# Checking Your Work:
## Properly Installed HVAC in High-Performance Homes

EEBA High-Performance Home Summit 2019

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United States Environmental Protection Agency


Introduction

# Installation defects in HVAC systems are commonplace

# Installation defects in HVAC systems are commonplace

- Improper airflow:
  - Average airflow ~20% below target. Blasnik et al. (1995)
  - Average airflow 14% below design. Proctor (1997)
  - Measured airflow ranging from 130 - 510 CFM / ton. Parker (1997)
  - 70% of units had airflow < 350 CFM / ton. Neme et al. (1999)
  - Improper airflow in 44% of systems. Mowris et al. (2004)

# Installation defects in HVAC systems are commonplace

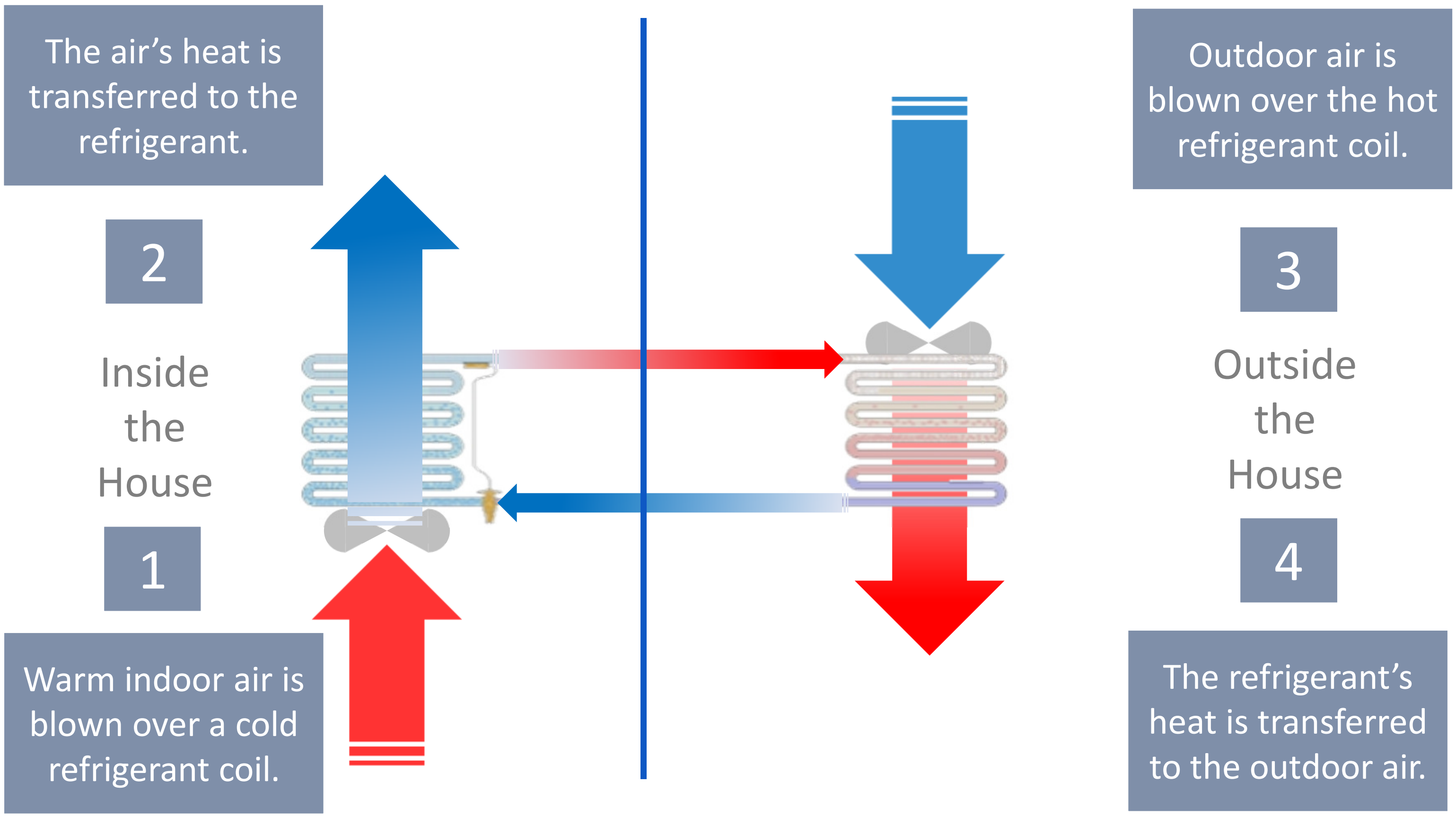
- Incorrect refrigerant charge:
  - In 57% of systems. Downey/Proctor (2002)
  - In 62% of systems. Proctor (2004)
  - In 72% of systems. Mowris et al. (2004)
  - In 82% of systems. Proctor (1997)

