U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Test Plan: Energy Savings with Acceptable IAQ through Air Flow Control in Residential Retrofit

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November 2016

Building AMERICA®
U.S. Department of Energy

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Test Plan:

Energy Savings with Acceptable IAQ through Air Flow Control in Residential Retrofit

Prepared for:

Building America

Building Technologies Program

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

Prepared by:

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Partnership for Advanced Residential Retrofit

Gas Technology Institute

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Prepared under Cooperative Agreement EE-0007057

November 2016

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Definitions

BA	Building America
GTI	Gas Technology Institute
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
ICRT	Indoor Climate Research and Training Group the University of Illinois at Urbana-Champaign, Applied Research Institute
NREL	National Renewable Energy Laboratory
PARR	Partnership for Advanced Residential Retrofit

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High-level Summary

If this project is successful, what new knowledge will we have gained?	If this project is successful, the energy retrofit industry will be able to confidently guide clients regarding optimizing energy savings and without sacrificing IAQ during interventions in existing homes. A package of air-flow management strategies will become part of energy interventions	
Technologies under test	A package of air flow management strategies	
Location(s)	Illinois and Iowa	
Type of home(s)		single-family, detached, existing
Number of homes	40	
Field data needed (check all that apply)	x	Long-term monitoring
	x	Short-term testing
	x	Surveys or other multi-home statistical information
NREL assistance requested (check all that apply)		Equipment provision
		Simulation & analysis support
		Hands-on field assistance
Briefly describe anticipated collaboration with or assistance from National Labs other than NREL		
Approximate field test duration	January 2017-July 2018	
Project partner(s)	Contractors to be determined	
Climate region(s) (check all that apply	x	cold/very cold
		hot-dry/mixed-dry

		hot-humid
		marine
	x	mixed-humid
Any other noteworthy elements relevant to high-level summary		

1 Background

1.1 Introduction

This project addresses air flows in houses, and their combined impact on energy use and indoor air quality.

The air flows considered in this study include:

- Air leakage (natural, uncontrolled infiltration)
- Duct leakage
- Forced-air system flow rate
- Mechanical ventilation

Infiltration-driven air exchange both removes contaminants that are already indoors – and increases dilution of indoor-emitted pollutants - and provides pathways for contaminants to enter the living space from outdoors and attached areas including basements and garages. Since it is uncontrolled the amount of dilution or transport can be highly variable. It is expected that some bypasses have greater potential to allow pathways for contaminants to enter the home (e.g. garage, crawl spaces) though they may not be the most common focus for energy savings (attics).

Duct leakage can carry a big energy penalty, and can also serve as a direct pathway for contaminant transport. Further, depending on the location of the leaks and whether they are supply or return they have the potential to adversely impact the pressures in the home and can therefore indirectly be a mechanism for contaminant transport as well. The impact of duct leakage will depend on the location of the ducts within the home. Ducts in basements – which are expected to be the dominant location in the study – will be an entry point for soil and foundation-space contaminants. Ducts in garages – expected to be present in a minority of homes – serve as an entry point for garage contaminants.

Forced-air system flow rate has impacts on energy, comfort, and IAQ. This is especially true for cooling, where the flow rate has a substantial impact on humidity control.

Mechanical ventilation carries an energy penalty, but is a core element of ventilation standards designed to mitigate IAQ hazards. Optimizing mechanical ventilation, to provide the best combination of contaminant control and energy use, is a goal of this project.

1.2 Benefits of the study

The goal of the study is to determine if a suite of airflow management measures will result in energy benefits at no IAQ penalty, or IAQ benefits at no energy penalty, or benefits in both energy and IAQ.

If this study is successful, and if the hypothesis is shown to be the case, then a common objection to the introduction of energy measures in buildings will be able to be overcome. Purchases of energy retrofits in buildings may then be made with greeater confidence that detrimental impacts will not occur.

