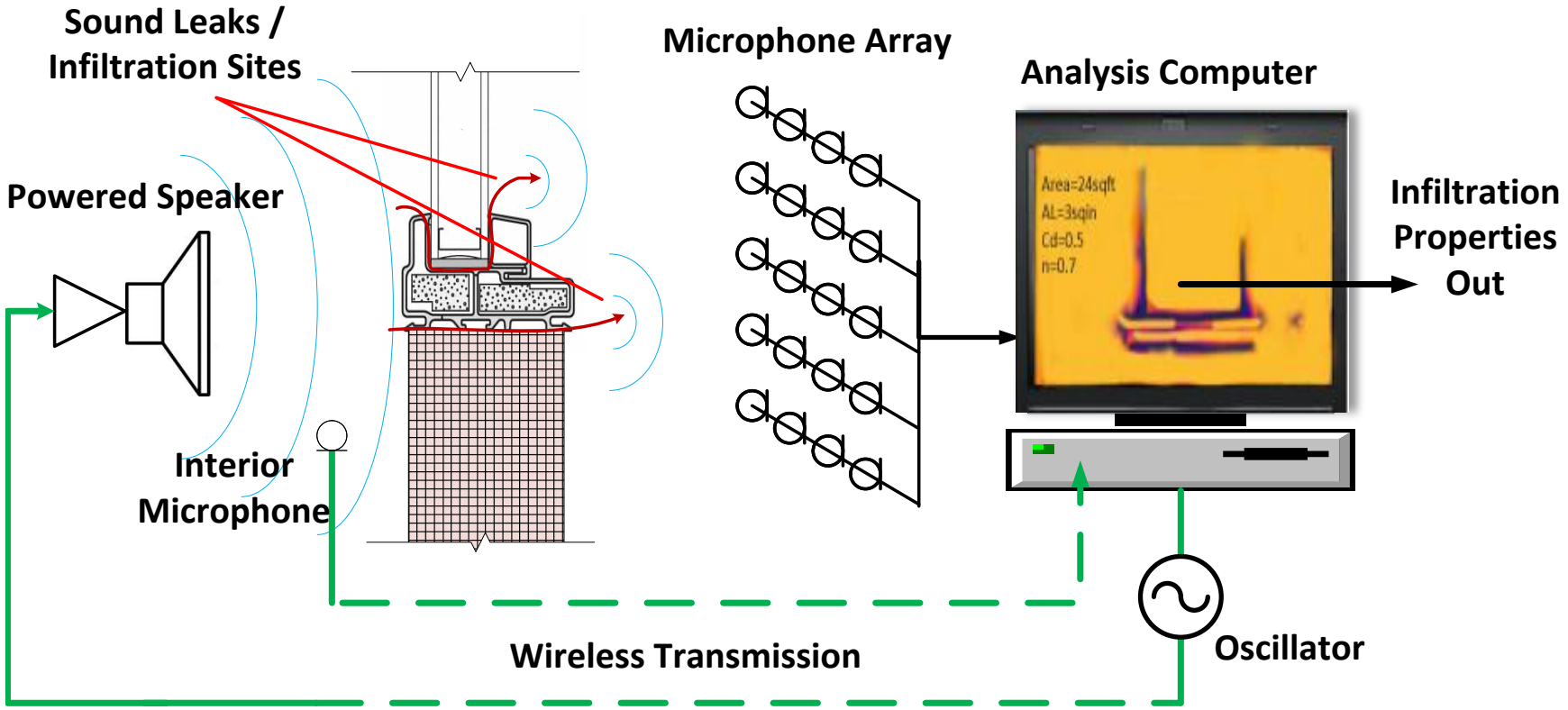
Acoustic Building Infiltration Measurement System (ABIMS):

2015 Building Technologies Office Peer Review



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

Ralph T Muehleisen, rmuehleisen@anl.gov
Argonne National Laboratory

Project Summary

Timeline:

