Codes and Standards Enhancement (CASE) Initiative **2022 California Energy Code**

# Evaluation of Test Procedures for Whole House Fan Airflow Measurement

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# 1. Background and Objectives

## 1.1 Purpose

This field study was conducted to satisfy two main objectives:

1. **Evaluate a New Attic Pressure Matching Procedure.** Evaluate the accuracy and practicality of use for a whole house fan (WHF) airflow measurement procedure that uses a fan flowmeter instrument ducted to the WHF inlet and uses a technique for pressure matching of the building's attic with respect to conditioned space. The procedure may be proposed to be added to 2022 Residential Appendix RA3.9 for use for HERS verification of WHF airflow.

2. **Reevaluate the Existing Blower Door Pressure Matching Procedure.** Reevaluate the accuracy of the RA3.9.4.1.1 WHF Airflow Rate Measurement procedure that uses a fan flowmeter mounted in a blower door apparatus and uses a technique for pressure matching of the conditioned space with respect to outside.

## 1.2 Background

### 1.2.1 Prescriptive and Performance Compliance Requirements for Whole House Fans

Whole house fans (WHFs) are prescriptively required by the 2019 Title 24, Part 6 Standards in Climate Zones 8 through 14 (Table 150.1-A). To meet prescriptive requirements one or more WHFs must be installed whose total airflow is equal to or greater than 1.5 cubic feet per minute per square foot (cfm/ft$^2$) of conditioned floor area. Section 150.1(c)12 requires at least one square foot of attic vent free area must be provided for each 750 cfm of rated WHF airflow. For prescriptive compliance, airflow is determined based on the airflow listed in the Energy Commission's database of certified appliances (MAEDBS).

When performance compliance requires installation of a whole-house fan, the ventilation airflow rate and fan efficacy must be field verified in accordance with the procedures in Reference Residential Appendix RA3.9. These procedures include measurement of airflow and efficacy to confirm that the values entered in compliance software are consistent with the measured values.

### 1.2.2 Fan Types and Airflow Capacity

The MAEDBS lists 164 WHF models from 11 manufacturers. Airflows range from 800 to 9,200 cfm and average 3,263 cfm across all models. The MAEBS defines four different fan types: belt drive single (7), belt drive dual (4), direct drive single (132), direct drive dual (13), and other (8). The direct drive single and belt drive categories include older style ceiling mounted fans with gravity operated shutters. Most of the listed direct drive single fans are ducted and include automatic insulated shutters. Approximately nineteen of the listed products are of the older ceiling mounted direct drive or belt drive types which tend to be noisier. The direct drive dual types are a newer style of ceiling mount fan and include automated insulated shutters.

### 1.2.3 Airflow Measurement Devices

Airflow measurement devices are certified by the Energy Commission and are listed at https://www.energy.ca.gov/rules-and-regulations/building-energy-efficiency/manufacturer-certification-building-equipment-9. Currently certified products for testing whole house fans include three blower door systems[1] and one capture hood that can be used with a blower door fan flowmeter as a powered capture hood. The sole powered capture hood listed by the Energy Commission is designated in the listing as QC Manufacturing Model PFD-WHF. The manufacturer's model number is WHF-PFH[2]. This hood is compatible with all three of the blower door systems  It can measure airflows up to 5400 cfm and can cover grille up to 26.5 inches x 38.5 inches, which is suitable for traditional 24 inch WHFs as well as newer styles.

The Energy Commission's list of certified devices does not currently include any non-powered capture hoods.

### 1.2.4 Airflow Measurement Test Procedures in the 2019 Residential Appendices

RA3.9.3 provides for three alternative means of airflow verification as follows:

**RA3.9.4.1.1**: **Blower Door Pressure Matching**. This procedure utilizes the same kind of blower door apparatus used to measure envelope leakage. With the blower door blocked off and the WHF set to exhaust the required cfm, window openings are adjusted to obtain a negative 10 Pa ±5 Pa WRT outside. Then the WHF intake is sealed off and the blower door fan flowmeter is operated and adjusted to obtain the same indoor-outdoor pressure difference, and the airflow is recorded.

**RA3.9.4.1.2: Powered Flow Capture Hood.** This procedure measures the airflow at the WHF inlet grille using a powered capture hood. The capture hood must fully cover the inlet grille. As in the prior test, windows are adjusted to maintain a negative 10 Pa

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[1] A "blower door system" consists of a fan flowmeter, a digital manometer, and a fabric and frame assembly for covering the doorway and to which the fan flowmeter attached.

[2] https://www.sierrabuildingscience.com/products/quietcool-hers-powered-flow-hood-model-whf-pfh?variant=32033317027910

±5 Pa WRT outside while the WHF is running. Then the capture hood is attached to the WHF inlet grille, the WHF is operated without changing the speed, and the fan flowmeter is adjusted to obtain a static pressure difference between the capture hood enclosure and indoor air that is no greater than 0.0 ± 0.2 Pa (.0008 inches water) and the airflow is recorded. The static pressure balancing may be accomplished using an automated function provided by the device, or the adjustment may be performed manually by adjusting the speed of the fan flowmeter.

**RA3.9.4.1.3: Traditional Non-Powered Capture Hood**: This procedure uses a passive (non-powered) flow capture hood device to measure airflow at the WHF inlet grille. Non-powered capture hoods (or balometers) are typically used for balancing the flow at supply grilles. This RA section similarly requires that the capture hood must be able to fully cover the opening.

### Attic Vent Area Considerations

The ability of whole house fans to deliver their specified volume of air can be limited by attic vent area. Inadequate attic vent area increases the pressure difference between indoor space and the attic, causing the fan to deliver less air because of the higher static pressure, and also because it increases the recirculation of air between indoors and the attic through air leaks in the ceiling.

The 2019 Title 24, Part 6 standards require an attic vent area of 750 cfm per square foot of conditioned floor area, but it is not required to be verified by a HERS Rater. Section 1203.3 of the California Building Code (Title 24, Part 2) requires a minimum net free ventilating area of 1/150$^{th}$ of the area of the space ventilated but it can be reduced to 1/300th if high and low vents are provided as specified in the code.

Compliance with California Building Code requirements may not be sufficient. For example, the 2,100 ft$^2$ single story Title 24 prototype house would require a 3,150 cfm fan (using the prescriptive 1.5 cfm/ft$^2$ airflow) and at least 4.2 ft$^2$ of attic vent area. Per the California Mechanical Code the attic vent area must be at least 14 ft$^2$ or may be 7 ft$^2$ if it complies with the California Mechanical Code requirements for high/low venting. For this example, the California Mechanical Code -required vent area is sufficient. For the 2,700 ft$^2$ two-story prototype the prescriptive whole house fan must deliver at least 4,050 cfm, and at least 5.4 ft$^2$ of attic vent area is required. If the attic area is half the conditioned floor area, then per the California Mechanical Code the attic vent area could be as low as 4.5 ft$^2$ if the builder uses the high/low venting option, and the attic vent area would not meet WHF vent requirements.

