lower condensing temperatures as well as reduced optimal subcooling. As the condensing temperature drops the condensing temperature gets closer to the entering ambient temperature which results in less optimal subcooling. Some have units that run as high as 25°F subcooling down to as low as 6°F subcooling. If a model was based on the 25°F subcooling, then it will significant over charge the high efficiency unit with 6°F subcooling.

Manufacturers are going to check into this further. It is initially believed that it is likely that some modifications to the existing tools will be required with information specific to the actual unit being checked. Also, many of the manufacturers believe that some type of validation of the charge checking tools is required, which many felt they could work into their test programs.

- Many of the manufacturer's charging charts and methods are OK. The issue is more that one generic model cannot fit all units due to the optimization of the designs and the impact on the subcooling. What will likely be required is a tool that has all the models built into the software.
- The manufacturers will evaluate further and get back to us, but at this time "some tools may be doing more harm than good."

4. It has been learned that Wal-Mart is developing a specification for an efficient and robust rooftop unit for its stores that will be shared with the industry some time in first quarter of 2007.

Follow up information updates will be sent periodically as events warrant. If you were not a participant and would like to receive updates, email:
Mark Cherniack, markc@newbuildings.org or
Vern Smith, vsmith@archenergy.com

APPENDICES

Included in this section are unexpurgated notes of the meeting that provide a summary of the dialog, the invitation and agenda, and two presentations made during the meeting.

Appendix A

Notes from Vern Smith & Kristen Frey

Ideal elements of residential/small commercial HVAC diagnostics:

- Low cost to implement
- Uses similar or same tools that techs use today
- Output that can provide feedback to the customer – statement of energy savings
- Diagnostic should be accurate, robust, with sufficient sensitivity
- Should provide good value: cost benefit ratio
- Operational vs. rated efficiency – being able to compare the unit apples to apples
- Have diagnostics box with readout mounted on unit or create an industry standard for diagnostics that would be reported by the built-in controller
- Energy savings calculation (including combustion efficiency)
- National standard by climate – a testing protocol per climate
- Link manufacturer warranty to annual inspection – make sure it is installed correctly, and checked annually
- Technical accuracy and measurement precision – relating to charge, is there a center line to which all equipment will be charged to? Must be related to performance; within 5%?
- Usable by typical technician – diagnostics can be used/interpreted by trained/certified technicians or by anybody?
- Ability to diagnose under all ambient and indoor conditions
- Feedback of service value to customer
- Fast – diagnostics should be performed under 30 minutes (residential and commercial)
- Proper incentive – what is the value to the homeowner/customer? For quality diagnostics and repair
- Identifies opportunity accurately – looks at system including duct leakage and thermostat
- Cost of performing, measure – from a contractor's stand-point; if they have an investment, what is the pay back over time? Can you identify a consistent clear path time and again from contractors and customers?
- Documentation that is sufficient but not overwhelming

Keith Temple's Mini-Presentation on Tune-up Protocol Objectives (Appendix F)

Comments after presentation:

- Different units have different evaporator and condenser temperatures. This complicates making a standardized diagnostic protocol.
- Manufacturers have not provided a wide enough range of performance data, including benchmarks and tune-up documentation

- A 2% change in efficiency occurs with a 1°F change in suction temperature
- Suction and discharge temperature monitoring will tell a lot about changes in unit condition
- Low evaporator temperatures (32 to 34°F) are the predominant problem in the northeast. Is it an airflow or charge issue?
- Some field research suggests that air flow is as much as 30% lower than design – duct installation issues are usually the cause.

Identify existing protocols and what would be your ideas for improvements:

- Direct airflow measurement instead of temperature split method. This is difficult to achieve with 10% accuracy due to built-in physical constraints in the units and in the buildings. The measurement must not be time consuming (must be commercially viable).
- Low ambient testing – being able to test units when it is cold outside (50-65°F)
- Evaluate superheat, subcooling, and evaporator and condenser temperatures on every unit.
- Accurate measurement of airflow – looking for 10% accuracy in the field. Duct blaster could be used to measure (uses same piece of equipment). Duct integrity should be measurable.
- Properly handle multiple simultaneous faults – low airflow and charge for example.
- Update program criteria to plug holes allowing poorly performing units to pass
- Measure fan watts

Improvements to Existing Test Protocols:

1. *Taking Measurements in Low Ambient Temperatures*

- Use tents over condenser units and use steam humidifiers inside zone to raise humidity. These have been used with limited success (time limitations, accuracy in readings, temperature stratification within the tent, wind). Many residential contractors pay flat rates to techs. It would be preferable to have manufacturer's test data to allow testing at low ambient conditions – don't want to fool the system with artificial conditions. But getting this data in the 50 to 60 F ambient condition introduces complications because the expansion valve behavior changes.
- Limited by disruption to occupants and time and expense to contractor.
- TXV over fixed orifice. TXV is expensive, but it would increase the range. Super heat with a fixed orifice maintains compressor integrity. Over-sizing a TXV results in unstable performance. Wide-range TXV's cost more than those typically specified.

- Need at least a rebate/incentive program presented by a utility (let the contractor decide how they achieve). Would contractors use low ambient tests without a utility incentive? Probably not.
- Adding technology adds costs to the unit: Standard unit 70%, Energy Star 25%, and real premium 5%.
- Alternatively, contractors could inspect other aspects of the unit when it is cold out (i.e. duct work, clean condensing coils). Examine it as a whole system.
- Set a standard to be followed by manufacturers. Make a standard for the machines themselves so measurements can be taken at lower temperatures. Unit should show to what percentage of the "ideal" it is operating.
- Role for ARI: Expand range of superheat and subcooling data tables and publish them. Identify the highest efficiency point.
- Superheat table should be examined and improved; manufacturers need to be involved. 100,000 field tests showed that charge measurements have a dependency on ambient and indoor conditions.
- Lab and field research to determine the charging tables for packaged units and superheat. They should match.

2. *Superheat table*

- Widen acceptance band for the utility programs
- Should there be a standard to how the unit is adjusted (when it hits the 6 degree limit)? As a percentage charge adjustment; need a quantitative way to adjust the unit.
- Design a comprehensive protocol for measurements.

3. *Charge verification for TXV units using sub-cooling*

- Values vary by unit, and not all are even available. Probably 10,000 different unit models and 30% do have data available in the field.
- Values should be pasted/branded on the inside of the unit by the manufacturer.
- Make a chart based on high (newer) efficiency vs. low (older) efficiency units for "rule-of-thumb" values for times when in doubt.
- Change in efficiency is about 0.5% per 1°F subcooling change. For TXV, a high efficiency unit 20°F approach at 95°F ambient; low efficiency unit 30°F approach at 95°F ambient.
- EXV (Electronic Expansion Valve) run at close to 0°F approach superheat (Carrier)
- TXV operation is sensitive to placement and attachment of the bulb
- Run a diagnostic procedure to determine whether the TXV is working; tiered/tree branching method to diagnosis – test only what needs to be tested
- Standards and test protocols: Performance (utility wants) vs. Prescriptive (contractor wants)

- Fixed orifice control matches refrigerant flow to airflow – tables should

4. *Temperature split method as a verification of indoor airflow for refrigeration cycle performance*
   - Table data is sensitive to how it is used and is inaccurate.
   - Lab data and field data do not match up well with published tables
   - Technicians don't take wet bulb temperatures accurately and allow ambient temperature to be affected by sun radiation. Consequently, the accuracy of collected data tends to be highly variable.
   - Measuring CFM and watts may help diagnose other problems that need to be fixed.
   - Temperature stratification is a significant issue on commercial packaged units with economizers. Accurately measuring air temperature in the mixing box is not easy.
   - On residential units return air flow is usually well mixed. The supply air flow can be highly stratified. Depending on where the temperature sensor is placed, Sensible Heat Factor (SHF) can vary between 0.6 and 0.7 for the same air stream. The bypass factor on the coil is also an issue.
   - Direct measurement of airflow can be done with an Energy Conservatory TrueFlow instrument ($745) or a duct blaster ($1875). Duct blasters can create problems in systems with VSDs.
   - What level of accuracy are you trying to achieve? Using this table is slightly better than none at all.
   - Existing tables have only return air conditions. Outdoor air temperature should added (even Title 24 does not require it now), but manufacturers may be reluctant to support the needed research.
   - At the very least take existing data and develop an algorithm to apply to most units and then field test it.
   - Manufacturers could put pressure taps on the inlet and outlet side of the cooling coil and document the airflow vs. delta P relationship.
   - Some other technical issues need to be considered because suction pressure drops with low cfm and increases with high cfm. Design suction temperatures also differ with refrigerant (e.g., 55°F for 410A and 45°F for R22).
   - Measuring fan power could also be useful to estimate airflow. Low airflows also means that economizer mode is less effective (e.g., actual 300 cfm/ton instead of design 400 cfm/ton, economizer is 25% less effective).

