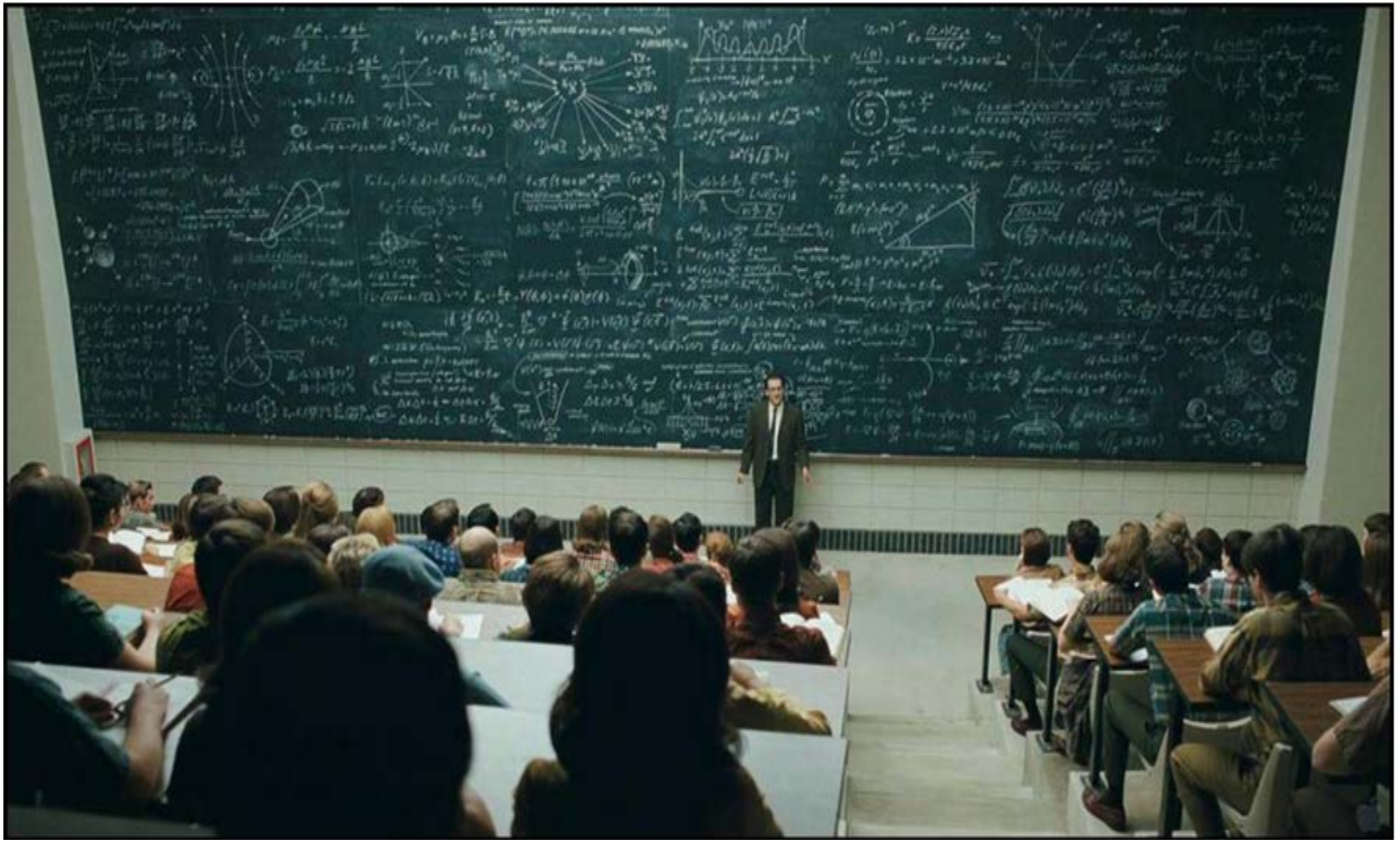
A Review of Research Conducted to Determine the Effectiveness of Air Barrier Installations

Mr. Peter Spafford

Air Barrier Association of America, Inc.

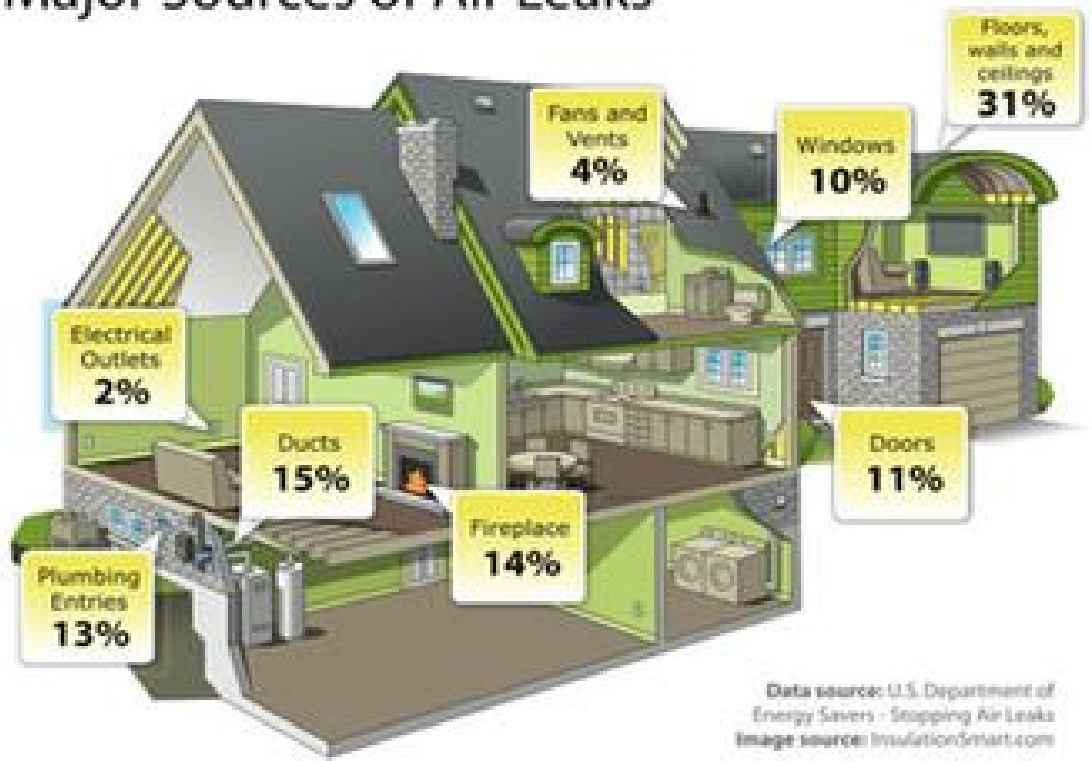


We now have the basic equation for assessing air leakage impacts for buildings……

We have always had air barriers

We know buildings leak

Major Sources of Air Leaks



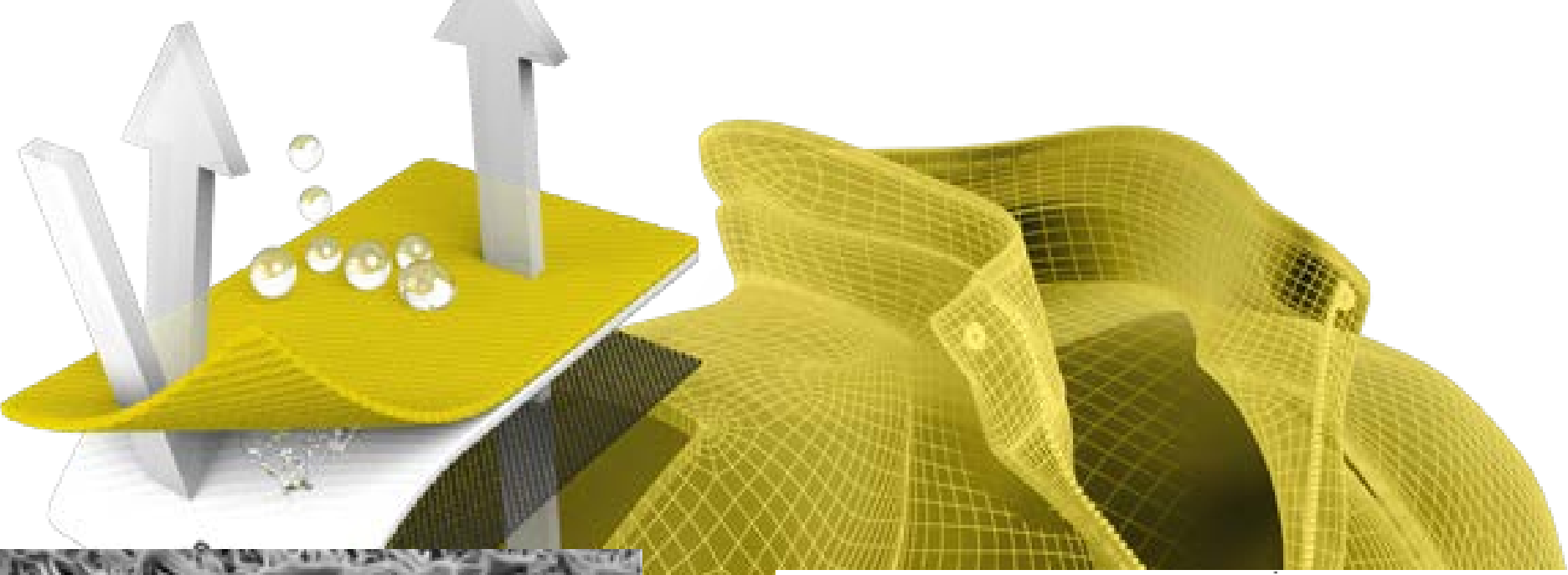
Data source: U.S. Department of Energy Savers - Stopping Air Leaks
Image source: InsulationSmart.com

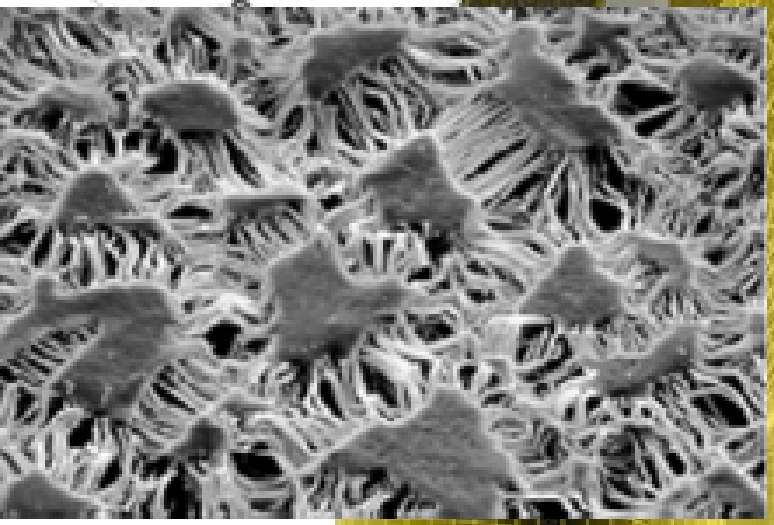
We have myths

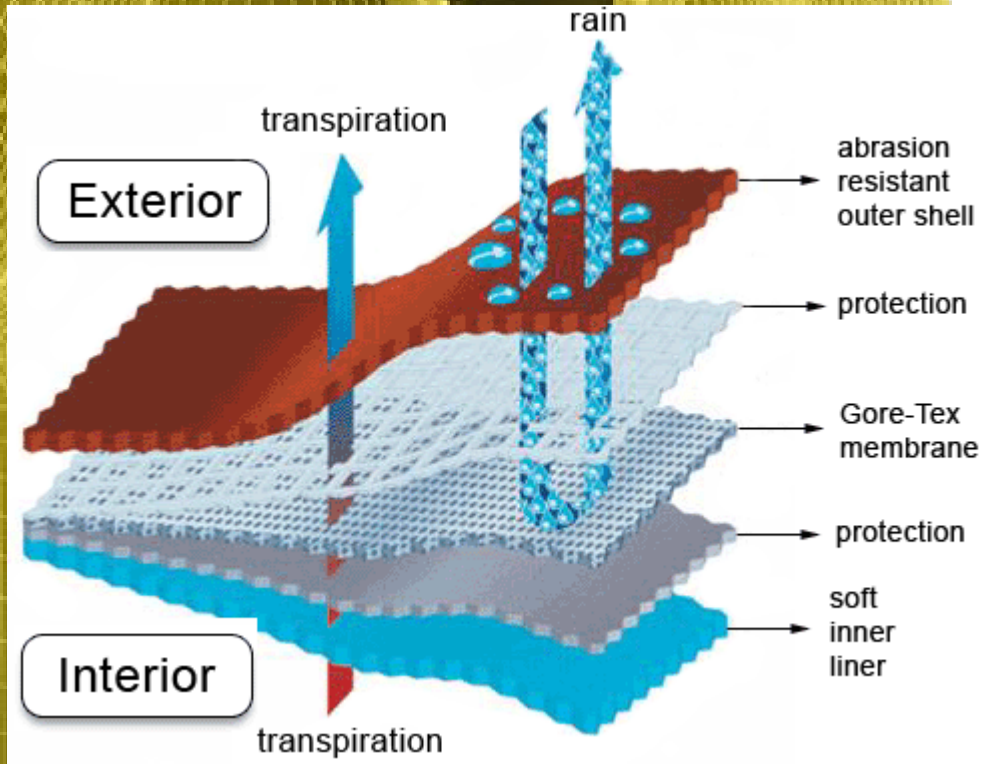
Myth: Buildings need to breathe – we cannot make buildings too tight

Buildings breathing does not equal air leakage

Buildings need to be kept dry and they need to dry out when they get wet



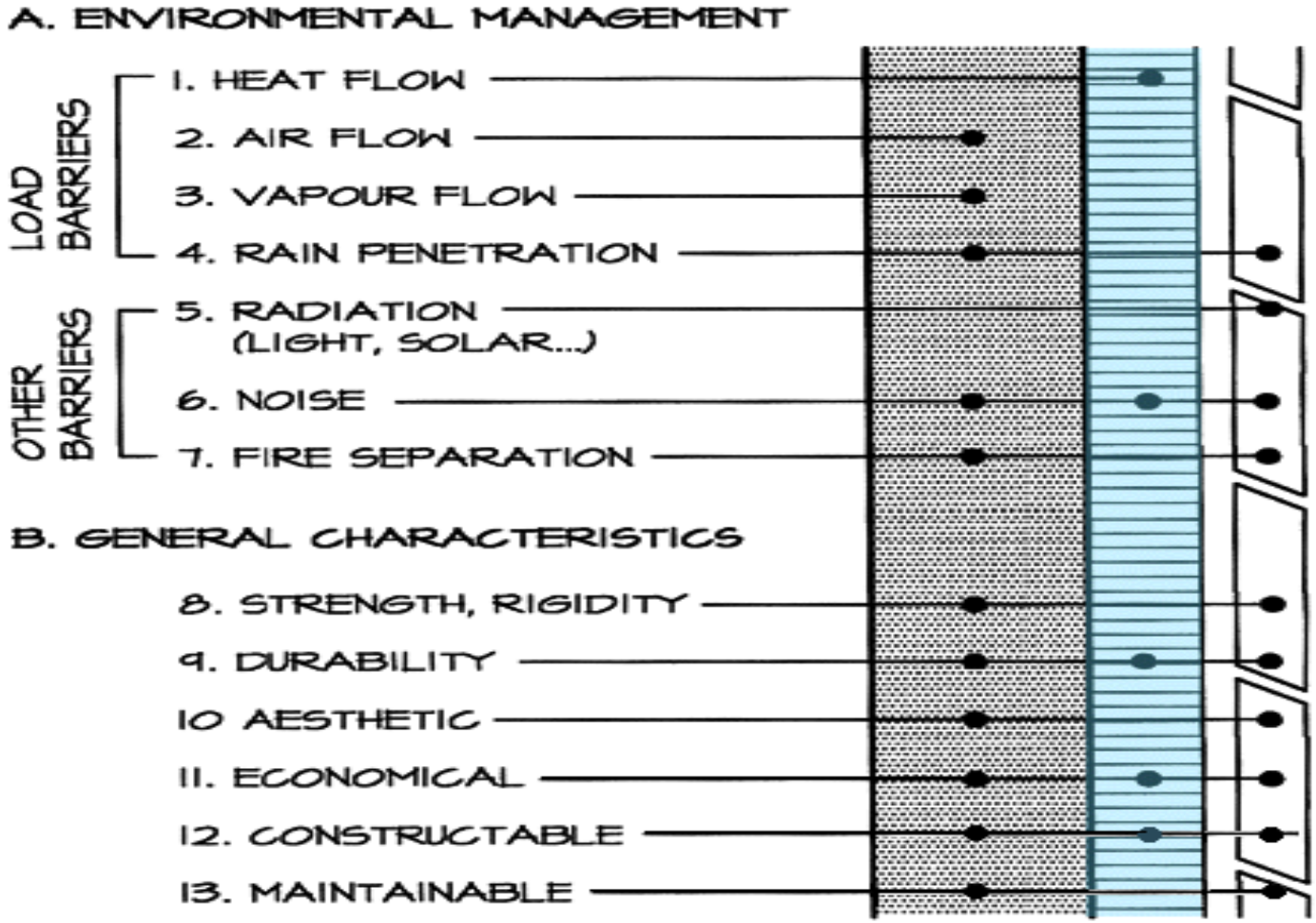



rain
transpiration
Exterior
abrasion
resistant
outer shell
protection
Gore-Tex
membrane
protection
soft
inner
liner
Interior
transpiration

Myth: We need natural ventilation to provide air for the occupants

Natural ventilation uses pressure differences to provide ventilation air in a controlled method –

Natural ventilation it is not a leaky building



ENVELOPE REQUIREMENTS (PRIMARY FUNCTIONS)

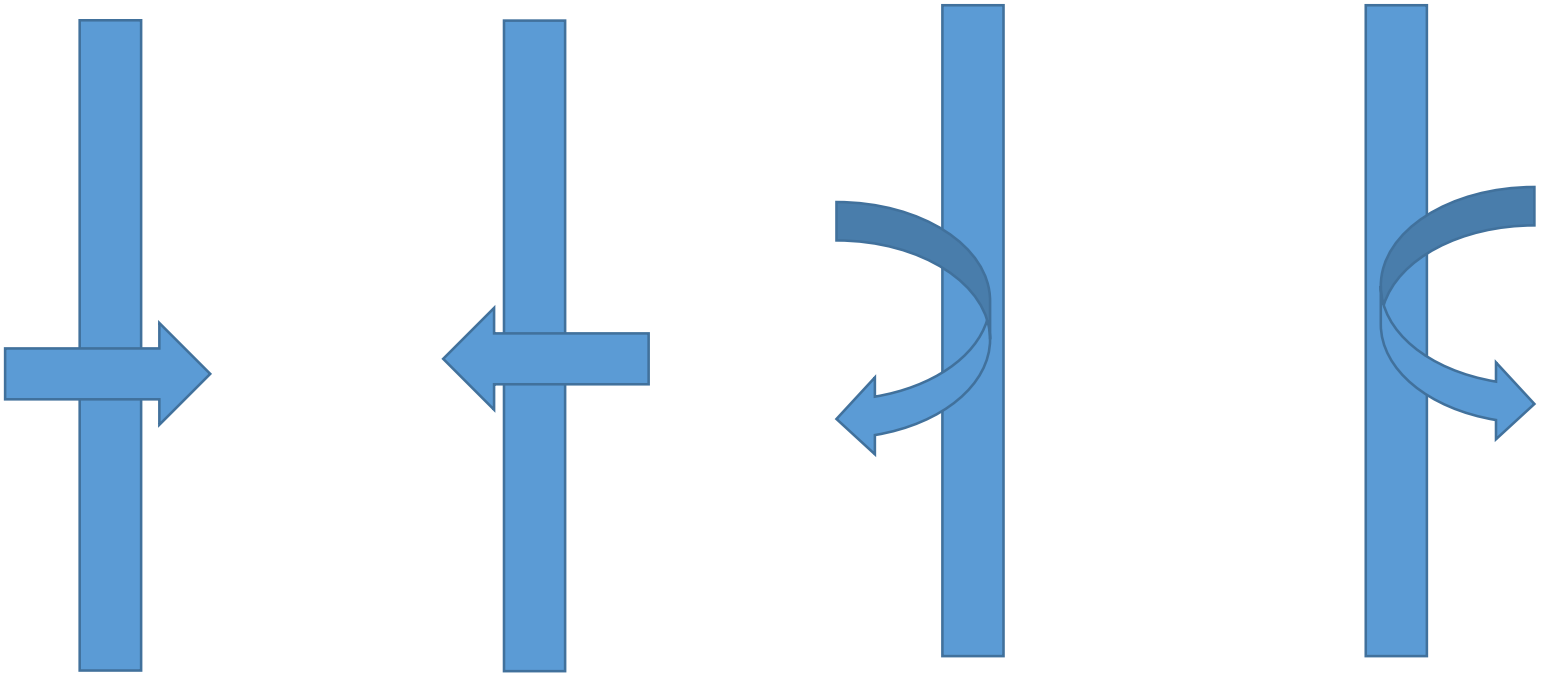
The problem

- Air barrier industry facing questions where there was little scientific data
  - Are buildings too tight?
  - Don’t buildings have to breathe?
  - Does an air barrier save energy?
  - How leaky is our present building stock?
  - How tight are we building today?