Earlier projects provide limited guidance with regard to the expected size of impacts from airflow management.

- Soil gases (e.g. radon). Terry Brennan found a potential 50%+ reduction due to sealing foundation connections to ground (Nitschke et al. 1988).
- Garage transport. We are seeing a potential of an average of about 50% reduction due to air sealing from our ASHRAE garage project (to be published).
- Regarding literature quantifying the impacts of duct leakage on IAQ, there are studies (Traynor et al., BA radon study) that suggest that forced-air systems help to equalize basement and first floor radon concentrations. Also, we have substantial anecdotal evidence that duct leaks in basements are a major source of combustion safety issues.
- Addressing issues with air handler flow can have about an 8% impact on latent removal capacity, going from 400 to 300 cfm/ton (Parker et al. 1997).
- Our recent HUD study showed a 25-30% reduction in contaminants due to adding 62.2-compliant ventilation (Francisco et al. 2016).

We do not expect to see all of these impacts at each house, nor do we think they are additive (that would be over 100%). Garages and soil gases are pretty much independent. System flow mainly focuses on moisture. Duct leakage can impact everywhere, as can ventilation. If all of these issues existed in a single home and we added the signals in quadrature (ignoring the duct leakage issue, and assuming the absolute magnitudes of contaminant issues were similar for all of the above mechanisms) we get about a 75% reduction. That may be unrealistic. Perhaps not even 50% is expected. However, these studies provide ample evidence that there is a substantial signal to the effects we are exploring.

2 Experimental Plan

2.1 Research Questions

1. Can the energy performance of a home be improved without an IAQ penalty, and or can IAQ performance be improved without an energy penalty?

2. Are some contaminants particularly responsive to systematic improvements in airflows?

    a. Does supply or exhaust ventilation have a stronger impact on some IAQ metrics?

3. Are some airflows particularly capable of making improvements in IAQ?

2.2 Technical Approach

2.2.1 Hypothesis

Through improved, systematic management of airflows, at least one of the following two outcomes will result:

- IAQ will be improved with the same energy savings
- Energy savings will be improved with the same IAQ

Improved, systematic management of airflows is considered as a package as well as a suite of up to four airflow management measures. The primary goal of the project is to determine the impact of the suite of measures on IAQ and energy. The secondary goal is to determine the impact of the individual measures on IAQ and energy.

Initial assumptions regarding the expected impact of various measures on contaminants and energy are shown in table xxx. In this table,

- "-" represents an anticipated negative impact
- "0" represents no anticipated impact
- "+", "++" and "+++" represent anticipated beneficial impact, by strength.

Table 1. Assumed impacts of airflow measures on contaminant exposures and energy

	CO_2	H_2O management	In PM2.5	Out PM2.5	radon	Garage CO	HCHO	Energy
Sealing – Attic	-	-	-	0	-	0	-	++
Sealing – Garage	0	0	0	0	0	+	0	+
Sealing – Basement-outside	0	+	-	+	-	0	-	+
Supply leakage to basement	0	0	0	0	-	0	0	0
Supply leakage to outside	0	0	-	+	+	+	+	++
Return leakage ~~to~~ from basement	0	+	0	+	+	0	0	0
Return leakage ~~to~~ from outside	0	0	0	+	-	+*	0	+
System flow	0	summer	0	0	0	0	0	0

Sealing – Basement-ground	0	+	0	0	+	0	0	0
Exhaust ventilation	+	seasonal	+	-	+/-	0	+	-
Supply ventilation	+	seasonal	+	-	+	0	+	-

2.2.2 Control and treatment.

The study will be conducted on 40 homes in two states—Iowa and Illinois—and will consist of 20 control homes with standard retrofits, and 20 treatment homes with "enhanced measures".

