Comments and Recommendations for Saturation Temperature Measurement Sensors (STMS)

Subtask 2.1D

Work Authorization # 6
Contract #400-09-001
Covering Tasks 3 Subtask 2

2013 RESIDENTIAL BUILDING ENERGY EFFICIENCY STANDARDS

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1. Administration

1.1. Objectives

1.1.1 Define revised requirements for Saturation Temperature Measurement Sensors (STMS) to be included as part of the refrigeration charge verification requirements.

1.1.1.1 The measure will be applicable to new systems. It will not apply when refrigeration charge verification is required for existing or retrofit systems unless a new outdoor unit is installed.

1.1.1.2 The measure will not be required when a Charge Indicator Display (CID) is provided.

1.1.2 The STMS will provide a means for a HERS rater to determine refrigerant saturation temperatures at the liquid line (condenser exit) and suction line (compressor inlet) which is non-intrusive from the perspective of the HERS rater, i.e., the HERS rater will not be required to attach pressure gauges to the systems.

1.1.3 The STMS system will include a means of data access for the user (technician or HERS rater).

1.1.4 The STMS system shall be factory installed on the outdoor unit or field installed in accordance with the requirements of the outdoor unit manufacturer.

1.2. Comments on Objectives

1.2.1 The required accuracy of the measurements needs to be defined.

1.2.1.1 This should include the identification of the measurement range and should consider the cost of corresponding sensors.

1.2.1.2 The current standard has a requirement for accuracy of refrigerant saturation temperature measurement of ±1.3°F but does not specify over what measurement range this accuracy is required.

1.2.2 The data access requirements need to be defined and should consider possible manufacturer solutions and existing approaches. There may be issues with having a visual display at the outdoor unit with regards to visibility in direct sunlight and resistance to outdoor conditions (temperature, humidity, etc.).

1.2.3 The manufacturers will most likely oppose a requirement for pressure sensors because of the possibility of system leaks; however, manufacturers have been using pressure switches for control and safety functions. The manufacturers are also likely to have a concern about the cost.

1.3. Consultant Tasks

1.3.1 Submit questions to CEC

1.3.2 Investigate current OEM pressure sensors including accuracy and approximate cost. Complete brief analysis for accuracy of saturation temperature versus accuracy of pressure measurement for R410a. Two sensor manufacturers have been identified.

1.3.3 Define performance requirements for measurements: required parameters, accuracy, measurement range, etc.

1.3.4 Define user interface requirements. Identify possible manufacturer approaches.

2. Background Research and Information

2.1. Questions for the CEC

2.1.1 What information is required to be available to the technician? Is it desirable to provide refrigerant saturation temperature or refrigerant pressure? Would either be acceptable? Is the primary objective to evaluate superheat and subcooling?

2.1.1.1 CEC response: yes the primary objective is to evaluate the superheat and subcooling, thus ultimately the saturation temperature is needed as determined by the pressure measurement and the refrigerant properties. Either refrigerant pressure or saturation temperature (or both) would be acceptable outputs as long as it was clear to the technician what the readout meant.

2.1.2 What forms of data access or user interface would be acceptable? A visual display may be the simplest for the user, but would likely provide a cost burden for the manufacturer. Manufacturers would probably prefer to provide some communications connection means that the technician would access with the appropriate tool. This could be a physical electrical connector or a wireless connection.

2.1.2.1 CEC response: A physical electrical connector or wireless connection would be acceptable or preferable if it could be specified to be a standard product useful for any/all of the installations of these pressure measurement devices and could also interface with some commonly available handheld digital display or datalogger instruments to read the output without having to perform a calibration of the interface. It would not be desirable to expect a field technician or HERS rater to have to accumulate many different types of interface tools to access information from many different types of data access technologies. Perhaps the cost of a tool(s) that a HERS rater would need to acquire should be comparable to the cost of a digital gage instrument. The visual display option should be considered acceptable if the manufacturers prefer it, however, if data access was not also provided, the visual display option may not be as desirable since diagnostic processes could benefit from data logging capability.

2.1.3 Is it desirable to allow field installation of the feature (in accordance with the requirements of the equipment manufacturer)?

2.1.3.1 CEC response: yes making field installation available would make the technology more available for more installations. Followup question (1): do you have an opinion or recommendation to the effect that we should not allow field installation? if so why (e.g. cannot control quality; might void manufacturer warranty; etc.). Followup question (2): If we determine to allow field installation, would it be reasonable to propose a default installation specification for the case when the manufacturer has not provided instructions for installation of the technology?

