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Passive Air Cavity Convection on the Wetting and Drying Behavior of Building Envelopes

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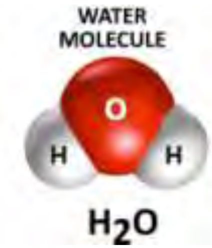
Owens Corning
Global Director, Building Science

Thank you

- All Students from Penn State, UofW
- All Technical staff from ORNL
- All Collaborators (FhG/IBP), VTT,WSU



Presentation Roadmap/Deliverables

- Why is it important ?
- Recent History…Past Literature
- Research
  - Development of CFD Analysis
  - Validation & Analysis of Laboratory Wetting/Redistribution/Drying
  - Validation with "Real Life" Field Conditions
  - Simulation Parametric Evaluation
- New Cavity Ventilation Approach in WUFI

Why is it important ?

- With the 2009 & 2012 IECC code enhancement f… higher efficiency requirements for … need to increase dryi… envelopes.
- B… …g Envelope Assemblies need to …thermally designed for moisture control
- Passive drying provided by air cavity ventilation would be a most welcomed means of providing free drying.

Risks for doing nothing are very high

Past Literature on Cavity Ventilation

- Burnett, Straube and Karagiozis [2005] (**Positive**)
- Straube and Burnett [1995] (**Positive**)
- Popp [1980] (**Positive**)
- Kuenzel [1983] (**No effect**)
- TenWolde [1985] (**Negative effect**)
- Hansen [2002] (**Negative effect**)
- Bassett & McNeil [2006] (**Positive effect**)
- Kristin Nore [2009] (**Positive**)

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Kuenzel and Mayer 1983

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Field meas … rey building

- Th … e **size**
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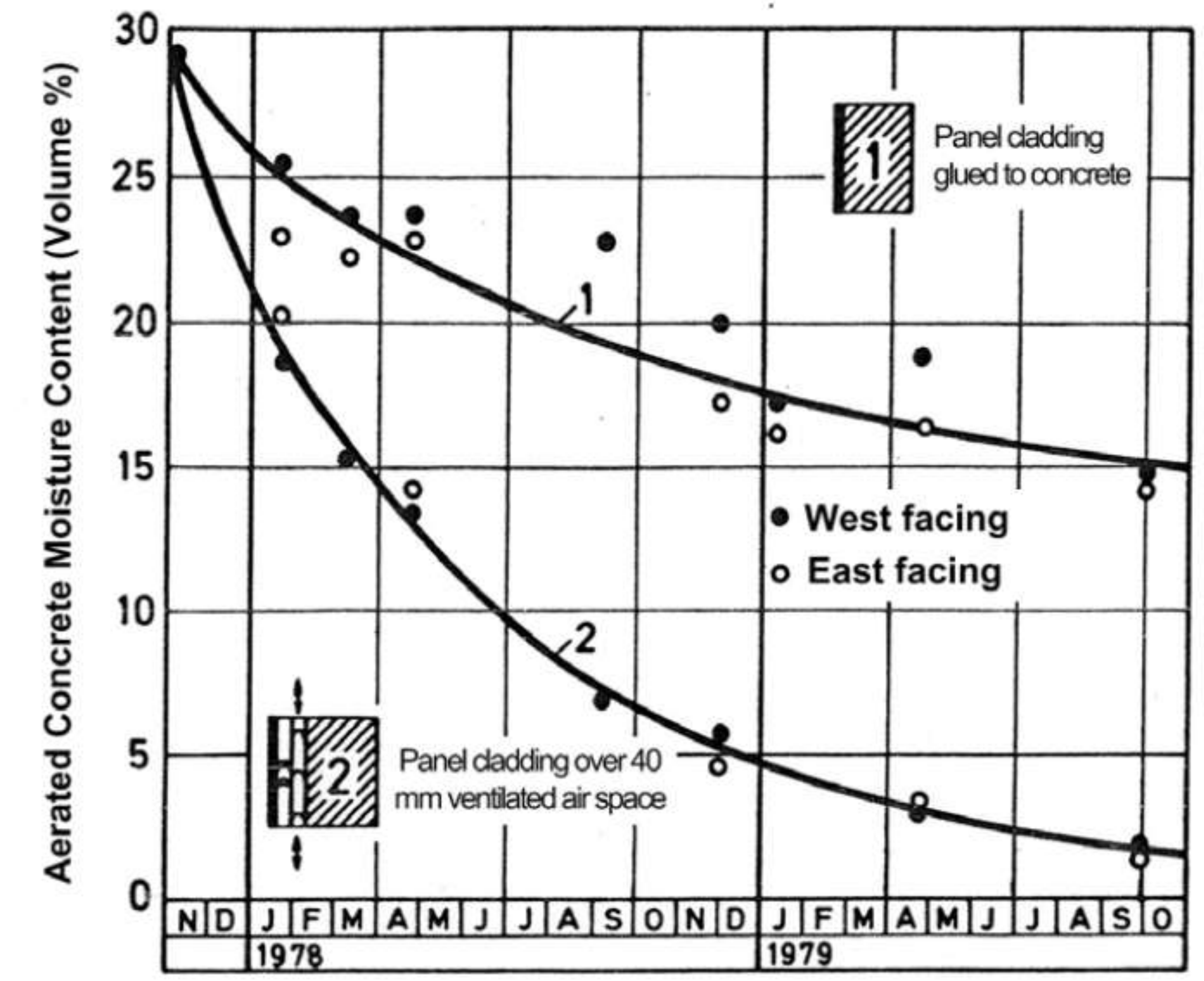


Kuenzel and Mayer 1983

- Hourly average air velocities of **0.05 to 0.15** m/s (0.16 to 0.49 ft/s) were measured in the wall cavities when the windspeed was between **1** to **3** m/s (3.28 to 9.8 ft/s). **Wind direction** influenced the ventilation air velocity **more** than **windspeed**.
- Walls with **non-airtight joints** (e.g., slate, shingles) were also shown to be **ventilated** (using tracer gas techniques), **albeit less** than **intentionally vented walls**.
- The **greater** the number of **joints** and the leakier the joint, the **more ventilated** the cavity.

Kuenzel and Mayer 1983

- The **pumping action** of the wind was postulated as the **ventilation mechanism** in these walls.
- It was observed that with **sufficient ventilation**, **condensation** on the backside of the cladding **rarely** occurred.

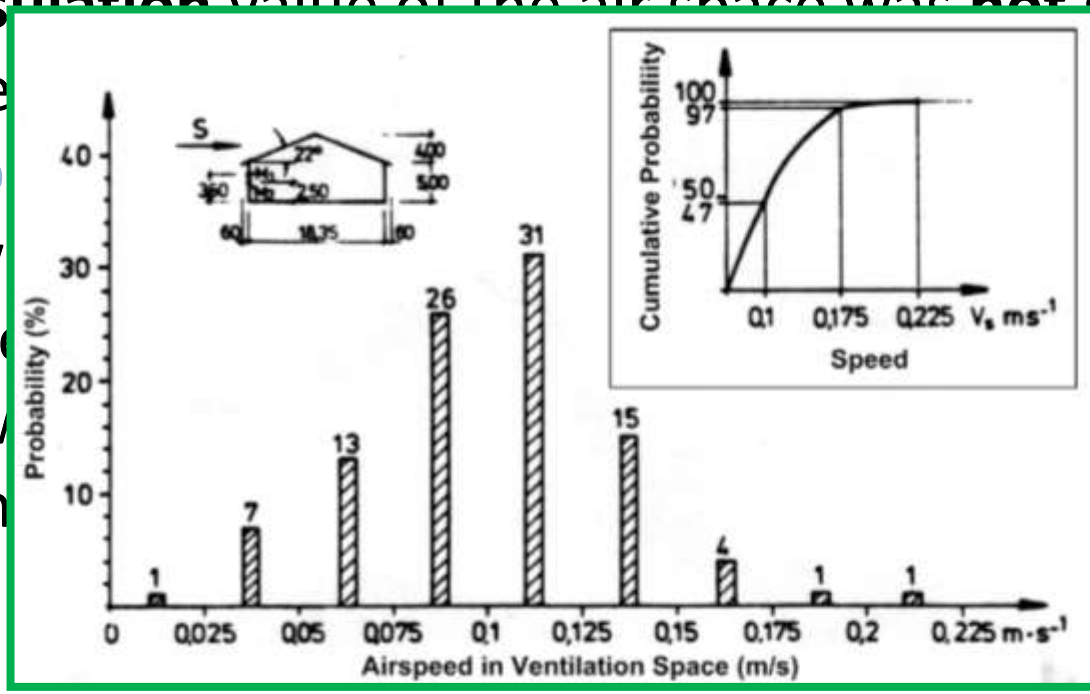
Kuenzel 1984 (Fraunhofer)

Brick veneers in walls with and without (the cavity was filled with insulation) an air space

- 100 gravimetric measurements were made of several different walls assemblies built in accordance with the German DIN 1053 masonry standard
- The authors concluded that the presence of an air space had **no noticeable effect** on the moisture content of the brick veneer or insulation.
- Another study by The German Institut für Ziegelforschung (Institute for Brick Research) conducted a unique field study of the effect of ventilation on the drying of brickwork [Jung 1985].

More Studies

- This ventilation velocity was deemed to be **slow enough** that the **ins**… significantly affecte… air exchanges per ho… tent of the brickw… wed that drying occurr… outside. Within three v… moisture conten…



Laboratorium voor Bouwfysica in Belgium (Field Study)

Masonry Walls

- Ventilation behind brick veneers study showed that ventilation has practically **no effect** on the **heat** transmission values of the air space, but it is was also found to be **difficult** to **quantify** the **benefit** of ventilation to moisture removal rates.
- **Recommended** that ventilation continue to be used in veneer walls with air spaces, **only drain openings** are **required in cavities** filled with insulation because the ventilation rates would **be very low in any case**.

Akoestisch Advies Bureau Peutz & Associes BV [Anon 1984]

Theoretical and wind tunnel study of the potential for ventilation in an open-jointed, small-panel cladding product.

- Analysis/Measurements with **large vent areas** could, on average, have ventilation velocities of **0.5 to 3 m/s**.
- For Dutch conditions, such large velocities result in **enough ventilation** to ensure that condensation would not occur on the backside of panels for typical backup wall assemblies.
- The panel sizes examined ranged from **200 to 800 mm** in height, were installed over a **20 mm** cavity, and had **full-length open joints 20 mm** wide.

CMHC Building Engineering Group at the Uof W [Straube and Burnett 1995]

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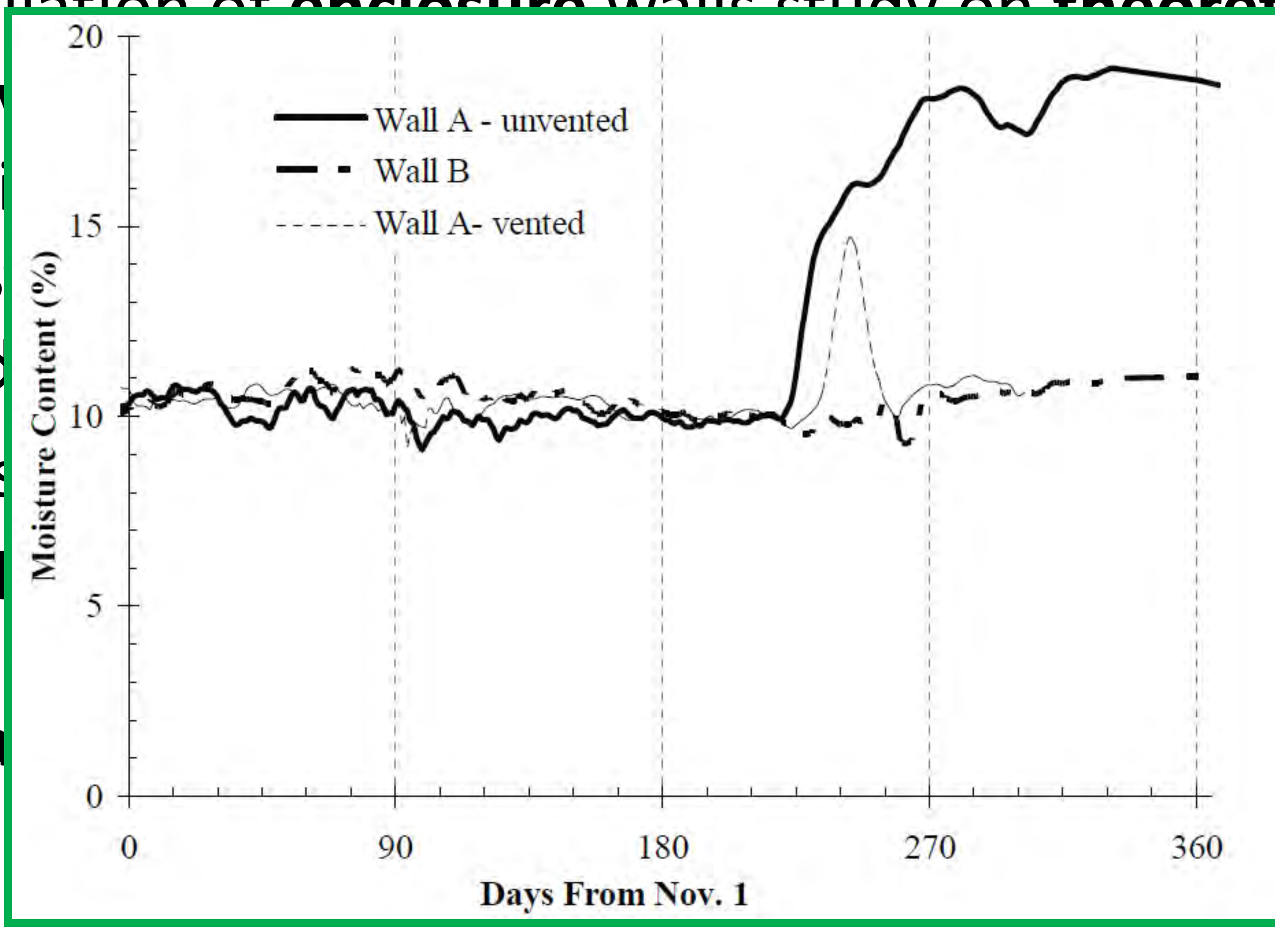
- Ventilation of **enclosure** walls study on **theoretical**
  anal… …ics of
  venti… …**ow**
  resis… …**ment** of
  wind…
- Inves… …**drying**
  and … …rated
  that … …control
  inwa…



Kenneth Sandin [1991] of Lund University, Sweden

- Extensive study of ventilation behind **brick veneer by** the Swedish Building Research Council. (0.3 to 8 ACH (20-50mm)
- When an entire brick was removed every **1200** mm were substantial ventilation rates of **3 to 25 ACH** measured.
- In other published work [Sandin 1993, 1990], Sandin questioned the effectiveness of ventilation in a climate (similar to Canada) where ventilation **drying** might remove **3 kg** of moisture per month and driving rain could **deposit 20** to **50 kg/month**.

Lawton, Brown and Lang, Lab drying study for CMHC

- Full-scale wall samples, 1.2x2.4 m, with stucco cladding where built and wetted by simply injecting 4 liters of water over 4 days.
- Water simply leaked out since little was absorbed.
- The walls were exposed to **10 °C** exterior conditions with no wind and no solar radiation.
- Authors state that these factors would have **no significant** effect on **drying**.
- The major conclusions of this study were that drying process for all specimens was **very slow** and took **months to achieve any significant effect**.

Lab climate chamber studies, Envelope Drying Rate Analysis

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- CMHC EDRA Test panels **submersion** in **water** prior to being assembled complete walls. In **Phase 1** steady conditions at **5 C and 70%** relative humidity were simulated. In **Phase 2** the panels exposed to simulated daily radiation peaking at **120 W/m2** (equivalent to diffuse radiation on the North side of a high latitude building) and a simulated wind pressure difference of **1-5 Pa** between the top and bottom to the assemblies.
- The sample walls included **stucco** and **vinyl cladding**, **vented**, and **ventilated designs**, **polymer** and **paper** based sheet sheathing membranes, and **OSB** and **plywood** sheathing.

Lab climate chamber studies, Envelope Drying Rate Analysis

Phase I:

Panels with ventilation spaces **dried faster** than comparable panels without such spaces, **wider ventilation spaces** dried **faster** than **narrow ventilation spaces**, **top and bottom** vented **ventilation spaces** dried faster than comparable panels with **bottom-only vented** spaces.

Phase II:

A second series tests that simulated **low levels of solar radiation**, **solar radiation** had **little** or **no effect** on panels without ventilation spaces, **solar radiation** caused an **increase in the panels' drying rate**, bottom venting performed similarly to panels with top and bottom venting.

Hansen, Nicolajsen, and Stang [2002] field ventilating cavities in timber frame wall

- Ventilation with **dry air removes** moisture from the construction whereas **ventilating with humid air** could **add moisture** to the construction.
- They conducted an experiment with 12 different wall assemblies with various types of cladding and wind barriers and ventilated/non-ventilated spaces and space/no space combinations
- The walls **were not wetted** in any way. All walls **remained below critical wood** moisture content levels (below 20% MC) and seasonal variations were observed.

Hansen, Nicolajsen, and Stang [2002] field ventilating cavities in timber frame wall

- It was concluded that **ventilation** had **no** significant **effect** on wood framed wall systems.

- The authors concluded, “the behavior of wood frame walls with non-ventilated cavities, in terms of the moisture content behind the wind barrier, was not found to be inferior to the behavior of wood frame walls with a ventilated cavity”.

Kristin Nore: Hygrothermal performance of ventilated wooden cladding 2009

- The cavity **reduces** the risk of moisture problems in wall assemblies
- It serves as a **safety valve**, discharging excess moisture by drainage and ventilation.
- Fields shows only a few **millimetre** cavity operates sufficiently.
- Although the four year study shows some results, the service life of a wooden cladding **might exceed** a **hundred years** with correct design and maintenance.

Pressnail et al (climate chamber drying study)

- Small wall assemblies with soaked wood cladding under conditions conducive to **solar driven inward vapor flow**. One test set had an exterior air cavity behind the cladding.
- Ventilation was definitively shown to **significantly reduce** or **eliminate solar-driven inward condensation**.

Bassett & McNeil (Field)

Measured ventilation rates in water managed wall cavities

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Ventilation rates driven by “realworld” fluctuating wind and stack pressures using a duel wavelength infra-red sensor was calibrated in the 0 to 3% range and assembled, together with gas lines and solenoid valves, to deliver tracer and sample air from the wall cavity. 2 to 12 cc/s, and the CO2 dosing rate was 0.3 and 4 cc/s.

CO2 Tracer absorption in building materials was studied.

- The tracer method has a long time constant (at least 10 minutes) not to be used to measure ventilation changes on a short time scale.

Bassett & McNeil (Field)

Measured ventilation rates in water managed wall cavities

- **Vented:** The high average measured ventilation rate (0.4 l/s.m) indicates that infiltration paths are likely to play an important role.
- **Ventilated:** In drained and ventilated cavities the average ventilation rates (over 60 days of measurement) was 1.4 l/s.m compared with 1.5 l/s.m predicted from climate data.
- **Drainage :** were an order of magnitude lower than those in the open rainscreen walls, averaging 0.04 l/s.m.

Past Work/Conclusions

- Although ventilation has been studied by a range of researchers, it is difficult to develop a **consensus** from the research.
- It can be said that **field research** tends to **support** the concept that ventilation airflow can be significant and that this **airflow causes drying** when clear open spaces exist.
- Results from **laboratory** and climate chamber studies tend to **show less** or **no drying**.
- Theoretical studies tend to show that ventilation has the potential for significant drying

The light has arrived……

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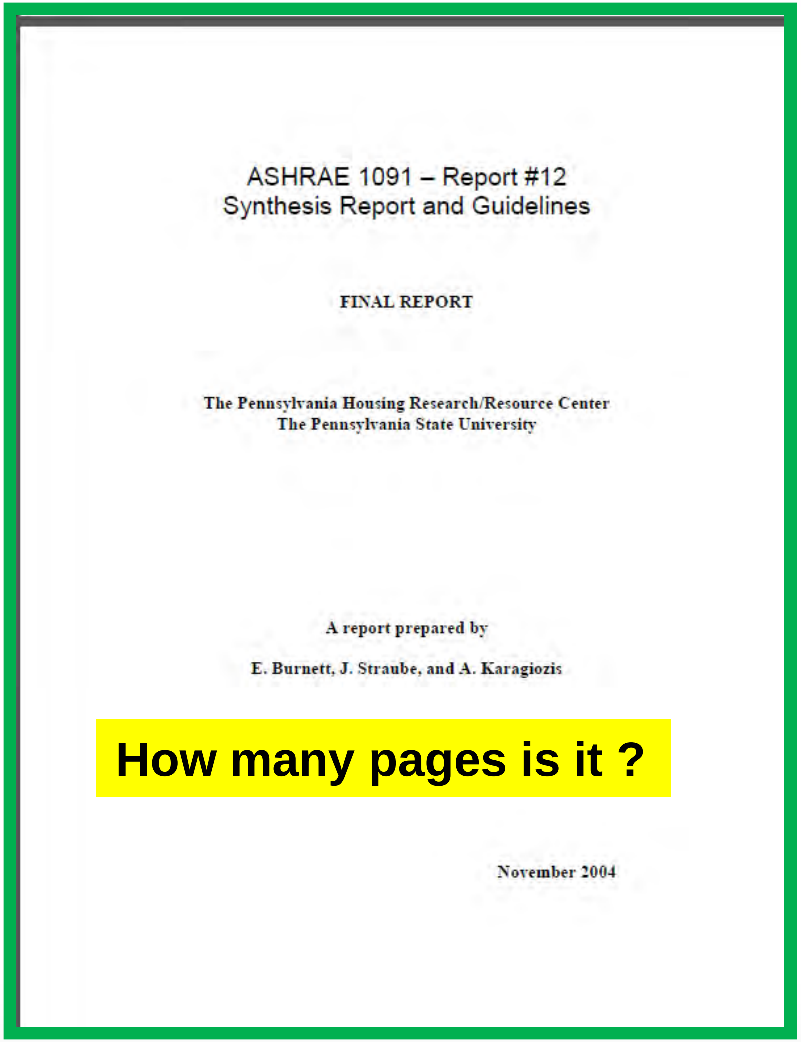

ASHRAE 1091 – Report #12
Synthesis Report and Guidelines

FINAL REPORT

The Pennsylvania Housing Research/Resource Center
The Pennsylvania State University

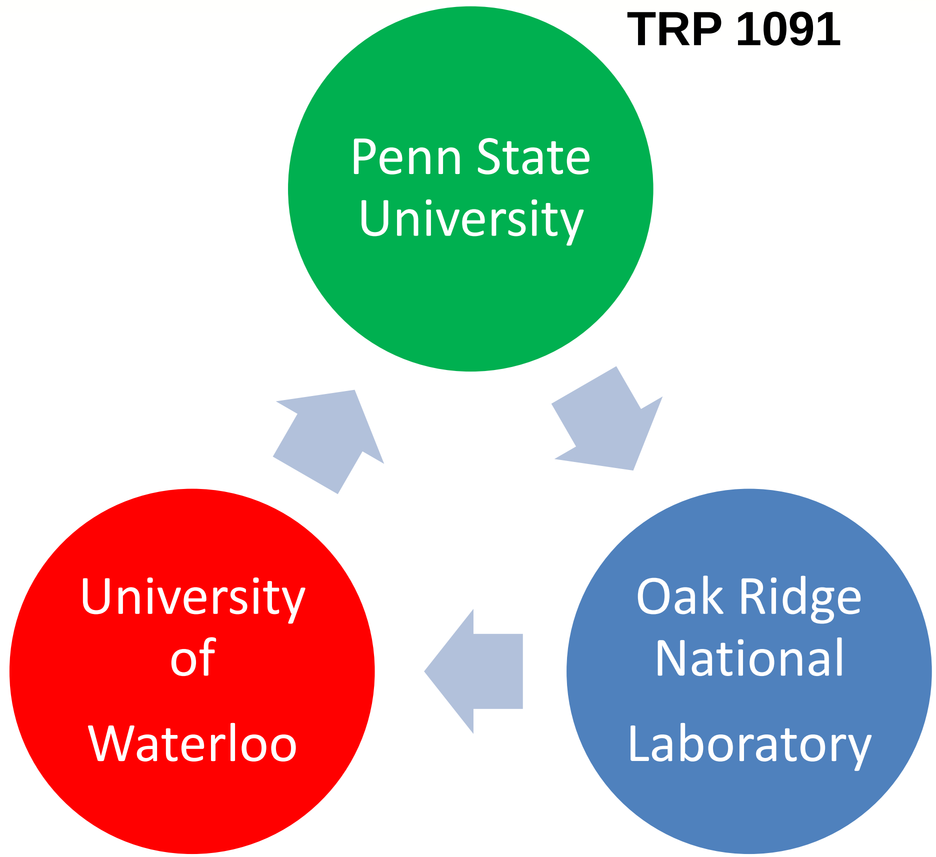
A report prepared by

E. Burnett, J. Straube, and A. Karagiozis

November 2004

How many pages is it ?

ASHRAE TC 4.4
TRP 1091



Three Institutions (2001-2004)

- Three institutions were involved in this project, namely, the Pennsylvania Housing Research/Resource Center at Penn State (PHRC/PSU), the Building Engineering Group at the University of Waterloo (BEG/UW), and the Building Technology Center at Oak Ridge National Laboratory (BTC/ORNL).

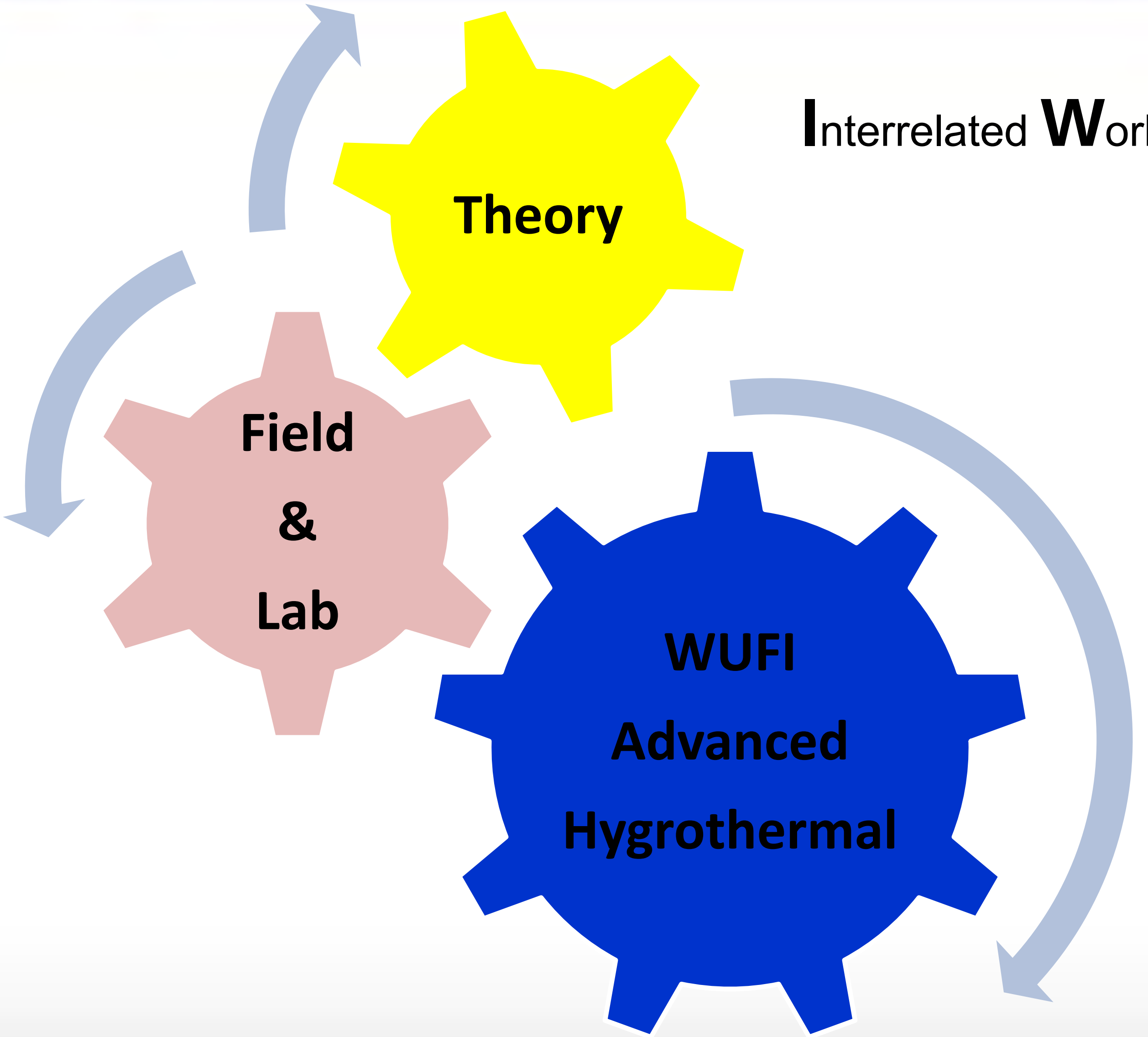
Project Tasks and Deliverables

Tasks		Type	Institution			Report number
No.	Topic		PHRC/ PSU	BEG/ UW	BTC/ ORNL	
0	Literature review and theory	R	**	***	*	1
1	Properties of relevant materials	EL	*	**	***	2
2	Sheathing membrane considerations	R	***			
3	Ventilation Airflow:					
3a	- Vinyl siding	EL		**		4
3b	- Metal, brick veneer, vinyl cladding	EL	***			5
4	Ventilation under natural conditions	EF		***		6
5	Ventilation drying in the laboratory					
5a	- Physical demonstration	EL	***			3
5b	- Climate chamber testing	EL	***			7
6	Ventilation drying in the field	EF		***		8
7	Analysis:					
7a	- CFD simulation	M	*		***	9
7b	- Benchmarking	M			***	10a & 10b
7c	- Parametric evaluation	M	*	*	***	11
8	Technology Transfer:					
8a	- Synthesis and guidelines	R	***	**	**	12
8b	- Papers, builder briefs, etc.	R	***	**	**	

Code: **E**-Experimental, **L**-Laboratory, **F**-Field, **M**-Modeling, **R**-Review

Approach

Interrelated **W**ork **S**egments



Objectives

- Understand of the nature and potential for ventilation drying, study, the contribution of sheathing membrane and the type of cladding to the overall performance of residential wall systems.
- To generate experimental data on the performance of ventilation strategies and their effect on the overall performance of wood-framed, screened wall systems

Objectives

- To benchmark and validate computer-based simulation procedures. A comprehensive program of advanced, state-of-the-art hygrothermal modeling was envisaged, mainly to extend the knowledge to other wall systems for at least six representative climatic areas. These data were then to be used to provide the basis for the development of air cavity design guidelines.

Theory

- Air Cavity Configuration
- Geometry considerations
- Vent opening types
- Duct air flow theory
- Vent Air Flow Forces
- Pressure Dynamics

Wall System- Terminology

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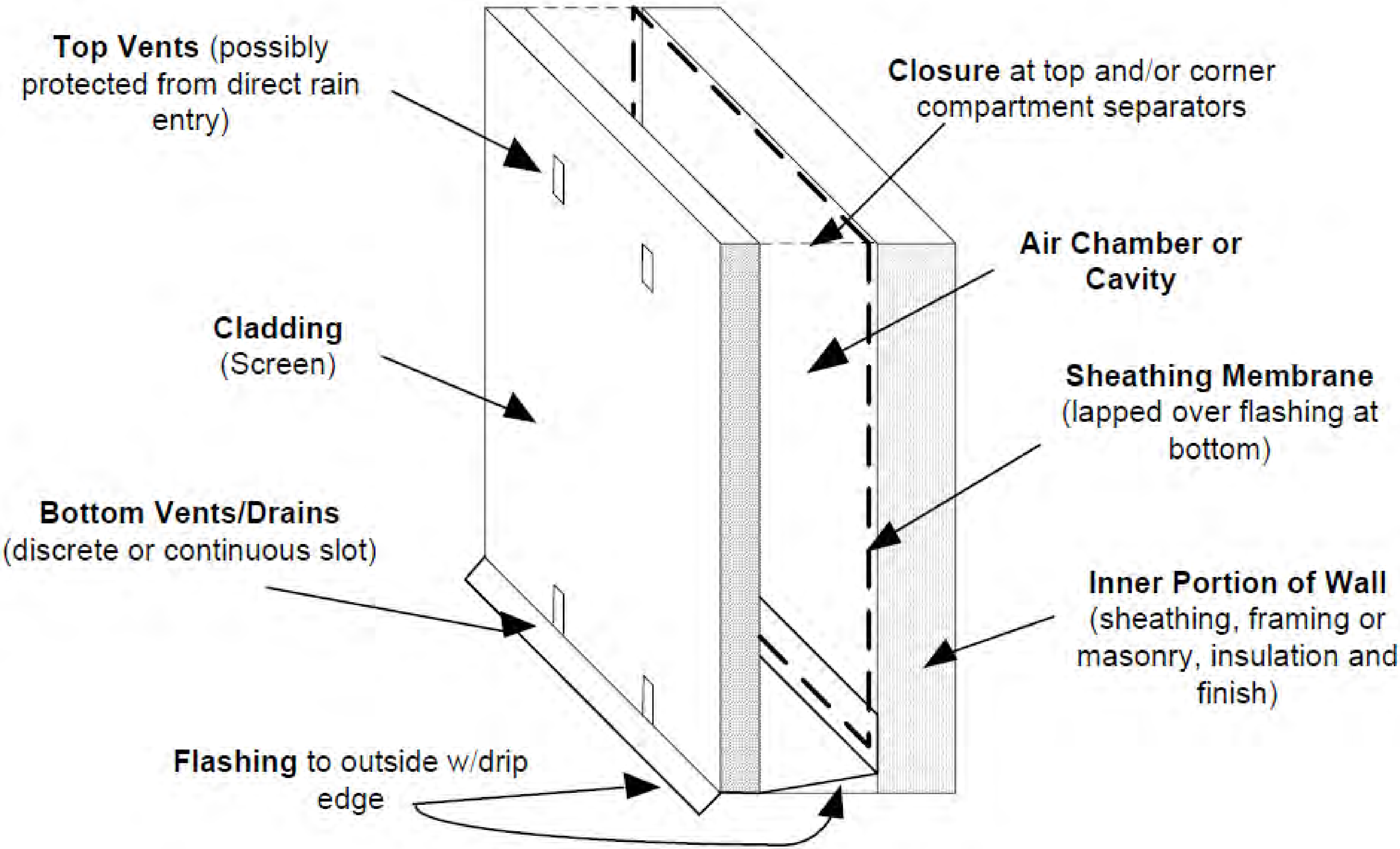
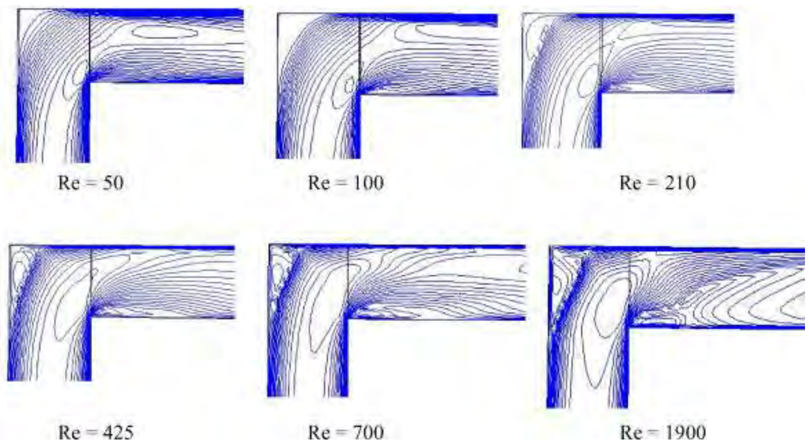
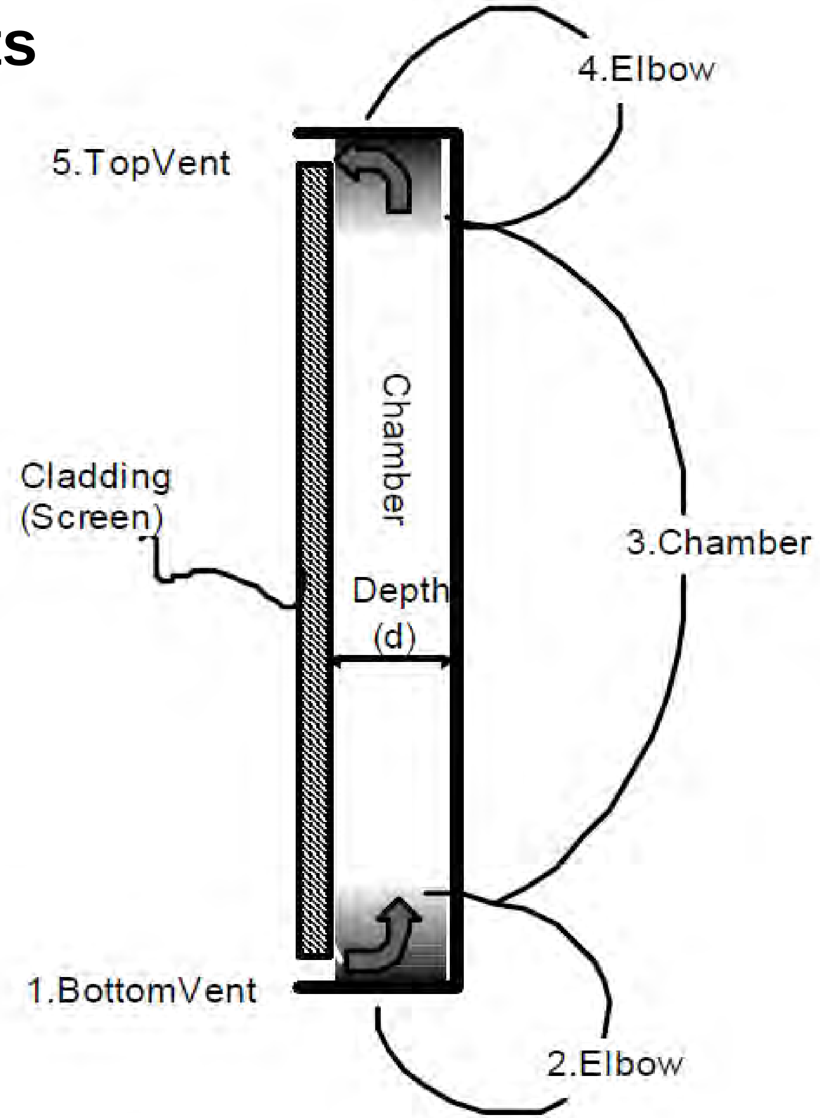


Ventilation Cavity Compartments

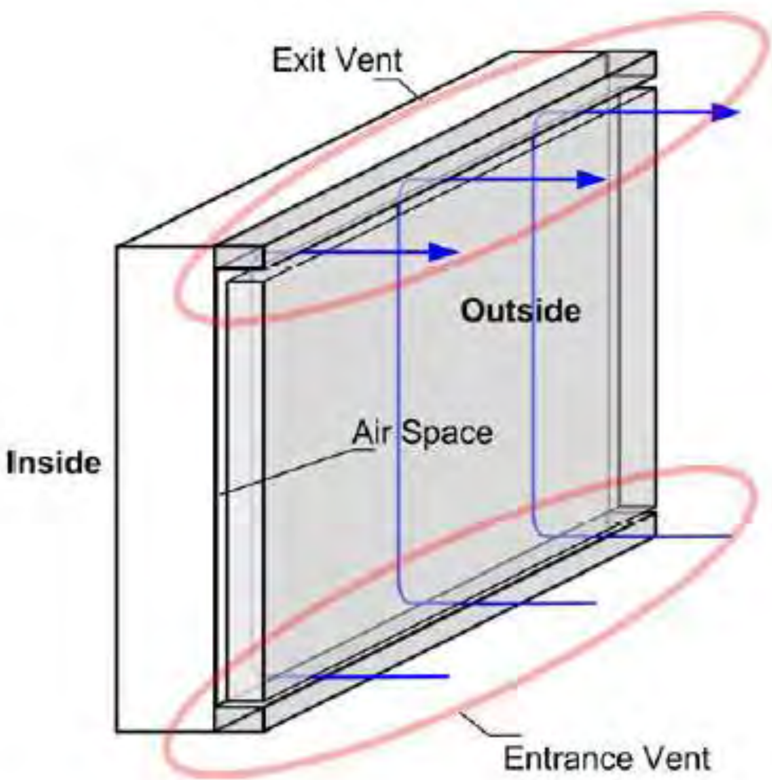
5 Critical Air Cavity Compartments



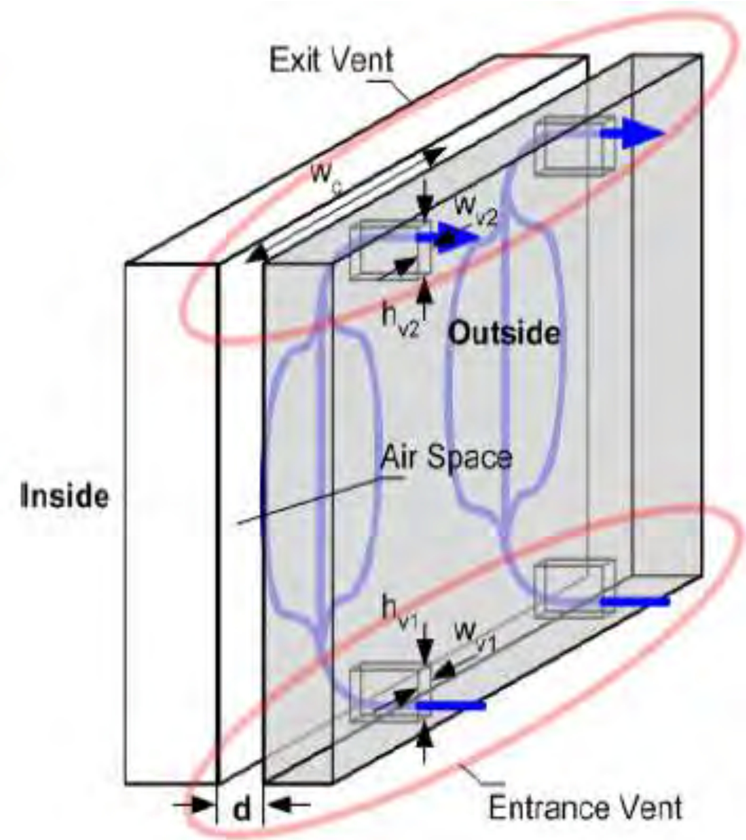


Vent types

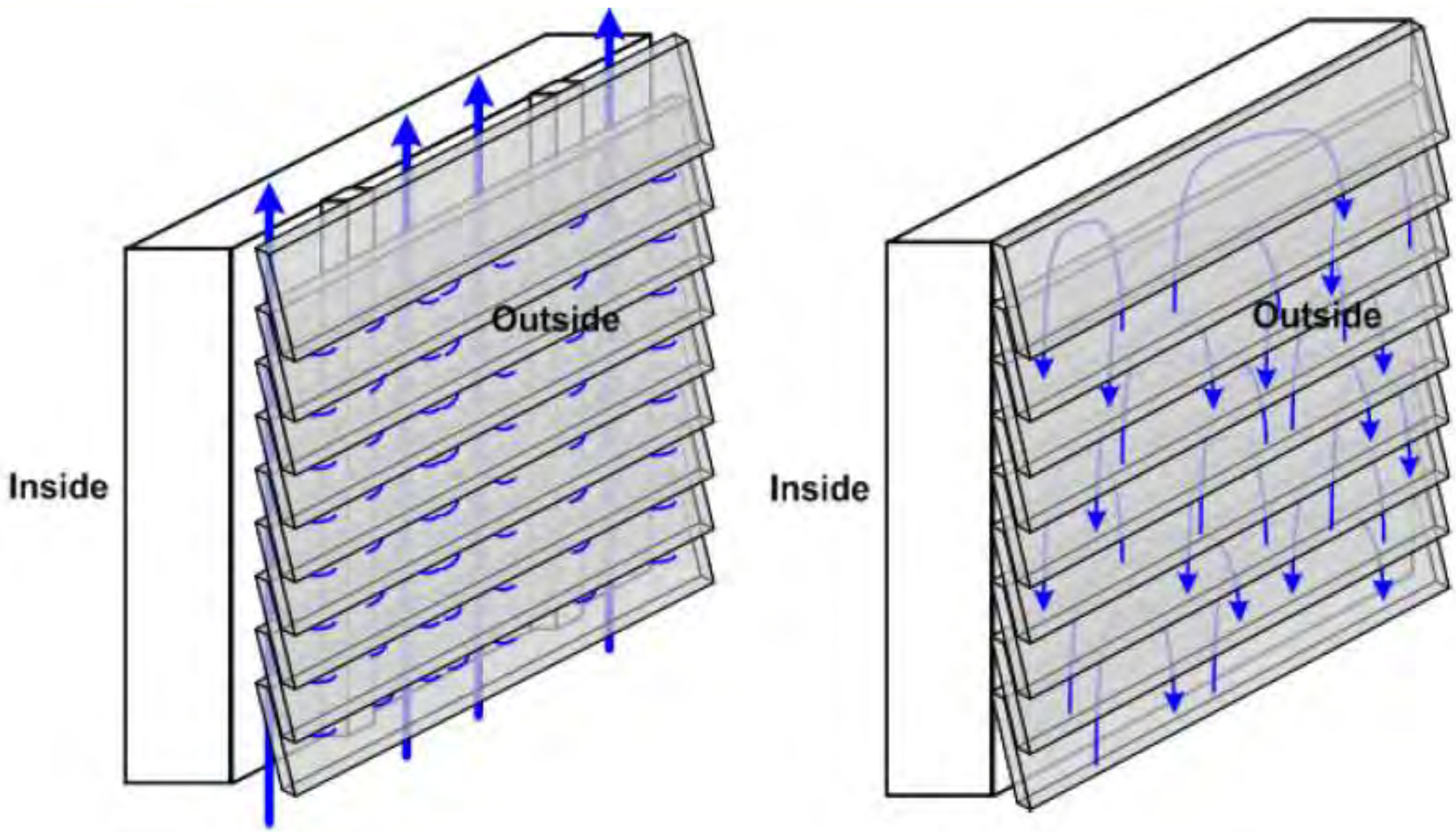
Ventilation Options



Continuous Slot



Discrete Slot


Inside
Outside
Inside
Outside

Ventilation Cavity Physics

- Flow velocity
- Roughness of the sides
- The size (depth) and shape of the cavity
- Number and size of obstructions and degree of baffling