# Installation defects in HVAC systems are commonplace

| 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 | New | 30 | 345 | 50% | | 8% | Est @ 33% combined charge/air flow correction benefits |
| Blasnik et al. 1995b | CA | New | 10 | 319 | 90% | | | |
| Blasnik et al. 1996 | AZ | New | 22 | 344 | 64% | 29% | 10% | Est @ 33% combined charge/air flow correction benefits |
| Hammarlund et al. 1992 | CA | New | 12 | | | 30% | 10% | Single family results |
| Hammarlund et al. 1992 | CA | New | 66 | | 76% | 14% | 12% | |
| Neme et al. 1997 | MD | New | 25 | 340 | | | | |
| Palani et al. 1992 | n.a. | n.a. | n.a. | | | | 4% | |
| Parker et al. 1997 | FL | Both | 27 | 270 | 89% | 7% | 10% | |
| Proctor & Pernick 1992 | CA | Existing | 175 | | 44% | | | |
| Proctor 1991 | CA | Existing | 15 | | | 33% | | |
| Proctor et al. 1995a | CA | Existing | 30 | 300 | 80% | 11% | | |
| Rodriguez et al. 1995 | n.a. | n.a. | n.a. | | | | 2% | |
| Rodriguez et al. 1995 | n.a. | n.a. | n.a. | | | | 10% | |
| VEIC/PEG 1997 | NJ | New | 52 | 372 | | 30% | 7% | |
| Average | | | | 327 | 70% | 22% | 8% | |

| 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 | 35% | 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. | | | | 6% | 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



# RESNET/ACCA Std. 310: Guiding Principles

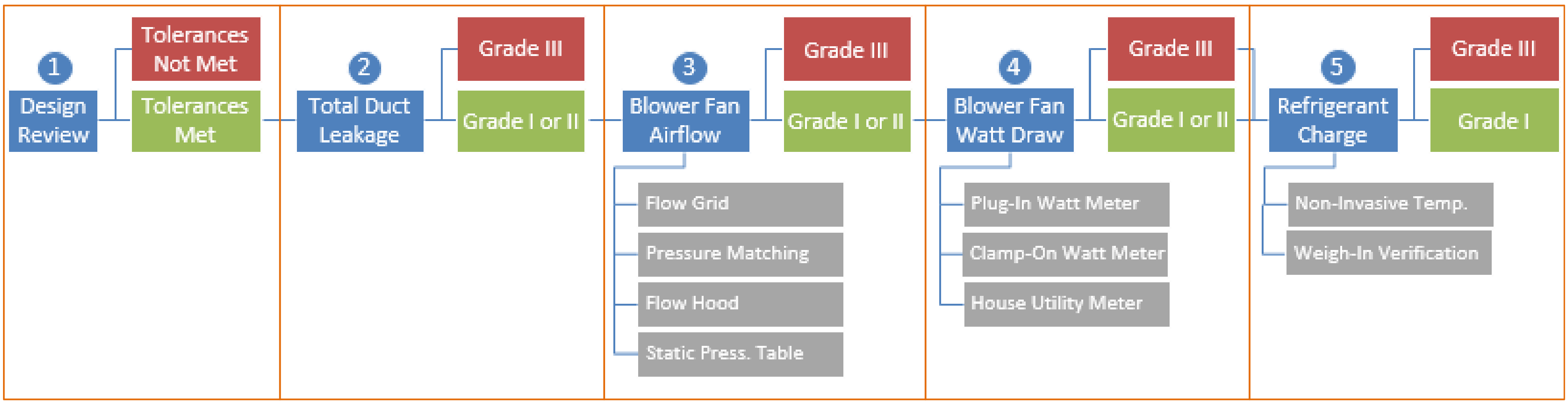
- Take a ‘carrot’ rather than a ‘stick’ approach.
- Reward incremental improvement.
- Include procedures applicable to both Rater and HVAC professionals.
- Ensure the procedures provide value in and of themselves.

# RESNET/ACCA Std. 310: Grading Concept

- Follow the insulation quality-installation model:
  - Grade III: The default. No assessment. No penalty and no credit.
  - Grade II: Assessment completed and the system is ok. Partial credit.
  - Grade I: Assessment completed and the system is very good. Full credit.