2.1.3.2 Consultant response: I have some reluctance to allow field installation of sensors because of quality control issues, in particular the possibility of a system leak if pressure sensors are installed. However, I would leave it to the manufacturers to determine if this is acceptable for their product and to provide the appropriate instructions. I do not think the standard should provide a default installation specification for several reasons. I do not think that a default saturation temperature sensor location can be defined that would be applicable to the variety of coil configurations. There are associated issues like the correction for pressure drop between the sensor location and the point where superheat or subcooling is being evaluated. There would also be issues with a default specification for pressure sensors include the appropriate mounting to address vibration issues and avoid possible refrigerant leaks.

2.1.4 Is it acceptable to define the requirement as a performance specification based on providing refrigerant saturation temperature corresponding to each of the two locations in the system? This would allow the manufacturers the opportunity to determine how this is accomplished (pressure sensors or other).

2.1.4.1 CEC response: this seems reasonable. Please tell me more about what you understand this potential to be. Perhaps we could consider specification of

direct pressure measurement as a starting point, then provide language that allows approval of alternatives based on staff review of the technology, and recommendations to the Executive Director.

2.1.5 What are the cost criteria for evaluation of this requirement?

2.1.5.1 CEC response: I will try to develop a response to this question by discussing with colleagues and managers, then respond in a separate message. My first reaction is to suggest that a ballpark cost to the consumer should be comparable to the present cost we impose upon this transaction (technology first cost + field technician(s) labor vs efficiency benefit for the life of the installation). I am not sure how to quantify that for you at this moment.

2.2. Current Title 24 Requirements (2008)

2.2.1 2008 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (December 2008, CEC-400-2008-001-CMF) Section 151 (f)

7. Space heating and space cooling. All space heating and space cooling equipment shall comply with minimum Appliance Efficiency Regulations as specified in Sections 110 through 112 and meet the requirements of subsections A and B:

A. When refrigerant charge measurement or charge indicator display is shown as required by TABLE 151-B , TABLE 151-C or TABLE 151-D, ducted split system central air conditioners and ducted split system heat pumps shall:

i. Have temperature measurement access holes (TMAH**) saturation temperature measurement sensors** (STMS), and proper refrigerant charge confirmed through field verification and diagnostic testing **in accordance with** procedures set forth in the Reference Residential Appendix RA3.2; or

ii. Be equipped with a charge indicator display (CID) clearly visible to the occupant. The display shall demand attention when the air conditioner fails to meet the requirements contained in Reference Joint Appendix JA6.2. The display shall be constantly visible and within one foot of the thermostat. Systems equipped with a CID shall meet the requirements of Residential Field Verification and Diagnostic Test Procedures of Reference Residential Appendix RA3.4 and the specifications of Reference Joint Appendix JA6.

2.2.2 Reference Appendices (December 2008, CEC-400-2008-004-CMF, Revised June 2009) Residential Appendix RA3

RA3.2.2.3 Refrigerant Gauges and Saturation Temperature Measurement Sensors (STMS)

A refrigerant gauge with an accuracy of plus or minus 3 percent shall be used. As an alternative, **two saturation temperature measurement sensors** (sensors) shall be placed in a manner and location determined by the equipment manufacturer as measuring the saturation temperature of the refrigerant in the evaporator coil and in the condenser coil within 1.3°F. These sensors shall be permanently mounted and have standard temperature sensor mini plugs accessible to the installing technician and the HERS rater without changing the airflow through the condenser coil. Other saturation temperature measurement sensor instrumentation methodologies shall be allowed if the specifications for the methodologies are approved by the Executive Director.

3. Analysis

3.1. Comments on Current Title 24 Requirements (2008)

3.1.1 2008 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (December 2008, CEC-400-2008-001-CMF) Section 151 (f)

3.1.1.1 None

3.1.2 Reference Appendices (December 2008, CEC-400-2008-004-CMF, Revised June 2009) Residential Appendix RA3

3.1.2.1 Section RA3.2.2.3 indicates that the sensors should have "mini plugs accessible to the installing technician and the HERS rater." There is no standard referenced in the document for the “mini plugs” or the sensor technology and associated method for interpreting the sensor signal. The only industry “standard” temperature sensor that could be identified is the thermocouple which has different types. The technician would need to know what type of thermocouple the manufacturer used (Type K, Type T, etc.) and have the corresponding device to read the thermocouples.

3.1.2.2 The sensor requirement does not appear to address the difference in refrigerant saturation temperature that occurs between points in the system due to refrigerant pressure difference. Fundamentally the saturation temperature at a point on the coil will be different than the saturation temperature at the exit of the coil and would result in a different calculated superheat or subcooling (without a correction). There is no indication of how this would be addressed such that the technician could use the measurement in the field to calculate an accurate superheat or subcooling value for comparison to the target value.