The hypothesis

- Air barriers in buildings save energy – up to 40% in heating climates and up to 15% in cooling climates, make buildings perform better and reduce liquid water damage

Air Leakage



The research project

- Participants include
  - Department of Energy (DOE)
  - Oakridge National Laboratory (ORNL)
  - New York State Energy Research and Development Authority (NYSERDA)
  - Syracuse University (SU)
  - Air Barrier Association of America, Inc (ABAA)
  - ABAA manufacturer members

Research plan

- Project administration
- Material property characterization
- Sub-system and wall characterization
- Laboratory wall testing
- Advanced moisture engineering modeling
- Exterior field testing of air barrier assemblies
- Wall optimization
- Information technology transfer

Overall Approach

- Identify cost-effective means to meet and exceed IECC 2012

- Evaluate the eight typical air barrier types

Membranes

Interior

Mechanically-fastened

Self-adhered

Fluid-applied non-foaming

Sheathings

Non-insulating

Insulating

Sealants

Spray-applied foam

- Tests

Field test

Sub-assembly tests

Material characterization

Background

- Air leakage is a significant contributor to HVAC loads
  - ~50% in residential buildings (Sherman and Matson 1997)
  - ~33% of heating loads in office buildings (Emmerich et al. 2005)
- Airtightness of buildings listed in (BTO prioritization tool)
- Building Technologies Office Prioritization Tool
- The U.S. Department of Energy's (DOE) Building Technologies Office (BTO) developed the Prioritization Tool to improve its programmatic decision-making by evaluating the long-term impact to energy consumption by technologies and activities. The tool provides an objective framework for most energy-saving measures and scenarios as well as methodology comparing long-term benefits and end-user costs applied to various markets, end-uses, and lifetimes.

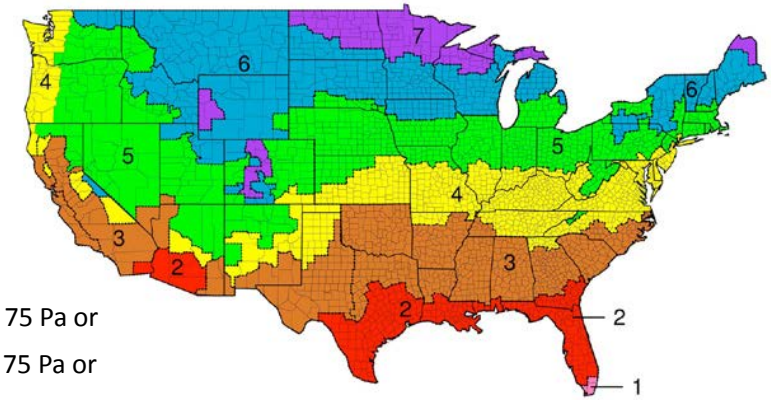
Background

- Airtightness of buildings listed in (BTO prioritization tool)

- IECC 2012 airtightness requirements

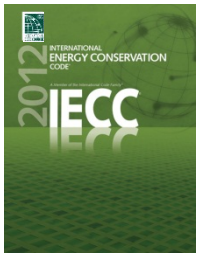
Residential Construction

- Zones 1 and 2: ACH50 $\leq$ 5
- Zones 3 through 8: ACH50 $\leq$ 3

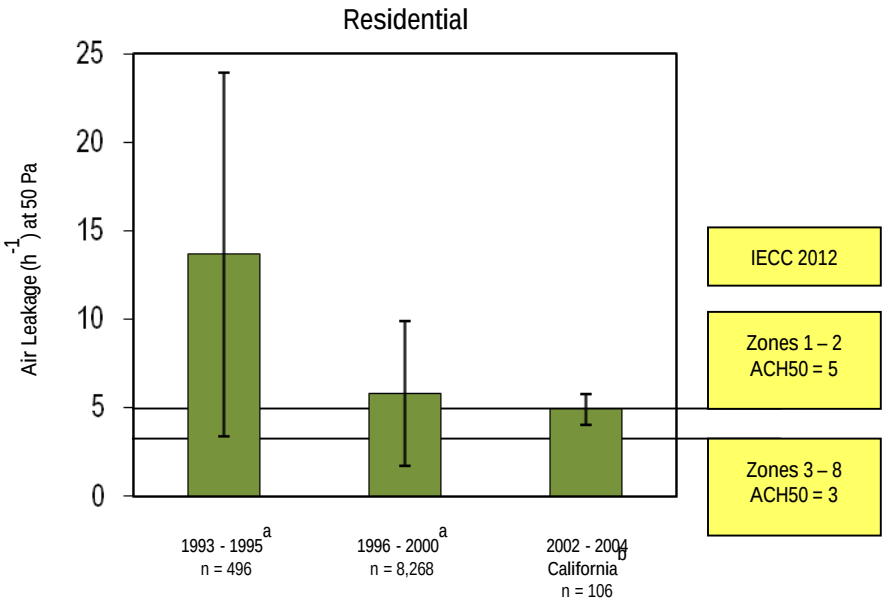


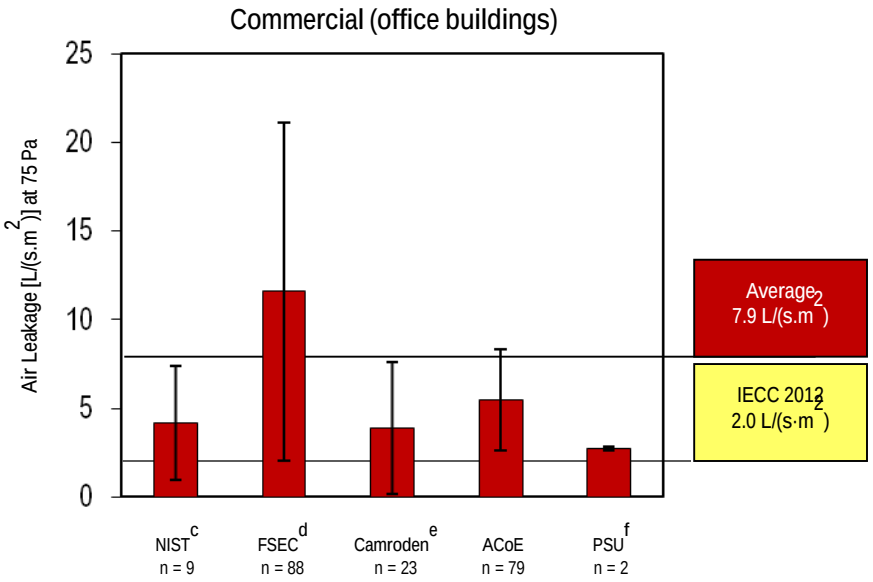
Commercial Construction

- Zones 1 through 3: no air barrier required
- Zones 4 through 8:
  - Air barrier material $\leq$ 0.02 L/(s·m^2) at 75 Pa or
  - Air barrier assembly $\leq$ 0.2 L/(s·m^2) at 75 Pa or
  - Building enclosure $\leq$ 2 L/(s·m^2) at 75 Pa



Field data vs. IECC 2012





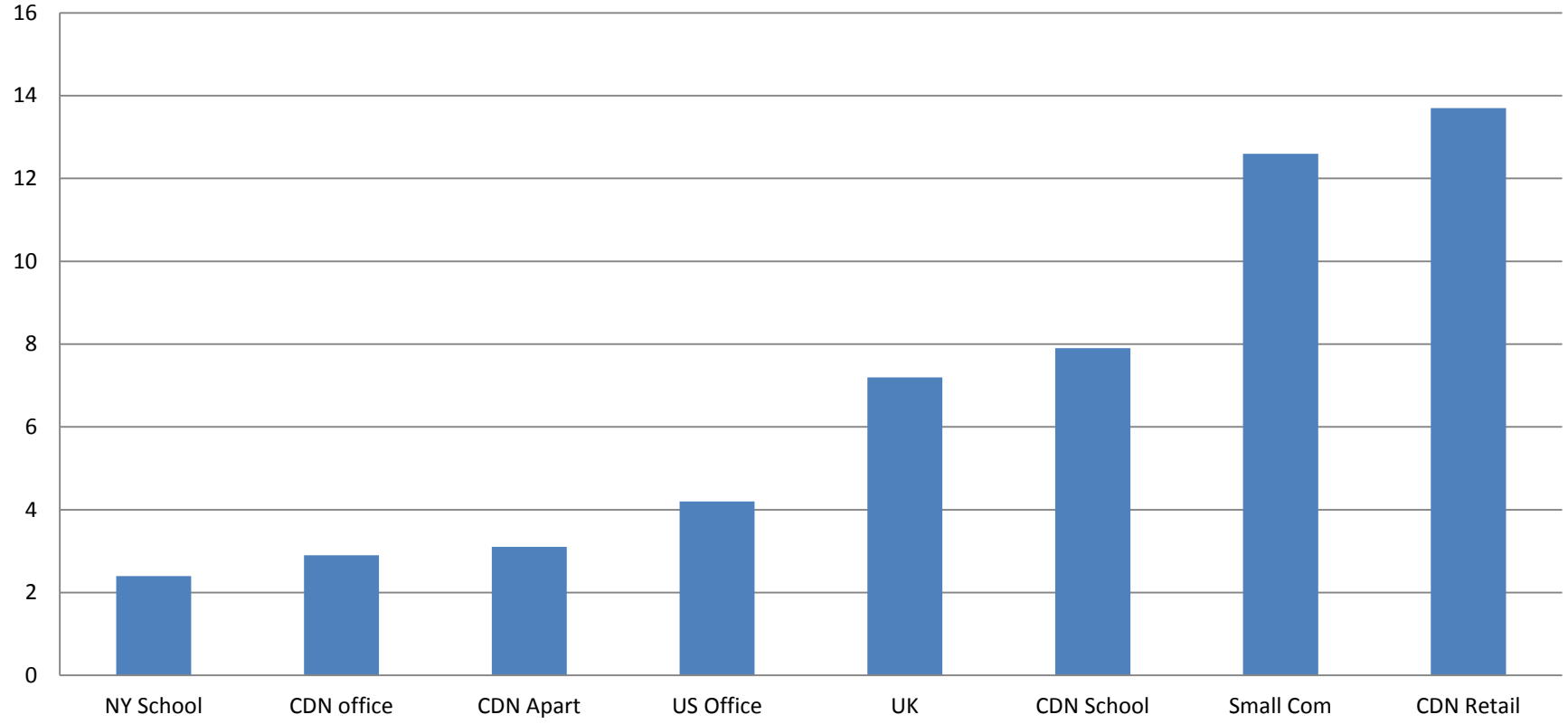
a. Sherman and Matson 2002
b. Offermann 2009
c. Persily and Grot 1986; Persily et al. 1991; Musser and Persily 2002
d. Cummings et al. 1996; Cummings et al. 2000
e. Brennan et al. 1992
f. Bahnfleth et al. 1999

ACoE: US Army Corps of Engineers
FSEC: Florida Solar Energy Center
NIST: National Institute of Standards and Technology
PSU: Penn State University

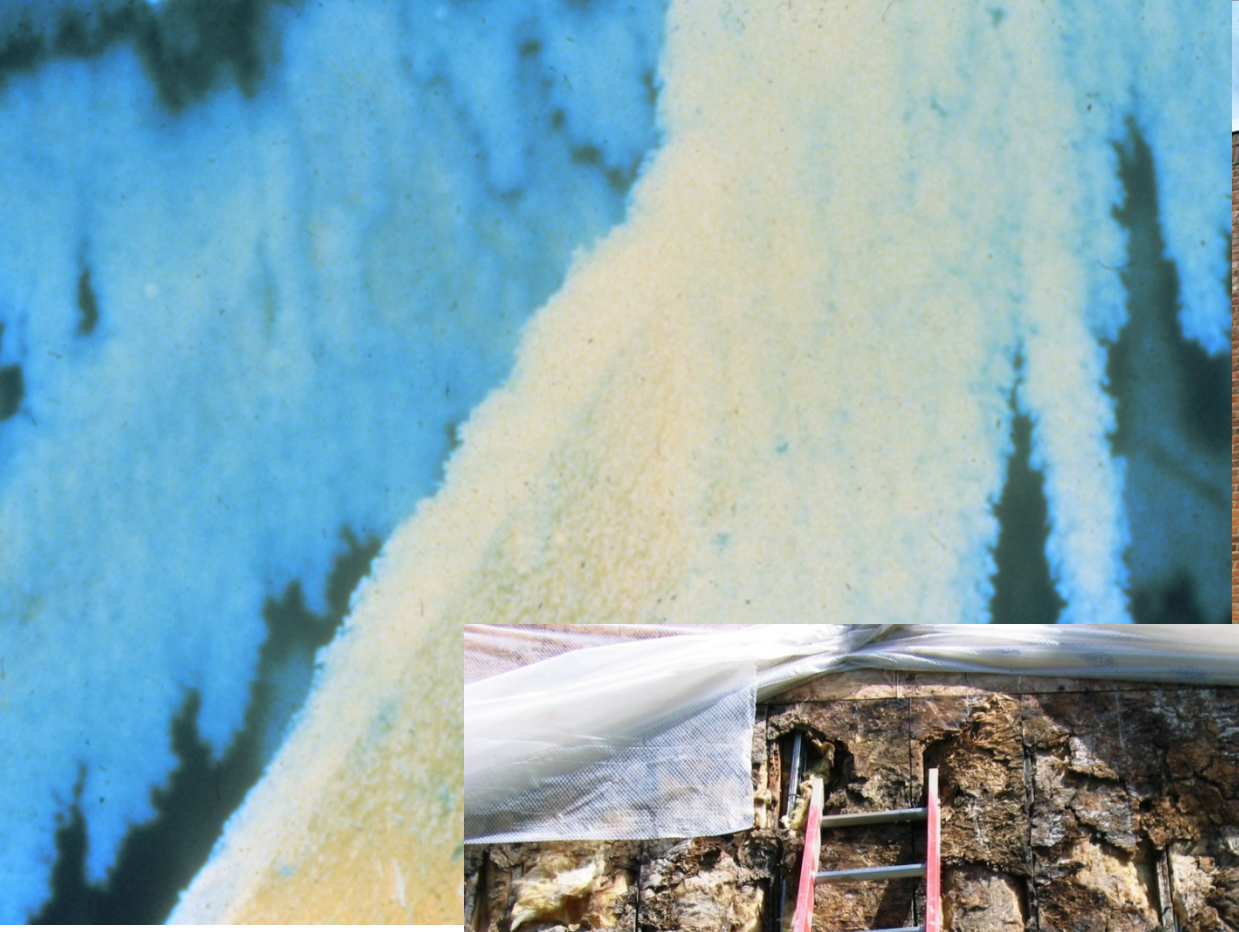
Overall goals

- Evaluate effects of air leakage
  - Energy use
  - Durability of materials in the building envelope
- Improve the performance of air barriers by collaborating with industry partners

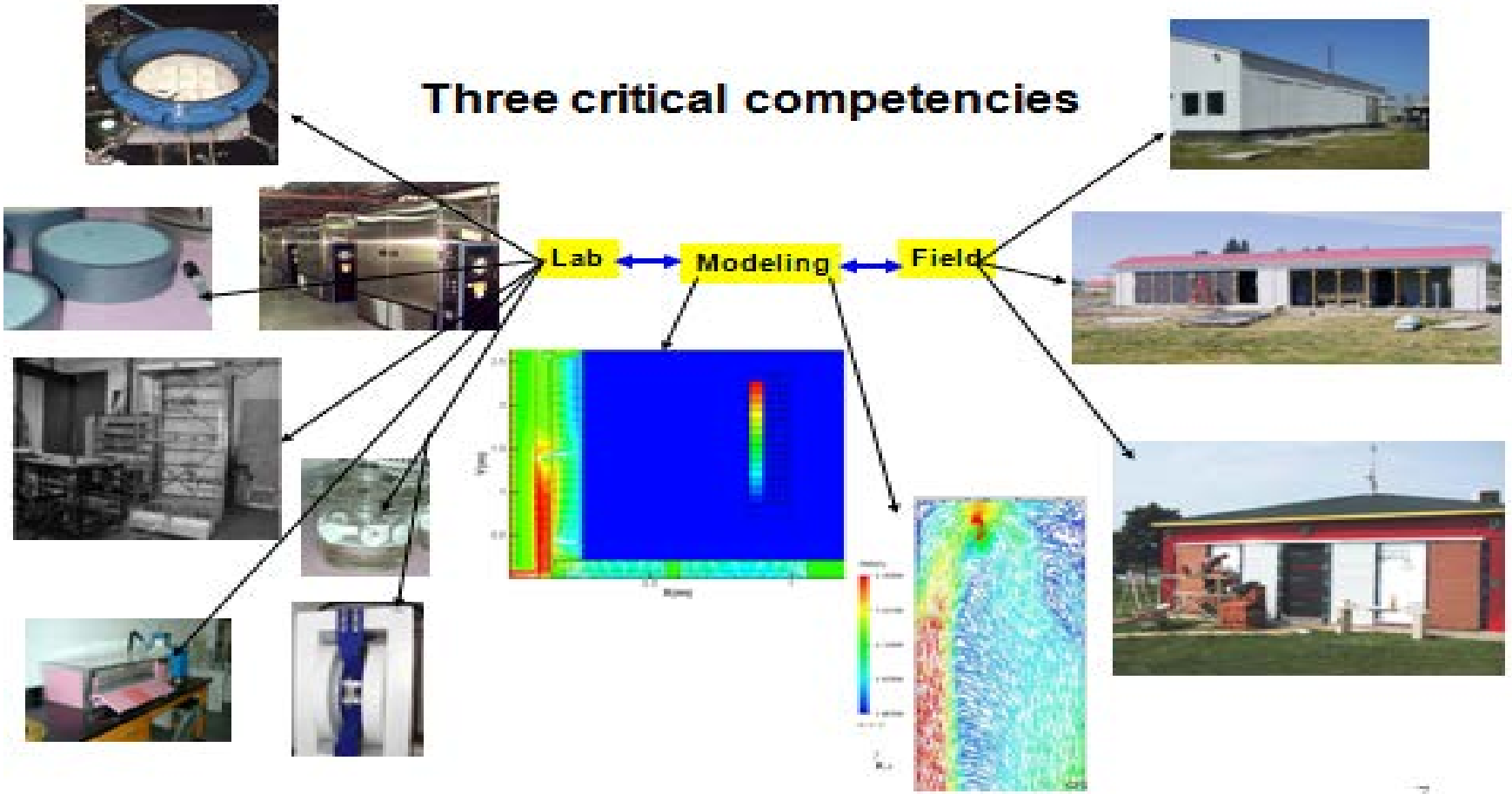
Existing Buildings



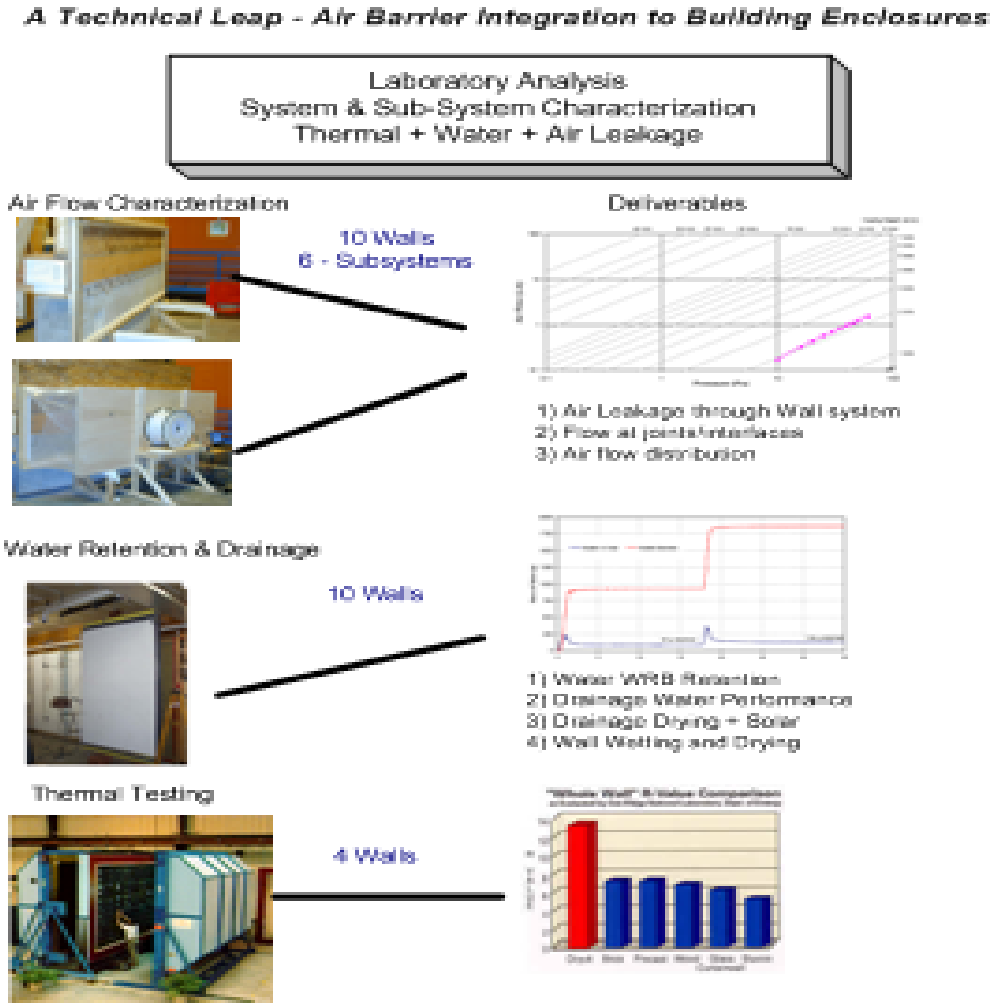
Airtightness Data of New and Existing Buildings