### 1.2.5 Prior Test Results and Issues with Current Verification Methods

Field research performed in 2017 to support updates to the 2019 California Energy Code found the blower door method produced lower airflows than the powered capture hood in three of the houses and greater airflows in the fifth house (California Energy Commission 2017). Results of those tests are shown in Table 1.

**Table 1: Results of 2017 Blower Door Tests**

| Test Method | House 1 | House 2 | House 4 | House 5 | House 5 |
|---|---|---|---|---|---|
| Capture Hood | 1,310 | 1,775 | n/a | n/a | n/a |
| Blower Door | 1,460 | 1,804 | 2,777 | 3,000 | 4,389 |
| Powered Capture Hood | 1,662 | 1,859 | 2,950 | 2,850* | 3,313* |
| Blower Door vs. Powered | -12% | -3% | -6% | 5% | 32% |

* Louver was taped to make up the difference in size between the louver and the smaller capture hood.

Subsequent to adoption of the 2019 Title 24, Part 6 Standards, Energy Commission staff and technical consultants performed additional field research and determined that the powered capture hood used in the 2017 field research mentioned above was not reliably accurate at high airflow rates, and that the RA3.9.4.1.1 blower door pressure matching procedure could yield results that are lower than actual flow through the WHF grill. The amount of the error corresponds to the amount of air leakage from the attic back into the conditioned space during WHF operation. The RA3.9.4.1.1 blower door pressure matching method is also susceptible to error when outdoor conditions are windy and the indoor-outdoor pressure differential (negative 10 Pa ±5 Pa) is not maintained.

## 1.3 Proposed New Attic Pressure Matching Procedure

A new test method is proposed that allows the use of a fabricated duct assembly. The test is conducted by running the whole house, determine the attic pressure, then connecting a fan flowmeter to the WHF intake using a duct, adjusting the fan speed to match the previous attic pressure, and recording the airflow. Because the attic-to-indoor air pressure differential is relatively large, higher accuracies may be attained. Additionally, this procedure yields important information about attic pressure and the proper installation of attic vents. This procedure allows any means to be used to connect a fan flowmeter to the WHF intake. The method is described in detail in Section 3.3 and is pictured in Figure 7 Appendix A.

# 2. Test Planning and Execution

## 2.1 House Selection and Recruitment

Houses built under the 2013, 2016, or 2019 Title 24, Part 6 Standards were targeted. In addition, homes were sought that meet the following criteria:

- Houses with single whole house fans representing a mix of types and models (at least two different manufacturers)
- Mix of one and two-story homes
- Range of floor areas from 1200 $ft^2$ to 3600 $ft^2$

Given the possibility that attic vent area is insufficient to maintain reasonably low attic pressure, it was important to test two story homes since attic pressures will be higher due to reduced soffit vent area which will impact ventilation airflow. This will be helpful in analyzing the performance of the RA3.9.4.1.1 blower door pressure matching accuracy since high attic pressure may drive increased leakage back into the conditioned space.

A $125 finder's fee was offered to contractors and a $400 incentive to builders and homeowners offering their homes for testing. Given the difficulty of securing access for testing, it was not possible to find houses with WHFs from more than two manufacturers.

To identify test sites, the following contacts were made:

- **Manufacturers:** Four manufacturers were contacted to gain support for the proposed testing and obtain suggestions for identifying test sites. They included AirScape, QuietCool, Tamarack, and Triangle Engineering. AirScape and QuietCool responded. Dealer contact information was obtained from manufacturer websites.
- **Dealers/Installing Contractors**: 22 dealers and installing contractors were contacted by email. Contractors included home improvement contractors and HVAC installers specializing in existing and new home construction. With one exception, these contacts did not yield any test sites. Installers were either not interested, too busy to respond, or reluctant to intrude on their customers particularly in view of the COVID-19 environment.
- **Builders**: Builder contacts were obtained from prior Frontier associations and through direct contact and referrals from QuietCool and their dealers. Two test sites were obtained by visiting sales offices in the Winters Stones Throw development and directly contacting construction superintendents for Homes by Towne and K Hovnanian. These homes were completed but not occupied. A third new home test site located in Fairfield was identified through a QuietCool installer (Site 5).

- **CalCERTS**: CalCERTS maintains a 1200 $ft^2$ home used for test purposes in Folsom and was willing to provide access for testing. However, the home is of an older vintage and deemed too small relative to current construction to use for these purposes.
- **Social Media**: NextDoor Davis was used to identify homeowners interested in testing and yielded a home built in 2017.
- **Internal:** A Frontier employee offered their home for testing. The home was built in the 1990's but was recently upgraded (windows and insulation) to 2013 code level. It is equipped with an AirScape fan. Since all other sites use QuietCool products it was desired to test at least one other WHF product.

Table 2 lists the sites that were selected for testing, their vintage, and fan type. All of the WHFs were of the ducted type, that is the fan is suspended from the roof trusses and ducted to an automatic damper installed in the ceiling.

**Table 2: Testing Sites and Descriptions**

| Site # | Location | House Description & Year Built | WHF Type |
|---|---|---|---|
| 1 | Winters, CA | Two-story, 1763 $ft^2$, 2020 | QuietCool |
| 2 | Winters, CA | Two-story, 2778 $ft^2$, 2020 | QuietCool |
| 3 | Davis, CA | Two-story, 2375 $ft^2$, 1988 upgraded to 2013 standards | AirScape |
| 4 | Davis, CA | Two-story, 2892 $ft^2$, 2017 | QuietCool |
| 5 | Fairfield, CA | One story, 1860 $ft^2$, 2020 | QuietCool |

## 2.2 Test Equipment

Test equipment included an Energy Conservatory blower door, fan flowmeter, and three Energy Conservatory DG-700 manometers. The same fan flowmeter was used to measure airflow for all tests.

A capture hood was recently developed specifically for measuring WHF airflow. This device can be used to measure airflow using the current RA3.9.4.1.2 (Powered Flow Capture Hood) method as well as the new proposed attic pressure matching method. Produced by QuietCool Manufacturing as the Model WH-PFH, it is referred to in this report as simply the "PFH".

In addition, an airflow capture assembly was shop-fabricated to test a fan flowmeter ducted to the inlet grille of the WHF (see Figure 7) to evaluate the attic pressure matching method using a duct connection instead of the PFH. This apparatus used a washing machine drain pan with a duct collar for applying over to the WHF grille, a plywood adapter for connecting to the fan flowmeter, and a 24 inch flex duct to connect the two. At one of the houses, measurements using this “fabricated duct assembly” were compared to measurements using the PFH for evaluating the new proposed test method at one of the houses...

In all, four airflow measurement procedures and devices were tested:

1. The RA3.9.4.1.1 Blower Door procedure that uses pressure matching of the indoor pressure with respect to outside.
2. The RA3.9.4.1.2, powered flow capture hood procedure.
3. The new attic pressure matching procedure using the PFH.
4. The new attic pressure matching procedure using the fabricated duct assembly.

The fabricated duct assembly was not available until the final house was tested (Site 5). For consistency of measurement, the same fan flowmeter was used with the Energy Conservatory blower door, the PFH, and the fabricated duct assembly.