Air Cavity Ventilation Systems

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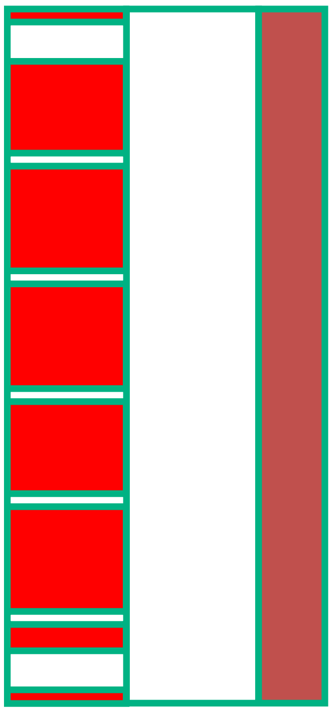
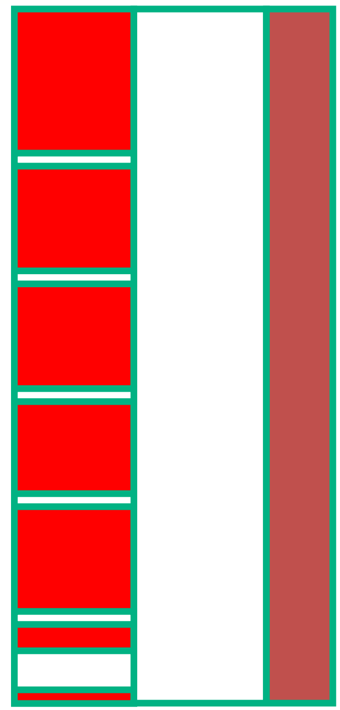
Open: Top & Bottom



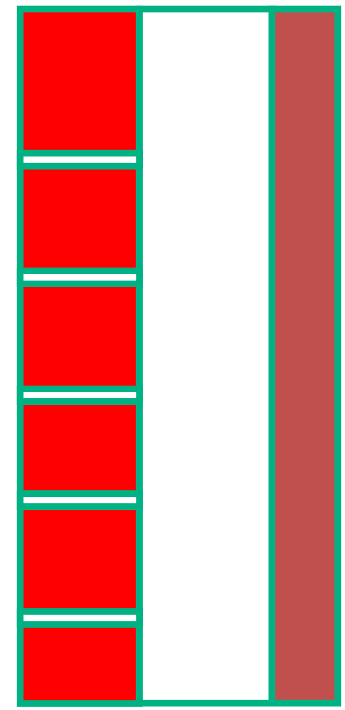
Ventilated

Open: Bottom



Vented

Open: No Opening



Unvented

Darcy-Weisbach Equations: Frictional Shear (Velocity profile

ASHRAE 2001 H2.8

$$\Delta P_{conduit} = f \cdot \left(\frac{L}{D}\right) \cdot (0.5\rho \cdot V^2)$$

f is the friction factor L is the pipe length, and D is the pipe diameter

For a rectangular conduit:

$$D_h = \frac{4 \cdot w \cdot d}{w + d + w + d}$$

Idelchik : Friction factor for rectangular conduit with any roughness in laminar flow

$$f = k_f \cdot f_{circular} = k_f \cdot \frac{64}{\text{Re}}$$

$$\Delta P_{conduit} = \frac{32 k_f \cdot V \cdot \mu \cdot L}{4 d_{eq}^{\ 2}}$$

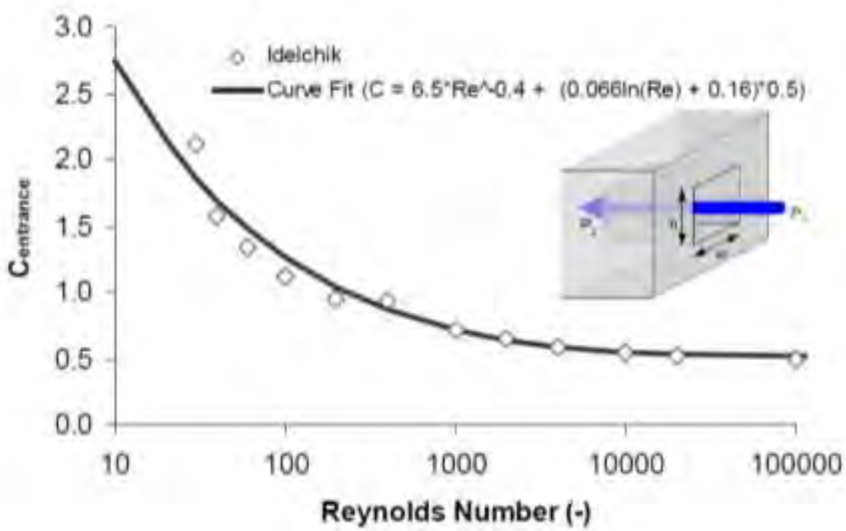
Table 3-1: Correction factor (k_f) for rectangular conduit (Idelchik 1995)

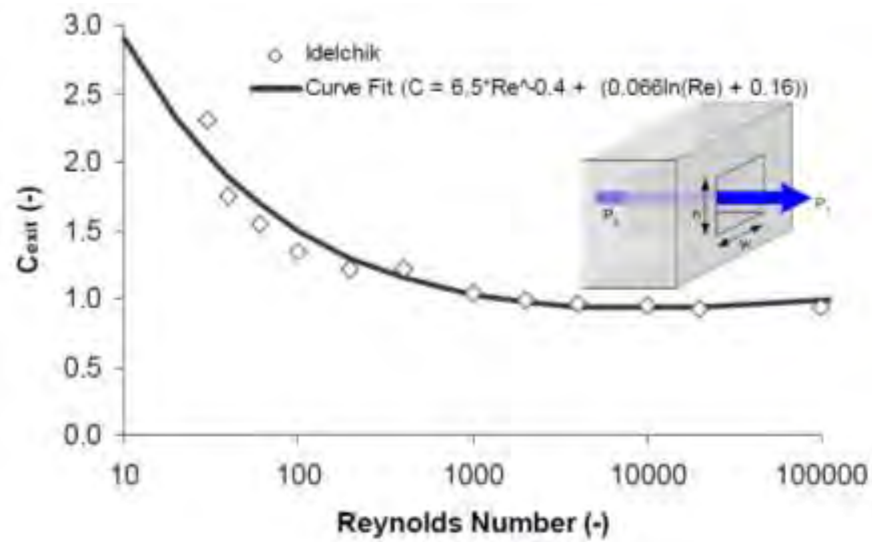
d/w =	0	.01	0.2	0.4	0.6	0.8	1.0
Laminar regime (Re < 2000)							
k_f =	1.50	1.34	1.20	1.02	0.94	0.90	0.89
Turbulent regime (Re > 2000)							
k_f =	1.10	1.08	1.06	1.04	1.02	1.01	1.0

Exit and Entrance Resistances

- Local disturbances of the flow,
- Separation of flow from surfaces, and
- Formation of vortices and strong turbulent agitation of the flow.

$$C = \frac{\Delta P_{local}}{0.5\,\rho \cdot V^2} = \frac{6.5\,\mathrm{Re}^{-0.4}}{\overline{A}^2} + (0.066\ln(\mathrm{Re}) + 0.16)\cdot C_t$$





Ventilation Cavity Physics

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Elbow & Turns Resistances

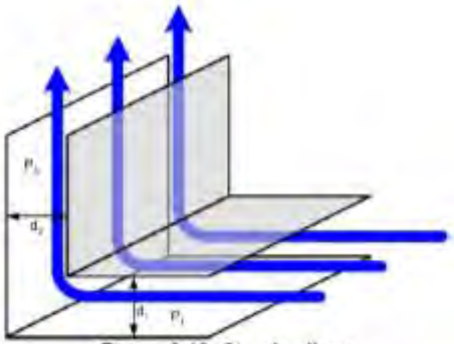
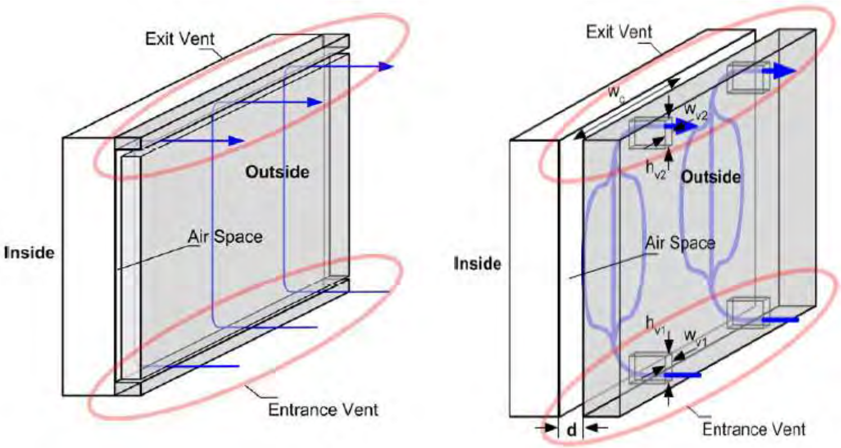


Figure 3.12: Simple elbow

$$C = 0.885 \cdot (\frac{d_1}{d_2})^{-0.86}$$

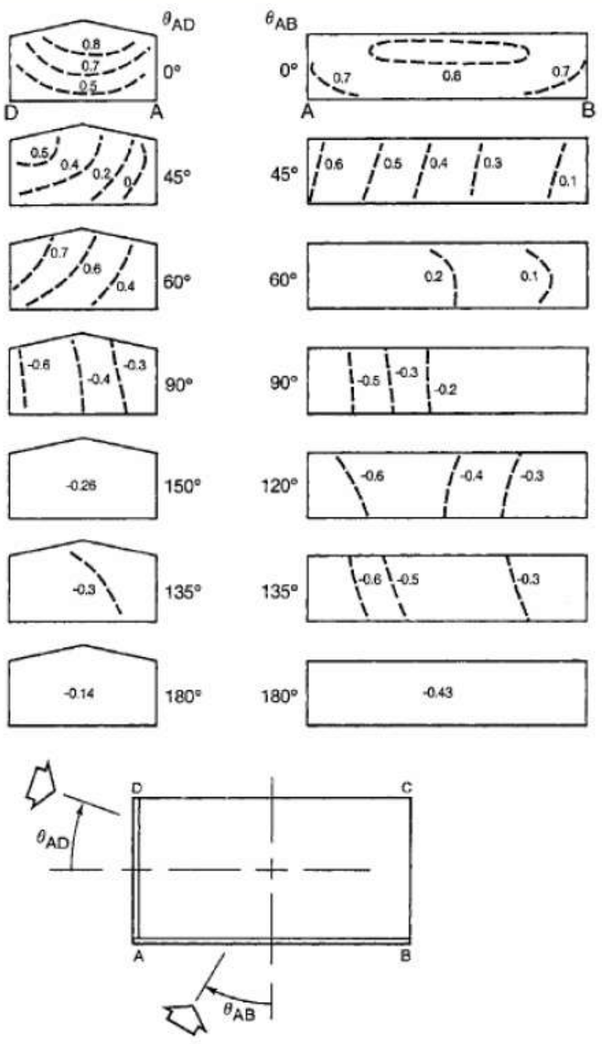


$$\Delta P_{Total} = \Delta P_{entrance} + \Delta P_{cavity} + \Delta P_{exit}$$

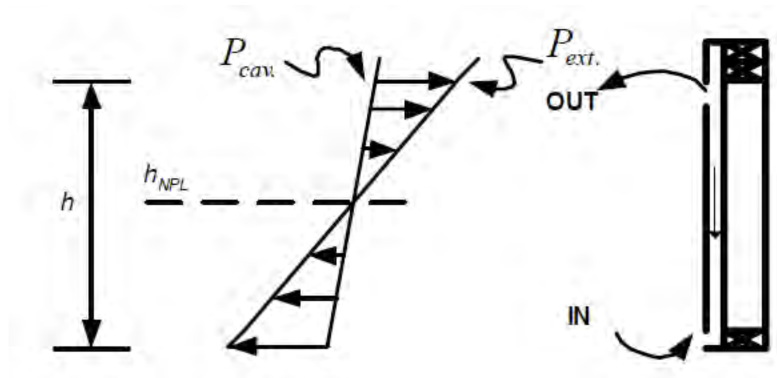
$$\Delta P_{Total} = C_{entrance} \cdot 0.5 \rho V^2 + \frac{32 k_f \cdot V \cdot \mu \cdot L}{\gamma \cdot D_h^{\ 2}} + C_{exit} \cdot 0.5 \rho V^2$$

Ventilation Cavity Physics

Exterior pressure coefficients for low-rise buildings



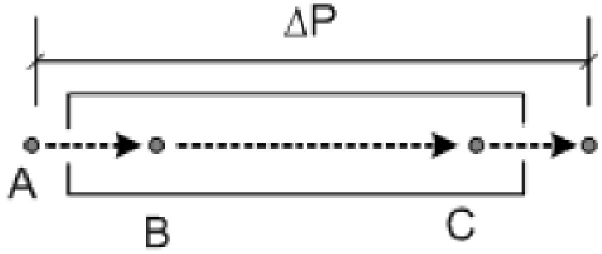
$$C_p(\phi)=\frac{1}{2}\left\{\begin{array}{l}\left[C_p(1)+C_p(1)\right]\cdot(\cos^2\phi)^{1/4}+\left[C_p(1)-C_p(1)\right]\cdot(\cos\phi)^{3/4}\\+\left[C_p(3)+C_p(4)\right]\cdot(\sin^2\phi)^2+\left[C_p(3)-C_p(4)\right]\cdot\sin\phi\end{array}\right\}$$

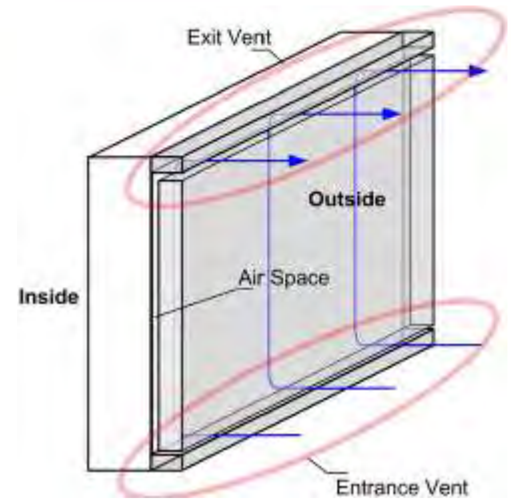


Stack Pressure

$$\Delta P_s=(\rho_{exterior}-\rho_{chamber})\cdot g\cdot(h-h_{NPL})$$

Ventilation Cavity Physics





$$\Delta P_{Total} = \Delta P_{in} + \Delta P_{cavity} + \Delta P_{exit}$$

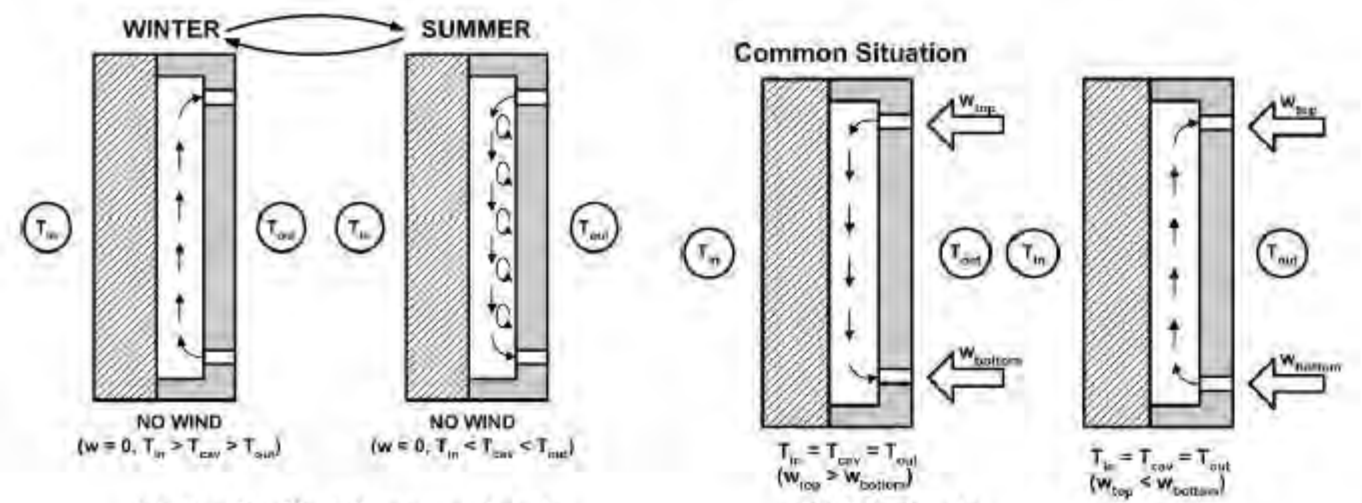
$$\Delta P_{Total} = C_{in} \cdot 0.5\,\rho\,v^2 + \frac{32k_f \cdot v \cdot \mu \cdot L}{\gamma \cdot D_h^2} + C_{exit} \cdot 0.5\,\rho\,v^2$$

$$\Delta P_{Total} = \Delta P_{wind} + \Delta P_{stack}$$

Climate Conditions

Table 4.4: Rough estimates of expected buoyancy pressures

Chamber Height (m)	Temperature Difference (Chamber – Exterior)	
	5° C → (0.25 Pa/m)	30° C → (1 to 1.6 Pa/m)
2.4 (1 floor)	0.60 Pa	2.4 to 3.84 Pa
4.8 (2 floors)	1.2 Pa	4.8 to 7.68 Pa
7.2 (3 floors)	1.8 Pa	7.2 to 11.5 Pa



(a) Stack effect (buoyancy) only

(b) Wind only

Theory Predictions

Brick veneers with chamber depths of 3/4 in. (19 mm)

Windward wall: 0.20 Pa – 0.60 Pa = -0.40 Pa
(upward flow – wind minus stack for 5 ^{o}C)

- - 0.40 Pa would drive 0.50 l/s (0.61 m3/(m2•hr) or **26.3ACH**

Windward wall: 0.20 Pa – 3 Pa = -2.7 Pa
(upward flow – wind minus stack for 30 ^{o}C)

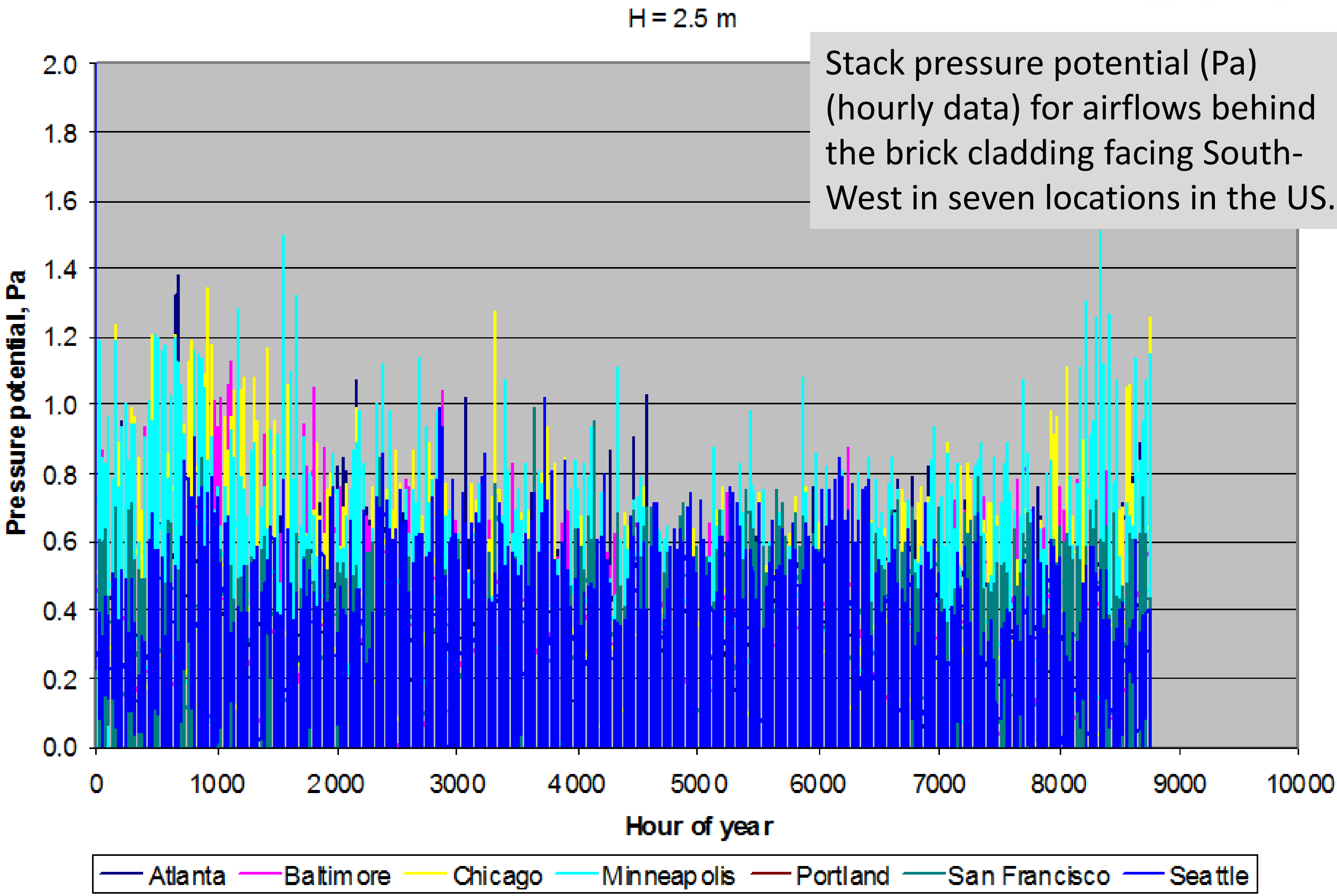
- - 2.7 Pa would drive 1.3 l/s (1.57 m3/(m2•hr) or **68.4 ACH**

Leeward walls and sidewalls: 0.60 Pa
(upward flow due to stack for 5 ^{o}C)

- - 0.60 Pa would drive 0.62 l/s (0.75 m3/(m2•hr) or **32.6ACH**

Climate: Stack Pressure (Pa) Brick Cladding South Facing

Stack pressure potential (Pa) (hourly data) for airflows behind the brick cladding facing South-West in seven locations in the US.



Climate: Stack Pressure (Pa) Brick Cladding South-West

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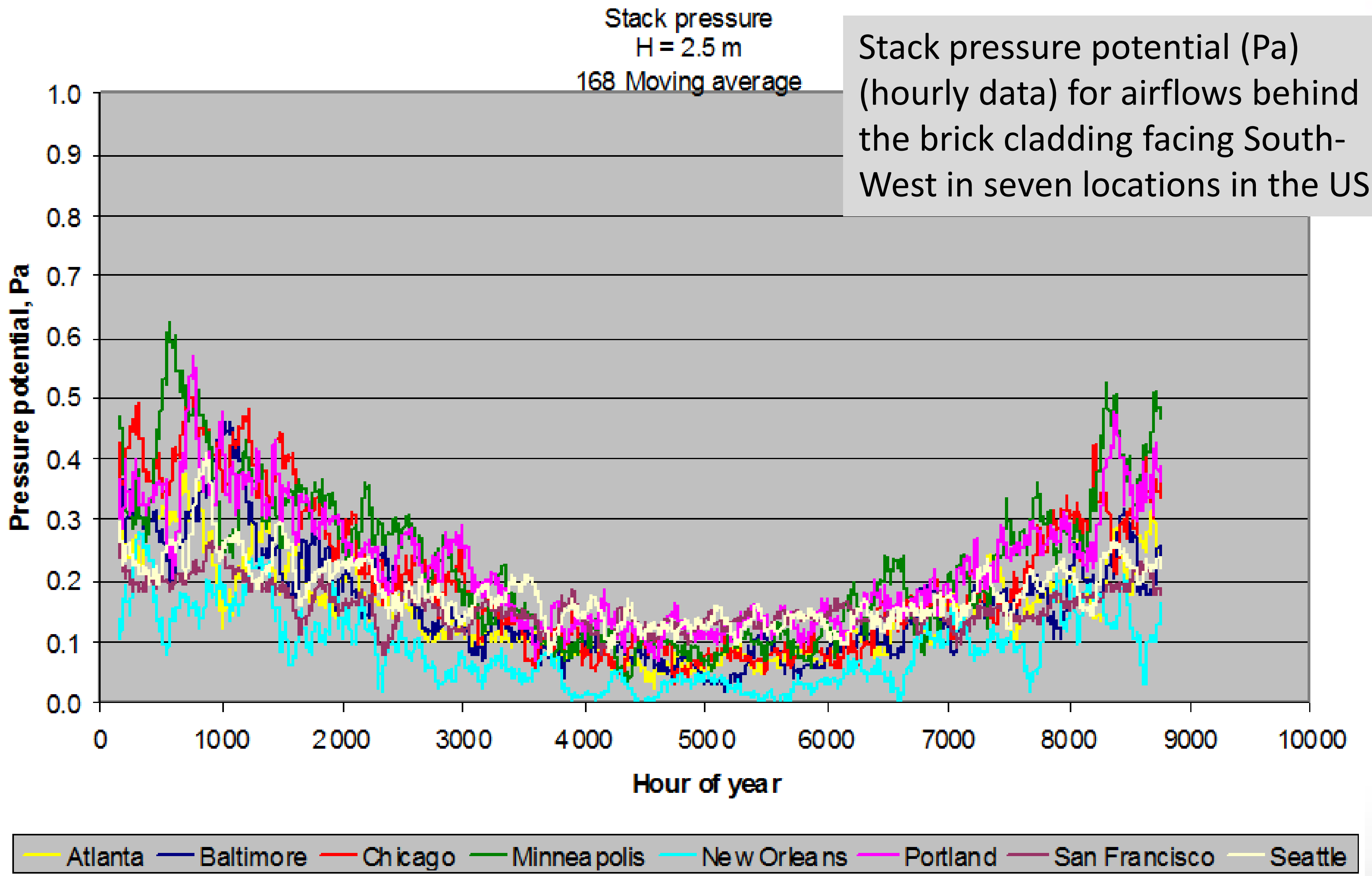
Stack pressure potential (Pa) (hourly data) for airflows behind the brick cladding facing South-West in seven locations in the US.



Climate: Wind Pressure (Pa) Brick Cladding South Facing

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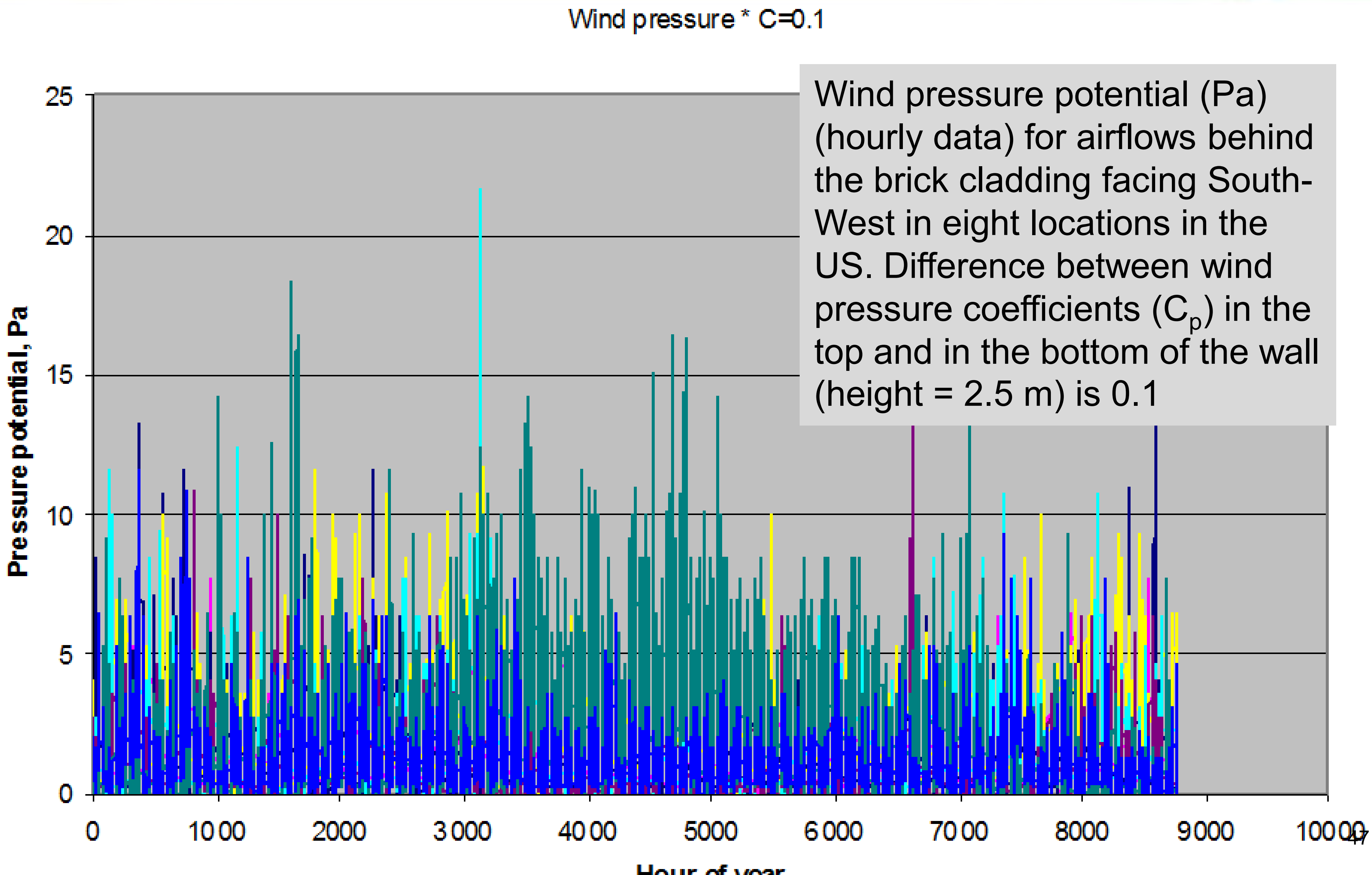
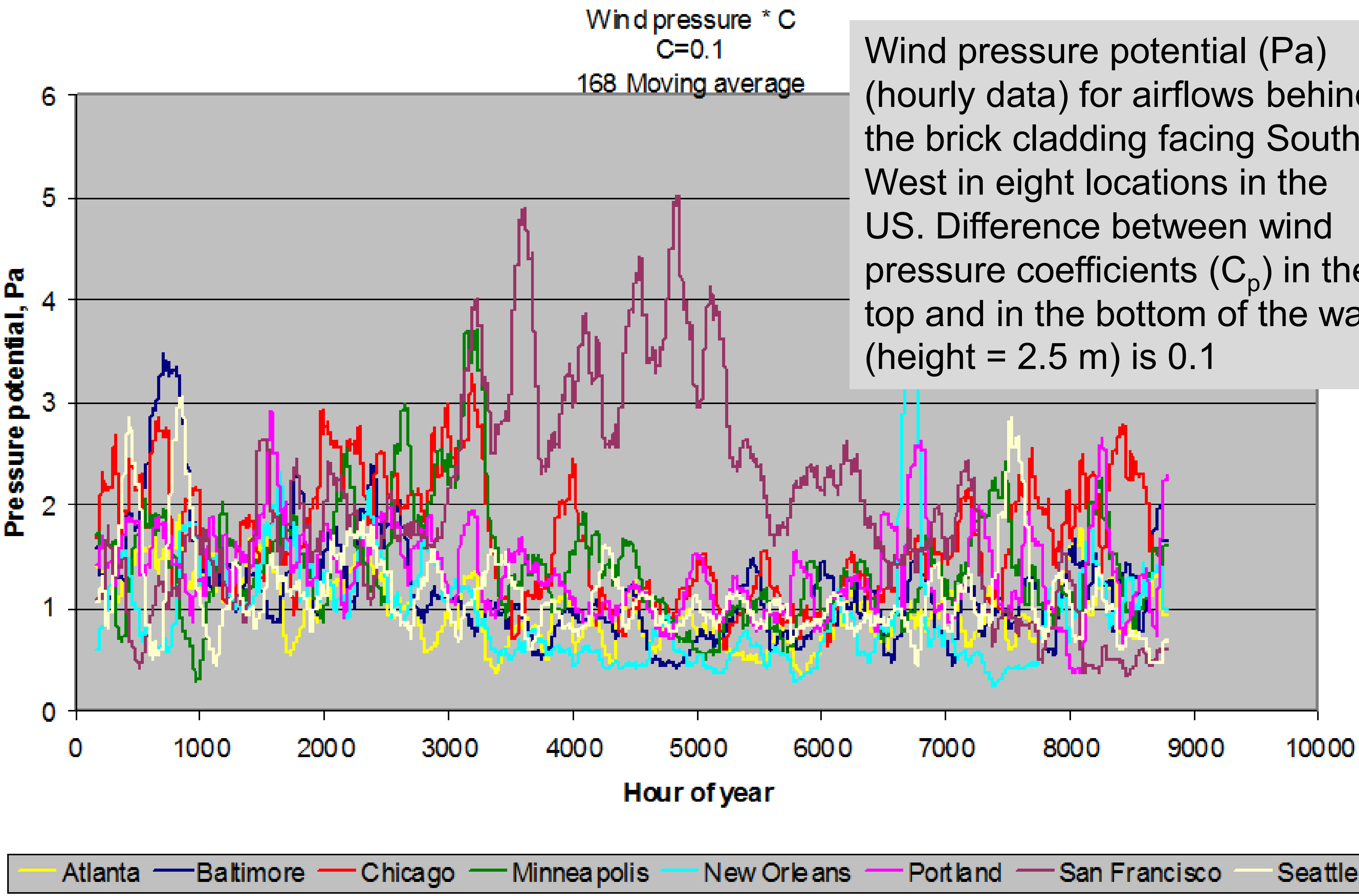


Wind pressure potential (Pa) (hourly data) for airflows behind the brick cladding facing South-West in eight locations in the US. Difference between wind pressure coefficients (C_p) in the top and in the bottom of the wall (height = 2.5 m) is 0.1

Climate: Wind Pressure (Pa) Brick Cladding South Facing



Wind pressure potential (Pa) (hourly data) for airflows behind the brick cladding facing South-West in eight locations in the US. Difference between wind pressure coefficients (C_p) in the top and in the bottom of the wall (height = 2.5 m) is 0.1

TC4.4: Project 1091-TRP

Development of Design Strategies for Rainscreen and Sheathing Membrane Performance in Wood-framed Walls

Three critical competencies

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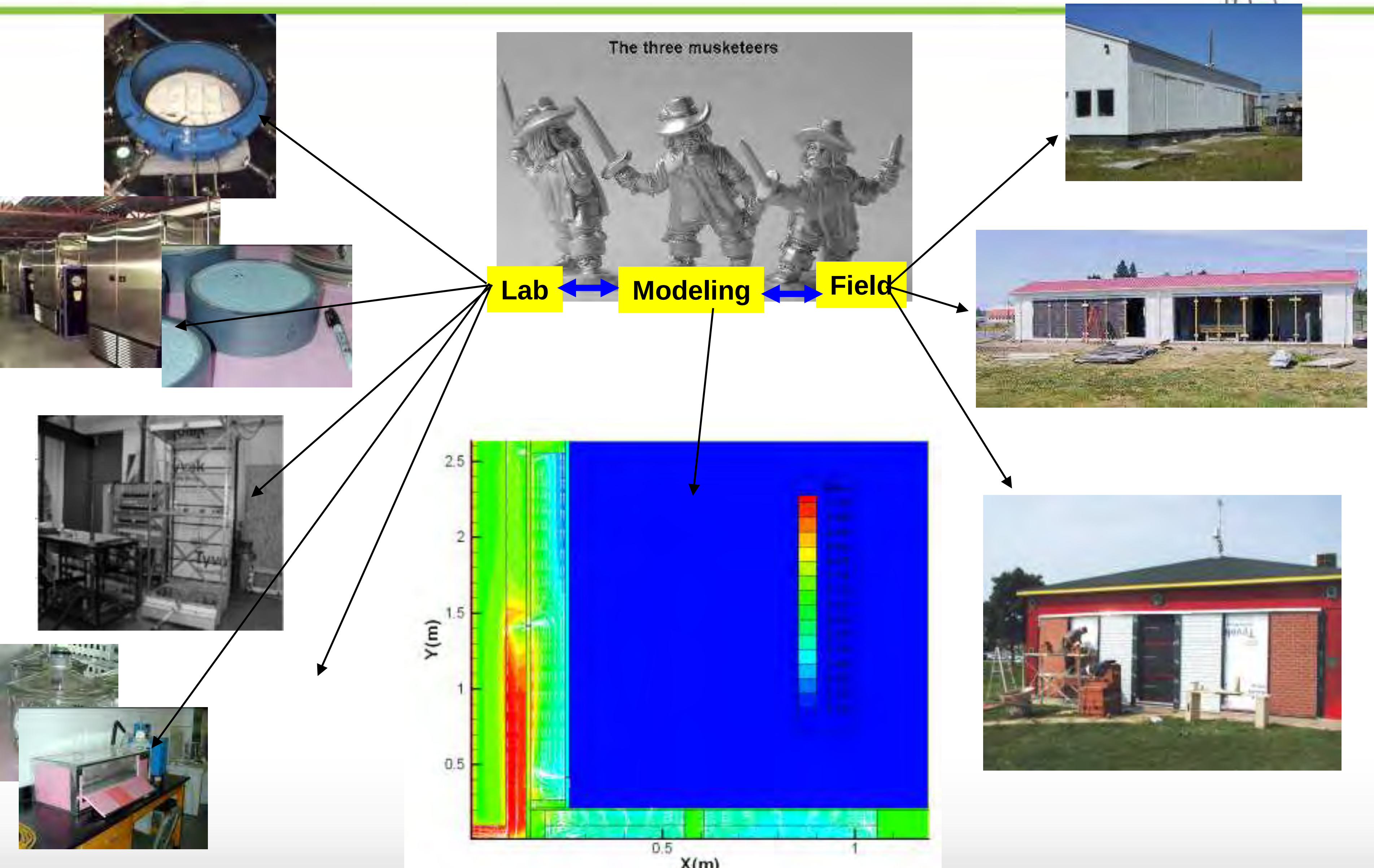


But the real question is where to get the Air Cavity Ventilation Numbers ?