Standard retrofits often do nothing regarding any of the airflows being considered except for overall envelope leakage, and envelope leakage often focuses only on leakage to the attic. This means that there will be reductions in energy consumption, and can reduce the entry of outdoor contaminants and potentially radon due to lower neutral levels. It does nothing to address entrainment of contaminants due to duct leakage or air handler flow and may not have much impact on the transport of garage contaminants. It also means that indoor-generated contaminants can build up.

The only required addition to the standard retrofit package will be the installation of ventilation compliant with ASHRAE 62.2-2016. This should reduce the time-averaged concentrations of indoor-generated contaminants.

Treatment homes will receive additional measures focused on airflow management, with an eye toward both IAQ and energy. These measures include:

- Increased focus on air sealing between the basement and outside, and between any crawl space areas and the home. Success will be determined using series leakage zonal pressure diagnostics.
- Increased focus on air sealing between the house and attached garages when there is not ductwork in the garage. Success will be determined using series leakage zonal pressure diagnostics.
- Duct sealing in foundation spaces. Success will be determined using Duct Blaster tests, or Delta-Q tests when Duct Blaster tests cannot be done and Delta-Q is practical.
- Forced-air system airflow commissioning. This includes both proper fan speed (especially important for summer dehumidification) and duct system pressures. Success will be determined by airflow measurements using a Duct Blaster or TrueFlow air handler flow measurement device, and by measuring plenum pressures.

We will sample homes in groups of 8-10. Homes will be split evenly between control and treatment homes. Control homes will get retrofits according to normal program processes, with the exception of requiring 62.2-compliant ventilation. Treatment homes will receive the airflow management package, the details of which will vary by house depending on characteristics. We do not expect that all 8-10 homes per group will be monitored over the exact same time, but control and treatment homes will be interleaved to ensure that environmental conditions are comparable. The basic approach for recruitment will be to identify a treatment home and then recruit a suitable control home.

2.2.3 Measures and Improvement Targets

Table 2 shows the minimum requirements for these metrics as well as preferred targets. The aim will be to achieve the preferred targets, but in no case shall a measure be considered successful if it does not meet the minimum. In this table, "All" (under "IAQ samples") includes all contaminants being measured, including CO_2, radon, humidity, formaldehyde, and (if possible) $PM_{2.5}$.

Table 2. Criteria for airflow management measures

Issue	Diagnostic	IAQ samples	Standard intervention	Enhanced intervention	Soft target	Hard target
Envelope air leakage	Blower door	All	Contractor choice	Depends on initial airtightness and opportunities	< 6.5 ACH50	Within 10% of soft target
Soil gas entry	Visual	Rn, T/RH	none	Sealed sump pumps, ground covers over bare dirt, large cracks sealed	--	--
Basement to outside leakage	Zonal Pressure Diagnostics	$PM_{2.5}$ (provisional), T/RH	Contractor choice	Air sealing between foundation and outside	Leakage area of foundation to outside should be less than leakage area of attic to outside	--
Duct leakage in foundation or garage spaces	Duct Pressurization, Delta-Q if Duct Pressurization not possible	T/RH, radon, $PM_{2.5}$ (provisional)	none	Seal supply leaks to outside, return leaks in basement or garage	20% total duct leakage	10% total duct leakage or 6% leakage to outside
Air handler flow	Pressure matching	RH	none	Adjust speed tap, reduce duct restriction, add	--	1) 300-350 cfm/ton for cooling

				ducted return, as appropriate		2) Provides suitable temperature rise for heating
Plenum pressures @ highest operating speed	Pressure w.r.t. duct ambient	--	none	Modify ducts as appropriate – focus on return or supply based on pressures measured	125 Pa external static, return measured upstream of filters/coils	50 Pa maximum in each plenum, return measured upstream of filters/coils
Ventilation	Flow meters	All	Exhaust unless contractor chooses otherwise	Exhaust unless contractor chooses otherwise, also supply in some homes	--	62.2-2016 compliant

In some homes we expect to install both supply and exhaust ventilation. Equipment and controls will be donated by industry partners. In the homes with both supply and exhaust ventilation we will perform two sets of post-retrofit tests, one with each ventilation strategy. This will provide data regarding differential impacts on individual contaminants depending on strategy.