Diagnostics for whole system efficiency

- Measure indoor fan power
- Measure airflow direction on outdoor fan (of condenser unit) – hand test

- System static
- Fan power and % OSA
- Condenser and evaporator coil diagnostics – at what point does it become so dirty/corroded that it becomes inefficient?
- Duct leakage
- Controls
- Envelope leakage – door pressure test, what effect does the mechanically driven air have on building leakage?
- Noise – depends on occupants, some want it noisy some don't. How do you measure?
- System distribution issues – not really part of utility programs.
- Need verification of current processes and products.
- Need uniform standard test procedures and benchmarks.
- Need a standard similar to BESTTEST for energy models.

Jim Braun Mini-Presentation new developments for test protocols (Appendix G)

- Have an integrated sensor system with standard locations. A diagnostic instrument could be attached to the unit to use the integrated sensor readings and create virtual sensor readings. This would allow us to leave the gas systems alone and avoid inadvertent leaks.
- Sensor location on the condenser side is critical; not so much on the evaporator coils.

Comments

- Some manufacturers and consultants have experimented with similar virtual sensor concepts. Deriving virtual pressures from temperature readings works well.
- For field testing, a location map would be most valuable. Physical access to spots where sensors should be mounted is also very important. Often it is difficult or impossible to place sensors in a good location because components are so tightly packed.

Enhanced Test Protocols

Charge, coil cleaning, and airflow test protocols

- Inspect, clean, correct/fix. Check for duct leakage, clean coils, then do refrigerant charge adjustment.
- Manufacturers could provide all performance data on an RFID chip inside the unit.
- What is the return on investment for coil cleaning? Make a distinction between commercial and residential buildings before making a standard protocol, esp.

when addressing condenser coil cleaning i.e. hose bibs and proximity to unit (many big box retail stores have no or only one hose bib on the roof). If this becomes necessary on a unit to do coil cleaning, how does that affect a protocol? Energy efficiency vs. compressor reliability should be examined. Condenser performance went down mostly when coils were extremely fouled.

- For locations without hose bibs, suggest using portable sprayers. "Spray-on, Leave-on" cleaning solutions could be used.
- Real coil cleaning equipment can result in 20% savings in amp draw (e.g., one example where it reduced pressure from 385 psi to 325 psi).
- Lab testing and field testing have shown that significant fouling is needed before heat transfer declines. But outcome depends on whether fouling material is baked onto the coil surfaces.
- NEED MORE research on coil fouling and cleaning, including a standard method.
- If power use is increased to gain increased airflow (back to design condition), will unit cycle more (assuming that decreased airflow to space means unit runs longer to satisfy setpoint)?
- Hot Button: Assertion – refrigerant charge is not sensitive to airflow. Counterpoint – disagree, it certainly is sensitive.

2. *Alternative refrigerant charge diagnostics as proposed by Purdue University*

- Would it be valuable to have a place to show this data that is being collected? Need to be able to examine the quality of the data (need to know the sensor and instrument types, accuracies, measurement uncertainties); testing methods should be analyzed. Industry calibration standards need to be included.

4. *Investigate alternative practical airflow tests other than indoor temperature split.*

- ASHRAE standards using the flow plate and duct blasters. Does the integrity of the data from the flow plate need to be investigated? Assertion – may have up 50% error. Nearby obstructions (within 6 to 12 inches) produce errors. Counterpoint: Have had few problems with flow plate method. NEED more research on flow plate measurement method.
- Set up an incentive to measure airflow. Note that the rule of thumb number (400 cfm/ton) doesn't work for all units; set different numbers for the threshold.
- Duct leakage can have a significant impact of airflow to the space (e.g., 350 cfm/ton at discharge and 250 cfm/ton delivered to space).
- Incentives for contractors are not large enough to add testing requirements that may or may not save energy but will definitely increase the amount of time in the field.
- Measuring straight airflow not practical for commercial applications; digital velometer could be used but would need to measure duct leakage and airflow, plus would have to determine which ducts go to which unit. It's common to find many 5 ton packaged units serving an open office floor plan with cubes and it's difficult to figure out what diffusers/ducts are connected to each unit. Duct leakage is also a problem with measurements taken at the diffusers with flow hoods.

- Tracer gas is not a practical method – it's not cost effective and is difficult to setup test conditions in the field.
- Measure other temps, and if the unit appears to be working correctly then don't need to do an airflow measurement. Virtual sensor methods may be a reasonable substitute for a direct airflow measurement.

4. *Condenser heat transfer*

- Addressed above.

<u>"Hot-button" topics and other unaddressed items:</u>

1. Priority of doing the diagnostic should be based on saving energy, cost of performing the diagnostic, and frequency of occurrence of the fault. Cost/benefit ratio by frequency.
2. Define a clean coil and how to measure it.
3. Quantify ROI for coil cleaning; equipment life, energy, reliability.
4. Lack of technical skills among maintenance sales personnel. The industry needs to adopt the attitude that training sales staff is valuable. Will industry consolidation help?
5. Is an airflow measurement necessary for charge check?
6. Are superheat tables applicable to RTUs?
7. Expand the data range for charge checking
8. Critical data available from manufacturers as pertains to sub-cooling
9. Defining locations for sensors (permanently or temporarily installed)
10. Energy calculations for utilities to assess savings
11. Modify existing protocols that currently pass poorly performing units
12. Investigate alternative airflow techniques, virtual sensors
13. Invite end users to the table
14. Should TXV sensing bulb insulation, orientation, contact, and location be corrected prior to diagnosing and/or correcting RCA?
15. Should proper unit sizing be included within the diagnostic protocol?

Day 2 – November 29, 2006

<u>Topics of General Consensus</u>

A universal protocol should cover the following areas (see Figure 1 for graphic):

1. *Building Shell*
   Load sizing – down to zero
   Occupancy and use
   HVAC location
   Unbalanced ventilation
   Climate
2. *HVAC Units*
   Coils – condensers and evaporators, matching
   Line sets
   Physical size of units (also pertains to building shell)
   Power side
   Refrigerant side
   Air side – indoor and outdoor
3. *Controls*
   Thermostat
   Economizer
   BMS
   People
   Demand control ventilation
   Load
   Zoning
   Fan – variable speed
   Compressor
   Embedded diagnostics
4. *Ventilation*
   Minimum OSA
   Multi-zone systems
   Heat recovery
   Building pressure control
5. *Distribution*
   Dampers – zone control
   Duct leakage
   Hydronic

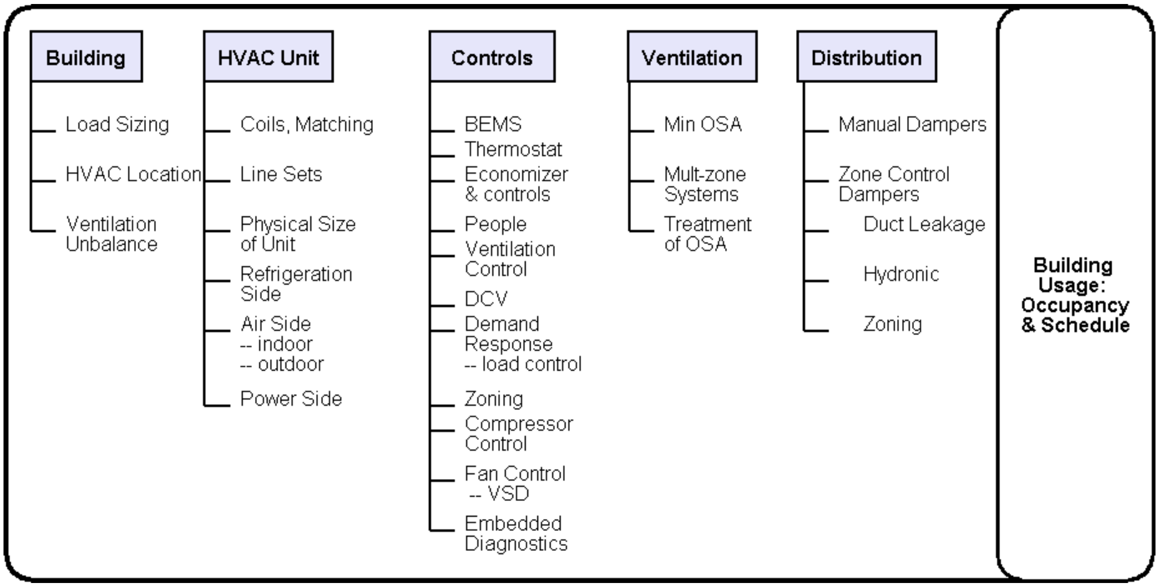


Figure 1 Items that influence packaged HVAC unit performance

Separate protocols should be established for residential and commercial systems.

