# Valuing HVAC Design & Installation In the HERS Index

RESNET Building Performance Conference

February 27th, 2018

# Introduction

# Installation defects in HVAC systems are commonplace

- Improper airflow.
- Incorrect refrigerant charge.

| Study Author | State | Existing or New Home? | Sample Size | Average Airflow | Airflow <350 cfm | Airflow w/in 10% of 400/ton | Energy Savings Potential | Notes |
|---|---|---|---|---|---|---|---|---|
| Blasnik et al. 1995a | NV | | | | | | | |
| Blasnik et al. 1995b | CA | | | | | | | |
| Blasnik et al. 1996 | AZ | | | | | | | |
| Hammarlund et al. 1992 | CA | | | | | | | |
| Hammarlund et al. 1992 | CA | | | | | | | |
| Neme et al. 1997 | MD | | | | | | | |
| Palani et al. 1992 | n.a. | | | | | | | |
| Parker et al. 1997 | FL | | | | | | | |
| Proctor & Pernick 1992 | CA | | | | | | | |
| Proctor 1991 | CA | | | | | | | |
| Proctor et al. 1995a | CA | | | | | | | |
| Rodriguez et al. 1995 | n.a. | | | | | | | |
| Rodriguez et al. 1995 | n.a. | | | | | | | |
| VEIC/PEG 1997 | NJ | | | | | | | |
| Average | | | | | | | | |

| Study Author | State | Existing or New Homes? | Sample Size | Charge correct to mfg spec | % over charge | % under charge | Energy Savings Potential | Notes |
|---|---|---|---|---|---|---|---|---|
| Blasnik et al. 1995a | NV | New | 30 | 36% | 5% | 59% | 17% | Est @ 67% combined charge/air flow correction benefits |
| Blasnik et al. 1995b | CA | New | 10 | | | | 8% | Est @ 67% combined charge/air flow correction benefits |
| Blasnik et al. 1996 | AZ | New | 22 | 18% | 4% | 78% | 21% | Est @ 67% combined charge/air flow correction benefits |
| Farzad & O'Neal 1993 | n.a. | n.a. | n.a. | | | | 5% | Lab test of TXV; 8% loss @20% overchg; 2% loss @20% underchg |
| Farzad & O'Neal 1993 | n.a. | n.a. | n.a. | | | | 17% | Lab test of Orifice; 13% loss @20% overchg; 21% loss @ 20% underchg |
| Hammarlund et al. 1992 | CA | New | 12 | | | | 12% | Single family results |
| Hammarlund et al. 1992 | CA | New | 66 | 31% | 61% | 8% | 12% | Multi-family results |
| Katz 1997 | NC/SC | New | 22 | 14% | 64% | 23% | | Charge measured in 22 systems in 13 homes |
| Proctor & Pernick 1992 | CA | Existing | 175 | 44% | 33% | 23% | | Results from PG&E Model Energy Communities Program |
| Proctor 1991 | CA | Existing | 15 | 44% | | | | Fresno homes |
| Proctor et al. 1995a | CA | Existing | 30 | 11% | 33% | 56% | | |
| Proctor et al. 1997a | NJ | New | 52 | | | | 13% | Est @ 67% combined charge/air flow correction benefits |
| Rodriguez et al. 1995 | n.a. | n.a. | n.a. | | | | 5% | Lab test of TXV EER; 5% loss at both 20% overchg & 20% underchg |
| Rodriguez et al. 1995 | n.a. | n.a. | n.a. | | | | 15% | Lab test of Orifice EER; 7% loss @20% overchg, 22% loss @ 20% underchg |
| Average | | | | 28% | 33% | 41% | 12% | |

# Installation defects in HVAC systems are commonplace

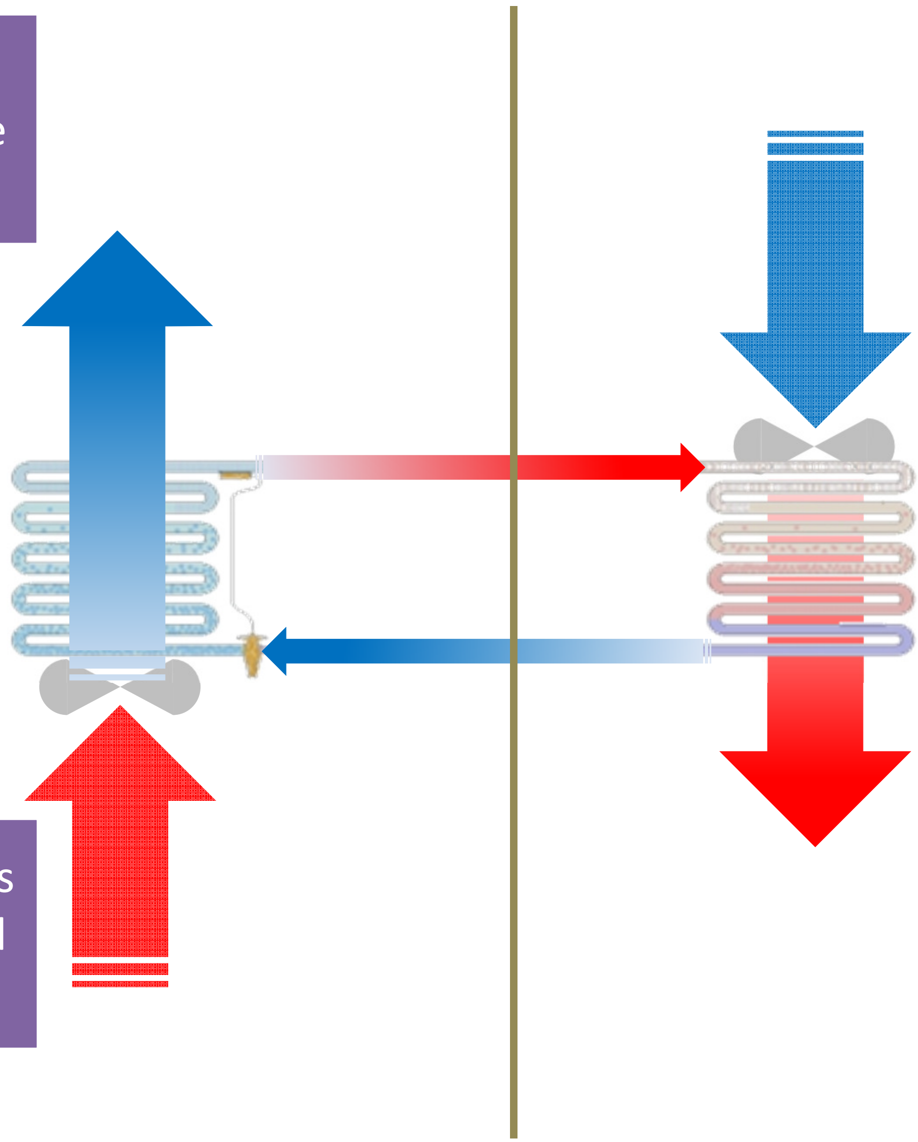
The air's heat is transferred to the refrigerant.

