CALIFORNIA
TECHNICAL FORUM

Subcommittee Recommendations: Residential HVAC Quality Installation Performance Parameter Data Sources

June 2015

Document Overview

This document details the recommendations from the Cal TF subcommittee regarding the best sources of information and data to inform Southern California Edison's Residential Quality Installation workpaper. This subcommittee convened five times over the course of April, May, and June 2015 via teleconference to discuss the performance parameters and data sources presented in Section 4 of this document. This document includes the following sections:

1. Subcommittee Objective Overview
2. Summary of Data Source Recommendations
3. Discussion of Recommendations
    - Recommended baseline values and source(s)
    - Recommended measure values and source (s)
    - Other sources considered – discussion of why the source was not selected
    - Other comments for future consideration – concerns raised during the course of subcommittee discussion suitable for a future phase of subcommittee review pending Cal TF approval of future topics.

1. Subcommittee Objective Overview

The objectives of the Residential HVAC Quality Installation subcommittee were to:

- Identify applicable data sources, including but not limited to Work Order 32, to inform the Residential HVAC Quality Installation performance parameters identified in the subcommittee summary.
- Discuss the suitability of each data source for informing the performance parameters.
- Select the most appropriate data source(s) for each performance parameter, with justification for each selection.

2. Summary of Data Source Recommendations

Table 1 below summarizes the recommendations from the Residential HVAC Quality Installation Subcommittee.

Table 1. Subcommittee Recommendations for Residential Quality Installation Data Sources

Evaluated Parameter	Baseline Value	Measure Value	Data Sources
Duct Leakage (%)	29.7%	10.5%	• Baseline value derived from a weighted average of 2014-2015 Res QI Program data and Title 24 maximum leakage allowance, weighted by % unpermitted and % permitted projects, respectively • Measure value derived from 2014-2015 Res QI Program Data
Equipment Sizing (%)	13.9%	0%	• % oversized baseline derived from pilot data based on a subset of Res QI program participating contractors (32 projects total)
Airflow Performance (W/CFM)	0.57	0.37	• Baseline value taken from CPUC HVAC Impact Evaluation (Work Order 32) • Measure value derived from 2014-2015 Res QI program data
Airflow capacity (CFM/Ton)	300	350	• Baseline value taken from CPUC HVAC Impact Evaluation (Work Order 32) • Measure value based on Title 24, within the range of Work Order 32 findings (338 CFM/ton) and findings from a Proctor Study (approximately 388 CFM/ton) – see section 3.4.1
System Efficiency	Title 24 (ROB)	DEER	• Measure efficiency based on DEER
Refrigerant Charge Adjustment (RCA)	-	-	• RCA considered compliant with Title 24

3. Discussion of Recommendations

3.1. DUCT LEAKAGE (%)

3.1.1. Recommendations

Table 2. Subcommittee Recommendations for Duct Leakage

Duct Leakage	Baseline	Measure
Value (% leakage)	29.7%	10.5%
Source	Residential Quality Installation 2014-2015 Program Data, Title 24, DNV GL Permitting Study	Residential Quality Installation 2014-2015 Program Data,

Baseline

The subcommittee recommends that baseline duct leakage rates be informed by the following sources, which in combination constitute the best available information: duct leakage data measured through the SCE's Quality Installation program in 2014 and 2015[i] (see Appendix A,

[i] 2014-2015 Residential Quality Installation program data; total duct leakage was measured using the "Minneapolis duct blaster" for virtually all jobs. The DuctBlaster method is standard industry practice. Duct leakage measured at 25 Pa. The average measured duct leakage prior to QI implementation of 1,024 jobs was 38.73%. The average measured duct leakage post QI measure implementation of 2,406 jobs was 10.51%. See Appendix A, item 1.

item 1), Title 24 maximum allowable duct leakage rates[1], and a residential permitting compliance study[2] implemented by DNV GL and commissioned by PG&E.