Start date: 10/1/2014

Planned end date: 9/30/2015

Key Milestones

1. Full Computer Simulation: 9/30/2014
2. First Prototype Lab Test: 6/1/2015
3. First Prototype Field Test: 8/1/2015

Budget:

Total DOE $ to date: $650K

Total future DOE $: $0

Target Market/Audience:

Infiltration measurement companies; construction contractors; commissioning agents

Key Partners:

Illinois Institute of Technology

Argonne NATIONAL LABORATORY

ILLINOIS INSTITUTE OF TECHNOLOGY

Project Goal:

Develop a new building infiltration measurement system using acoustics to replace blower door and trace gas testing.

The new system will be capable of being used on commercial buildings of all sizes and at all stages of construction completion.

Purpose and Objectives

Problem Statement:

- Infiltration represents a significant portion of a buildings heating and cooling loads, especially in heating climates.
- Infiltration measurement of commercial buildings is difficult so building energy code does not require infiltration measurement to show compliance.
- Commercial energy code levels for infiltration are set higher than code developers would prefer, in part because of the inability to measure it.
- Weatherization of existing commercial buildings is difficult because of the inability to quantitatively measure infiltration to quantify savings.

Target Market and Audience:

- Target market is the entire commercial and residential building market
- Infiltration accounts for up to 0.7 quad of waste energy annually.
- The specific target audience is firms that provide infiltration measurement, building commissioning, and building weatherization.

Purpose and Objectives

Impact of Project:

- The main outcome of this project is a new technique for measuring building infiltration and the development of a prototype ready for commercialization

ABIMS will be a *disruptive technology* because it will make quantitative infiltration measurement on all commercial buildings practical for the first time. ABIMS will

- Enable stricter infiltration rates in building energy code
- Improve compliance with code
- Allow quantitative assessment of energy savings from weatherization and infiltration reduction of existing buildings which is required to justify and finance such retrofits