Labeling of performance data, inside the unit for protection

- Subcooling and superheat goals should be included in the data set provided by manufacturer),
- Support from manufacturer to distributor/contractor

Hot-button Topics – Ranking Top Three

Added to the list:

4. Benchmarking existing protocols. Gather protocols and data and post them to a common place. Where it works and where it doesn't?

"End-users" in #13 should be renamed "Stakeholders".

The top four topics were selected by having each participant rank the top three issues from the 16 "hot-button" items (15 were identified yesterday and one was added today). The final rankings were:

1. (No. 16 with 12 votes) **Benchmarking existing protocols. Gather protocols and data and post them to a common place. Where it works and where it doesn't?**
2. (No. 1 with 6 votes, including No. 10 with 5 votes) **Priority of doing the diagnostic based on saving energy, cost, and frequency of occurrence of the fault. Cost/benefit ratio by frequency.** Hot-button No. 10 received 5 votes, and it was agreed to include it here: ***Energy calculations for utilities to assess savings (and did the savings occur).*** ASHRAE is attempting to create a benchmark for an improvement of 30% savings. DEER needs a steering committee; need to check analysis to ensure that it is not flawed.

3. (No. 7 with 5 votes) **Expand range for charge checking – expand to include dry bulb/coils; lower limit to include 50 F outside air temperature; upper limit to include 120 F outside air temperature.**

After ranking the top three, the following points were discussed:

- Dick Lord and Karim Amrane agreed to discuss Ranked Item #3 (Hot-Button #7) next week at a meeting of the ARI RTU Engineering Committee. [see Part II for follow up]
- In expanding the data tables in Ranked Item #3 (Hot-Button #7), the focus should be on finding performance methods rather than prescriptive methods.
- Research agenda for Ranked Item #1 (Hot-Button #16) should be coordinated with or through ASHRAE.
- ASRHAE 90.1 references 15 climate zones and benchmark buildings in each zone.
- Ranked Item #1 should be the focus of most of the research funding because it applies to all of the faults.
- ARI has sponsored research in the past to identify frequency of faults in large units and the cost to repair.
- NBI published a study in October 2004 that was a meta-study of frequency of faults in RTUs.
- The next round of DEER needs peer review (starts Jan 7, 2007 ?)
- ADM has an ASHRAE-sponsored research project working on 250 – 300 units around the US to identify faults and measure performance.
- Concepts from the Hot-Dry project should be included.
- Coordination is needed at the national level – a National Cooling Initiative should be established.
- The newly established Western Cooling Efficiency Center headed by Dick Bourne should be a good resource.
- Coordination should include the California HVAC PAGette sponsored by PG&E.
- Coordination should also include the Emerging Technologies Coordinating Council (consisting of the California investor owned utilities and representatives from the CEC and others).

Appendix B

Notes from Iain Walker, LBNL

What Do Contractors Need?

Things like NATE certification are not helping to get better diagnostics or to get more systems tested. Contractors need a written diagnostic that can be performable by anyone not just highly trained HVAC technicians. Requiring a high degree of training limits the number of technicians so that it will be difficult to change the market due to there being too few trained people.

The IDEAL is a single automated push button – or taking a step back – test procedures that are easy to use with no training. This allows the use of $30/hour tech instead of $70/hour tech – this reduces cost to do testing.

Survey data from several hundred technicians indicate that current maintenance contracts are just filter changes. Therefore we need to change the way that contractors think about servicing.

NEED to do one-time commissioning of installation. Periodic testing that breaks into refrigerant lines is one of the problems (that is how refrigerant is lost).

The diagnostics should identify problems techs can fix otherwise they have no motive to do testing. If they find things they can fix then they will want to do the tests as it generates extra work.

NEED evaporator and condenser performance charts for a wider range of temperatures (units usually have ARI rating conditions only and these don't exist in real field testing). According to John Proctor, even current published superheat tables need improvement. Buck Taylor suggests adding accumulators and receivers for package units to make Super Heat (SH) or Sub Cooling (SC) tables more applicable due to internal storage effects.

NEED to be able to test charge when it is cold outside (go down to 50 F), or dry inside (need dry coil data – current charts require indoor humidity that is too high for hot-desert climates like inland CA or NV). Possible ARI research effort.

NEED a better way to link test data to performance (efficiency or cost-to-operate).

NEED a nationally recognized standard for consumer confidence. I suggest maybe EPA is a path to labeling testing/certification. Standard should include:

- Test procedures
- Labels
- Cost/efficiency calculations

Diagnostic Improvements

IDEAL diagnostic includes system effects: so as well as charge we need to measure air flow (above 200 cfm/ton roughly linear for non-TXV with fractional change in efficiency about 1/3 of fraction change in air flow, so 30% airflow reduction is 10% less A/C efficiency. Below 200 cfm/ton things go bad facts – coil freeze up, compressor slugging etc., duct leakage, and fan watts). Also need to ensure indoor and outdoor heat exchangers are clean.

Role for ARI developing OBD. Make it similar to automobile smog check – need a universal plug for all manufacturers and universal protocol for data. Have ARI require manufacturers to install data on board for manual diagnostics. Plate would include commissioning SH/SC data. Possibly have SH/SC charts for a wide range of conditions (indoor and out door dry bulb and wet bulb temperatures) onboard on chip that can be scanned with a simple diagnostic scanner.

Test over a wider range of conditions: down to 50F outside and with dry coil (for lower indoor wet bulb).

One way is to change the test:

- It is possible to put a tent over the condenser to recirculate air leading to higher condenser air temp. But it is hard to not change total air flow or air flow pattern that might invalidate the test as the temperature (and pressure?) of refrigerant is not uniform in the coil and depends on these total and local air flows.

- For indoor humidity – use steam indoor humidifiers.

Other way is to change way equipment operates – needs manufacturer-based research via ARI.

Sensitivity of test results to measurement error:
Subcooling 1F change is about 0.5% of charge.
For incentive programs don't use a simple deadband when testing charge – everyone ends up at the minimum requirement. I propose a combination of deadband and a minimum charge change to get credit for incentive.

Refrigerant could be diagnosed using well-measured line temperatures at appropriate locations (that could be marked in the future by manufacturers) – work by Jim Braun at Purdue.

Air Flow – don't use temperature split – too unreliable. Use pressure matching in residential. For rooftop package units, access is a problem so
- for tight ducts measure air flow at returns with powered flowhood or good commercial hood (TSI).

4. tracer systems are not practical due to sampling/mixing issues.

Action Items

Get ARI involved in research to look at improving SH/SC tables and extending range of SH/SC testing to 50F ambient and for dry coils.

ARI to work with manufacturers on data plates for commissioning for new installations (factory installed) and re-commissioning of existing systems (plate/label installed by technician).

ASHRAE:
Develop OBD spec. and research on diagnostics.

Technical Committees to contact:
TC 6.3 Central Forced-Air Heating and Cooling Systems (Chair is Mike Lubliner: TC0603@ashrae.net))
TC 8.4 Air-to-Refrigerant Heat Transfer Equipment (Chair is Steve Memory: TC0804@ashrae.net)
TC 8.8 Refrigerant Controls and Accessories (Chair is Mohsen Farzad TC0808@ashrae.net)

Change DOE/ASHRAE/ARI test pressures for furnaces and air handlers and require measured blower power.

NEED a meta-analysis of field testing protocols: joint ARI/ASHRAE project. Look through ARI research, ASHRAE Transactions, NBI report, DEER. LBNL Commissioning guidelines etc.

Other possible research contact is Western Cooling Efficiency Program: Dick Bourne at UCDavis.

WE should set up a National Cooling Initiative led by Mark @ NBI.

Hot Button items

1. Do meta analysis to benchmark protocols
2. Efficiency and cost estimates for testing and equipment performance
3. Increase range of conditions over which charge can be checked.

END

Appendix C

Notes from Buck Taylor, Roltay, Inc.

Agenda: Brainstorm on hot topics included broad scope of items from building shell (loads) to equipment, controls etcetera.

Overarching concerns: savings calculations, protocols being used, and concern over faults affecting actions of techs in the field; if they are not looking/screening for and correcting these faults first, SH and SC evaluated alone can be affected strongly by faults. Also discussed was the evaluation of airflow and appropriate ways to measure, and if, or when it actually needed to be measured.

Minimum data to be collected was discussed, and the following was determined as necessary; LT/LP (CT), ST/SP (ET), AMB, and evaporator fan watts.

Some concern expressed by RMA that SH table didn't apply to all rooftop equipment. The purpose of SH is to protect the compressor. 1 degree of SH back to the compressor is fine if it doesn't result in slugging. Part of RMA concerns may be attributable to units that use accumulators and receivers to help control flood back and aid in systems with large elevation differences (lifts) between condenser and evaporator. These systems could have "unexpected" SH values when properly charged using the Carrier SH charts.