Some Engineering Magic

Modeling

Model Inputs:

- Accurate representation of components/materials
- System/sub-systems characterization
- Physics
- Appropriate loads (Boundary Conditions)

Promised:

- be as complex and comprehensive as possible when accuracy is needed
- be as complex and comprehensive as needed when relative accuracy is sufficient

Project Objectives:

Two Main Objectives

- Nature and relevance of air cavity ventilation
- Performance and contribution of sheathing membrane

How was work proposed:

a) Generate laboratory data (benchmark model + understanding)

b) Generate field data (realistic input to model + performance data)

c) Use modeling to extend understanding to other walls and climates (supplemented by 3-D CFD)

Numerical Modeling

CFD

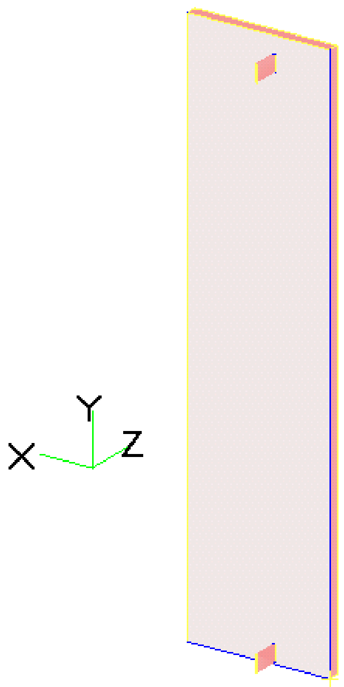
- Turbulent 3-D air flows
- Acceleration/Deceleration forces, Shear stress at boundaries
- Entry and Exit pressure drops
- Real dynamic wind pressures
- Air flow movement

A series of 3-D Simulations were performed:

Conjugated Heat and Mass transfer were performed

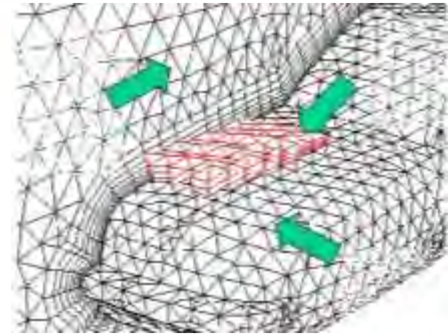
Goal – Quantify Internal Convection Effects for Wall Cavities

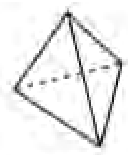
- Heat and Moisture Transport
- Computational Models
- Experimental Benchmarks

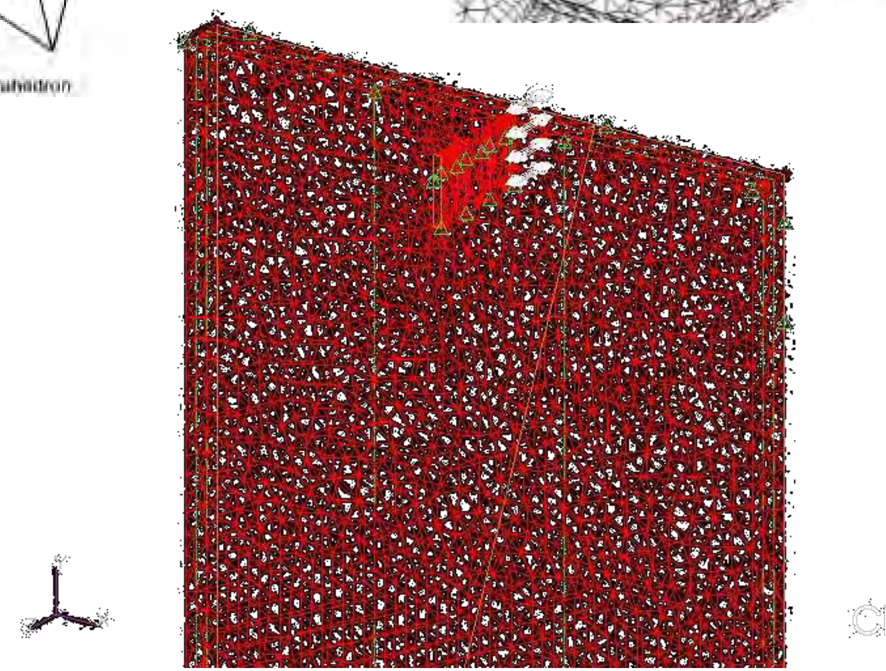


CFD Tool Used – CFX 5.5

- Tetrahedral/prism mesh
- Locally refined mesh (near edges and high velocity gradients)
- Scaleable wall functions
- Multiple turbulence models
- Permits multiple fluids



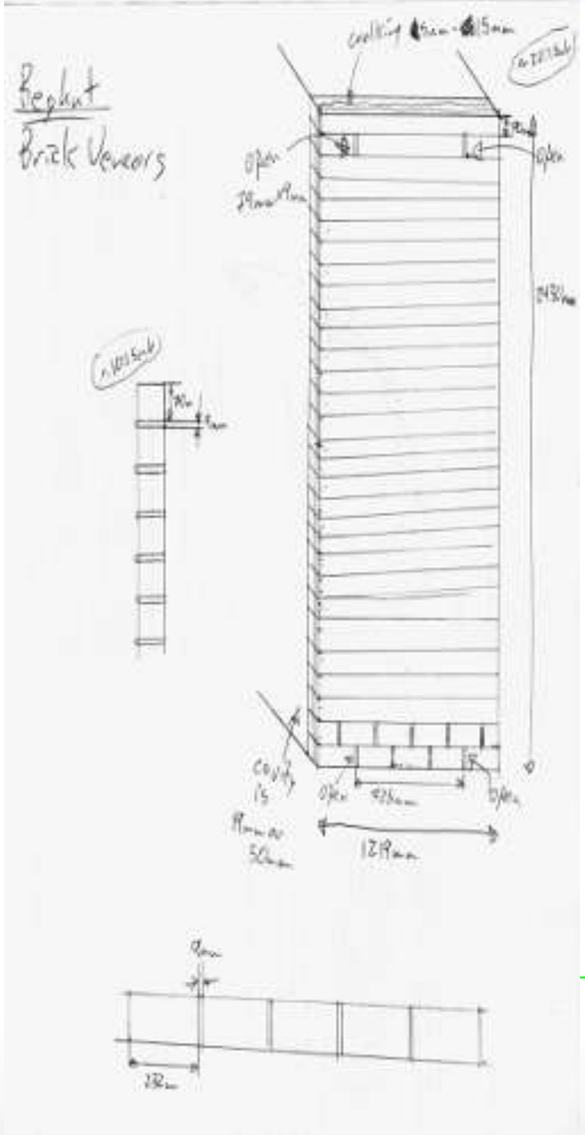


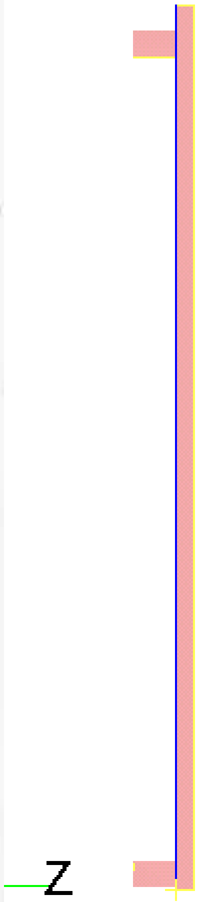


T. Stovall (ORNL)

Geometric Model Considerations

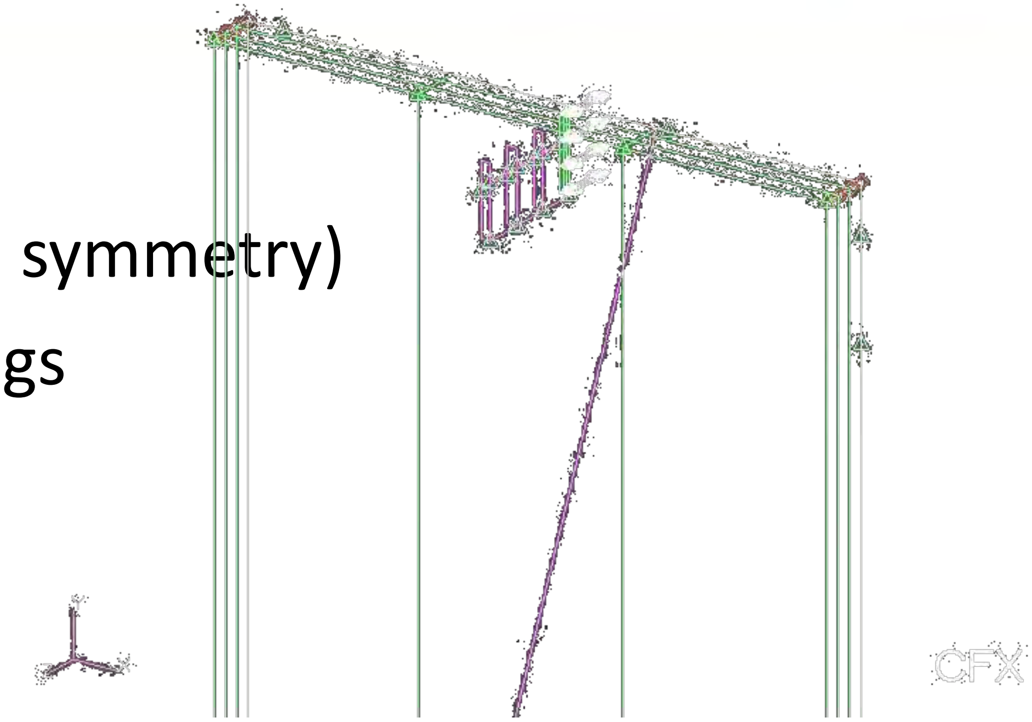
- Brick/mortar roughness
- Depth of cavity
- Openings
- Physical phenomena/time





Initial Model – 3D

- 50 mm depth
- 2.43 m height
- 0.61 m width (between symmetry)
- Bottom and top openings



Parameters Varied for Model of Brick Rainscreen Wall:

- Wind speed: 0, 1, 4, 7, 10 m/s (normal)
- Solar radiation: 0, 629, 903 W/m^2
- External air temperature: 250 and 305 K
- Cavity depth: 19 and 50 mm
- Ventilation slot height: 79 and 158 mm (10 mm wide)

Parametric Analysis

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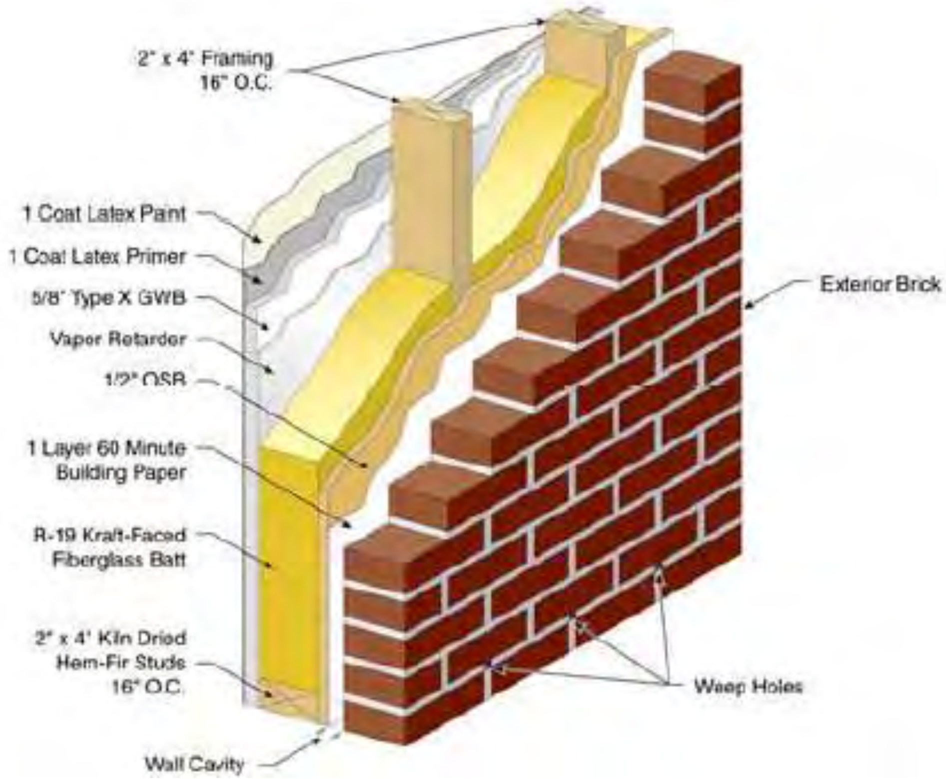
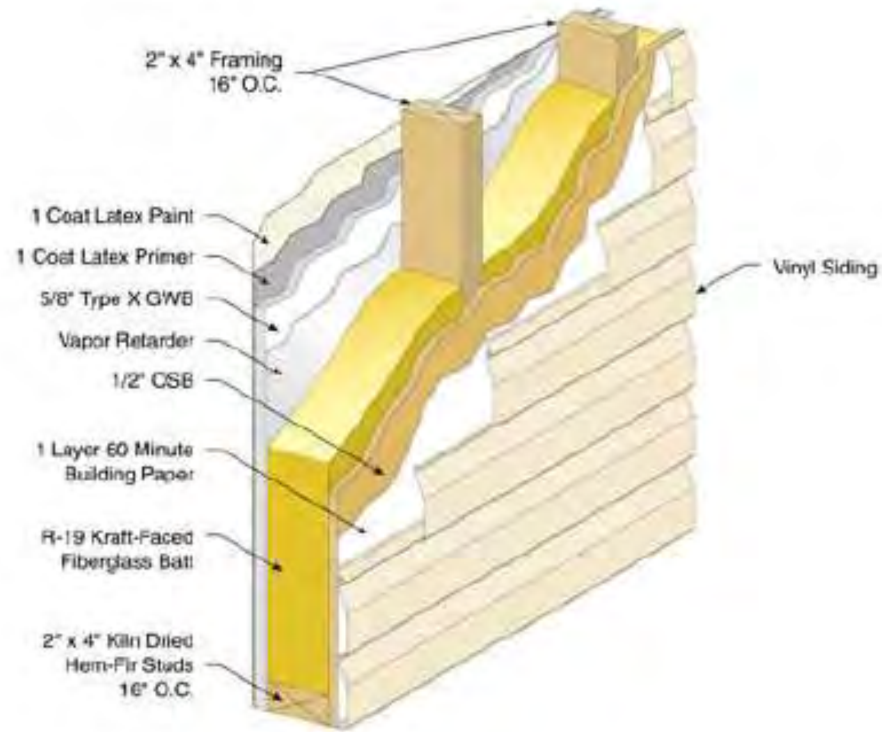
Table 2. Brick Wall Model Case Summary

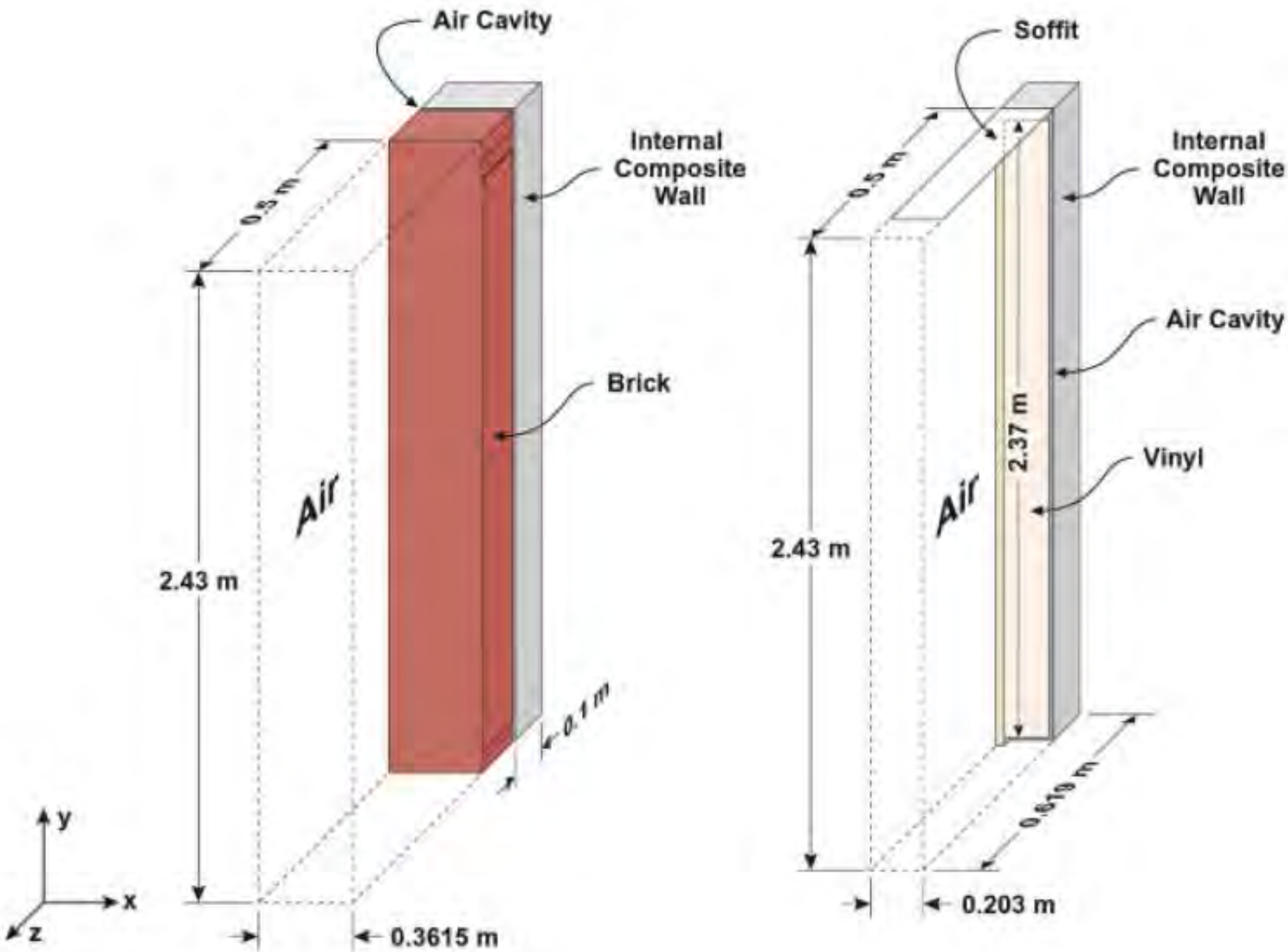
	Wind velocity normal to wall (m/s)	Outside air temperature (K)	Solar Radiation on Wall (W/m^2)	Height of Ventilation Slot (mm)	Ventilation Cavity Depth (mm)
Winter day, no wind	0	250	629	79	50
winter day, light wind	1	250	629	79	50
winter night, moderate wind	4	250	0	79	50
winter night, moderate wind	4	250	0	79	19
winter day, moderate wind	4	250	629	79	50
winter day, moderate wind	4	250	629	79	19
winter day, moderate wind	4	250	908	79	50
winter day, strong wind	10	250	629	79	50
summer day, no wind	0	305	629	79	50
summer day, light wind	1	305	629	79	50
summer day, light wind	1	305	629	79	50
summer day, light wind	1	305	629	79	19
summer night, moderate wind	4	305	0	79	50
summer night, moderate wind	4	305	0	79	19
summer day, moderate wind	4	305	629	79	50
summer day, moderate wind	4	305	629	79	19
summer day, moderate wind	4	305	629	158	50
summer day, moderate wind	4	305	629	158	19
summer day, moderate wind	4	305	908	79	50
summer day, high wind	7	305	629	79	50
summer day, strong wind	10	305	629	79	50
summer day, strong wind	10	305	629	79	19

CFD Wall Analysis: Two Walls

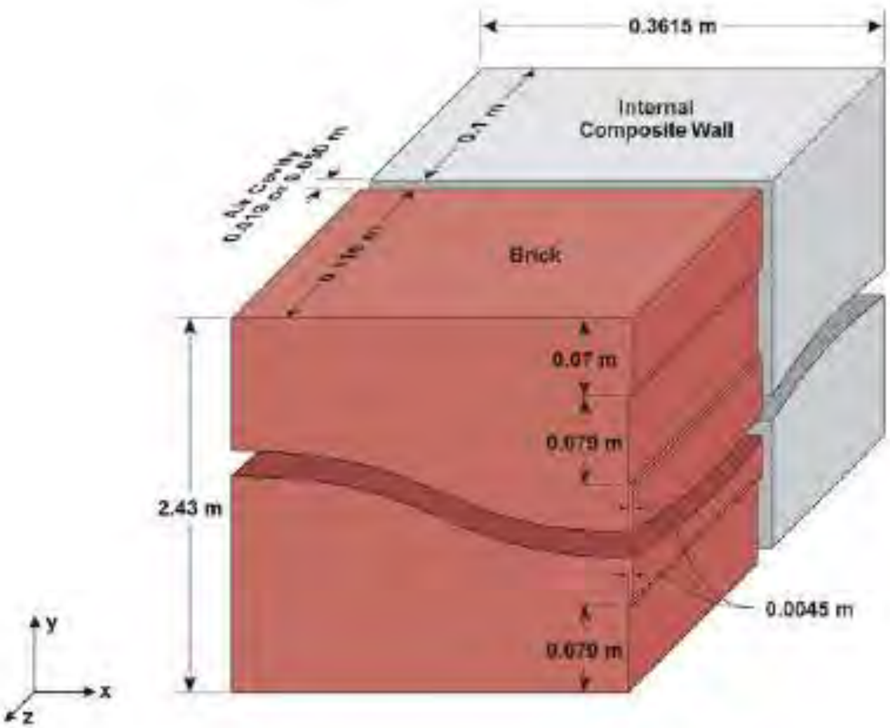


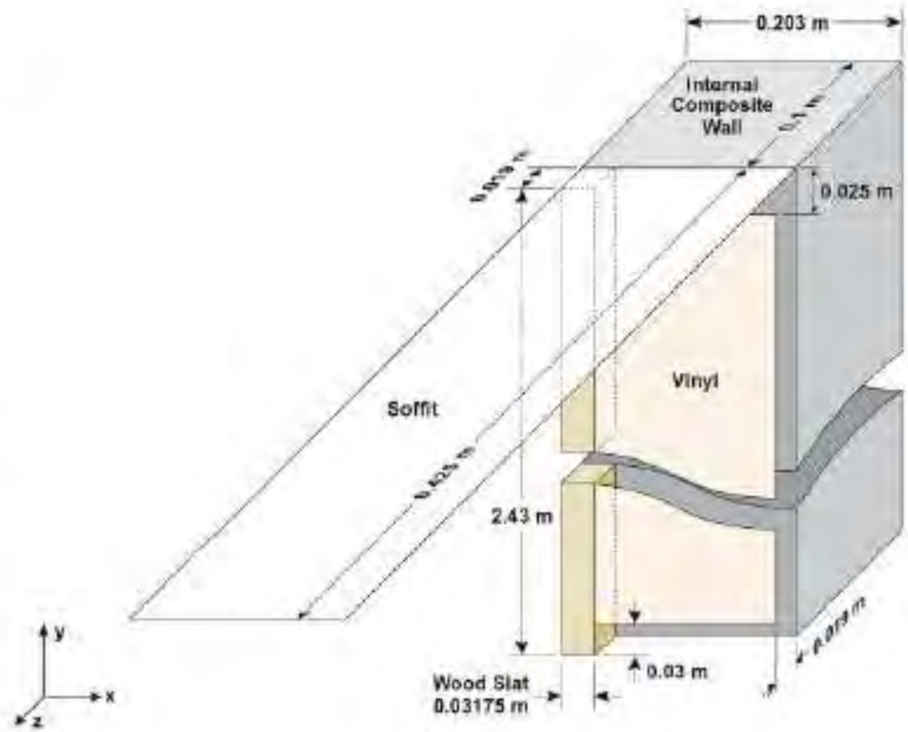


CFD Geometry



CFD Geometry





Results (Center of cavity)
50mm, with 4 m/s wind speed

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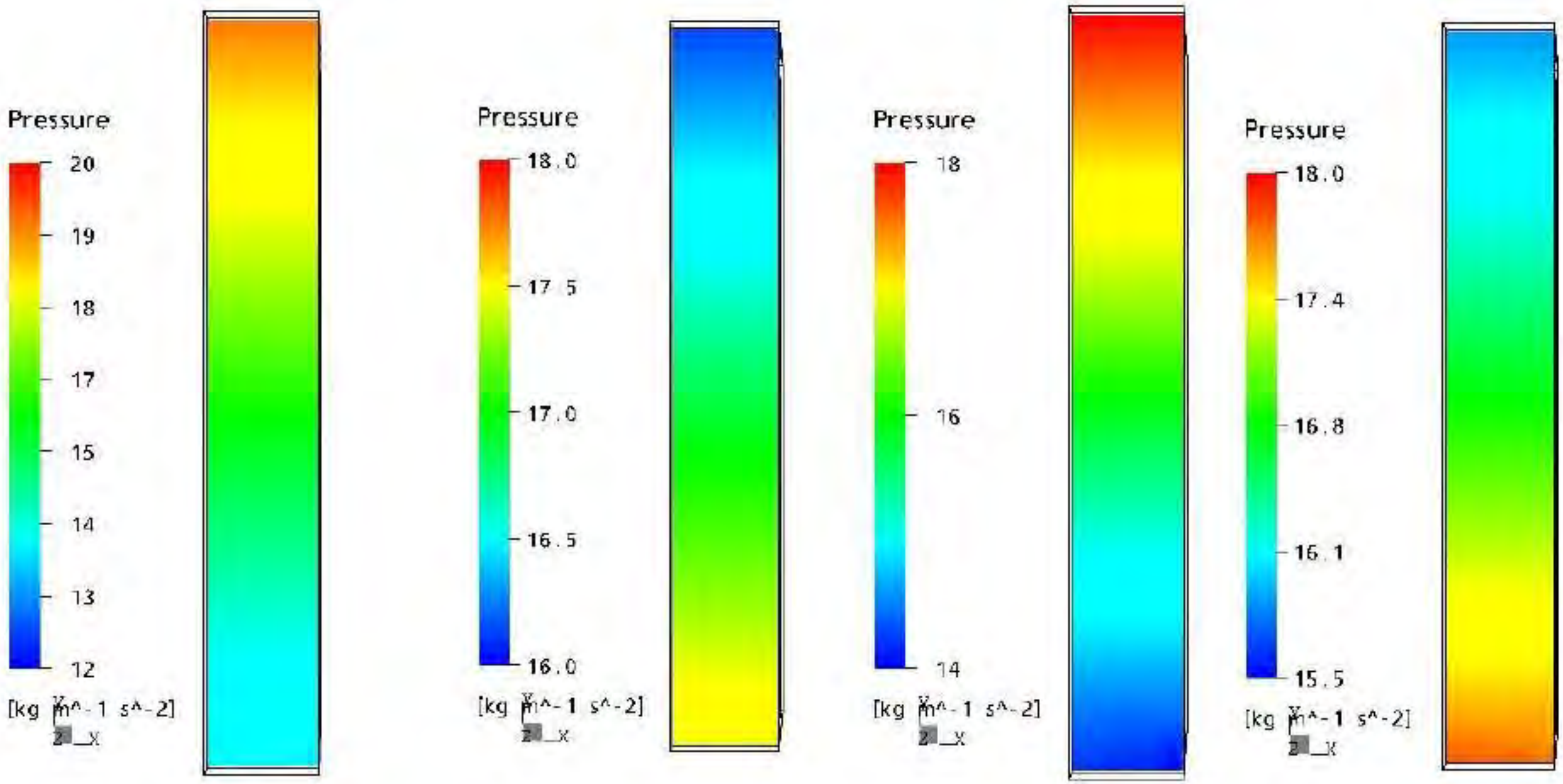
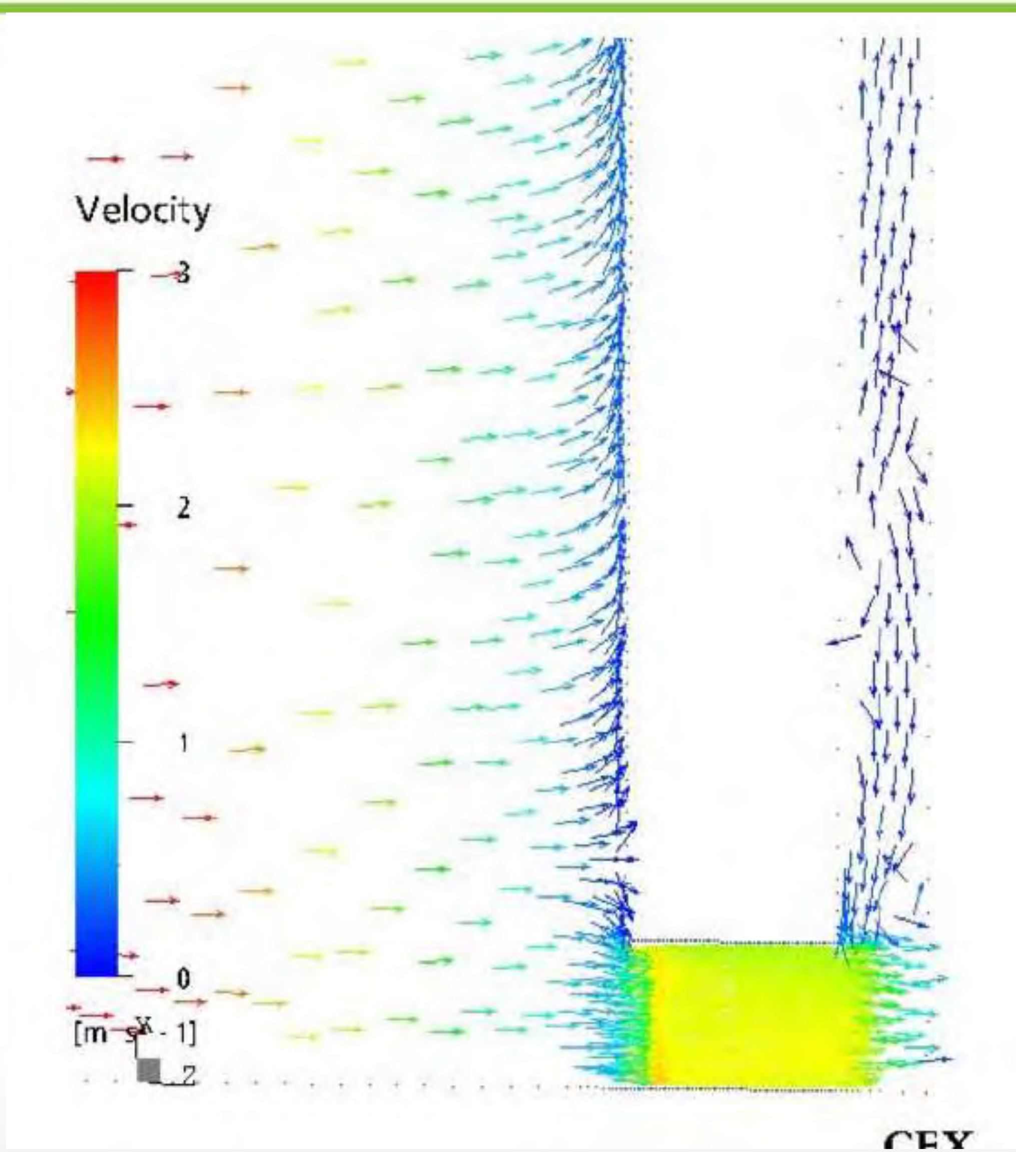
OWENS CORNING
INNOVATIONS FOR LIVING™

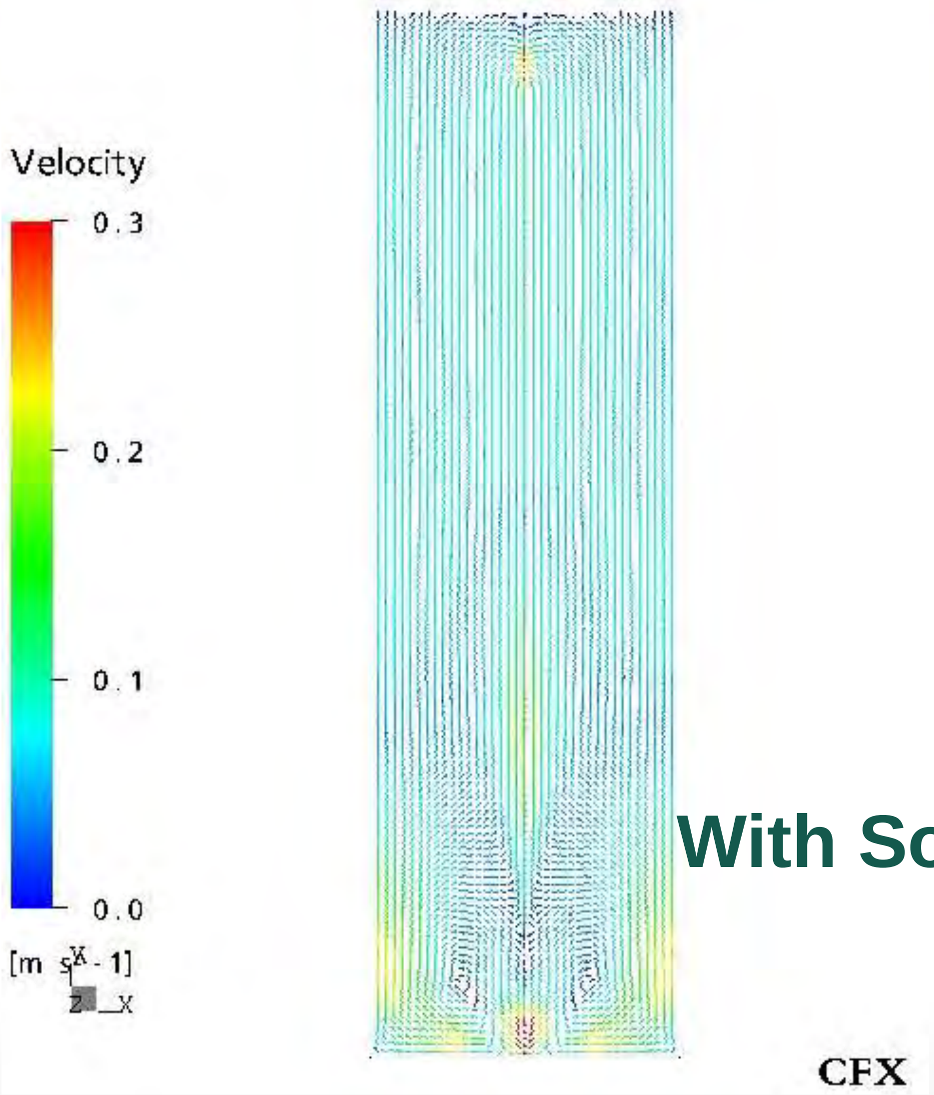
Summer **Winter** **Summer** **Winter**





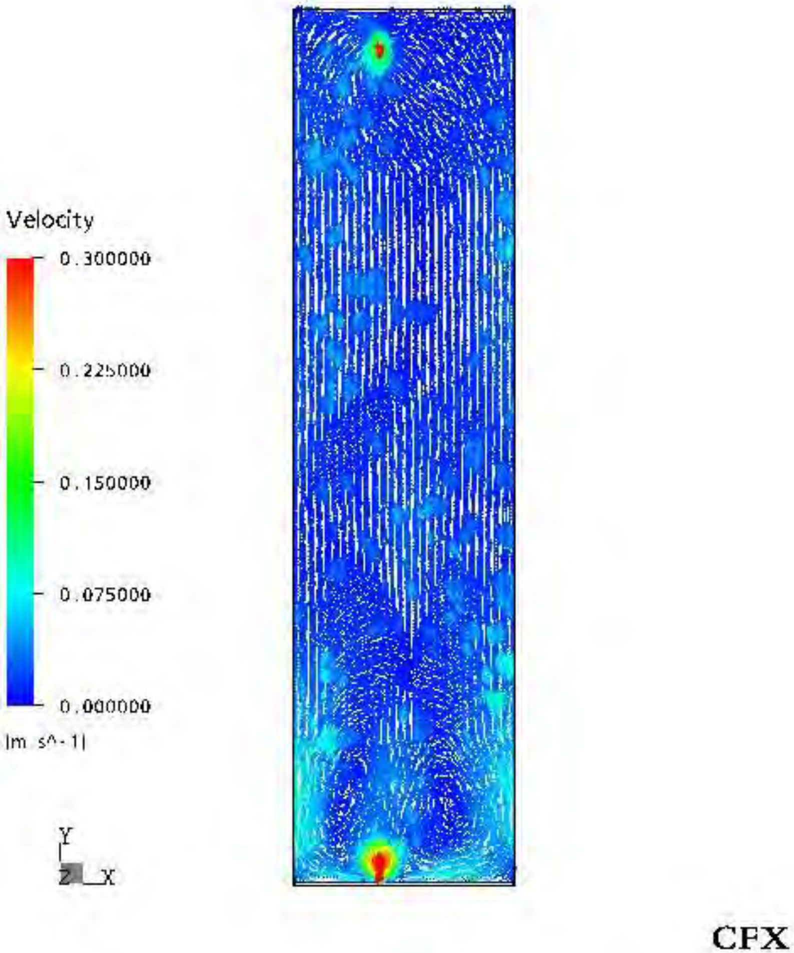
Side view of velocity field at bottom bisecting the ventilation slots.

Air Flowed From Bottom to Top

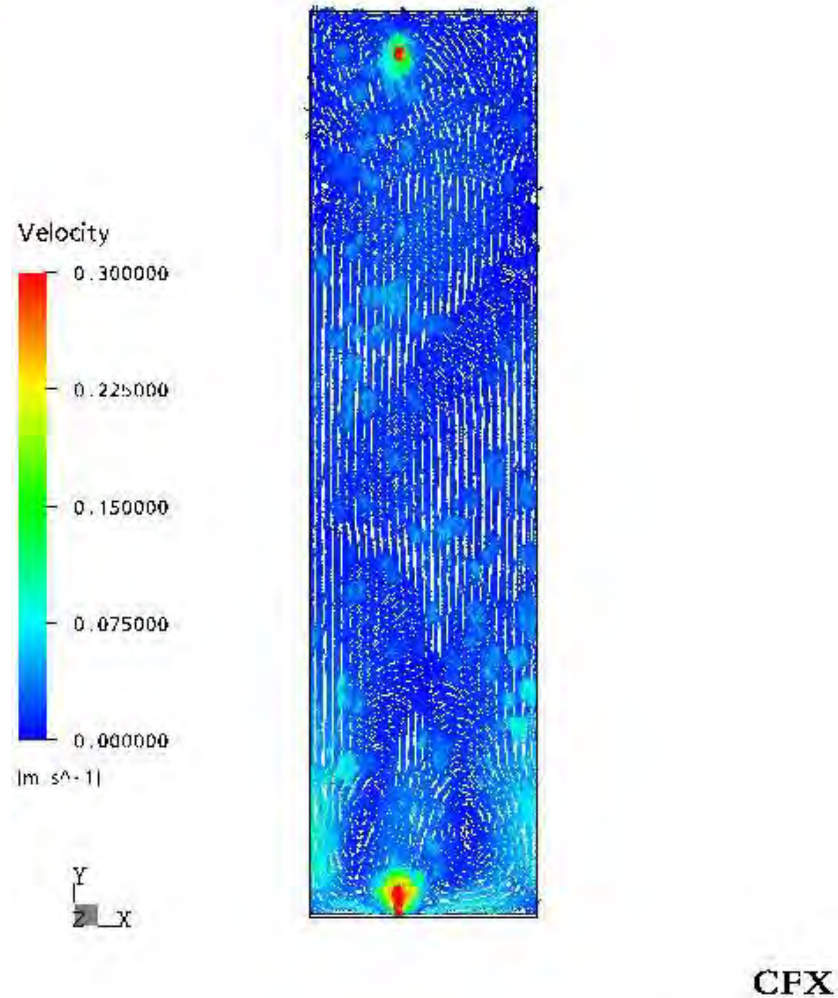


With Some Recirculation Areas

Slight Differences in Velocity Profiles 5 mm From Rough Wall Surface

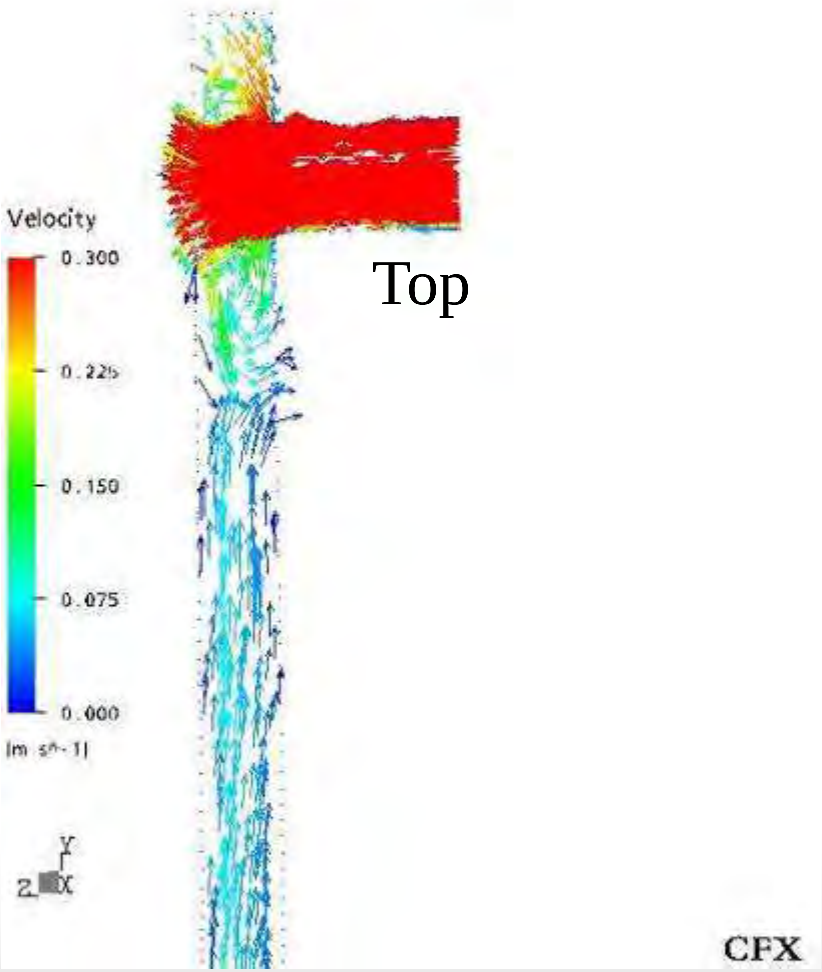


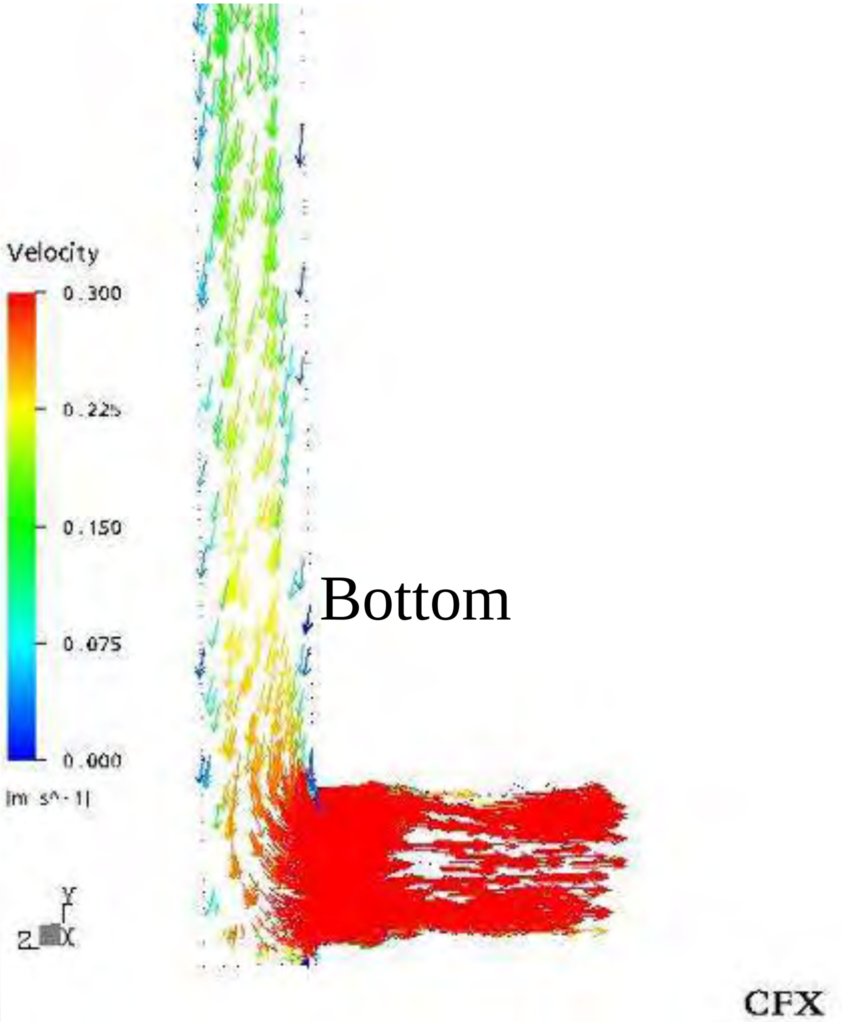
Smooth



3 mm k_s

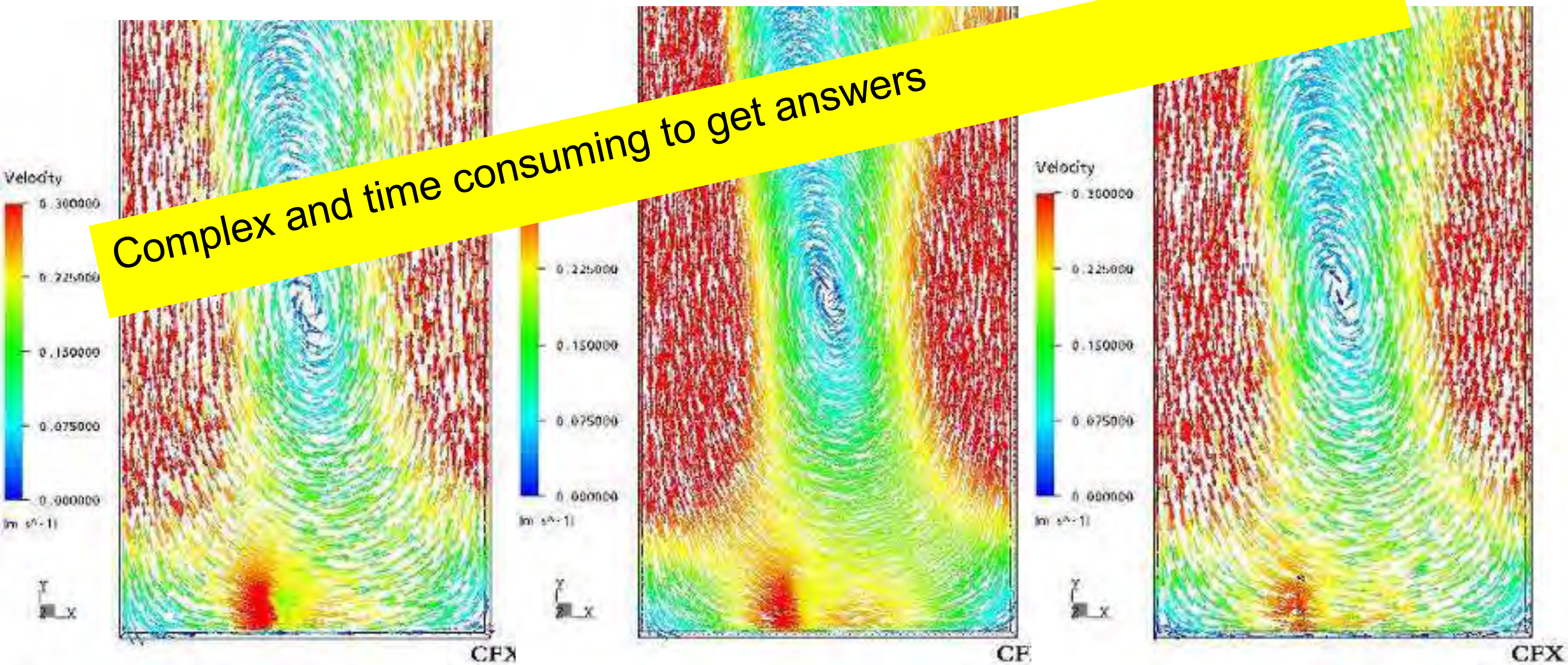
Flow Separation and Recirculation Apparent at Top Opening in Applied 2 Pa Pressure Differential, Cold Winter