2

Inside the House

1

Warm indoor air is blown over a cold refrigerant coil.



Outdoor air is blown over the hot refrigerant coil.

3

Outside the House

4

The refrigerant's heat is transferred to the outdoor air.

## Installation defects in HVAC systems are commonplace

- Airflow is impacted by the installation:
  - Fan-speed setting
  - Components attached to the system (like the filter)
  - Duct system installed
- Refrigerant charge is impacted by the installation:
  - Length of refrigerant line
  - Change in height between indoor and outdoor sections

## Lessons learned from the ENERGY STAR Certified Homes program

- + This is an area that deserves a lot of attention.
- + Our partners all benefit from understanding and communicating about this.
- + Requirements that can easily be verified by Raters results in improvement.
- - The industry, as a whole, doesn't deliver proper design and installation by default yet.
- - Lack of uniform, practical, standards led to inconsistencies between contractors and raters.
- - Workflow challenges trumped technical challenges.
- - No credit in the HERS/ERI index was a significant obstacle.

## Where Do We Go From Here?

- ACCA initiated a proposal that RESNET include an evaluation of HVAC design and installation in the HERS index.
- In Summer 2016, EPA started leading a working group to draft a standard that will accomplish this.
- The working group encompasses a diverse set of stakeholders interested in solving this problem:

| | | |
|---|---|---|
| Jim Bergman, Measure Quick | Dean Gamble, EPA | Dave Roberts, NREL |
| Michael Brown, ICF | Dan Granback, Energy Ins. | Mike Serrano, Sonoran Air |
| Greg Cobb, Apicis Energy | James Jackson, Emerson | Dennis Stroer, CalcsPlus |
| Wes Davis, ACCA | Rob Minnick, Minnick's Inc. | Iain Walker, LBNL |
| Brett Dillon, IBS Advisors | Brian Mount, Tempo Air | Dan Wildenhaus, ClearResult |
| Philip Fairey, FSEC | Chris Reynolds, AE | Jon Winkler, NREL |

## Guiding Principles

- Take a ‘carrot’ rather than a ‘stick’ approach.
- Reward incremental improvement by HVAC professionals and Raters.
- Rely upon procedures that:
  - Can be performed by both HVAC professionals and Raters.
  - Favor consistency over breadth.
  - Provide value in and of themselves.

## Grading Concept

- Follow the insulation quality-installation model:
  - Grade III: The default. No QI is done. No penalty and no credit.
  - Grade II: Rater reviews key design parameters for accuracy and takes accurate measurements of key installation parameters. The resulting values indicate that the system is not great, but not terrible.
  - Grade I: Rater duplicates the tasks in Grade II, but the resulting values indicate that the system is pretty top-notch.

# Status Update

## Status Update

- Two major parts:
  - Standard 310: Standard for Grading the Installation of HVAC Systems
    - Brand new standard.
    - Covers all the things that the Rater will do.
  - Standard 301: Standard for the Calculation and Labeling..
    - Updated so that Standard 310 impacts the HERS index.

## Status Update

- Process:
  - Complete a Working Draft that the working group approves.
  - SDC 300 subcommittees approve.
  - SDC 300 approves.
  - ACCA reviews Std 310.
  - Public comment period(s).
  - SDC 300 holds a final vote.
  - SMB approves.
  - Standard is submitted to ANSI for review and approval.
  - SMB sets implementation date.
  - HERS software programs get updated, Raters get trained, and then everyone starts using the standard.

# Overview of Standard 310
# (A work in progress)

EPA

## Overall Organization of the Standard

- All of the Rater procedures will go into a new standard, Standard 310 - Standard for Grading the Installation of HVAC Systems.

| # | Section | Status |
|---|---|---|
| 1 | Purpose | 2nd draft complete |
| 2 | Scope | 2nd draft complete |
| 3 | Procedure for Evaluating the Design of the Forced-Air System | 1st draft complete |
| 4 | Procedure for Evaluating the Total Duct Leakage | 1st draft complete |
| 5 | Procedure for Evaluating the Blower Fan Volumetric Airflow | 2nd draft complete |
| 6 | Procedure for Evaluating the Blower Fan Watt Draw | 2nd draft complete |
| 7 | Procedure for Evaluating the Refrigerant Charge | 1st draft complete |
| 9 | Definitions / References / Appendices | Ongoing |

## Key Terms in the Standard

- Forced-Air System – Equipment used to heat or cool a Dwelling or Dwelling Unit that incorporates a Blower Fan to move heated and/or cooled air, combined with supply and/or return distribution ducts.
- Blower Fan – The fan inside the equipment of a Forced-Air System that forces the heated and/or cooled air to be distributed within the Dwelling or Dwelling Unit.

## Std. 310: Purpose

- The provisions of this document are intended to establish standards for measuring and/or evaluating:
  - The design;
  - The total duct leakage;
  - The Blower Fan volumetric airflow and Blower Fan watt draw in heating, cooling, or fan-only operating mode; and,
  - The refrigerant charge

  .. of a Residential Forced-Air Heat Pump or Air Conditioning System.

  These standards are intended for use by parties evaluating the performance of residential buildings and dwelling units including home energy raters, energy auditors, or code officials.
- Air conditioners paired with furnaces can be tested, but the furnace itself won't earn you extra points in heating mode, even if it's properly installed.

## Std. 310: Scope

- This standard is applicable to Residential Forced-Air Heat Pumps and Residential Forced-Air Air Conditioning Systems:
  - In single family dwelling units, and,
  - In dwelling units in multifamily buildings, where each dwelling unit has its own Forced-Air System separate from other dwelling units.

## Std. 310: Evaluating the Design of the Forced-Air System

- Overall approach to drafting this section was to:
  - Start with the ENERGY STAR HVAC Design Report,
  - Strip it of references to ENERGY STAR, and,
  - Translate it into standards language.
- Overall, if you're doing ENERGY STAR today, the design documentation collection and review will be very similar for single-family homes.
- Have started to explore what changes to make for multi-family dwelling units.