Concern expressed about easy availability of both performance data and SC goal values, or a legitimate default value or method for determining goals for techs in the field. Carrier states their information is available on the web, however not all manufacturers attended/represented, and web data may still not help technicians on the roof.

General protocols (test procedures) and items of concern where outlined. Some concern was expressed about calibration, and protocols related to sensor placement by techs in the field.

Many expressed concerns about Title 24, and savings algorithms used by California utilities and VSP providers using the DEER database for determining savings. There was a strong consensus that the DEER database was not applicable for determining potential savings for tune-up activities.

There was evidence provided by Proctor and RMA that showed a larger deviation of SH (from goal) resulted in smaller degradations in performance than previously thought. Proctor proposed that a deviation of up to 7 degrees was fine for "energy" purposes. RMA proposed that it should be much tighter! He claims when you know how to charge, and know how much to add, this is easy. The rest of the participants didn't see any clear benefits to tightening the standard (and potential barriers) if there was no clear benefit.

According to some manufacturers data (and theoretically true), near zero SC results in higher efficiency, however this may result in low-head for air-cooled DX systems, resulting in improper metering device operation. The sensitivity of SC charge in relation to efficiency was characterized as being more sensitive in high-efficiency units than older, less-efficient units.

A presentation was made by Jim Braun, Purdue University, on the use of "virtual" sensors to get condensing information rather than using direct pressure measurements to convert into temperature. Data and research from Purdue University appeared very promising in that the direct measurement of "pipe" temperatures could be used to indicate actual condensing temperatures without "opening" up the system. Carrier stated that they have a product line with sensor mounting locations – specific for just such measuring. ARI/Carrier to look into creating a standard for manufacturers for specification and purpose of designated sensor mount locations for equipment. There is much concern about technicians putting gauges on these systems, as it is an opportunity to release gas, and introduce contaminants. Direct measurements would theoretically reduce the probability that techs would adjust charge after commissioning, and actually deal with the heat exchange surfaces/properties first. It was generally agreed by attendees (including contractors present), that it would be preferable if technicians didn't use pressure gauges on equipment to perform any services unless absolutely necessary.

A presentation by FDSI on the use of a new charge evaluation method that was relatively insensitive to other faults was given. The method looks at both SH and SC together since they have to be in thermodynamic balance even with a fault (this is already known and partially dealt with SA, but not addressed by protocols) present. Some additional info from manufacturers could make this a simple and robust protocol.

There were brisk discussions about benchmarking the current protocols to help determine sensitivity and applicability in predicting/creating savings.

A "universal" map of items that could affect A/C use was created. There was some discussion on creating an overarching protocol – however the focus of the meeting and work items will be limited to those that can be performed by an HVAC technician.

Roltay and LBNL will look into approaching ASHRAE on creating an industry standard for measuring and checking charge/faults/protocols etcetera. Roltay, Carrier and ARI will also discuss the feasibility of enhanced data sets to be supplied/permanently affixed to units (moving forward), to better help techs perform fault detection/correction. An example of this would be to create a standard mounting location for SH/SC information for techs to reference when servicing equipment. Some concern expressed about manufacturers wanting to protect "proprietary" information. We will argue it is a moot point. Carrier stated biggest concern was from Chinese intellectual theft, not theft by American competitors.

Sizing issues: with the exception of RMA, all other parties agreed that over sizing relative to load is not a big problem for energy use (kWh). There in fact appears to be some savings associated with over sizing and use of setbacks with big push downs (at least in California data). RMA was concerned about over sizing and use of A/C during "heat storms" resulting in the need to overbuild generation assets and impact on global warming (total kW).

California was experimenting with some ICE reservoir coil cooling on residential condensers. This is load shifting strategy. Clearly the industry needs load interruption/intervention/shifting for the short term. The "market" needs to be much more aggressive about load control moving forward, as A/C technology has pretty much hit the thermodynamic wall. There was some brief discussion about engaging manufacturers about "what next" for compressor technology or alternates.

There were some heated discussions about breaking the current conservation mold – society can't keep doing what results in small short-term electric savings measures. Programs need to do what's "right" in the context of overall savings – as it all impacts the same thing – ENERGY and resources.

The "group" through NBI will present a letter to the CEC and CPUC regarding some of these issues, and also propose that some BERG funding be directed to do more research on the protocols and savings potential/impact for various measures.

Regarding discussions about savings due to airflow and coil cleanings: more needs to be known. Evidence from Proctor shows that in some cases, increasing airflow resulted in 0 or negative savings due to increased fan power usage. LBNL and others felt that fan power should be included as a required measurement to help determine the impact of airflow on overall energy savings. LBNL also stated that fan power, especially ECM motors, are/will have a bigger percentage impact on total system efficiency moving forward, especially in commercial systems with integrated ventilation (or economizers).

There was a good deal of discussion about getting information/ability to test systems at lower driving temperatures. For fixed metering devices, the lower limit has probably already been reached. Carrier stated that most current equipment with TXV's could probably not go much lower (60 degrees), however with better (wider range/extended range) TX valves, this might be possible. Cost would be a couple of dollars per unit. Roltay proposed an extended ARI testing spec down to 50 degrees AMB and 40 degree wet-bulb (basically a dry coil). Proctor and LBNL all agreed that this would help them too, but also need a higher upper limit (115 degrees AMB) for desert locations. Carrier and ARI will discuss with the ARI rooftop committee to see if this is feasible and down to what temps.

Carrier stated that interpretation of SH changes on savings needs to be re-thought because "choke" velocity metering valves are designed to operate independently from airflow, so SH charge does not track airflow as closely as previously thought, and certainly not as spelled out in the CAL-VSP protocol. This will be considered in any additional research on the subject.

We also raised the concern about the ease of testing units – and the need for an "easy button" for techs to put the unit into test mode quickly and easily.

There was some discussion about performance data as mentioned above, and how the current information may be leading us to make improper decisions. ARI also agreed that current single-point rating system is problematic. We, the rest of the industry and interested parties, need to propose or state our goals, and let the manufacturers work on a solution. They have clearly heard this many times before, so we need to keep beating the drum. I will also discuss some possibilities with Carrier. As mentioned above, there was concern about where to put all the data in the unit. I proposed that it might be less expensive to just start putting their information on an RFID tag instead of using labels. In volume, these would be pennies each, and would open up the potential to store and get instant field access to large amounts of engineering data for use by techs. This was relatively well received (at least by Carrier, Aaon did not flinch, and ARI seemed to think it might be worth talking about as a solution to all the data needs moving forward.

Ways to measure and evaluate airflow was discussed. The temperature split method/table was discussed. We all agreed it was not the best, but better than nothing. It was mentioned that this table was missing an important driver (outdoor air temp –AMB), and that a revised table that takes this into account needs to be developed. This will go into the BERG proposal and also discussed by ARI. Roltay and LBNL will also discuss as possible research project with ASHRAE.
END

Appendix D

Invitation to Participants

Dear Participant: Architectural Energy Corporation and New Buildings Institute would like to invite you to participate in a:

Dialogue on Critical Technical & Research Issues for Current and Emerging Utility HVAC Energy Efficiency Programs

Problem Statement

Existing studies as well as field work completed (and ongoing) through utility air conditioning service programs, have clearly demonstrated a wide range of problems with the installation and ongoing maintenance of residential central HVAC systems as well as larger-sized commercial rooftop HVAC units. This field reality along with a need to dramatically improvement electricity end-use efficiency has led electric utilities in California to implement through a variety of program implementers, large scale HVAC service programs especially focused on, but not limited to, refrigeration charge and air flow correction. A number of utilities in the Pacific Northwest and Northeast are contemplating the appropriate design of HVAC service programs and related field service protocols and approaches.

There appear to be several fundamental technical questions and issues that have been raised by experienced HVAC industry professionals that remain unresolved related to the methods and protocols appropriate for utility program designers/implementers as well as field technicians. These issues have a direct relationship to the potential for achieving more substantial, cost-effective, and persistent energy and demand savings from the operation of utility-sponsored residential and commercial HVAC service programs in California, as well as nationally. Currently, there is no obvious national-level venue for a discussion of the merits of the topics noted and for resolution of the issues raised that are both technical in nature and utility energy efficiency program design related.

Recommended Action

New Buildings Institute (NBI) and Architectural Energy Corporation (AEC) have proposed convening a group of knowledgeable and interested individuals for a 1.5 day dialogue on the proposed topics noted below. The California Energy Commission's (CEC) Public Interest Energy Research Program (PIER) is providing financial support for the dialogue.

Proposed Schedule

We are proposing that the dialogue be held in California at the Courtyard Oakland Airport facility Wednesday-Thursday, November 28-29, 2006. Call in facilities will be available, although face-to-face is always better.

Invited Participants

We are well aware that the invitation list could have been far longer. And it may well be by the time we get together. We wanted to limit the ultimate size in order to ensure a functionally interactive discussion that will conclude with an initial action plan for the priority action items identified by an as yet to be determined consensus decision making process.