The baseline represents the system retrofit that would have taken place in the absence of the Quality Installation incentive program. In this case, 62% of system retrofits would not be permitted, and the remaining 38% will be permitted based on a DNV GL study commissioned by PG&E. Based on the collective professional experience in residential HVAC, the subcommittee believes that unpermitted system retrofits will most likely replace "like for like" and result in little to no change to the system's duct leakage. Therefore portion of unpermitted system retrofits should be represented by the average existing (or "test-in") duct leakage measured prior to program intervention (38.73% leakage per the 2014-2015 program data). The portion of permitted system retrofits should be represented by the Title 24 maximum duct leakage allowance (15% leakage). These two values should be weighted together based on the DNV GL study permit rate of 38% to produce a weighted average permitted leakage rate for the baseline.

The Res QI program requires compliance with the Title 24 maximum duct leakage allowance of 15%, however the measure duct leakage rate is assumed to be lower than 15% (unlike the baseline) because the program requirements for contractor intervention are more stringent than contractor standard practice and typically result in duct leakage below 15%.

Measure

The measure case will be represented by the 2014 and 2015 duct leakage program data[Error! Bookmark not defined.] measured after program intervention. The program data, comprised of a large sample size of over 2,400 customer sites for post-program intervention measurements, is considered the best available.

Limitations of the data

- Data representativeness: The Res QI program data is focused on the southern California region and may not be representative of Northern California homes. Other data sources should be explored in the future that may provide duct leakage estimates that are more representative of statewide values. The Energy Upgrade California (EUCA) data may be usable if weighted by vintage according to RASS weights.
- Several DEER assumptions are not supported by studies or other evidence and should be vetted, including a) the split between leakage to unconditioned space (75%) and conditioned space (25%), b) infiltration, c) outside air, and d) modeling all systems in the attic instead of other possible locations (such as the crawl space).
- The DuctBlaster leakage measurement use of 25 Pa reference pressure may not be representative of actual pressures across leaks during normal operation.
- Permitting rate values: The subcommittee considers the DNV GL study to be limited in terms of its statistical reliability and representativeness of anecdotal field observations. More robust studies for permitting compliance rates should be considered for future workpaper revisions. Should a CPUC-sponsored evaluation of the residential HVAC permitting compliance rate be available later this year, that study should be considered for use in the workpaper. Some possible options for evaluating permitting in long term by the program team include:
    1. Comparing equipment sales data from manufacturers to permits issued, based on region

2. Get data from HERS raters doing the compliance reporting: inspections done annually multiplied by air conditioning saturation, compared with replacement rate of homes with air conditioning.

3.1.2. Other Sources Considered

Work Order 32[3]

Work Order 32 is not considered to be the best available information compared to the 2014-2015 Res QI program data for the following reasons:

- Work Order 32 leveraged a sample size 50 program participants and 50 non-participants, while program data leverages a sample size of between 1,000 and 2,400 (for leakage rates pre- and post- program intervention, respectively).
- Separate groups were selected to represent "pre" and "post" program treatment conditions (program nonparticipants and participants, respectively) instead of a single customer group evaluated prior to and after program treatment. The duct leakage of the nonparticipant group was selected to represent the baseline leakage while the leakage of program participants represented the measure leakage. The IOU program data demonstrates the leakage reduction for individual customers based on Res QI program intervention, and therefore the results are more representative of leakage reductions that will be achieved by the Res QI program.

Summary of Work Order 32 findings for duct leakage:
Baseline (non-participants): 16.6%
Measure (participants): 11.5%

DEER[4]

The DEER model assumption for the duct leakage measure is 24% leakage for the baseline and 12% leakage for the measure, however the basis of the DEER assumptions could not be vetted due to lack of documentation.

Mowris, Robert, Jones, Ean, and Eshom, Robert[5]

(Laboratory Measurements and Diagnostics of Residential HVAC Installation and Maintenance Faults)
This ACEEE paper presents the results of a laboratory study of a new 13-SEER split-system air conditioner test unit, with simulated installation and maintenance faults. This study demonstrates the performance losses due to installation and maintenance faults and does not provide empirical results from a real-world sample for performance parameters that would feed into the workpaper. Therefore this is not considered an appropriate data source for this workpaper.