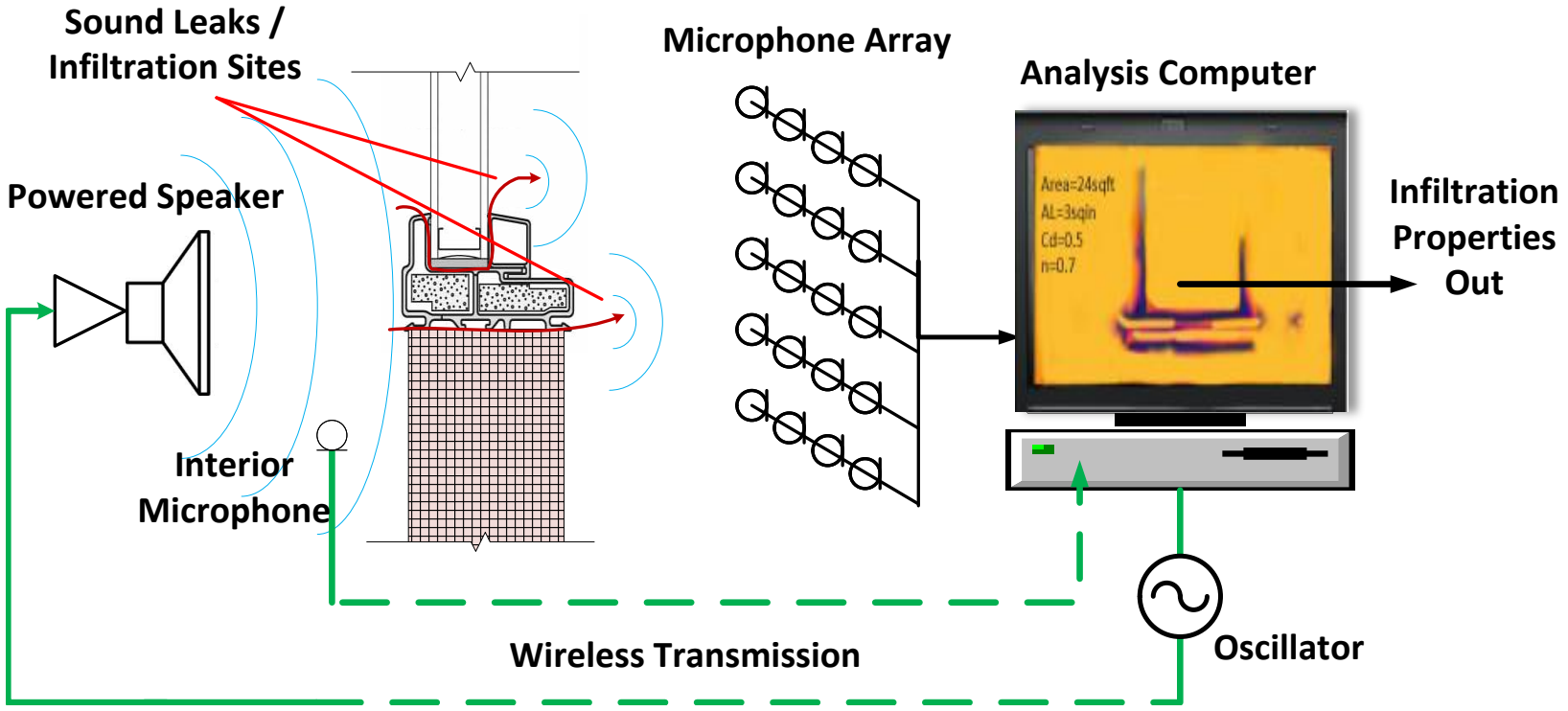
Achievement will be measured by

- **Near Term: Patent Application** 
- Short Term: Commercialization of the technology within 2-3 years
- Long Term: Adoption of the technology by industry and changes to building code

Approach

Approach:

- ABIMS ensonifies a portion of a building enclosure, measures the sound leakage using Nearfield Acoustic Holography (NAH) and uses the acoustic leakage information to estimate the infiltration properties



Approach

Key Issues:

- Need to quantitatively measure acoustic properties of leaks at a distance.
  - At a distance is necessary to make measurements practical and low cost.
- Need to be able to take measurements with other intruding sounds present
  - Want to be able to measure during construction or when occupied.
- Need to develop relations between acoustic properties and infiltration properties of an enclosure section.
  - Relations required to get infiltration information from acoustic data.

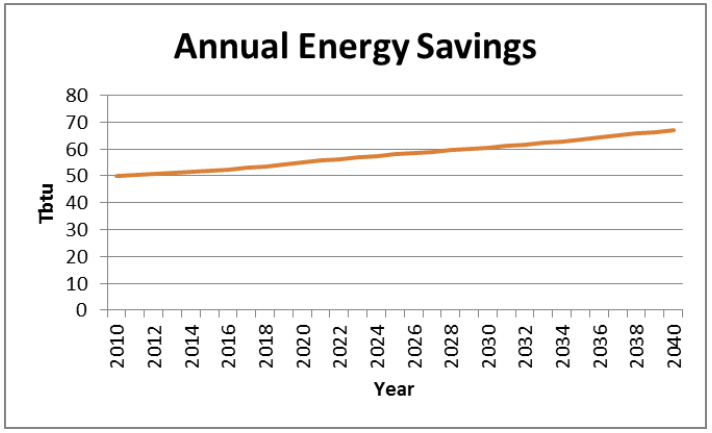
Distinctive Characteristics:

- We will use patent pending advanced acoustic measurement techniques to isolate and quantify the acoustic properties of the leaks, reject background noise, and convert acoustic properties to infiltration properties