2.2.4 Eligibility

To be eligible, treatment homes must be expected to have post-retrofit airtightness of no more than 6.5 ACH50. Since homes will be enrolled prior to retrofits being installed this will be based on projections using pre-retrofit airtightness levels and common reductions based on experience.

The focus of the project will be on homes with unfinished basements. Homes may or may not have attached garages, and those may or may not have living space above them. Presence or absence of an attached garage will be a primary criterion for pairing treatment and control homes. Matching whether or not there is living space above is desired but is not considered essential.

Homes with smokers will be excluded.

Homes with boiler heating systems, or with multiple furnaces serving multiple zones will be excluded. Use of minor heating appliances, other than unvented gas space heaters, does not lead to exclusion.

Control and treatment homes will be matched according to the factors listed below. Once a treatment candidate has been identified we will work with partner contractors to identify a suitable control home among the many other homes being worked on. Key factors:

Essential

- Air leakage. Pre-retrofit air leakage should be within 2 ACH50 of the treatment home (e.g. a control should be in the 6-10 range for a treatment home with a starting value of 8 ACH50).
- Presence/absence of attached garage.
- Presence/absence of ducts in the basement.

Preferred

- Number of stories.
- Presence/absence of crawl space section attached to basement.
- Presence/absence of ducts in the garage.
- Foundation wall type.
- Type of furnace/water heater (electric/gas, Type I/Type IV).
- Dryer in basement.
- Vented range hood.
- Presence/absence of central air (essential for homes tested in the summer).

2.2.5 Test methods to answer research questions

1. Can energy performance of a home be improved without an IAQ penalty, and/or can IAQ performance be improved without an energy penalty?

Contaminants will be measured pre- and post-intervention. In homes where the energy performance has improved the contaminant levels may be shown to have remained constant or dropped.

Energy performance will be monitored pre- and post-intervention. For homes with improved IAQ performance the data may show stable or improved energy performance.

2. Are some contaminants particularly responsive to systematic improvements in airflows?

The measured contaminants will be analyzed and reported individually

   a. Does supply or exhaust ventilation have a stronger impact on energy and/or IAQ?

Some homes will be studied with both supply and exhaust ventilation operating alternately on a week-by-week basis. Correlations between the ventilation strategy and the contaminant responses will be analyzed and reported.

3. Are some airflows particularly capable of making improvements in IAQ?

Within the sample of homes the changes in air flows will not be uniform but will be a function of the needs and potential in each house. Correlations between the extent of airflow control and the contaminant responses will be analyzed and reported.

2.3 Measurements

2.3.1 Contaminants to be measured

In this project we will measure contaminants representing a number of different categories:

1. Occupant-generated: this will be done with CO2 using Telaire CO2 monitors attached to HOBO loggers, 3-4 weeks before and after retrofit, located in a central location in the home. The focus on the analysis will be the "typical baseline" levels in the central part of the home, meaning that we will remove large spikes that often result from cooking.
2. Continuously-emitted pollutants: this will be done with formaldehyde using passive badges sent to a certified lab for analysis, 1 week before and after retrofit; to the extent that we are able to install both supply and exhaust ventilation in the same homes we will do a 1 week test in each mode after retrofit, located in a central location in the home
3. Soil: this will be done with radon using passive electrets, 1 week before and after retrofit; to the extent that we are able to install both supply and exhaust ventilation in the same homes we will do a 1 week test in each mode after retrofit, located in central locations in the basement and first floor
4. Humidity using HOBO loggers, 3-4 weeks before and after retrofit, located in a central location in the home

Additionally, to the extent that equipment is available, we will measure particles. Center for Energy and Environment has said that they may be able to loan us some equipment. Brett Singer at LBNL may be able to as well. To the extent that our particle measurement instruments are not required for other projects at the time of deployment we will use those. We recognize that we may not be able to measure particles in all homes but we also recognize that particles are important and should be measured whenever possible.