An unscheduled measurement was made at Site 5 using a Shortridge CFM-88L non-powered flow hood as permitted under RA3.9.4.1.3 (see Figure 8). This device incorporates vanes that can be manually operated to impose a restriction which it uses to adjust the airflow measurement to compensate for the overall restriction imposed by the flow hood. While this test was not requested, the flow hood was available, and it required little additional time to complete the measurement.

## 2.3 Detailed Test Procedures

### 2.3.1 Initial Setup

1. Set up the blower door in an outside doorway as described in Reference Appendix RA3.8.3.
2. Set up the powered flow capture hood as described in Section 2 of the PFCH Operation Manual so it is ready to install immediately after the blower door tests are complete.
3. Set up three manometers, one for measuring indoor-outdoor pressures, one for indoor-attic pressures, and one for reading airflow using the fan flowmeter.

### 2.3.2 Airflow Measurement Test Procedure

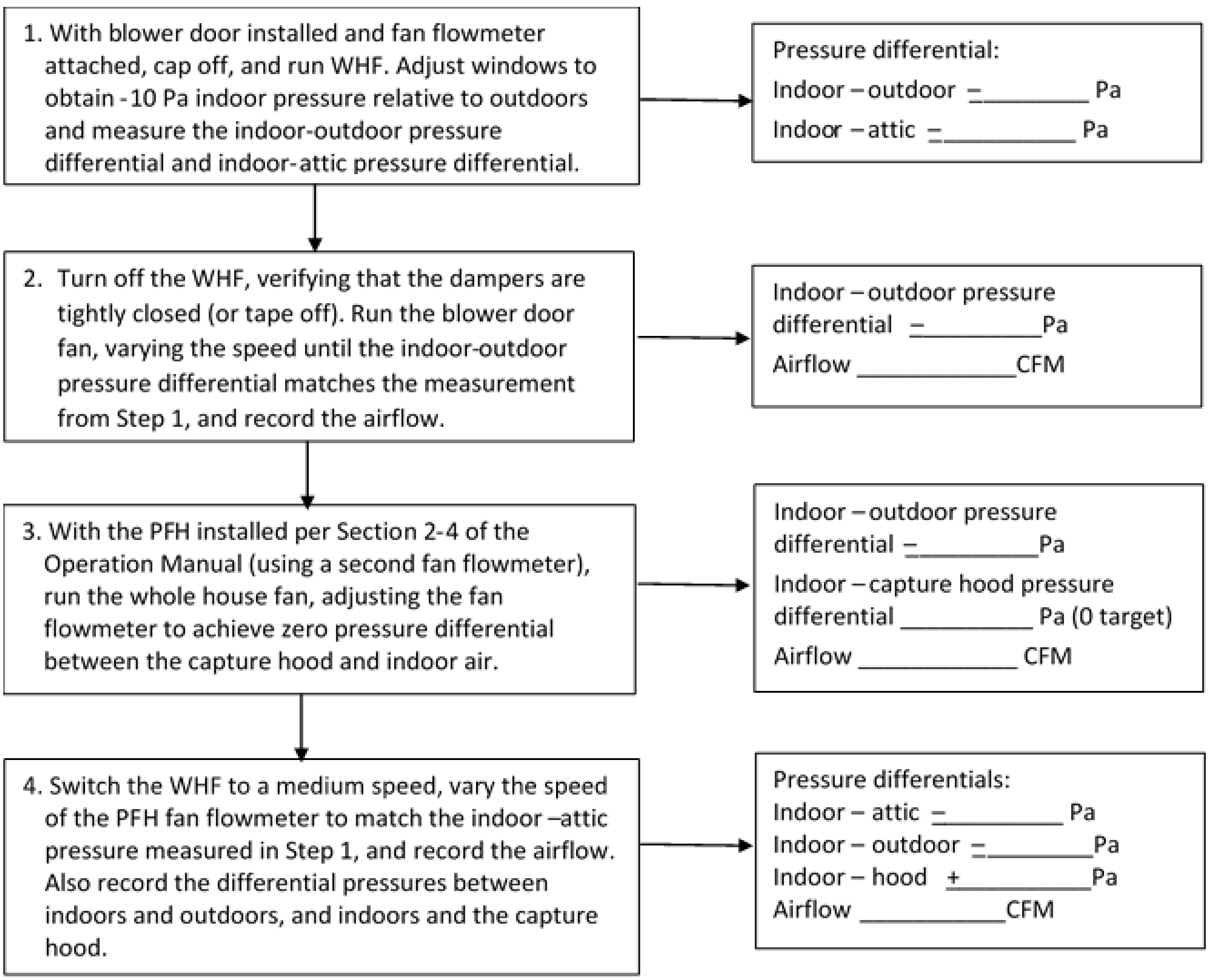
Forms were developed and filled out for each site to record the name of the owner or builder, the key contact person (including phone and email address), the address or lot number of the test site, names of those completing tests, the date and time of the tests, and house information including:

- Floor area and number of stories
- The required WHF ventilation rate (at 1.5 cfm per $ft^2$)

- The brand of the fan and the model number if available
- The speed at which testing was completed
- Estimated wind velocity
- Other notable observations

A data sheet (see Figure 1) was also created that outlines the test procedures and provides for recording measurements and results. Measurements were first taken using the blower door then using the PFH. The indoor-attic pressure differential used for pressure matching in Step 4 was obtained during the blower door tests completed in Step 1.

**Figure 1: Test Data Sheet**



When setting the indoor pressure and when matching pressures, the manometers were first set to average on 1 or 5 second intervals. When readings were close to the desired pressure, they were switched to 10 second averaging and the average of three subsequent 10 second readings was recorded. When using the averaging feature of the DG-700 digital manometers, it is easy to make the mistake of not clearing prior data which can lead to erroneous readings. Averaged data was cleared after each measurement before taking new readings using the *Start* button.

### 2.3.3 Analysis of Test Data

Airflows measured using the three methods were reviewed to compare measured airflows and pressure readings that might explain differences in the measurements. For example, if high attic pressures were observed the possibility of correlating attic pressure to airflow reading error was reviewed to determine whether a correction factor could be applied to the blower door tests.

## 2.4 COVID-19 Safety Protocols

Prospective test candidates were provided with Frontier / PG&E COVID-19 safety guidelines and a description of the purpose of testing. A sample is provided in Appendix B. Approvals for visits were processed through Frontier's Field Work Request and a Stage 2 Project Checklists were provided to PG&E.