Progress and Accomplishments

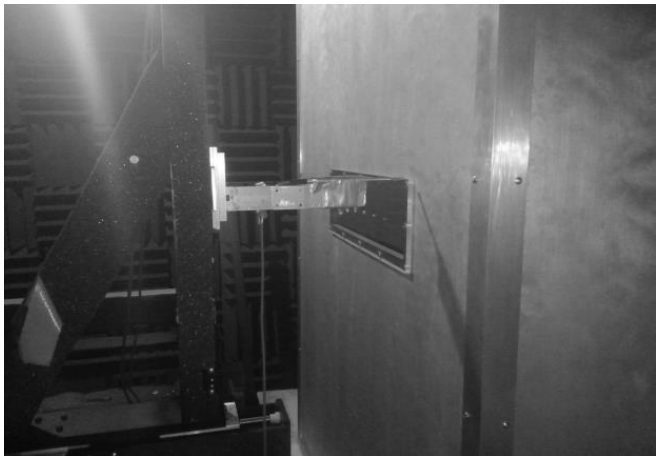
Technical Potential Energy Savings from Code Changes Estimated

- Technical Potential Energy Savings from infiltration code changes alone (no retrofits) was estimated to be in excess of 50 TBtu/yr
- Infiltration reduction from retrofits of old buildings will only increase this savings



Test Chamber Designed and Built

- Test chamber for controlled lab experiments completed ahead of schedule



Other Progress

- Progress toward Q3 milestones (Analytic Work and Acoustic Measurement) are all on track

Market Impact

- None Yet

Awards/Recognition:

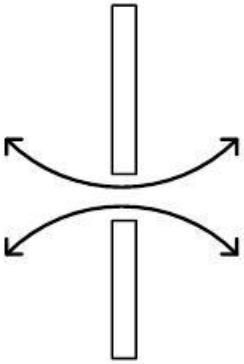
- Patent Application Filed

Progress and Accomplishments

- Developed Analytic Relations Between Pressure Drop and Flow for several leakage types

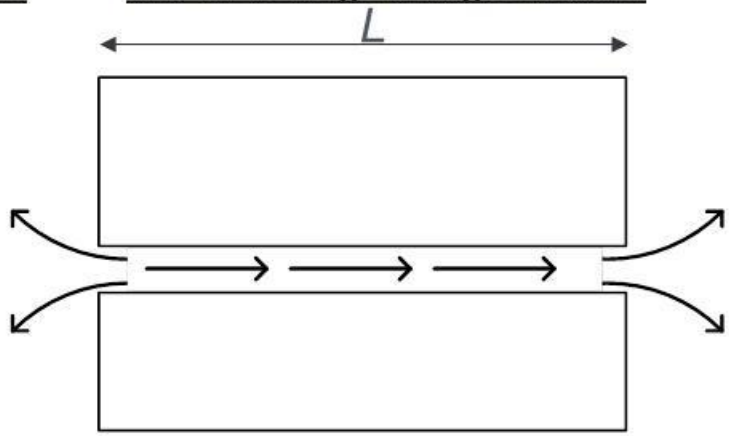
$$\rho(\vec{v}\cdot\vec{\nabla})\vec{v} = -\vec{\nabla}p + \mu\nabla^2\vec{v} \quad Q = \int \vec{v}\cdot\vec{n}da$$

DxHxL Very Short Crack



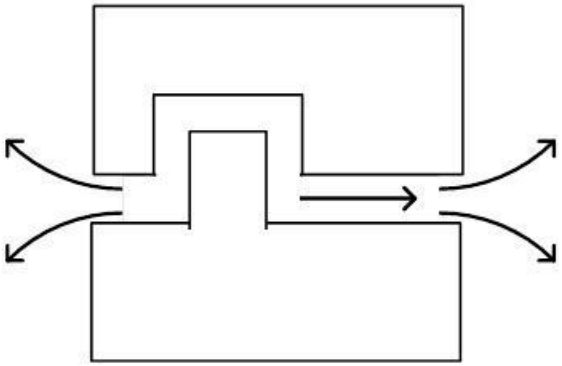
$$\Delta p = \frac{1}{2}\frac{\rho}{D^2H^2}Q^2$$