Velocity Profiles, Bottom Section, Winter, 2 Pa Pressure Gradient, Smooth Walls

Near bricks | center of gap | or wall



Complex and time consuming to get answers

Multivariate Regression Used with CFD Results from 22 Cases

- Examine:
  - Total Ventilation Flow Through Cavity
  - Vertical Cavity Pressure Change
  - Pressure Drop in Ventilation Slot
- As a function of :
  - Wind Speed
  - Outdoor Air Temperature
  - Solar Radiation
  - Cavity Depth and Ventilation Slot Height

Multivariate regression analysis

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$$X = C_1 + C_2V_{air} + C_3V_{air}^2 + C_4(T_{air} - 295) + C_5(E_{solar}) + C_6(H_{slot}) \qquad \text{Eq. 1}$$

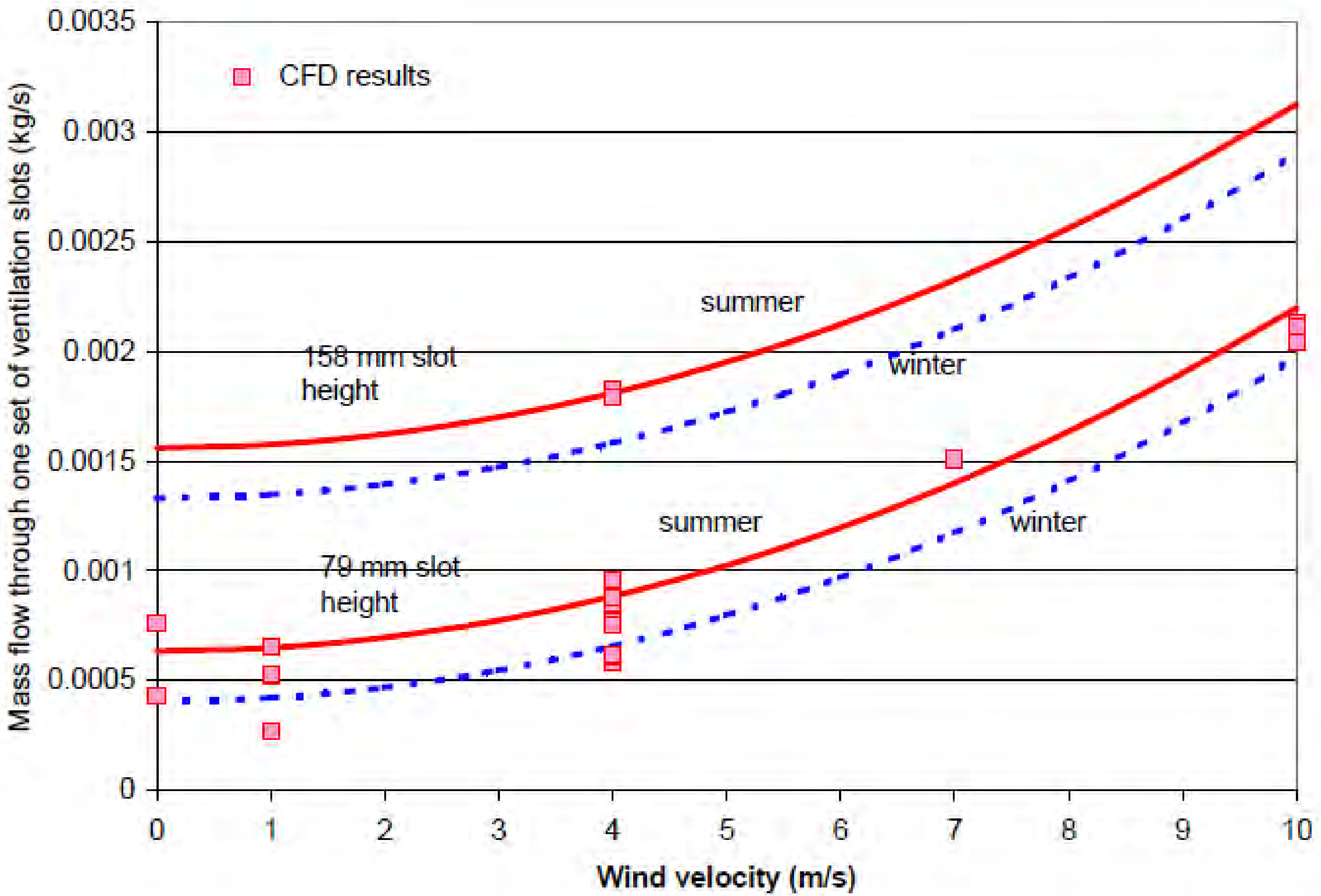
where

X	=	Desired quantity, pressure drop or flow rate,
C_1-C_6	=	Coefficients determined by multivariate regression, see Table 3
V_{air}	=	Wind velocity, normal to wall, m/s,
T_{air}	=	Temperature of the outside environment, K,
E_{solar}	=	Incident solar radiation, W/m^2,and
H_{slot}	=	Height of ventilation slots, mm (79 for one brick course, 158 for two brick courses).

Table 3. Coefficients for Eq. 1 for Ventilation Cavity Pressure Changes and Flow Rate

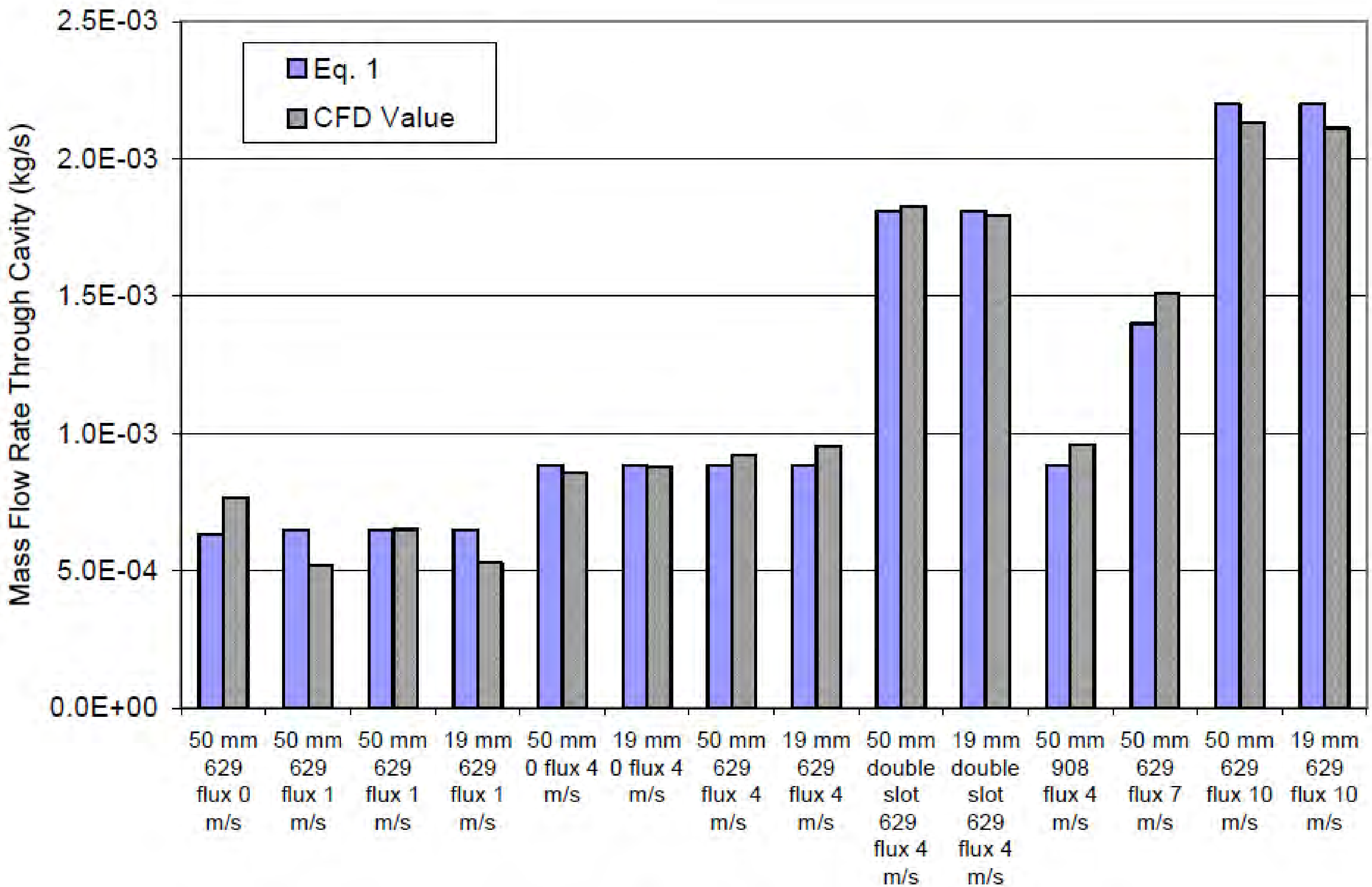
X	Vertical Pressure Increase in Cavity, P_{top}-P_{bottom} (Pa)		Pressure Drop Through Top Ventilation Slot, P_{cavity}-$P_{outside}$ (Pa)		Flow Rate Through Each Pair of Ventilation Slots (kg/s)	
Adj. R^2	0.98		0.99		0.98	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
C1	3.88400	0.34220	1.18100	0.47630	-0.00068	1.660E-4
C2	-0.44970	0.10680	-0.32570	0.14860	0.	0.
C3	0.02124	0.00984	0.23160	0.01370	3.14E-05	1.225E-6
C4	0.09990	0.00363	0.02864	0.00510	8.30E-06	1.501E-6
C5	0.00312	0.00037	0.00164	0.00052	0.	0.
C6	0.00000	0.00000	0.00000	0.00000	2.34E-05	1.753E-6

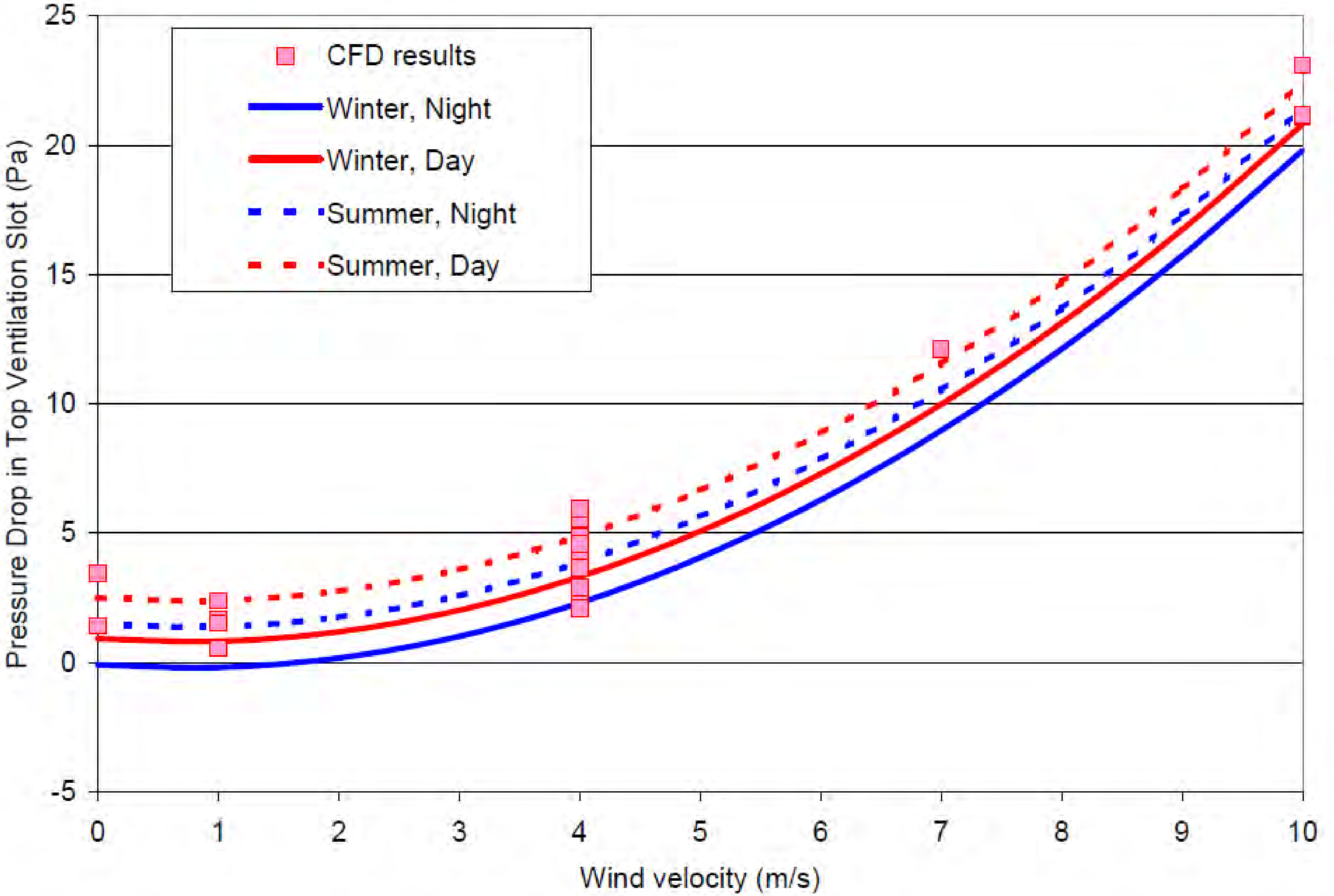
Equation



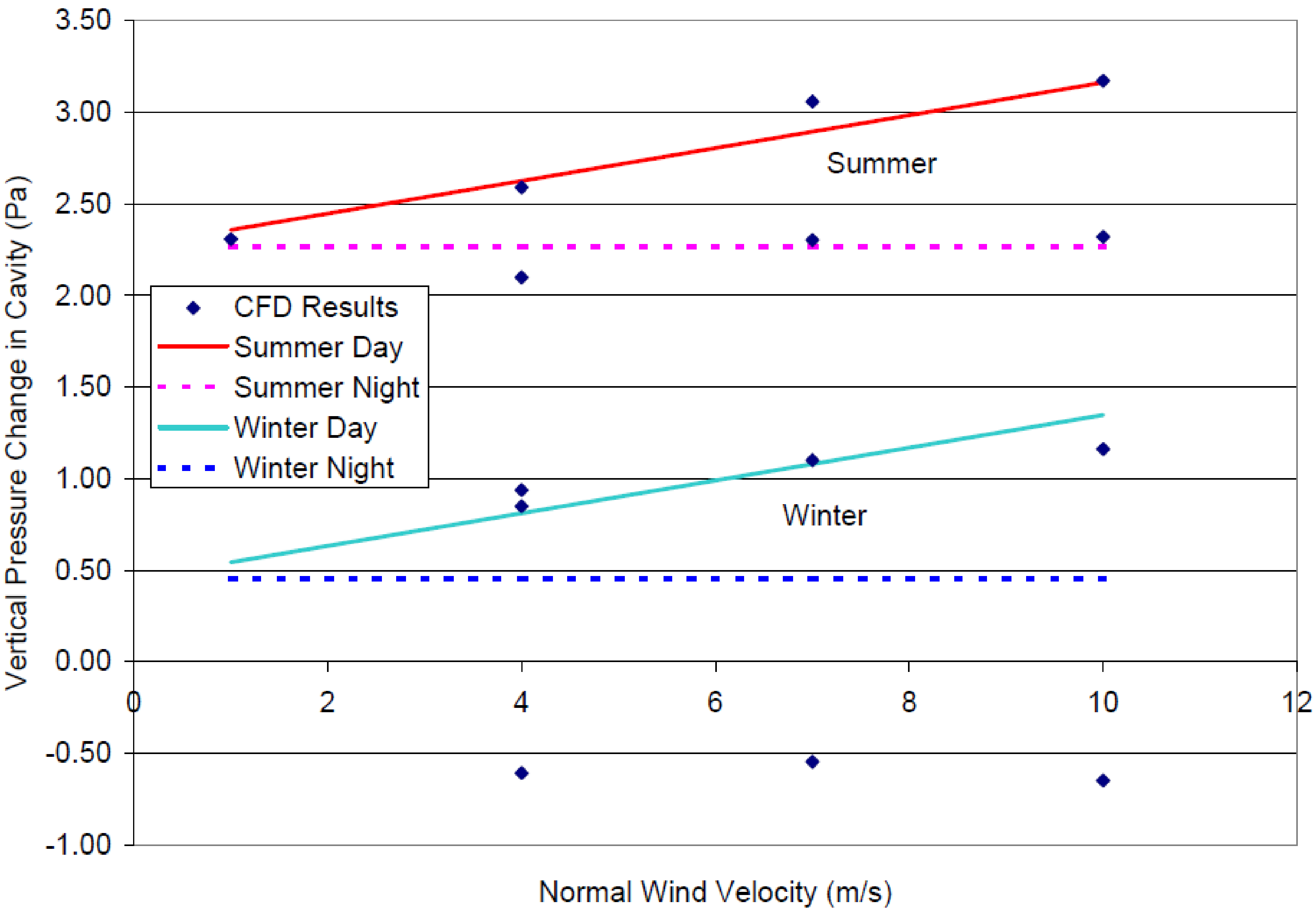
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Mass flow through one set of ventilation slots (kg/s)
CFD results
summer
winter
158 mm slot height
summer
winter
79 mm slot height
0
1
2
3
4
5
6
7
8
9
10
Wind velocity (m/s)

Comparison between Eqn 1 & CFD




CFD results
Winter, Night
Winter, Day
Summer, Night
Summer, Day
Pressure Drop in Top Ventilation Slot (Pa)
25
20
15
10
5
0
-5
0
1
2
3
4
5
6
7
8
9
10
Wind velocity (m/s)

Vinyl



3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0
2
4
6
8
10
12
Vertical Pressure Change in Cavity (Pa)
Normal Wind Velocity (m/s)
Summer
Winter
CFD Results
Summer Day
Summer Night
Winter Day
Winter Night

What have we learned

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Approach 1:

- Develop flow equations based on Duct analogy flow (Simple Theory)
- We can determine Pressure f… … and wind by simple correlations.

Using these two methods derive ACH in the ventilation cavity

Approach 2:

- Develop flow equations based on CFD (True resistances)
- Superimpose pressures from stack and mechanical pressures with CFD wind (or use simple CFD derived correlation)

How do I deploy cavity ventilation in Hygrothermal modeling ?

Let’s look at the transport..

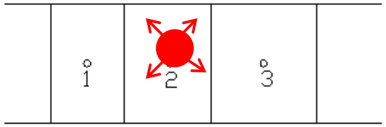
Transport Equations in WUFI®

Heat Transport

$[J/m^3K]$ Heat Capacity of the wet material

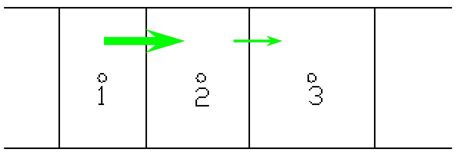
[K/s] Change of Temperature in Time (solution)

[W/m³]
External Heat Source
New in Ver. 4.1



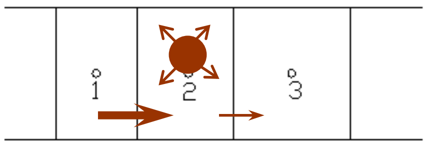
$$\frac{dH}{d\vartheta}\cdot\frac{\delta\vartheta}{\delta t} = \nabla\cdot\underbrace{(\lambda\nabla\vartheta)}_{Heat\ Flux} + \underbrace{h_v\nabla g_v}_{Latent\ Heat\ Source} + s_h$$

Change of the Heat Flux in Depth



$\lambda\ [W/mK]$ Heat Conductivity of the wet material

Change of the Diffusion Flux g_v
In Depth => Heat Source due to sorption

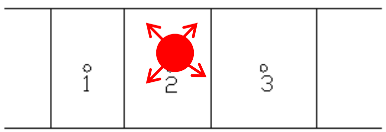


$h_v\ [J/kg]$ Evaporation Enthalpy of water

Transcport Equations in WUFI®

Moisture Transport

[kg/sm³]
external Moisture Source
neu ab Ver. 4.1

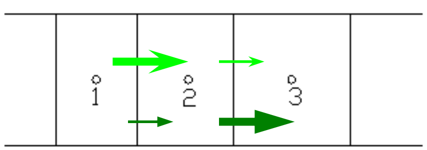


[kg/m³] Moisture Storage Capacity of the material

[1/s] Change of RH in Time (solution)

$$\frac{dw}{d\varphi}\frac{\delta\varphi}{\delta t} = \nabla\cdot\Big(\underbrace{D_\varphi \nabla\varphi}_{Capillary\ Moisture\ Flux} + \underbrace{\frac{\delta_l}{\mu}\nabla(\varphi p_{sat})}_{Vapor\ Diffusion\ Flux}\Big) + s_w$$

Change of he total Moisture Flux in Depth



D_φ [kgm/s]	Liquid Transport Coefficient of Water
δ_l [$kg/msPa$]	Vapor Diffusion Transport Coefficent (in Air)
μ [$-$]	Vapor Diffusion Resistance Factor
p_{sat} [Pa]	Vapor Saturation Pressure

Heat Sources

[W/m³] External Heat Source Density

[W/m²] External Heat Source

$$s_h \cdot \Delta x = S_h$$

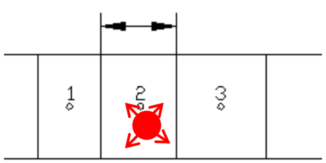
Fraction of the Solar Radiation

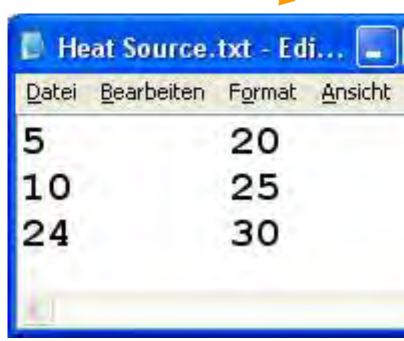
$$S_h = f \cdot I_s$$

f	[-]	Fraction
I_s	[W/m²]	Solar Radiation on the Surface

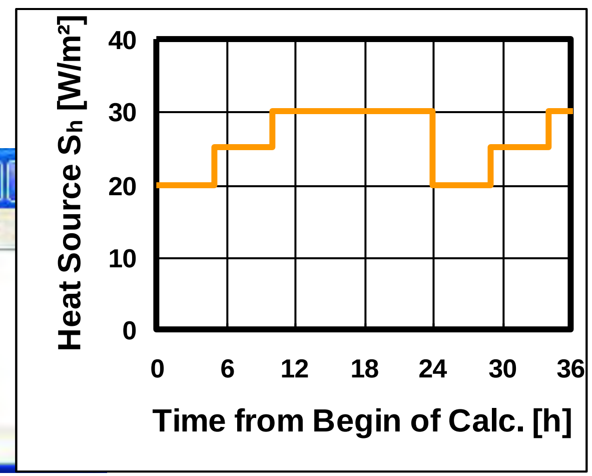
From File

Δx [m] Element Thickness





5	20
10	25
24	30



Sources/Sinks

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Moisture Sources

$$S_w = f \cdot \frac{R}{3600}$$

f [-] Fraction
R [mm/h] Driving Rain on the Surface
[l/hm²]; [kg/hm²]

[kg/sm³] External Moisture Source Density

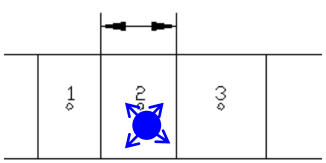
[kg/sm²] Ext. Moisture Source

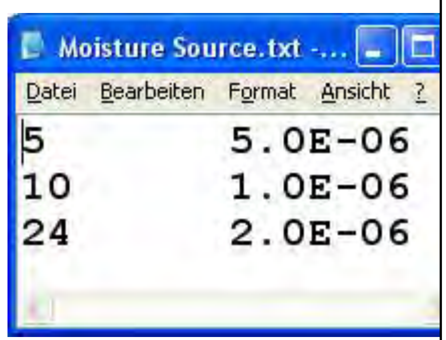
$$s_w \cdot \Delta x = S_w$$

Fraction of driving Rain

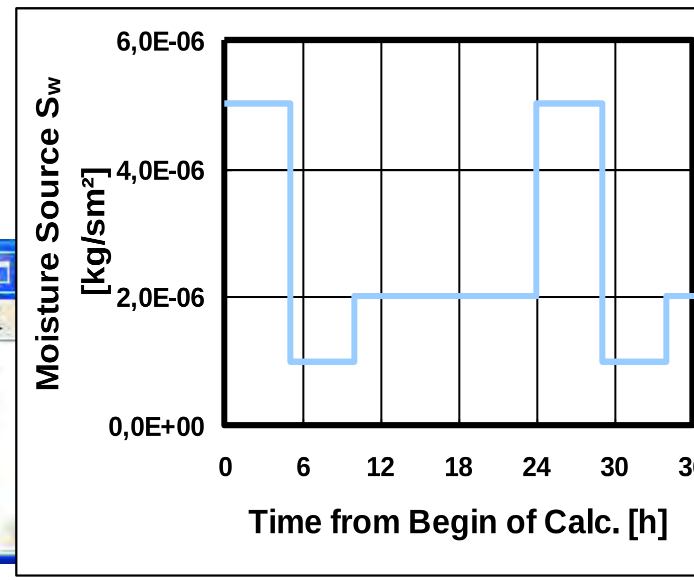
From File

Δx [m] Element Thickness




Moisture Source.txt -...
Datei Bearbeiten Format Ansicht ?

5	5.0E-06
10	1.0E-06
24	2.0E-06



Sources/Sinks for Ventilation

Calculation of the Source Term due to Ventilation

Heat Source:

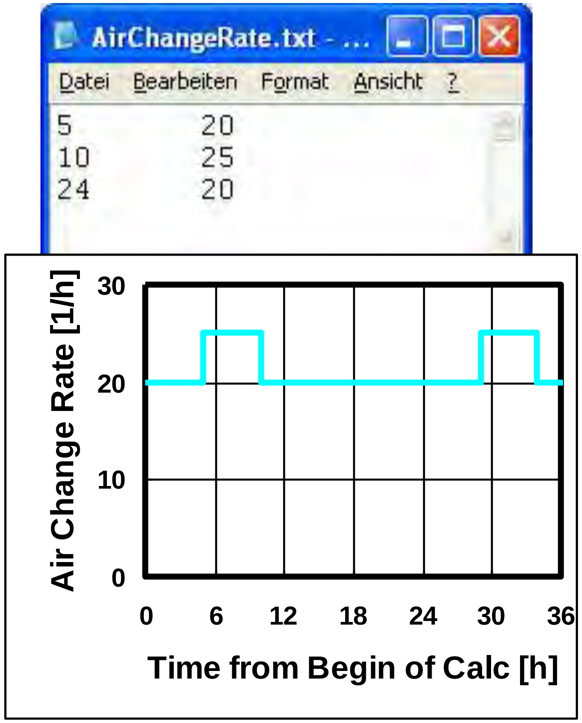
$$S_h = \rho_{out} \cdot \frac{ACH}{3600} \cdot d_{Vent} \cdot C_{p,Air} \cdot (T_{Out} - T_{Vent})$$

- S_h: Heat Source [W/m²]
- ρ_{out}: Density of the exterior Air [kg/m³]
- ACH: Air Change Rate in the ventilated Layer [1/h]
- d_{Vent}: Thickness of the ventilated Layer [m]
- $C_{p,Air}$: Spec. Heat Capacity of Air [J/kg K]
- T_{out}: Temperature; Outdoor [K]
- T_{Vent}: Temperature in the ventilated Layer [K] (mean value of all Elements)

Moisture Source:

$$S_w = \frac{ACH}{3600} \cdot d_{Vent} (c_{Out} - c_{Vent})$$

- S_w: Moisture Source [kg/m²s]
- c_{out}: Water Vapor Concentration in the Air; Outdoor [kg/m³]
- c_{Vent}: Water Vapor Concentration in ventilated Layer [kg/m³] (mean value of all Elements)



Question 1:

Ok… we can sort get a **reasonable estimate** for **air flow** in exterior claddings..

But

How well can we model the moisture transport ??

Laboratory and Field Measurements

- Let's start with Laboratory measurement… see if we can predict the same transport phenomena

- If successful let's move to the field.. !!

- If not successful let's go to the beach …

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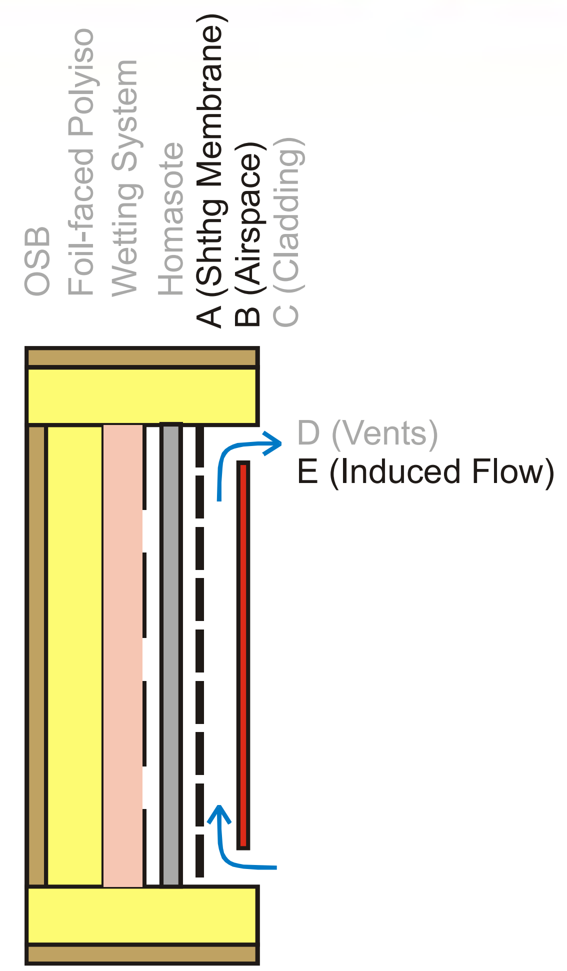
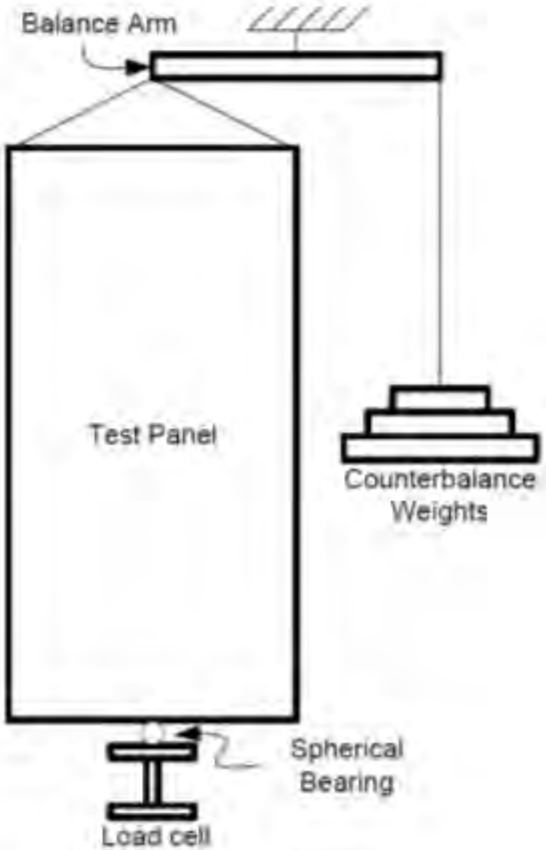
Penn State

Variables Studied

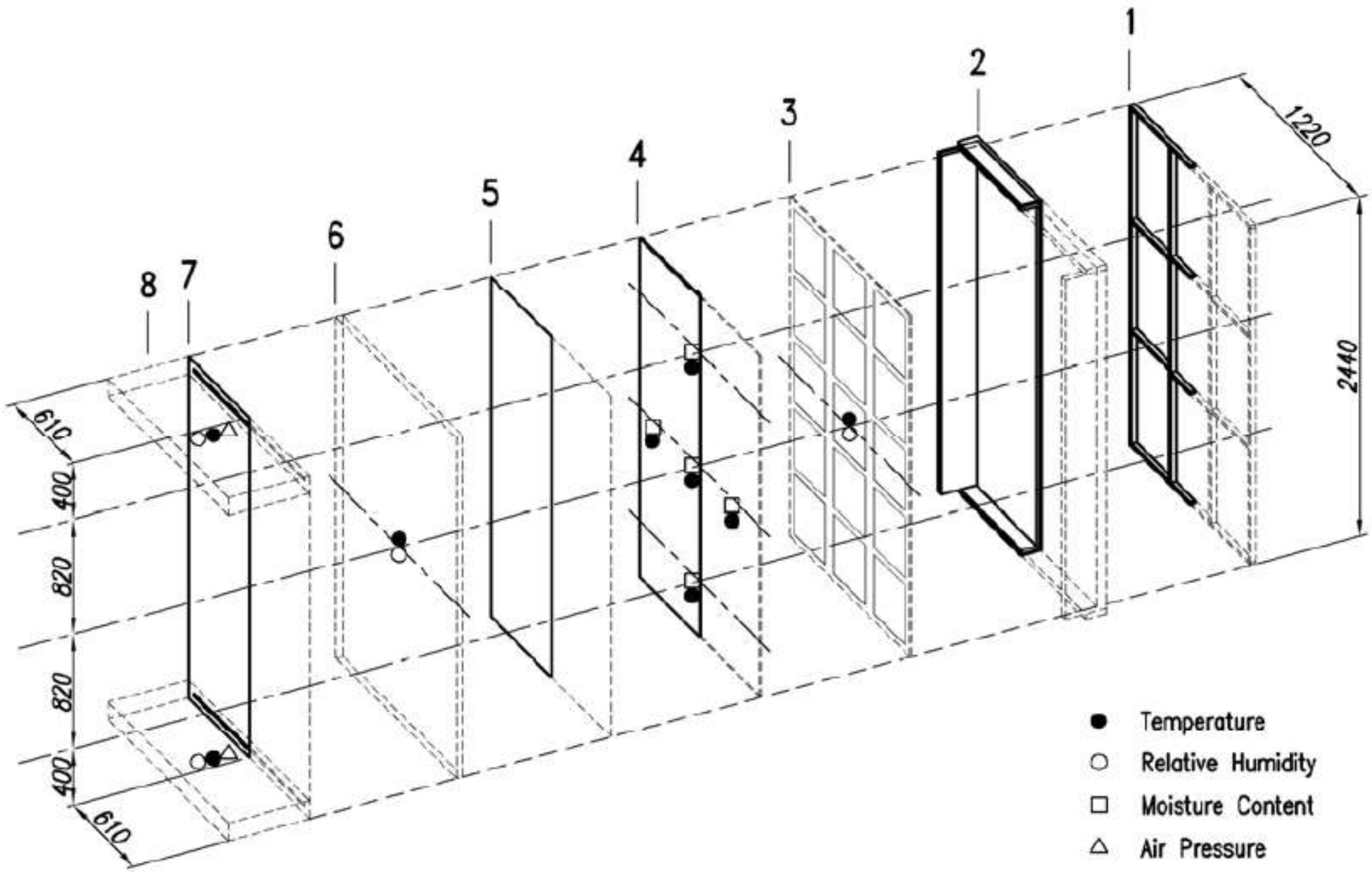
- sheathing membrane (A)
- Airspace (B) volume
- induced flow rate (E)
- Cladding (C)
- Vents (D)



Panel ventilation drying apparatus



Test Panel Assembly: Laboratory



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Wetting Mechanism

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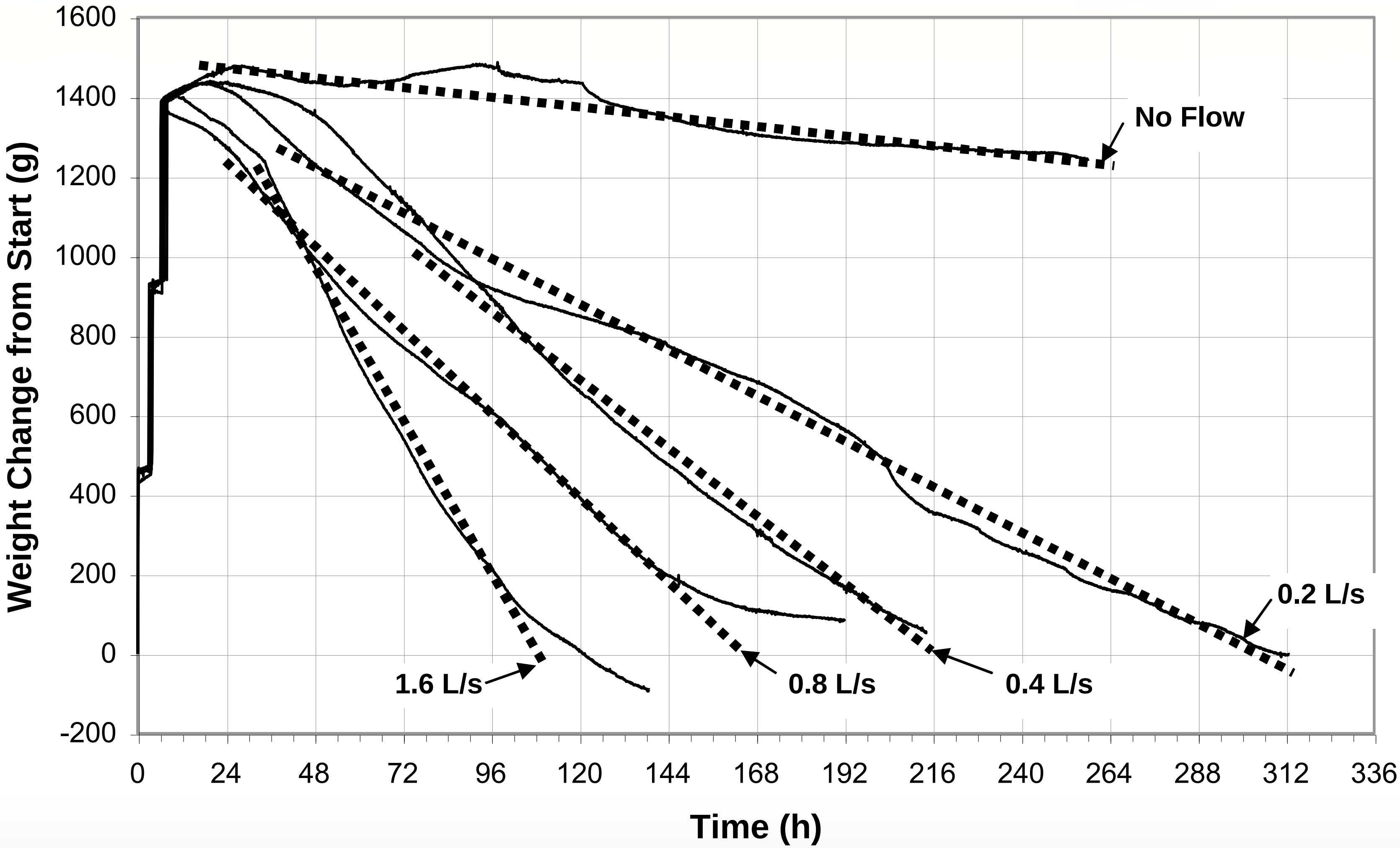
Van Straaten, MscE

Drying rates (None to 1.6 L/s)



Summary table

Flow Rate(L/s)	Air Change Rate(ACH)	Approx. Drying Rate(g/h)	Drying Time(days)
1.6	40	17	4.4
0.8	20	9	6.9
0.4	10	8	8.5
0.2	5	5	12.6
No Ventilation Airflow	0	1	Did not dry completely

Advanced Hygrothermal Modeling to predict drying in this 2D case

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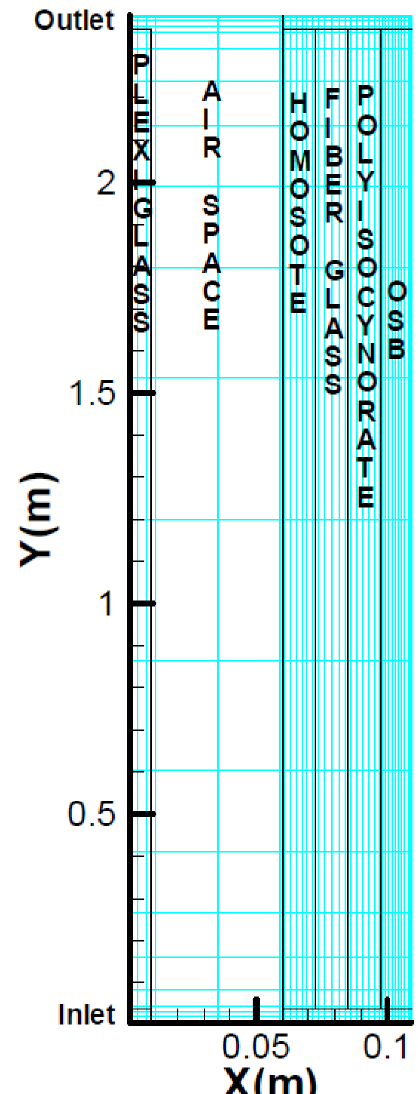
Model Features

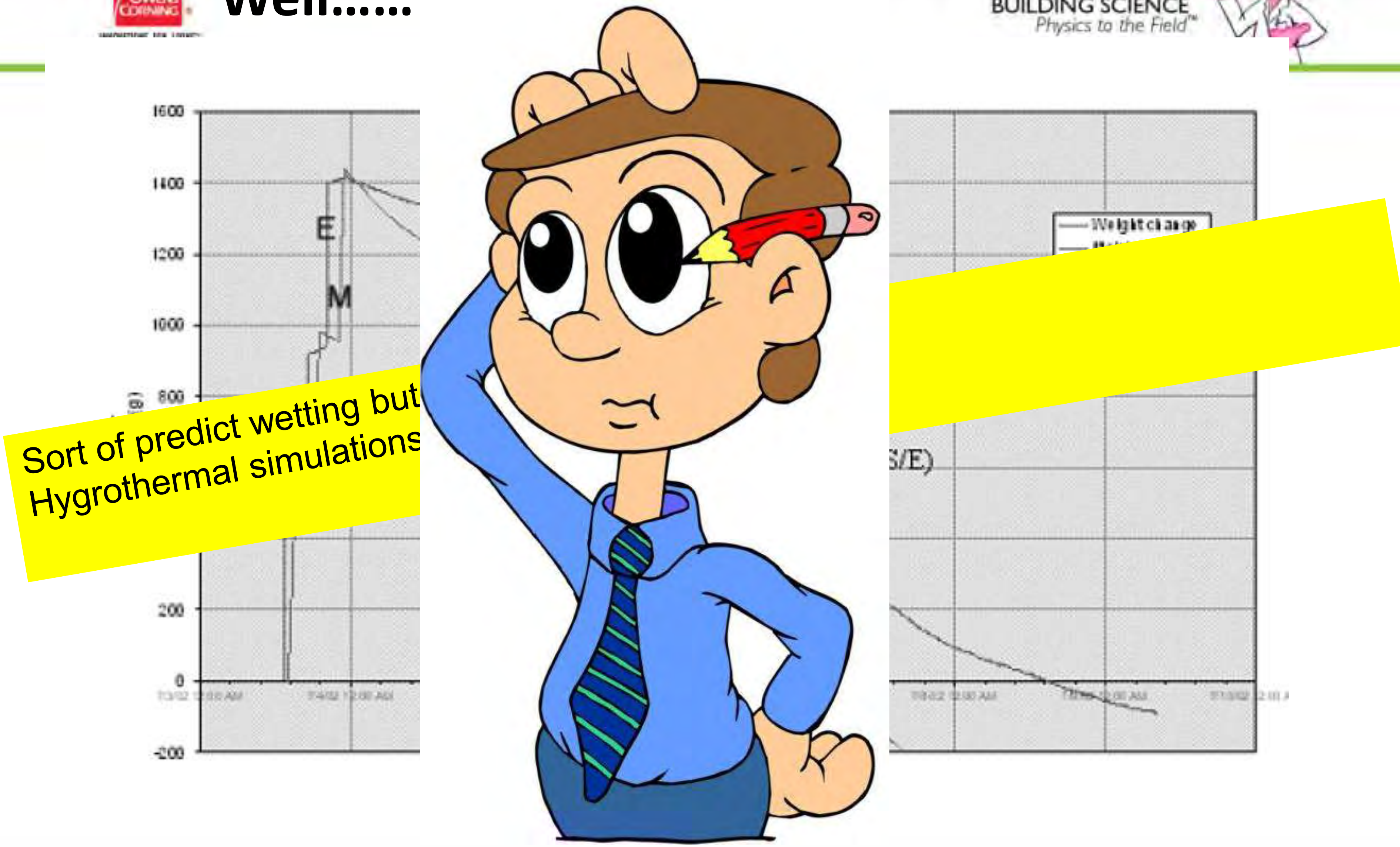
- 1-D or 2-D
- Vapor Air Flow
- Vapor and Liquid Diffusion
- Solar and Sky Radiation
- Wind-Driven Rain
- Moisture-Thermal Sources and Sinks
- Dynamic Stack and HVAC Effects
- Liquid Transport as a function of process



Node Sizes

18 x 13
35 x 25
70 x 50
140 x 100

Well……



First never done before….