Desired Outcomes

a) Determination of, and/or consensus on, the merits and potential benefits of resolution of each issue noted below or introduced at the meeting;
b) Identification of priorities for action;
c) Consensus on the means by which the resolution may best be accomplished;
d) Options for implementing the associated research, testing and/or analytic work;
e) Estimate of the time, financial, research (field/lab) and/or engineering resources required to resolve the issues, along with potential sources of funding;
f) Identification of specific steps for implementation of the prioritized issues;
g) Resolution on the future of this group.

Meeting Structure

In order to achieve the proposed outcomes, we expect to structure the meeting as follows:

1. Introductions/agenda and why we are here.
2. Presentation of additional concerns or issues for group review.
3. Which are the hot button topics from either a research engineering, field engineering, field maintenance, utility program participant (utility or service provider)

   Discussion framework – Consider these questions as guidance for the discussion. Some questions have yes or no answers, some require detailed discussion.

   - What is at issue? Does this issue have technical merit, and says whom and why?
   - Is the issue clearly described?
   - Has this issue already been resolved to 90% of people's way of thinking?
   - Is there an obvious means for resolution?
   - Is this issue unresolvable either technically or due to field realities?
   - Would additional lab or field data resolve the issue and how much data of what kind?
   - How does the issue impact utility HVAC service protocols?
   - How does the issue impact utility program costs?
   - Is the technical resolution compatible with field conditions and program requirements?
   - Is there an effective technician training procedure for the protocol?
   - How does the issue impact kWh and kW savings?
   - How does the issue impact persistence of kWh/kW savings?
   - Does the resolution of each specific issue depend on the resolution of any of the other issues?
   - Is this a high, medium or lower priority issue compared with the other issues?

4. We will summarize the areas of direct agreement and action. We will catalog the issues where substantial disagreement may exist until there is further assessment or research to resolve the disagreements.

Support for Participants

For those participants requiring financial support to participate, AEC will provide funds for travel and per diem in accordance with California Energy Commission's Travel Policy and contracting requirements.

Initial Dialogue Topics

The following technical issues have been identified as needing at least some discussion or path to resolution or potentially additional research in order to be useful to HVAC service program administrators and implementers in California and nationwide. There may be additional related topics on related issues that they would like addressed.
*Please send additional issues or questions about the topics to Mark Cherniack (markc@newbuildings.org) at NBI in time for him to send them out to participants ahead of the meeting or they will be addressed at the meeting.

Please take sufficient time to read and consider the topics described here. The very first activity at the meeting will be to determine their merits, and then to discuss and prioritize next steps. We expect some differences of opinion about some of these issues, so let's all be ready to have a good talk about them.

Improvements to Existing Test Protocols

1. Verification of refrigeration cycle performance is typically restricted to conditions when the outdoor air (dry-bulb) temperature is above 55°F and the return air wet-bulb temperature is above 50°F. This potentially prevents technicians from conducting tests during fall and spring when workloads tend to be lighter. Expanding test protocols to address low ambient testing of refrigeration cycles is required. This is a frequent request of program administrators.
2. The standard superheat table for a unit with a fixed expansion device is limited at approximately 6°F of superheat. This prevents testing when outdoor air temperature is high and return air wet-bulb temperature is low. Investigation of approaches to testing under these conditions is required.
3. The current charge verification test for a unit with a TXV uses a fixed subcooling value based on the manufacturer's recommended value. Is this value readily available in the field? What is the recommendation when the technician cannot determine the goal value? What is the impact of the variation of the subcooling goal value with changes in driving conditions (outdoor air temperature, etc.)?
4. The temperature split method is currently allowed as a means of verifying indoor airflow for refrigeration cycle performance. The lookup table used to determine the goal value for the temperature split method (evaporator airside) does not consider outdoor air temperature (independent variables are return dry-bulb and return wet-bulb temperature). This results in estimated errors on the order of 10%

in the goal value at high or low outdoor air temperature. Enhancing the method to include outdoor air (dry-bulb) temperature dependence is required.

Enhanced Test Protocols

1. The common charge and airflow test protocols that are used in many existing programs do not directly address low evaporating temperature and high condensing temperature (over outdoor ambient), which are indicators of reduced efficiency. A simplified test protocol has been suggested, but additional work is needed to define a test protocol and programmatic pass/fail criteria that address low evaporating temperature and high condensing temperature (over outdoor ambient) when evaluating refrigeration cycle performance.
2. An alternate refrigerant charge diagnostic has been proposed by Purdue University and Field Diagnostic Services, Inc. (see attached summary) that uses both superheat and subcooling and reduces the sensitivity of the diagnostic to other system faults when compared to using superheat or subcooling alone. Additional work is needed to further validate the approach and define the test protocol including the target superheat/subcooling line and the allowable tolerance for determining acceptable charge level.
3. Investigate alternative practical airflow tests other than indoor temperature split.
4. Condenser heat transfer problems are known to reduce air conditioning system efficiency. Some programs have required heat exchanger cleaning, while other programs require visual inspection of heat exchangers by the technician. Can condenser heat transfer problems be adequately assessed by visual inspection? Does the test protocol need to include measured performance of the condenser?

Implementation Issues

1. How do technicians effectively identify the nameplate cooling efficiency of a unit in the field? Should the value be SEER or EER? What is the impact on program results?
2. Should there be a different test protocol for evaluating the refrigeration cycle of existing units and new (actual vintage range) units or should there been one protocol that adequately addresses the problems that can exist for all units

Appendix E

Roundtable on Refrigeration Charge/Airflow Testing and Diagnostic Protocols for Residential and Small Commercial HVAC Systems

This Roundtable was organized by Architectural Energy Corporation and New Buildings Institute and is supported by the California Energy Commission Public Interest Energy Program.

What do we know?
What do we know we don't know?
What do we know that isn't so?
And what is it that we need to know?

November 28-29, 2006
Courtyard Oakland Airport
350 Hegenberger Road
Oakland, California 94621
510-568-7600

Workshop Schedule

Day 1: Tuesday November 28, 2006

8:30 Welcome-Vision & Goals: Mark Cherniack/Vern Smith

8:45 Introductions: Facilitator Rick Diamond (LBNL)

9:00 Group exercise: **What are the ideal elements of a residential/small commercial HVAC diagnostic?**

9:20 Mini-Presentation: **What do we know about existing test protocols for residential and small commercial HVAC?** Keith Temple, FDSI

9:30 Group exercise: **What are the top 3 technical improvements for existing protocols for residential and small commercial HVAC?**

10:30 Break

10:50 Group exercise: **What are the top 3 implementation/programmatic issues for existing protocols for residential and small commercial HVAC?**

12:00 Lunch

1:00 Mini-Presentation: **What do we know about *new or enhanced* test protocols for residential and small commercial HVAC?** Jim Braun, Purdue University

1:15 Group exercise: **What are the top 3 technical improvements for enhanced protocols for residential and small commercial HVAC?**

2:15 Group exercise: **What are the top 3 implementation/programmatic issues for existing protocols for residential and small commercial HVAC?**

3:15 Break

3:30 Group Exercise: **What are the priority items from the previous discussions and can we rank them?**

4:30 **What are the "hot-button" and unresolved issues for further discussion?**

5:30 Adjourn

Day 2: Wednesday November 29, 2006

8:30 Recap of Day 1 Mark Cherniack/Vern Smith

8:45 Group Discussion: **Re-cap: What are the "hot button" and other unresolved issues?**

9:00 Group exercise: **How do we resolve the unresolved issues?**

9:30 Group exercise: **What do we agree we know we know?**

10:30 Break

10:50 Group Exercise: **What work needs to be done?**

11:45 Group Exercise: **What is the continued role and follow activities for this group?**

12:00 Lunch for those who can stay

1:00 Adjourn

Appendix F

Presentation by Keith Temple, Field Diagnostic Services, Inc.