We do not intend to measure CO or NO2. CO is highly event driven and is only an issue at a small fraction of homes and so general airflow management is not the best mechanism for dealing with CO problems. NO2 is primarily from cooking (except for homes in which there are unvented space heaters) and we believe that prior research has shown that kitchen ventilation is the best way to address it. We do not consider that a critical component for this project.

We will also measure indoor and outdoor temperatures and humidity levels.

2.3.2 Airflows to be determined

<u>Infiltration:</u> measured using blower door tests.

Mechanical ventilation: measured using exhaust fan flow meters and/or Duct Blaster pressure-matching (for exhausts) or static pressure probes/flow grids (for supply systems)

Duct leakage: measured using Duct Blasters whenever possible; measured using Delta-Q when Duct Blasters not possible.

Forced-air system flow rate: measured using Duct Blasters whenever possible; measured using TrueFlow when Duct Blasters not possible.

Amperage and/or pressures will be logged in all mechanical ventilation fans and in duct systems to indicate when the system is on.

2.3.3 Energy measurements

We will clock gas meters for gas furnaces. We will log amperage for energy consumption of fans and conditioning systems using current transducers and HOBO loggers. We will log on-times of gas valves for gas furnaces using current transducers, or state loggers, and HOBO loggers.

2.4 Equipment

The equipment to be used inconducting the measurement and diagnostic tests is shown in Table 3.

Table 3. Equipment table

Contaminant Measurement	Equipment Needed	Sample interval	Information
CO2	Telaire 7001 monitor	continuous	Central location.
	HOBO logger Onset CTV-A	1 hour interval	Long term
HCHO	Passive badges	1 week integrated	Short term. Central location.
Radon	Passive electrets Radelec E, S chamber	1 week integrated	Short Term. Central location plus basement.
Humidity	HOBO logger UX100-011	1 hour interval	Long term. Central location plus basement.
PM2.5	TSI DustTrak 8530		Where used, long term.
Energy measurement	**Equipment Needed**		

Fan State (Ventilation, HVAC)	Onset UXX90-001	state	
Furnace Consumption	Onset CTV-A	Time-of-use	
Air Handler Run time	Onset CTV-A	Time-of-use	
Plenum Temperature	Onset TMC6-HE	continuous	
Plenum temperature	Omega TT-K-40-25	continuous	
Air Flow Measurement	**Equipment Needed**	**Status**	
Infiltration	Blower door		Includes zone pressure measurement
Mechanical ventilation	Exhaust fan flow meter	Primary	
	Duct blaster	If needed	
Duct leakage	Duct blaster	Primary	
	Delta-Q	If needed	
Forced-air system flow rate	Duct blaster	Primary	
	TrueFlow	If needed	

3 Analysis & Reporting

While PARR will compare contaminant values to published standards/guidelines (when available) the key metric will be the comparison between control and treatment homes of changes relative to pre-retrofit conditions. The same approach will be taken for analyzing energy savings.

Analyses will be done separately for summer and winter groups. The same basic analysis will be done within each group.

The primary analysis technique, for both energy and IAQ, will be a difference-of-differences approach. Specifically, for each contaminant, how much change was there in the treatment homes compared to any change in the control homes? This makes it vital that we interleave deployments between treatment and control homes, so that similar environmental conditions are present in both sets.

This difference of differences technique will be used for energy consumption, radon, formaldehyde, CO_2, and, where appropriate $PM_{2.5}$.