## Std. 310: Evaluating the Design of the Forced-Air System

Step 1. All of the following design information shall be collected for the Forced-Air System under test.

- A design overview
- An overview of the Whole-Dwelling Mechanical Ventilation System design, if such a system is specified in the design
- An overview of the room-by-room heating and cooling loads
- An overview of the air conditioner or heat pump equipment, if specified
- An overview of the furnace equipment, if specified
- An overview of the filter specified for the Residential Forced-Air Heat Pump or Air Conditioning System
- An overview of the duct system design, if specified, for the Residential Forced-Air Heat Pump or Air Conditioning System

# Std. 310: Evaluating the Design of the Forced-Air System

Step 2. The design documentation collected shall be reviewed to verify that all required information has been provided.

## Std. 310: Evaluating the Design of the Forced-Air System

Step 3. The design documentation collected shall be compared to the home to be rated and the following parameters verified:

- The name of the house plan matches the plan of the home to be rated.
- The elevation(s) and set(s) of architectural options of the home to be rated are encompassed by the design.
- The outdoor design temps. used in the loads are within the limits defined.
- The # of occupants used in the loads are within ± 2 of the home to be rated.
- The conditioned floor area used in the loads are between 100 sq. ft. smaller and 300 sq. ft. larger than the home to be rated.
- The window area used in the loads is 0-60 sq. ft. larger than the home to be rated.
- The predominant SHGC used in the loads is ± 0.1 of the home to be rated.
- At least one orientation associated with the heat gain matches home to be rated.
- The difference btw max and min total heat gain across orientations is ≤ 6 kBtuh.
- The Cooling Sizing % is within the applicable Cooling Sizing Limit.
- The Heating Sizing % is within the applicable Heating Sizing Limit.

# Std. 310: Evaluating the Total Duct Leakage

- This short procedure simply directs the Rater to measure the total duct leakage according to Standard 380, evaluate the results, and assign a grade:

| Grade | Test Stage | # Returns | Total Leakage Limit |
|---|---|---|---|
| I | Rough-In | < 3 | 4 CFM/100 sqft or 40 CFM |
| | Rough-In | ≥ 3 | 6 CFM/100 sqft or 60 CFM |
| | Final | < 3 | 8 CFM/100 sqft or 80 CFM |
| | Final | ≥ 3 | 12 CFM/100 sqft or 120 CFM |
| II | Rough-In | < 3 | 6 CFM/100 sqft or 60 CFM |
| | Rough-In | ≥ 3 | 8 CFM/100 sqft or 80 CFM |
| | Final | < 3 | 10 CFM/100 sqft or 100 CFM |
| | Final | ≥ 3 | 14 CFM/100 sqft or 140 CFM |
| III | N/A | N/A | No Limit |

- Then, in the procedure to evaluate Blower Fan airflow:
  - Any test procedure can be used if Grade I duct leakage is achieved.
  - A subset of procedures can be used if Grade II duct leakage is achieved.
  - Airflow testing not permitted if Grade III duct leakage is achieved.

## Overall Organization of the Standard

- All of the Rater procedures will go into a new standard,
  Standard 310 - Standard for Grading the Installation of HVAC Systems.

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| 9 | Definitions / References / Appendices | Ongoing |

## Std. 310: Evaluating the Blower Fan Volumetric Airflow

Step 1. Complete prerequisites before evaluating airflow:

- Evaluate the Design of the Forced-Air System
- Verify that installed equipment matches design documentation
- Evaluate the Total Duct Leakage and achieve Grade I or II

Step 2. Prepare the dwelling and Forced-Air System for testing

Step 3. Select one of four test methods and evaluate airflow:

- Pressure Matching
- Flow Grid
- Flow Hood
- OEM Static Pressure Table

# Std. 310: Evaluating the Blower Fan Volumetric Airflow

## #1. Pressure Matching

1. Measure static pressure created in supply plenum during operation of HVAC system.
2. Turn off HVAC system, connect a fan-flowmeter, and block other return air flow paths.
3. Turn on flowmeter fan and adjust to achieve same static pressure in supply plenum.
4. Determine HVAC airflow by recording airflow of flowmeter fan.

# Std. 310: Evaluating the Blower Fan Volumetric Airflow

## #1. Pressure Matching

| Pros | Cons |
|---|---|
| Accurate: +/- 5% | Can't reach high flows for big systems: needs extrapolation |
| Uses equipment many Raters already own | If installed at a return – need to account for duct leakage |
| | Need at least one large low air flow resistance return duct |

# Std. 310: Evaluating the Blower Fan Volumetric Airflow

## #2. Flow Grid

1. Measure static pressure created in supply plenum during operation of HVAC system.
2. Install calibrated flow grid in filter slot.
3. Measure pressure difference using flow grid. Correct pressure using value measure in Step 1.
4. Determine HVAC airflow by converting corrected pressure to airflow.

# Std. 310: Evaluating the Blower Fan Volumetric Airflow

## #2. Flow Grid

| Pros | Cons |
| --- | --- |
| Easy/simple for many systems | Multiple returns are hard to deal with |
| Can work at higher flows | Need to make sure a good seal is achieved around the plate perimeter |
| | Less accurate +/- 15% |

# Std. 310: Evaluating the Blower Fan Volumetric Airflow

## #3. Flow Hood

1. Turn on HVAC system.
2. Connect flow hood to return grille.
3. Turn on flow hood and allow reading to stabilize.
4. Resulting airflow of flow hood determines HVAC airflow.

- May require additional step to account for back-pressure.
- For example, some manufacturers require you to test twice – once with a flap open and again with a flap closed.
- While other manufacturers do this correction automatically without user intervention.