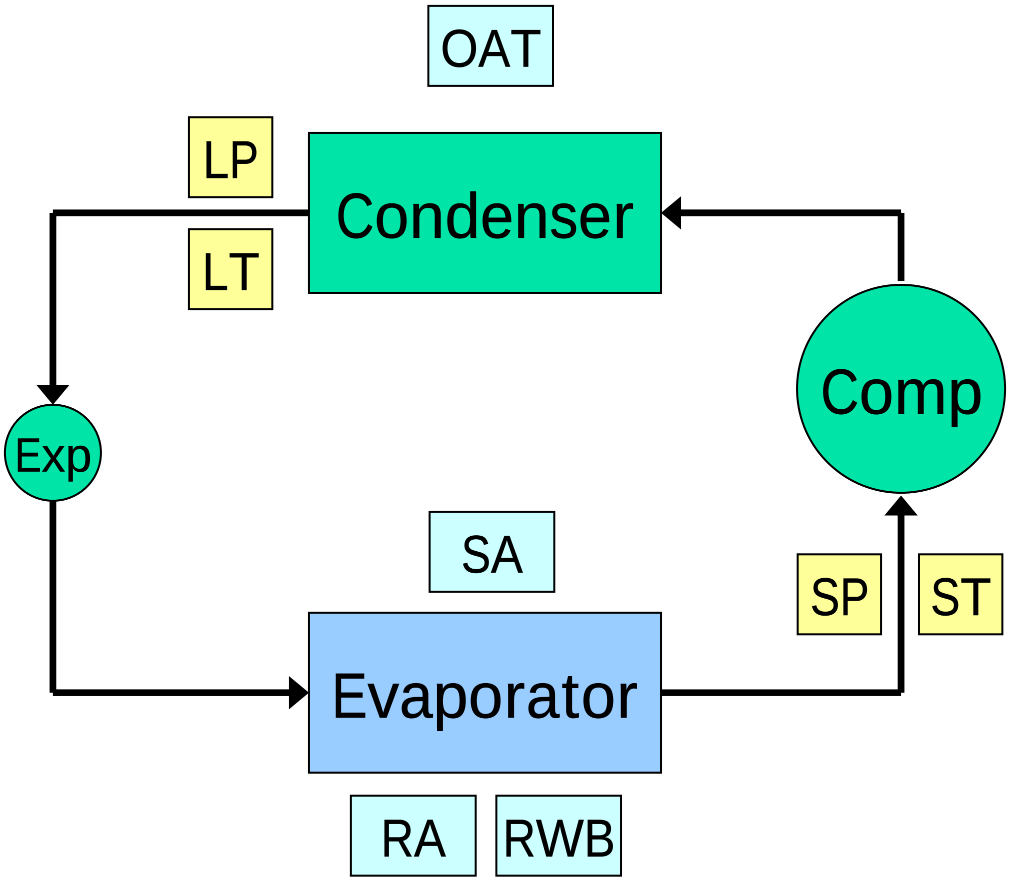
Tune-up Protocol Objectives

- Primary objectives:
  - Improve AC operating efficiency
  - Reduce effective peak electric demand
- Secondary objectives:
  - Provide guidance consistent with industry service protocols
  - Guide tune-up that promotes equipment performance and life

Existing Protocol Elements

- Indoor Airflow Evaluation
  - Direct airflow measurement
  - Evaporator airside temperature split (±3°F)
- Refrigerant Charge Evaluation
  - Fixed orifice (FO): superheat (±5°F)
  - Thermal expansion valve (TxV): subcooling (±3°F)