DxHxL Long Straight Crack



$$\Delta p = \frac{12\rho\mu L}{DH^3}Q$$

General Crack (mixed)



$$\Delta p = AQ + BQ^2$$

Progress and Accomplements

- A is related to viscous losses and hence real part of acoustic impedance. We can estimate crack impedance from NAH measurements of pressure and velocity

$$A \propto \mathrm{Re}\left\{ Z_{crack}\left(\omega\right)\Big|_{\omega \to 0} \right\}$$

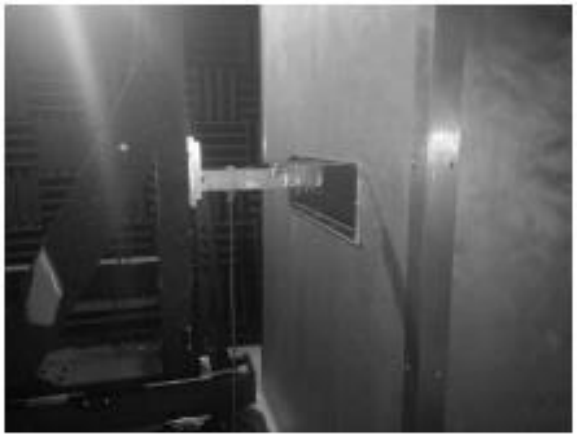
- B is inversely related to area of crack. We can estimate the area from the NAH measurements of pressure or velocity

- Alternately, we can develop correlations between the acoustic impedance Z_{crack} and the coefficients A and B through lab experiments when lab prototype is complete