# Std. 310: Evaluating the Blower Fan Volumetric Airflow

## #3. Flow Hood

| Pros | Cons |
|---|---|
| Easy to use | Can be heavy/unwieldy |
| Flowmeters with high flow resistance less sensitive to placements and flow non-uniformity | Can be sensitive to placement |
| | Can be expensive |
| | Will not always fit around air inlet |

# Std. 310: Evaluating the Blower Fan Volumetric Airflow

## #4. OEM Static Pressure Table

1. Turn on HVAC system.
2. Measure external static pressure of system's supply side and return side.
3. Determine fan-speed setting through visual inspection.
4. Using blower table information, look up total external static pressure and fan-speed setting to determine airflow.

| Motor Speed | Tons AC[1] | External Static Pressure, (Inches Water Column) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.1 | | 0.2 | | 0.3 | | 0.4 | | 0.5 | | 0.6 | 0.7 | 0.8 |
| | | CFM | Rise | CFM | Rise | CFM | Rise | CFM | Rise | CFM | Rise | CFM | CFM | CFM |
| High | 3 | 1,498 | N/A | 1,446 | N/A | 1,368 | N/A | 1,302 | N/A | 1,227 | N/A | 1,145 | 1,059 | 954 |
| Med | 2.5 | 1,223 | N/A | 1,182 | N/A | 1,153 | 30 | 1,099 | 31 | 1,051 | 32 | 982 | 901 | 813 |
| Med-Lo | 2 | 983 | 35 | 971 | 35 | 945 | 36 | 919 | 37 | 878 | 39 | 813 | 746 | 659 |
| Low | 1.5 | 816 | 42 | 794 | 43 | 758 | 45 | 734 | 46 | 678 | 50 | 637 | 597 | 523 |

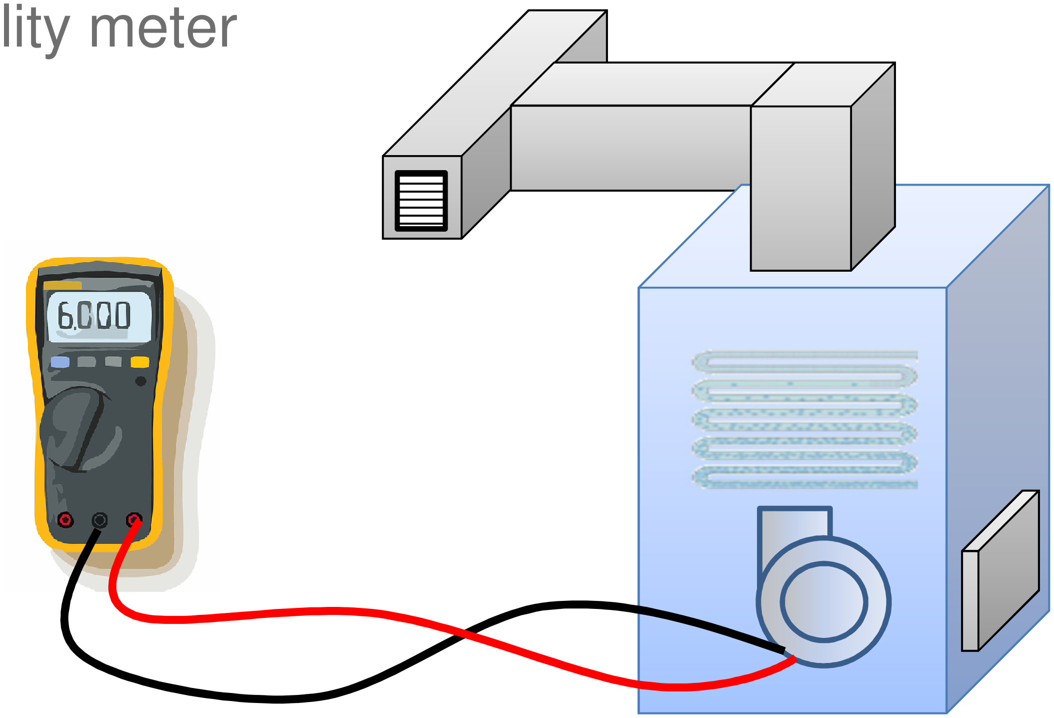
# Std. 310: Evaluating the Blower Fan Volumetric Airflow

## #4. OEM Static Pressure Table

| Pros | Cons |
|---|---|
| Requires only pressures to be measured | Rater required to get OEM Blower Table for installed equipment |
| Works for all flows | Need to coordinate with contractor to drill holes in plenums/equipment |
| Inexpensive equipment | Ned to place holes in consistent proper location for accurate measurement |

# Std. 310: Evaluating the Blower Fan Watt Draw

- Two procedures are included:
  1. Portable Watt meter for direct measurement
  2. Utility meter



## Std. 310: Evaluating the Blower Fan Watt Draw

### Portable Watt Meter: Direct Measurement

1. Plug in portable watt meter and blower fan equipment into standard electrical receptacle.
2. Turn on equipment in required mode.
3. Record reading from portable watt meter.

# Std. 310: Evaluating the Blower Fan Watt Draw

## Portable Watt Meter: Direct Measurement

| Pros | Cons |
|---|---|
| Simple | New equipment needed (Watt meter) |
| Direct measurement of equipment (accurate) | Not compatible with all equipment (hard-wired) |

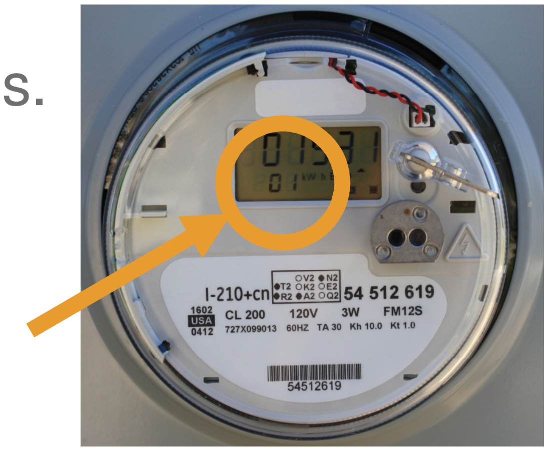
# Std. 310: Evaluating the Blower Fan Watt Draw

## Utility Meter: Indirect Measurement

1. Turn off all circuits except air handler's.
2. Turn on equipment in required mode.

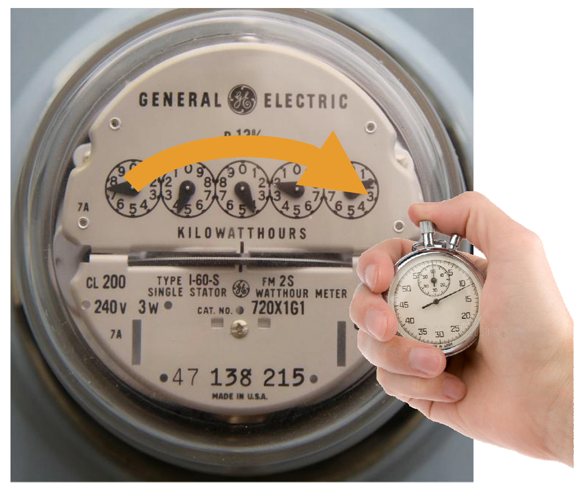
For a digital utility meter:

3. Record watt draw from utility meter.




For an analog utility meter:

3. For 90+ seconds, record the number of meter revolutions and time.
4. Calculate watt draw.



# Std. 310: Evaluating the Blower Fan Watt Draw

## Utility Meter: Indirect Measurement

| Pros | Cons |
|---|---|
| Works with all equipment | Indirect measurement of equipment |
| No new equipment needed | More steps required<br>(turning off all other circuits) |

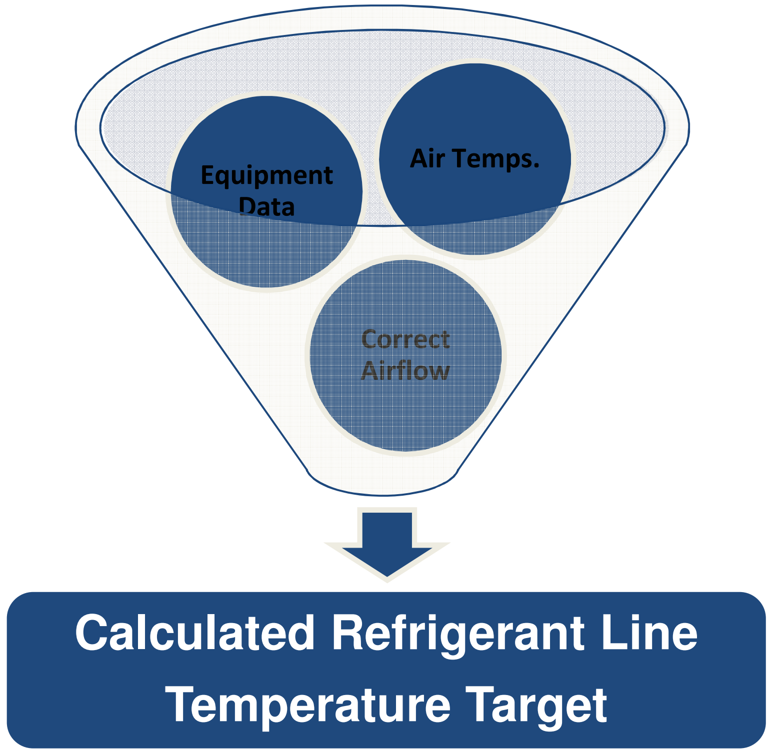
## Std. 310: Evaluating the Refrigerant Charge

### Industry-Standard Method:

- Standard charge verification uses refrigerant gauges.
  - Checks superheat and subcooling.
- Burdens / risks for Raters.

## Std. 310: Evaluating the Refrigerant Charge

## Non-Invasive Method:




- Our working group's Jim Bergman has been instrumental in helping develop this procedure.

## Std. 310: Evaluating the Refrigerant Charge

### Non-Invasive Method: Theory / Overview

- Design Temperature Difference (DTD)
  - DTD = Return Air Temp – Suction Line Saturation Temp
  - Used for systems with fixed-orifice metering device.
- Condensing Temperature Over Ambient (CTOA)
  - CTOA = Liquid Line Condensing Temp – Outdoor Air Temp
  - Used for systems with a TXV
- DTD / CTOA do not change during the life of the system, unless there is an:
  - Airflow restriction,
  - Component failure, or
  - Refrigerant flow restriction.

## Std. 310: Evaluating the Refrigerant Charge

## Non-Invasive Method: Theory / Overview

- Why are DTD and CTOA consistent between manufacturers?
  - Heat Transfer Rate is based on:

| Time | Turbulence | Temperature Difference |
|---|---|---|
| (air velocity) | (coil design) | (air and refrigerant) |

  - All manufacturers design to similar targets:
    - Time: Air can't go too fast or too slow.
    - Turbulence: Similar coil designs, limited by static pressure.
    - Heat Transfer Rate: Same capacities.
    - Temperature Difference: With all other variables consistent, temperature differences (DTD / CTOA) are also consistent.

# Std. 310: Evaluating the Refrigerant Charge

## Non-Invasive Method: Procedure

1. Determine key equipment characteristics.
2. Measure outdoor air and return air temperatures.
3. Calculate target refrigerant line temperatures.
4. Measure refrigerant line temperature.
5. Compare.

# Std. 310: Evaluating the Refrigerant Charge

## Non-Invasive Method

| Pros | Cons |
|---|---|
| No refrigerant handling certification | New procedure to learn |
| Low risk of refrigerant contamination and leaks | Minimum outdoor air temperature required |
| Less Rater liability | |

# Overview of Adjustments to Standard 301 (Also a work in progress)

## The NIST Study

- In September 2014, NIST published an important study that analyzed the sensitivity of installation faults on HVAC performance.
  - Conducted a literature review on HVAC faults.
  - Used laboratory testing to derive equations that correlate design and installation faults with COP impacts.
- HVAC WG intends to use the study as the underpinning of an HVAC grading system in the RESNET standard.

# Faults Analyzed in NIST Study

| Fault Type | Fault Levels (%) | |
|---|---|---|
| | Cooling mode | Heating mode |
| Heat Pump Sizing (pg. 46) | -20, 25, 50, 75, 100 | -20, 25, 50, 75, 100 |
| Duct Sizing (pg. 48) | 80, 100, 125, 150, 175, 200 | 80, 100, 125, 150, 175, 200 |
| Duct Leakage (pg. 54) | 0, 10, 20, 30, 40, 50 | 0, 10, 20, 30, 40, 50 |
| Adjusting Thermostat (pg. 55) | 2°F, 4°F | - |
| Indoor Coil Airflow (pg. 60) | -36, -15, 7, 28 | -36, -15, 7, 28 |
| Refrigerant Undercharge (pg. 64) | -10, -20, -30 | -10, -20, -30 |
| Refrigerant Overcharge (pg. 66) | 10, 20, 30 | 10, 20, 30 |
| Excessive Subcooling (pg. 67) | 100, 200 | - |
| Non-Condensable Gases (pg. 68) | 10, 20 | 10, 20 |
| Electric Voltage (pg. 69) | -8, 8, 25 | -8, 8, 25 |
| TXV Undersizing (pg. 71) | -60, -40, -20 | - |

## The NIST Study

- Equations created for:
  - Refrigerant-side, and total, cooling and heating capacity
  - Outdoor unit, and total, power
  - COP
- Equation inputs are:
  - Outdoor dry-bulb temperature
  - Indoor dry-bulb temperature
  - Fault type and level

# Quality Installation (QI) Calculator

## Heat Pump COP Degradation Calculator

**Instructions**

1) Select a fault type. Fault types can be seen below in the table below, with the fault ranges studied by NIS

| Fault | Definition of fault level | Fault Range(%) |
|---|---|---|
| Improper indoor airflow rate | % above or below correct airflow rate | -50% to 20% |
| Refrigerant undercharge | % mass below correct (no-fault) charge | -30% to 0% |
| Refrigerant overcharge | % mass above correct (no-fault) charge | 0% to 30% |
| Improper liquid line refrigerant | % above the no-fault subcooling value | 0% to 200% |
| Presence of non-condensable gases | % of pressure in evacuated indoor section | 0% to 20% |
| Improper electric line voltage | % above or below 208 V | -8.7% to 25% |
| TXV undersizing,cooling | % below the nominal cooling capacity | 20% to 60% |

2) Input your indoor and outdoor dry-bulb temperature.