For moisture, there is, at present, no standard accepted method for determining building wetness as a single property calculable from measured data. This is complicated by the fact that outdoor conditions play a large role in indoor humidity. Measurement at different periods requires normalizing for outdoor conditions. The data collected in this program will help refine the analysis method. The following analysis techniques, with possible variants, will be evaluated:

- (Change in) moisture balance: pros – accounts for outdoor conditions, has an established standard to reference; cons – wasn't developed for cooling, dehumidification impacts. T technique was intended to evaluate the structure only, not cooling and dehumidification systems.
- (Change in) absolute humidity: pros – as a ratio of indoor to outdoor humidity, this comparison appears to provide the most linear of the comparison methods, is intuitively clear, and provides linear regression coefficients that correspond well to heating season (intercept) and summer (slope); cons – as a difference between indoor and outdoor humidity, dehumidification results are difficult to interpret.
- (Change in) RH: pros – matters for mold growth, highly recognized metric; cons – temperature dependent, doesn't directly account for outdoor humidity levels

In addition to using diagnostic measurements to evaluate the success of the installation of the enhanced measures, we will also use the diagnostic measurements, along with work orders showing what measures were installed, to explore what factors are most correlated with changes in IAQ.

The results of the analysis will be presented with appropriate statistics (mean, p) where appropriate. Relations with statistical significance will be called out.

If the findings warrant by their significance a strong association between measures and impacts, then these relations will be described in report findings and conclusions, so that they may be adopted in regions where appropriate.

4 Logistics

This project relies on close cooperation between the research team and the contractors who will be delivering either standard treatment or control treatment to clients.

Contractor identifies home as a "treatment" home candidate based on initial diagnostics, recruits and enrolls home

↓

Contractor identifies suitable "control" home, recruits and enrolls home

↓

Visit for instrumentation installation scheduled, conducted (ASAP following recruitment)

↓

Baseline measurements recorded 3-4 weeks

↓

Interventions completed (ASAP following baseline)

↓

Post-intervention measurements recorded 3-4 weeks; homes with supply and exhaust measured an additional 3-4 weeks (ASAP following interventions)

Field tests will be conducted in heating months and in cooling months. Testing during swing seasons will be avoided due to the likelihood of window opening.

Table 4. Field test schedule

	2017												2018						
	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Ma	Jun	Jul
10 homes																			
10 homes																			
10 homes																			
10 homes																			

The measurement period will typically be 3 months or longer. The sampling periods pre- and post-intervention are 3 to 4 weeks.

Table 5. House schedule

Event / week	0	1	2	3	4	5	6	7	8	9	10	11
Contractor identifies home as a "treatment" home candidate based on initial diagnostics, recruits and enrolls home	■											
Contractor identifies suitable "control" home, recruits and enrolls home	■											
Visit for instrumentation installation scheduled, conducted (ASAP following recruitment)	■											
Retrieval of short term instrumentation after 7 days		■										
Baseline measurements recorded 3-4 weeks		■	■	■	■							
Interventions completed (ASAP following baseline)						■						
Retrieval of short term instrumentation after 7 days							■					
Post-intervention measurements recorded 3-4 weeks;							■	■	■			
Homes with supply and exhaust measured an additional 3-4 weeks (ASAP following interventions)							▒	▒	▒	▒	▒	▒

Contractors will complete a data collection form, See Appendix 2. This form contains all of the site information to be used in the analysis, and provides a record of diagnostic results and insulation placement and retrieval. The form in MS Excel prforms necessary calculations such as anticipated post-intervention airtightness, zone opening sizes (from zone pressure measurements) and ASHRAE 62.2 compliance requirements.

Milestones for the project are shown in Table 6.

Table 6. Milestone Schedule

Milestone	**Date**	**Team Member Responsible**
Preparing instrumentation for first deployment	31 December 2016	Francisco/Rose
Training of Illinois and Iowa contractors	31 December 2016	Francisco/Rose
Recruitment of first home group	15 January 2017	Jonas/Milby
Recruitment of second home group	31 May 2017	Jonas/Milby
Recruitment of third home group	31 December 2017	Jonas/Milby

Occupant cooperation is essential to the project. Contractors will discuss participation with occupants. A Participation Handout has been prepared, See Appendix 1.The material in this handout will be expanded to become a Homeowner Authorization, with signature lines.