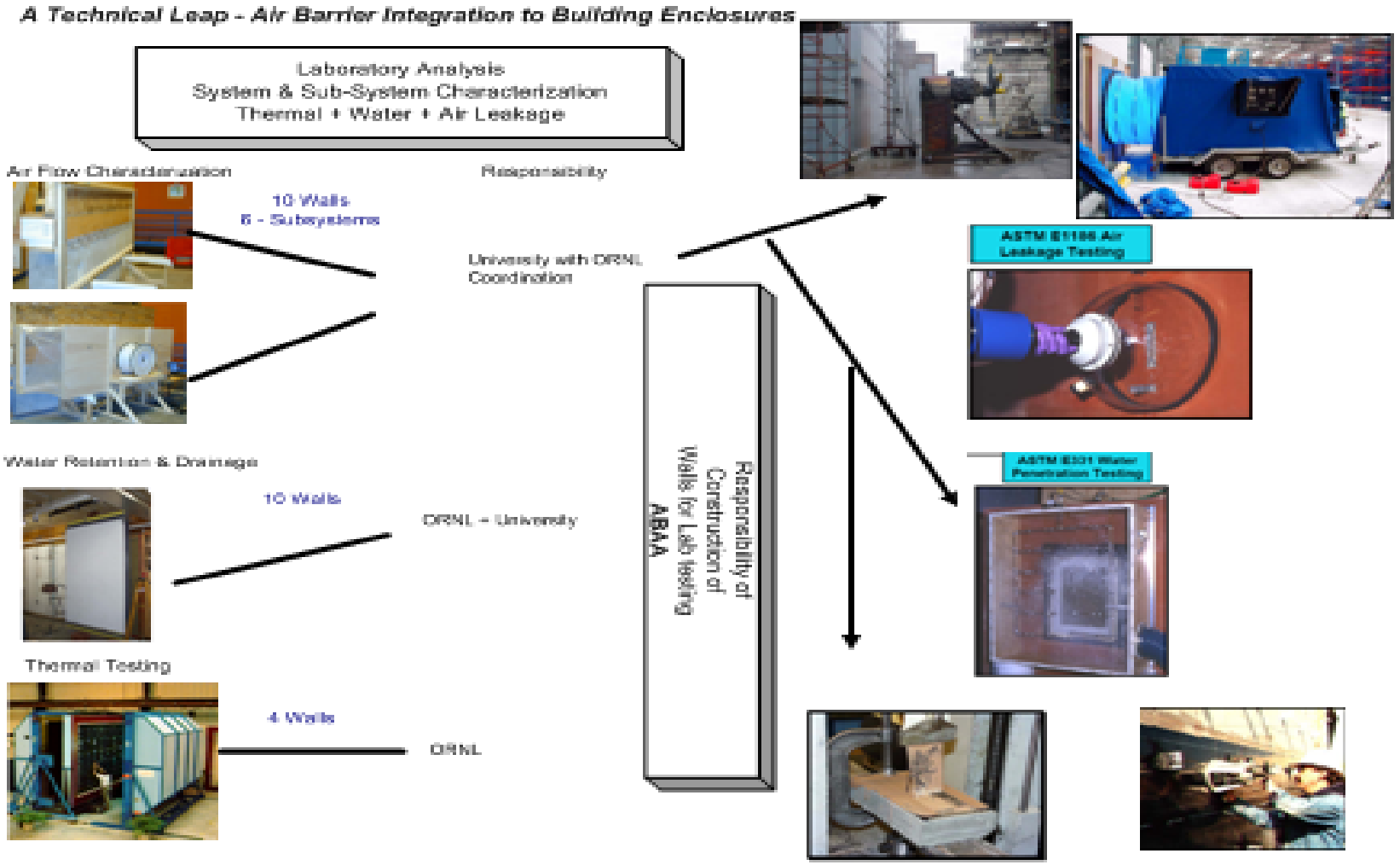
RESEARCH WORK BEING DONE



RESEARCH WORK BEING DONE



RESEARCH WORK BEING DONE



Material property characterization

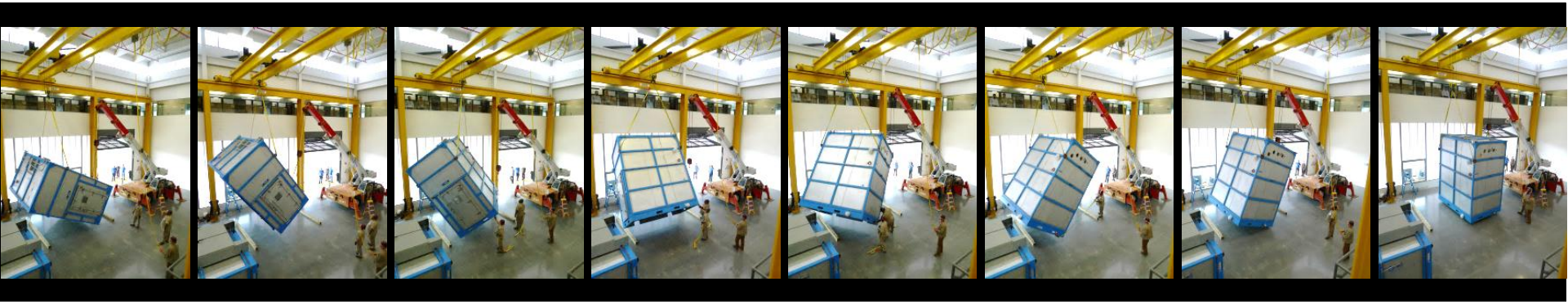
- Conducted by ORNL in Oakridge TN
- To confirm air leakage rate and hydrothermal properties of the materials to be used in the project
- Materials were also outdoor aged

Material property characterization

ORNL Wall Air and Moisture Penetration Test Chamber

Parameters

- Temperature
- Relative humidity
- Pressure
- Rain
- Infrared radiation



Sub-assembly and wall characterization

- Project currently being conducted
- Objective to quantify the air leakage rate of each type of hole or crack
- Conducting tests on eight different types of air barrier
- Work on wood walls completed
- Steel stud CMU pending funding

Laboratory wall testing

Exterior field testing of air barrier assemblies

- Laboratories provide you with results using controlled climates and controlled inputs
- Modeling provides you with expected performance of materials and assemblies
- Needs to be confirmed in the real world

Location, Location, Location

- Test air barriers in cold and windy area
- Syracuse, NY
  - DOE Zone 5
  - Heating load dominated

Storm of 1932

David Lassman / The Post-Standard

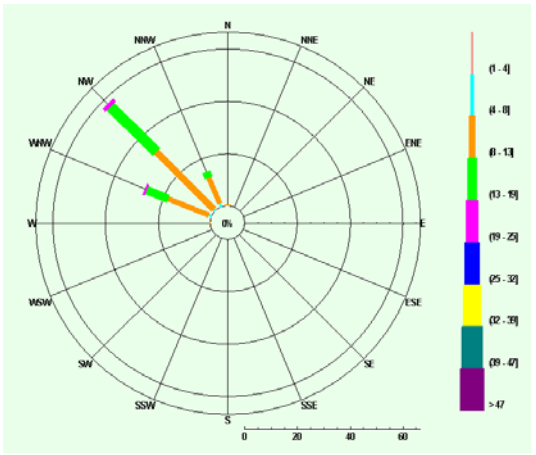
The Post-Standard

Syracuse Natural Exposure Testing Facility

- **2-story facility**
  - Syracuse University campus
  - Controlled indoor environment
  - (34) 4’ × 9’ wall panels

- **Weather station**
  - Temperature
  - Relative humidity
  - Atmospheric pressure
  - Wind velocity
  - Solar radiation
  - Rain accumulation

Daily Wind Rose



Pyranometer
Campbell Scientific LI200X

Pyranometer
Hukseflux LP02

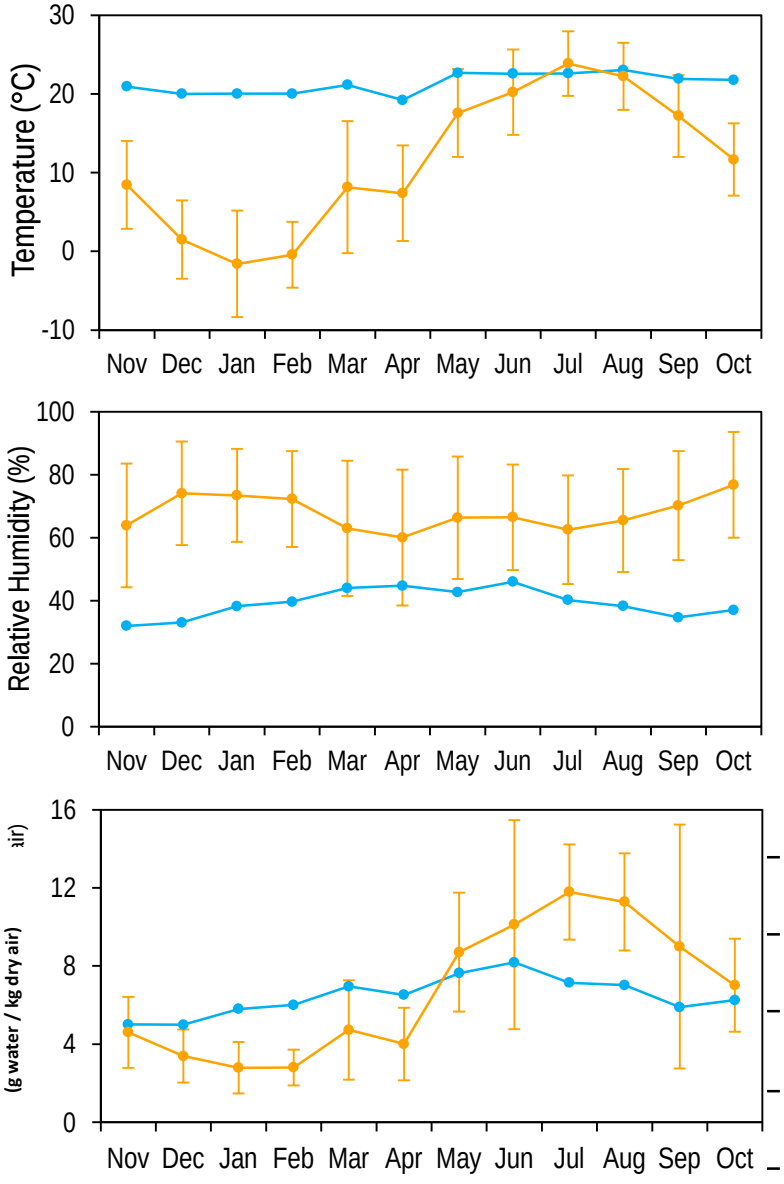
Rain Gage
Texas Electronics TE252WS

Temperature & Relative Humidity
Campbell Scientific CS215

Wind Sensor
Gill Windsonic

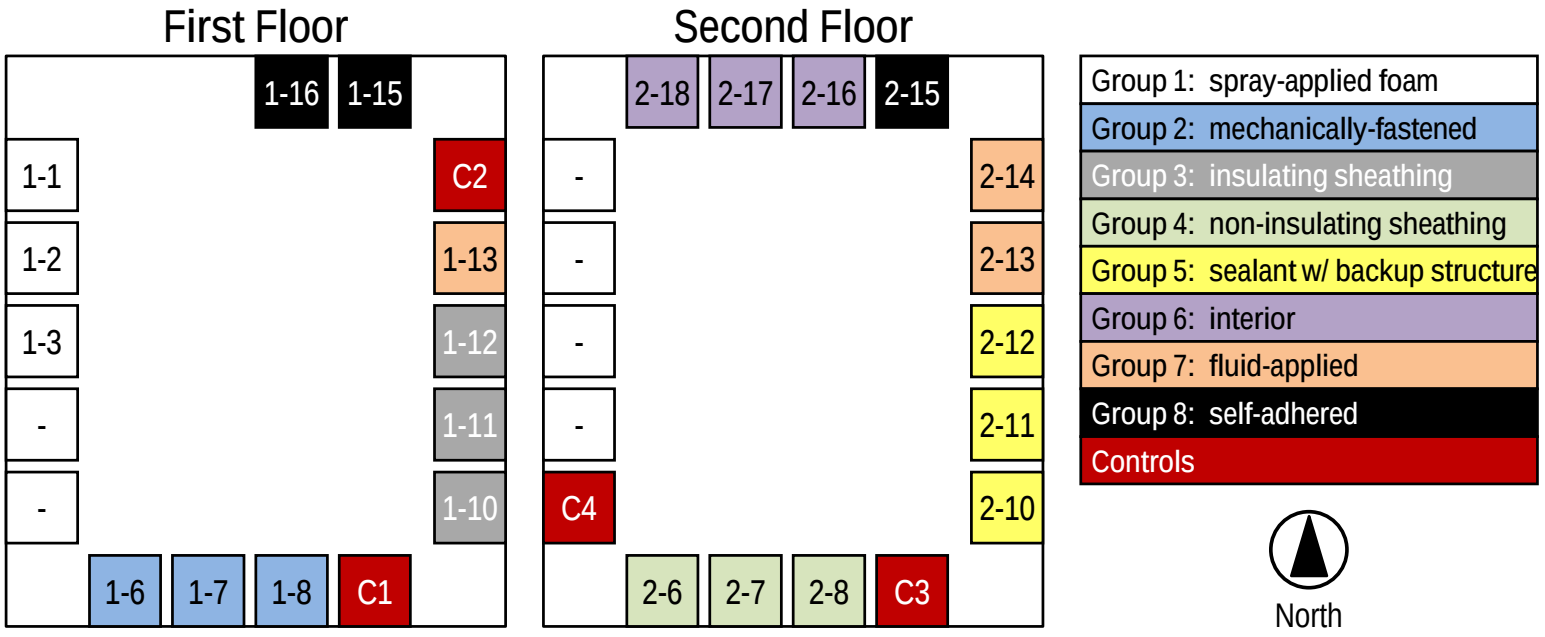
Environmental conditions

- Syracuse, NY, DOE Zone 5
- Vapor pressure drive
  - Summer > winter
  - Summer: vapor transport from outdoors
  - Vapor retarder recommended on exterior side of wall



The test facility

Wall Layout at NET Facility




26.07.2009 11:10

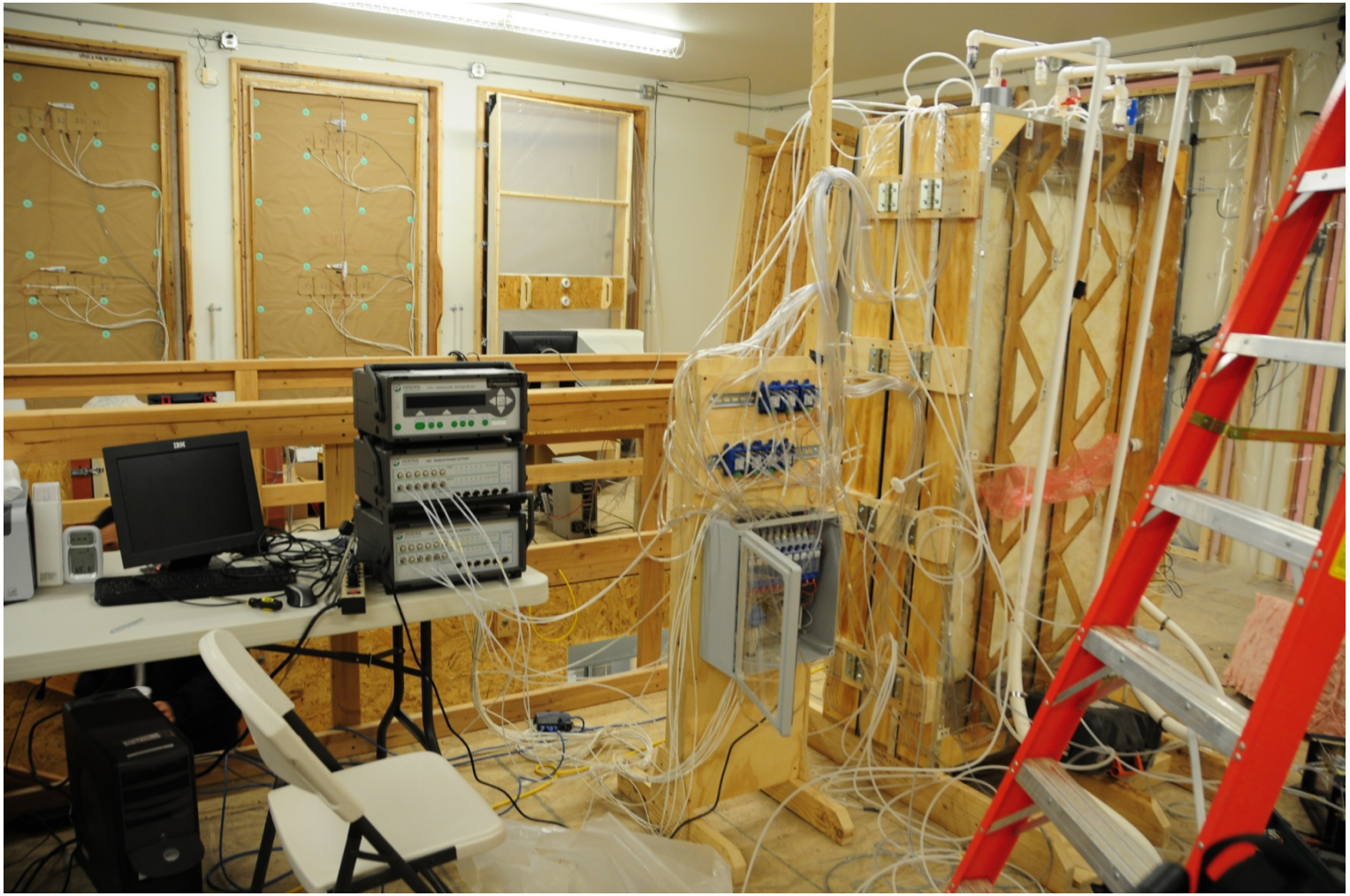

26.07.2009 11:12


26.07.2009 15:28

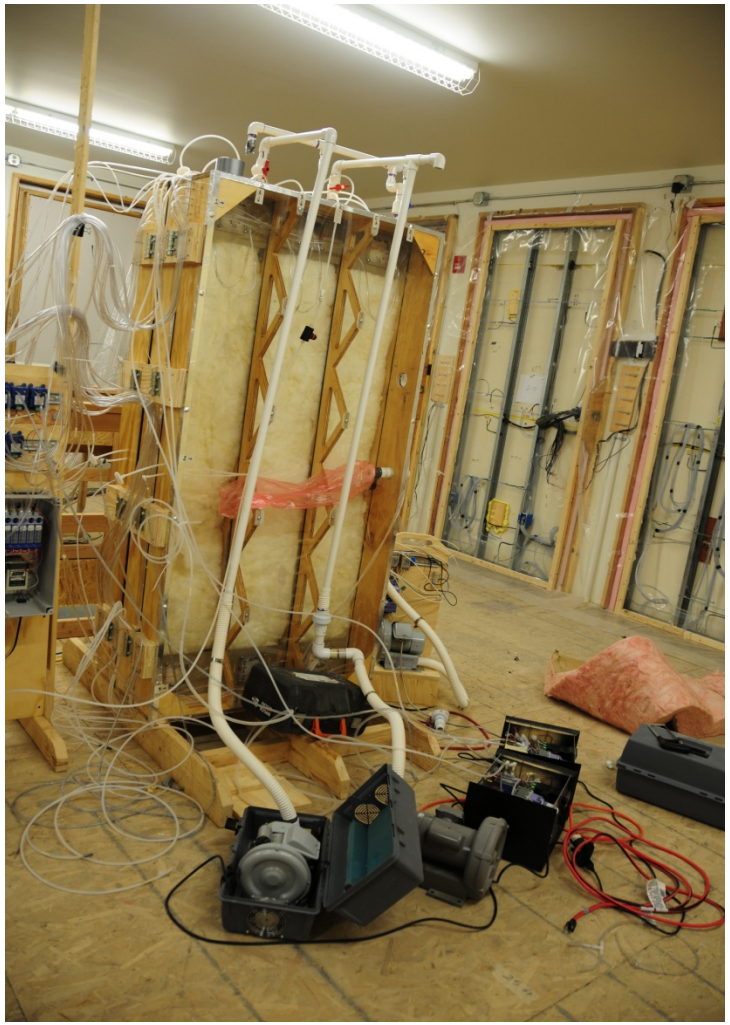

Tyvek
HomeWrap
26.07.2009 11:11

The test facility

The test facility



The test facility



The test facility

The test facility


25.07.2009 06:41


25.07.2009 06:41


APC
25.07.2009 06:42


25.07.2009 06:41

Syracuse Natural Exposure Testing Facility

- **Wall panel data**
  - Air leakage
  - Pressure distribution
  - Temperature
  - Relative humidity
  - Moisture content
  - Heat flux