Problem…. **ASHRAE data** for Wood fiber board were Asphalt Coated.

The Penn State Homosote were not Asphalt Coated.

ORNL performed Hygrothermal Material Properties
And these were used….

Let's see if this **helped** ??

ASHRAE Homosote

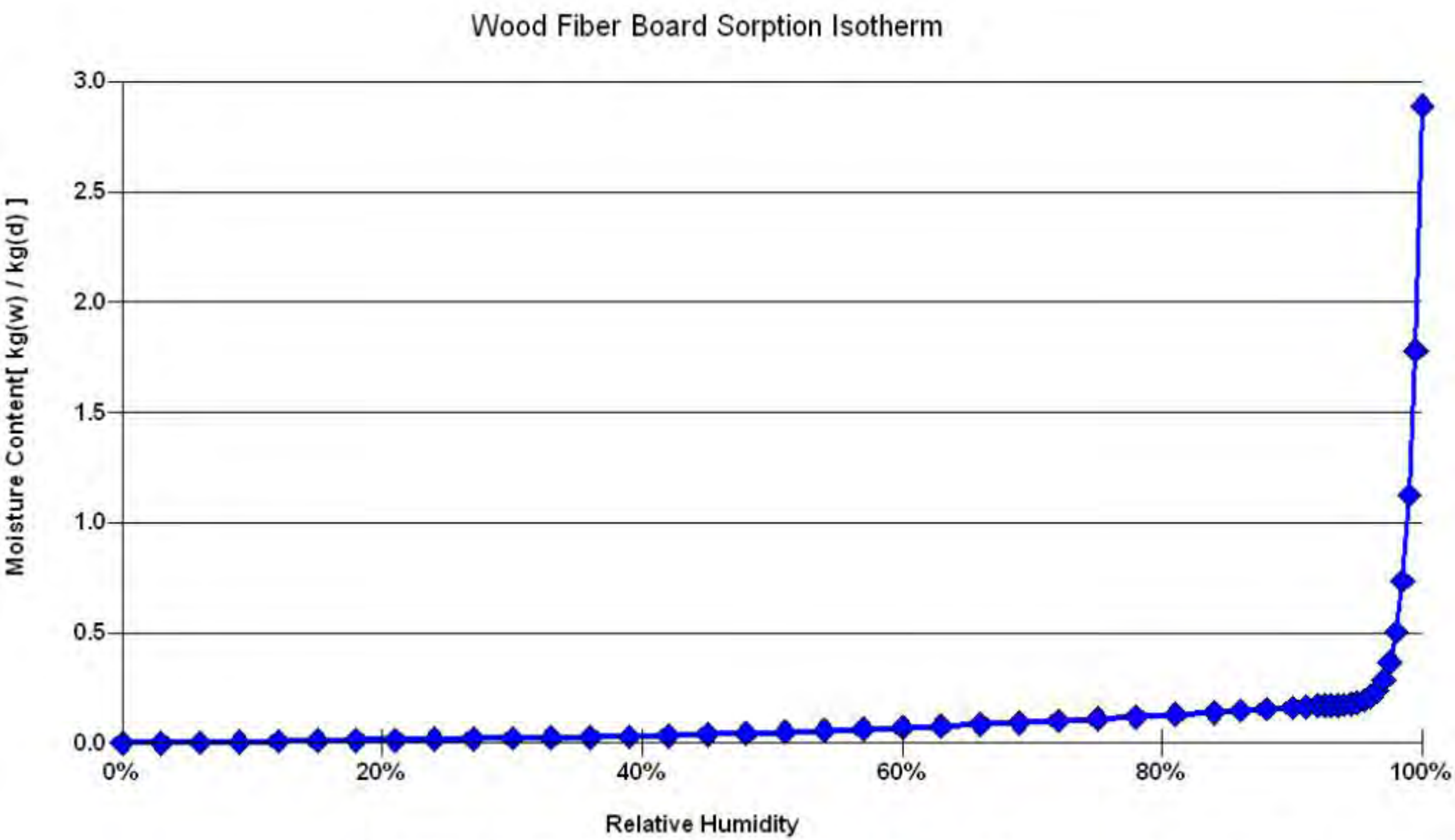


Figure 4: ASHRAE TRP-1018 Wood Fiberboard Sorption/Suction Data

Laboratory Validation (0.8 Lps)

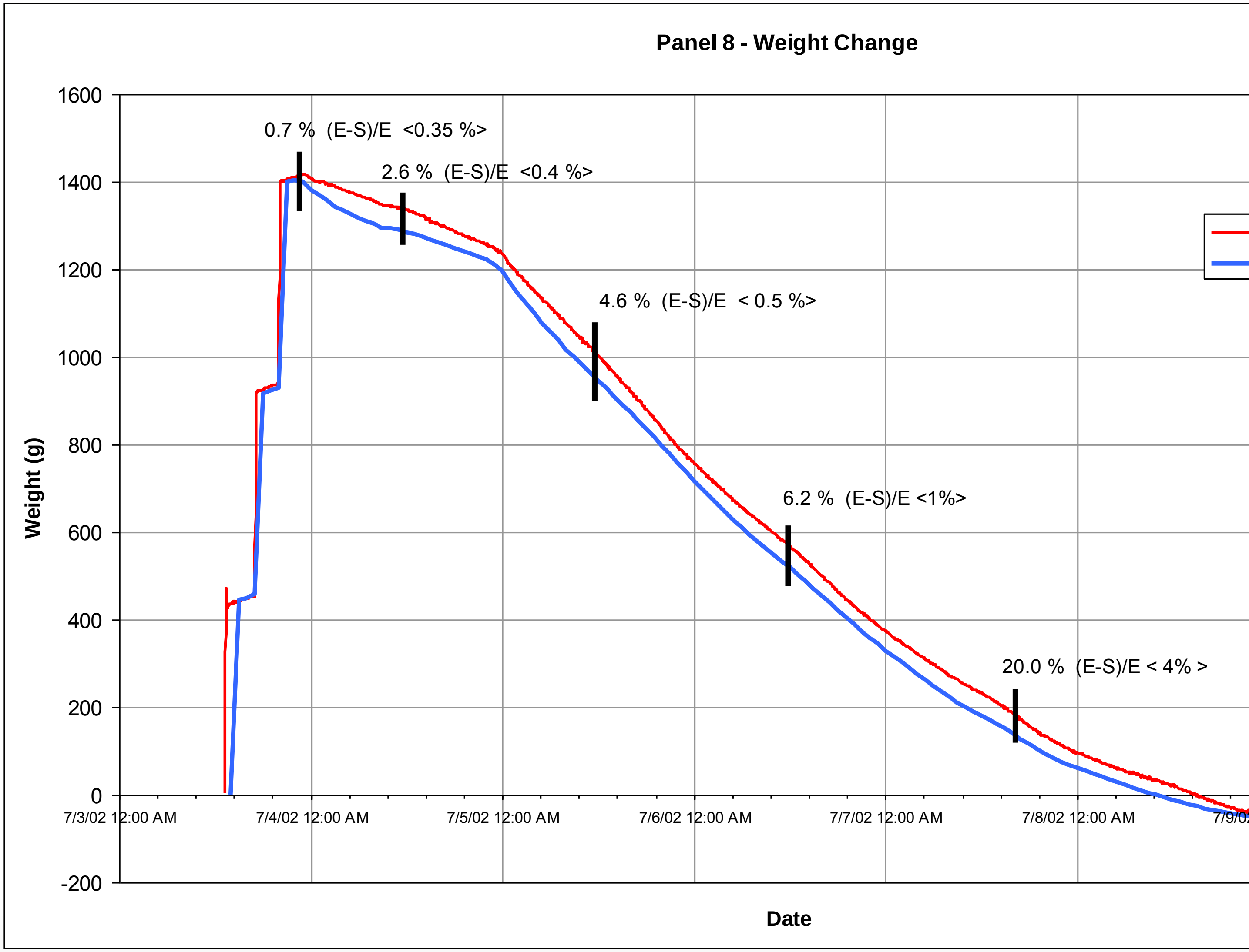


Figure 3. Airflow manifolds connected to test panel on counterbalance system (Burnett et al [2004])

Laboratory Validation (1.6 Lps)

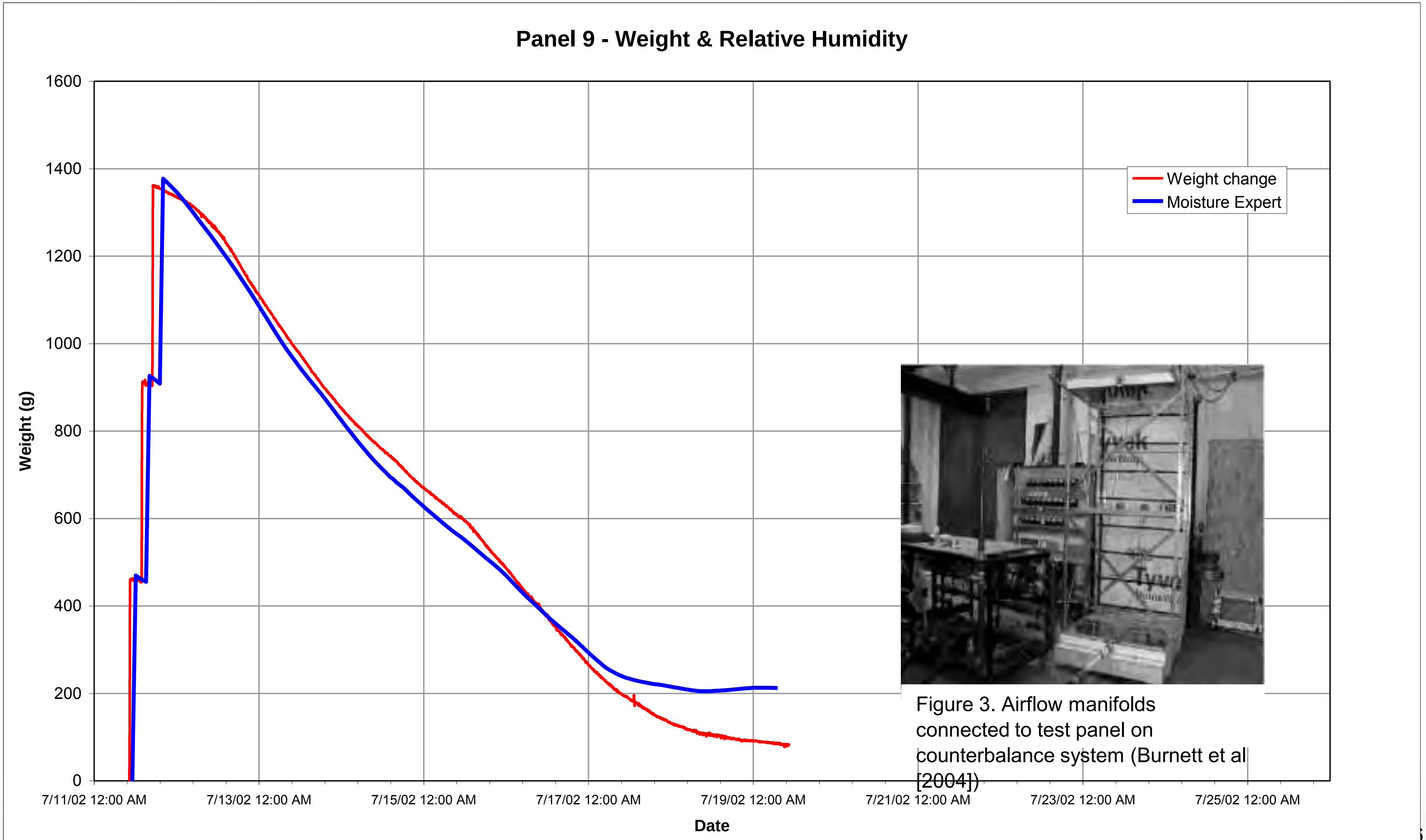
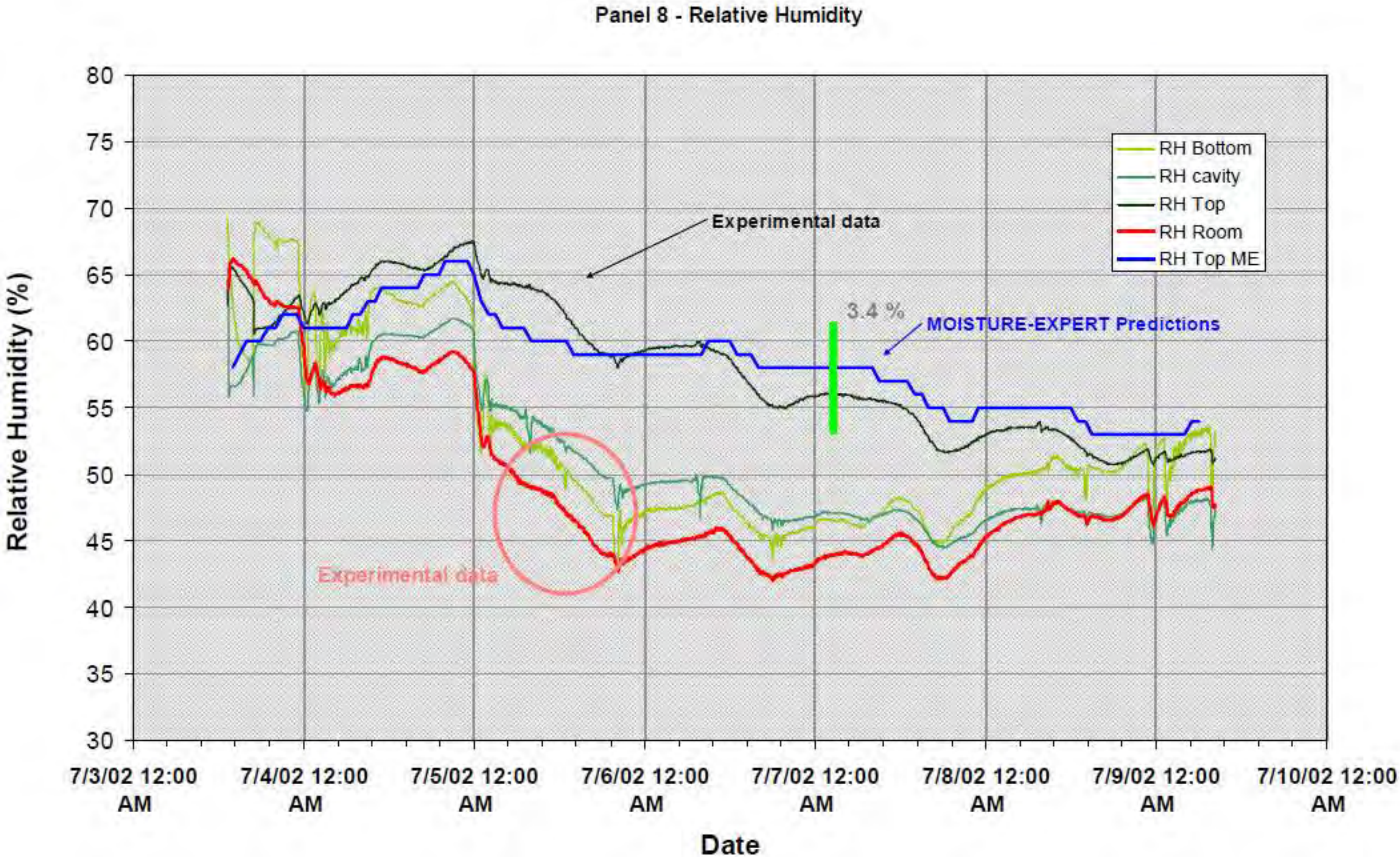
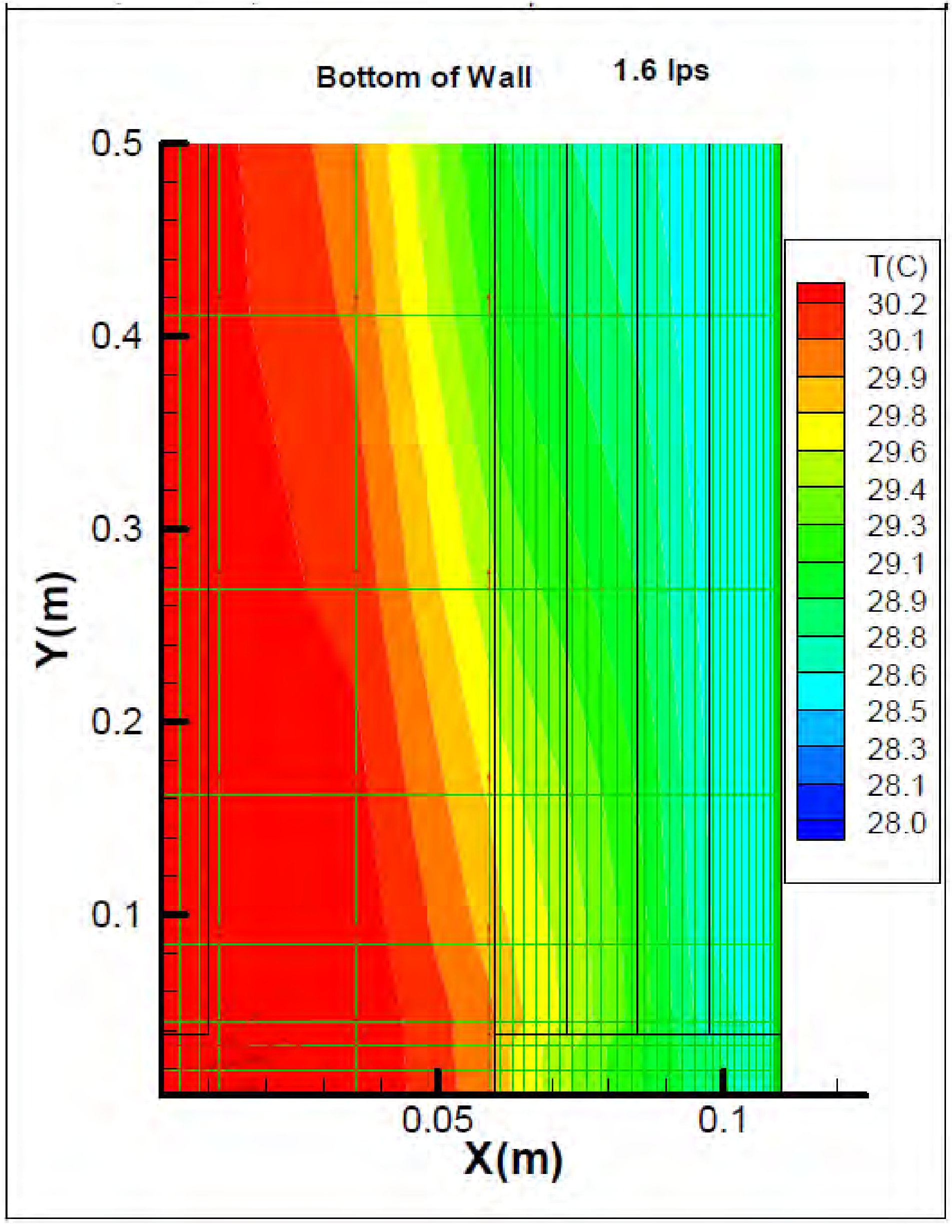


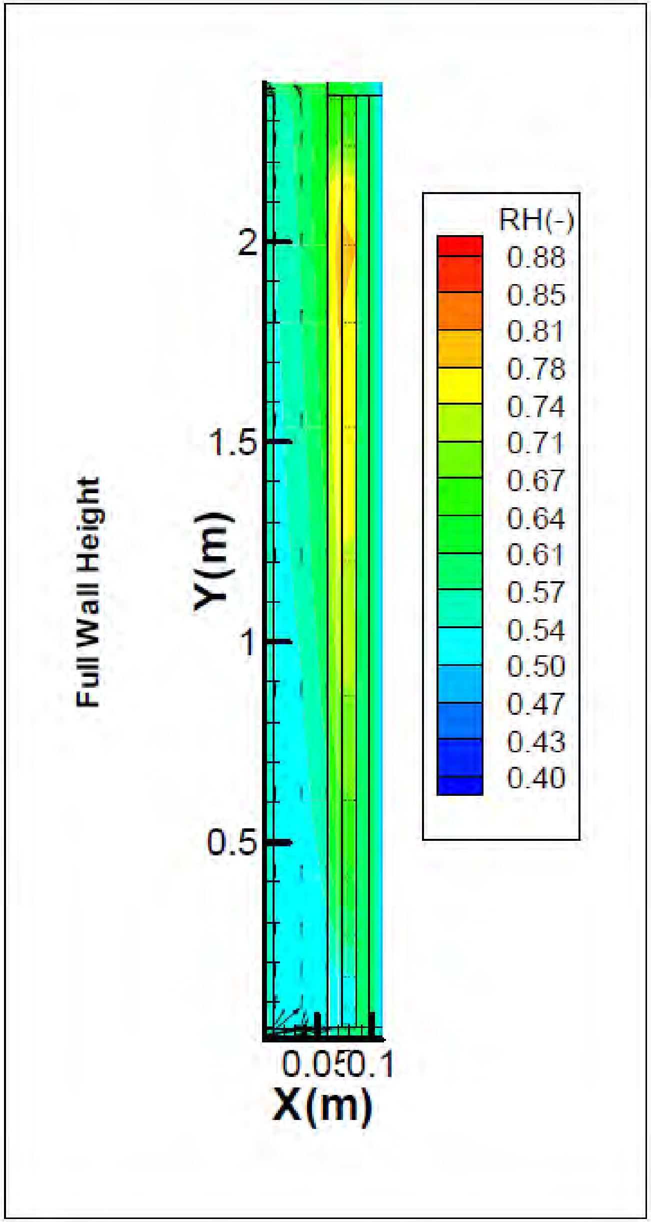
Figure 3. Airflow manifolds connected to test panel on counterbalance system (Burnett et al [2004])

Relative Humidity Comparison

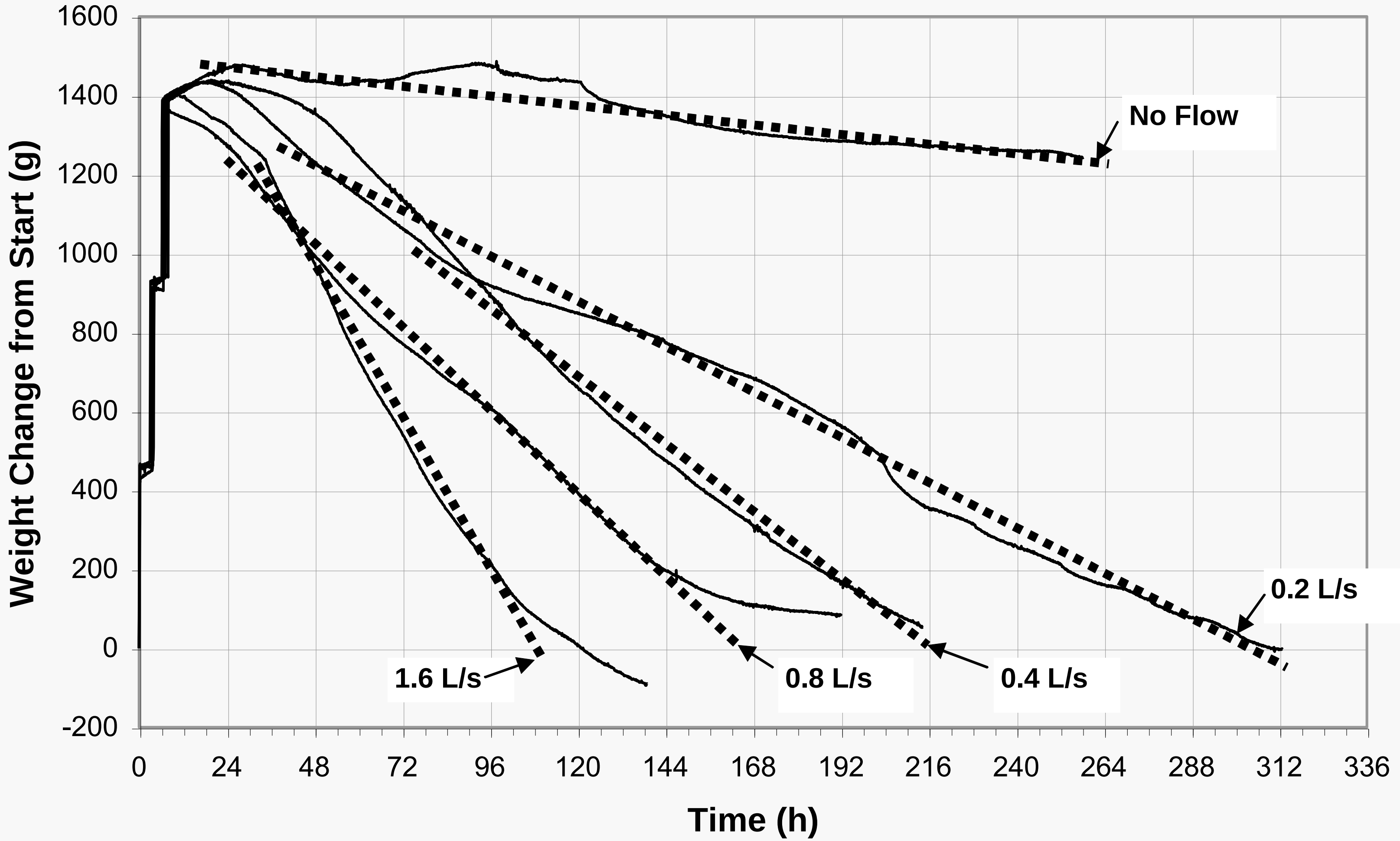


Spatial T & RH Distributions

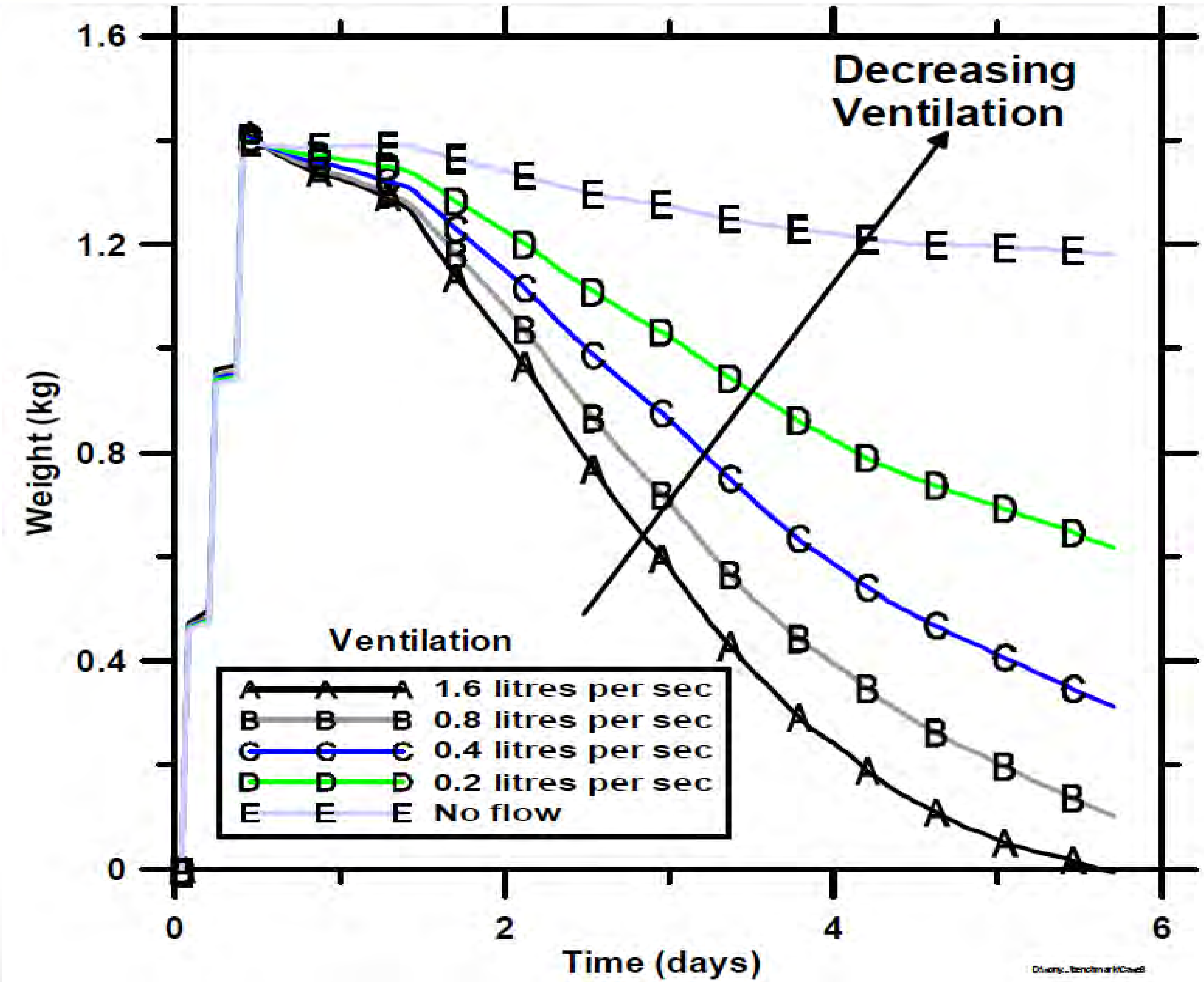




Experimental Drying rates



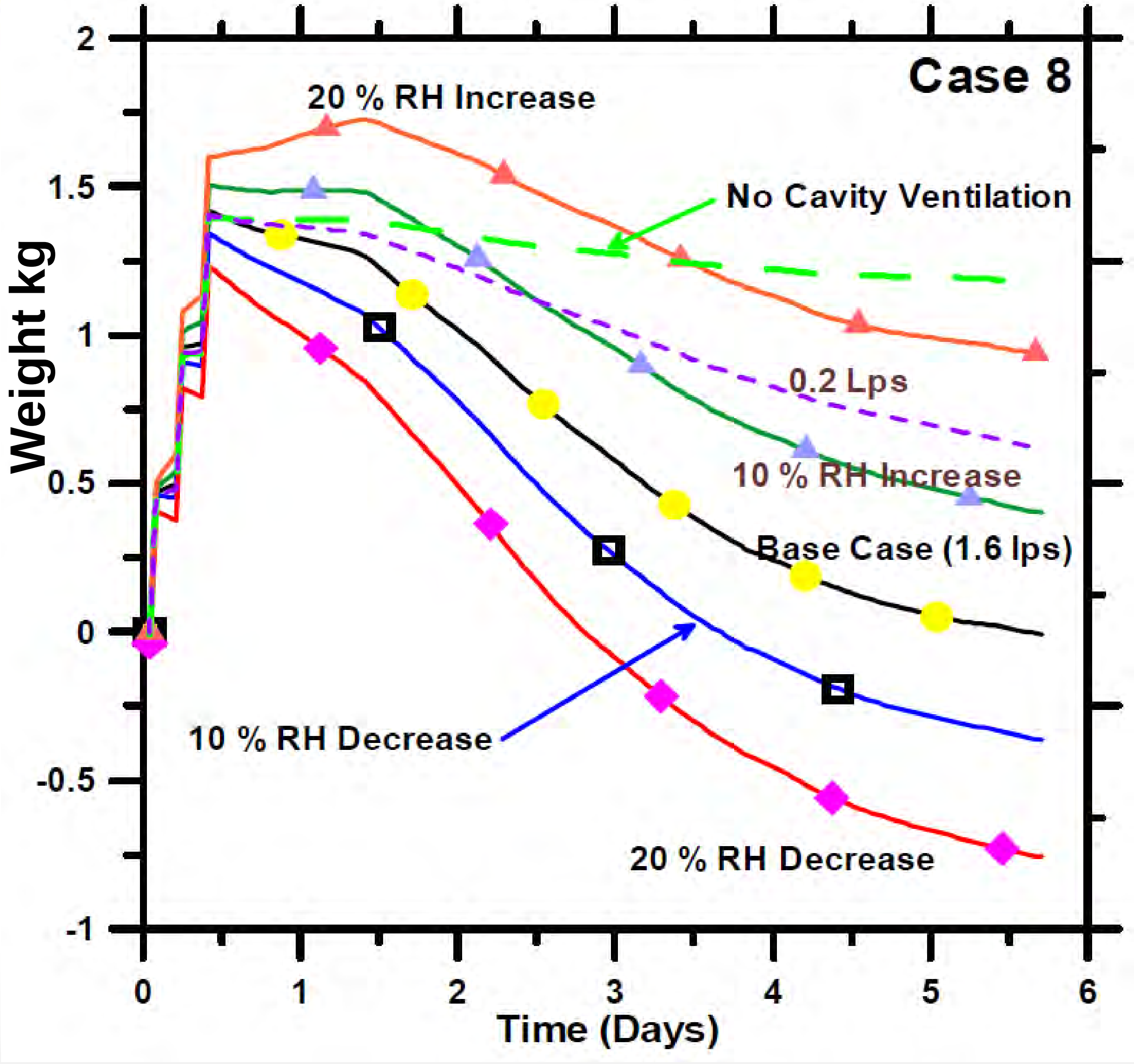
Fix the Experiments…..



When Interior conditions are Kept constant

Expand the experiments (Go Crazy)

Case 1.6 lps



What happens when RH_{in} is 10 %, 20 % Lower ? or higher ?

0.2 lps

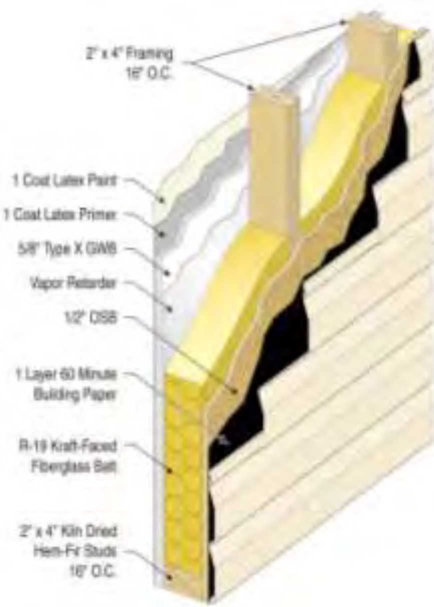
Got arrogant with modeling !!

Even corrected the laboratory data…

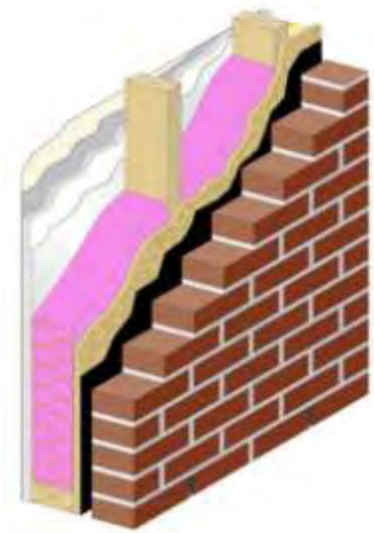
This could mean trouble..!