# 3. Test Results

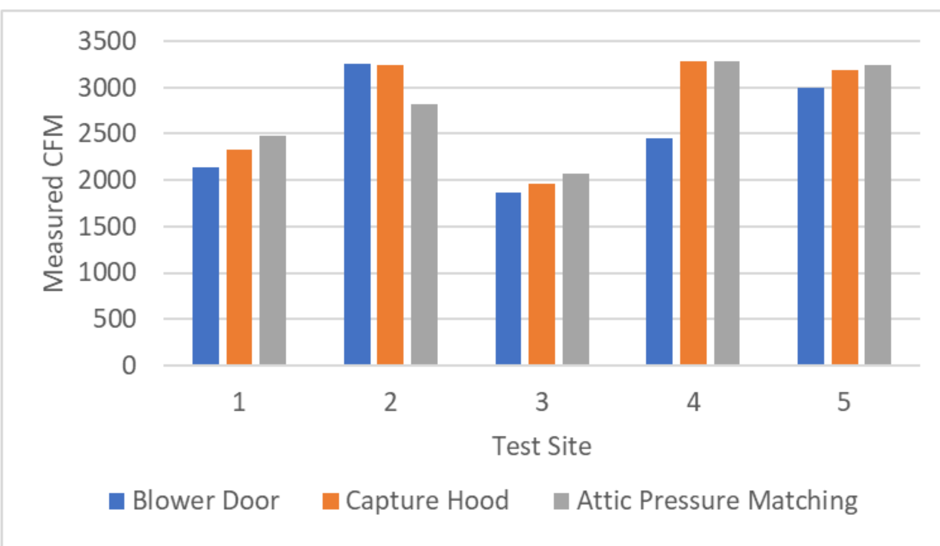
## 3.1 Results from Planned Tests

Table 3 shows results of all tests except for the two tests completed at Site 5 using the fabricated duct assembly. Figure 2 shows these results graphically. The whole house fan capture hood (PFH) with fan flowmeter was used to obtain attic pressure matching results. Indoor – attic pressure differentials were all taken during the blower door test (blower door blocked and WHF operating) and were used for attic pressure matching.

**Table 3: Test Results for All Sites**

| | Differential Pressures, Pa | | Measured Airflow, CFM | | |
|---|---|---|---|---|---|
| Site # | Indoor - Outdoor | Indoor - Attic | Blower Door Pres. Match | Powered Capture Hood | Attic Pressure Matching |
| 1 | -10.5 | -25.7 | 2136 | 2323 | 2484 |
| 2 | -10.4 | -20.5 | 3250 | 3243 | 2813 |
| 3 | -9.9 | -15.7 | 1865 | 1965 | 2076 |
| 4 | -9.9 | -54.2 | 2446 | 3283 | 3286 |
| 5 | -10.4 | -15.0 | 2933 | 3193 | 3238 |

**Figure 2: Comparison of WHF Airflows**



In all cases but one (Site 2) the blower door method yielded lower airflows than the powered capture hood method or the attic pressure matching method. The percentage difference varied between 0.2 percent and -25.5 percent and averaged -10.3 percent. If Site 2 is treated as an outlier, the average difference was -14.0 percent.

It is of note that Site 4 had the highest attic pressures and the largest difference between the blower door and PFCH results. The indoor-attic pressure differential was very high at 54.2 Pa. Relatively high WHF airflow and attic vent restrictions can explain the high attic pressure seen at that site. Attic vent area was not measured at any of the sites. It can be a challenging undertaking to measure free vent area of O'Hagin roof vents and second story eve vents.

For Site 2 the apparent higher accuracy of the blower door test cannot be explained by low attic pressures, but perhaps by less leakage area between indoor space and the attic. The fire code requirement that fire sprinkler penetrations not be sealed results in a significant leakage pathway. Those penetrations may have been tighter at this house.

In general, these results fairly consistently show there was air leakage between the attic and the house that contributed to lower measured airflows for the blower door test. The blower door method only reports the volume of air entering the house and misses air that leaks between the lower pressure indoor space and the higher pressure attic.

## 3.2 Additional Test Results

Two additional test apparatus were used at the Fairfield house (Site 5).

1. Fabricated duct assembly with fan flowmeter. The fabricated duct assembly described in Section 3.2 and shown in Figure 7 was used to measure airflow using the new proposed attic pressure matching method.
2. Traditional Non-Powered Flow Capture Hood. Another measurement was completed using a the Shortridge backpressure compensated non-powered flow hood described in Section 3.2 and pictured in Figure 8. Its hood was large enough to fully cover the WHF grille. Measurements were taken for uncompensated and compensated flow, first with the vanes open and again with them closed. For the second measurement the device calculates the effect the hood has on increasing the static pressure on the fan.

Results from these tests are provided in Table 4. The variance was calculated from results using the PFH with attic pressure matching as the standard.

**Table 4: Results from Additional Tests**

| Measurement Method (Site 5) | CFM | Variance |
|---|---|---|
| PFH, attic pressure matching | 3238 | - |
| PFH, pressure balancing | 3193 | -1% |
| Fabricated duct assembly, attic pressure matching | 3281 | 1% |
| ShortRidge without compensation | 2350 | -27% |
| ShortRidge with compensation | 2750 | -15% |

For the attic pressure matching tests, the fabricated duct assembly proved to be quite accurate and yielded airflows very close to the pressure matching measurements using the PFH. The Shortridge non-powered capture hood had very low accuracy, even using the compensation feature of the hood, and is clearly not useful at high airflows.

## 3.3 Discussion of Results

### 3.3.1 Blower Door Method

Air leakage between the attic and indoors caused the blower door method to generally measure lower airflows than the methods used to measure airflow at the fan. The difference between these measurements is the volume of air that is recirculated between indoor space and the attic and is a function of the attic pressure and the leakage area between the indoor pressure boundary and the attic. Site 4 provides the best illustration of the effect of attic pressure.

Blower doors may be more susceptible to inaccuracy due to pressure differentials created by windy conditions, though that was not observed. The method compensates for changing indoor-outdoor pressure resulting from windy conditions but not for changing attic pressure. Given the uncertainty that is typical in field measurements, the Energy Commission should consider applying an adjustment when compliance is verified using the blower door method.

### 3.3.2 Powered Capture Hood Method

The use of powered capture hoods for airflow verification described in RA3.9.4.1.2 appears to provide a reliable means of measuring airflow at the fan. This method is less susceptible to changing pressures than the blower door method because the measurement is taken in one step. The availability of a laboratory tested capture hood designed for WHFs allows this method to be used with larger fans, and it is the preferred test instrument for measuring airflow at the fan. QuietCool and AirScape fans are both powered by ECMs. Hysteresis sometimes occurs when fans in series are attempting to maintain a set torque or airflow. This would be recognized by observing the airflow ramping up and down at some frequency but this was not experienced.

### 3.3.3 New Attic Pressure Matching Procedure

The equipment setup is similar to that for the powered capture hood method except that it can be reliably used with either a fabricated duct assembly or a PFH to connect the fan flowmeter to the WHF intake.

Unlike the powered capture hood method where the pressure inside the capture hood is balanced to the same pressure as measured indoors, this method first measures the indoor-attic pressure differential with the WHF running, then matches that pressure differential by running the fan flowmeter that is ducted to the WHF inlet. It was necessary to run the WHF to obtain the target pressure differential, so both fans were running in series for these tests. The major advantages of the attic pressure matching test is that it measures airflow at the fan and can use any apparatus that ducts air between the WHF and the fan flowmeter.