Overview of Standard 310:
Standard for Grading the
Installation of HVAC Systems

# Std. 310: Standard for Grading the Installation of HVAC Systems



# Task 1: Design Review

# Task 1: Evaluating the design of the forced-air system

1. Rater collects design documentation for the dwelling with the HVAC system under test.
2. Rater reviews design documentation for completeness and compares it to the dwelling to be rated. Key features must fall within tolerances defined in the standard. For example:

| | | |
|---|---|---|
| Floor Area | Outdoor Design Temps | Insulation Levels |
| Window Area | # Occupants | Infiltration Rate |
| Indoor Design Temps | Window SHGC | Ventilation Rate |

3. If tolerances are met, proceed to next task. Otherwise stop here.

# Task 2: Total Duct Leakage

# Task 2: Evaluating the total duct leakage

1. Rater measures total duct leakage according to Std. 380, evaluates the results, and assigns 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 |

2. If Grade I or II is achieved, proceed to next task. Otherwise stop here.

# Task 3: Blower Fan Airflow

# Task 3: Evaluating the Blower Fan Volumetric Airflow

- Raters measure the total volumetric airflow going through the blower fan using one of four test methods:
  A. Pressure Matching
  B. Flow Grid
  C. Flow Hood
  D. OEM Static Pressure Table
- This is just a single measurement. It is not measuring the airflow from each register and summing those.

# Task 3: Evaluating the Blower Fan Volumetric Airflow

## A. Pressure Matching

1. Measure static pressure created in supply plenum during operation of HVAC system.
2. Turn off HVAC system, connect a fan-flowmeter at the return or at the blower fan compartment.
3. Turn on the HVAC system and the flowmeter fan and adjust to achieve same static pressure in supply plenum.
4. Determine HVAC airflow by recording airflow of flowmeter fan.

# Task 3: Evaluating the Blower Fan Volumetric Airflow

## A. Pressure Matching

| Pros | Cons |
|---|---|
| Uses equipment many Raters already own | Can't reach high flows for big systems: needs extrapolation |
| Accurate: +/- 3% | Need at least one large return duct or must connect at equipment |
| | Requires hole in supply plenum |

# Task 3: Evaluating the Blower Fan Volumetric Airflow

## B. Flow Grid

1. Measure static pressure created in supply plenum during operation of HVAC system.
2. Install flow grid in filter slot.
3. Measure pressure difference at flow grid and convert to airflow.
4. Re-measure static pressure in same location as Step 1, and correct airflow.

# Task 3: Evaluating the Blower Fan Volumetric Airflow

## B. Flow Grid

| Pros | Cons |
|---|---|
| Easy/simple for many systems | Multiple filter slots in a single system require multiple flow grids |
| Can work at higher flows | Need to make sure a good seal is achieved around the plate perimeter |
| | Slightly less accurate +/- 7% |
| | Requires hole in supply plenum |

# Task 3: Evaluating the Blower Fan Volumetric Airflow

## C. Flow Hood

1. Turn on HVAC system.
2. Connect flow hood to return grille.
3. Turn on flow hood and allow reading to stabilize. This may require an additional step to account for back-pressure.
4. Resulting airflow of flow hood determines HVAC airflow.

# Task 3: Evaluating the Blower Fan Volumetric Airflow

## C. Flow Hood

| Pros | Cons |
|---|---|
| Accurate: +/- 3% | Can be heavy/unwieldy |
| Easy to use | Can be sensitive to placement |
| Does not require hole in supply plenum | Can be expensive |
| | Will not always fit around air inlet |

# Task 3: Evaluating the Blower Fan Volumetric Airflow

## D. 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 |

# Task 3: Evaluating the Blower Fan Volumetric Airflow

## D. OEM Static Pressure Table

| Pros | Cons |
|---|---|
| Inexpensive equipment | Rater required to get OEM Blower Table for installed equipment |
| Works for systems of all sizes and airflows | Needs carefully-placed hole in supply-side and return-side, sometimes in equipment housing |
| | |

# Task 4: Blower Fan Watt Draw

# Task 4: Evaluating the Blower Fan Watt Draw

- Raters evaluate the watt draw of the blower fan using one of three test methods:
  A. Plug-In Watt Meter
  B. Clamp-On Watt Meter
  C. Utility Meter

# Task 4: Evaluating the Blower Fan Watt Draw

## A. Plug-In Watt Meter

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

# Task 4: Evaluating the Blower Fan Watt Draw

## A. Plug-In Watt Meter

| Pros | Cons |
|---|---|
| Simple | Not usable with hard-wired equipment |
| Direct measurement of equipment | |

# Task 4: Evaluating the Blower Fan Watt Draw

## B. Clamp-On Watt Meter

1. Turn on equipment in required mode.
2. Connect clamp-on watt meter to measure voltage and current at either the service disconnect or through a service panel (not at breaker panel).
3. Record reading from clamp-on watt meter.