3.1.3. Other Comments for Future Consideration

- The modeling methodology should be evaluated for potential alternatives to DOE2; the DOE2 calculations do not model energy savings correctly in some cases. The following should be considered:
    - The DEER DOE2 building prototype outputs for duct leakage should be compared to ASHRAE Standard 152.
    - The impact of variable speed fans on duct leakage
    - Laboratory efforts pursued by a) EPRI, Davis, PG&E, and b) SCE.

    - The impact of continuous fan operation on duct leakage
- Other duct leakage measurement methods besides the DuctBlaster test should be explored that may capture leakage rates more accurately, including a technique included in the new ASRHAE standard for commercial buildings that may be suitable for residential. See Appendix A under item 2.
- Tom Eckhart (TF Member) asserts that an impact evaluation should be pursued to demonstrate a statistically supported correlation between energy savings and duct leakage reduction strategies currently employed by the California IOUs. Because no impact evaluations appear to be available to support the savings claims, Tom asserts there is a need to conduct an appropriate impact evaluation to address this matter. The basis for his recommendation is:
    - No field study currently demonstrates there to be a correlation between IOU duct leakage reduction strategies and utility bill savings.
    - The Bonneville Power Authority has reduced rebates the past year for all duct seal measures in residential buildings and the Northwest Regional Technical Forum reduced approved energy savings for this measure.

3.2. EQUIPMENT OVERSIZING (%)

3.2.1. Recommendation

Table 3. Subcommittee Recommendations for Equipment Oversizing

Equipment Oversizing	Baseline	Measure
Value (% oversized)	13.9%	0%
Source	Residential Quality Installation Pilot Program Data, based on a subset of Res QI participating contractors	-

Baseline

The subcommittee recommends that Residential Quality Installation pilot program data[ii] be used to inform the equipment oversizing assumption of about 13.9% for the workpaper. This analysis is considered to reasonably the best available information for a rough estimate of system oversizing, but a more robust analysis with a larger sample size and statistical analysis should be pursued in the long term. The measure data and an accompanying description are included in Appendix A, item 3.

Limitations of the analysis

- The analysis reflects an older version of Manual S didn't delineate between variable and multi-speed requirements. The new version of Manual S allows for a different percentage oversizing depending on the type of type of equipment (i.e., single stage, variable flow).
- As EE programs push for higher SEER efficiencies, end up with variable stage/ multiple flow which complicates nominal tonnage, as well as run time, etc.
- Sample size is 32 and no statistical analysis was performed.

[ii] Pilot data based on a subset of contractors participating in the Res QI program. Sample size was 32. Installing contractor tested both the existing system and new replacement system using an NCI test method to capture overall system efficiency. For more details on pilot program and data characteristics, see Appendix A, item 3.

- The pilot measurements/testing was done by better contractors who are more proactive about learning about system performance than other contractors

3.2.2. Other Sources Considered

Work Order 32[3]

Work Order 32 is not considered to be the best available information compared to the pilot program data analysis due to the Work Order 32 evaluation methodology, despite the program data limitations. Unlike the program pilot data which used the Manual S procedure to compare equipment sizes pre- and post- program intervention (allowing for a comparable comparison based on design capacity), Work Order 32 did not perform the Manual S procedure on the control group which represents pre-program intervention conditions. Rather, they used the sensible heat ratio (SHR) value of the load to determine size based on AHRI rating capacity as an absolute value compared to load and they did not replicate this method for the test group (QIV projects) to compare the results of the contractors Manual S procedure to the load SHR. Manual S requires determining the system capacity at design load, not AHRI rating. Work Order 32 did not properly address the Manual S procedure to differentiate the process of Manual S equipment selection from the non-participant control group. Furthermore, there is no data to show what was installed the participant group's sites prior to change-outs, so we don't know the real effects of Manual S in this situation – in other words, did any down-sizing actually occur in either group. [iii]

In contrast, the program data analysis shows the change in installation design capacity for individual customers before and after Res QI program intervention. This is a better approximation of system oversizing for individual customers prior to program intervention than Work Order 32's comparison of two different customer groups, one using nominal capacity and the other using design capacity.