Wood Framing

Light Gage Steel Framing

Pressurization Setup

Temperature
Fenwal 192-103LET-A01

Relative Humidity
Honeywell HIH-4000

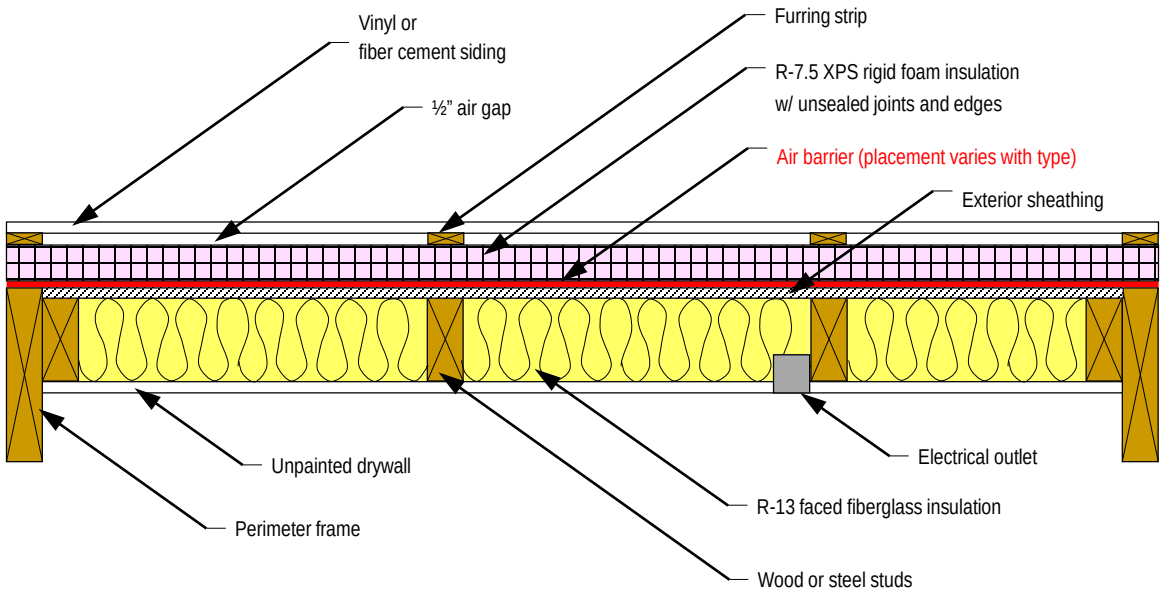
Mass Fowmeter
TSI 40211

Pressure
Energy Conservatory APT

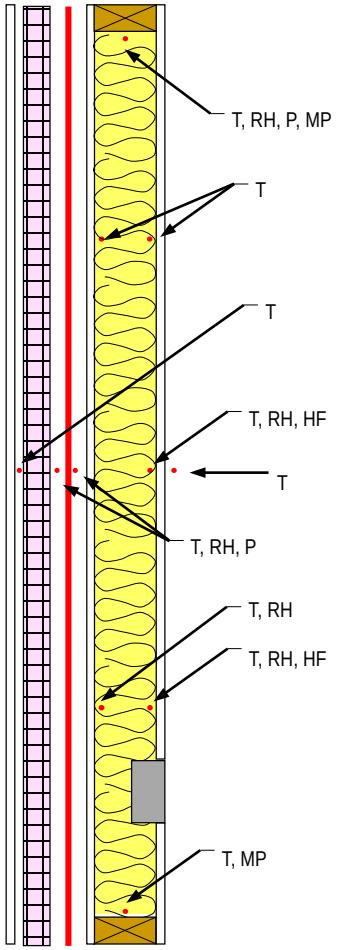
Data Loggers
Campbell Scientific CR1000

Wall Assembly

General Material Layout
Horizontal Cross Section of Wall



General Sensor Layout
Vertical Cross Section of Wall



HF: heat flux
MP: moisture pin
P: pressure
RH: relative humidity
T: temperature

The wall specimens

The wall specimens

The wall specimens

The wall specimens

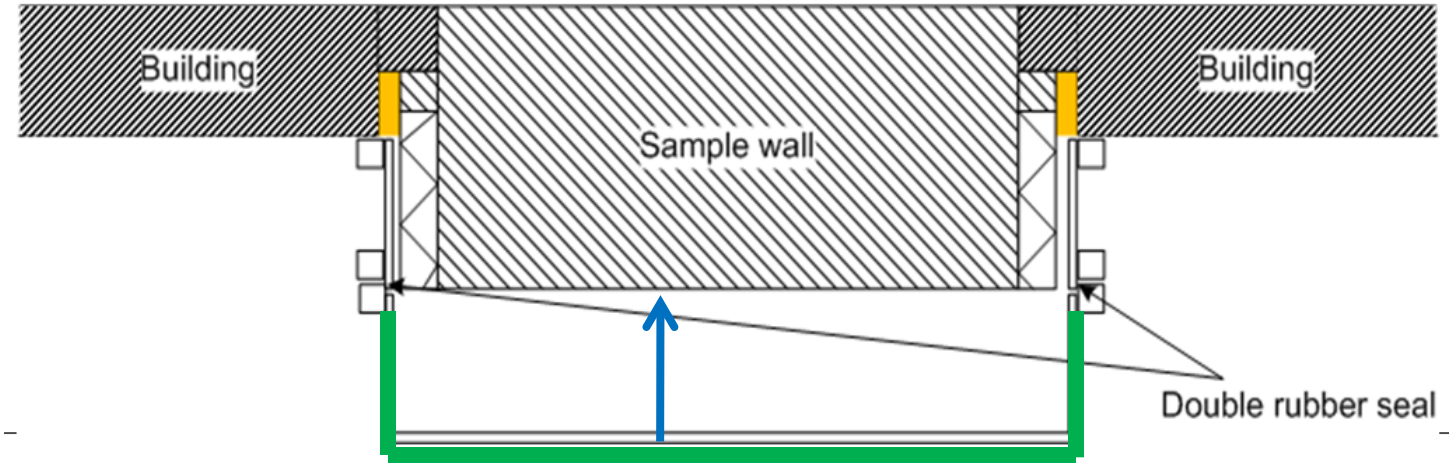
The wall specimens

The wall specimens

Forensic evaluation of the test wall assemblies

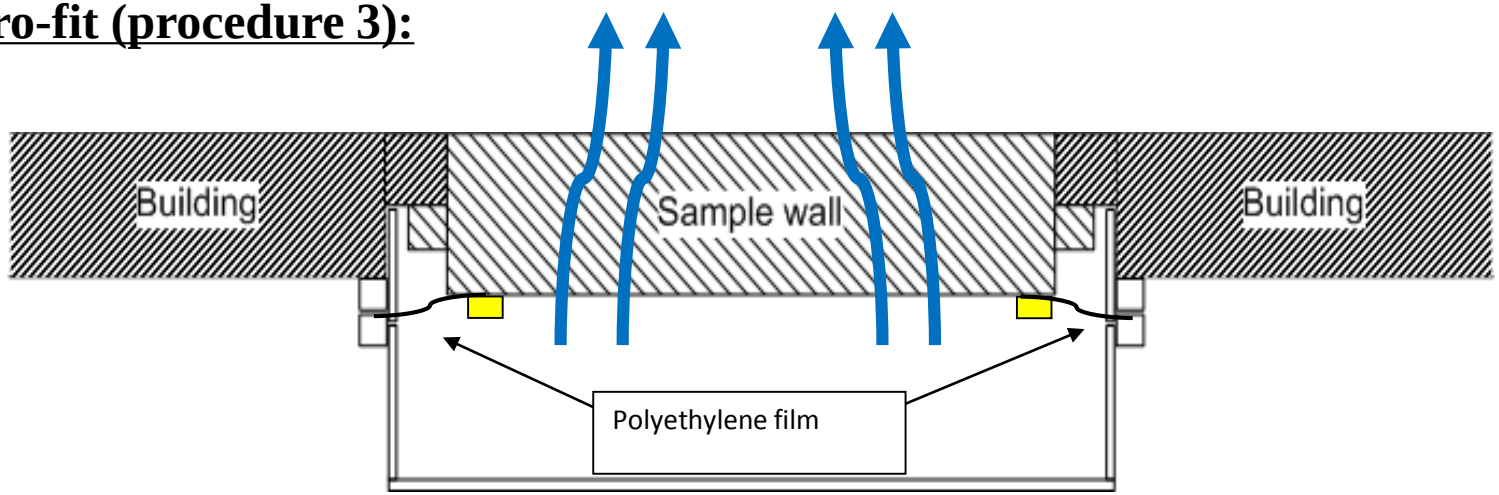
- After the one year data gathering the walls were removed
- Walls were examined to determine where and why there was air leakage

Test Set-up:



75 Pa

Retro-fit (procedure 3):



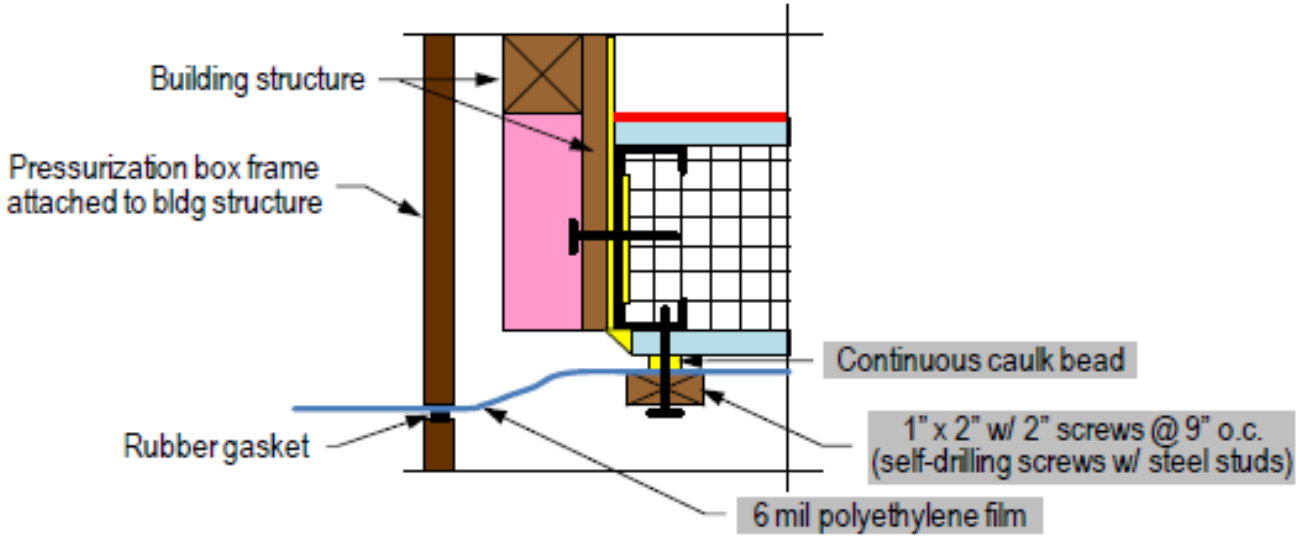


Image courtesy of Hun, Diana

Three main types of assemblies:

Wood Stud

Steel Stud

Masonry

Three main types of assemblies:

Wood Stud Steel Stud Masonry

Wood Panel Assemblies

PANEL AB4

0.373 L/s*m^2 @ 75 Pascal

Wood Panel Assemblies cont…

PANEL AB11

$0.805\ L/s*m^2$ @ 75 Pascal

Wood Panel Assemblies cont…

PANEL AB16-1

$0.213\ L/s*m^2$ @ 75 Pascal

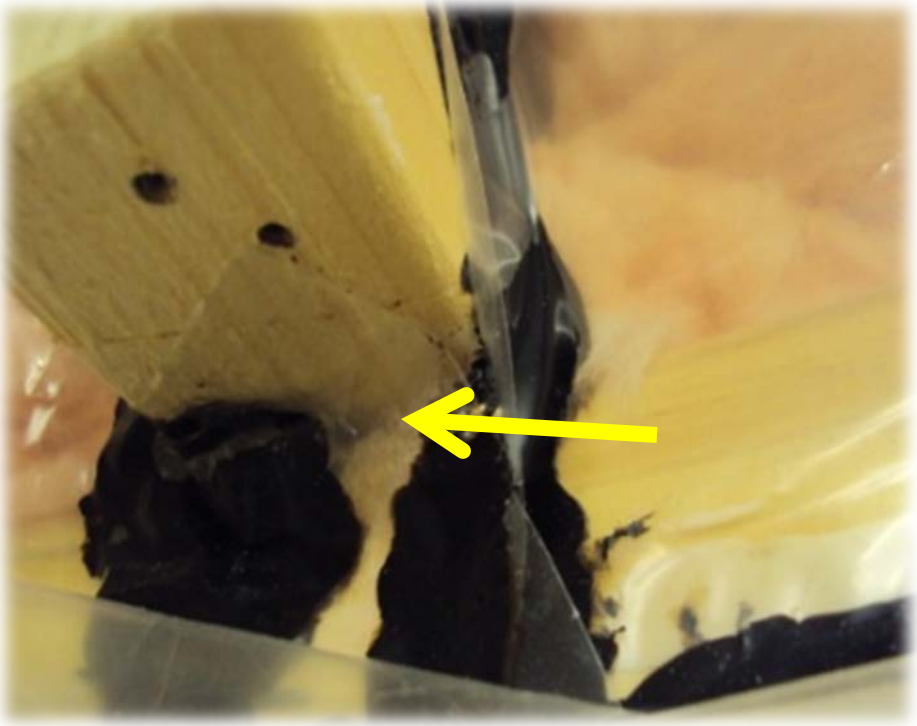
Wood Panel Assemblies cont…

PANEL AB27

$$0.134 \text{ L/s*m}^2 \quad @ 75 \text{ Pascal}$$

Wood Panel Assemblies cont…

PANEL AB23-2



0.568 L/s*m^2 @ 75 Pascal

Three main types of assemblies:

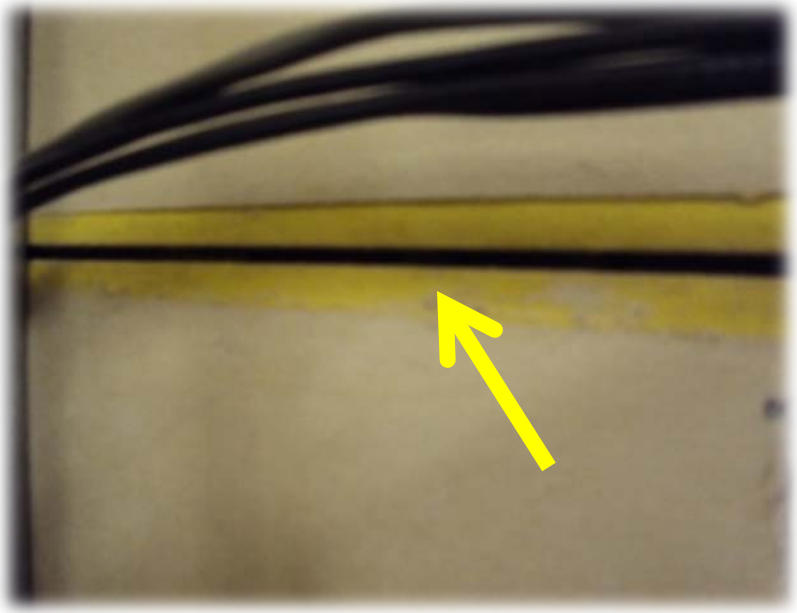
Wood Stud

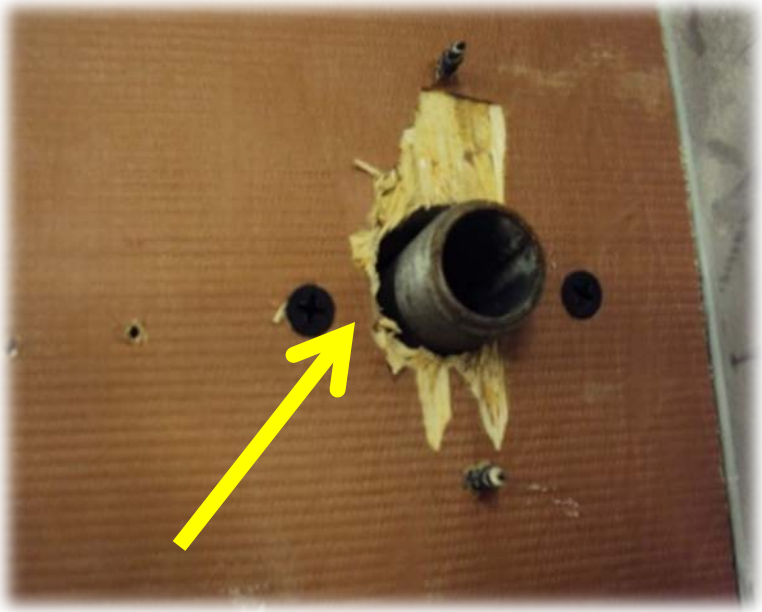
Steel Stud

Masonry

Steel Stud Panel Assemblies

PANEL AB8-1

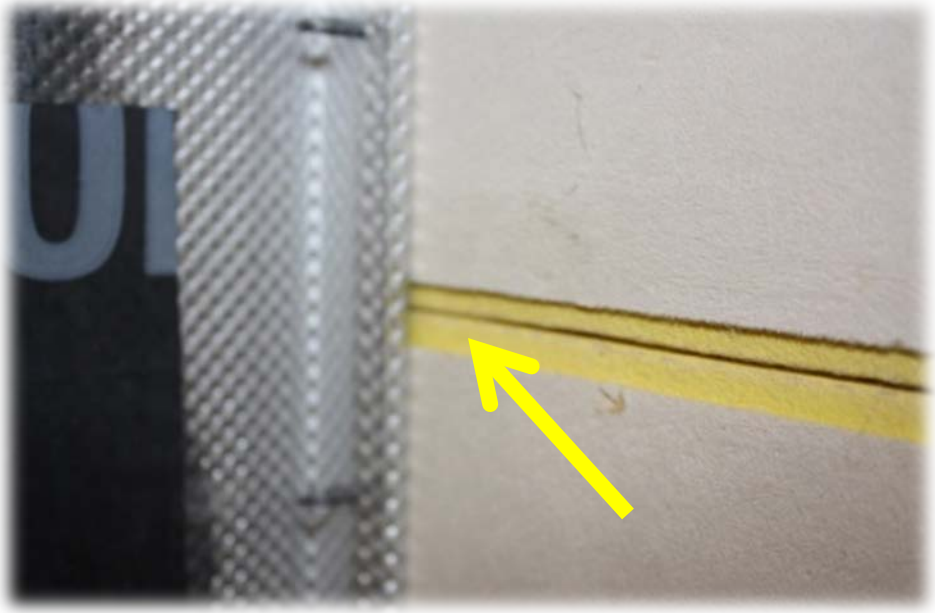




1.09 L/s*m^2 @ 75 Pascal

Steel Stud Panel Assemblies cont…

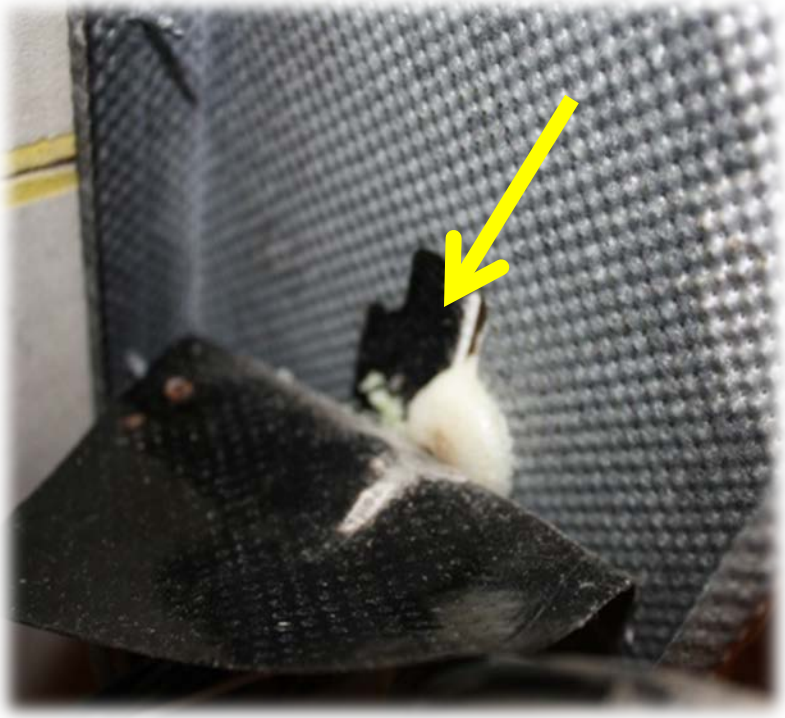
PANEL AB10



0.295 L/s*m^2 @ 75 Pascal

Steel Stud Panel Assemblies cont…

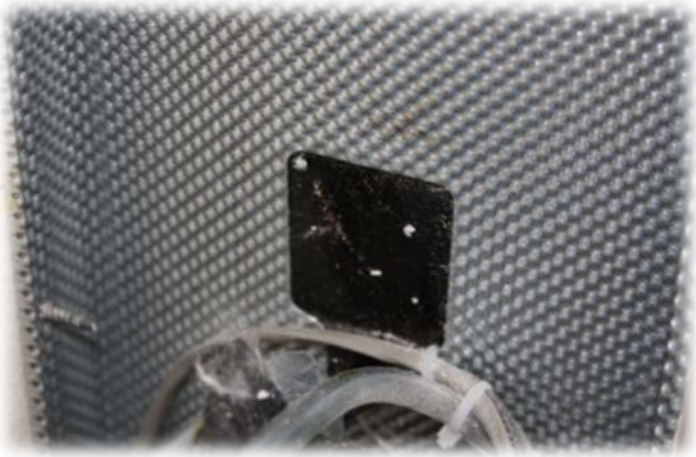
PANEL AB6

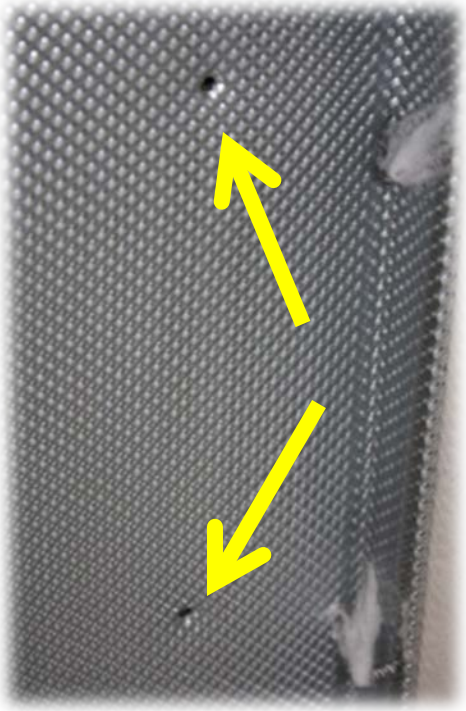


0.302 L/s*m^2 @ 75 Pascal

Steel Stud Panel Assemblies cont…

PANEL AB21





1.19 L/s*m^2 @ 75 Pascal

Steel Stud Panel Assemblies cont…

PANEL AB25

1.17 L/s*m^2 @ 75 Pascal

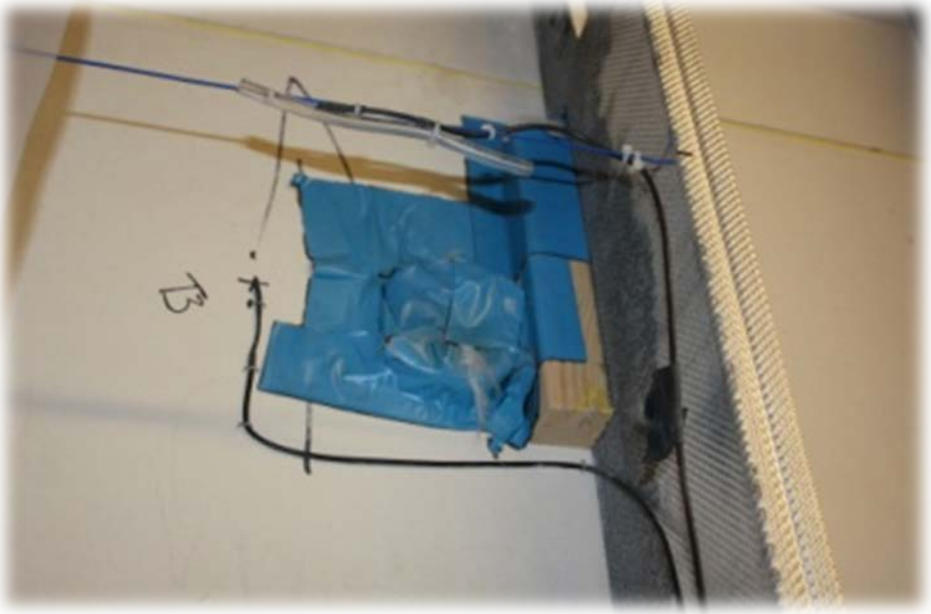
Steel Stud Panel Assemblies cont…

PANEL AB25

Phase 1 vs. Phase 2

Steel Stud Panel Assemblies cont…

PANEL AB19



1.03 L/s*m^2 @ 75 Pascal

Three main types of assemblies:

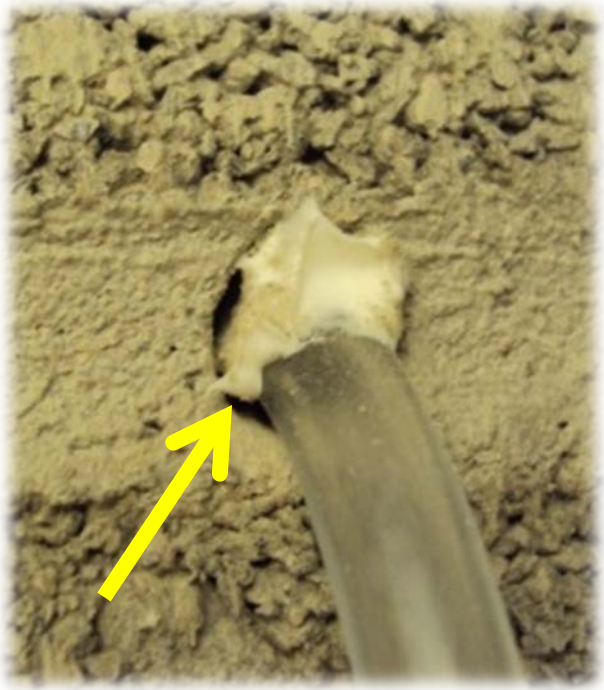
Wood Stud

Steel Stud

Masonry

Masonry Panels

PANEL AB13-1

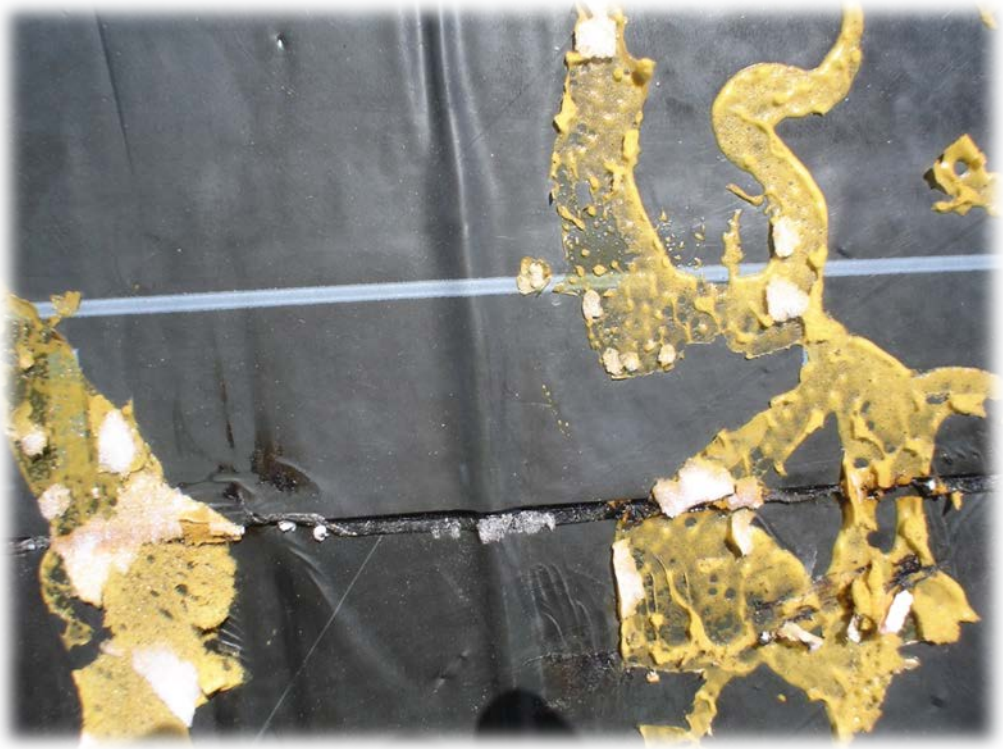


1.17 L/s*m^2 @ 75 Pascal

Masonry Panels: Porous CMU Panel

Condition of Air Barriers

Condition of Air Barriers : Self-Adhered



Condition of Air Barriers:
Fluid Applied

Condition of Air Barriers: Fluid Applied

Condition of Air Barriers : Perimeter examples

Condition of Air Barriers : Spray Foam

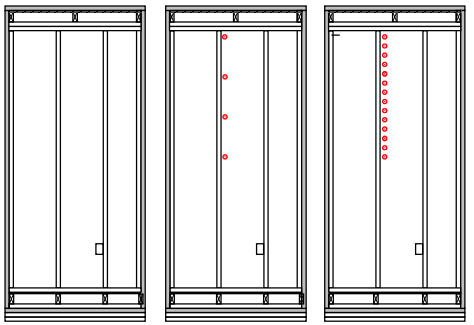
Condition of Air Barriers : Non-Insulated Boardstock

Test walls 2nd year

- Effect of air leakage on energy and durability
  - Material: Level 1 → 0.02 L/(s·m^2) @ 75 Pa → Baseline
  - Assembly: Level 2 → 0.2 L/(s·m^2) @ 75 Pa
  - Enclosure: Level 3 → 1L/(s·m^2) @ 75 Pa
- Eight air barrier types

Syracuse natural exposure test facility

- Three walls per air barrier type
  - Representative of residential or commercial construction
  - Simulated imperfections
- Data collection from Nov 2011 to Dec 2012



Panel material layout

Residential Construction

Air Barrier Types

1. Non-insulating sheathing
2. Interior air barrier
3. Sealants with backup structure

Materials

1. Vinyl siding
2. R-7.5 rigid insulation w/o sealed edges
3. OSB sheathing
4. 2x4 wood studs at 16” o.c.
5. R-13 faced fiberglass insulation
6. Unpainted gypsum board

Commercial Construction

Air Barrier Types

1. Insulating sheathing
2. Fluid-applied non-foaming membrane
3. Self-adhered membrane
4. Spray-applied foam
5. Mechanically fastened membrane

Materials

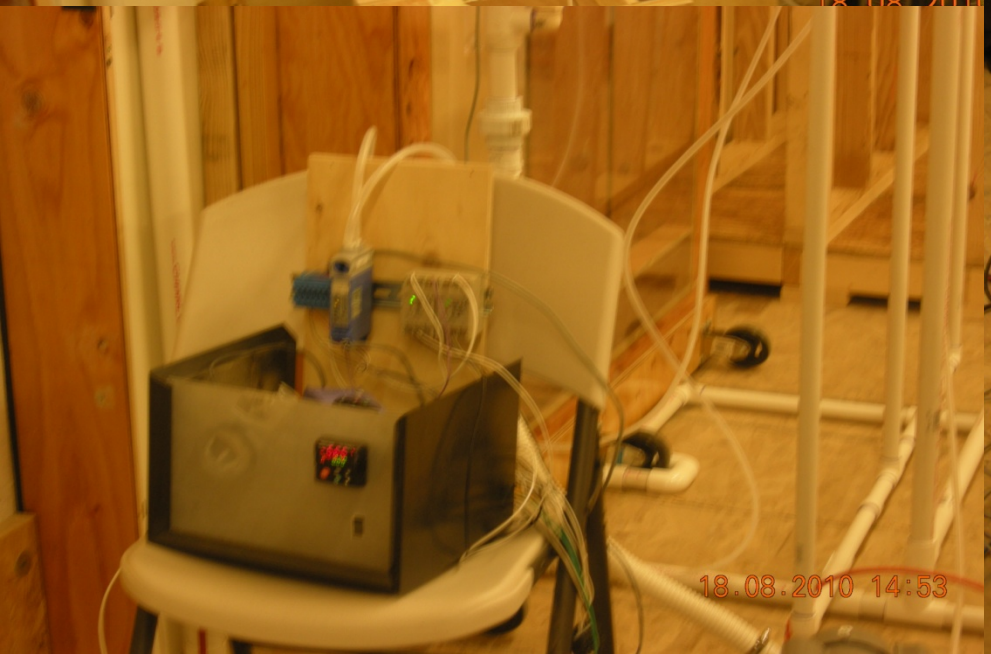
1. Fiber cement siding
2. R-7.5 rigid insulation w/o sealed edges
3. Exterior gypsum sheathing with fiberglass mat
4. 3 ½” steel studs at 16” o.c.
5. R-13 faced fiberglass insulation (where applicable)
6. Unpainted gypsum board


EXIT
18.08.2010 14:51


18.08.2010 14:52


18.08.2010 14:53


18.08.2010 14:54


18.08.2010 14:53

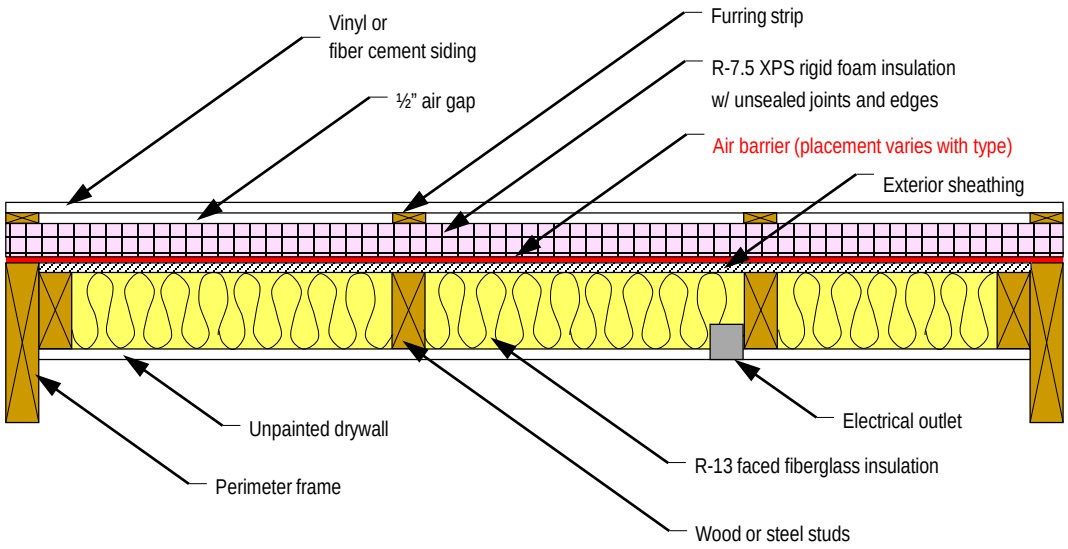

18.08.2010 14:54
NALGENE


GRACE
Perm-A-Barrier
THE VOLCOM STONE CO.

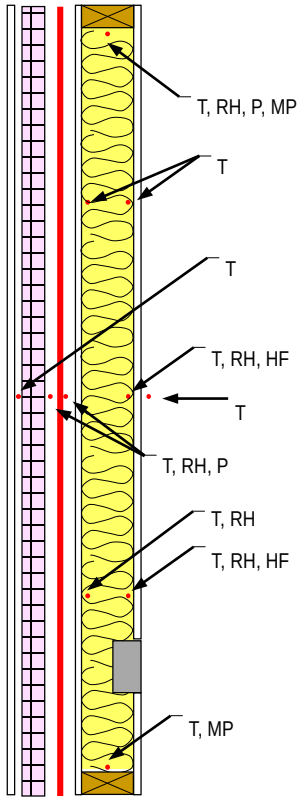
Wall assembly

Air barriers and continuous insulation per IECC 2012

General Material Layout
Horizontal Cross Section of Wall



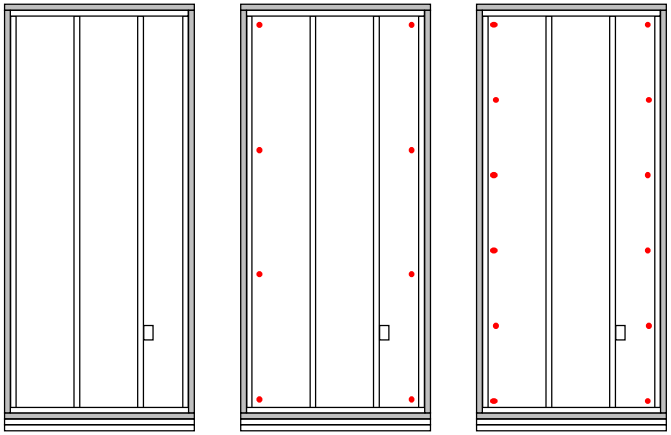
General Sensor Layout
Vertical Cross Section of Wall



HF: heat flux
MP: moisture pin
P: pressure
RH: relative humidity
T: temperature

Group 1: Spray-Applied Foam

Simulated imperfection: foam detachment due to improper installation



Level 1
< 0.02 L/(s·m^2)

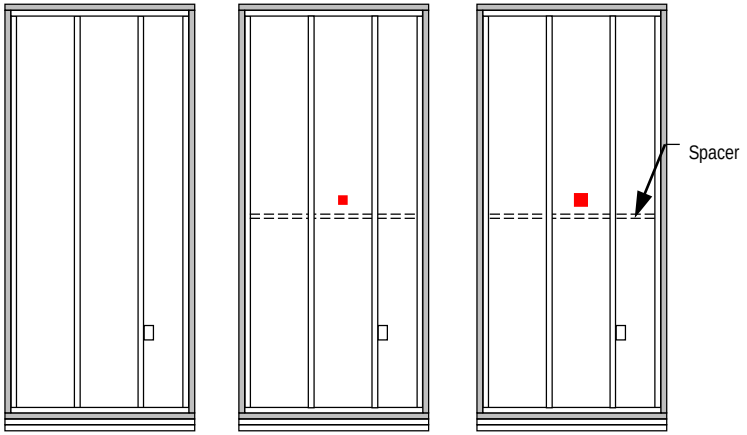
Level 2
0.2 L/(s·m^2)

Level 3
0.79 L/(s·m^2)

@ ΔP = 75 Pa

Group 2: Mechanically-Fastened Membrane

Simulated imperfection: penetration through air barrier

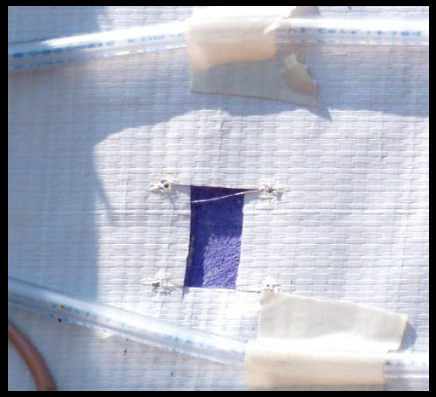


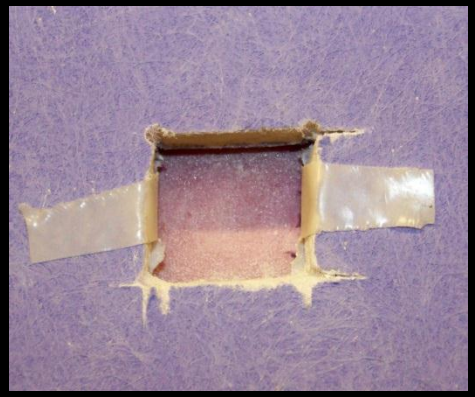
Level 1 $0.07\ L/(s \cdot m^2)$

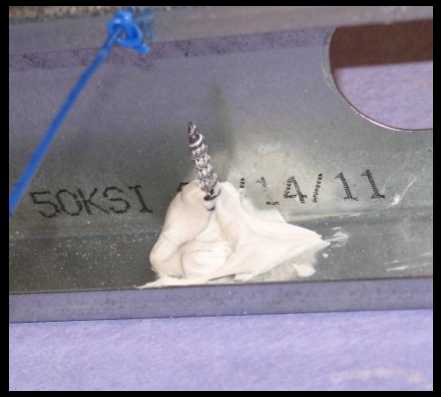
Level 2 $0.28\ L/(s \cdot m^2)$

Level 3 $0.73\ L/(s \cdot m^2)$

@ $\Delta P = 75$ Pa

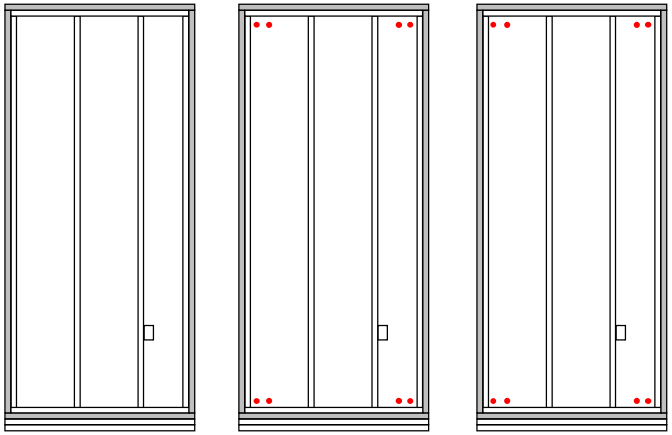






Group 3: Insulating Sheathing

Simulated imperfection: gaps between top/bottom tracks and studs



Level 1 $0.03\ L/(s \cdot m^2)$

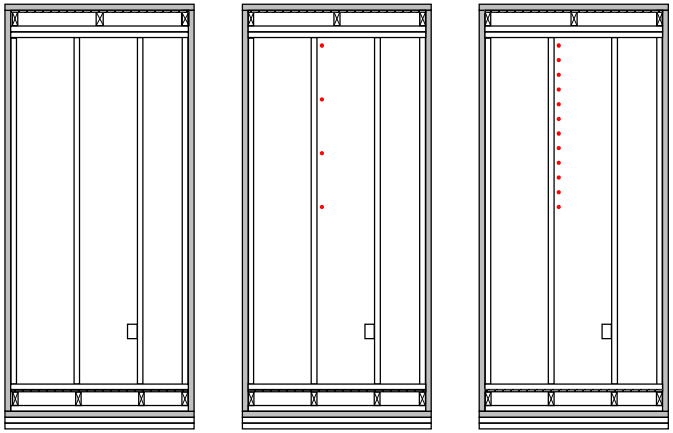
Level 2 $0.36\ L/(s \cdot m^2)$

Level 3 $0.5\ L/(s \cdot m^2)$

@ $\Delta P = 75$ Pa

Group 4: Non-Insulating Sheathing

Simulated imperfection: unsealed OSB joint at stud

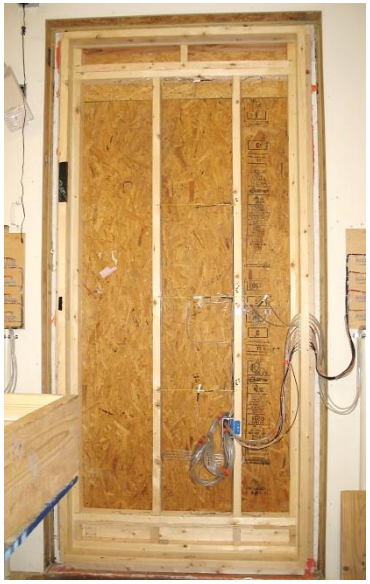


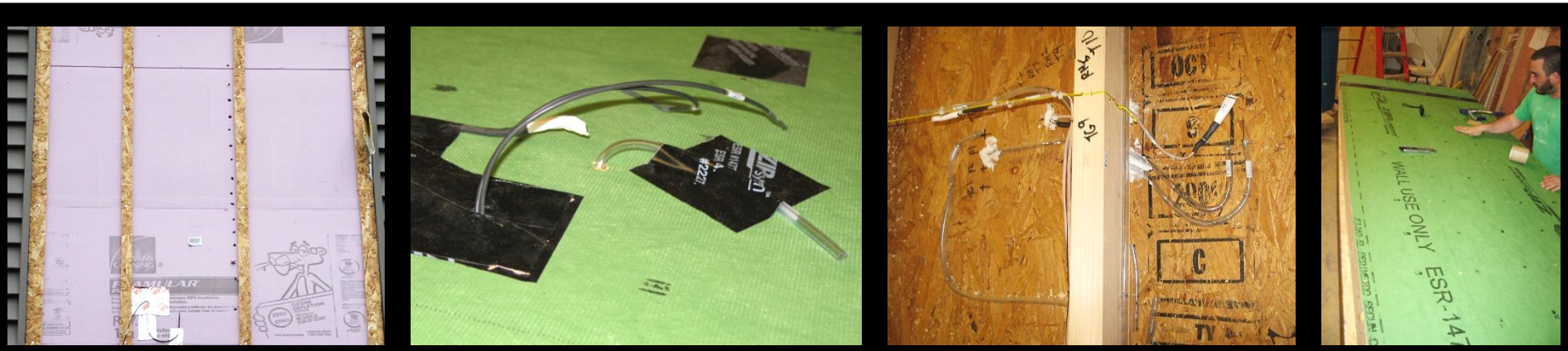
Level 1
< 0.02 L/(s·m^2)