With the exception of Site 2, differences between the powered capture hood/flow balancing tests and the attic pressure matching tests varied from 0.1 percent to 6.9 percent with the attic pressure matching method yielding higher airflow measurements. For reasons that cannot be explained, the airflow at Site 2 using attic pressure matching was 13 percent lower than for the powered capture hood (pressure balancing) test. The attic pressure matching method is more susceptible to changing attic pressures due to wind than the powered capture hood method. It takes a few minutes to set up the hood or attach the duct after the attic pressure is recorded, and the attic pressure can change during that time.

The additional step required makes the attic pressure-matching method a little less efficient than the powered capture hood method, but it should be allowed, especially since it does not require an approved capture hood and produce comparable results. HERS Raters must be attentive to minimizing air leakage when fabricating duct assemblies.

# 4. Conclusions and Recommendations

## 4.1 Compliance Method Considerations

Before decisions are made regarding changes to test methods in the Reference Appendices or other standards documents, it is useful to review fan rating methods and consider how airflow measurements are used by compliance software.

### 4.1.1 Airflow Ratings and the Compliance Software Default Degradation Factor

A January 2019 Energy Commission Staff Report ( (California Energy Commission 2017) indicated that MAEDBS airflow listings are typically much higher than found in field tests and that ratings appear not to be based on HVI 920, which rates airflow for Whole House Comfort Ventilators at 0.1 inches w.c. (25 Pa).[3] The staff report concludes that many WHFs that used MAEDBS airflow rates are not providing the airflow required for compliance and may have been based on a static pressure of zero. This finding led to the application of a degradation factor for performance compliance if airflow is not field verified.

The staff report also includes results of laboratory tests completed by CSUS and BR Labs. The two CSUS tests showed a 16 percent airflow degradation between 0 Pa and 30 Pa, and the BR Labs test showed a 27 percent degradation between 0 Pa and 32 Pa. The mean static pressure difference between indoors and attic in the five field tests completed in this field study was 29 Pa. The default 67 percent degradation factor described in the Residential ACM Manual may be inordinately high considering that the difference between HERS verified and unverified airflow may not vary greatly (see Figure 3).

### 4.1.2 Attic Ventilation Area and Performance Compliance

For the two-story houses tested the measured WHF exhaust rate varied from 58 percent to 93 percent of the prescriptively required 1.5 cfm/ft$^2$. The WHF in the single-story house provided 114 percent of the required airflow and had the lowest indoor-to-attic pressure differential. HERS verification of the 750 cfm/ft$^2$ attic free vent area required in the 2016 and 2019 standards is not required. Builders may be adhering to the CBC requirements and ignoring the Title 24 requirement, resulting in higher attic pressures and airflows lower than the prescriptive amount. Compliance software could apply different airflow degradation factors to single and two story houses to account for the smaller vent area in two story houses.

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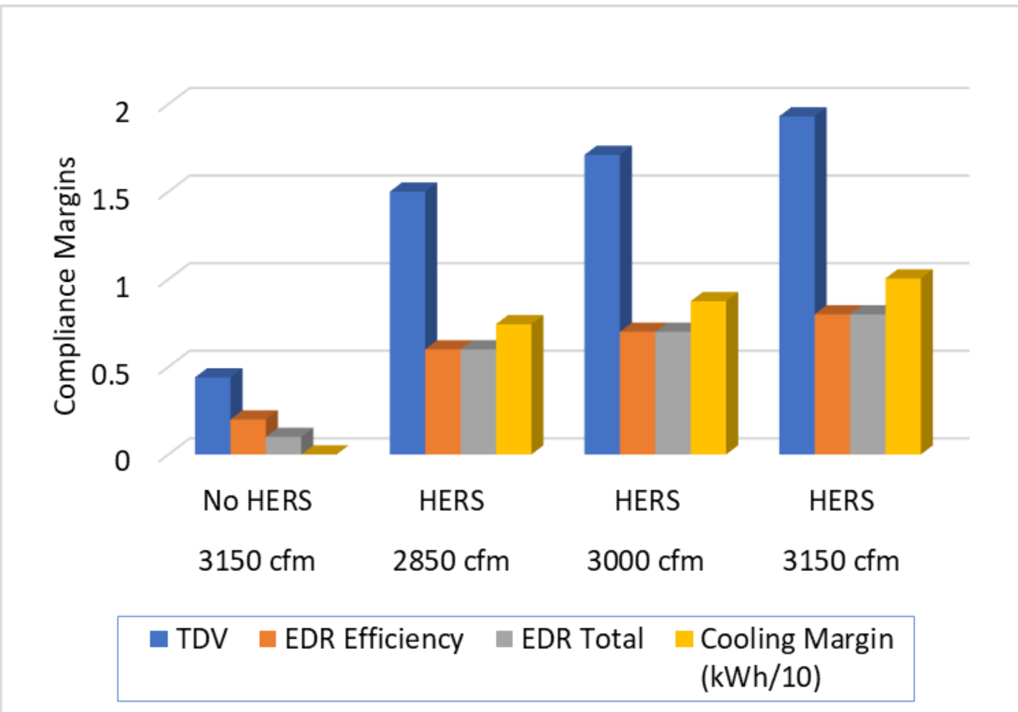
[3] Title 20 references HVI 916 for the method of test, but not HVI 920 for the means of reporting ratings.

Measuring the free area of in-roof vents (e.g. O'Hagin) and second story eve vents would require raters to climb on roofs which can be challenging and dangerous, especially with steep roof pitches and tile roofs. It is very easy to measure attic pressure relative to indoors and should provide a good measure of the adequacy of attic venting. The 750 cfm/ft$^2$ attic free vent area could be replaced with a maximum attic – indoor pressure differential requirement, for example 15 Pa, but this may not always be a reliable indicator. For example, the attic pressure differential at Site 3 was 15.7 Pa but the airflow was 42 percent below the prescriptive requirement, while the attic pressure differential at Site 5 (the one-story house) was 15.0 Pa and the airflow was 28 percent higher than the prescriptive requirement.

Standards documentation is not clear on whether verified airflow can be lower that the prescriptive value, but CBECC-Res (2019) allows it. CBECC-Res was used to look at how performance compliance varies with airflow rate. Figure 3 was developed using the 2100 ft$^2$ Energy Commission prototype house in Climate Zone 12.

**Figure 3: WHF Compliance Benefit**




For this case, the TDV and EDR margins increase linearly with airflow rate. (Some leveling off would be expected at higher airflows due to diminishing cooling effect and higher fan energy.) The "No HERS" compliance margin shows the extent to which the ventilation cooling benefit is reduced when there is no HERS verification.

### 4.1.3 Airflow Assumptions Used in Compliance Software

The Residential ACM Reference Manual does not mention whether entered and verified airflow rates are degraded to account for leakage between indoor space and the attic, but it is most likely the verified rates are used directly to calculate cooling energy. The value of ventilation cooling is better represented by the volume of air that is drawn in through windows and exhausted than by the volume of air that is measured at the WHF.

WHF manufacturers have no control over the amount of cooling their products deliver because that is determined by how the fan interacts with the house. The primary question has been whether to do away with the blower door test method. But accuracy questions aside, that method provides a better gauge of the impact on cooling energy than the direct measurements taken at the fan, which ignores recirculated air. The question might instead be whether airflows measured at the fan using the PFH and attic pressure balancing methods should be degraded to account for recirculated air.