**Output**

| | |
|---|---|
| COP Degradation from Fault-free | -6.14% |

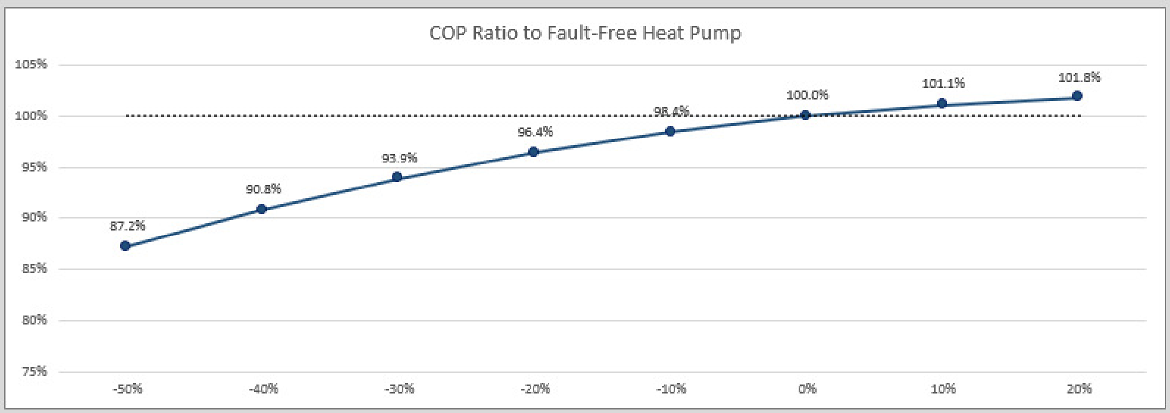
| Fault % | Y.COP |
|---|---|
| -50% | 87.2% |
| -40% | 90.8% |
| -30% | 93.9% |
| -20% | 96.4% |
| -10% | 98.4% |
| 0% | 100.0% |
| 10% | 101.1% |
| 20% | 101.8% |

**Inputs**

| | |
|---|---|
| Fault | Improper indoor airflow rate |
| Fault (%) | -30% |

*Acceptable Range: -50% to 20%*

| | |
|---|---|
| Indoor dry-bulb Temperature | 75 |
| Outdoor-dry bulb Temperature | 95 |
| Temperature Unit | Fahrenheit |



# Literature Review for Airflow Defects

- Reviewed 24 papers & presentations for information about typical airflow defects.

| Description | # Systems | Average Airflow (CFM/ton) | Average % Defect | Std Deviation | Author | Date |
|---|---|---|---|---|---|---|
| Field measurements | 4,168 | 281 | @350: 20%<br>@400: 30% | Not defined | Mowris, R.J., et. al. | 2004 |
| Summary of studies | n/a | 327 | @350: 7%<br>**@400: 18%** | ~22% | Neme, et. al. | 1999 |
| Field measurements | 28 | 344 | @350: 2%<br>**@400: 14%** | 16% | Proctor | 1997 |
| Field measurements | 42 | 350 | @350: 0%<br>**@400: 13%** | Not defined | Titus | 2006 |
| Field measurements | 8 | 319 | @350: 9%<br>**@400: 20%** | 38% had defects ≥ 25% | Blasnik, et. al. | 1995 |
| Field measurements | Unknown | 289 | @350: 17%<br>**@400: 28%** | Not defined | Neal, referencing Parker 1997 study | 1998 |
| Field measurements | Unknown | 344 | @350: 2%<br>**@400: 14%** | Not defined | Neal, referencing Proctor 1992 study | 1998 |
| Assumption | n/a | 300 | **@350: 14%**<br>@400: 25% | Not defined | Wilcox | 2007 |
| Assumption | n/a | n/a | **@350: 15%**<br>@400: 26% | Not defined | Walker | 1998 |

# Literature Review for Refrigerant Charge Defects

- Reviewed 24 papers & presentations for information about typical refrigerant charge defects.

| Description | # Systems | Average Defect (% Dev. from Correct Charge) | Worst-Case/Bad Defect (% Dev. From Correct Charge) | Std Deviation | Author | Date |
|---|---|---|---|---|---|---|
| Field measurements | 55,462 | 14% | 90% | Not defined | Proctor | 2003 |
| Field measurements | 4,168 | 16% | n/a | Not defined | Mowris, R.J., et. al. | 2004 |
| Field measurements | 405 | 15% | 48% | Not defined | Downey and Proctor | 2002 |
| Field measurements | 28 | 16%<br>11% lineset var. < 10 ft<br>33% lineset var. ≥ 10 ft | 45% | 13% | Proctor | 1997 |
| Assumption | n/a | 15% | 30% | Not defined | Walker, et. al. | Unknown |
| Assumption | n/a | 15% | 30% | Not defined | Walker, et. al. | 1998 |

## Literature Review Summary

- Typical worst-case, or Grade III, defect would be:
  - -25% airflow relative to design
  - -25% refrigerant charge relative to design
- The HERS Reference Home would be configured with these defect levels.
- Rated homes that are not evaluated would be configured with the same defects.