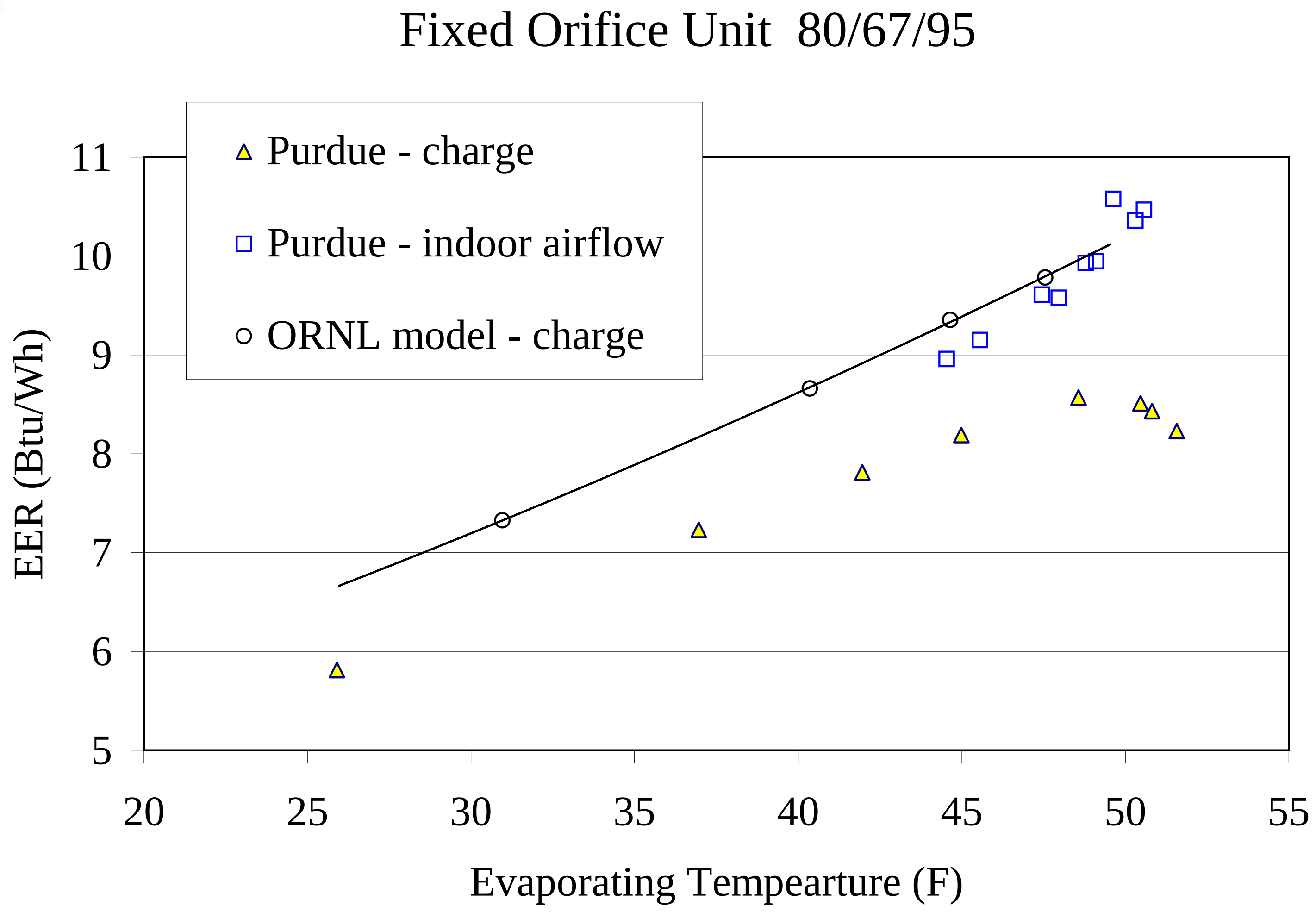
Refrigeration Measurements



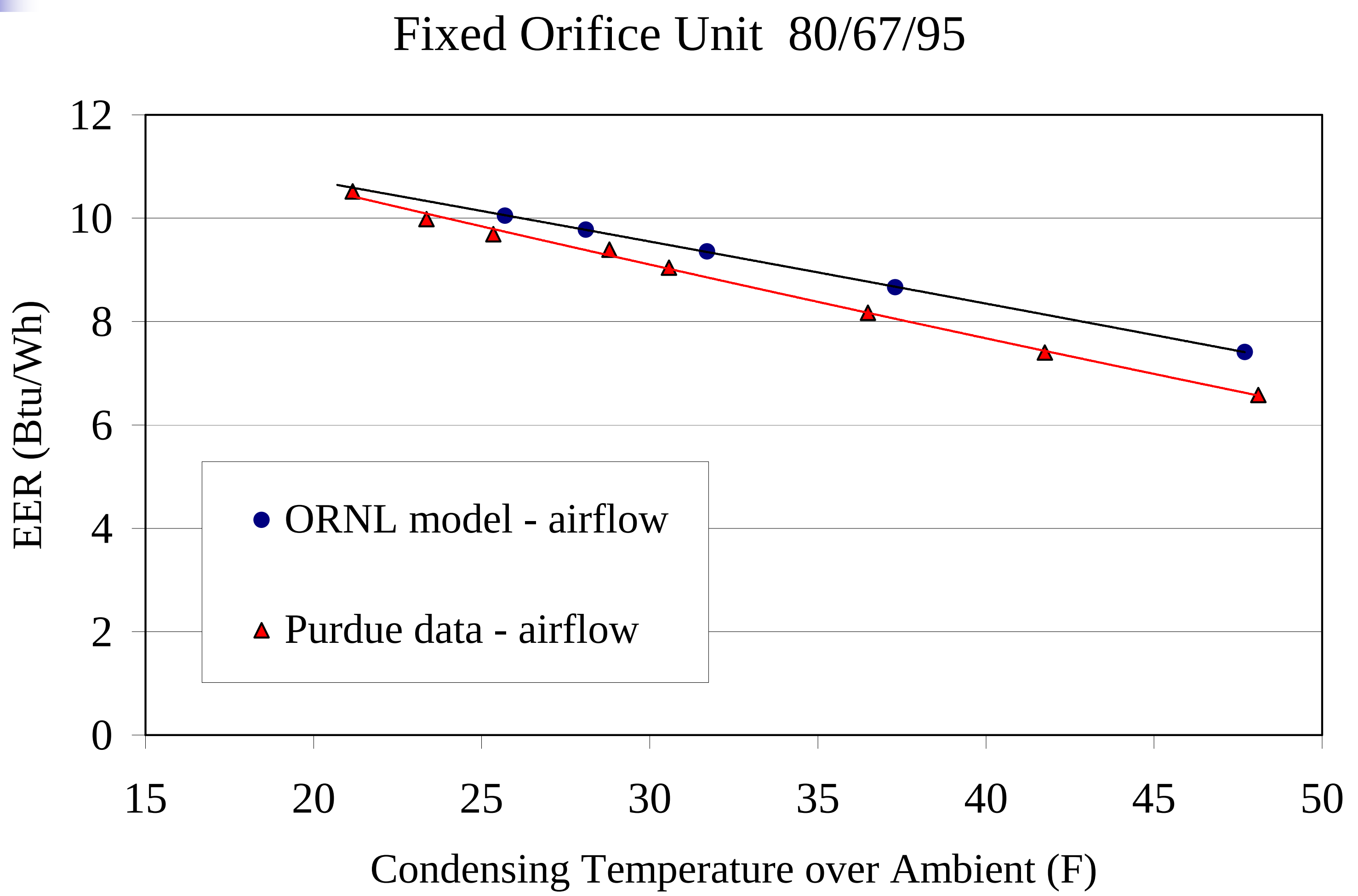
Performance Parameters

- Evaporating temperature
  - ET = f(SP)
- Condensing temperature
  - CT = f(LP)
  - COA = CT - OAT
- Superheat
  - SH = ST - ET
- Subcooling
  - SC = CT - LT

Evaporating Temperature



Condensing Temperature



Existing Protocol Assessment

- Causes of low evaporating temperature
  - Evaporator heat transfer problem
  - Liquid line restriction
  - Low refrigerant charge
- Causes of high condensing temperature
  - Condenser heat transfer problem
  - High refrigerant charge
  - Non-condensable gas in system

Existing Protocol Assessment

- Causes of superheat deviation (FO)
  - Low or high charge
  - Liquid line restriction (high)
  - Evaporator heat transfer problem
- Causes of subcooling deviation (TxV)
  - Low or high charge
  - Liquid line restriction (high)

Existing Protocol Assessment

- Current protocols do not directly address low ET and high CT
- Current charge diagnostic protocol is sensitive to other faults
- There is an opportunity to improve the results (energy and demand reduction) of tune-up programs by implementing an improved protocol

Appendix G

Presentation by Jim Braun, Purdue University

New Diagnostic Protocols for Residential and Small Commercial HVAC

November 28, 2006

Jim Braun

School of Mechanical Engineering

Purdue University

NEW DEVELOPMENTS

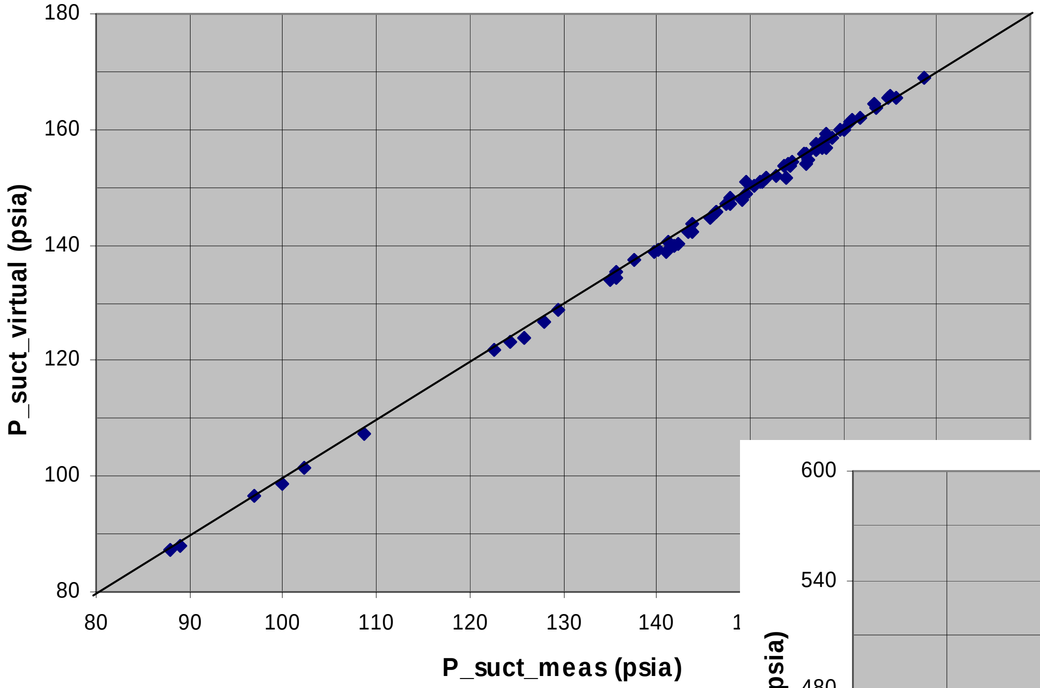
- TEMPERATURE-ONLY DIAGNOSTICS
- DECOUPLED FEATURES & VIRTUAL SENSORS
- COST IMPACTS OF SERVICE

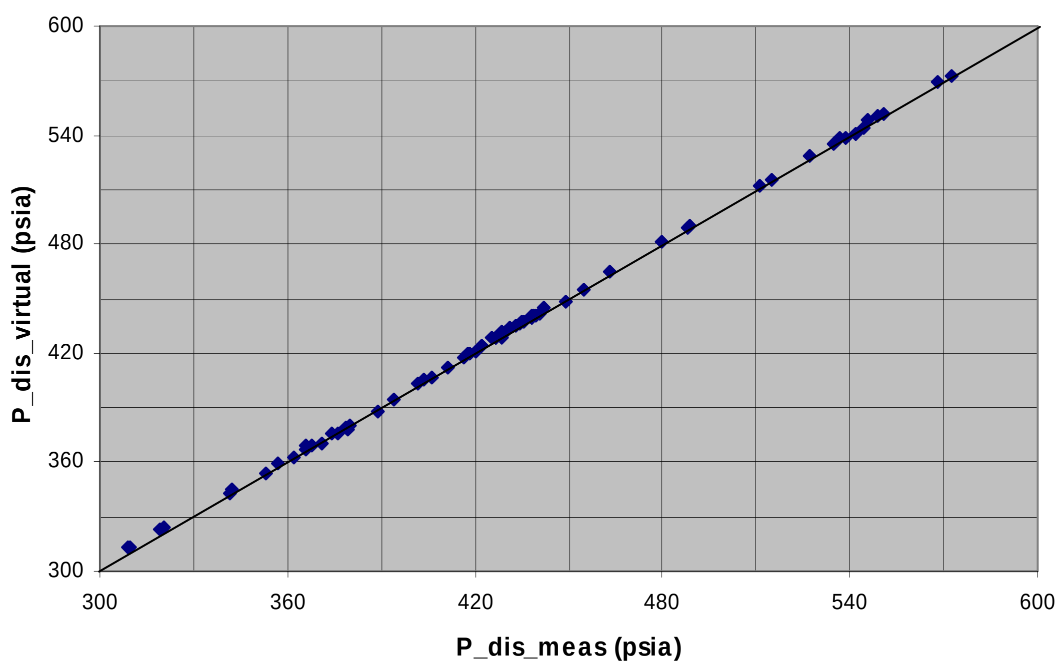
Temperature-Only Diagnostics

- Use virtual pressure sensors → saturation pressure associated with temperature sensors mounted to return bends in evaporator and condenser
  - Non-invasive measurement → reduces problems associated with installation of pressure sensors (particularly important for embedded solutions)
  - Reduces cost → could permanently install sensors
  - Sensor location is critical
- Validated for multiple units in the laboratory
- Currently being evaluated in the field