Field Monitoring

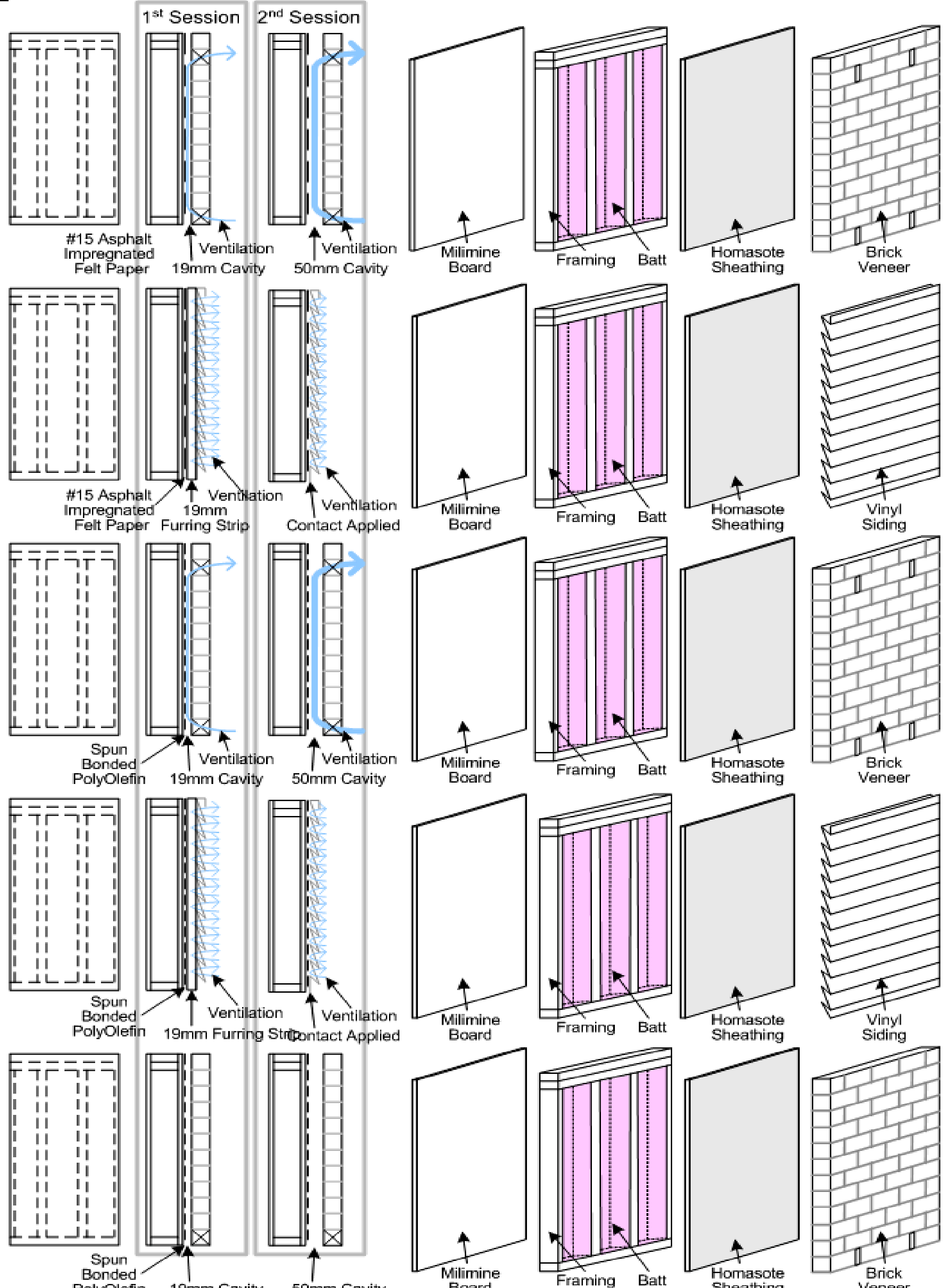
Vinyl Wall



Brick Wall



UNIVERSITY WATERLOO



Brick Veneer
19mm / 50mm Cavity
Ventilated
#15 Asphalt - Impregnated Felt Paper
B19VF / B50VF

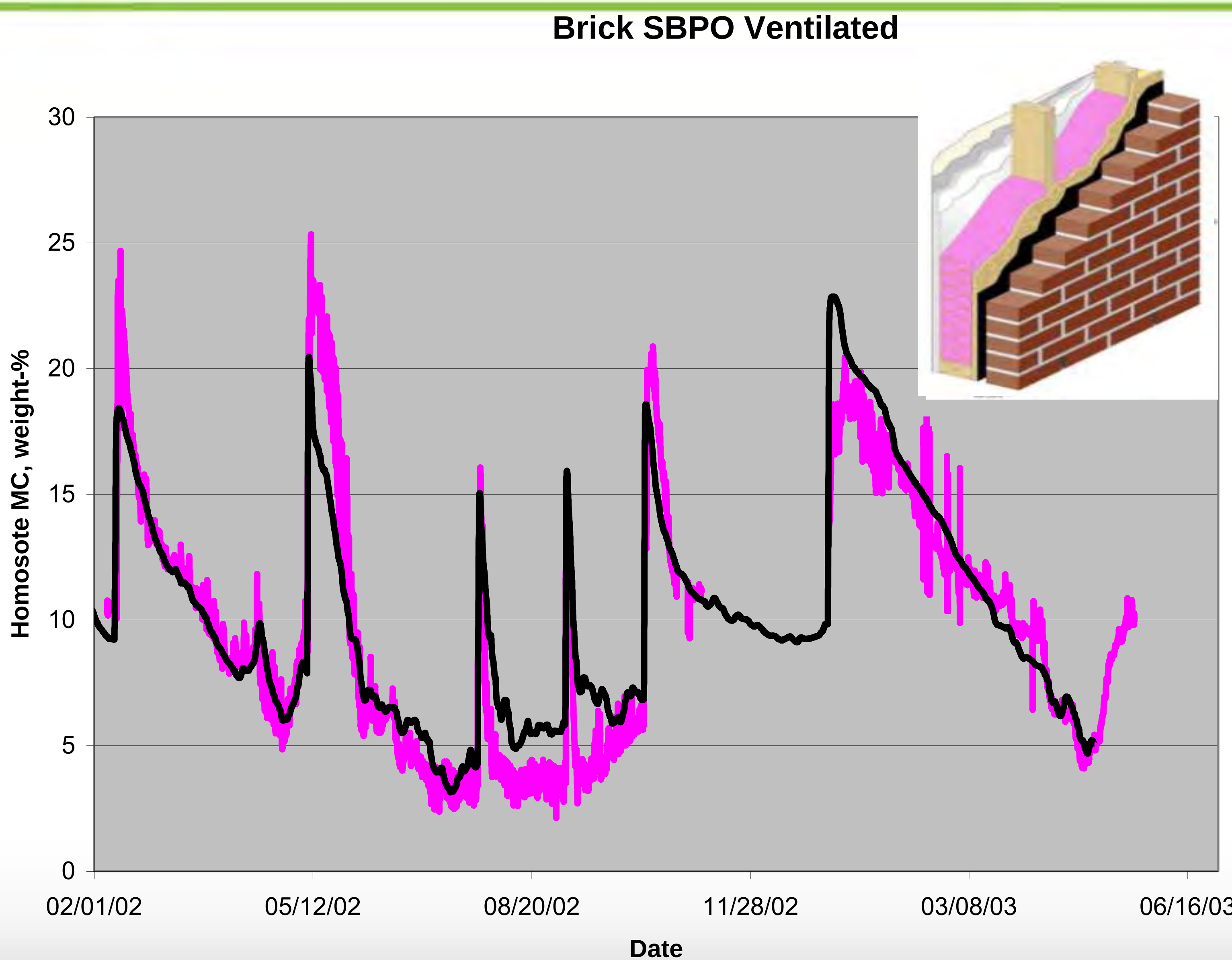
Vinyl Siding
19mm Furring Strips / Contact Applied
Ventilated
#15 Asphalt - Impregnated Felt Paper
V19VF / V0VF

Brick Veneer
19mm / 50mm Cavity
Ventilated
Spun Bonded PolyOlefin
B19VT / B50VT

Vinyl Siding
19mm Furring Strips / Contact Applied
Ventilated
Spun Bonded PolyOlefin
V19VT / V0VT

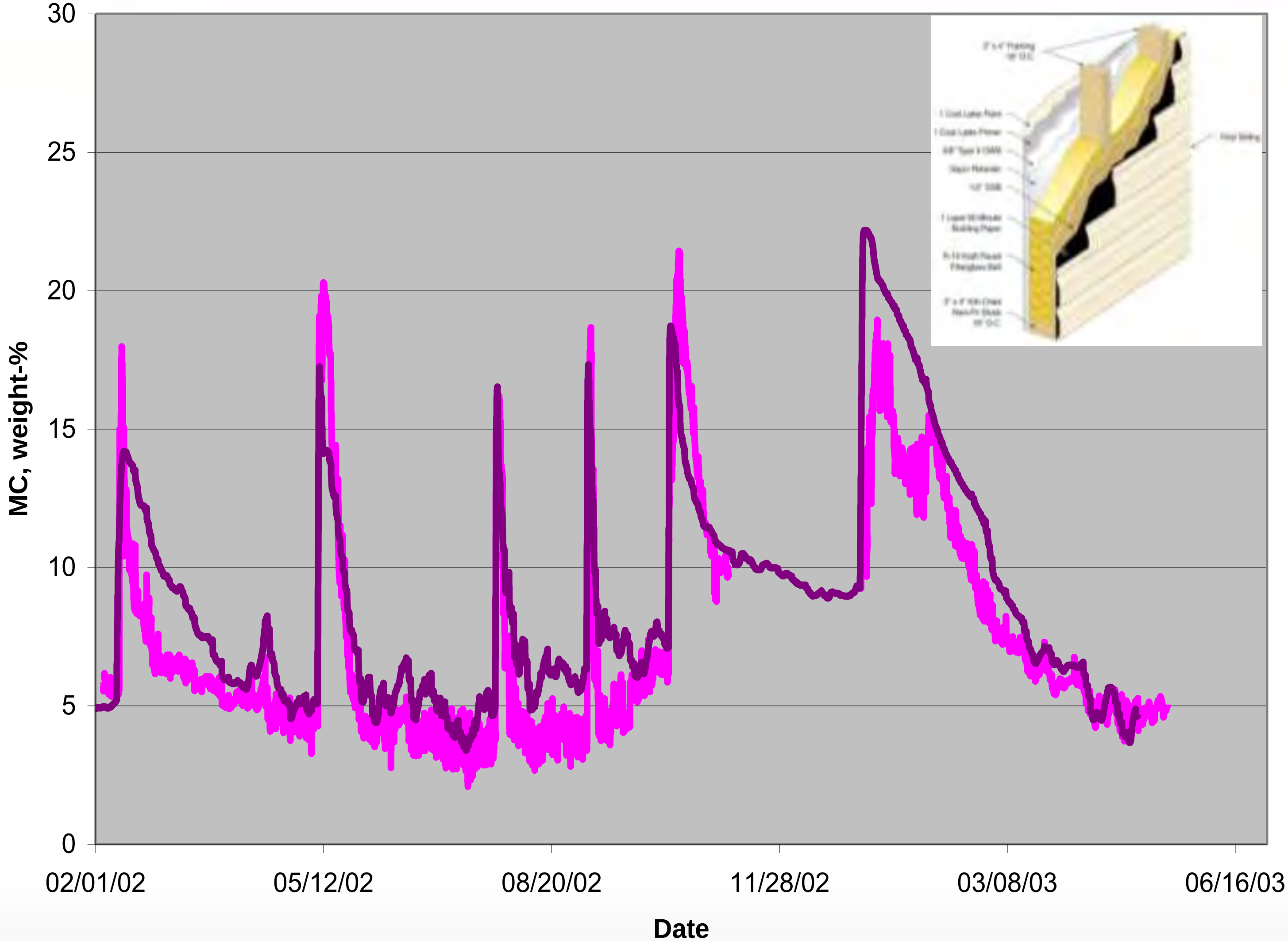
Brick Veneer
19mm / 50mm Cavity
Not Ventilated
Spun Bonded PolyOlefin
B19NT / B50NT

Field Validation at BEGHUT



Field Validation

Vinyl SBPO Ventilated



Validation (LAB + FIELD)

- ME has been validated for Brick & Vinyl Walls
- Excellent Agreement was found
- Complex Processes Involved:
  - Liquid Penetration (Incidental Water)
    - Redistribution of Water
    - Ventilation drying
    - Diffusion Transport

Validation for another site..

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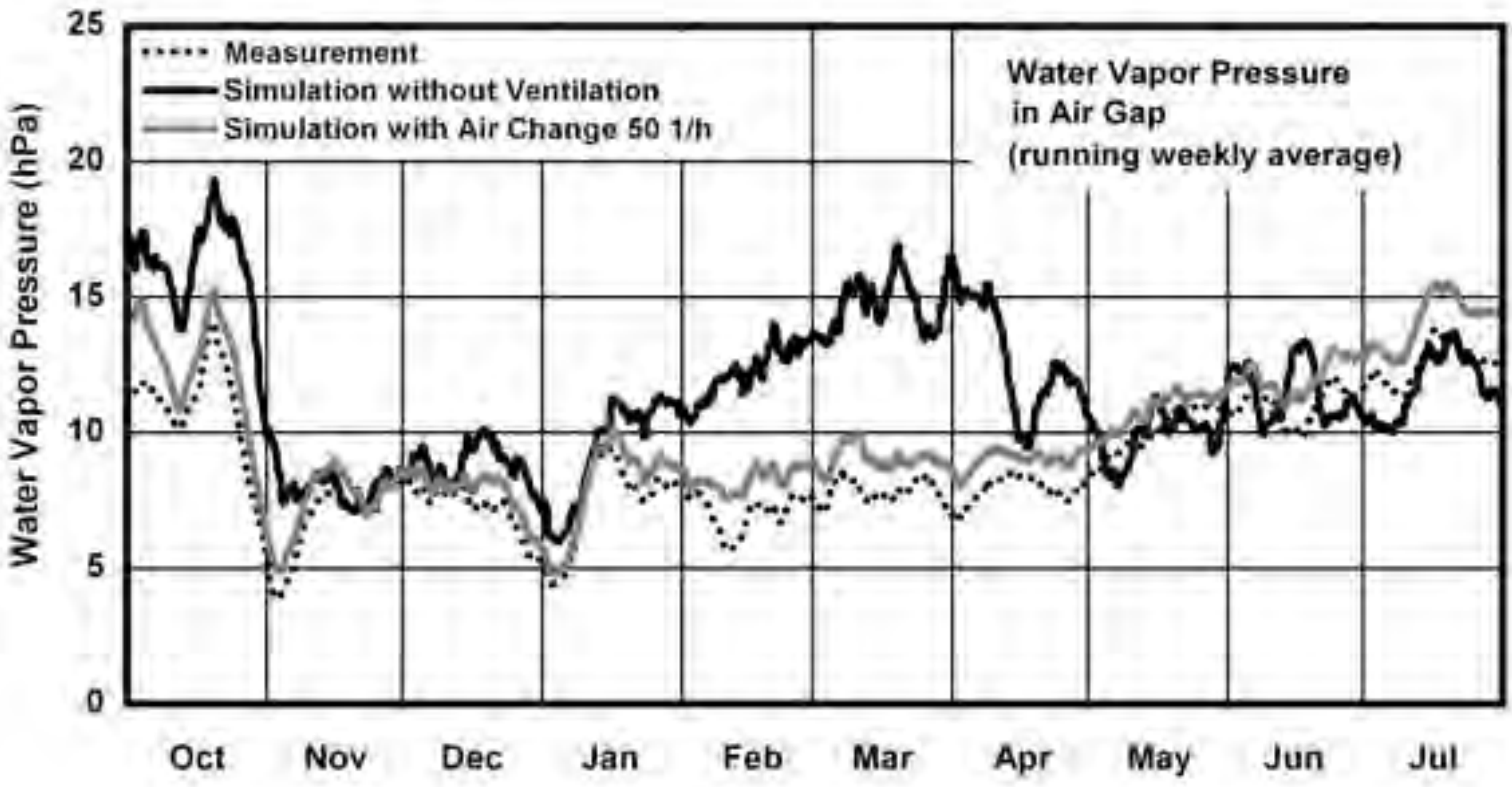
Validation in Puyallup WA

Validation with WUFI



Parametric Analysis

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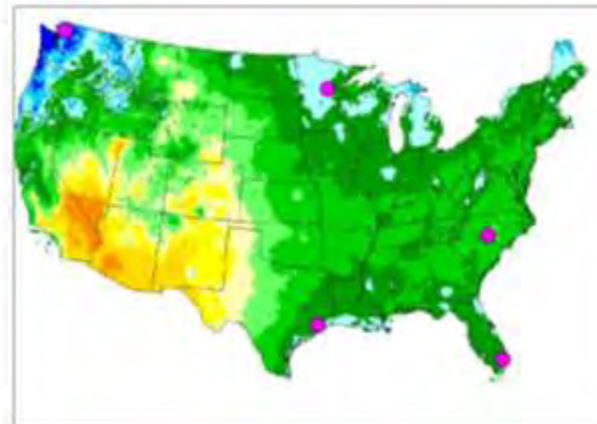
City	Insulation		Ventilation Strategy E-Ventilated F-Vented V-Vinyl B-Brick	Initial Conditions RH 80 % Except OSB (EMC)		Membrane SPBO or felt15#	Retarder
	2x4	2x6					
Minneapolis		x	BE-19mm, BF-19mm VE-19mm, V-0mm	16 %	32 %	SPBO 15 # Felt	4 mil Poly
Seattle		x	BE-19mm, BF-19mm VE-19mm, V-0mm	16 %	32 %	SPBO 15 # Felt	Kraft
Charlotte	x		BE-19mm, BF-19mm VE-19mm, V-0mm	16 %	32 %	SPBO 15 # Felt	None
Houston	x		BE-19mm, BF-19mm VE-19mm, V-0mm	16 %	32 %	SPBO 15 # Felt	None
Miami	x		BE-19mm, BF-19mm VE-19mm, V-0mm	16 %	32 %	SPBO 15 # Felt	None



Interior conditions

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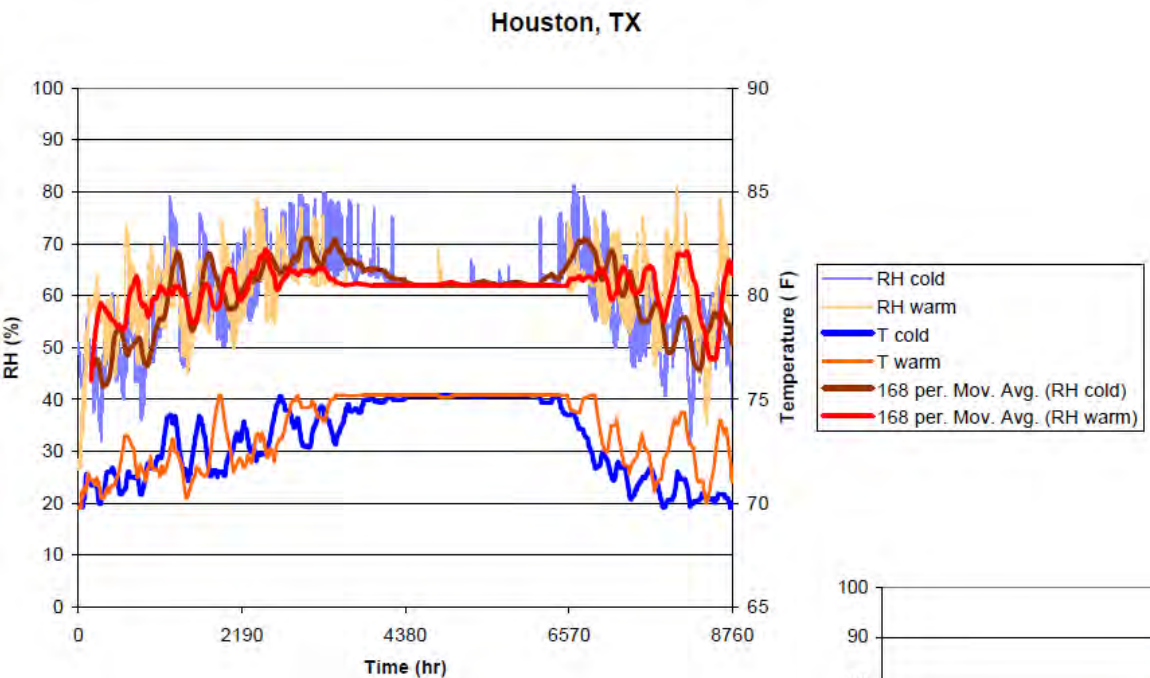
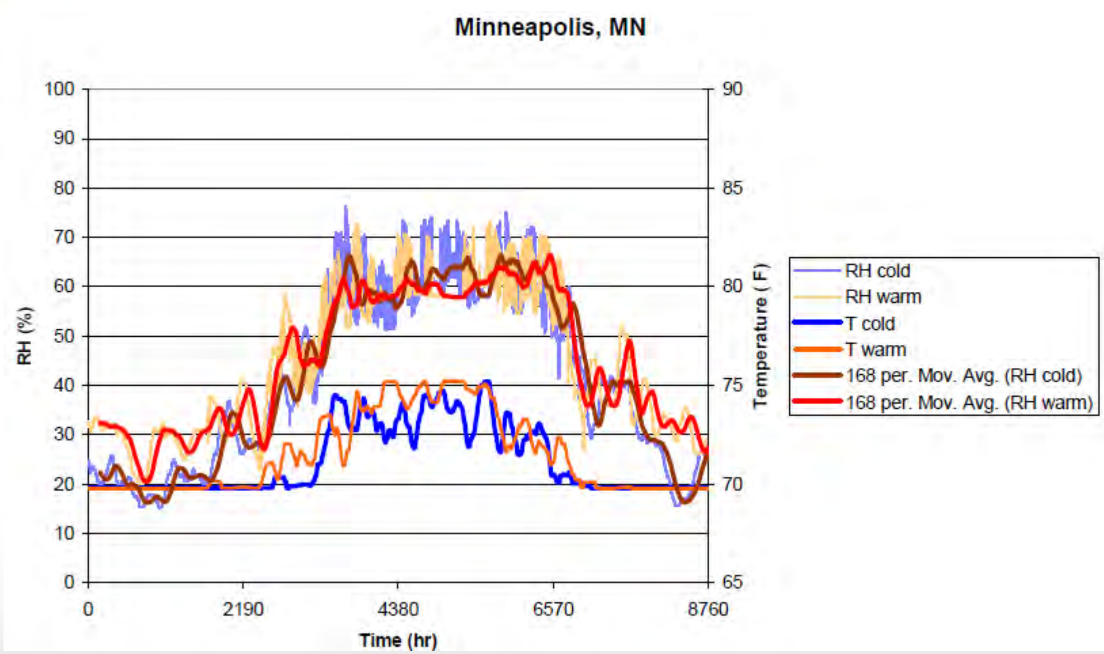


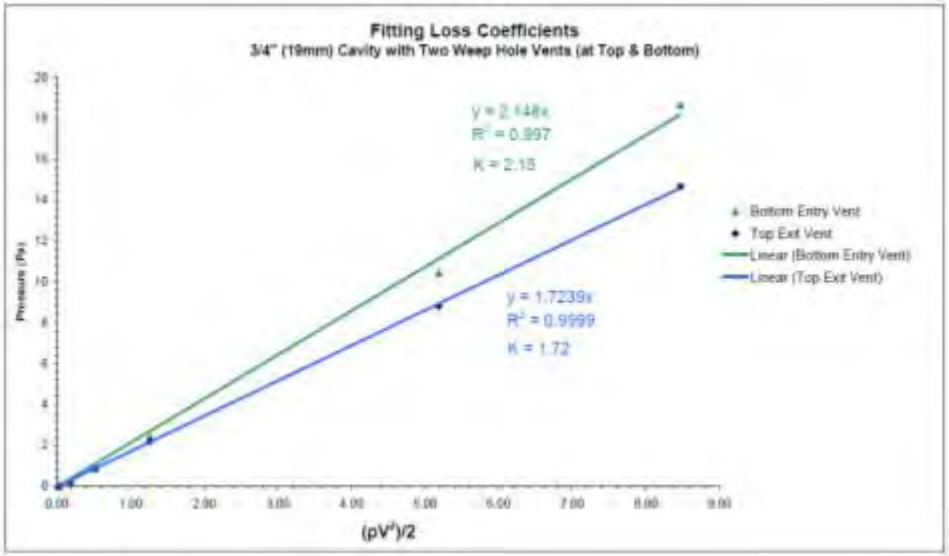


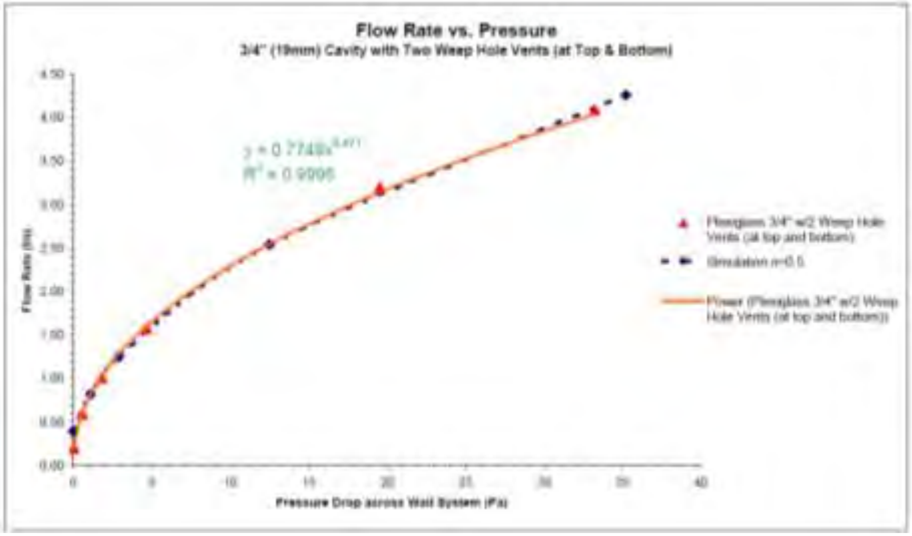
Parametric Analysis

Acronyms

BFV1e : Brick Veneer, Felt Paper, Ventilated Case (Exterior Node in OSB)
BFV1i : Brick Veneer, Felt Paper, Ventilated Case (Interior Node in OSB)
BTV1e : Brick Veneer, Spun Bonded Polyolefin, Ventilated Case (Exterior Node in OSB)
BTV1i : Brick Veneer, Spun Bonded Polyolefin,Ventilated Case (Interior Node in OSB)
BFVte : Brick Veneer, Felt Paper, Vented Case (Exterior Node in OSB)
BFVti : Brick Veneer, Felt Paper, Vented Case (Interior Node in OSB)
BTVte : Brick Veneer, Spun Bonded Polyolefin, Vented Case (Exterior Node in OSB)
BTVti : Brick Veneer, Spun Bonded Polyolefin, Vented Case (Interior Node in OSB)
VFV0e : Vinyl, Felt Paper, Direct Applied Case (Exterior Node in OSB)
VFV0i : Vinyl, Felt Paper, Direct Applied Case (Interior Node in OSB)
VTV0e : Vinyl, Spun Bonded Polyolefin ,Direct Applied Case (Exterior Node in OSB)
VTV0i : Vinyl, Spun Bonded Polyolefin, Direct Applied Case (Interior Node in OSB)
VFV1e : Vinyl, Felt Paper,Ventilated Case (Exterior Node in OSB)
VFV1i : Vinyl, Felt Paper, Ventilated Case (Interior Node in OSB)
VTV1e : Vinyl, Spun Bonded Polyolefin, Ventilated Case (Exterior Node in OSB)
VTV1i : Vinyl, Spun Bonded Polyolefin, Ventilated Case (Interior Node in OSB)
(The interior and exterior nodes refer to the inner or outer most control volume locations that temperature, relative humidity and moisture content were solved by MOISTURE-EXPERT).

Fitting Loss Coefficient





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Results

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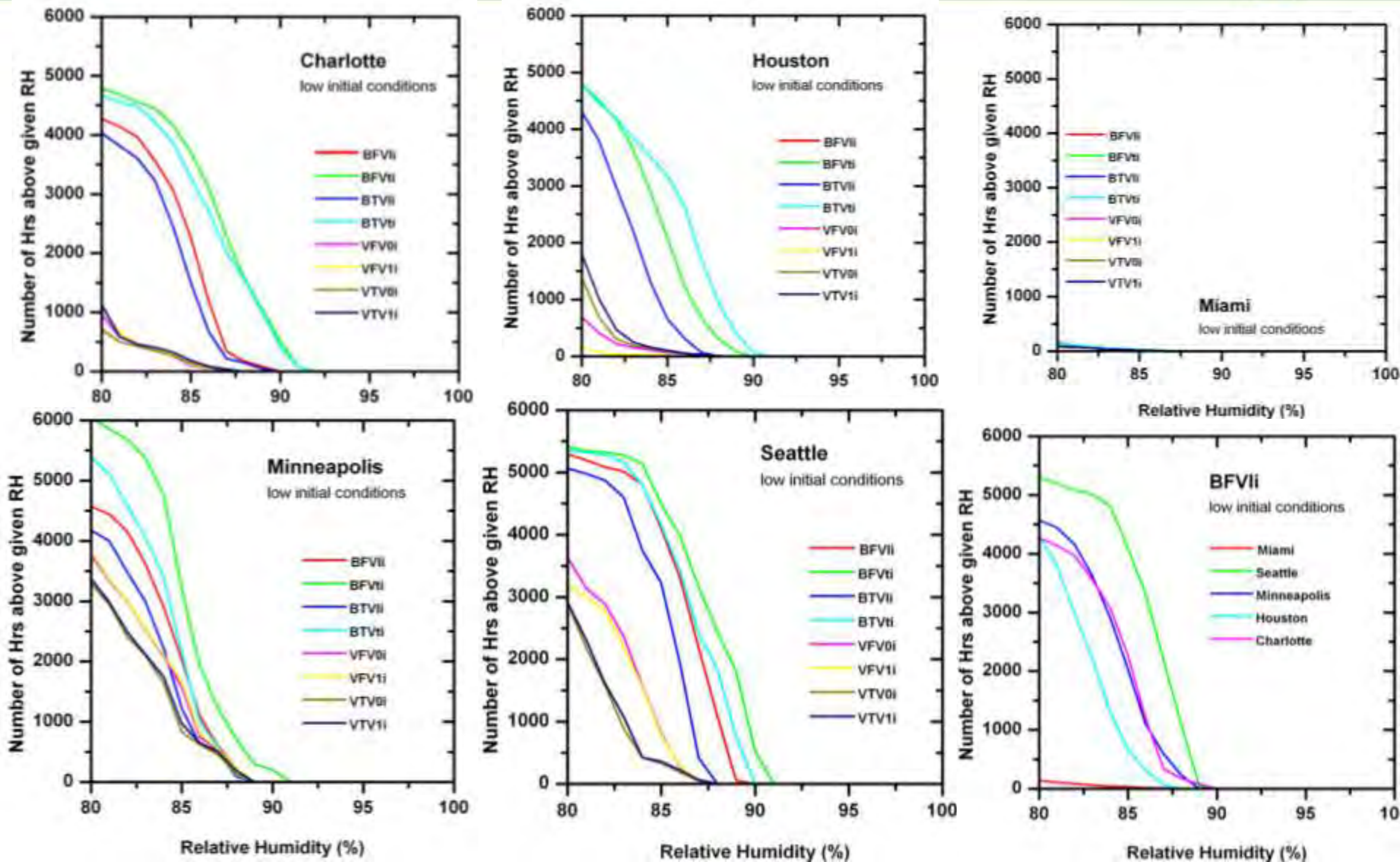
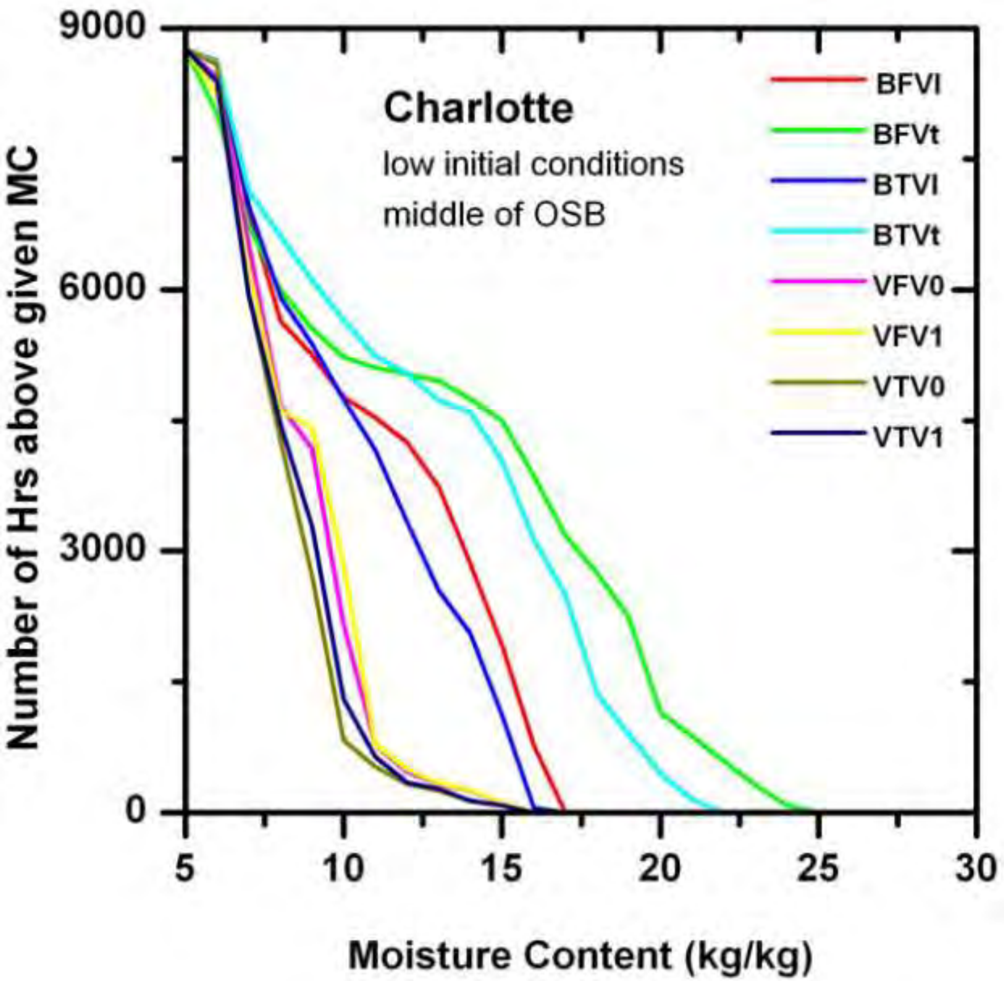
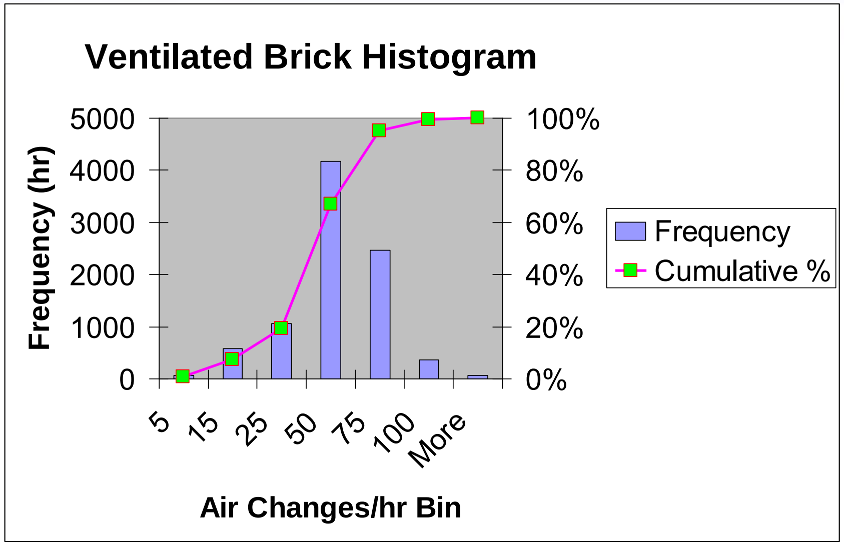
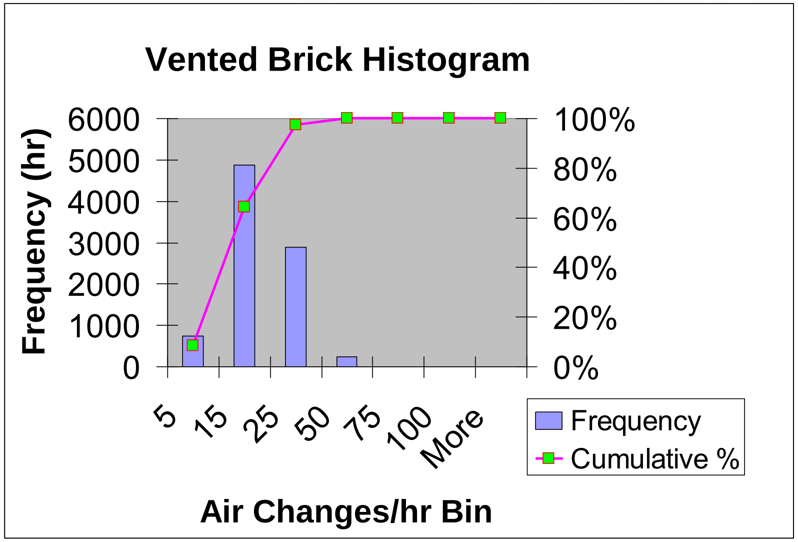


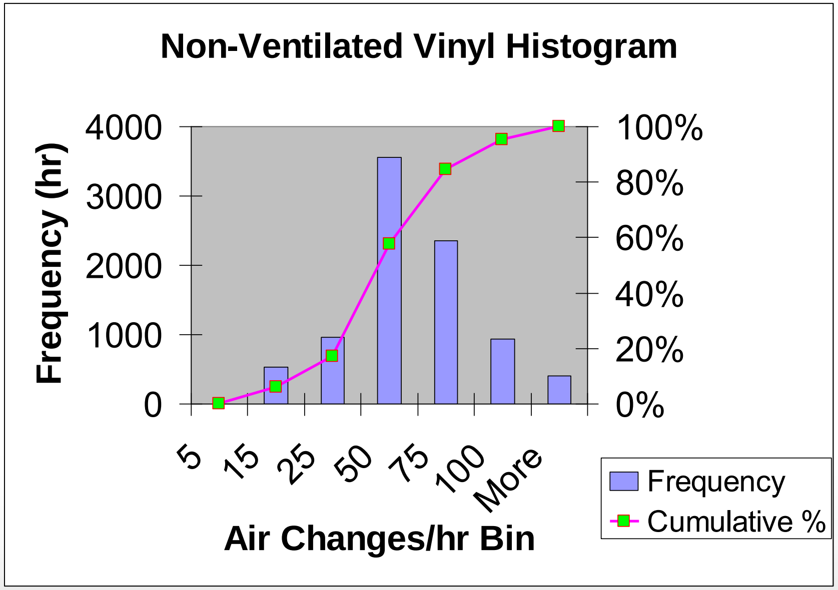
Results

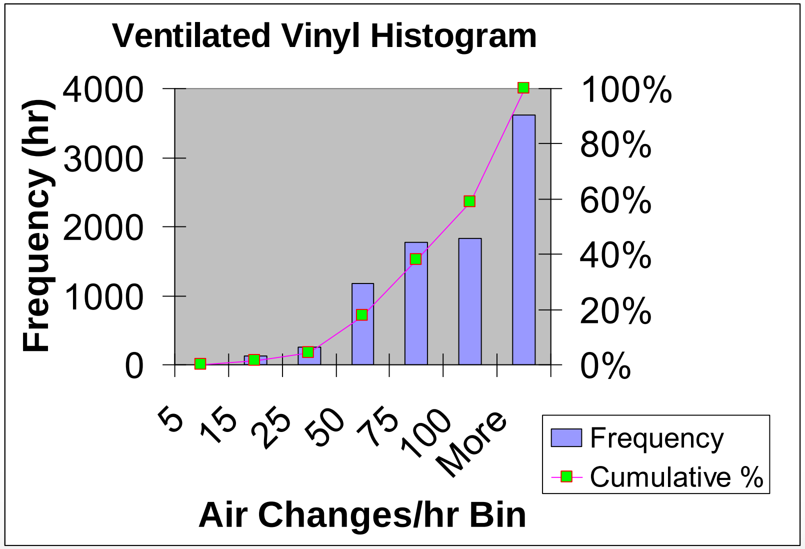

Charlotte
low initial conditions
middle of OSB
BFVI
BFVt
BTVI
BTVt
VFV0
VFV1
VTV0
VTV1
9000
6000
3000
0
5
10
15
20
25
30
Number of Hrs above given MC
Moisture Content (kg/kg)