Contact information for team members is shown in Table 7.

Table 7. Contact Information

Company Name	Team Member	Email	Phone
GTI	Larry Brand	Larry.Brand@gastechnology.org	(570) 758-2392 x 201
ICRT-UofI	Paul Francisco	pwf@illinois.edu	(217) 244-0667
ICRT-UofI	Bill Rose	wrose@illinois.edu	(217) 333-4698
MEEA	Kara Jonas	kjonas@mwalliance.org	(312) 673-2484
MEEA	Mark Milby	mmilby@mwalliance.org	(312) 784-7249

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Appendix 1. Participant Handout

Research Project: Energy Savings with Acceptable IAQ through Air Flow Control in Residential Retrofit

Would you like to participate?

The US Department of Energy (DOE) conducts a Building America program which aims to improve residential construction and retrofit—energy and indoor air quality. This research project is for homes that are participating in the Illinois Home Performance/Iowa HVAC SAVE program, provided they meet certain criteria. This project aims to see if a set of measures which go beyond standard energy upgrade measures (Enhanced Measures) delivers benefits in terms of energy or indoor air quality or both.

Your contractor will determine if your home qualifies. This depends on basement construction, a certain range of initial airtightness and other criteria. If your home qualifies, then here is information to help you decide if you'd like to participate or not. Please know this: if you choose not to participate, the energy improvements being done to your home still represent the current state-of-the-art.

Here is what participation in the research program will mean for you:

1. Instruments will be placed in your home prior to the work and after the work. The instruments are rather inconspicuous; they are harmless and noiseless.
2. There will be instrument monitoring periods of 3-4 weeks both before and after the contractor's work. Research requires establishing a pre-treatment baseline in order to find out the results of the intervention, thus the delay in getting the work done.
3. Half of the participants will receive Standard Upgrades, and half will receive Enhanced Measures. Contractors will make that selection based on participant input.
4. Additional work will be done by the contractor for the Enhanced Measure homes. The cost of this additional work will be borne by the research program, by the contractor and by the participant. Your contractor will be able to tell you how much the additional work will cost, and what part of that cost will be your responsibility.
5. Opening windows reduces the quality of the data. We are scheduling the work in heating and cooling seasons, and avoiding the shoulder seasons. We will give you a calendar which will show the seven-day period where it is critical to keep windows closed, and the other days of the study where we ask you to note if the windows are opened—time opened and time closed.
6. Data about your house will be masked so that conditions measured cannot be associated with your house, by any readers of the research. (radon?)

We hope you will consider participating. We will be available to discuss what we are finding in your house and in the study in general. We will provide you with a copy of the final report.

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Appendix 2. Site visit form

House Visit and Diagnostic Report Form

Fill in visit cells	*Pre-treatment visit cells*		*Automatic calculation*	*Post-treatment visit cells*	
House name, add. or ID					
Date pre-treat visit			Date post-treat visit		
Time pre-treat visit			Time post-treat visit		
House dimensions	Floor Area		Height	Volume	
FINISHED basement				0	
1st	1500		8	12000	
2nd				0	
Totals	1500		OK or too leaky?	0	
			OK		
	Heating System			**Water Heater**	
Type	Forced air		Combustion exhaust	Electric: no draft	
Combustion exhaust	Forced-draft/Power-Vented		Location	Basement	
Location	Basement			**Air-Conditioning**	
Rated temperature rise			Type	Window Units	
Rated capacity			rated tons		
Comments					
Blower Door Test	**Pre-**			**Post-**	
CFM50 Pre	1500		CFM50 post		
ACH50 Pre	0.0		ACH50 post	0.0	
	Target CFM50		1350		
Comments					
Zone Pressure Diagnostics to Foundation Space					
Blower door with zone ***closed***	**Pre-**			**Post-**	
	attic	**basement**		**attic**	**basement**
House pressure			Pa		
Air flow			cfm50		
Zone pressure			Pa		
Blower door test with zone ***open.*** *Ensure that zone pressure difference between open and closed is > 5.5.*					
House pressure			Pa		
Air flow			cfm50		
Zone pressure			Pa		
Output: opening area...					
House to zone	#VALUE!	#VALUE!	in2	#VALUE!	#VALUE!
Zone to outdoor	#VALUE!	#VALUE!	in2	#VALUE!	#VALUE!