# Potential HERS Impact

## House Parameters Consistent Across CZ's

| Parameter | Value |
|---|---|
| Number of Stories | Two |
| Conditioned Floor Area per Floor ($ft^2$) | 1,200 |
| Total Conditioned Floor Area ($ft^2$) | 2,400 |
| Perimeter (ft) | 30 x 40 |
| Ceiling Height (ft) | 8.5 |
| Bedrooms | 4 |
| Window Area & Distribution | 15%, Even |
| Exterior Door Quantity & Total Area ($ft^2$) | 2 Doors, 42 $ft^2$ |
| Space Heat., Cool. & DHW | Gas Furnace, AC, Gas DHW |

## House Parameters Varied Across CZ's

| Parameter | CZ 2 | CZ 4 | CZ 6 |
|---|---|---|---|
| Location | Tampa, FL | St. Louis, MO | Burlington, VT |
| Foundation Type | Slab | Unconditioned Basement | |

## Efficiency Tiers

| Efficiency Tiers |
|---|
| HERS Reference Home |
| ENERGY STAR v3 |
| ENERGY STAR v3.1 |

# Potential HERS Impact

Defect Levels

| Parameter | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| Airflow Defect | -25% | 0% | -25% | 0% |
| Refrigerant Charge Defect | -25% | -25% | 0% | 0% |

# Potential HERS Impact

- COP impacts calculated using NIST calculator

## Heat Pump COP Degradation Calculator

**Instructions**

1) Select a fault type. Fault types can be seen in the table below, with the fault ranges studied by NIST:

| Fault | Definition of fault level | Fault Range(%) |
|---|---|---|
| Improper indoor airflow rate | % above or below correct airflow rate | -50% to 20% |
| Refrigerant undercharge | % mass below correct (no-fault) charge | -30% to 0% |
| Refrigerant overcharge | % mass above correct (no-fault) charge | 0% to 30% |

2) Input your location to determine Climate Zone indoor and outdoor dry-bulb temperature.

| | |
|---|---|
| State | MO |
| Location | St Louis Spirit O |
| Cooling Design Temp | 90 |
| Heating Design Temp | 11 |
| IECC CZ | 4 |

3) Input the equipment relevant fault and associated Fault % (within acceptable ranges listed)

| | | | | |
|---|---|---|---|---|
| Fault 1 | Improper indoor airflow rate | Fault (%) | -25% | *Acceptable Range: -50% to 20%* |
| Fault 2 | Refrigerant undercharge | Fault (%) | -25% | *Acceptable Range: -30% to 0%* |

**Output**

| | |
|---|---|
| COP Degradation from Fault-free (Cooling Mode) | 11.1% |
| COP Degradation from Fault-free (Heating Mode) | 3.7% |

**Individual Fault Results (% COP Degradation)**
**Cooling**

| | |
|---|---|
| 4.9% | Improper indoor airflow rate |
| 6.8% | Refrigerant undercharge |

**Individual Fault Results (% COP Degradation)**
**Heating**

| | |
|---|---|
| 4.1% | Improper indoor airflow rate |
| -0.1% | Refrigerant undercharge |

# Potential HERS Impact

| Heat Fuel Type | Efficiency Tier | CZ | Defect Level: -25% Airflow -25% Charge, SEER x COP Impact | -25% Airflow -25% Charge, HSPF x COP Impact | 0% Airflow -25% Charge, SEER x COP Impact | 0% Airflow -25% Charge, HSPF x COP Impact | -25% Airflow 0% Charge, SEER x COP Impact | -25% Airflow 0% Charge, HSPF x COP Impact | 0% Airflow 0% Charge, SEER x COP Impact | 0% Airflow 0% Charge, HSPF x COP Impact |
|---|---|---|---|---|---|---|---|---|---|---|
| Gas | HERS Ref | CZ2 | 11.5 | - | 12.1 | - | 12.4 | - | 13.0 | - |
| | | CZ4 | 11.6 | - | 12.1 | - | 12.4 | - | 13.0 | - |
| | | CZ6 | 11.6 | - | 12.1 | - | 12.4 | - | 13.0 | - |
| | ESv3 | CZ2 | 12.9 | - | 13.5 | - | 13.8 | - | 14.5 | - |
| | | CZ4 | 11.6 | - | 12.1 | - | 12.4 | - | 13.0 | - |
| | | CZ6 | 11.6 | - | 12.1 | - | 12.4 | - | 13.0 | - |
| | ESv3.1 | CZ2 | 13.3 | - | 14.0 | - | 14.3 | - | 15.0 | - |
| | | CZ4 | 11.6 | - | 12.1 | - | 12.4 | - | 13.0 | - |
| | | CZ6 | 11.6 | - | 12.1 | - | 12.4 | - | 13.0 | - |
| Electric | HERS Ref | CZ2 | 11.5 | 6.6 | 12.1 | 7.3 | 12.4 | 6.9 | 13.0 | 7.7 |
| | | CZ4 | 11.6 | 7.4 | 12.1 | 7.7 | 12.4 | 7.4 | 13.0 | 7.7 |
| | | CZ6 | 11.6 | 7.9 | 12.1 | 7.9 | 12.4 | 7.7 | 13.0 | 7.7 |
| | ESv3 | CZ2 | 12.9 | 7.0 | 13.5 | 7.8 | 13.8 | 7.3 | 14.5 | 8.2 |
| | | CZ4 | 12.9 | 8.2 | 13.5 | 8.5 | 13.8 | 8.2 | 14.5 | 8.5 |
| | | CZ6 | 12.9 | 9.7 | 13.5 | 9.7 | 13.8 | 9.5 | 14.5 | 9.5 |
| | ESv3.1 | CZ2 | 13.3 | 7.0 | 14.0 | 7.8 | 14.3 | 7.3 | 15.0 | 8.2 |
| | | CZ4 | 13.3 | 8.2 | 14.0 | 8.5 | 14.3 | 8.2 | 15.0 | 8.5 |
| | | CZ6 | 13.3 | 9.7 | 14.0 | 9.7 | 14.3 | 9.5 | 15.0 | 9.5 |

# Potential HERS Impact

1. User enters rated equipment efficiency and defect levels into HERS software
2. HERS software uses inputs and equations derived from NIST study to calculate COP degradation
3. HERS software models equipment with COP degradation in lieu of rated efficiency

# Potential HERS Impact

| | | | REM/Rate v15.3 | | | | |
|---|---|---|---|---|---|---|---|
| | | | Degradation Level | | | | Point Potential |
| Heat Fuel Type | Efficiency Tier | CZ | -25% Airflow -25% Charge | 0% Airflow -25% Charge | -25% Airflow 0% Charge | 0% Airflow 0% Charge | REM 15.3 |
| Gas | HERS Ref | CZ2 | 105 | 103 | 101 | 99 | 6 |
| | | CZ4 | 100 | 99 | 98 | 97 | 3 |
| | | CZ6 | 100 | 99 | 99 | 99 | 1 |
| | ESv3 | CZ2 | 78 | 76 | 77 | 74 | 4 |
| | | CZ4 | 80 | 79 | 79 | 78 | 2 |
| | | CZ6 | 75 | 75 | 75 | 74 | 1 |
| | ESv3.1 | CZ2 | 67 | 66 | 66 | 64 | 3 |
| | | CZ4 | 64 | 63 | 63 | 62 | 2 |
| | | CZ6 | 60 | 60 | 60 | 59 | 1 |
| Electric | HERS Ref | CZ2 | 106 | 103 | 102 | 99 | 7 |
| | | CZ4 | 100 | 98 | 99 | 97 | 3 |
| | | CZ6 | 97 | 97 | 98 | 97 | 0 |
| | ESv3 | CZ2 | 79 | 77 | 77 | 74 | 5 |
| | | CZ4 | 83 | 82 | 82 | 82 | 1 |
| | | CZ6 | 78 | 78 | 78 | 79 | -1 |
| | ESv3.1 | CZ2 | 69 | 67 | 67 | 65 | 4 |
| | | CZ4 | 67 | 66 | 66 | 65 | 2 |
| | | CZ6 | 64 | 63 | 63 | 63 | 1 |