Level 2
0.26 L/(s·m^2)

Level 3
0.7 L/(s·m^2)

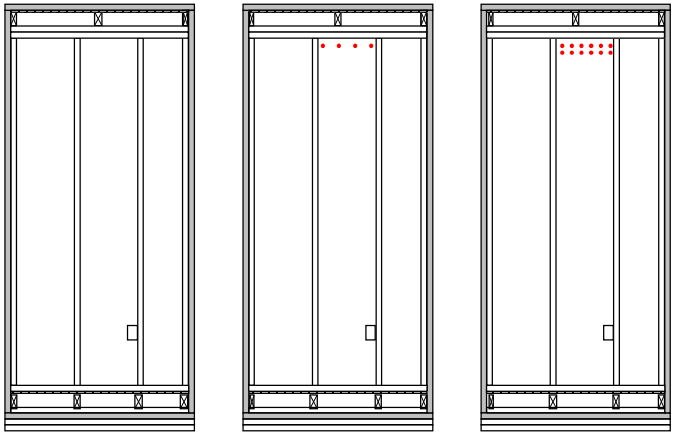
@ ΔP = 75 Pa





Group 5: Sealant w/ Backup Structure

Simulated imperfection: unsealed joint at top plate

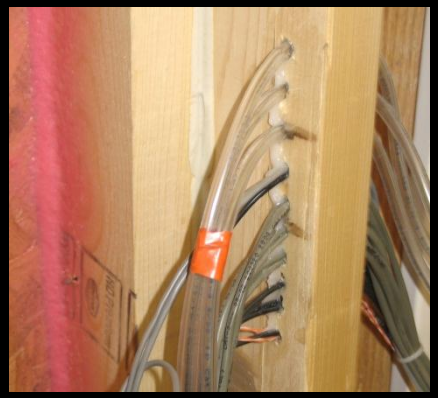


Level 1 $0.09\ L/(s \cdot m^2)$

Level 2 $0.19\ L/(s \cdot m^2)$

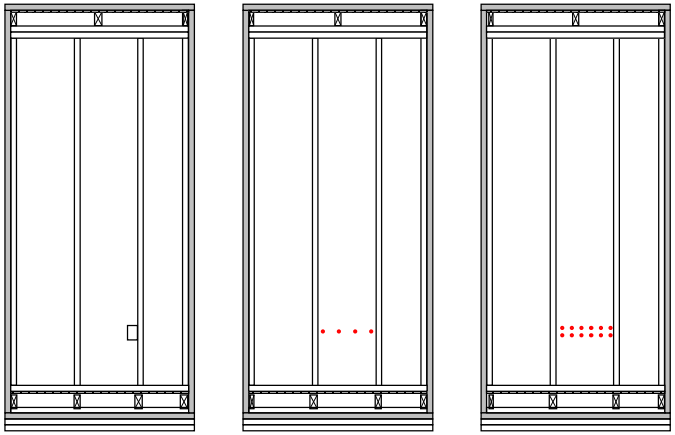
Level 3 $0.52\ L/(s \cdot m^2)$

@ $\Delta P = 75$ Pa



Group 6: Interior Membrane

Simulated imperfection: penetration through air barrier

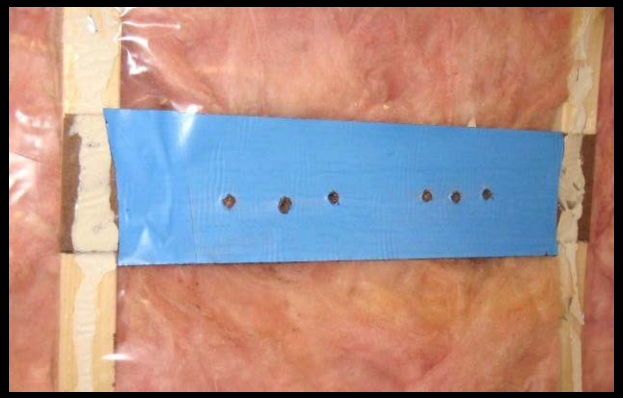


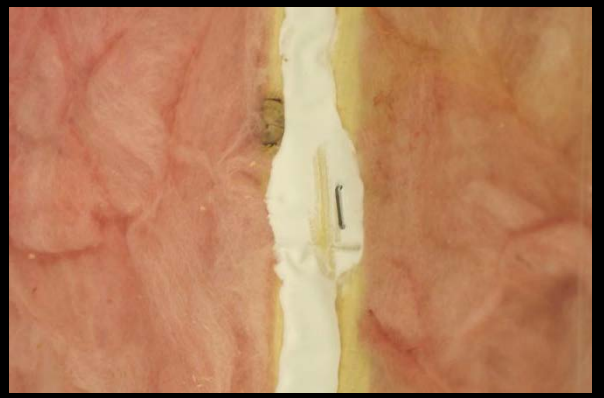
Level 1 $0.08\ L/(s \cdot m^2)$

Level 2 $0.2\ L/(s \cdot m^2)$

Level 3 $0.55\ L/(s \cdot m^2)$

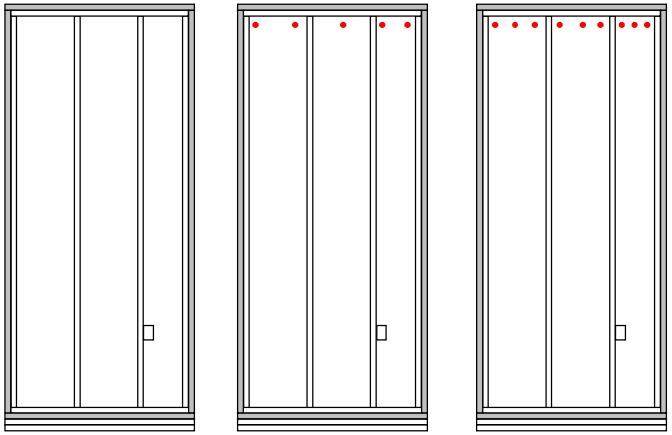
@ $\Delta P = 75$ Pa





Group 7: Fluid-Applied Membrane

Simulated imperfection: unsealed exterior sheathing to top track

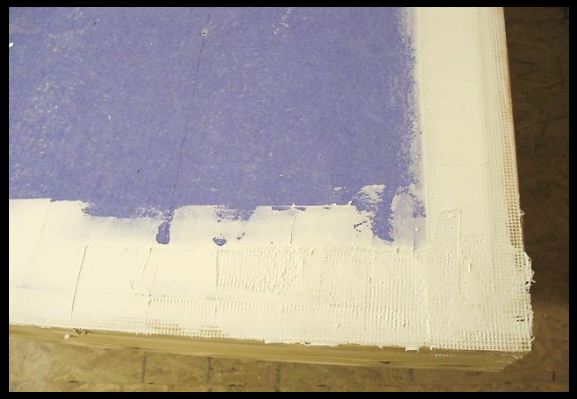


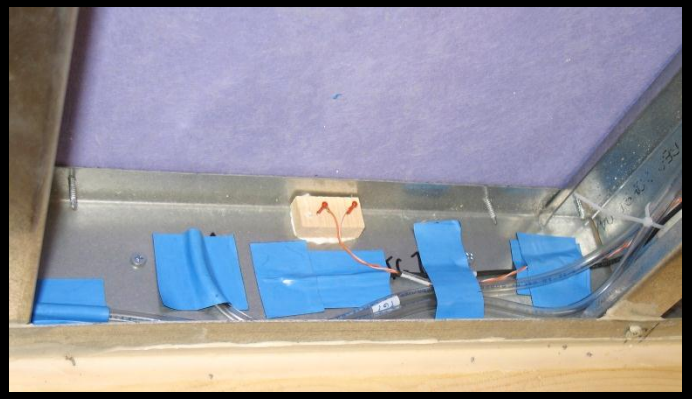
Level 1
< 0.02 L/(s·m^2)

Level 2
0.17 L/(s·m^2)

Level 3
0.74 L/(s·m^2)

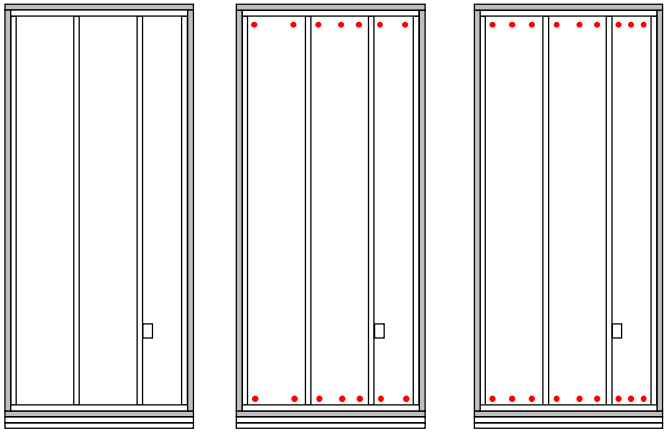
@ ΔP = 75 Pa





Group 8: Self-Adhered Membrane

Simulated imperfection: unsealed exterior sheathing to top/bottom track

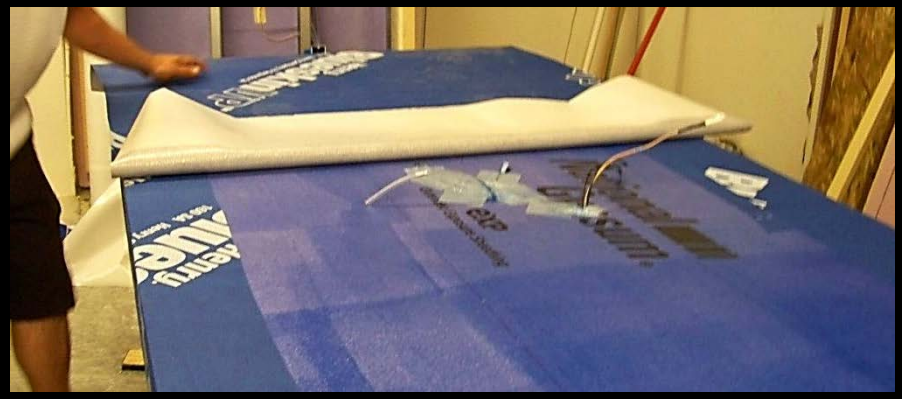


Level 1
< 0.02 L/(s·m^2)

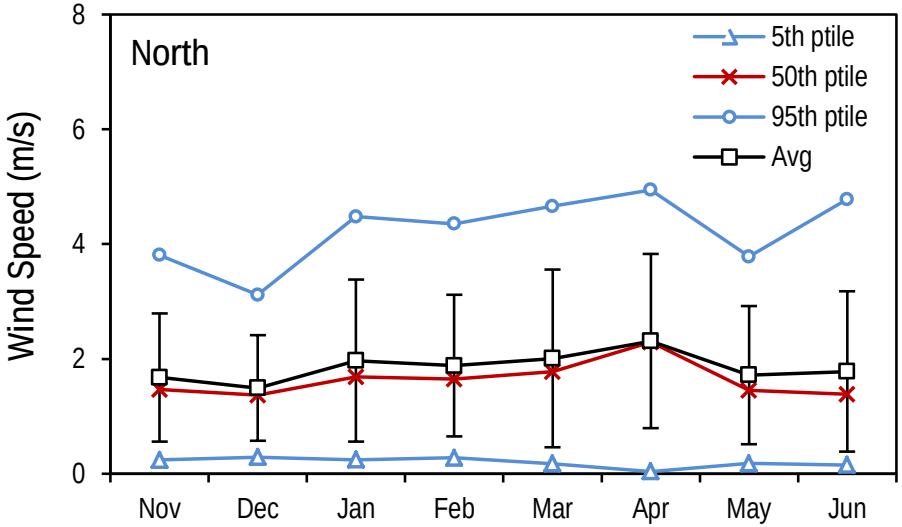
Level 2
0.19 L/(s·m^2)

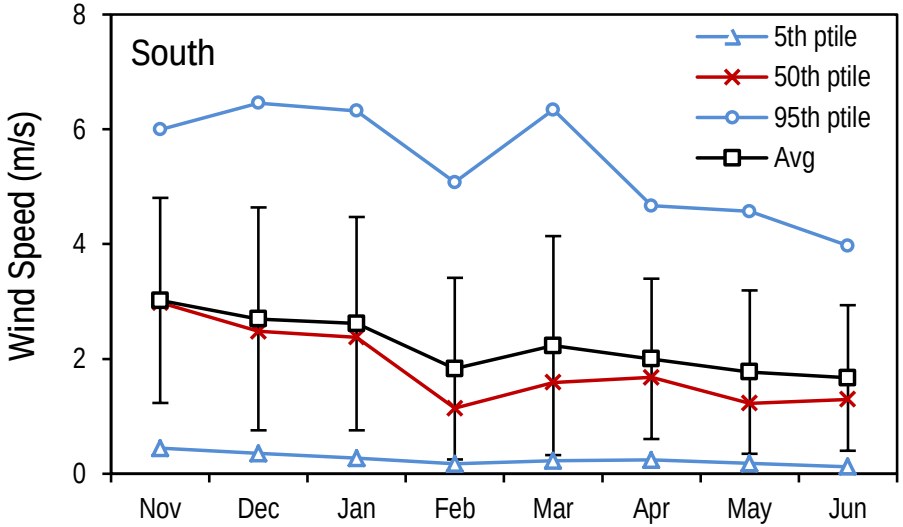
Level 3
1.03 L/(s·m^2)

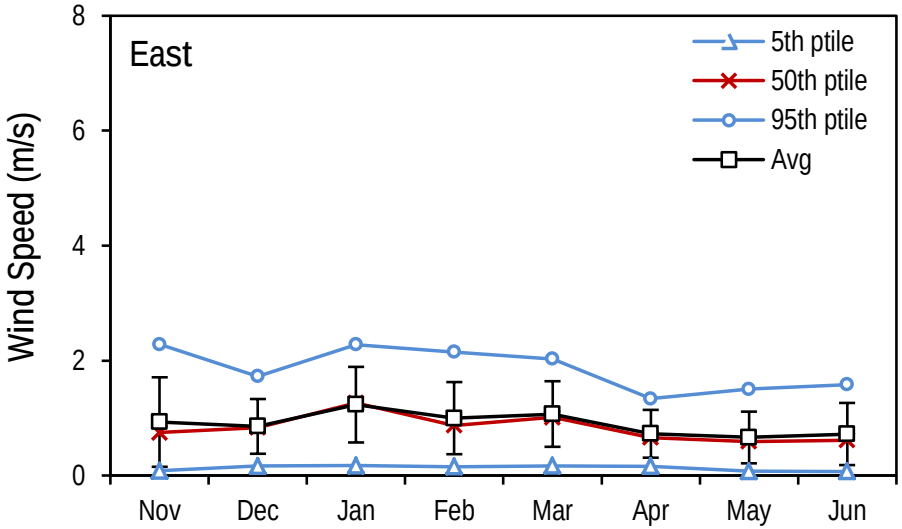
@ ΔP = 75 Pa

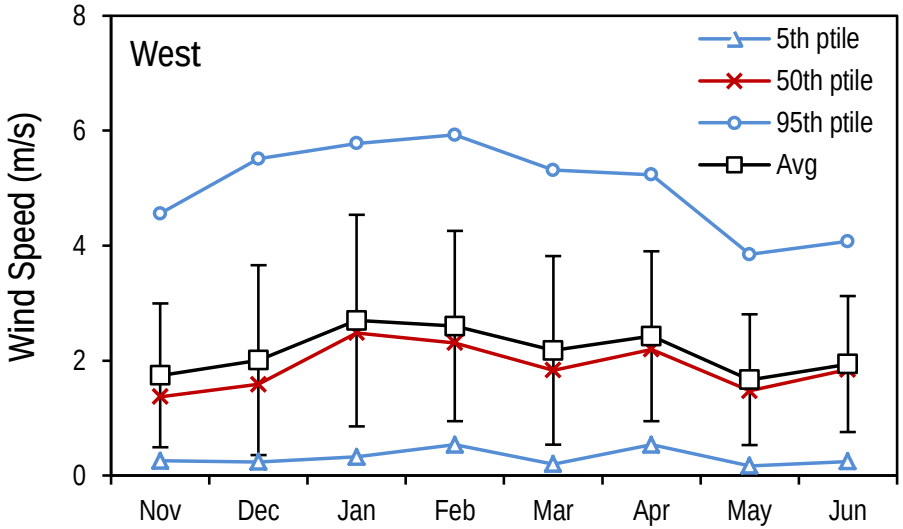


Wind Speed

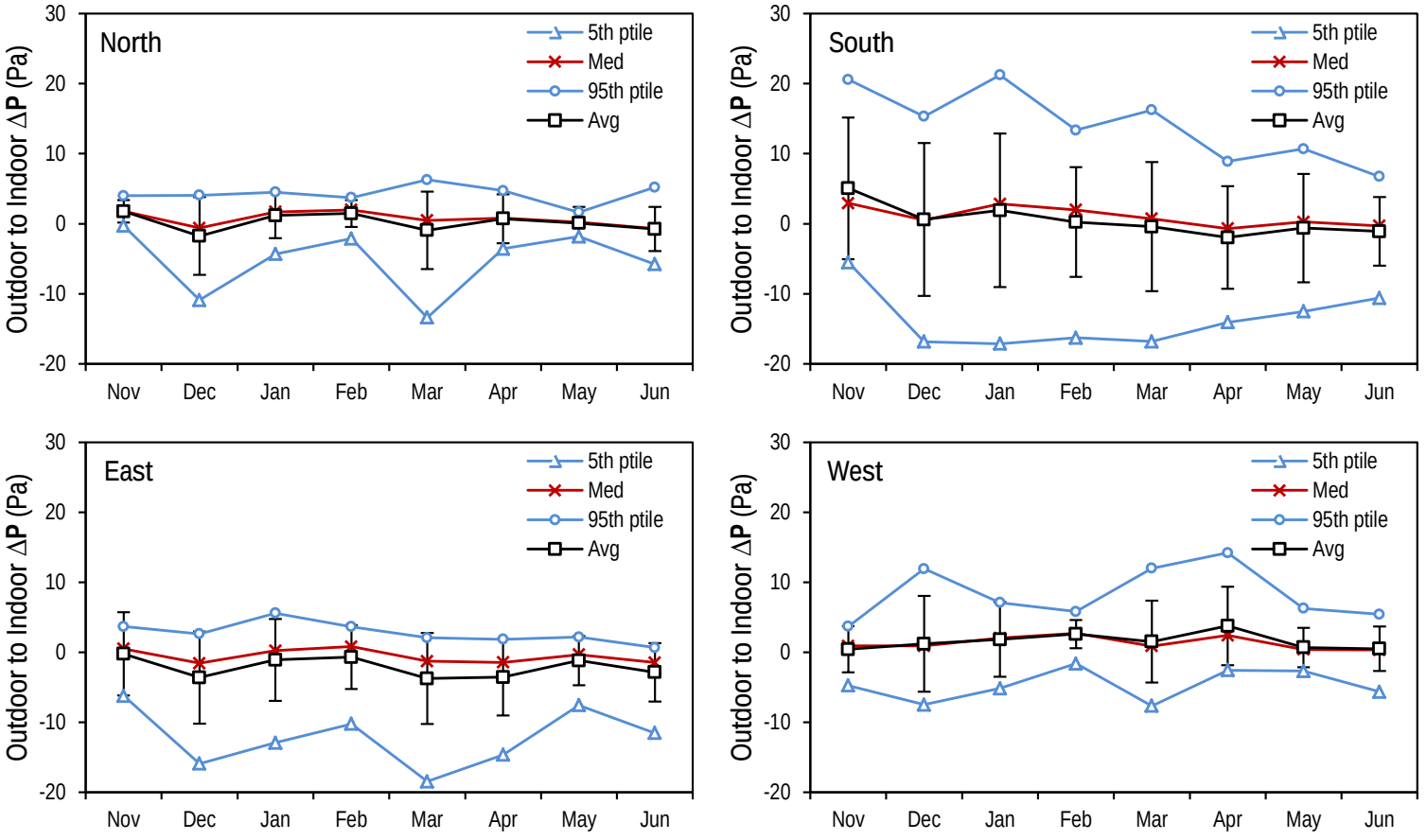

North
5th ptile
50th ptile
95th ptile
Avg
Wind Speed (m/s)
0
2
4
6
8
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun


South
5th ptile
50th ptile
95th ptile
Avg
Wind Speed (m/s)
0
2
4
6
8
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun


East
5th ptile
50th ptile
95th ptile
Avg
Wind Speed (m/s)
0
2
4
6
8
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

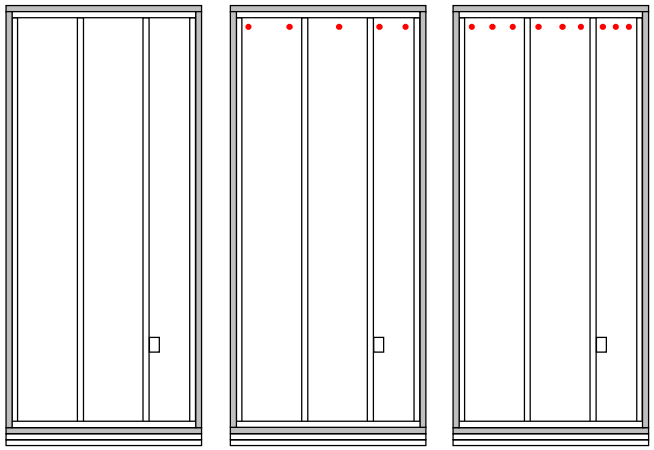

West
5th ptile
50th ptile
95th ptile
Avg
Wind Speed (m/s)
0
2
4
6
8
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