# Task 4: Evaluating the Blower Fan Watt Draw

## B. Clamp-On Watt Meter

| Pros | Cons |
|---|---|
| Useable with hardwired equipment that has service panel or service disconnect | Requires proper training and safety equipment |
| Direct measurement of equipment | |

# Task 4: Evaluating the Blower Fan Watt Draw

## C. Utility Meter

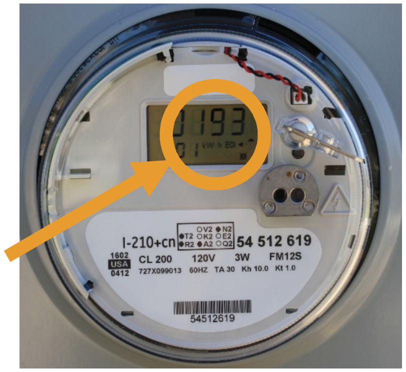
1. Turn off all circuits except air handler’s.
2. Turn on equipment in required mode.

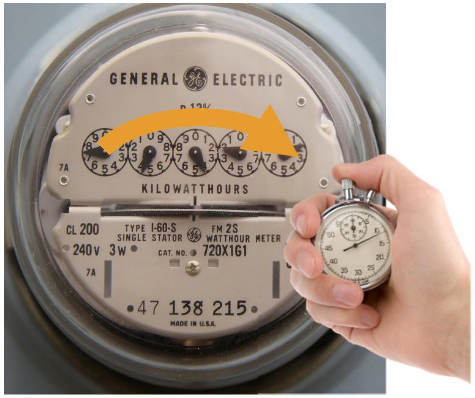
For a digital utility meter:

3. Record watt draw from utility meter.

For an analog utility meter:

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



# Task 4: Evaluating the Blower Fan Watt Draw

## C. Utility Meter

| Pros | Cons |
|---|---|
| Works with all equipment | Indirect measurement, and some meters are less sensitive to low watt draw. |
| No new equipment needed | Turning off all other circuits can be disruptive |

# Task 5:
# Evaluating Refrigerant Charge

# Task 5: Evaluating the Refrigerant Charge

- Raters evaluates the refrigerant charge of the system using one of two test methods:
  A. Non-Invasive Method
  B. Weigh-In Verification Method - Only for select equipment & conditions

# Task 5: Evaluating the Refrigerant Charge

## A. Non-Invasive Method

- ‘Non-invasive’ means no gauges connected to refrigerant system.
- Instead, the temperature of the air and refrigerant lines are used.
- Triage systems into two bins:
  - Grade I – Charge is okay
  - Grade III – Charge is not okay

Refrigerant Gauges Not Connected

Temperature Sensors Used Instead

# Task 5: Evaluating the Refrigerant Charge

## A. Non-Invasive Method

1. Determine SEER and mfr-specified superheat / subcooling value.
2. Measure outdoor air and return air temperatures.
3. Use to calculate target temperatures for suction line and liquid line.
4. Measure actual temperatures for suction line and liquid line.
5. Compare target to actual temperatures; if they are close enough, then the system is properly charged.

# Task 5: Evaluating the Refrigerant Charge

## A. Non-Invasive Method

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

# Task 5: Evaluating the Refrigerant Charge

## B. Weigh-In Verification Method

- Non-invasive method can't be used for:
  - All outdoor conditions.
  - Mini/multi-split systems.
- In such cases, the weigh-in verification method is used instead.
- Method is primarily a document review rather than a performance test.

# Task 5: Evaluating the Refrigerant Charge

## B. Weigh-In Verification Method

- Contractor provides:
  A. Weight of refrigerant added / removed
  B. Line length and diameter
  C. Default line length from factory charge (usually 15 feet)
  D. Factory supplied charge
  E. Geotagged photo of scale with weight added / removed

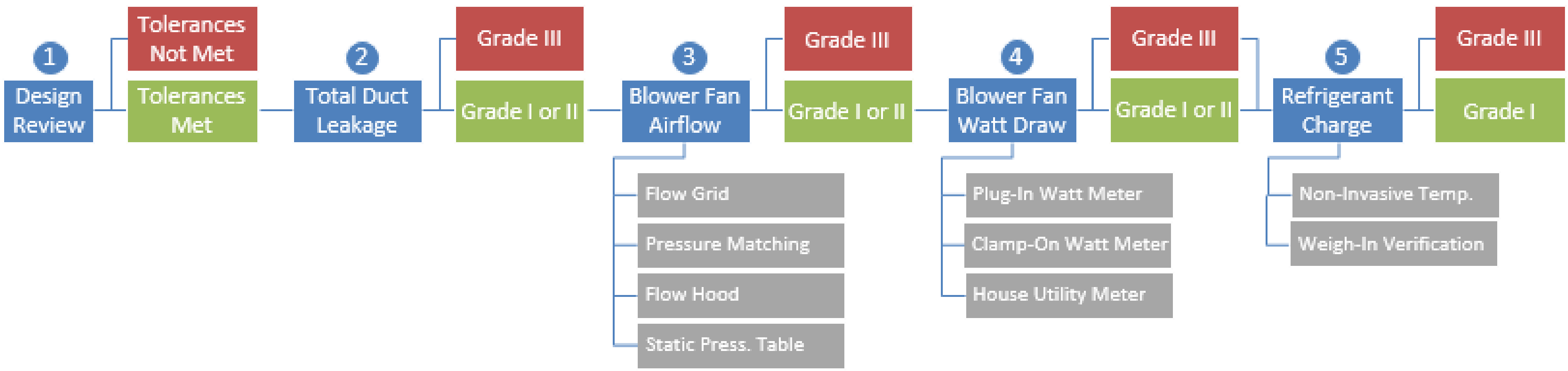
- Rater then:
  1. Measures line length and diameter
  2. Uses lookup table to determine how much refrigerant should have been added / removed
  3. Verifies the deviation between the lookup and contractor values are within tolerance
  4. Verifies location of geotagged photo matches the location of the equipment