Air Exchange per Hour (ACH) (Outputs) Seattle

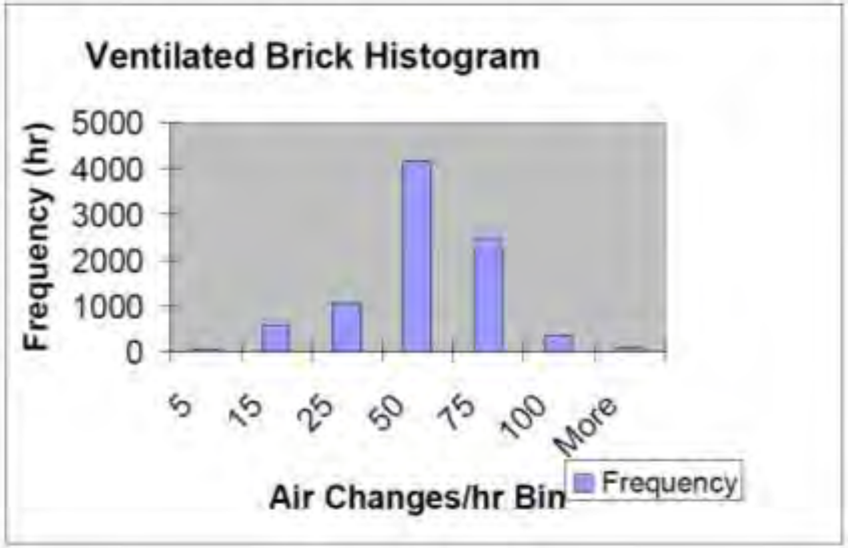


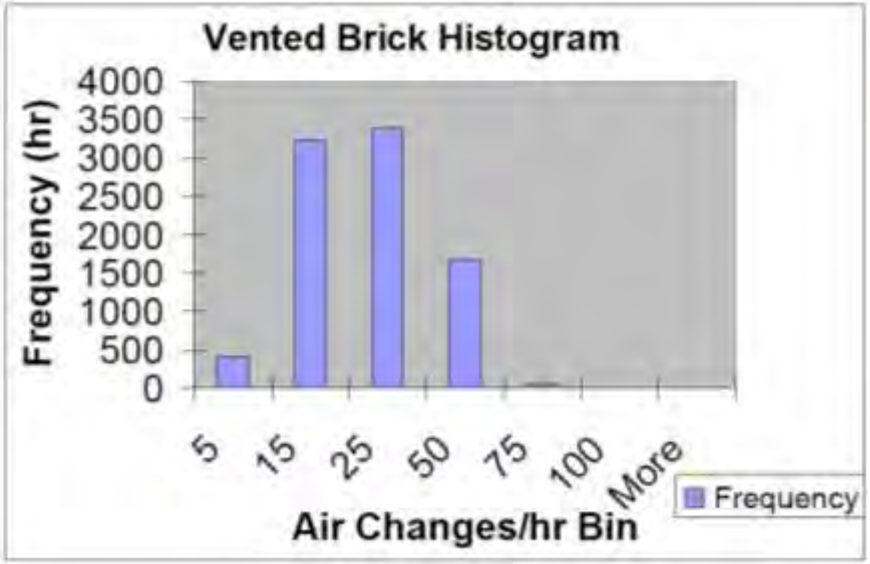


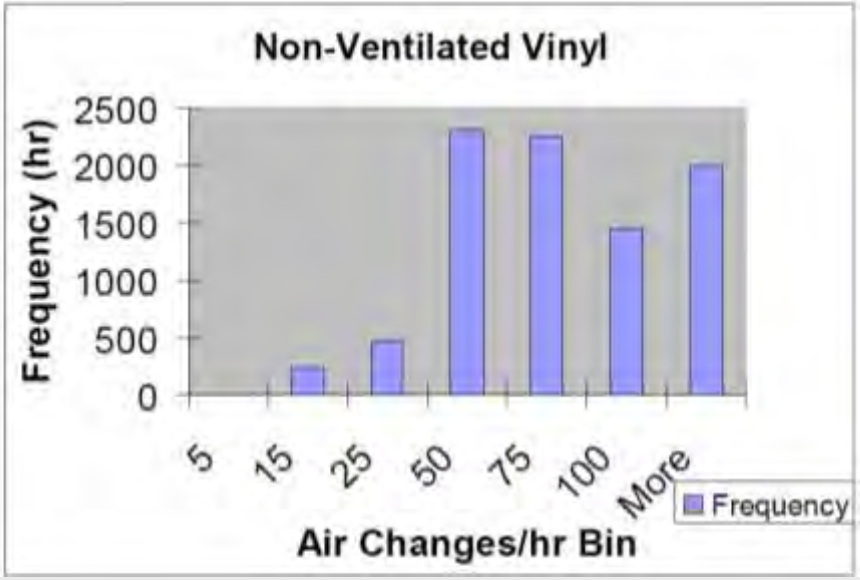


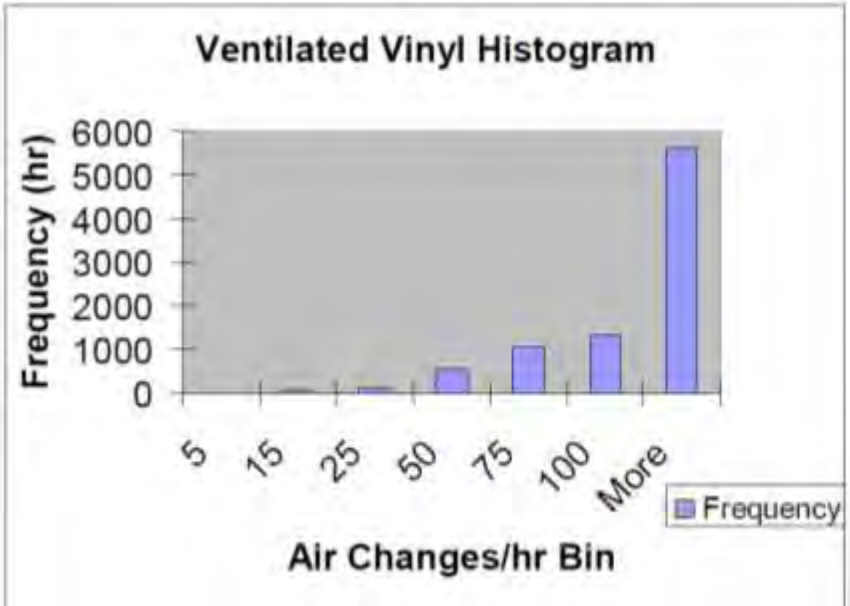


Air Exchange per Hour (ACH) (Outputs) Minneapolis

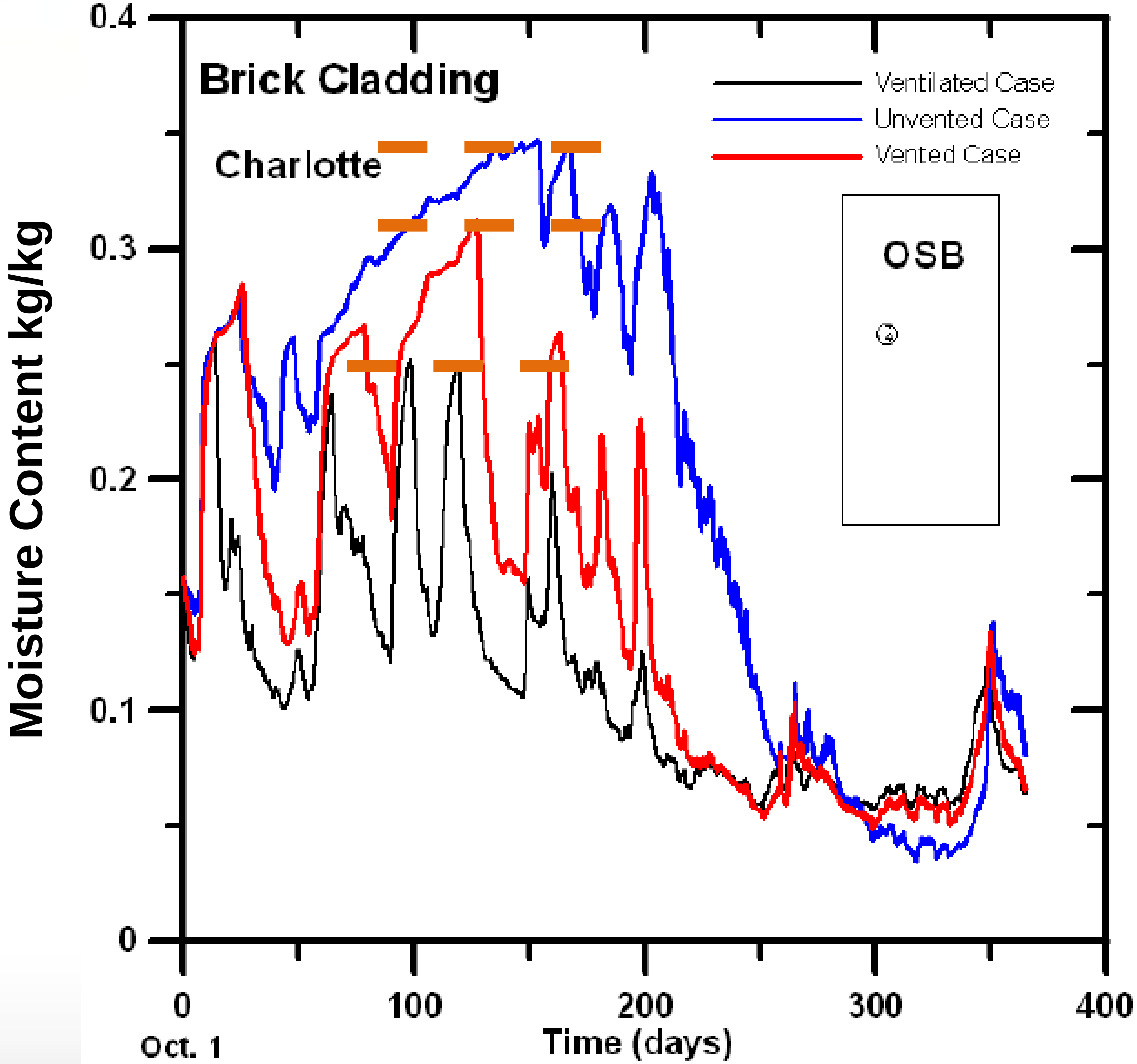








Concept of Safety Factor



SF= 1 % Water Penetration

Ventilation reduces MC_max load by 41 %

Venting reduces MC_max load by 28 %

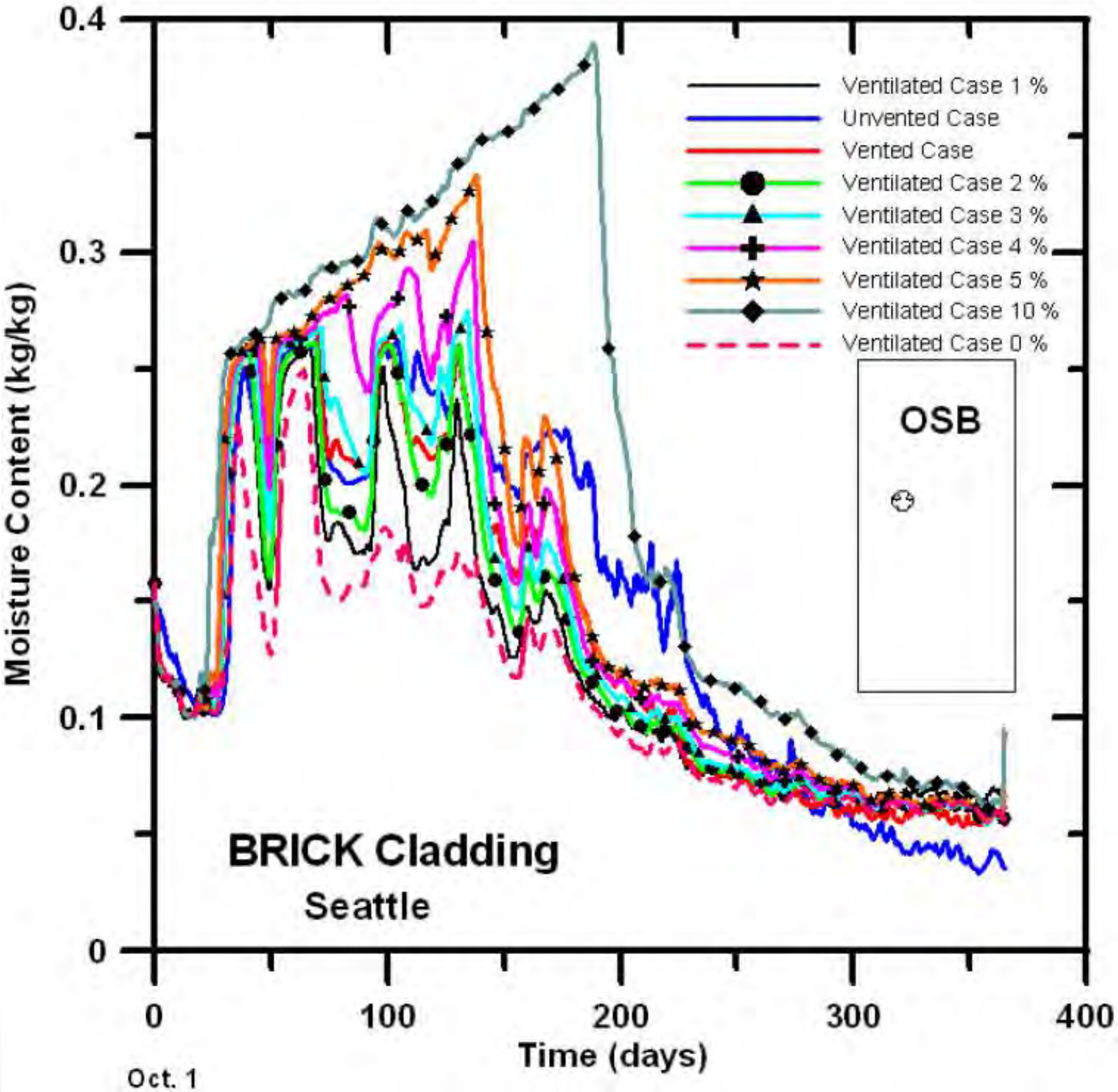
Risk Assessment/Safety Factor

- Safety

Factor of safety of 1 implies no safety at all. Hence some engineers prefer to use a related term, Margin of Safety (MoS) to describe the design parameters. The relation between MoS and FoS is

$$MoS = FoS - 1.$$

Concept of Safety Factor



Seattle

Ventilation can tolerate wetting loads for WDR 2%
For Seattle

Concept of Safety Factor

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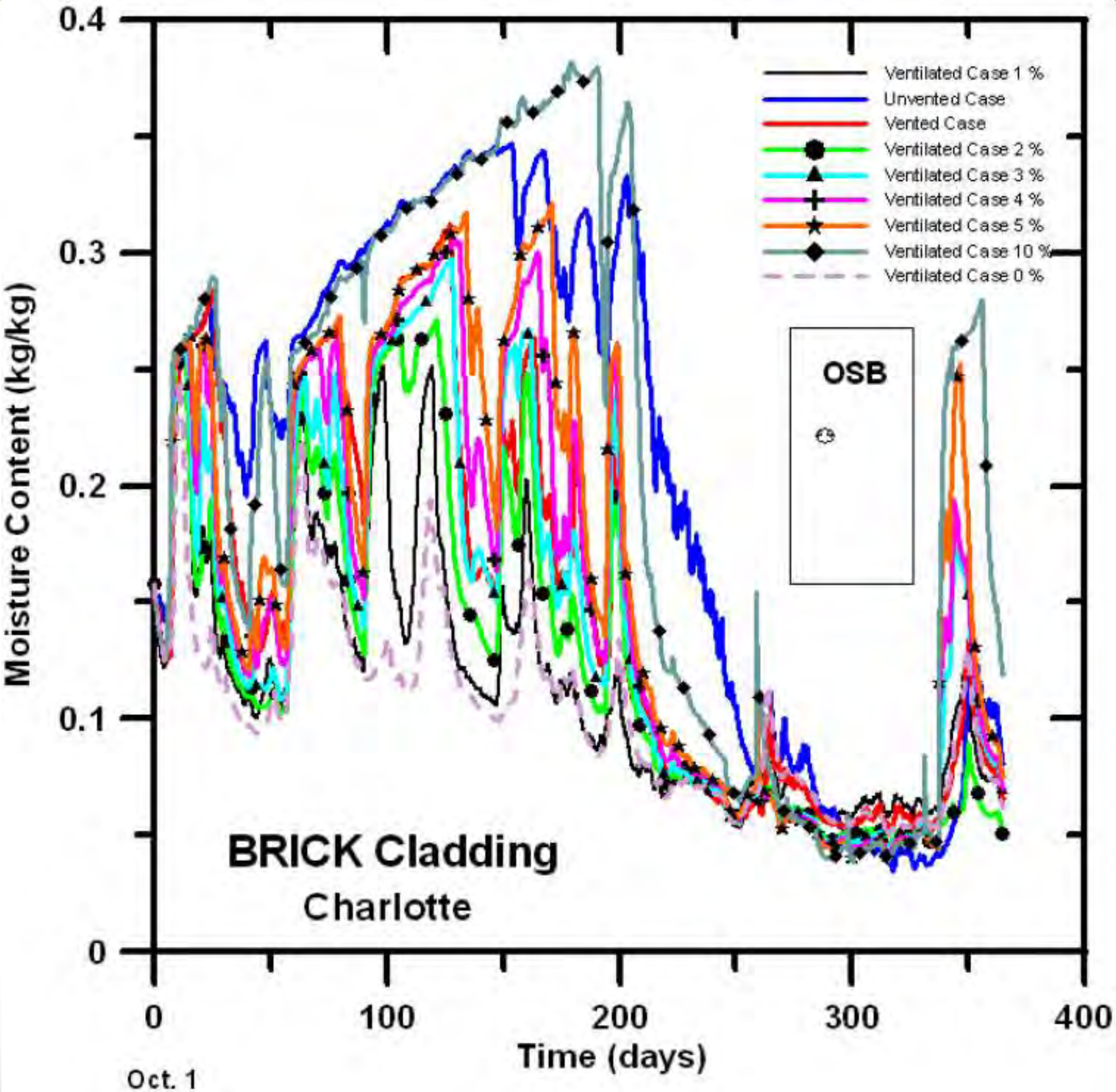

Charlotte

Ventilation can tolerate wetting loads for WDR 3%
For Charlotte

Summary

- Presented a simplified resistance network model that was shown to be sufficient for prediction of air cavity ventilation. Good moisture transport predictions.
- WUFI has included the capability as a design tool to prediction this phenomena
- Two independent field test confirm applicability of new approach
- Mass flows in a cavity are more sensitive to vent dimensions than cavity depth in the 20 to 50 mm range.
- Ventilation is a safety factor close to 2% of current ASHRAE SPC 160 loads (2013)

Conclusions

- Implementation of the ventilation air cavity strategy enhanced the overall drying performance of absorptive cladding wall systems (brick veneer) in all five climates examined in this study.
- In some climates, early fall conditions showed a net increase in moisture accumulation due to the presence of cladding ventilation, but the sheathing was below 10 % moisture content (i.e, well within the safe zone).
- Vented cavity wall systems had substantially less drying potential for the absorptive cladding wall systems when compared to ventilated systems, this was due to less ventilation air flow.

Conclusions

- Non-absorptive wall systems were found to benefit from ventilation , but at a much lesser extent due to inherit leaky structure of the vinyl siding.
- From the parallel simulation activity with two different initial construction moisture conditions, all absorptive cladding wall systems that started with a moisture content of the OSB at 32 %, had difficulty in drying within (4 weeks to below 80 %).
- Problems did exist for the location of Seattle to dry within an acceptable time for the vented system for brick clad walls.

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Conclusions

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- The effective ventilation rate behind the cladding depended on both the wall system and the exterior climate. In Miami and Minneapolis, high winds and temperature gradients allowed large ventilation air changes in the walls. Cladding ventilation rates ranged between 0 to 150 air changes per hour.
- The results showed that sheathing membranes for climates like Minneapolis (cold) did show some influence even though this was secondary to the choice of the ventilation strategy.

Conclusions

- The higher the IC moisture, the more influence of the choice of the sheathing membranes. In most climates, in some period of year the 15 # felt performed better and in other period the SBPO membrane. These conclusions are based on using the OSB as the sheathing of the wall.
- Additional analysis has conclusively demonstrated the superior performance of cladding ventilation versus vented and unvented strategies.
- The beneficial effects of air cavity ventilation seem to be directly dependent on climate.

Call to Professors/Farmers

UnKnowns: Limited Understanding air flows in cases with fluctuating wind pressures and infiltration paths.

The ventilation rates need to be measured and reported that at least driven by "realworld" fluctuating wind and stack pressures.

Simple software apps for a wide range of geometries to produce ACH in air cavities..

Smart Air Cavity Designs

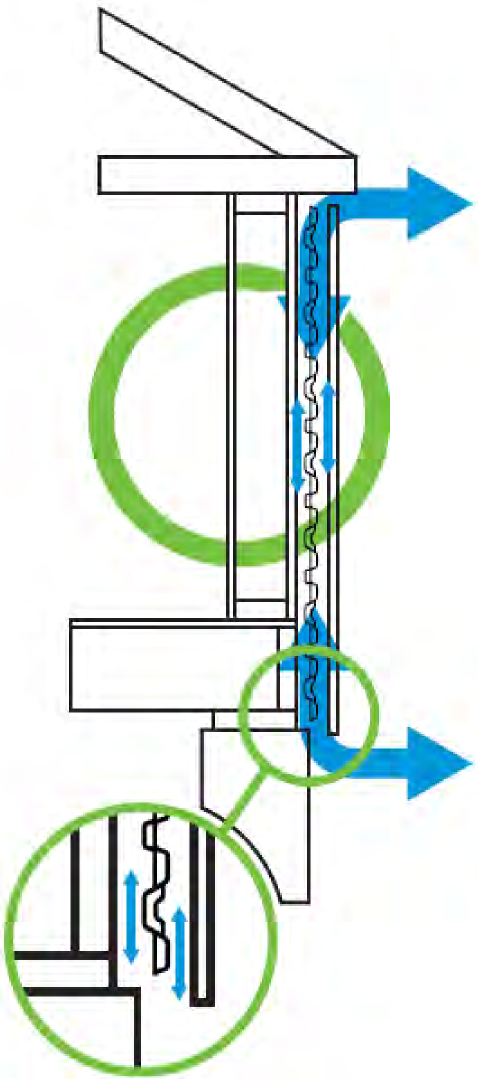
In 2007 approached by Manufacturer of innovative product… a dimpled sheet of polyethylene (John & I)

" Let's use it as a ventilated Rainscreen and yes in ***C****old Climates and why not everywhere else ?"*

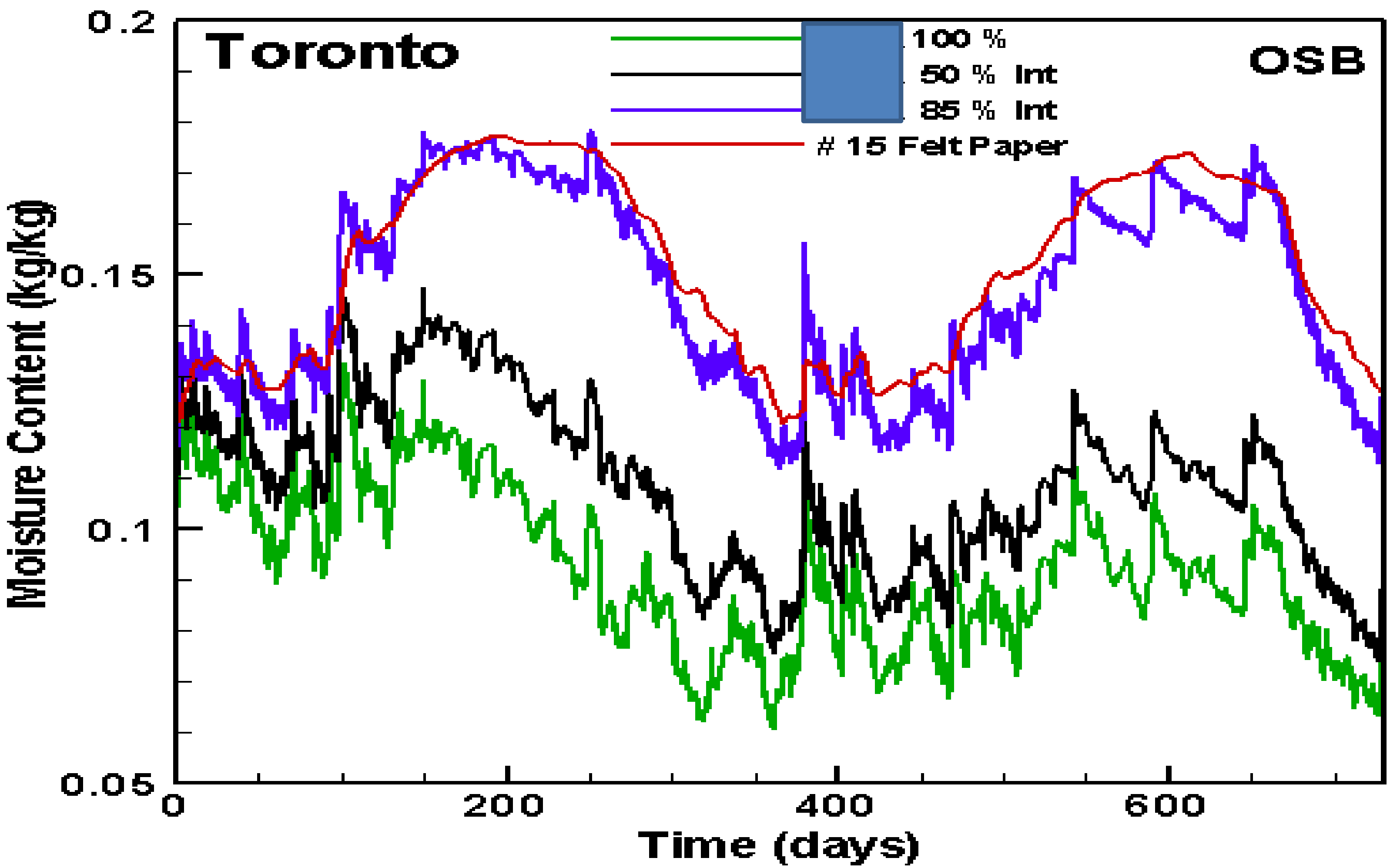
- **Understand drainage, air flow resistance of wall system with Dimple PE sheet and Drying tests performed by J. Straube**