Pressure Difference Across Walls



East Facing Walls: Group 7

Air barrier type: fluid-applied membrane

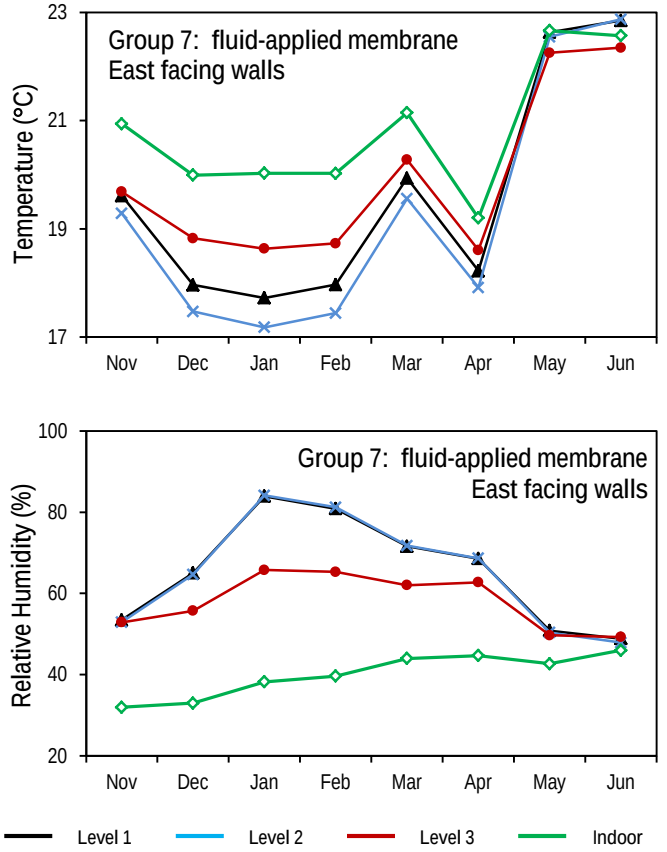


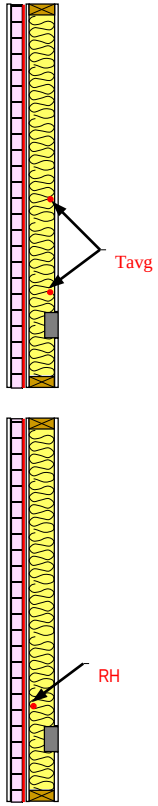
Level 1 - Baseline
< 0.02 L/(s·m^2)

Level 2
0.17 L/(s·m^2)

Level 3
0.74 L/(s·m^2)

@ 75 Pa

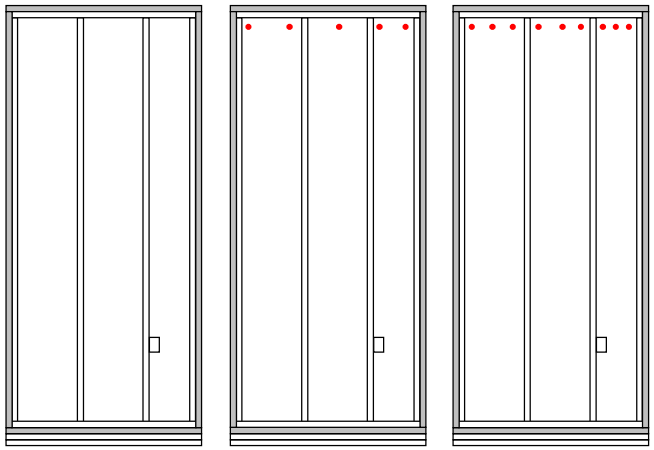




- East walls subjected to less solar radiation and primarily to exfiltration
- Level 3 panel warmer likely because of air leakage
- Level 3 panel showed lower RH in winter

East Facing Walls: Group 7

Air barrier type: fluid-applied membrane

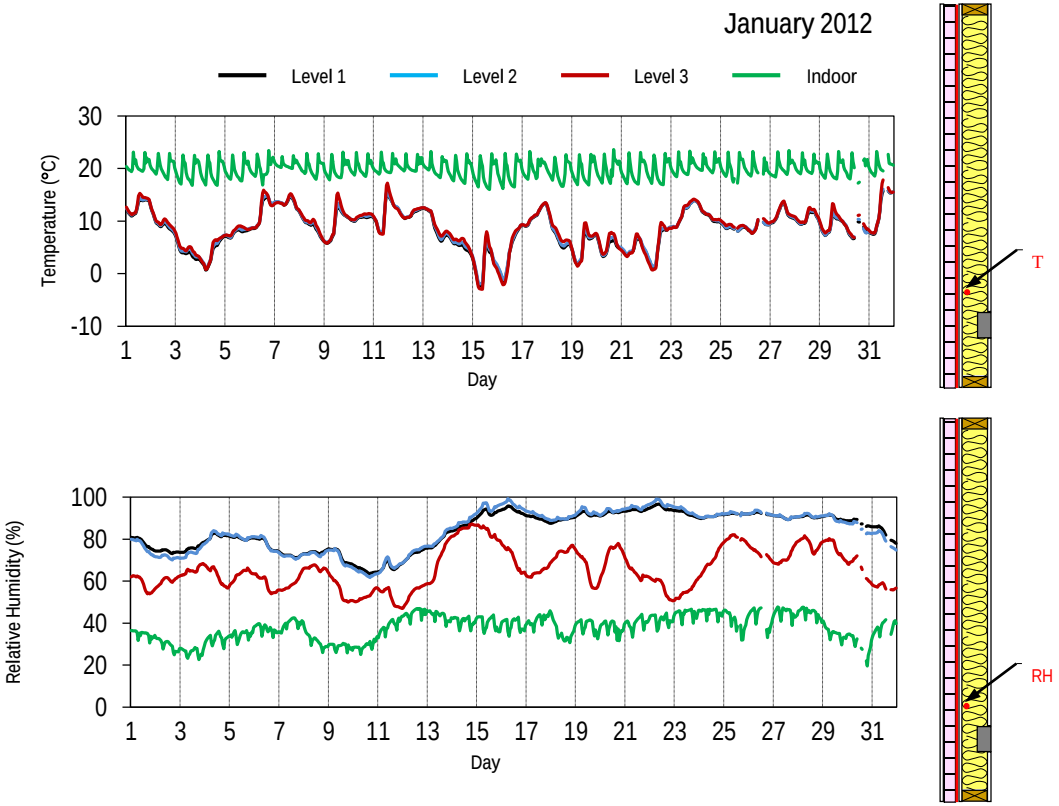


Level 1 - Baseline
< 0.02 L/(s·m^2)

Level 2
0.17 L/(s·m^2)

Level 3
0.74 L/(s·m^2)

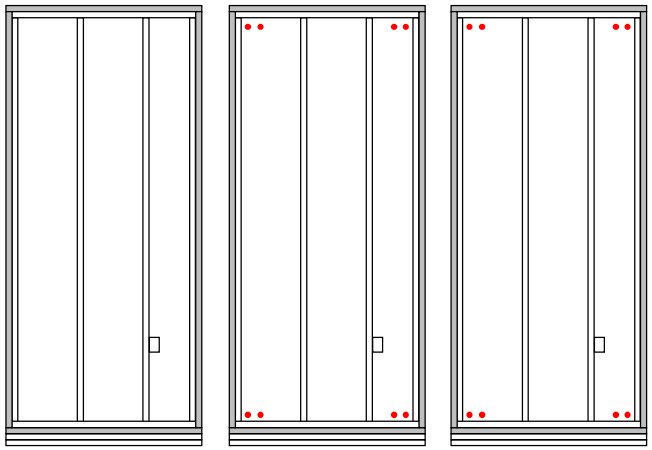
@ 75 Pa



- Airtightness lessened drying potential

East Facing Walls: Group 3

Air barrier type: insulating sheathing

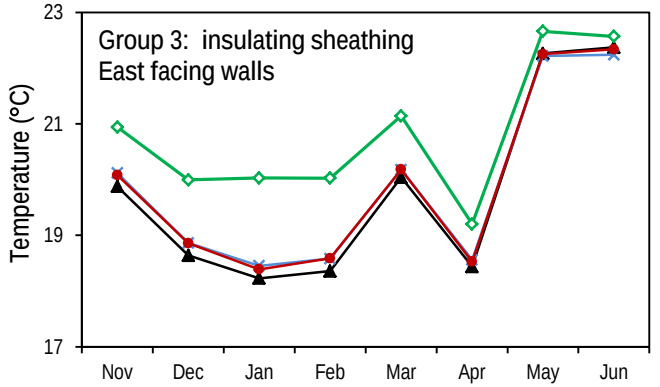


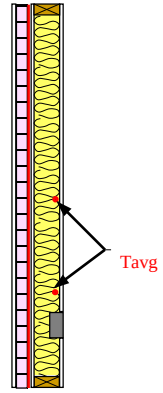
Level 1 - Baseline
0.03 L/(s·m^2)

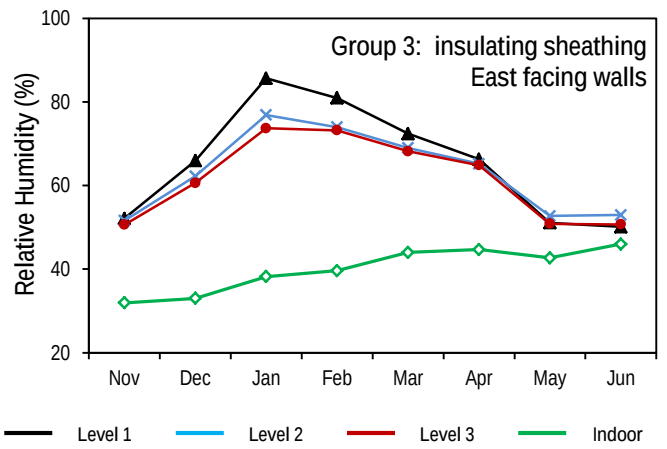
Level 2
0.36 L/(s·m^2)

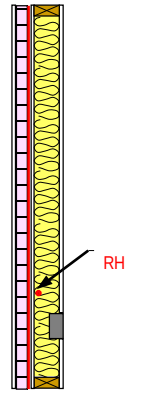
Level 3
0.5 L/(s·m^2)

@ 75 Pa





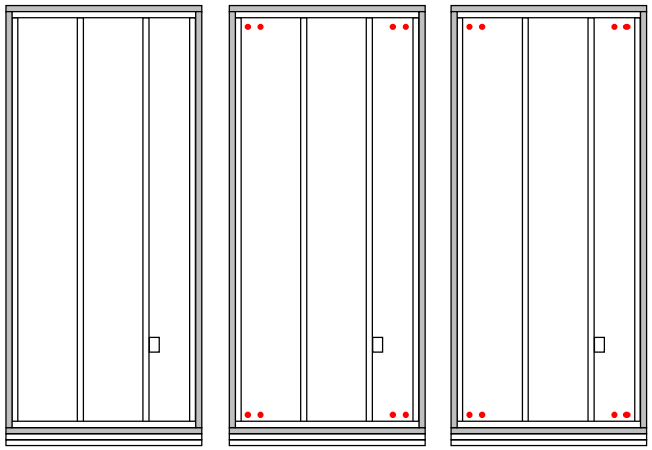




- East walls subjected to less solar radiation and primarily to exfiltration
- Level 3 panel warmer likely because of air leakage
- Level 3 panel showed lower RH in winter

East Facing Walls: Group 3

Air barrier type: insulating sheathing

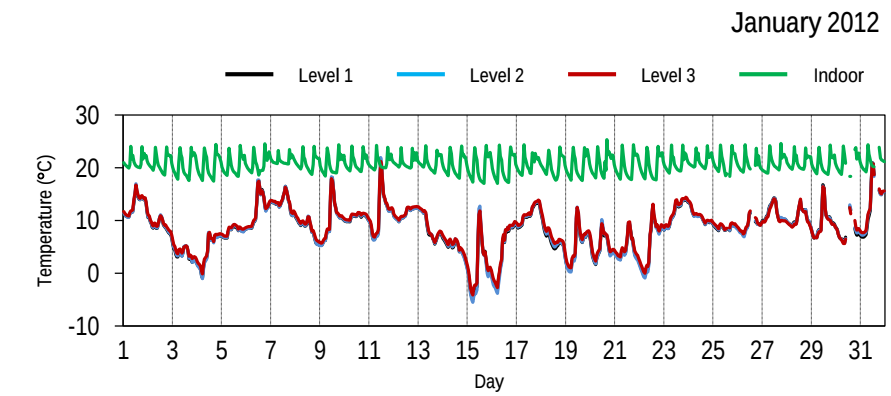


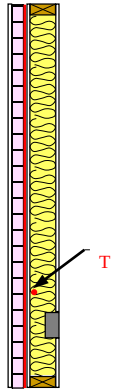
Level 1 - Baseline
0.03 L/(s·m^2)

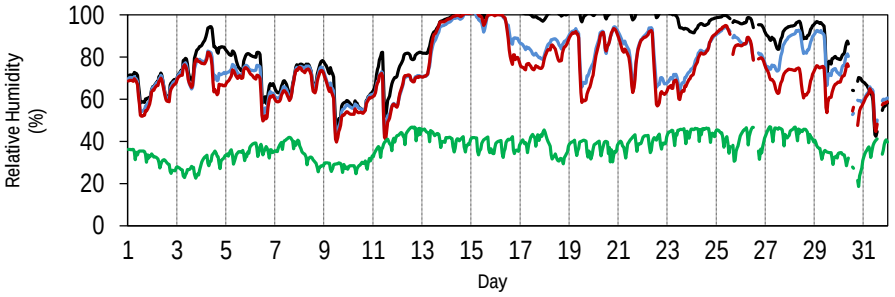
Level 2
0.36 L/(s·m^2)

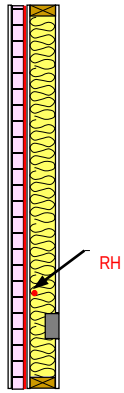
Level 3
0.5 L/(s·m^2)

@ 75 Pa





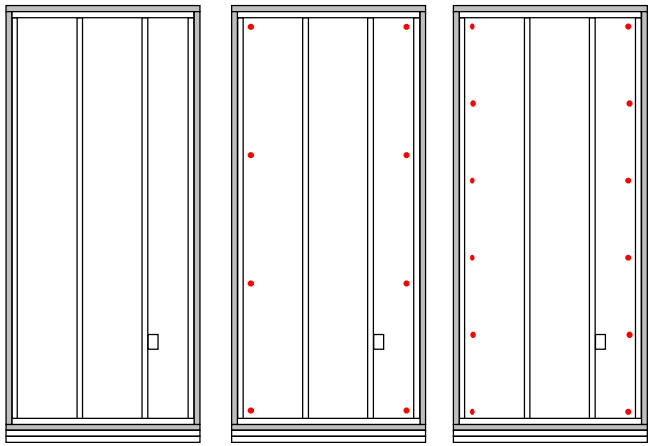




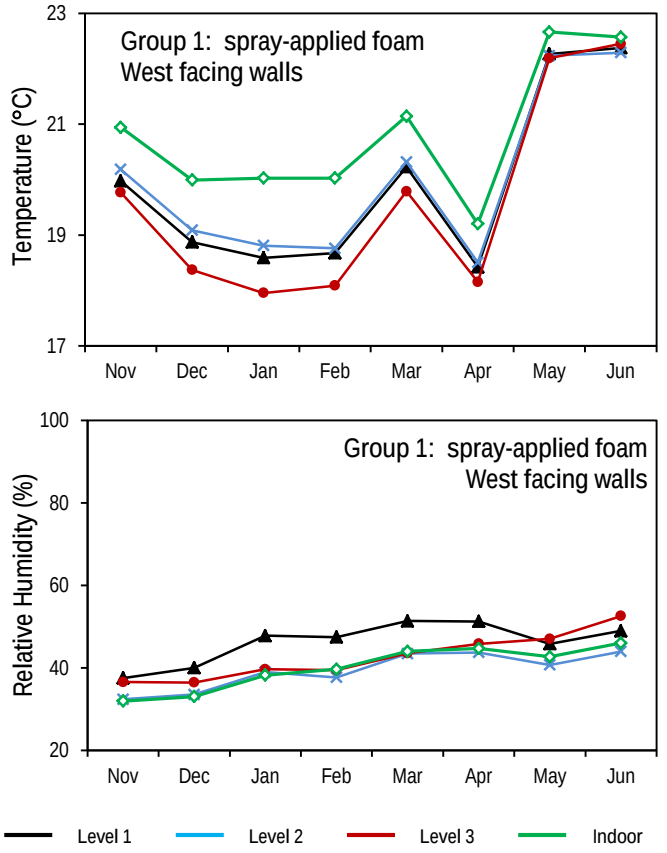
- Airtightness lessened drying potential
- Condensation occurred in Level 1 panel despite the R-7.5 XPS exterior insulation

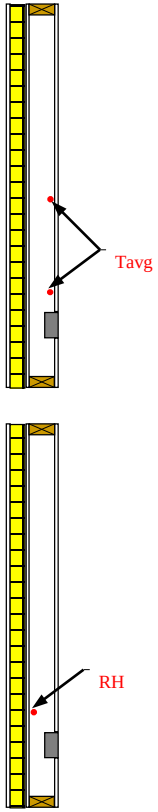
West Facing Walls: Group 1

Air barrier type: spray-applied foam



Level 1 < 0.02 L/(s·m^2)
Level 2 0.2 L/(s·m^2)
Level 3 0.79 L/(s·m^2)
@ 75 Pa

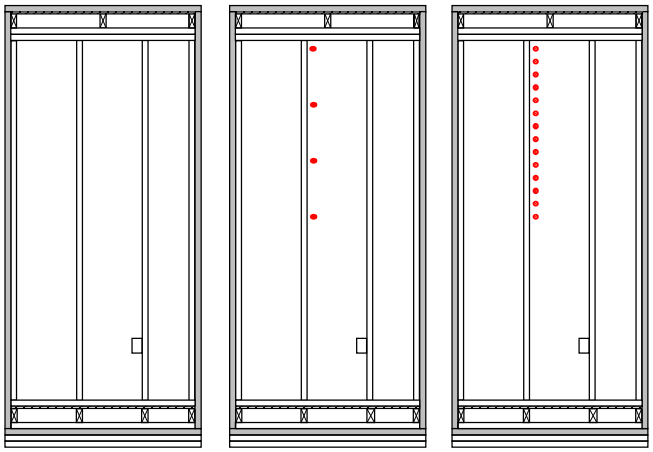


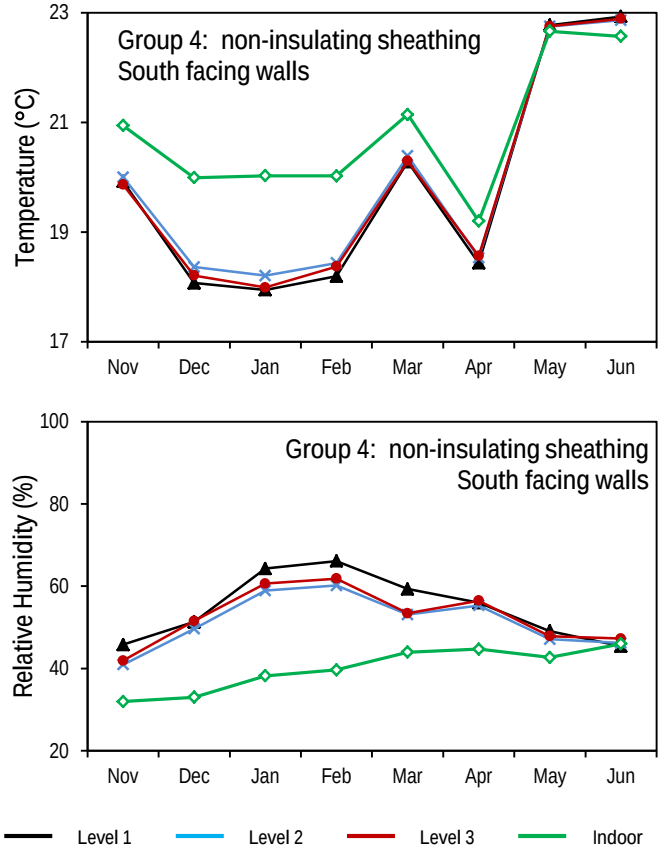


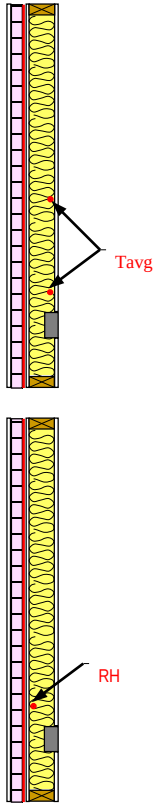
- West walls subjected to infiltration and exfiltration
- Level 3 panel colder in winter likely because of air leakage
- Highest RH in Level 1 panel but no condensation due to by R-21 exterior insulation