Duct Pressurization Test	*Note any inaccessible registers/grilles:*				
Leakage to...?	Total Leakage				
CFM25 Pre			CFM25 Post		
Moisture noted?				**Clock the gas meter**	
Visible mold?	Yes				
Basement wetness	Signs of past wetness			Seconds for 1 cubic foot	
Crawl Space wetness	Dry-no ground cover			of gas with furnace on	
Air Handler Flow Measurement					
Filter Slot Size					
PRE			**POST**		
Heating Speed			*Heating Speed*		
NSOP			**NSOP**		
NROP			**NROP**		
Flow (cfm)			**Flow**		
Cooling Speed			*Cooling Speed*		
NSOP			**NSOP**		
NROP			**NROP**		
Flow			**Flow**		
Cooling Speed CFM/ton			*Cooling Speed CFM/ton*		
heating speed temp rise	#VALUE!		*heating speed temp rise*	#VALUE!	
Ventilation	CFM		Operable Window	Deficit	
Bath #1			Yes	30	
Kitchen #1			Yes	80	
Bath #2			Room Non-existent	0	
Bath #3			Room Non-existent	0	
Bath #4			Room Non-existent	0	
Bath #5			Room Non-existent	0	
Kitchen #2			No	100	
Weather factor	Champaign -		infiltration cfm	32	
Number of occupants			weather factor	0.57	
Number of bedrooms			occupant load	1	
Number of stories	1		story factor	1	
			base	52.5	
Required Target Ventilation	73		deficit	52.5	
Post treatment ventilation	105		assessment sizing	1080	
			post infiltration cfm	0	
	Target adjusted CFM50			Post Adjusted CFM50	
select room	Bath #1			Bath #1	
Adjusted ventilation	65			97	

Instrumentation			
Living space	Serial Number		Serial Number
T/RH		*stays in place to end of measurement period*	
CO2		*stays in place to end of measurement period*	
Particulates		*Not all homes receive particulate counters*	
State logger	*Install state loggers on exhaust devices where feasible*		
bath fan	bath fan	range hood	dryer
Furnace			
Sensor assembly	no serial number	*stays in place to end of measurement period*	
Furnace sensor assembly includes two current clamps, thermocouple, and datalogger			
Foundation	T/RH sensor placed in basement		
T/RH		*stays in place to end of measurement period*	
Formaldehyde sensors in living space only			
Radon samplers in living space and basement			
Formaldehyde and radon samplers require exact date and time (nearest hour) for placement and retrieval.			
Living space			
Date/time of placement		Date/time of placement	
Formaldehyde		Formaldehyde	
Radon sampler		Radon sampler	
Date/time of retrieval		Date/time of retrieval	
Basement			
Formaldehyde and radon samplers require exact date and time (nearest hour) for placement and retrieval.			
Date/time of placement			
Radon sampler			
Date/time of retrieval			
If additional formaldehyde and radon samplers are used			
Date/time of placement		Date/time of placement	
Formaldehyde		Formaldehyde	
Radon sampler		Radon sampler	
Location		Location	
Date/time of retrieval		Date/time of retrieval	
Date/time of placement		Date/time of placement	
Formaldehyde		Formaldehyde	
Radon sampler		Radon sampler	
Location		Location	
Date/time of retrieval		Date/time of retrieval	

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