Summary of Work Order 32 findings for equipment oversizing:
Baseline (non-participants): 13%
Measure (participants): 10%

Energy Center of Wisconsin[6]

This was the original study used to support the workpaper assumption of 20% oversizing, however program data within SCE's jurisdiction is considered to be better data than data from another (Midwestern) region. Both studies leverage similar sample sizes. The Wisconsin study used an empirical assessment of 39 sites to estimate oversizing. The study indicated that most systems have 2-3 tons of cooling capacity, and about a third of systems are oversized by ½ ton (16% - 25%), 40% are oversized by 1 ton or more (30% - 50%). Additionally, this study employed a simplified analysis which used nominal sizing and did not use manual S; using adjusted capacity is a more reasonable approach.

Mowris, Jones, and Eshom[7]

(Peak Demand and Energy Savings from Properly Sized and Matched Air Conditioners)
Program data values were selected as representative of Res QI customers, and are conservative relative to the oversizing reported in this study. This study indicates that research studies have

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[iii] Comments excerpted from Buck Taylor's write-up posted to the Cal TF subcommittee website, http://www.caltf.org/tf-subcommittees/; these comments reflect discussion during the subcommittee call. See Appendix A, item 4.

shown that 50 to 70 percent (%) of residential and commercial air conditioning systems are oversized by 120% or more (James, et al 1997; Sonne, et al 2006; Mowris, 2006; Nadel 1998; Parker 1993; Jacobs 2003; Felts 1998; ACCA 2006). Air conditioners are typically oversized to compensate for installation design flaws and defects, such as cooling equipment installed in hot attics, leaky ducts, improper refrigerant charge and airflow (RCA), improper maintenance, or mismatched evaporator and condenser coils (Mowris et al 2007).

3.2.3. Other Comments for Future Consideration

- The modeling of equipment efficiency degradation in DOE2.2 should be explored to determine if the modeling is reasonable and how the model responds to equipment sizing and variable capacity equipment.
- The saturation of variable capacity equipment in the market should be investigated.
- Pushing the SEER limit for replacement equipment can lead to lower system performance than expected (in which delivered system efficiency is lower than rated system efficiency). Higher SEER units are typically designed with larger evaporator coils which can lead to reduced pressure drops across the coil, resulting in poor system performance. Contractors should focus on higher overall system efficiency. The program should be consider ways to incentivize contractors to improve engineering and overall system performance.

3.3. AIRFLOW PERFORMANCE (W/CFM)

Table 4. Subcommittee Recommendations for Airflow Performance

Airflow Performance	Baseline	Measure
Value (W/CFM)	0.57	0.37
Source	CPUC HVAC Impact Evaluation (Work Order 32)	2014-2015 Res QI Program Data

Baseline

The baseline should use the Work Order 32[3] value of 0.569 W/CFM as this constitutes the best available information. Three significant digits implies an unreasonable level of precision, so 0.57 W/CFM should be used instead to reflect the precision obtainable through measurement and

Measure

The measure airflow should be based on the 2014-2015 Res QI program data average of 0.37 W/CFM based on a sample size of 1,970. [iv] This large sample size of program data is considered the best available information and can be viewed in Appendix A, item 1.

3.3.1.Other Sources Considered

Work Order 32[3]

[iv] 2014-2015 Residential Quality Installation program data, sample size for airflow of 1,970. System airflow - There are 3 methods allowed in the program for measuring air flow including (1) Flow hood at the return (‘s); (2) rotating vane 4” anemometer measured at the return(‘s); and (3) Flow plates measured at the furnace entrance or the return(‘’s). Note that since most of the measured air flow was at the returns it does not include return duct leakage. This means that the evaporator air flow is actually greater than measured and that the fan watt draw/ CFM is actually lower. It is the understanding that most evaporator's motors in evaluated system were ECM. PF assumption informed by Contractor's field measurements typically never greater than 0.55 as well as Contractor's verification reports. Estimated system airflow performance (kW/cfm) conservatively assume in the order of 0.78.