# Potential HERS Impact for 25% Defect Level Across Software

| Heat Fuel Type | Efficiency Tier | CZ | Point Potential: REM 15.3 | Point Potential: Ekotrope 2.1 | Point Potential: EG v5 | Point Potential: Delta |
|---|---|---|---|---|---|---|
| Gas | HERS Ref | CZ2 | 6 | 6 | 6 | 0 |
| | | CZ4 | 3 | 2 | 2 | 1 |
| | | CZ6 | 1 | 0 | 0 | 1 |
| | ESv3 | CZ2 | 4 | 3 | 5 | 2 |
| | | CZ4 | 2 | 1 | 2 | 1 |
| | | CZ6 | 1 | 0 | 0 | 1 |
| | ESv3.1 | CZ2 | 3 | 3 | 4 | 1 |
| | | CZ4 | 2 | 1 | 1 | 1 |
| | | CZ6 | 1 | 0 | 1 | 1 |
| Electric | HERS Ref | CZ2 | 7 | 6 | 6 | 1 |
| | | CZ4 | 3 | 3 | 3 | 0 |
| | | CZ6 | 0 | -1 | 0 | 1 |
| | ESv3 | CZ2 | 5 | 3 | 6 | 3 |
| | | CZ4 | 1 | 0 | 3 | 3 |
| | | CZ6 | -1 | -3 | 0 | 3 |
| | ESv3.1 | CZ2 | 4 | 3 | 5 | 2 |
| | | CZ4 | 2 | 1 | 2 | 1 |
| | | CZ6 | 1 | 0 | 0 | 1 |

# Potential HERS Impact Summary

- For homes where the HVAC design and installation is not assessed, score should be about the same as today.
- For homes where the HVAC design and installation is assessed, impact will be:
  - Dependent on climate
  - Dependent on how efficient the rest of the house is
  - Dependent on how well the system is designed and installed.
- While this is still subject to refinement, we predict the following rough impacts for an ENERGY STAR home:
  - Up to ~3 points in hot climates
  - Up to ~2 points in mixed climates
  - Up to ~1 point in cold climates

# Alternative Compliance Paths

## Alternative Compliance Paths

- Primary goal of working group is to define a standard for Raters to assess HVAC design and installation.
- With HVAC design and installation, there may be a reason to include alternative compliance paths in addition to the Rater-verification path.
- Two possible pathways:
  - On-board diagnostics that directly provide data to Raters.
  - Third-party verifiers that collect and provide data in lieu of Raters, with oversight outside of RESNET.

## On-Board Diagnostics

- Key characteristic is that parameters are assessed without human intervention.
- For example, an on-board diagnostic system might assess any or all of the following:
  - Actual system airflow
  - Superheat / subcooling or equivalent
  - Fan wattage
- These values would be accessible to the Rater during the rating process.
- On-board diagnostics would have to meet or exceed the defined accuracy limit of Rater-verified tasks.
- RESNET would rely upon manufacturer claims of accuracy for the short-term.
- RESNET would maintain a list of equipment manufacturer and model numbers that incorporate on-board diagnostics.
- Because Raters will be verifying manufacturer and model numbers, this information could be used as part of a quality assurance initiative.

## Third-Party Verifiers

- Key characteristic is that someone other than a Rater is permitted to collect field data and provide it to the Rater.
- An MOU would likely need to be signed between RESNET and the oversight organization(s) for these alternative verifiers. The oversight organization would need to:
  - Certify/credential the verifiers
  - Provide oversight to their work
  - Perhaps would use the same procedures as Raters to collect the data
  - May need to collect and review the design documentation
  - Preferably would provide data to Raters in a standard format
- This is similar, but more robust, than the current oversight model offered by ACCA and Advanced Energy in support of the ENERGY STAR Homes program.

# Summary

## Summary

- We’ve made a lot of progress since last year.
- 2018 will be a key year for moving this towards completion.
- Hopefully when we see you next year, we’ll have a final or nearly final standard.
- If you’re doing ENERGY STAR today, this new standard will look very familiar to you. The key difference will be the field tests.
- Why wait to get familiar with those?

# Sample Equipment List from CEC

| Product Type | Manufacturer | Model # | Retail Cost | Accuracy | Airflow Range (CFM) |
|---|---|---|---|---|---|
| Pressure Matching | The Energy Conservatory | Minneapolis Duct Blaster Series B | $2,595 | ±3 % of mv | 2.4 - 1,500 |
| Pressure Matching | Retrotec | Model 341 DucTester | $1,745 | ±3 % of mv | 10 - 810 |
| Manometer | The Energy Conservatory | DG-500 | $985 | Greater of ±1 % of mv or ±0.15 Pa | N/A |
| Manometer | Retrotec | DM32 | $1,150 | Greater of ±1 % of mv or ±0.25 Pa | N/A |
| Static Pressure Probe | AAB | PRB-KIT | $25 | N/A | N/A |
| Static Pressure Probe | Fieldpiece | ASP2 | $19 | N/A | N/A |
| Flow Grid | The Energy Conservatory | Trueflow Air Handler Flow Meter | $850 | ±7 % of mv when used with a 1% pressure gauge | 365 - 2,100 |
| Flow Hood | Testo | 420 Flow Hood Kit | $1,975 | ±3 % of mv + 7 CFM | 50 - 2,000 |
| Flow Hood | Alnor (TSI) | EBT730 | $3,272 | ±3 % of mv + 7 CFM | 25 - 2,500 |
| Flow Hood | Kanomax | Capture Hood Model 6710 Version 2 | $2,480 | ±3 % of mv ± 5 CFM | 24 - 2531 |
| Flow Hood | Kanomax | TABmaster Model 6715 | $3,280 | ±3 % of mv ± 5 CFM | 24 - 2531 |