# Task 5: Evaluating the Refrigerant Charge

## B. Weigh-In Verification Method

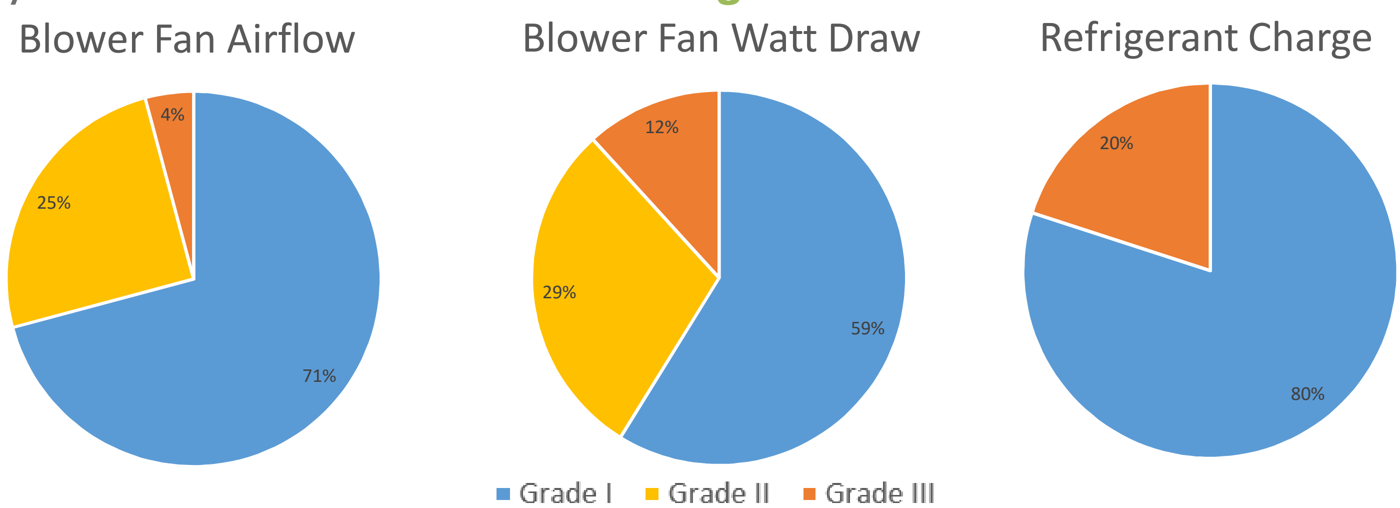
| Pros | Cons |
|---|---|
| No refrigerant handling certification needed | Requires information from contractor |
| Works at any outdoor temperature | Not a true performance test |

# Std. 310: Standard for Grading the Installation of HVAC Systems



# Field Test

- Six providers evaluated **18 systems** and performed **63 individual tests**.
- Required HVAC warm-up time is 15 minutes, but Raters can do other tasks during this time. After that, average time for all tests was **26 minutes**.
- Most systems achieved a **Grade I designation**:



# How HVAC Grading Will Improve Your Homes

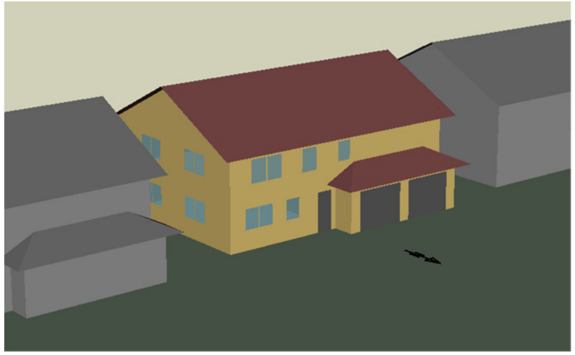
# #1 - Extra Points in Energy Ratings

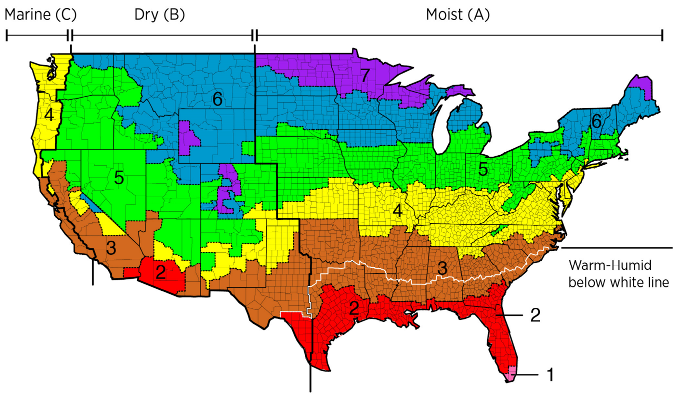
# Acknowledgment

- Jon Winkler, Ph.D.
  - Senior Research Engineer
  - Building Energy Science Group
  - National Renewable Energy Laboratory

# House Parameters

- New construction, single-family home
  - 3 bed + 2 bath; 2,500 sq. ft
  - Construction based on 2009 IECC
  - Construction and foundation type varied by climate
  - Simulations followed RESNET Standard 301
- Simulated locations
  - CZ 2 – Houston, TX
  - CZ 3 – Atlanta, GA
  - CZ 4 – Washington, DC
  - CZ 5 – Chicago, IL





# Equipment Assumptions

- Equipment types
  - SEER 14 air conditioner and gas furnace
  - SEER 14, 8.2 HSPF central heat pump
- Equipment assumptions
  - 0.5 W/cfm fan efficiency
  - Manufacturer recommended airflow is 400 cfm/ton

# Defect Scenarios

- Four scenarios were analyzed, where the 'fault' is the % deviation from manufacturer-recommended values:

| Parameter | Scenario 1: No Fault | Scenario 2: Airflow Fault | Scenario 3: Charge Fault | Scenario 4: Both Faults |
|---|---|---|---|---|
| Airflow defect level | 0% | -25% | 0% | -25% |
| Refrig. charge defect level | 0% | 0% | -25% | -25% |

- Generally speaking, in Standard 310:
  - Grade III = -25% fault
  - Grade I = 0% fault

# Estimated Maximum ERI Impact

| System Type | Location | | Scenario 1: No Fault | Defect Scenario Point Potential | | |
|---|---|---|---|---|---|---|
| | | | | Scenario 2: Airflow Fault | Scenario 3: Charge Fault | Scenario 4: Air & Charge Fault |
| AC | Houston, TX | CZ 2 | 71 | 1.5 | 2.9 | 4.5 |
| | Atlanta, GA | CZ 3 | 76 | 1.2 | 1.6 | 2.9 |
| | Washington, DC | CZ 4 | 78 | 0.9 | 1.1 | 2.1 |
| | Chicago, IL | CZ 5 | 80 | 0.5 | 0.3 | 0.8 |
| HP | Houston, TX | CZ 2 | 72 | 1.9 | 4 | 6.0 |
| | Atlanta, GA | CZ 3 | 75 | 2.8 | 4.7 | 7.0 |
| | Washington, DC | CZ 4 | 77 | 3.3 | 4 | 6.7 |
| | Chicago, IL | CZ 5 | 74 | 3.5 | 3.6 | 6.1 |