Work Order 32 is not considered to be the best available information compared to the program data for the measure case. The program data sample size is much larger than that used in Work Order 32 (participant sample size 50) and is more representative of the overall participant population.

Summary of Work Order 32 findings for airflow performance (W/CFM):
Baseline (non-participants): 0.569
Measure (participants): 0.486

Proctor and Parker Study[8]
An ACEEE paper submitted by Proctor and Parker complied static pressure measurements of residential air handlers from multiple field tests in the United States and Canada between 1994 and 1998. Field tests were conducted in Las Vegas, Phoenix, Arizona, Florida, New Jersey, Canada, and California. The data from California consisted of 5 new evaporatively cooled AC units in existing sites from various places in 1998 and 40 existing home AC sites in the Coachella Valley of California in 1995 (the latter site did not produce W/CFM data). For all sites, overall fan motor power demand was found to be 0.510 W/CFM in single family new construction and 0.492 – 0.574 W/CFM in existing single family construction. Both the overall new and existing construction values include results from a majority of homes outside of California from the 1990's with likely different building codes than California. This data would not be for either the workpaper measure or base case, however the existing construction data that would represent the base case indicates an airflow performance range that includes the proposed workpaper measure value of 0.57 from Work Order 32.

3.4. AIRFLOW CAPACITY (CFM/TON)

3.4.1.Recommendations

Table 5. Subcommittee Recommendations for Airflow Capacity

Airflow Capacity	Baseline	Measure
Value (CFM/ton)	300	350
Source	CPUC HVAC Impact Evaluation (Work Order 32)	Title 24 estimate, between Proctor study data and Work Order 32 study data

Baseline
The subcommittee recommends that the Work Order 32[3] non-participant airflow capacity value of 300 CFM/ton be used as it is considered best available information to inform the baseline. This value is considered consistent with data reported by Proctor & Parker[8] in a study of field test results conducted between 1994 and 1998 in multiple United States locations. Specifically, a sample of 40 existing equipment units in Coachella Valley is considered the closest representation of the baseline with an airflow capacity value of approximately 310 CFM/ton.

Measure
The subcommittee recommends using the value of 350 CFM/ton, consistent with Title 24 guidelines. This value was selected because it falls between the measured data from Work Order 32[3] (338 CFM/ton) and data reported by Proctor & Parker[8] in a study of field test results

conducted between 1994 and 1998 in multiple United States locations. Specifically, for the measure case, CFM/ton for "Las Vegas, new" by Proctor et al 1996a and "California, replacement" by Proctor and Downey 1998 were selected as the closest representation of the upper range for the Res QI program measure case at 388 and 377 CFM/ton, respectively. These two field trials were selected of the trial results reported based on the new equipment and consistent authorship (Proctor). Results for all field trials in this study are shown in Table 6 below.

Table 6. Measured Air Handling Equipment Performance Data for North American Installations (excerpted from Proctor and Parker)

Reference	Study Location and Equipment Age	Number of Units in Sample	Average Capacity (tons)	Average Inside Fan Watts	Average CFM	Average Watts per 1000 CFM	Average External Static (IWC)[2]
Air Conditioners							
Blasnik et al. 1995a	Las Vegas, new	40	3.4		1150		.41
Blasnik et al. 1996	Phoenix, new	28	3.6	620	1220	510	.48
Parker 1997	Florida, existing	9	2.5	420	850	490	.55
Proctor et al. 1995	Cochella Valley CA, existing	40	4.0		1240		.53
Proctor et al. 1996a	Las Vegas, new	37	3.5		1320		.50
[3] Proctor and Downey 1998	California, replacement	5	3.4	760	1320	570	
Proctor et al. (unpublished)	New Jersey, new townhouses	15	2.7		1050		.45
Non-AC							
Phillips 1995	Canada post-1990 heating speed	32		510	1120	450	.52
Phillips 1995	Canada pre-1990 heating speed	39		370	860	440	.38

Limitations of the Data

- CFM/ton calculations should be based on adjusted capacity which more accurately captures actual system capacity at design conditions than nominal capacity. Work Order 32 results were based on nominal capacity based on AHRI ratings.