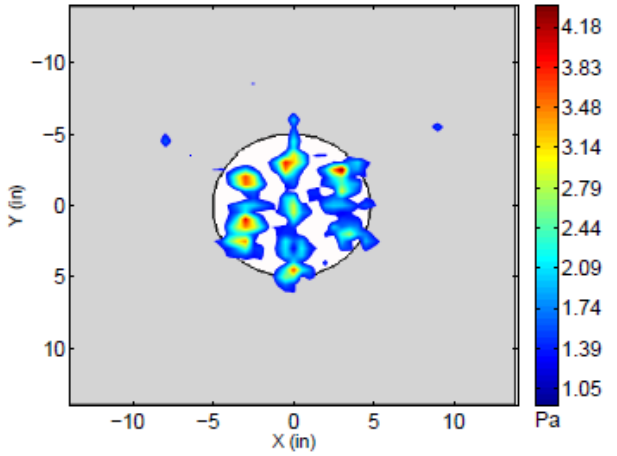
Progress and Accomplishments

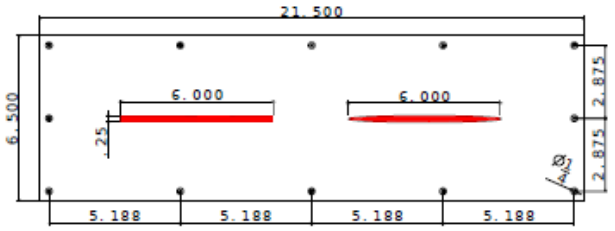
- Measurement Algorithms in Summer 2014

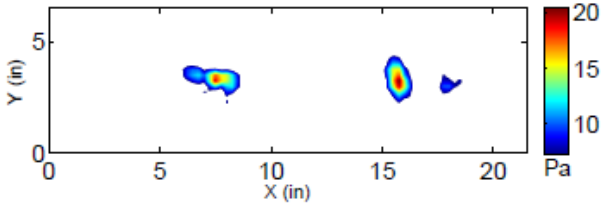
(a) Qualification test



(b) Leakage test





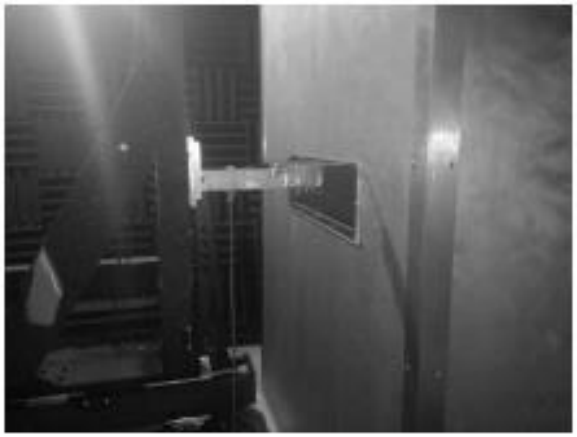


U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

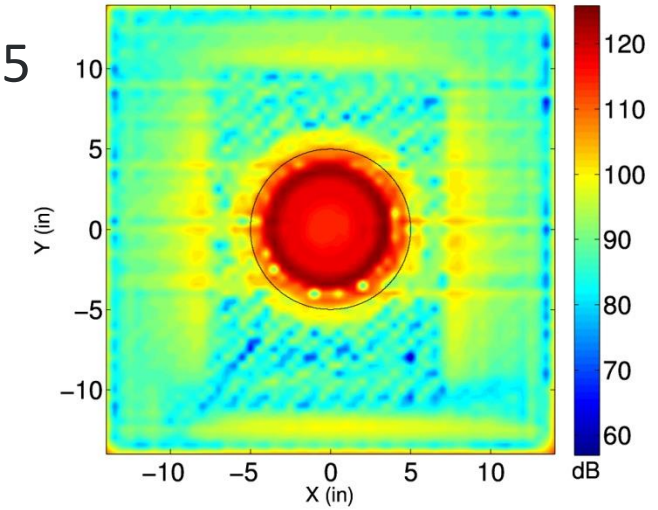