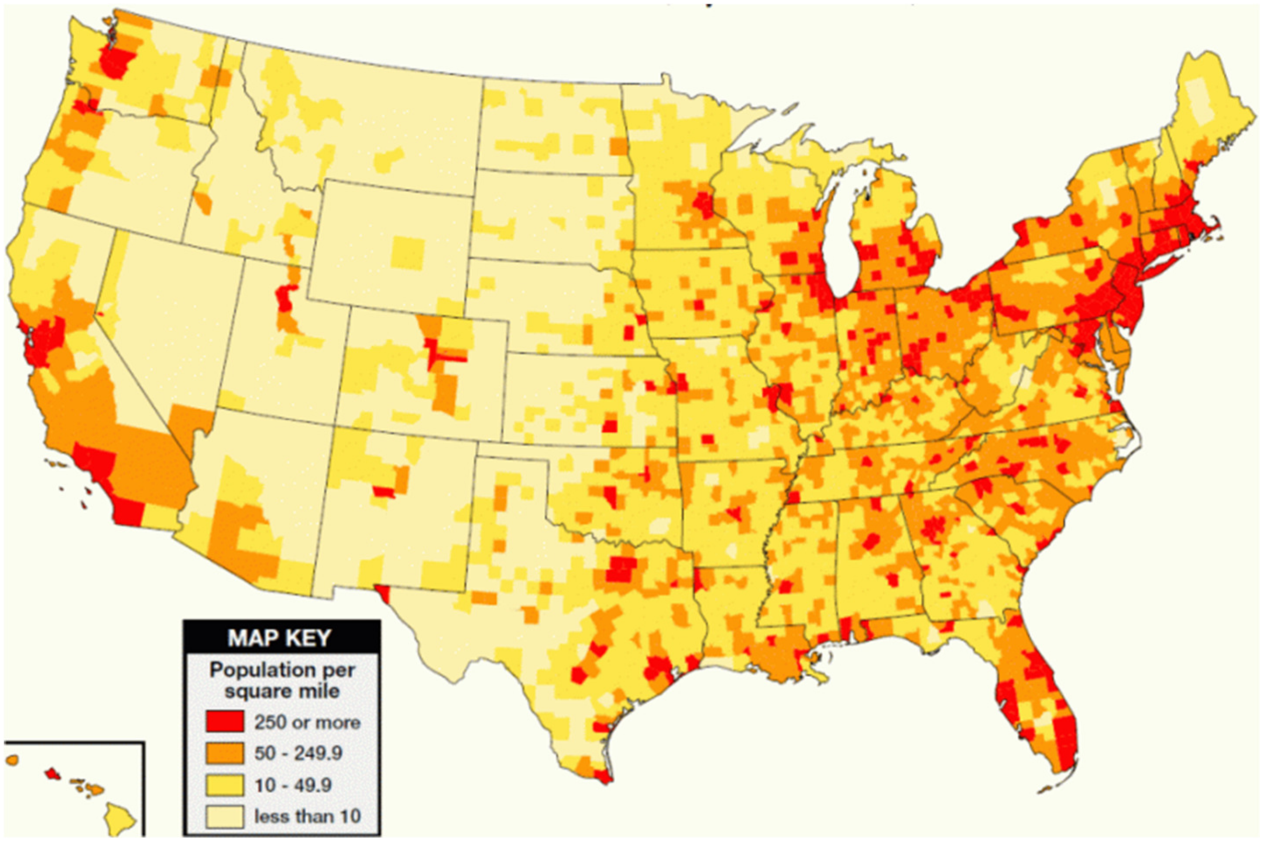
- Caveats:
  - For homes better than 2009 IECC, smaller point potential
  - This is the max potential. Many homes will get partial credit.
  - Fine-tuning may still occur in Standard 310

# Modeling Summary

- Previous work by RESNET Working Group:
  - Initial estimate of point potential using cursory modeling.
  - Air conditioners:
    - Hot climates: ~3 points
    - Mixed climates: ~2 points
    - Cold climates: ~1 point
  - Heat pumps: Non-intuitive low potential in cold climates.
- NREL's approach:
  - Shows similar trends for air conditioners, but with higher potential, partially due to lower efficiency home.
  - More intuitive results for heat pumps.
  - Lays groundwork for software programs to ensure installation quality impacts get modeled consistently.

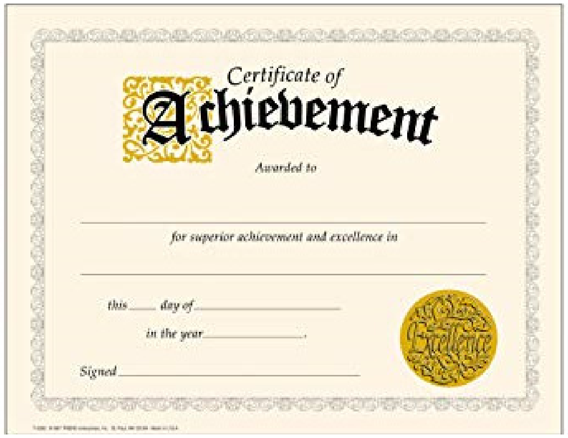
# #2 - Provides Alternative to Requirement for Credentialed Contractor