3.1.2.3 It is questionable if a manufacturer could reasonably comply with the requirement for saturation temperature measurements "within 1.3°F" when sensor uncertainty and sensor location error are considered. Additionally, the standard does not indicate under what operating conditions this requirement must be satisfied.

3.2. Pressure Sensor Data

3.2.1 Several applicable refrigerant pressure sensors were investigated to provide information on current sensor accuracy and costs. The sensors are identified below.

3.2.2 Sensata Technologies

3.2.2.1 2CP5/2CP50 Series HVAC/Refrigeration Pressure Sensor

3.2.2.1.1. Ceramic capacitive sensor

3.2.2.1.2. Total error band ±1.0% of full-scale

3.2.2.1.3. Pressure ranges 150, 200, 300, 400, 500 psi

3.2.3 Kavlico

3.2.3.1 P528 Refrigeration Pressure Sensor

3.2.3.1.1. Ceramic capacitive sensor

3.2.3.1.2. Total error band ±2.0% of full-scale

3.2.3.1.3. Pressure ranges 100, 150, 300, 400, 500 psi

3.3. Sensor Analysis

3.3.1 A brief sensor analysis was prepared for refrigerant pressure sensors to investigate the relationship between pressure measurement error and the associated error in calculated refrigerant saturation temperature. The analysis was made for refrigerant R410a. The data are presented in Table 1 for a range of suction pressures and in Table 2 for a range of liquid line pressures.

3.3.2 A sensor accuracy of ±2.0% of full-scale or better would be required to limit the error in saturation temperature to less than 1.8°F for the suction saturation temperature and 2.6°F for the liquid line saturation temperature (2.0°F maximum error at higher outdoor operating temperatures).

3.4. User Interface

3.4.1 No applicable industry standards could be identified that could be adopted for specifying a user interface. In particular, a digital interface would be desirable for data transfer. It is possible that there is a standard interface used in the automotive industry or another industry that could be adopted. These were not investigated.

3.5. Cost Analysis

3.5.1 A rough cost estimate was prepared for a STMS system using pressure sensors and including the necessary user interface. A cost for 2% total error pressure sensors was obtained from a sensor manufacturer based on an annual quantity of 5000 units. The microprocessor based analysis module with interface may not be required for outdoor units that have a control board.

3.5.2 The cost estimate is presented in Table 3 and based on the rough estimate of $105.30, it is estimated that the manufacturer's cost to add the feature would likely be between $50 and $150.

3.6. Field-Installed Option for Saturation Pressure Measurement – Comments and Discussion

3.6.1 There are three areas of concern associated with a field-installed option for refrigerant pressure sensors if based on guidelines provided by the standard as opposed to those provided by the equipment manufacturer: a) sensor location and mounting, b) sensor power and signal processing, and c) possible voiding of manufacturer's warranty.

3.6.2 Sensor location and mounting: Without specific manufacturer provisions, the most feasible location for field-installed pressure sensors is at the unit service ports. Cutting into the refrigerant piping of the outdoor unit to install fittings for the pressure sensors would be expensive and there may not be adequate space within the unit. Providing a tee fitting at each of the service ports would allow mounting the pressure sensors and still allow connection of a service hose. This would locate the sensors outside of the outdoor unit enclosure and would expose them to the weather and potential damage including vandalism. Without additional support the stress on the fittings due to vibration and the sensor weight may result in leaks over time. It is not clear if the manufacturers would object to this installation.

3.6.3 Sensor power and signal processing: The pressure sensors require a power supply (typically 5V DC) and signal processing to convert the output signal to engineering units and communicate information to the installer (technician). This consultant is not aware of an off-the-shelf component that would provide these functions. These functions could potentially be provided by a microprocessor-based controller that the manufacturer would likely provide in a heat pump or an air conditioner with variable speed control. There may not be adequate space in the control section of the unit if the manufacturer does not plan for this feature.

3.6.4 Possible voiding of manufacturer's warranty: Cutting into the system to install fittings would most likely void the manufacturer's warranty. Attaching fittings to the service ports may also result in voiding the manufacturer's warranty.

3.6.5 Refer to 4.2.8 for recommendation regarding a field-installed option.

4. Proposed Title 24 Requirements

4.1. 2008 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (December 2008, CEC-400-2008-001-CMF) Section 151 (f)

4.1.1 In paragraph 7.A.i replace the requirement for "saturation temperature measurement sensors (STMS)" with requirement for "permanently installed sensors for determination of the refrigerant saturation temperature at the condenser outlet and the compressor suction" (or alternate language).