Progress and Accomplishments

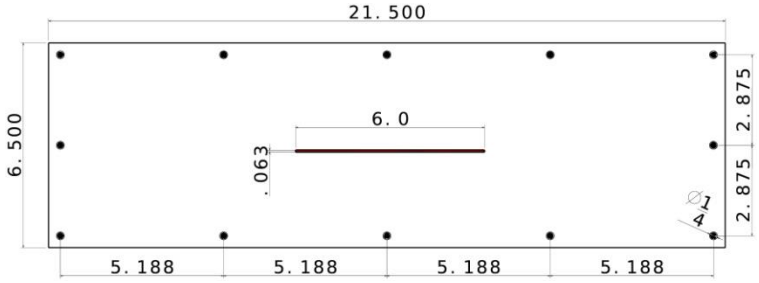
- Measurement Algorithms Spring 2015

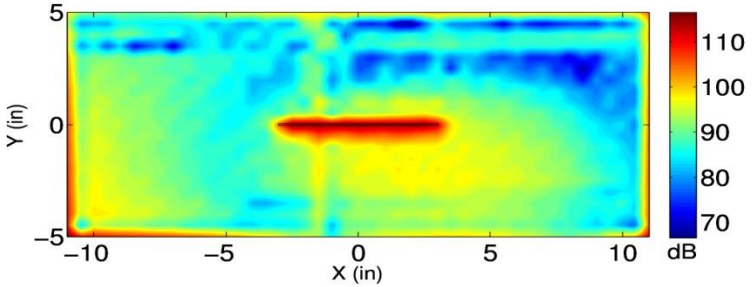
(a) Qualification test



(b) Leakage test

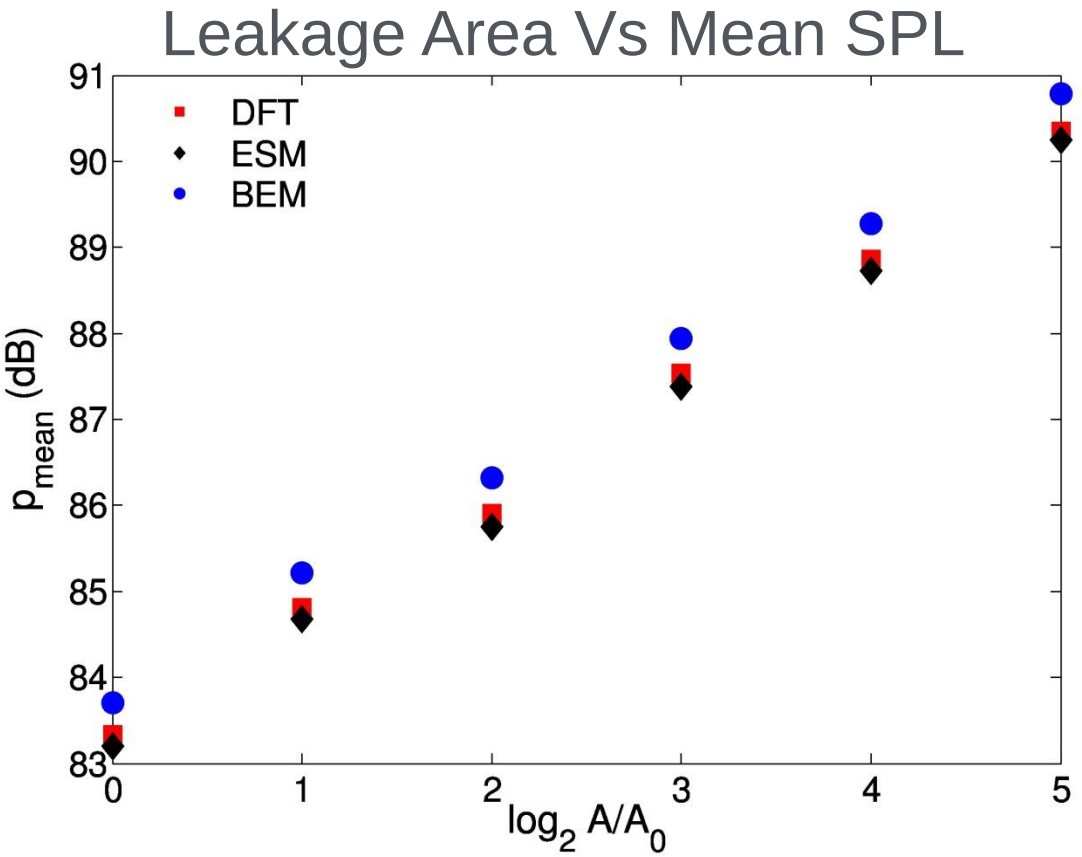






Progress and Accomplishments

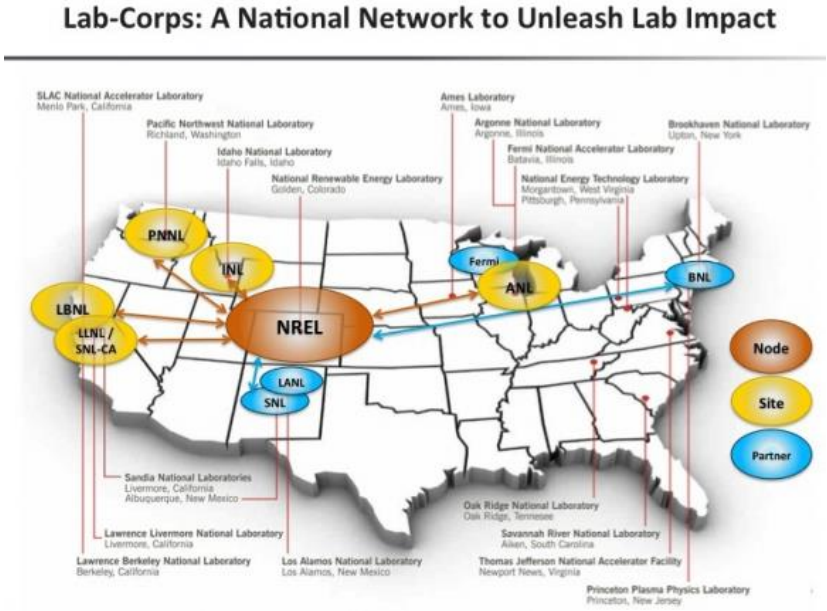
- Showed relationships between transmitted acoustic sound level and leakage area