## 4.2 Recommended Changes to WHF Verification Procedures

Airflow measurement variations and lack of repeatability are to be expected since field conditions cannot be maintained as they are in the laboratory; consequently, requirements should provide some latitude for error. Prior research has shown that air conditioning energy savings are not very sensitive to ventilation cooling rate when fan energy is accounted for. If the airflow rate is 10 percent lower than the prescriptive 1.5 cfm/ft$^2$ the effect on cooling energy may not even be detectable. The recommended course of action for modifications to RA3.9.4.1 follow.

**RA3.9.4.1.1**: With one exception, the blower door method was confirmed to measure lower airflow than the PFH or attic pressure matching methods because the blower door method accounts for air recirculated between the house and attic that does not provide cooling. For the two-story houses the blower door tests measured airflows averaging 16.5 percent less than attic pressure matching tests (excepting the Site 2 outlier). For the one single story house the difference was 9 percent. The is no evidence that blower doors are more susceptible to wind effects than other test methods.

The cost of acquiring a WHF capture hood may impose a hardship on HERS Raters who already own blower doors. To avoid the need for raters to increase their inventory of test equipment and for reasons noted in Section 4.1.3, it is recommended that RA3.9.4.1.1 be retained.

**RA3.9.4.1.2**: The powered flow capture hood method should be retained and limited to the use of CEC-listed and approved capture hoods and fan flow measurement devices. The current language could also benefit from adding more detail about equalizing the pressure between the capture hood and indoor air. The Energy Commission may consider whether measured airflow should be reduced to account for the recirculated air that does not contribute to cooling, for example 16 percent for two-story houses and 9 percent for single-story houses. This can be implemented either by HERS raters or within compliance software.

**RA3.9.4.1.3:** Although non-powered hoods may be standard equipment for HERS Raters and take the least time to use, this method should be eliminated or limited to fans with very low flows (e.g. multifamily units) for the following reasons:

- Non-powered capture hoods can only measure up to 2500 cfm and are thus limited to house sizes smaller than 1667 $ft^2$
- Common capture hoods may not have a large enough opening for most WHFs.
- They impose a pressure resistance on the WHF that results in a reduced airflow measurement, as was seen with the Shortridge hood.

Quoting from LBNL research completed around 2000 on the use of non-powered flow hoods for measuring return air grille flow, “Potential errors are about 20% to 30% of measured flow, due to poor calibrations, sensitivity to grille flow non-uniformities, and flow changes from added flow resistance.” The lack of Energy Commission listings of certified flow hoods for whole house fan airflow verification could the suggested elimination of this method moot.

## 4.3 Proposed New Attic Pressure Matching Test Method Procedure

A new verification method should be added to RA3.9 for use of a fan flowmeter ducted to the WHF intake grille using any means that ensures complete coverage and adequate airflow, and that applies the same attic pressure matching method investigated in this study. Because this method is not susceptible to the effects of turbulence in the connection between the fan flowmeter and the grille, in theory it should provide equivalent results as when an approved capture hood (PFH) is used to connect the fan flowmeter to the WHF grille. A 24-inch diameter flex duct should be sufficient to carry the 4800 cfm needed for a 3200 $ft^2$ or smaller house (based on a duct velocity of 1500 fpm). Only the fan flowmeter would need to be listed as an approved device.

The same reduction to measured airflow recommended for powered flow capture hoods should be applied to this method to account for recirculated air.

### 4.3.1 Procedure Using Attic Pressure Matching and Fabricated Duct Assembly with Fan Flowmeter

The following test protocol was offered by Energy Commission staff.

(a) Open the window(s) that are typically opened during WHF operation.

(b) Place a pressure probe in the attic. Use a suitable means such as taping the perimeter of the attic access hatch to prevent leakage if a gap is created by the pressure sensing tube.

(c) Attach the attic pressure sensing tube to the digital pressure gage such that it will measure attic pressure WRT the dwelling unit conditioned space.

(d) Turn on all WHFs required to meet the dwelling unit WHF airflow rate. Adjust multiple or variable speed WHFs to operate at an airflow rate that will be greater than or equal to the rate required for compliance.

(e) Adjust the dwelling unit window openings to bring the dwelling unit pressure a negative pressure of 10 Pa ± 5 $P_a$ WRT outside (the WHF-OP).

(f) Measure and record the actual dwelling unit depressurization ($P_a$) WRT to the attic ($P_{attic}$) at the WHF-OP.

(g) Turn off the WHF

(h) Do not change the window openings. The same dwelling unit window opening configuration used to establish the WHF-OP shall be used for the pressure matching measurements specified below.

(i) Attach a capture hood to cover the entire inlet grille of the WHF and ensure the capture hood is securely ducted to the fan flow meter outlet.

(j) Turn on the WHF and turn on the fan flowmeter. Adjust the fan flowmeter until the pressure in the attic WRT conditioned space matches $P_{attic}$ determined in step (f).

(k) Record the flow through the fan flowmeter.

# 5. Summary

**Test Procedure Recommendations**: The only WHF test method that should be considered for elimination is the non-powered flow hood method due to its inaccuracy and limited ability of instruments to measure typical WHF airflows. The new proposed attic pressure matching method using a fabricated duct assembly has been shown to be accurate relative to the existing powered flow capture hood method and should be added to the Reference Appendices. For the reasons stated, the blower door method should be retained, and measured airflows should be adjusted upwards by a factor of 1.16 for two-story houses and 1.09 for one-story houses to account for recirculated air. These adjustments should provide rough equivalency with the direct measurement methods. From a modeling perspective it would be more accurate to adjust airflows from PFCH and attic pressure matching methods downward by 16 percent and 9 percent respectively (see Performance Compliance).

**Prescriptive Compliance and Non-HERS Verified WHFs:** The Energy Commission should consider reducing the arbitrary 67 percent degradation factor for non-HERS-verified whole house fans. It is not likely that builders or homeowners would accept non-operational WHFs. If the current degradation factor is intended to account for less-than-ideal operation by homeowners, then HERS verification will not improve the way that fans are operated. The factor should however account for the difference between MAEDBS listed airflow [4](at zero static pressure) and airflow at a more realistic static pressure of about 30 Pa (0.12 inches w.c.).

**Performance Compliance**: Given that most WHFs are HERS verified to gain compliance credit commensurate with the added expense, and that measured airflows are used to calculate cooling load by compliance models, accuracy of the models could be improved by accounting for the volume of outside air that is actually delivered. As noted, verification methods that directly measure airflow at the fan do not account for recirculated air, and either adjustments to the measurements should be made by HERS Raters or adjustments could be added to compliance software. The airflow degradation should be larger for two-story than for single story homes because the ratio of attic vent free area to WHF air volume is very likely to be less.

The Residential Compliance Manual should clearly state that for performance compliance the prescriptive volume of 1.5 cfm/ft$^2$ is a recommendation, and that lower airflows are accommodated by compliance software. This allows corrections to be made

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[4] According to Energy Commission Staff, future Title 24, Part 6 Standards will reference HVI listings instead of the MAEDBS.

to compliance calculations and documents if measured airflow is lower than what is listed in the documents.