4.1.2 The requirement for sensors for determination of refrigerant saturation temperatures will be applicable to existing or retrofit systems only when refrigeration charge verification is required and a new outdoor unit is installed.

4.2. Reference Appendices (December 2008, CEC-400-2008-004-CMF, Revised June 2009) Residential Appendix RA3, section RA3.2.2.3

4.2.1 Revise the name of section RA3.2.2.3 to be consistent with the language used in the Building Energy Efficiency Standards, Section 151 (f), paragraph 7.A.i.

4.2.2 Require permanently installed pressure sensors for measurement of refrigerant pressures and determination of the refrigerant saturation temperature at the condenser outlet and the compressor suction.

4.2.3 Other refrigerant saturation temperature measurement sensor instrumentation methodologies shall be allowed if the specifications for the methodologies are submitted by the equipment manufacturer and approved by the Executive Director. Saturation temperature measurement methods shall have a minimum accuracy of ±2.0°F including sensor accuracy.

4.2.4 Pressure sensors (transducers) used for measurement of refrigerant pressure to determine refrigerant saturation temperature shall have a minimum accuracy of ±2% of the sensor full-scale value.

4.2.5 A user interface shall be provided such that the installer or technician shall be able to obtain the current operating values of the measured refrigerant pressures or

refrigerant saturation temperatures. The user interface shall provide access to the data without the need for special tools or devices.

4.2.6 Identify the required operating range over which measurement accuracy must be maintained:

4.2.6.1 65°F ≤ (Outdoor air dry-bulb temperature) ≤ 115°F
4.2.6.2 70°F ≤ (Return air dry-bulb temperature) ≤ 84°F
4.2.6.3 50°F ≤ (Return air wet-bulb temperature) ≤ 76°F

4.2.7 Sensors for measuring refrigerant pressure or other sensors associated other methodologies shall be installed in accordance with instructions provided by the manufacturer of the outdoor unit.

4.2.8 Recommendation on field-installed pressure sensors: Only allow field installation of pressure sensors in accordance with guidelines provided by the equipment manufacturer and for the specific model. (Refer to discussion in Section 3.6.)

Table 1. Suction Refrigerant Pressure Analysis: R410a, 2% error and 200 psi full-scale sensor

Pressure (psig)	Dewpoint Temperature (F)	Temperature Error (F)	Notes
110	36.4	1.80	
120	40.9	1.70	
130	45.1	1.61	
140	49.1	**1.54**	
150	53.0	1.47	
160	56.6		

Table 2. Liquid Refrigerant Pressure Analysis: R410a, 2% error and 500 psi full-scale sensor

Pressure (psig)	Bubble Temperature (F)	Temperature Error (F)	Notes
250	83.8	2.58	
260	86.4	2.52	
270	88.9	2.44	
280	91.4	2.39	
290	93.8	2.32	
300	96.1	2.27	

Pressure (psig)	Bubble Temperature (F)	Temperature Error (F)	Notes
310	98.4	2.22	
320	100.6	2.17	
330	102.8	2.12	
340	104.9	2.07	
350	106.9	2.04	
360	109.0	1.99	
370	111.0	1.95	
380	112.9	1.91	
390	114.8	1.88	
400	116.7	1.84	
410	118.6	1.81	
420	120.4	1.77	
430	122.1	1.75	
440	123.9	1.71	
450	**125.6**	**1.69**	
460	127.3	1.65	
470	128.9	1.64	
480	130.6	1.60	
490	132.2	1.58	
500	133.8	1.56	
510	135.3		

Table 3. Estimated STMS System Cost (Pressure Sensors)

Component	Quantity	Unit Material Cost	Unit Installation Cost	Total Cost	Notes
Refrigerant line fitting	2	0.50	10.00	21.00	
Refrigerant pressure sensor (2% error)	2	21.40[1]	5.00	52.80	
Wiring harness	2	0.75	5.00	11.50	
Microprocessor based analysis module and interface	1	15.00	5.00	20.00	
Total				$105.30	

5. References

5.1. Pressure Sensor Data

5.1.1 Sensata Technologies: www.sensata.com

5.1.2 Kavlico: www.kavlico.com

6. Correspondence

6.1. June 8, Message A

From: Jeff Miller <Jmiller@energy.state.ca.us>
To: Keith Temple <ktemplepe@aol.com>
Subject: Re: RWA06 Temple Task 2.1
Date: Wed, Jun 8, 2011 12:47 pm