Project Integration and Collaboration

Project Integration:

- Argonne team is short listed in the Argonne/DOE Lab-Corps program to enhance commercialization efforts
- Plans to apply to Chicago Innovation Exchange as well
- Interest from Energy Foundry in helping find an industry partner



CHICAGO INNOVATION EXCHANGE

AT THE UNIVERSITY OF CHICAGO

ENERGY FOUNDRY

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

Project Integration and Collaboration

Partners

- IIT is the only project partner.
- ANL does analytic work, techno-economic analysis, and commercialization
- IIT develops NAH, constructs prototype
- IIT and ANL collaborate on testing

Team Members

- Argonne: Ralph T Muehleisen, Eric Tatara
- Argonne Lab-Corps team: Ralph T Muehleisen (PI) , Cathy Milostan (EL), Todd Levin
- IIT: Ganesh Raman, Kanthasamy Chelliah, Hiren Kumar Patel





Project Integration and Collaboration

Communications:

- Work is being presented at many meetings
  - ASME,
  - Acoustical Society of America (ASA),
  - Institute of Noise Control Engineers (INCE),
  - Berlin Beamforming Conference (BeBeC),
  - Internoise

- Two journal papers under preparation

Conference Papers and Presentations

Conference Papers

Raman, Ganesh, Manisha Prakash, Rakesh C. Ramachandran, Hirenkumar Patel, and Kanthasamy Chelliah. 2014. “Remote Detection of Building Air Infiltration Using a Compact Microphone Array and Advanced Beamforming Methods.” In Berlin Beamforming Conf.

Raman, Ganesh, Kanthasamy Chelliah, Manisha Prakash, and Ralph T. Muehleisen. 2014. “Detection and Quantification of Building Air Infiltration Using Remote Acoustic Methods.” In INTER-NOISE 2014, 249:3976–85. Institute of Noise Control Engineering.

Chelliah, Kanthasamy, Ganesh Raman, and Ralph T. Muehleisen. 2014. “Leakage Detection Techniques Using Nearfield Acoustic Holography.” In *Proceedings of 4th Joint US-European Fluids Engineering Summer Meeting & 12th International Conference on Nanochannels, Microchannels, and Minichannels*. ASME.

Conference Presentations

Muehleisen, Ralph T., Eric Tatara, Ganesh Raman, and Kanthasamy Chelliah. 2014. “Acoustic Building Infiltration Measurement System (A).” The Journal of the Acoustical Society of America 136 (4): 2172–2172.

Muehleisen, Ralph T., Eric Tatara, and Brett Bethke. 2014. “Relationship between Air Infiltration and Acoustic Leakage of Building Enclosures (A).” The Journal of the Acoustical Society of America 135 (4): 2379–2379.

Next Steps and Future Plans

Q2 FY15: Simulation of complete system completed and used to test potential performance as well as determine individual component requirements. Three potential commercialization partners identified.

Q3 FY15: First Prototype Complete and Tested in Lab

Q4 FY15: Prototype Field Experiments Complete

Now through End of Grant

- Lab-Corp application for Commercialization Training for ABIMS
- Application to new DOE Tech Commercialization program if applicable

Soon After Grant:

- Commercialization Partner Engaged and Technology Licensed

REFERENCE SLIDES

Project Budget

Project Budget: $325K in FY14, $325K in FY15
Variances: None
Cost to Date: $417K + $213K Encumbrance for IIT Subcontract
Additional Funding:

- IIT providing cost share through tuition reduction.
- Argonne applying to Lab-Corp for commercialization assistance

Budget History					
FY2014 (past)		FY2015 (current)		FY2016 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$325K	$17k	$325K	$17k		

Project Plan and Schedule

Project on schedule and all deliverables on time as of March 25, 2014