South Facing Walls: Group 4

Air barrier type: non-insulating sheathing



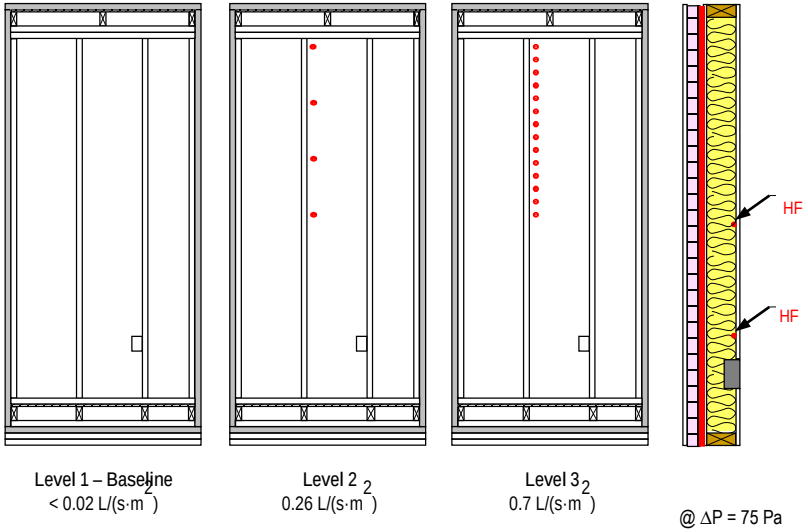


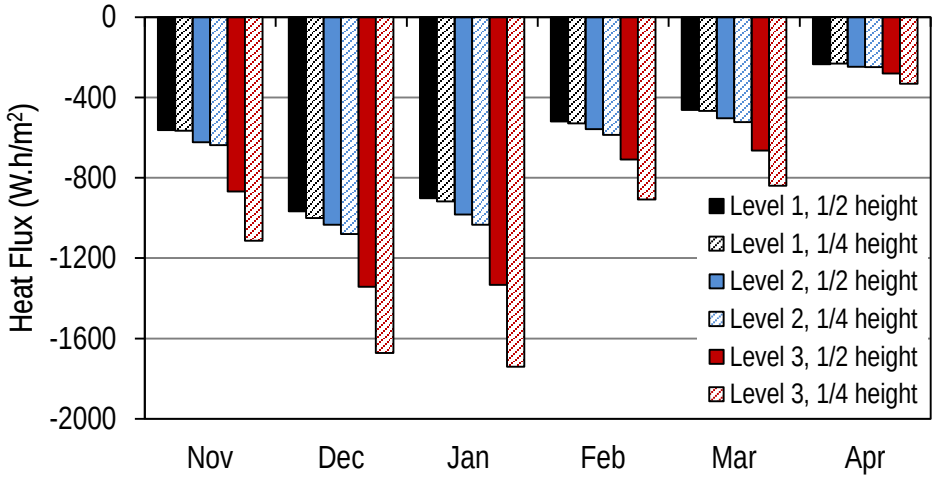


- Dominant south wind
  - Max monthly avg wind speed ~6 m/s
  - Max monthly avg ΔP across walls ~15 Pa
- Winter solar radiation increased drying potential of Level 1 panel

South Facing Walls: Group 4

Air barrier type: non-insulating sheathing



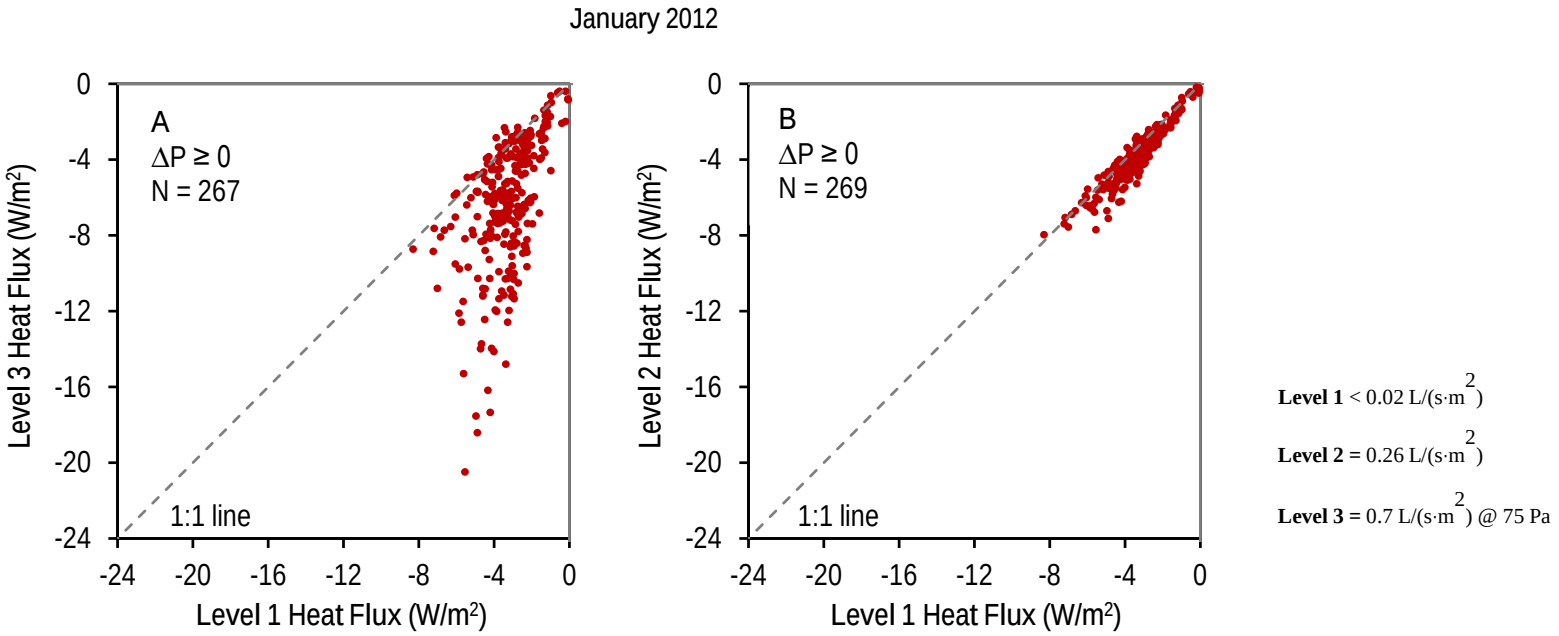


% Increase in Heat Flux

Compared air leakage levels	Sensor location	Nov	Dec	Jan	Feb	Mar	Apr
Level 3 vs. Level 1	½ height	54	39	48	37	44	19
Level 2 vs. Level 1		11	7	9	7	9	5
Level 3 vs. Level 1	¼ height	97	67	90	71	80	43
Level 2 vs. Level 1		13	8	13	11	12	8

South Facing Walls: Group 4

Concurrent heat flux measurements (sensor at ¼ panel height)



Level 1 < 0.02 L/(s·m^2)

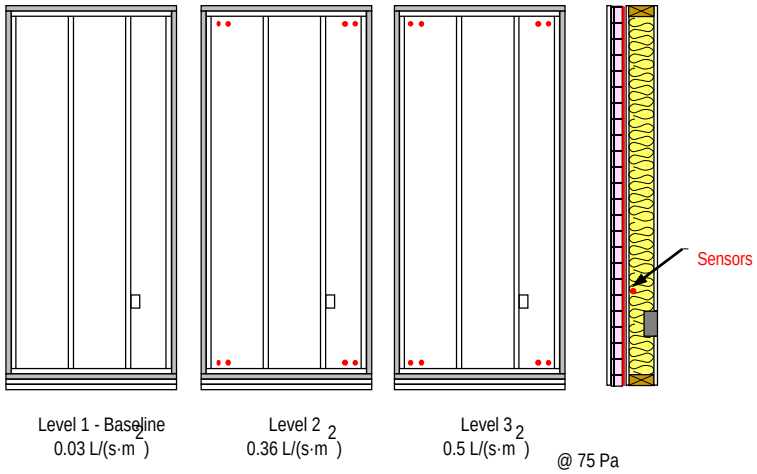
Level 2 = 0.26 L/(s·m^2)

Level 3 = 0.7 L/(s·m^2) @ 75 Pa

- Differences in heat flux due to air leakage
- Minimal heat flux penalty due to 0.26 L/(s·m^2) at 75 Pa

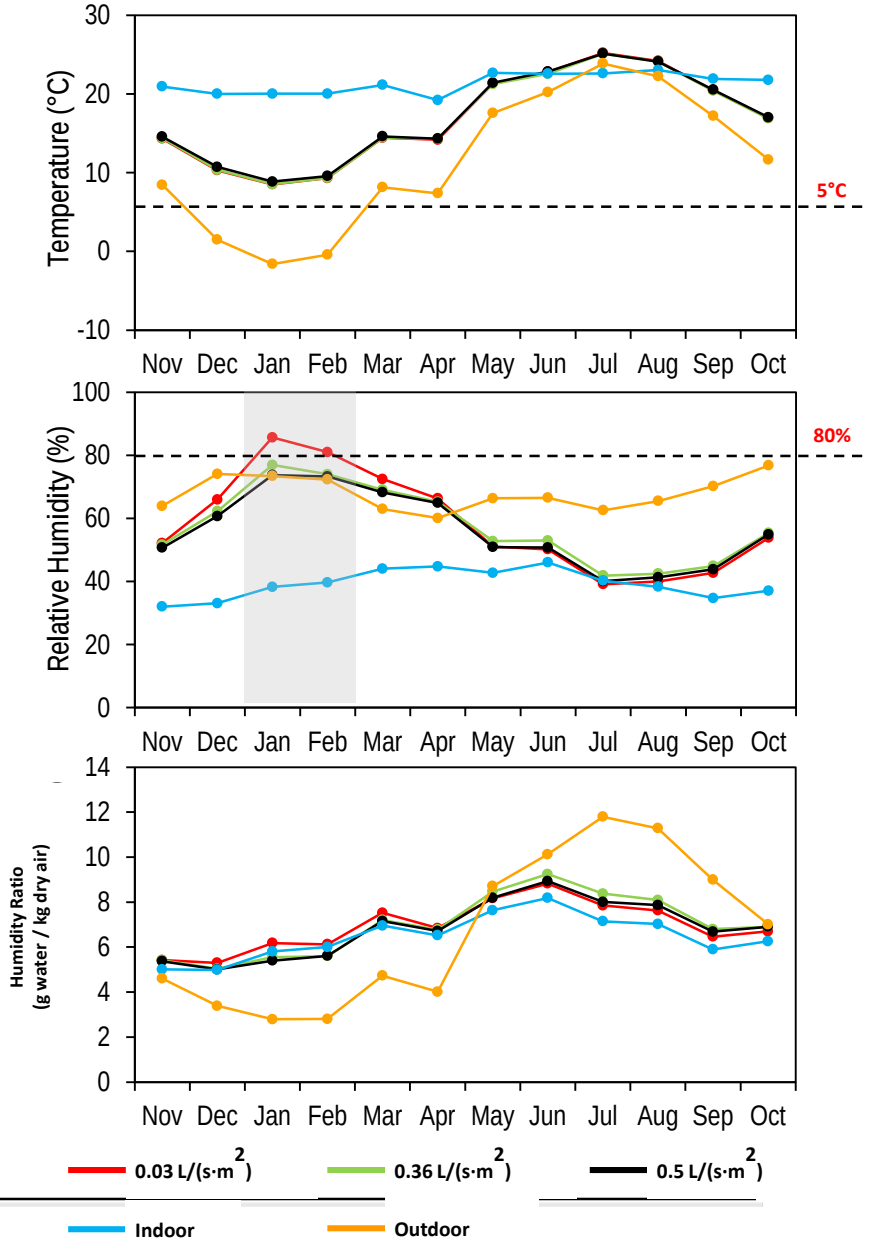
East-facing walls: Group 3

Air barrier type: insulating sheathing



- Airtight wall high RH in winter
  - Potential for mold growth: Jan - Feb
  - Lower drying potential: diffusion
  - XPS sheathing
  - No exterior drywall

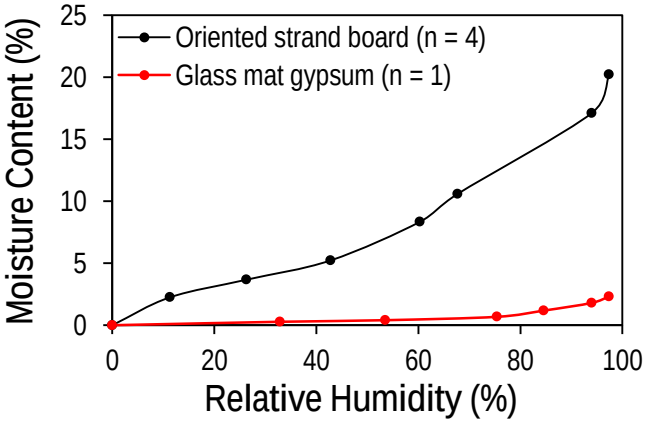
Low moisture storage capacity



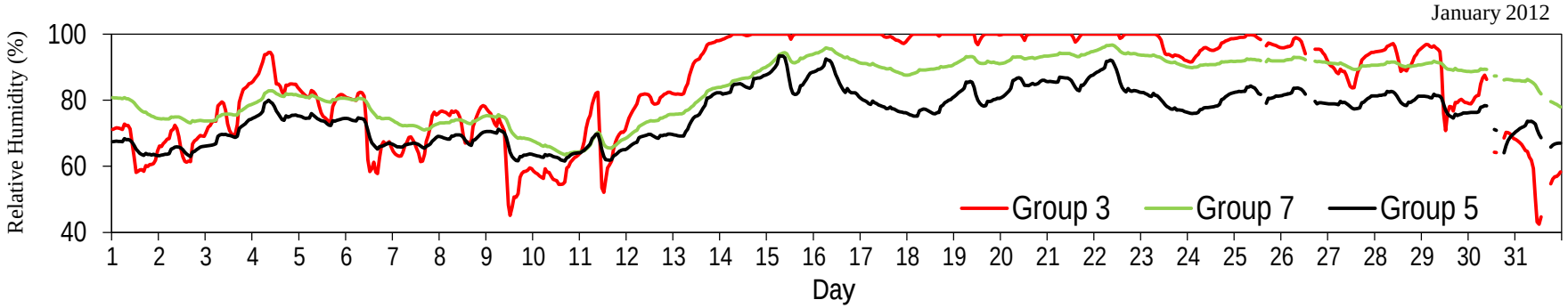
Effect of moisture storage capacity

Tightly-built, east-facing walls (~0.04 L/(s·m^2) @ 75 Pa)

Wall	Sheathing
Group 3	XPS
Group 7	Glass matt gypsum
Group 5	OSB

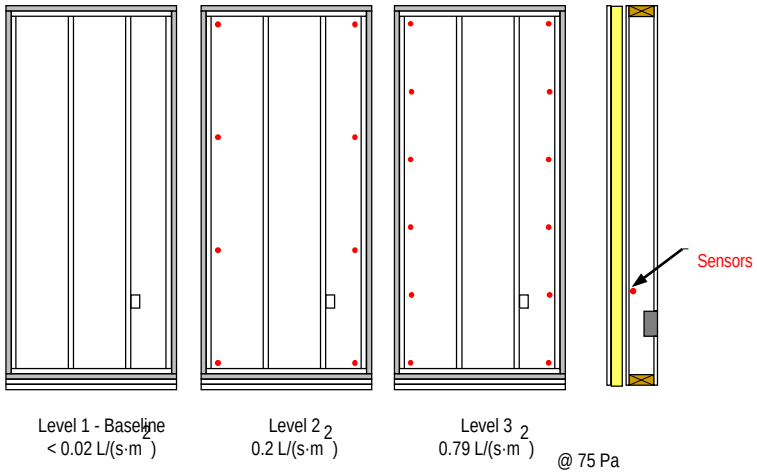


Moisture capacity of wood > 10 × Moisture capacity of glass matt gypsum & XPS

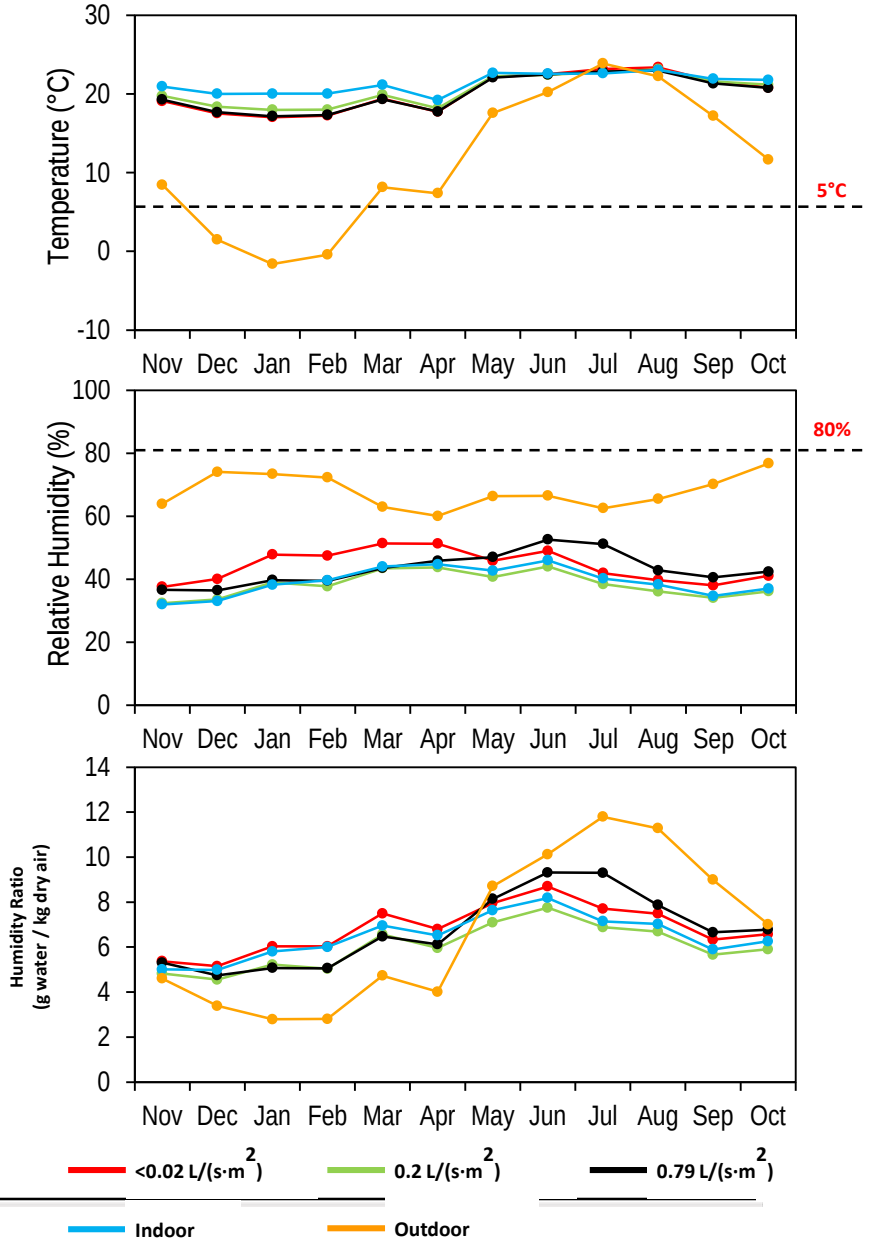


West-facing walls: Group 1

Air barrier type: spray foam insulation

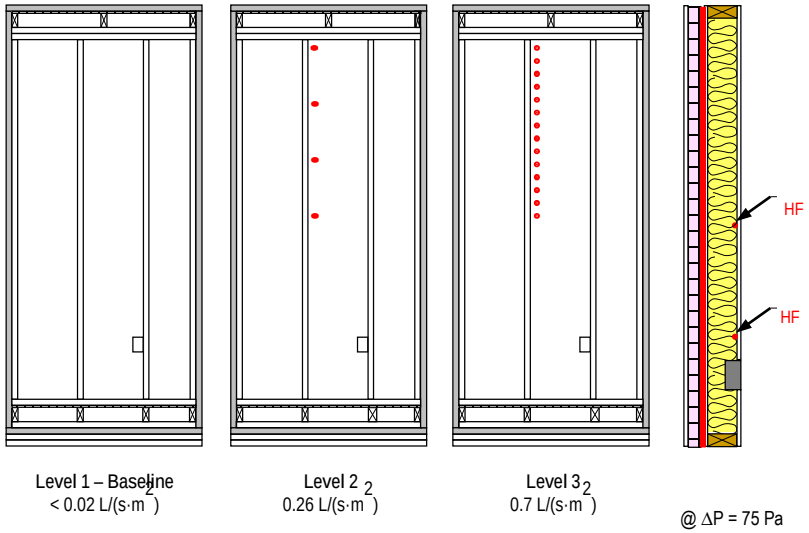


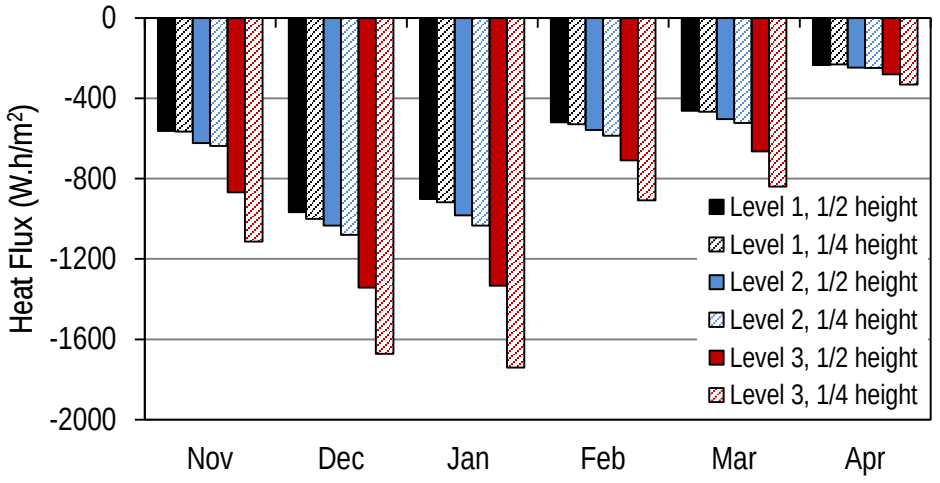
- R-21 exterior continuous insulation
  - Tsheathing, avg >> 5ºC
  - RHsheathing, avg << 70%
- Very low potential for mold growth



South-facing walls: Group 4

Air barrier type: non-insulating sheathing





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Contribution from air leakage is higher as R-value increases

Future plans

- Offer durability protocol to ASTM E06 Committee on Building Systems for comment and standardization
- Develop accelerated exposure protocol for specific climate zones
- Identify low-risk and energy efficient walls
  - New construction
  - Existing construction
- Improve modeling tools
  - Better estimate air leakage contribution to energy loads

Future plans

- Sub-assembly testing
  - Determine the amount of air leakage per opening
  - Residential walls (wood) just completed and commercial walls (steel and CMU) to be done

Conclusions

- Air barrier materials generally perform as intended
- Materials need to be combined into assemblies and then into systems
- The devil is in the details
- Trained, qualified and certified have a great impact on an installed air barrier system

Conclusions

- Everybody in the chain needs education from design professional to inspector
- “Looks airtight” does not cut it
- Most problems can be avoided by proper installation
- Guidance on the details is required

Questions?

Thank - You

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