**Attic Ventilation Requirements**: The 1 $ft^2$ per 750 cfm vent requirement is not enforced and should be removed, which will effectively improve compliance since it is likely most builders only adhere to the CBC requirements. Enforcement by HERS Raters would be challenging, time consuming, and unsafe.

# 6. References

California Energy Commission. 2017. *Staff Supplement - Whole House Fan: Field Verification and Diagnostic Testing.* Staff Report, Sacramento, CA: California Energy Commission. https://efiling.energy.ca.gov/getdocument.aspx?tn=222308.

Wray, C. I. Walker, M. Sherman. 2002. "Accuracy of Flow Hoods in Residential Applications." *American Council for an Energy Efficient Economy Summer Study.* https://aceee.org/files/proceedings/2002/data/papers/SS02_Panel1_Paper27.pdf.

# Appendix A: Photos

All photos by Frontier Energy Inc. Permission to duplicate is not required.

**Figure 4: Many newer homes have 8 foot or taller front doors that blower doors do not fit, which requires creative solutions such as using sliding doors or doorways to the garage. Leaks around the blower door are not critical as long as a negative pressure of 10 Pa can be maintained in the house.**

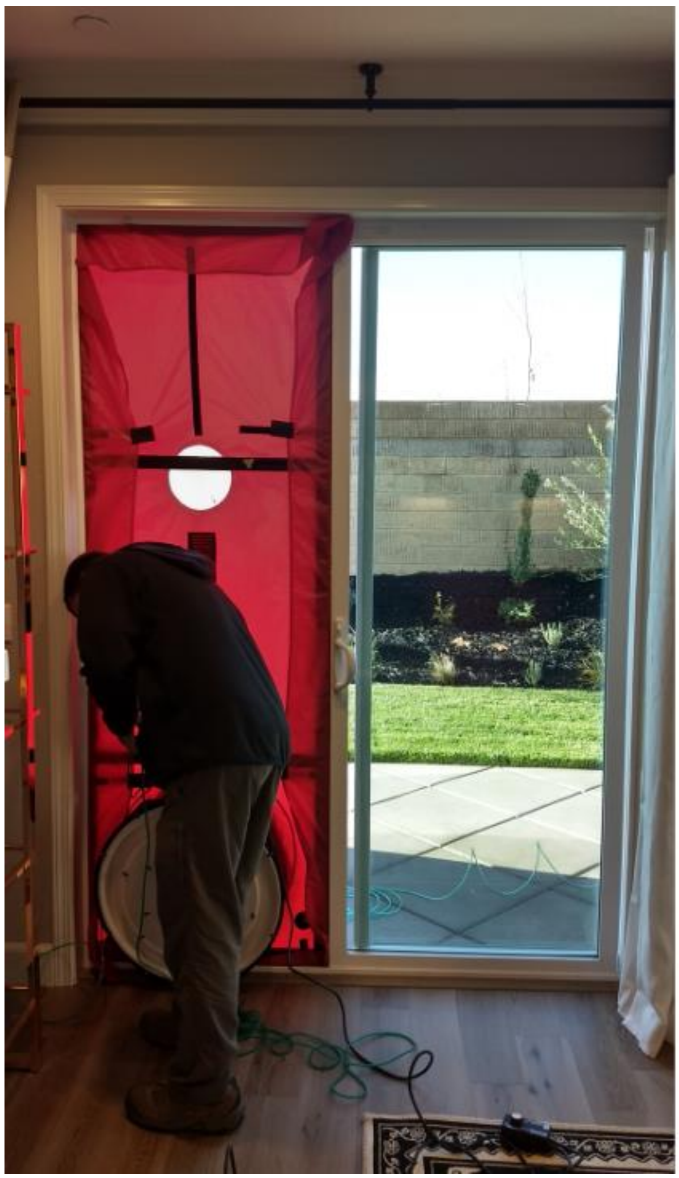

Figure 5: The PFH uses a standard fan flowmeter to measure airflow.

Figure 6:The QuietCool PFH installed

**Figure 8: This fabricated duct assembly used a washing machine drain pan to cover the  WHF grille, an adapter to the fan flowmeter, and a 20” flex duct to connect them.**

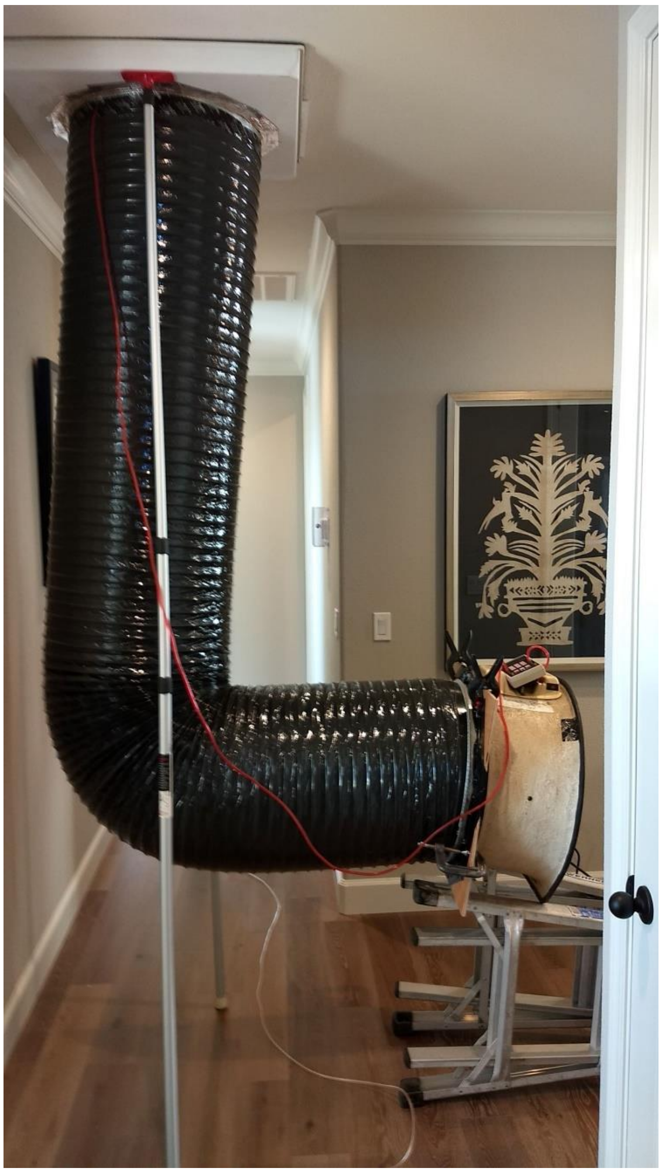

**Figure 7: Testing airflow using a non-powered  Shortridge flow hood.**

# Appendix B: COVID-19 Field Protocol

**Overview**. Thank you for agreeing to participate in our research project, sponsored by Pacific Gas & Electric and conducted by Frontier Energy on behalf of the Statewide Utility Codes and Standards team. The purpose is to test an alternative verification method for whole house fans that is used by Home Energy Raters to certify California Energy Commission energy code compliance.