Keith,
Essentially, we would remove any STMS language in RA3.2 and 151(f)7, and place a new appendix in JA to specify the new technology as we have done for CID in JA6, then revise **151(f)7Ai** to say (draft language follows):

... i. Have temperature measurement access holes (TMAH) installed according to the specifications in Reference Residential Appendix RA3.2.2.2.2; digital refrigerant pressure measurement devices (RPMD) that meet the requirements of Reference Joint Appendix [JA#tbd] that are installed permanently by the air conditioning equipment manufacturer or according to the air conditioning equipment manufacturer specifications to provide digital indication of the condenser saturation pressure and the evaporator saturation pressure; and proper refrigerant charge confirmed through field verification and diagnostic testing in accordance with procedures set forth in the Reference Residential Appendix RA3.2; or ...

[1] Price estimate from sensor manufacturer based on annual quantity of 5000 units

The concept is to create an opportunity for a HERS rater to determine the saturation temperatures of both high side and low side using the permanently installed device that provides a digital indication of the saturation pressures. The Rater would not need to hook up his own gages. The details for the spec are not developed, thus your knowledge of how that might best be accomplished would be really helpful. Or if you see this as a problematic proposal, any kind of feedback to that effect will be welcome too.

If you want to have a phone chat about this let me know.
jeff

>>>
From: Keith Temple <ktemplepe@aol.com>
To: <Jmiller@energy.state.ca.us>
Date: 6/8/2011 8:02 AM
Subject: Re: RWA06 Temple Task 2.1

Jeff,
You indicated in your message the following: "But I have been asked to investigate the possibility that we could substitute a requirement for installation of pressure sensing instrumentation (either at factory or in the field) that could provide the same utility for non-intrusive saturation temperature measurement, that would remain as a permanent part of the system."
Is this what you meant to write? Any refrigerant pressure measurement would be considered intrusive and be a potential opportunity for a leak in the system. As I understand, there are manufacturers using pressure sensors and pressure switches have been used for many years. There are manufacturers who make a combination pressure and temperature sensor that could potentially be used for this application.
Is the intent to have a mandatory requirement for new systems?
RA3.2.2.3 indicates STMS as an "alternative". Section 151 (f) 7 of CEC-400-2008-001-CMF seems to indicate this as a requirement.
What is the objective of this requirement?

Keith Temple

6.2. June 8, Message C

From: Jeff Miller <Jmiller@energy.state.ca.us>
To: Keith Temple <ktemplepe@aol.com>
Subject: Fwd: EFFICIENCY-LIST: Notice of postponement of the June 14, 2011, Staff Workshop on Draft Revisions for
Residential and Nonresidential Buildings for Possible Inclusion in the 2013 Building Efficiency Standards
Date: Wed, Jun 8, 2011 8:21 pm

Hi Keith,
the June 14 workshop has been postponed (see string below). So this gives more time to prepare and distribute your comments and suggestions, and you don't need to stress about getting your comments/suggestions completed prior to the 14jun date. But I should urge you to continue pushing forward with your work so that we can get your contributions engaged in the preparation of the Staff recommendations asap.

I think clarifying the alternative to STMS (permanently installed digital pressure measurement device) is a significant priority for Staff proposals, and the other Tech contractors have not done work on that yet. So at this point you could be our technical consultant lead for helping us with clarifying the specifications for that feature

if you are agreeable to taking on that task, and if you feel it is a viable option. The first cost will be a significant consideration.

I will be out of the office on Friday, so if we are going to get together via phone it will have to be tomorrow thursday09jun or monday13jun, or sometime next week. Let me know when you are available and I will coordinate with you for a phone conversation.
jeff

6.3. June 15 Message

From: Jeff Miller <Jmiller@energy.state.ca.us>
To: Keith Temple <ktemplepe@aol.com>
Subject: Fwd: Re: RWA06 Temple Subtask 2.1 - Status
Date: Wed, Jun 15, 2011 9:34 pm

STMS/digital pressure gages:
I chatted with Mazi today on the cost criteria topic=> he said that we should rely on you to **identify the least cost technology that is available that is of sufficient quality to provide the required service**. That should include the most simplistic data interface. He suggested that if this feature is a substitute for pressure gages, then the most simple output might be gage pressure (only). Then this minimal cost package of sensors and processor and data interface would be subjected to an economic evaluation that might involve digging into history documentation to determine the basis for the justification of cost effectiveness when the refrigerant charge verification requirement was first introduced. Is that enough guidance on the cost criteria?

more feedback later
jeff