# Service providers are harder to find in small markets



# HVAC grading provides a new alternative

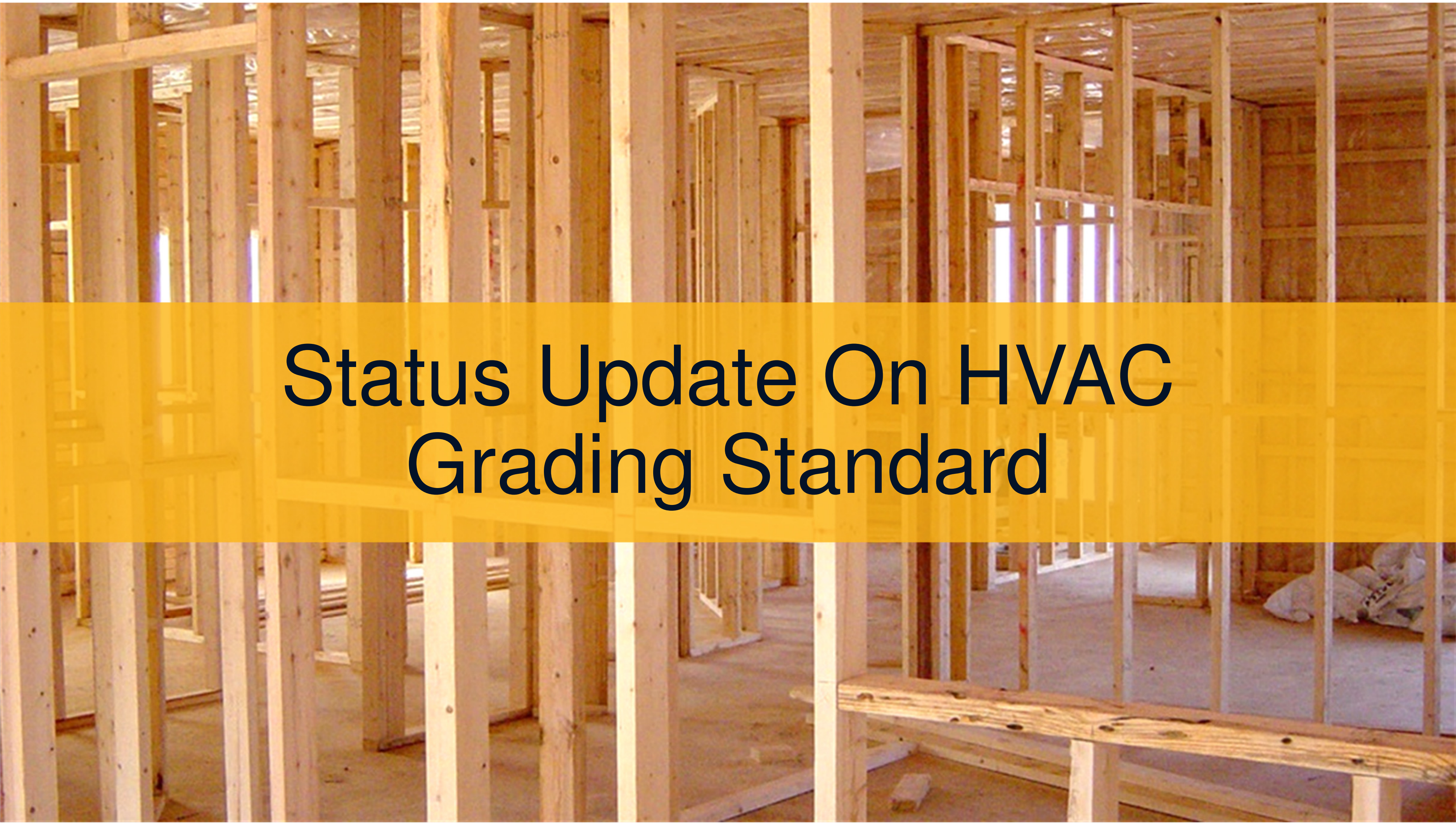
- You may still choose to work with credentialed contractors.
- But like duct leakage, standard Rater procedures can be used in lieu of a credential.




# #3 - Streamlines ENERGY STAR Program Requirements

# Streamlines ENERGY STAR program requirements

- An energy rating completed with certain features locked in:
  - Target score
  - Grade I insulation
  - Grade I or II HVAC grading
  - Minimum insulation levels, window/door ratings, duct leakage
- Plus:
  1. Bedroom pressure-balancing for comfort
  2. Reduced thermal bridging for comfort
  3. Air sealing details for efficiency and comfort
  4. Indoor air quality features for health
  5. Water management system features for durability, required by code


Status Update On HVAC
Grading Standard

# Status Update

1. **Standard 310: HVAC Grading Standard**
   - **What it does:** Defines how the Rater completes the design review, field tests, and designates the grade.
   - **Status:**
     - 1st comment period has concluded
     - 2nd comment period should commence in November
     - Aiming to finalize in Q1 2020

# Status Update

2. **Standard 301: Energy Ratings Update (Non-calcs):**
   - **What it does:** Integrates Std. 310 into the overall rating process; updates definitions, minimum rated features, and on-site inspection protocols.
   - **Status:**
     - Submitted in September
     - Aiming to finalize in Q1 2020

# Status Update

3. **Std. 310 HVAC Design Report Templates:**
   - **What it does:** Incorporates Std. 310 design documentation requirements into Wrightsoft and RHVAC templates.
   - **Status:**
     - Discussions have started
     - Aiming to finalize in Q2 2020

# Status Update

4. **RESNET Rater Training:**
   - **What it does:** Trains raters on new requirements in Std. 310, prior to use.
   - **Status:**
     - Development has started
     - Aiming to finalize in Q2 2020

# Status Update

5. **Calculations Update:**
   - **What it does:** Updates standards and software to provide credit for properly installed HVAC systems.
   - **Status:**
     - In process – discussing with RESNET the value of rewarding properly installed HVAC systems in both ERI ratings and HERS ratings.
     - More to come..


Q & A
BLUE STAR LINE