Testing of this method cannot be achieved without willing participants such as yourself, and we appreciate the opportunity to safely conduct testing at your property. During the COVID-19 pandemic, procedures have been developed to keep Frontier Energy staff and others as safe as possible, while permitting necessary work to continue. This document details the procedures utilized by Frontier Energy to provide a safe field site environment during testing. These procedures were developed by referencing numerous state requirements in our areas of operation, and have been well received by our utility, state and federal agencies, and individual clients.

Prior to a site visit to conduct tests, you will be contacted by the Site Responsible Team Member (SRTM) by phone who will coordinate the testing schedule, describe the consent forms that will need your signature, and answer questions. To minimize personal contact, consent forms may be delivered by email and can be either signed and returned or collected upon the arrival of the testing personnel. The Frontier Energy Site Responsible Team Member is:

Name ____________________________________________ Phone ____________

Email address ________________________________________________________

The following describes what you can expect from Frontier Energy while work is performed at your home:

1. **Guiding Principles.** Our field procedure was developed under the following guiding principles:
    - **Safety**: The safety of our employees, customers and study participants are our top priority.
    - **Compliance**: Frontier Energy will comply with applicable laws, legal orders, and guidelines regarding COVID-19 risk mitigation, as well as with OSHA and other safety regulations regarding the performance of our work.
    - **Timing:** Adhere to scheduled times, conduct tests as rapidly as possible, and limit in-person interactions if possible. It is expected that the test will require one and a half hours.

- **Distance:** Maximize the distance between individuals in the homes. Maintain a minimum of six feet distance when interacting with customers and co-workers.
- **PPE:** Use shielding/PPE as indicated by local or state official guidance, or in all situations where individuals have a possibility of coming within 6 feet of each other.
- **Record-keeping:** Maintain appropriate records for assisting with contact tracing efforts should exposure occur.

2. **Filing of a Workplan**. Any work activities that take place outside of Frontier Energy's home office, requires a detailed workplan to be filed. The workplan indicates the location and timing of any work activities, the names of all staff to be on site, and any site-specific requirements needed to fulfill the principles above. Field work can only be executed after the workplan has been reviewed and authorized by an officer of Frontier Energy. A copy of the workplan is available to the homeowner upon request.

3. **Staff Health Screening.** Prior to the commencement of home visits, Frontier Energy staff must perform a personal health self-assessment. This health screening is performed electronically using the company's IT infrastructure – we would make the records available to a necessary party in the event of any contact tracing. HIPPA restrictions limit whom in Frontier Energy can access these records. The screening addresses the following questions:

[YES/NO] I affirm that I am not experiencing any of the following symptoms (per CDC) of COVID-19:

- Body temperature of 100.4°F or greater (as measured today)
- Cough
- Sore throat
- Body aches
- Headache
- Chills
- Nausea/diarrhea/vomiting
- Significant fatigue
- Loss of taste or smell
- Shortness of breath or difficulty breathing
- Persistent pain or pressure in chest

[**YES**/NO] I affirm that during the past 14 days, I have not had contact with an individual that I understand to have been diagnosed as COVID-19 positive.

Employees are not allowed to work anywhere beyond their home residences if they fail to pass the self-screening by answering NO to either question, or failure to perform and document the screening on the Frontier systems.

4. **Site Health Screening.** To maintain the safety of Frontier Energy staff, we will confirm our site visit with the homeowner as close as in practicable to the date of the site visit. Contact with the participant via email will include this form and a questionnaire (separate document). Please answer these questions and return the form to dspringer@frontierenergy.com.

Responses will be documented. Additional documents can be provided to the participants that address risks of COVID if needed.

If the answer is **No** to all the health screening questions, the on-site visit can proceed, at the participants discretion. If the answer is **Yes** to any questions, the site visit will need to be rescheduled for a minimum of 14-days in the future.

5. **Required PPE.** Frontier Energy staff shall always wear the following PPE while working away from their home offices, including field sites.

   **Masks or face coverings** – a suitable mask or face covering must always be worn while performing field duties. The mask or face covering shall be worn to **cover both the nose and mouth**. Masks or face coverings shall be either purpose-built medical-style masks, or fabric with suitable closure mechanisms to maintain the mask in position while performing work activities. Masks or face coverings shall **not** have any relief valves or other airflow diverting mechanism.

   **Gloves** – protective gloves shall always be worn while performing field duties. At a minimum one layer of latex or nitrile gloves shall be worn to prevent contamination of the field site. Work gloves shall be worn in addition to protective gloves for rough activities where the protective glove may be compromised.

   **Failed PPE** – any PPE that is damaged or cannot fulfill its intended purpose shall be discarded and replaced immediately with fresh PPE. Changing of masks shall occur only outside and away from all others at a minimum social distancing spacing of 6-feet. **No used PPE shall be discarded at the home**. Used PPE shall be collected and disposed of properly at a location separate from the worksite.

6. **Sharing of tools and equipment**. Tools and equipment sharing shall be minimized, with any shared tools cleaned with a disinfectant wipe between uses.

7. **Site and personal cleanliness**. Frontier Staff shall maintain a clean worksite, and shall clean and/or disinfect all applicable surfaces disturbed during the course of fieldwork. Frontier staff shall perform regular hand cleaning throughout the course of activities. Washing with soap and water shall be preferred, however use of alcohol-based hand sanitizer shall be used if not suitable wash location is available. Hand cleaning will be performed after use of any restroom facilities, or whenever general cleanliness requirements dictate.

8. **Communication.** Public health safety is a two-way street, and clear communication is important. If the procedures documented above do not meet the property owner's needs, or additional site-specific procedures are required by the local jurisdiction, please raise them with the Frontier Energy SRTM. Conversely, as the individual responsible for the property you must notify the SRTM if you or anyone in the house has tested positive within the past two weeks. If others in the home cannot abide by reasonable PPE and distancing requests, Frontier shall halt site activities until mutual agreement of the protective measures are achieved.The Parties acknowledge that they are entering into this agreement with knowledge of the existing global COVID-19 pandemic. Despite the existence of the pandemic, the Parties currently believe that they can perform their respective obligations under this agreement. The Parties recognize that during performance of the work, the pandemic and associated governmental actions might result in delays which could temporarily interfere with the Parties' ability to perform their obligations under this agreement. If a Party experiences such a delay, it shall provide prompt written notice to the other Party of the fact of delay and shall continue to keep the other Party updated. The Parties agree to cooperate with each other and to employ reasonable mitigation measures to minimize the delay and its effects, including but not limited to negotiation of reasonable schedule changes. I acknowledge that **Frontier Energy** has notified me of their policies and procedures that include adherence to the State and local COVID-19 safety guidance. I approve them to complete work at my property.I, ____________________________________ of _____________________acknowledge that that **Frontier Energy** has notified me of their policies and procedures that include adherence to the State and local COVID-19 safety guidance and I approve them to complete work at my property.