Temperature-Only Diagnostics

Virtual Pressure Sensor Accuracy

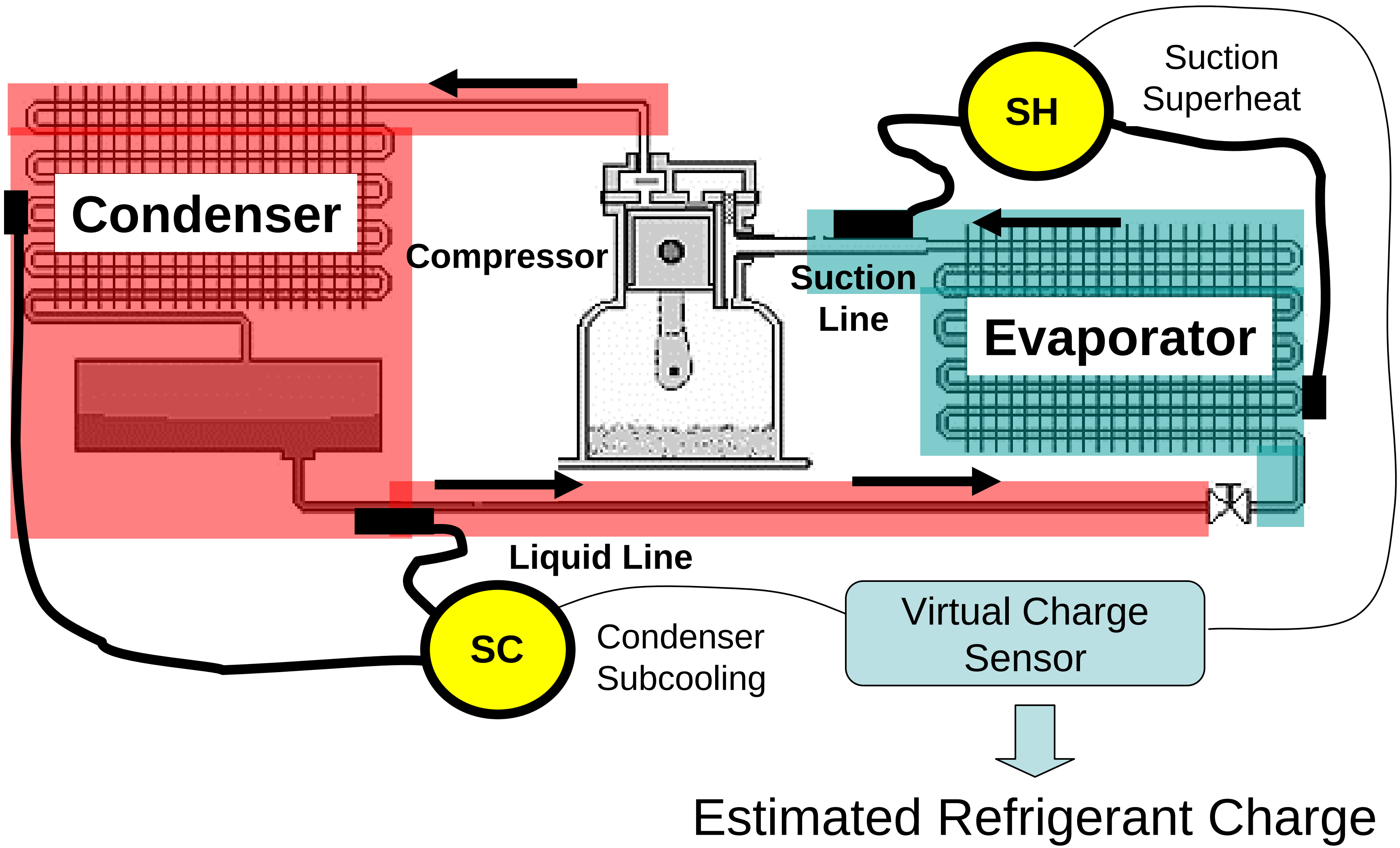




Decoupled Features & Virtual Sensors

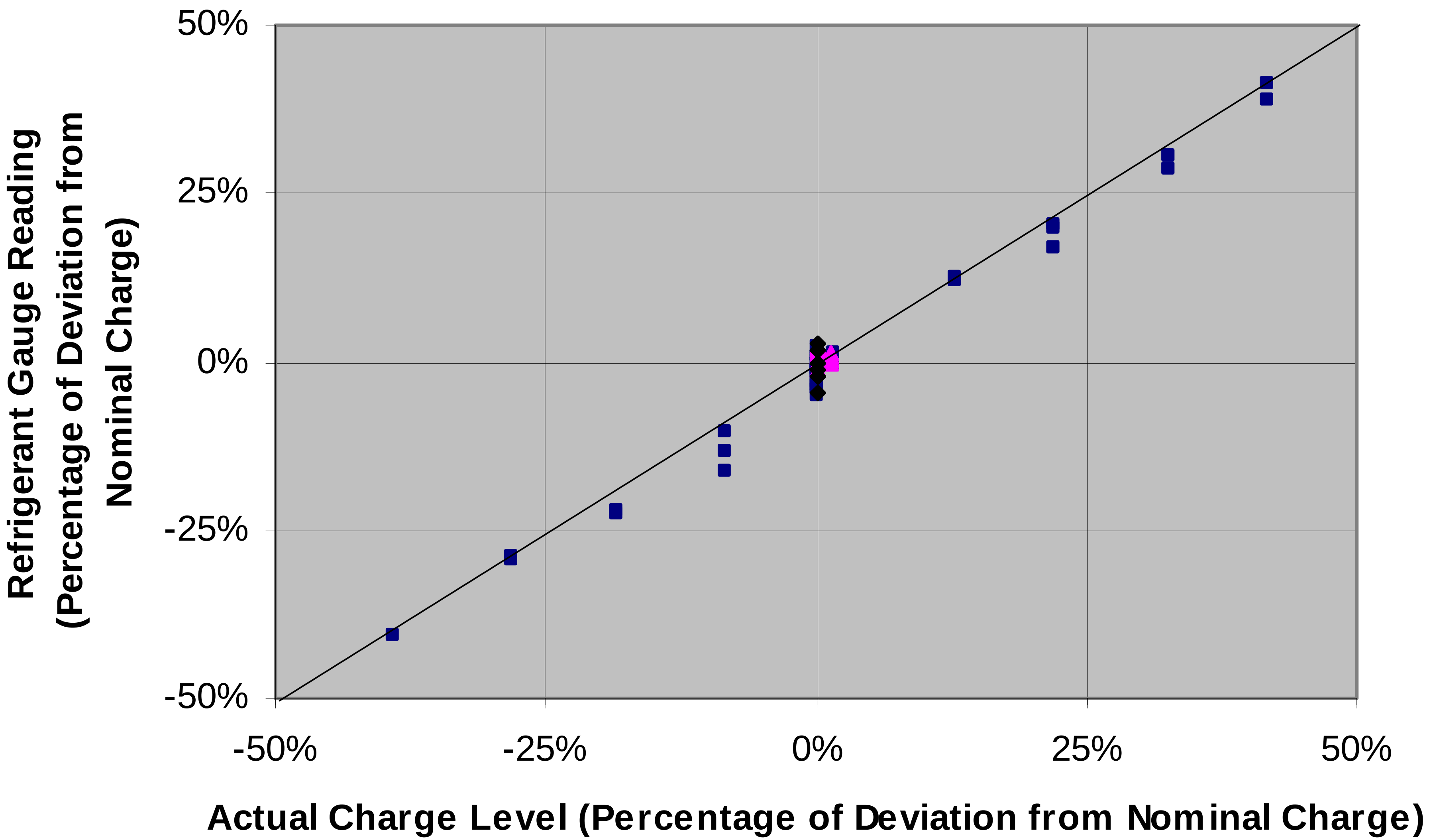
- Use diagnostic features that only depend on individual faults (decoupled from other faults)
  - Air flow → evaporator or condenser fouling/fan problems
  - Refrigerant flow → compressor or liquid-line problems
  - Refrigerant charge → leakage or inadequate service procedure
- Use virtual sensors → infer flows or other quantities from a simple model using low-cost measurements
- Rationale
  - Handles multiple simultaneous faults
  - Provides meaningful measure of magnitude of fault
  - Potential for eliminating ambient dependence

Virtual Refrigerant Charge Sensor



Virtual Charge Sensor Demonstration

Virtual Charge Sensor Performance



Other Virtual Sensors

- Compressor power → compressor map with virtual pressure and actual temperature measurements
- Refrigerant flow → compressor map and/or energy balance with virtual pressure and actual temperature measurements
- Cooling capacity → energy balance with virtual refrigerant flow, virtual pressure, and actual temperature measurements
- EER → from capacity and power
- Condenser air flow → energy balance with virtual refrigerant flow, virtual pressure, and actual temperature measurements
- Evaporator air flow → energy balance with virtual refrigerant flow, virtual pressure, and actual temperature and humidity measurements

Cost Impacts of Service

- Estimate economic impact of faults
  - Increased energy and demand due to loss in efficiency and higher latent load
  - Reduced equipment life due to greater run time (lower capacity)
- Estimate payback for service
- Could use representative models for fault impacts
  - Expected capacity and power for normal operation
  - Time variation in loads and ambient conditions
  - Local utility information

NEW PROTOCOLS?

- MIXED-AIR TEMPERATURE AVERAGING
- ECONOMIZER DIAGNOSTICS
- VIRTUAL PRESSURE SENSORS
- DECOUPLED FEATURES & VIRTUAL SENSORS
- EVALUATE COST IMPACTS OF SERVICE