3.4.2.Other Sources Considered

Mowris, Robert, Jones, Ean, and Eshom, Robert[5]

(Laboratory Measurements and Diagnostics of Residential HVAC Installation and Maintenance Faults)

This ACEEE paper presents the results of a laboratory study of a new 13-SEER split-system air conditioner test unit, with simulated installation and maintenance faults. This study demonstrates the performance losses due to installation and maintenance faults and does not provide empirical results from a real-world sample for performance parameters that would feed into the workpaper. Therefore this is not considered an appropriate data source for this workpaper.

3.4.3.Other Comments for Future Consideration

- The Res QI program should consider the feasibility of collecting data on airflow capacity moving forward.
- The adjusted capacity should be used over the nominal capacity because it reflects system capacity and design conditions.

3.5. SYSTEM EFFICIENCY

3.5.1.Recommendation

Baseline
The baseline will reflect Title 24.

Measure
The subcommittee recommends using DEER[9] as the basis for system efficiency. SEER ratings and tiers on equipment efficiency in 2015 version of the workpaper, including both Air Conditioners and Heat Pumps, will be consistent with that documented in 2015 DEER updates, which includes additional tier levels and size ranges as required by the code update.

3.5.2.Other Comments for Future Consideration

- Consider the use of Title 24 gas furnace efficiencies in the DEER model.
- The impact of duct systems on equipment should be considered in the equipment efficiency.

3.6. REFRIGERANT CHARGE ADJUSTMENT

3.6.1.Recommendation

While refrigerant charge is considered compliant with Title 24 requirements in the current workpaper version, the workpaper developer should consider addressing refrigerant charge in the long term due to the issues faced by contractors during implementation. The baseline represents what the customer would have done without the program. Not all contractors will pull permits, and not all units will be properly charged.

- Problems with misidentification of sub-cooling
- Contractors are not necessarily identifying correct charge because they're not looking at the refrigerant lines and OEM requirements, and don't even know how much charge is in the lines to begin with
- There is the potential for refrigerant charge savings based on same permit/unpermitted split used for duct leakage assumptions.

4. Attachments

Residential Quality Installation Subcommittee Summary
Residential Quality Installation Tracking Sheet, Meeting 1
Residential Quality Installation Tracking Sheet, Meeting 2
Residential Quality Installation Tracking Sheet, Meeting 3
Residential Quality Installation Tracking Sheet, Meeting 4
Residential Quality Installation Tracking Sheet, Meeting 5

5. Appendix A

1. 2014-2015 Res QI program data used to establish duct leakage rates

   2014 2015 RQI Program Data Leakag

2. Memo from subcommittee member Mark Modera on duct leakage measurement

   MEMO on Duct Leakage Measuremen

3. Equipment oversizing analysis prepared by Buck Taylor of Roltay Energy, Inc. using subset of Res QI program participating contractors selected for a pilot

   Companion Document to RQI Pro(

   RQI Program Data_MAN J_S CAPAC

4. Comments from subcommittee member Buck Taylor on all performance parameters

   Cal-TF-Section_II_Recommendations_Buck T

REFERENCES

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[8] Proctor, John, and Parker, Danny, *Hidden Power Drains: Residential Heating and Cooling Fan Power Demand*. Accessed at http://aceee.org/files/proceedings/2000/data/papers/SS00_Panel1_Paper19.pdf

[9] Database for Energy Efficient Resources (DEER), accessed at https://www.deeresources.com