- **Calibrated model for flow and Validated drying model with good results**

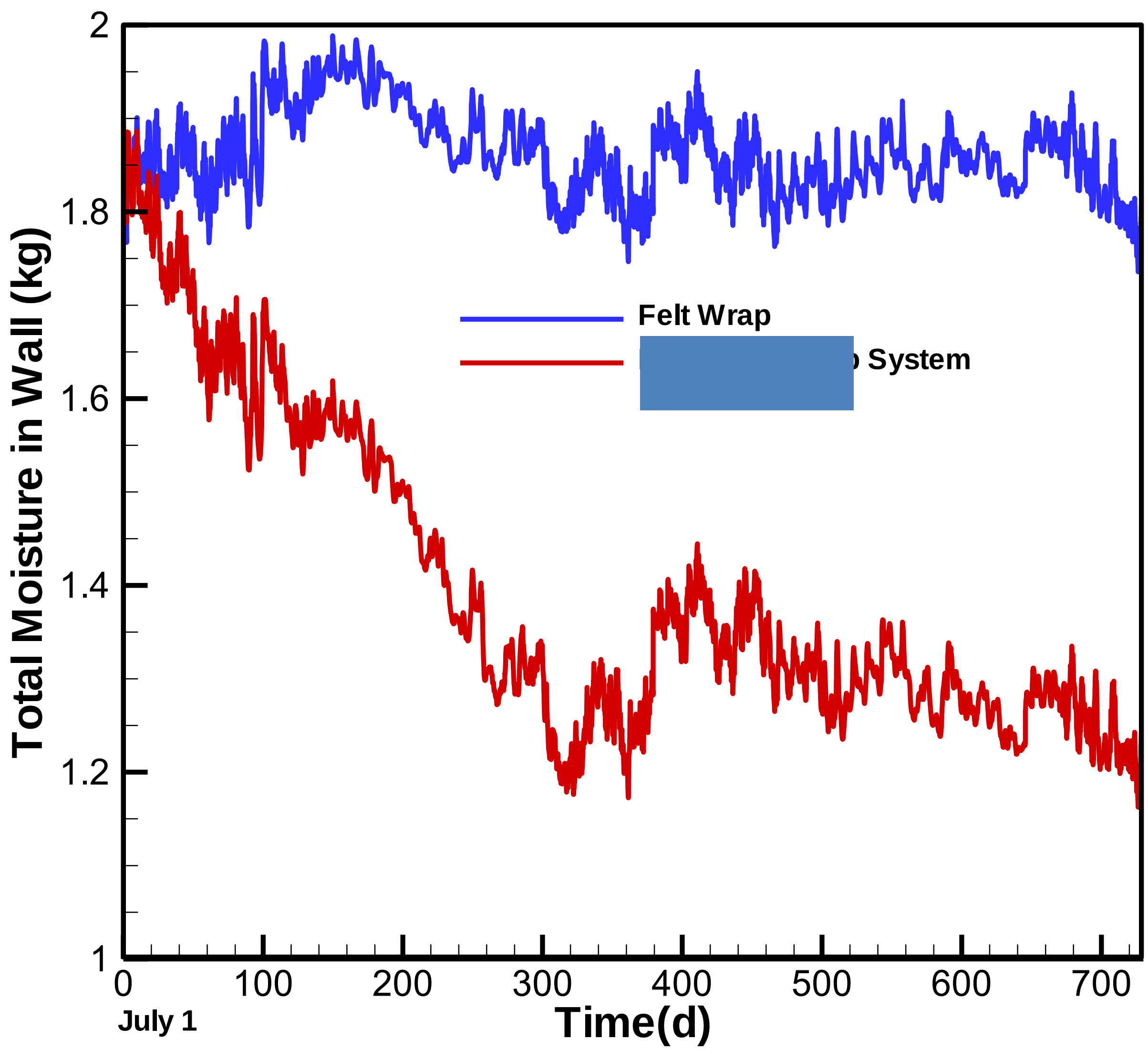
Smart Air Cavity Designs



Modeling Analysis

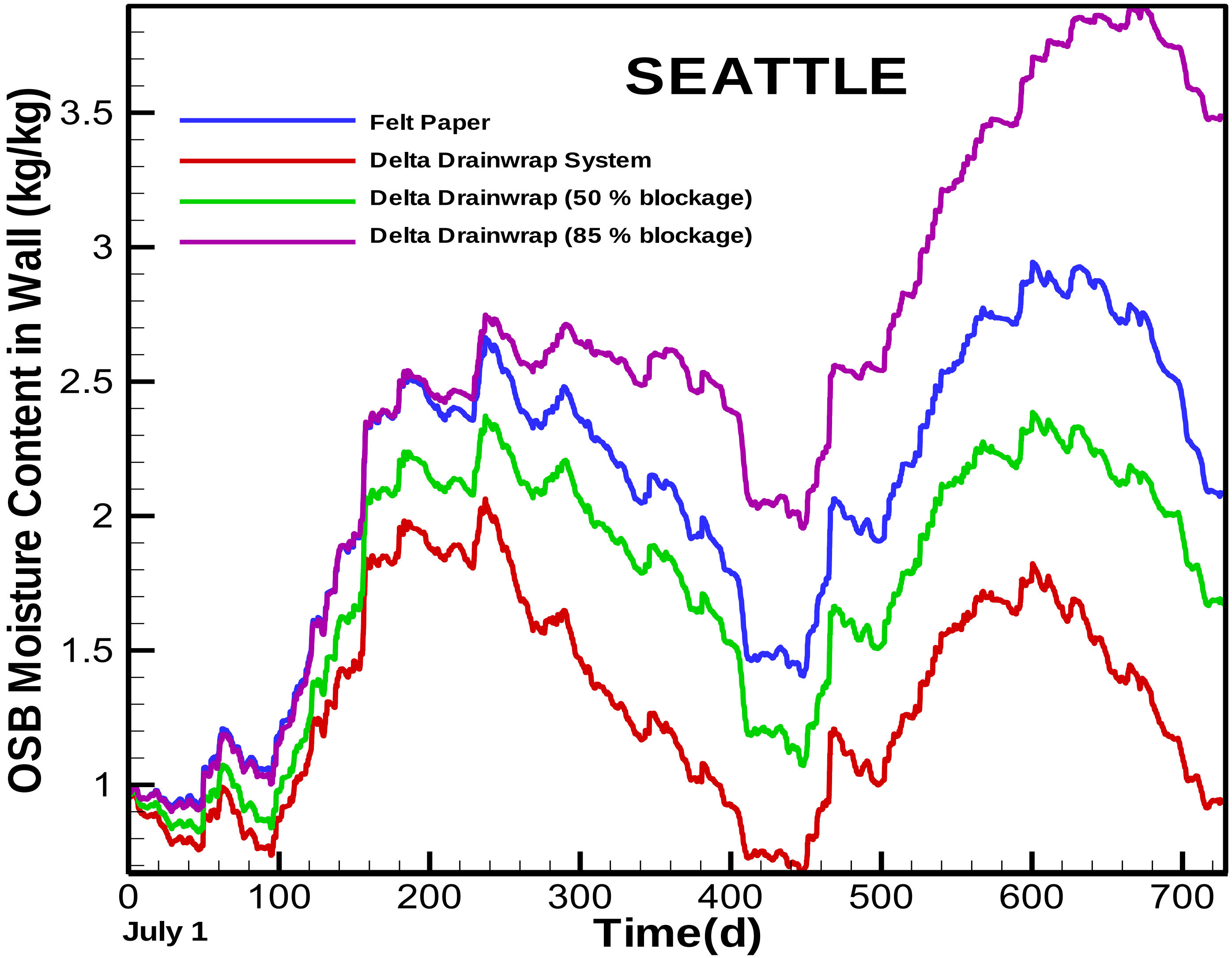


Modeling Analysis

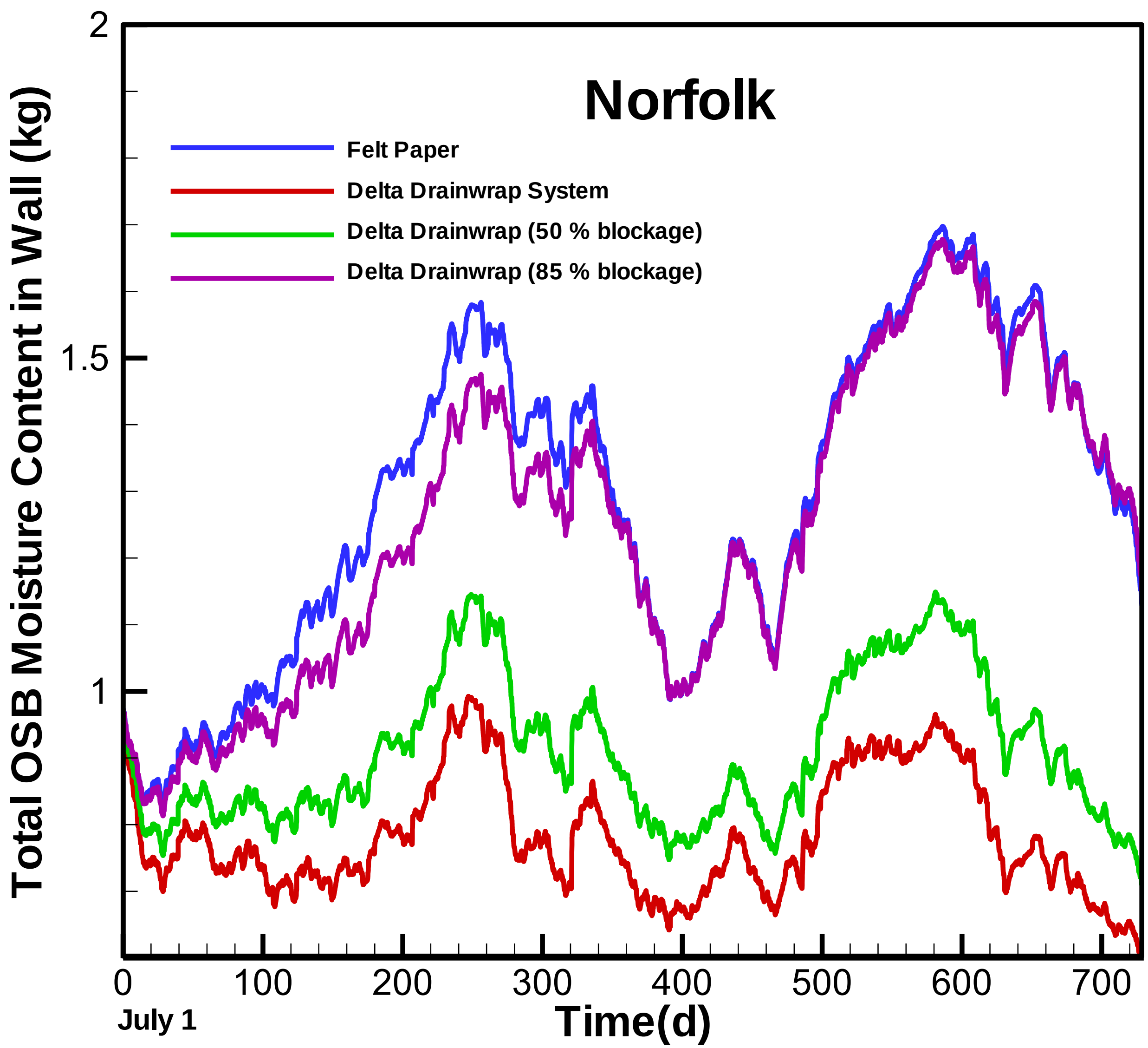


Toronto

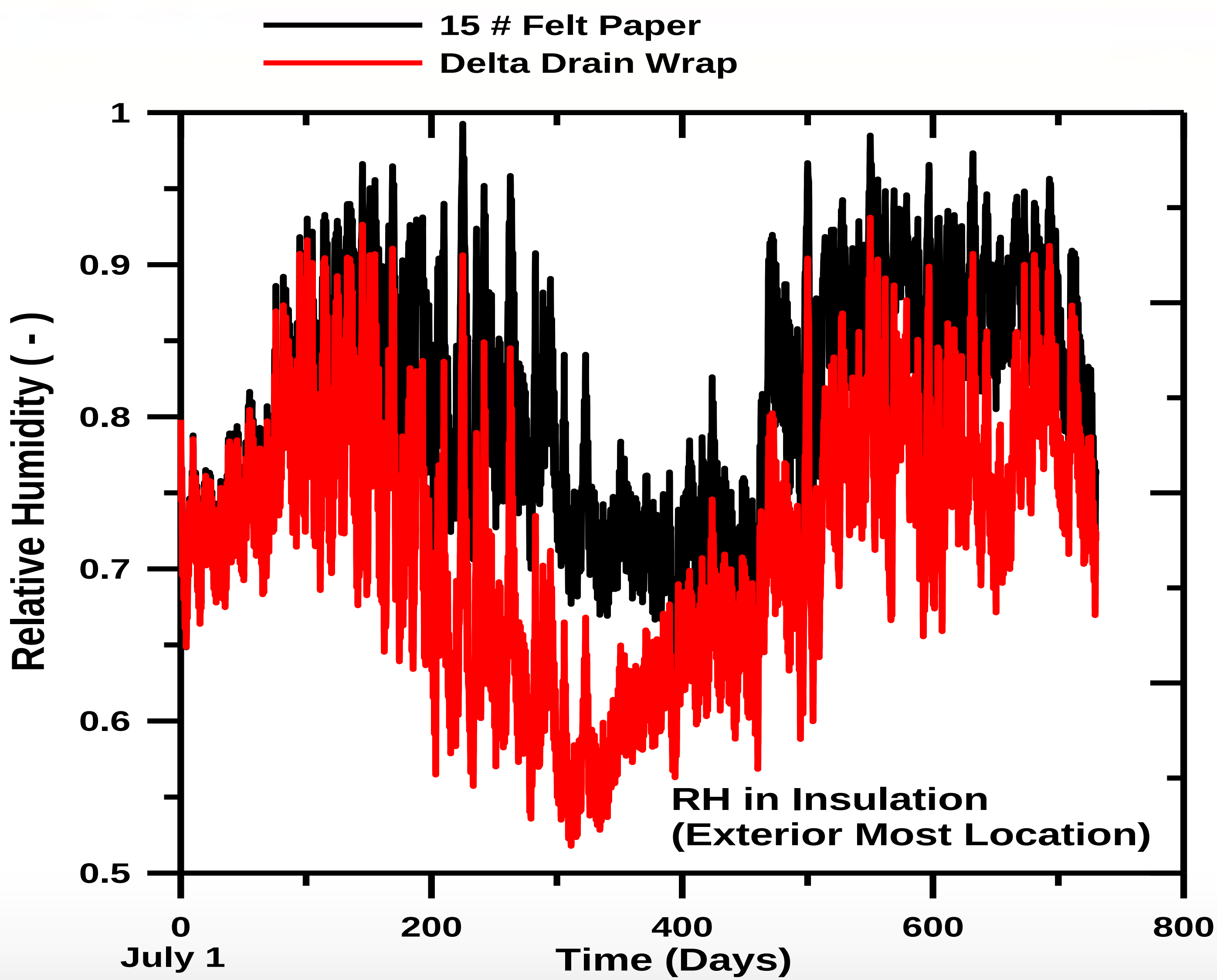
Modeling Analysis



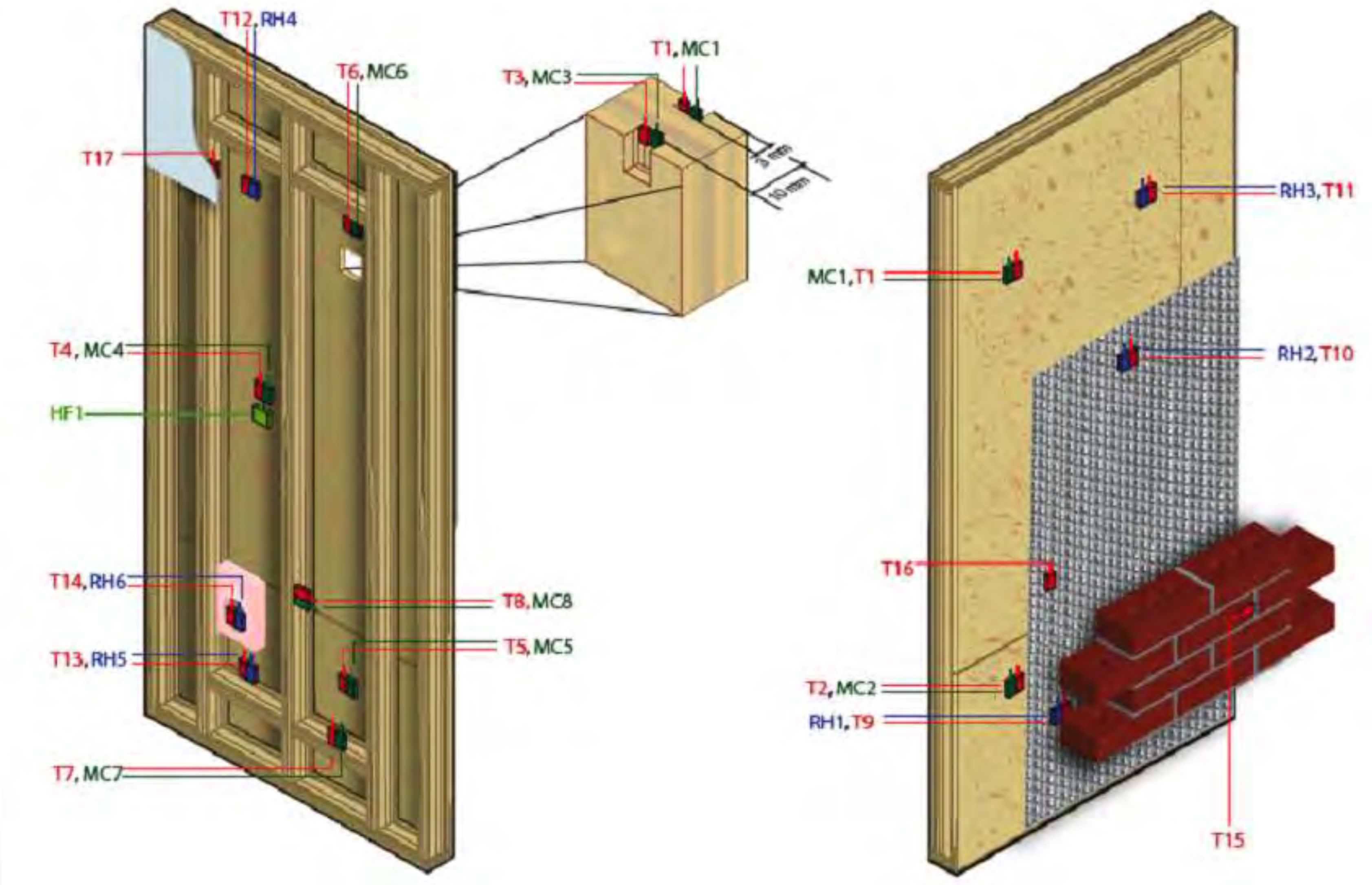
Modeling Analysis



Modeling Analysis



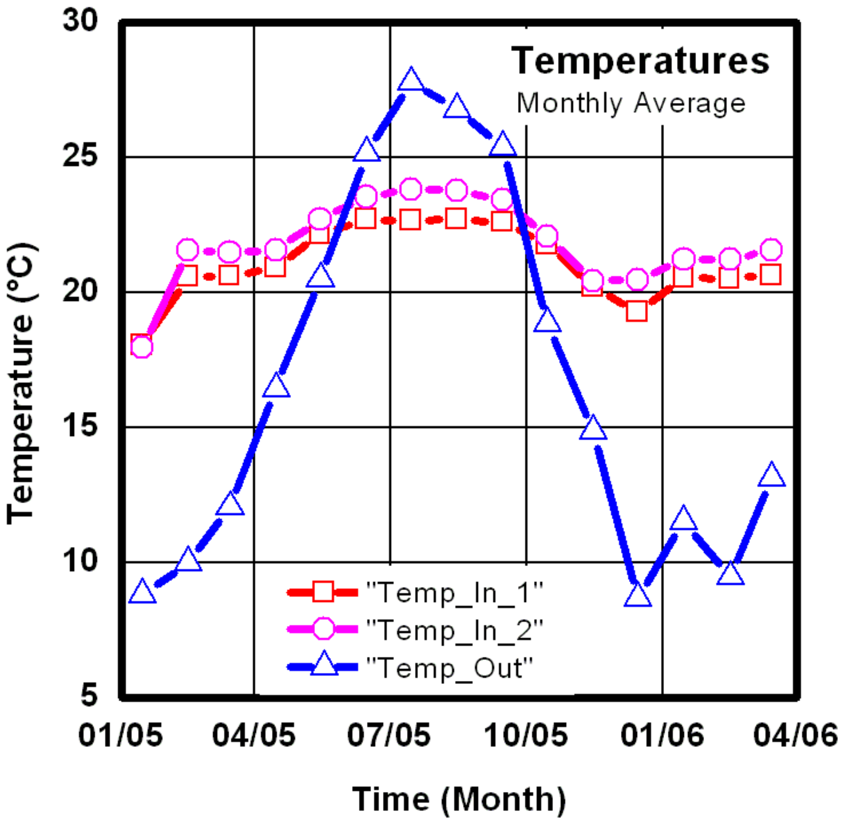
Experimental Set-up

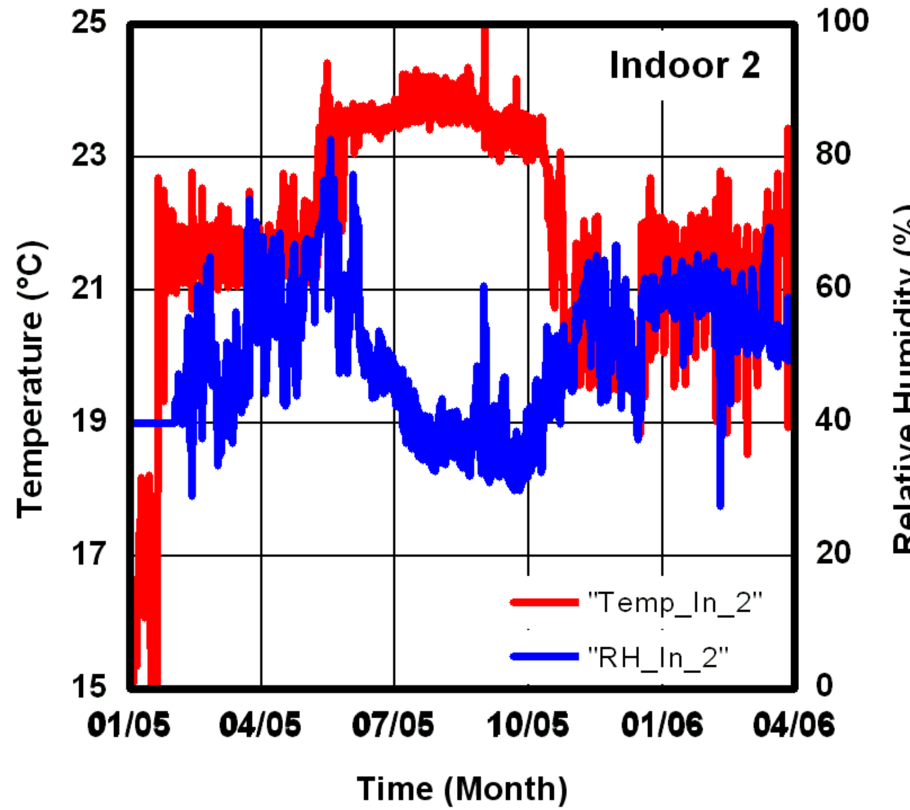


Experimental Set-up

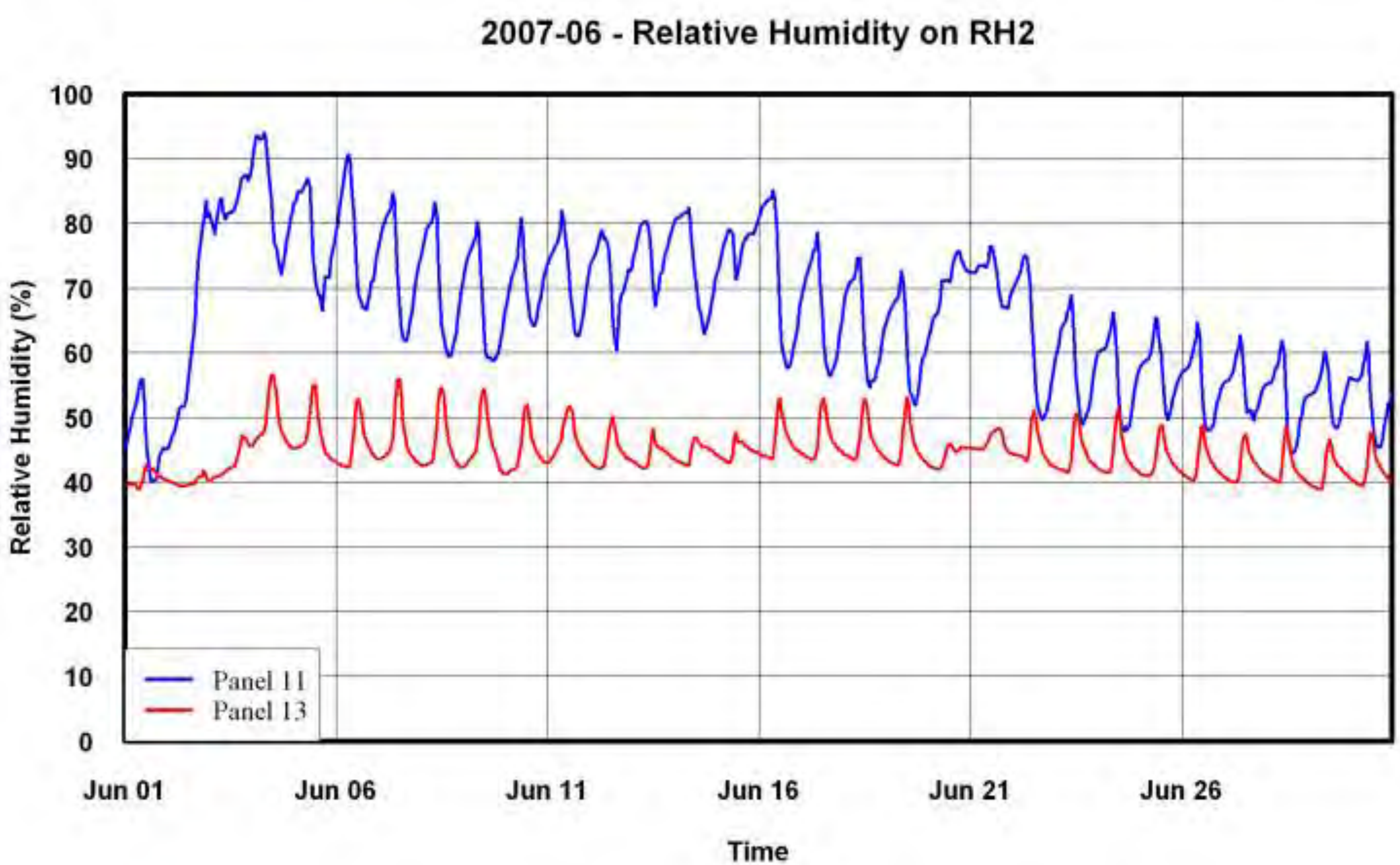
ORNL Test Facility: Charleston SC

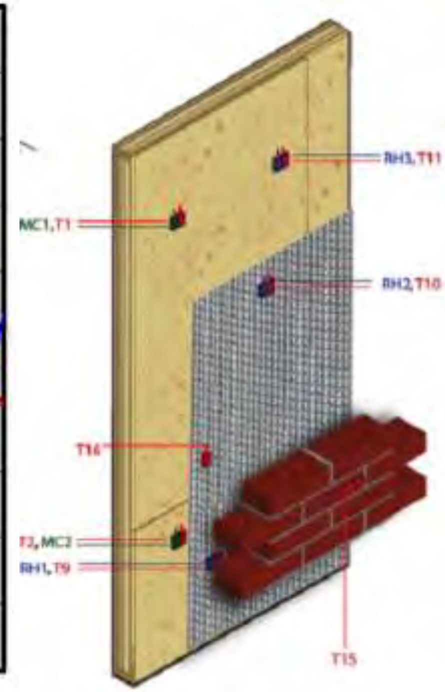
Exterior & Interior Conditions



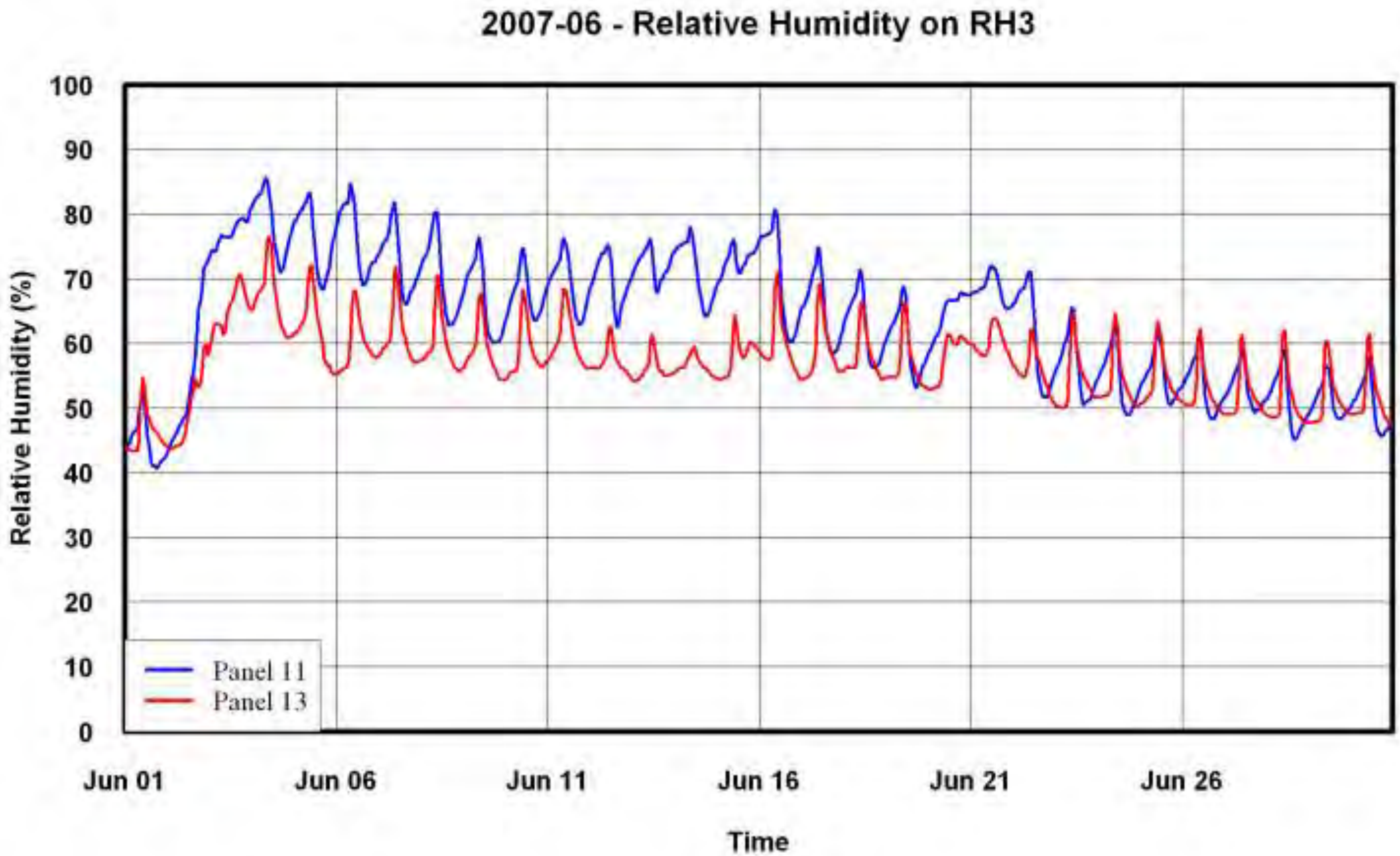


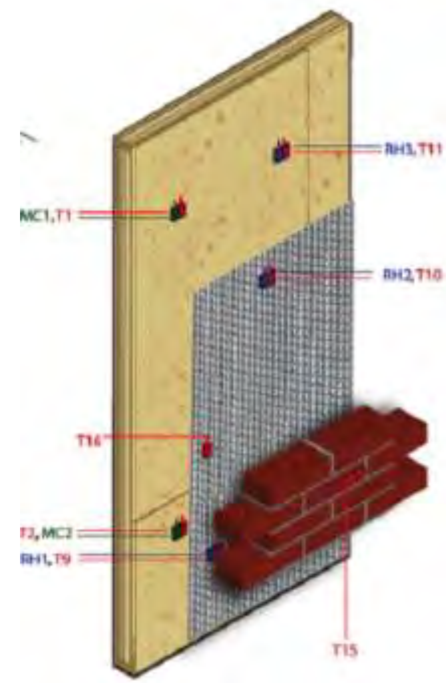
Measurements (Month of June)





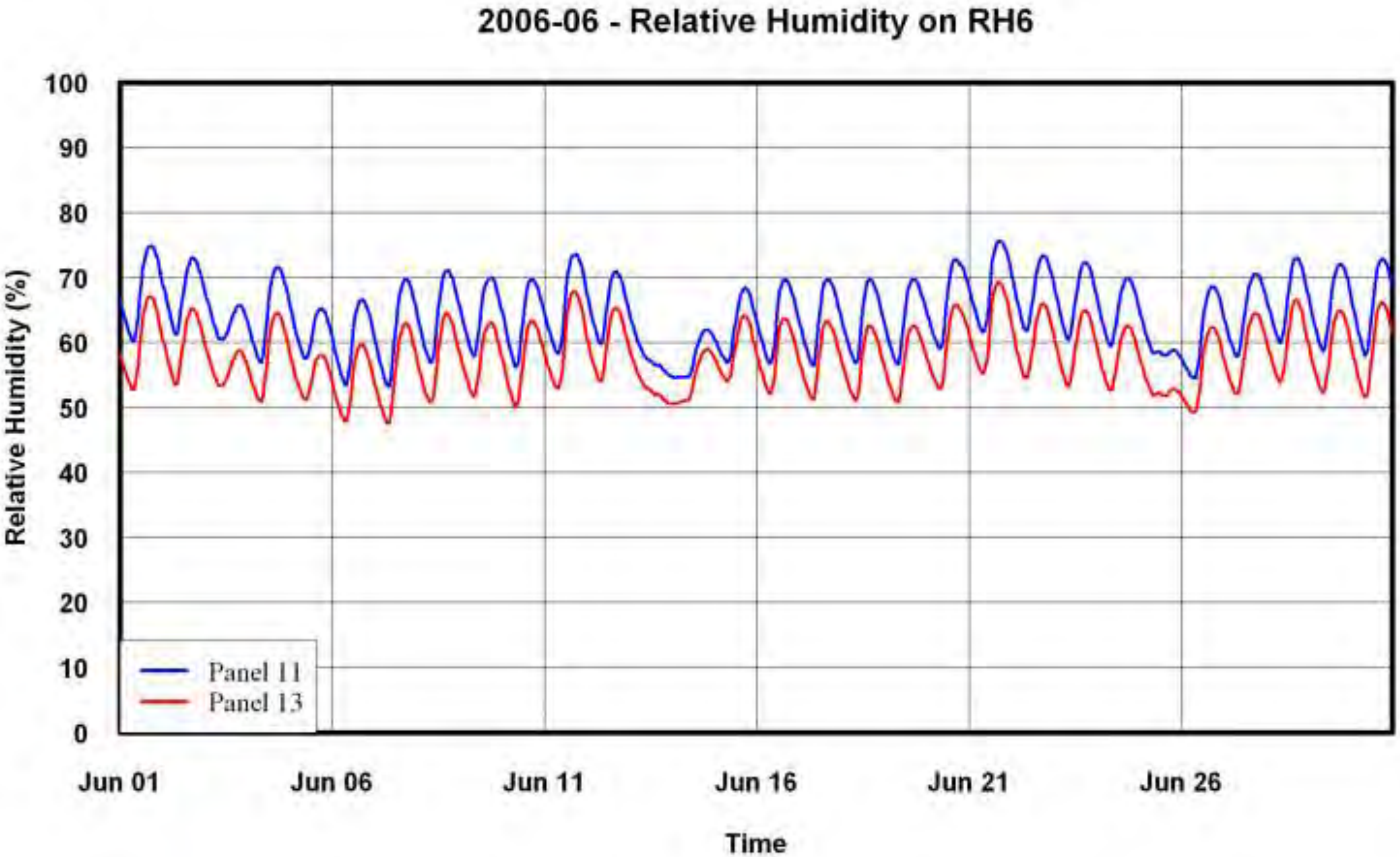
Measurements (Month of June)

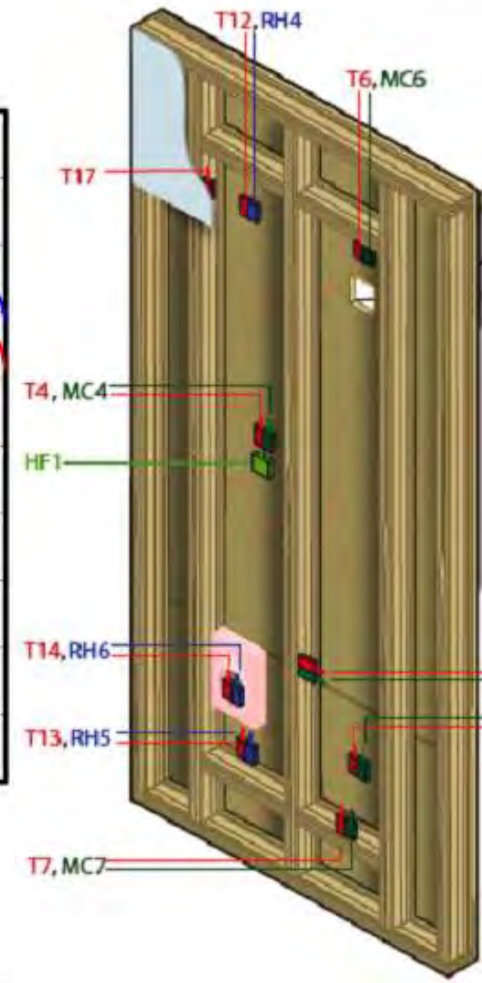




Measurements (Month of June)

Exterior Gypsum





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Measurements (Month of Feb)

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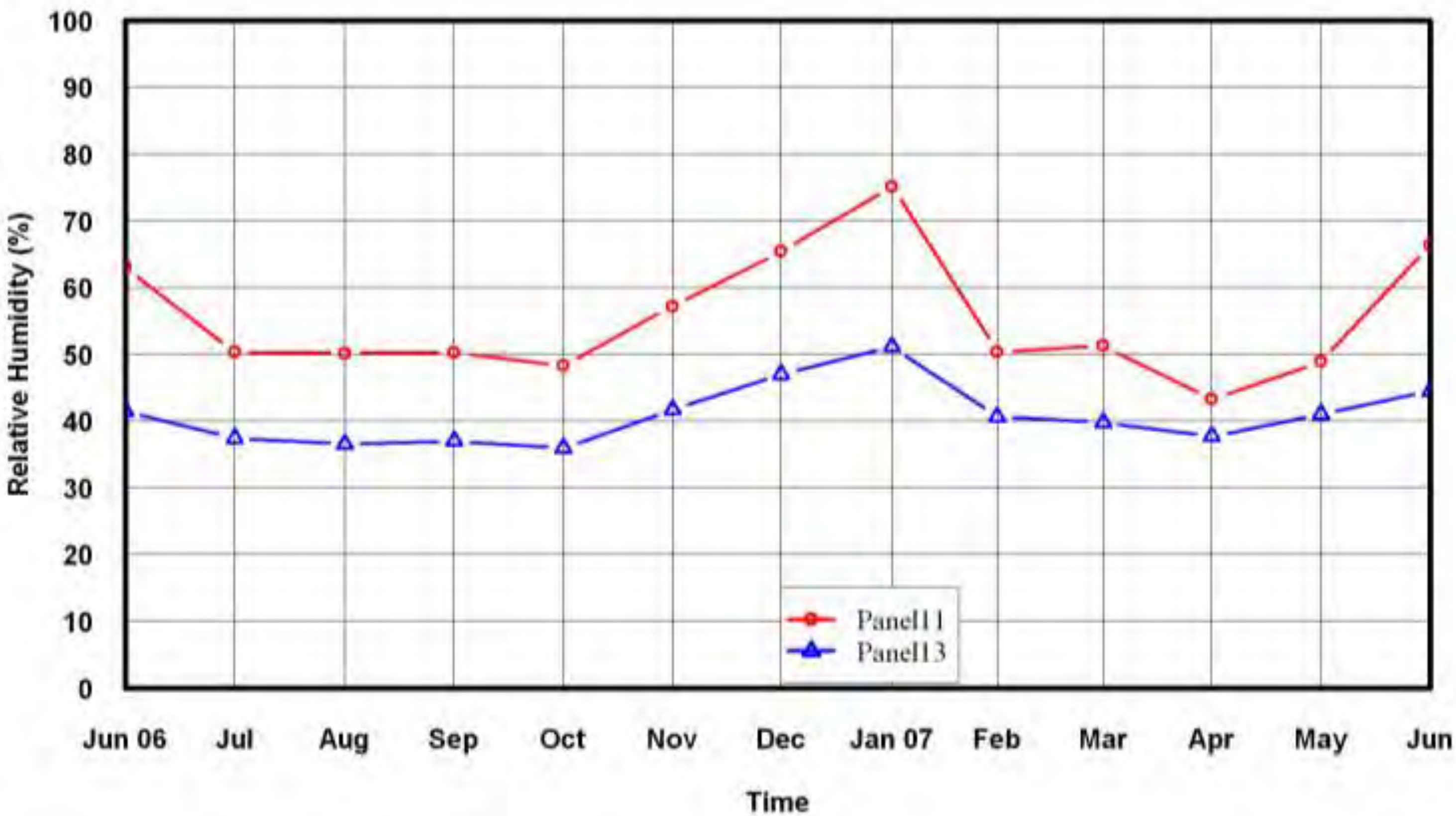
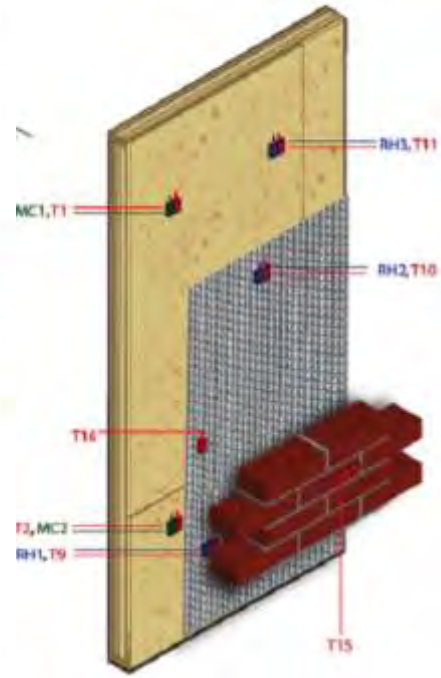
Monthly Average Relative Humidity

RH 2

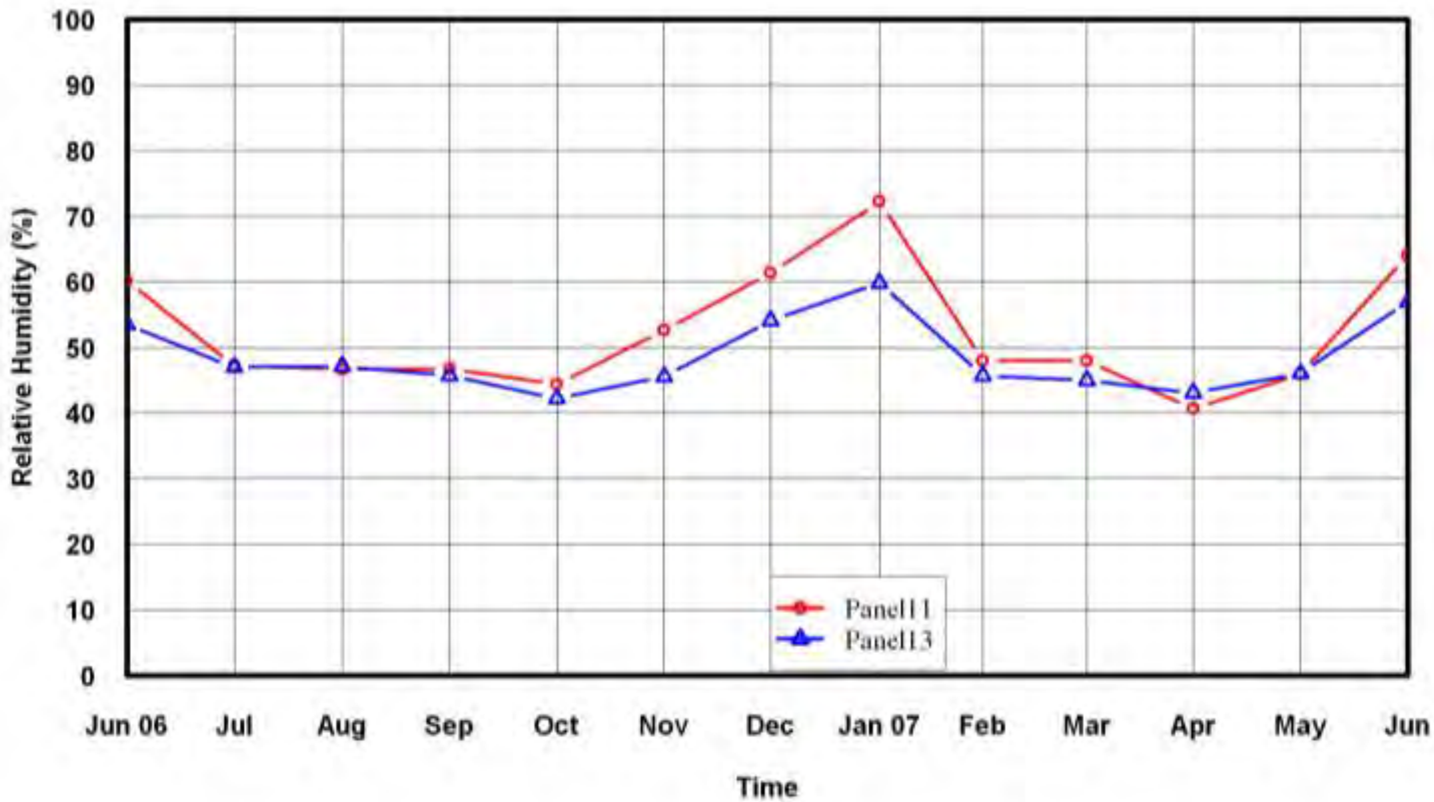


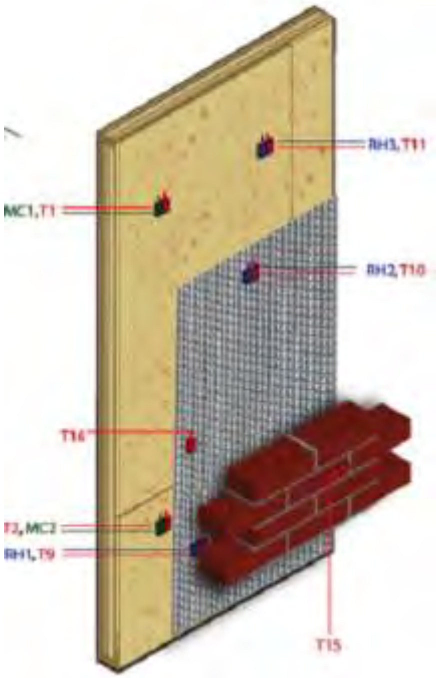


Measurements (Month of Feb)

Monthly Average Relative Humidity

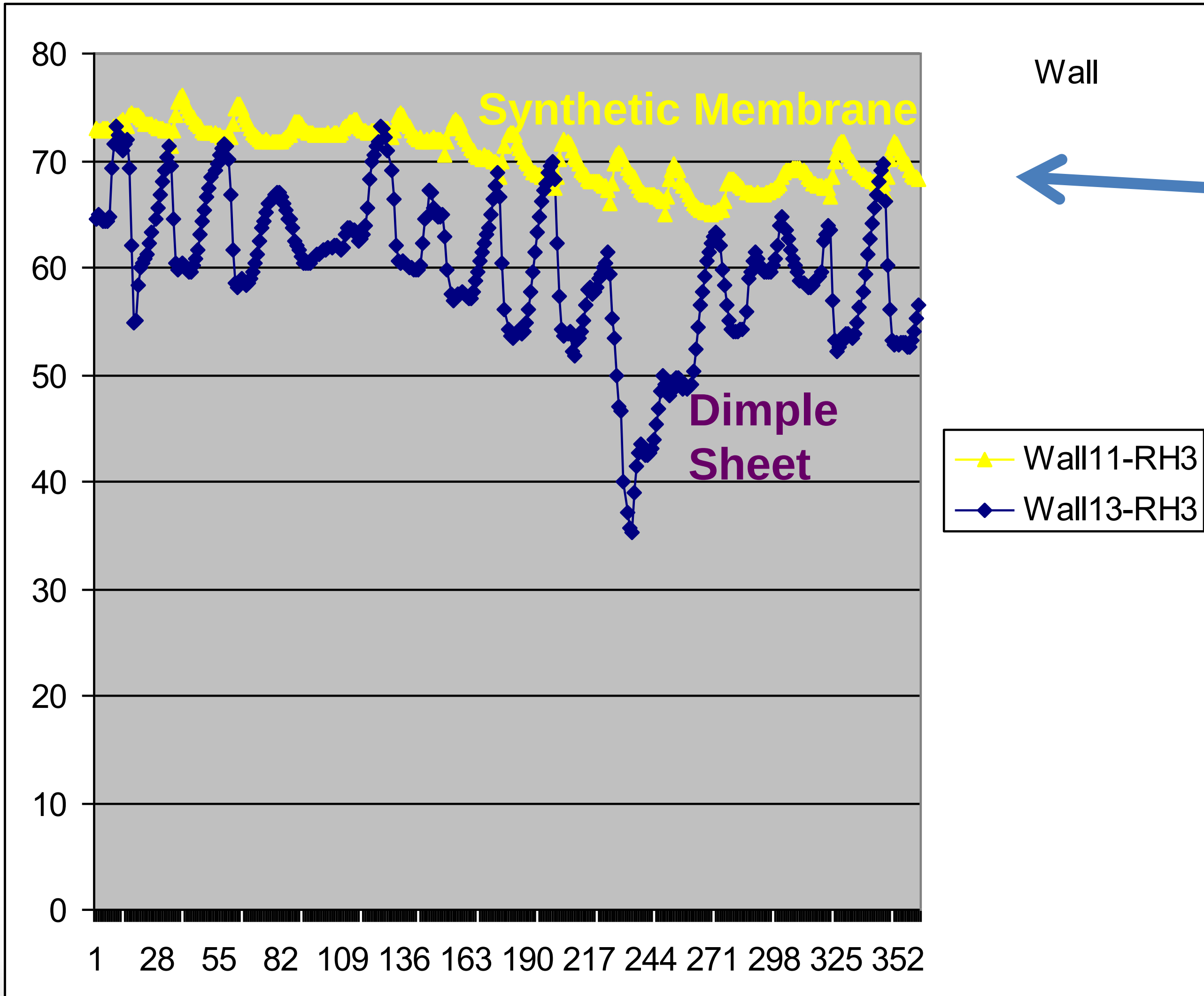
RH 3

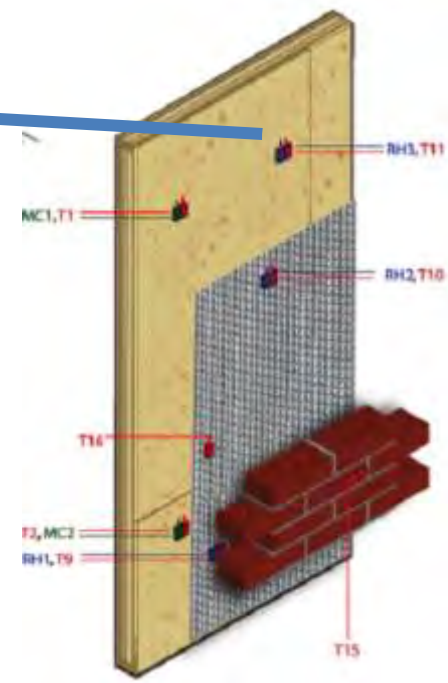




Measurements (Month of Feb)

OSB **Hourly** **Winter Period**

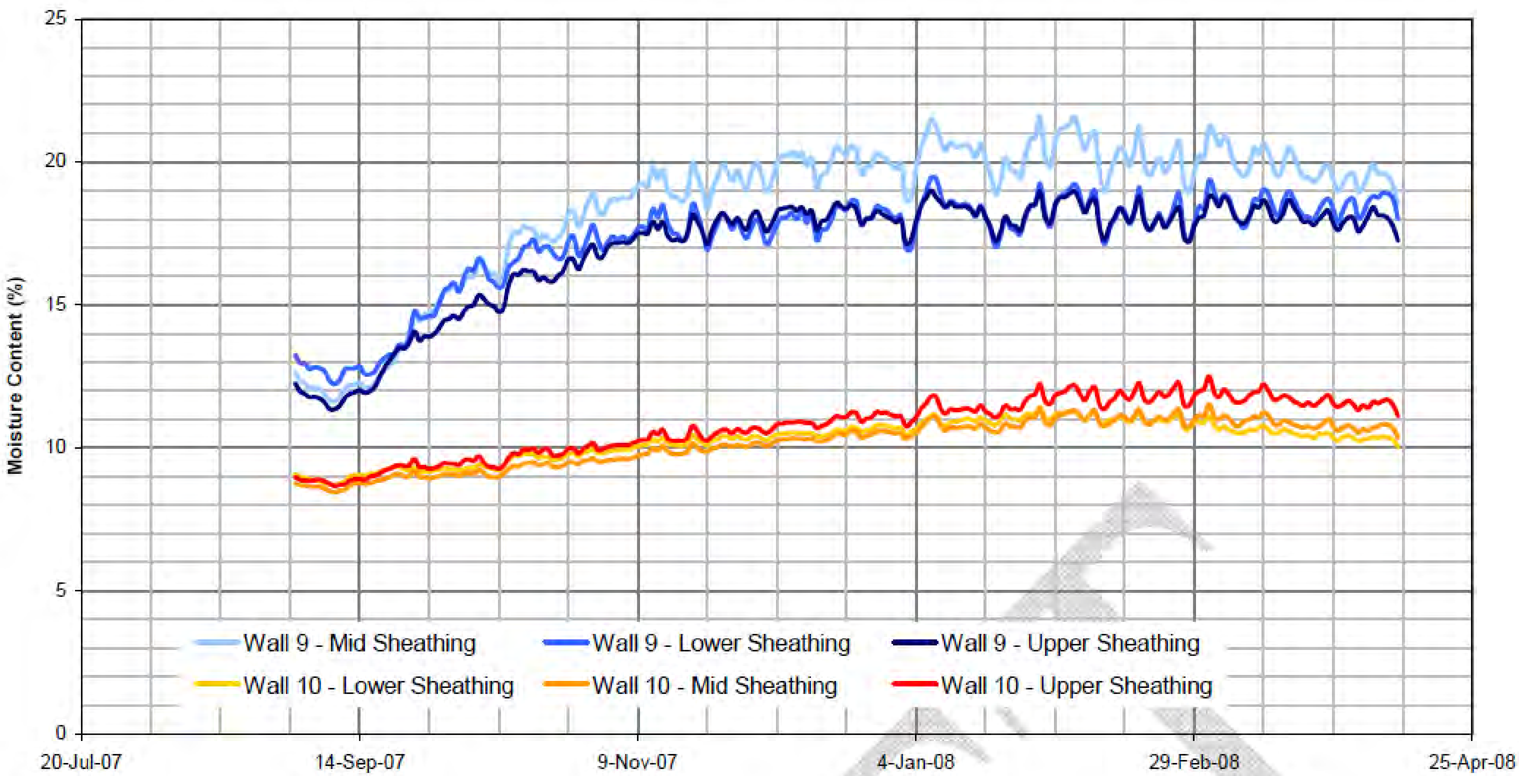




Measurements (Yearly)

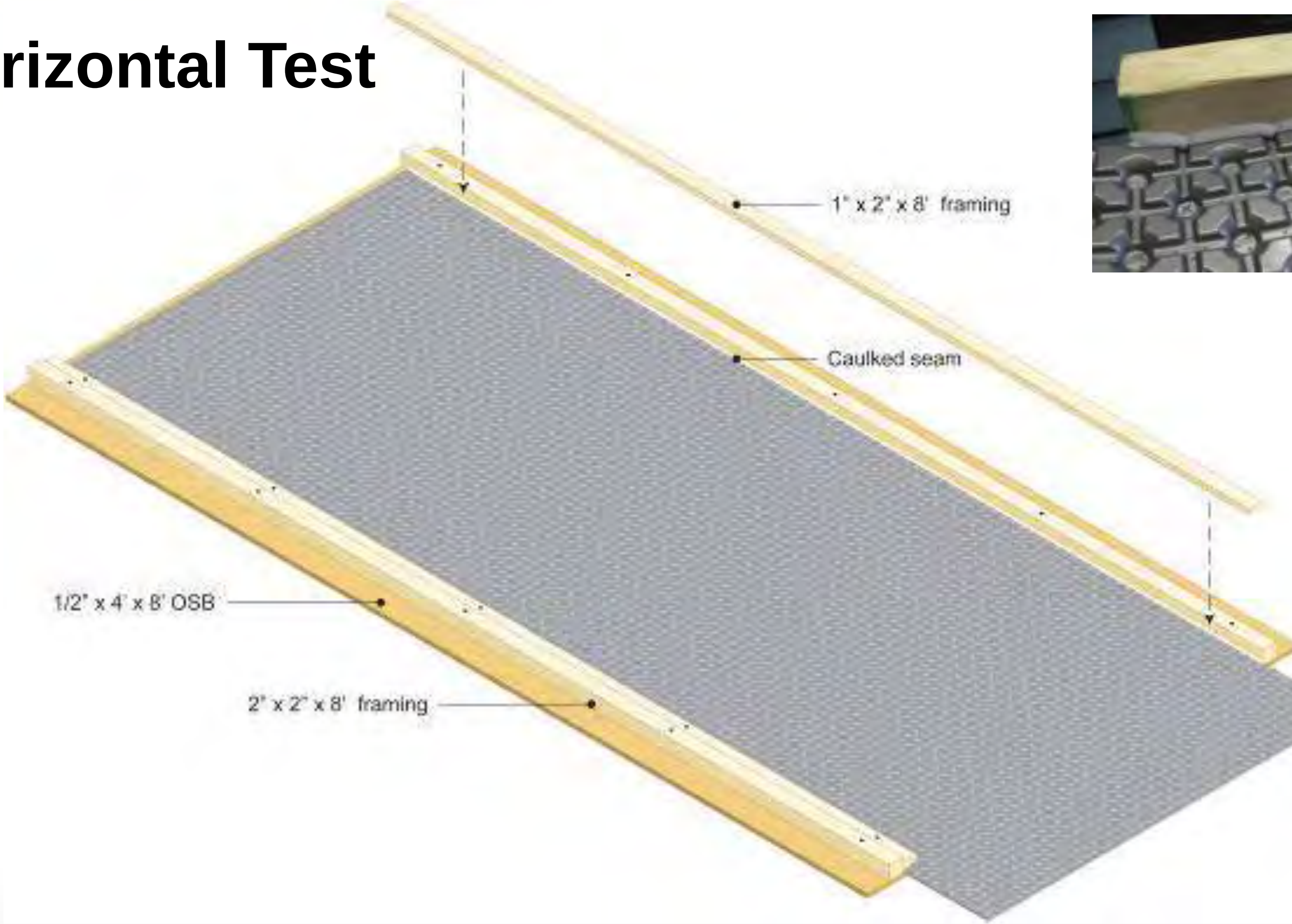
OSB

J.F. Straube
BSC Field Study



Sheathing moisture content comparison on the north orientation

Horizontal Test



Air Flow Dynamics

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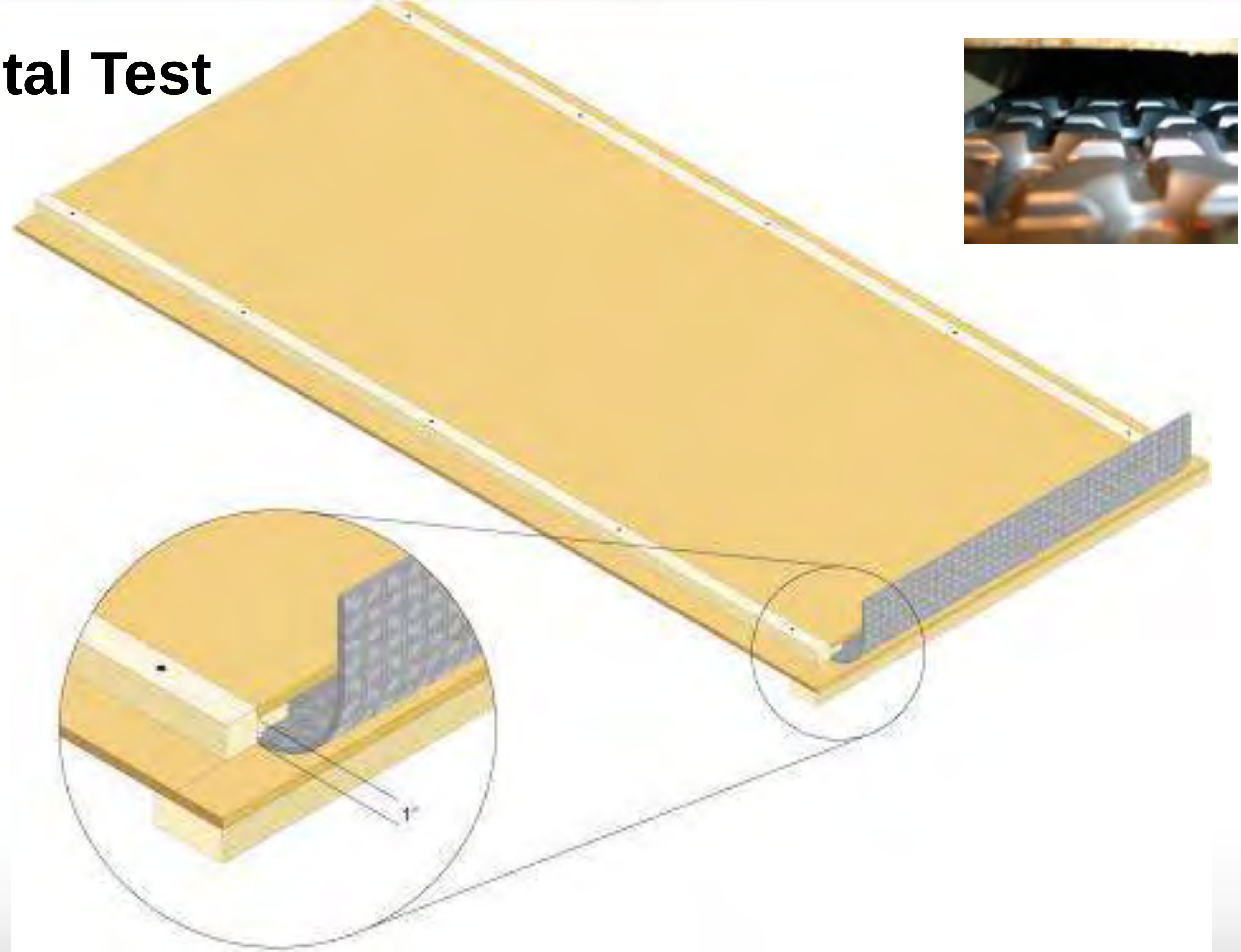
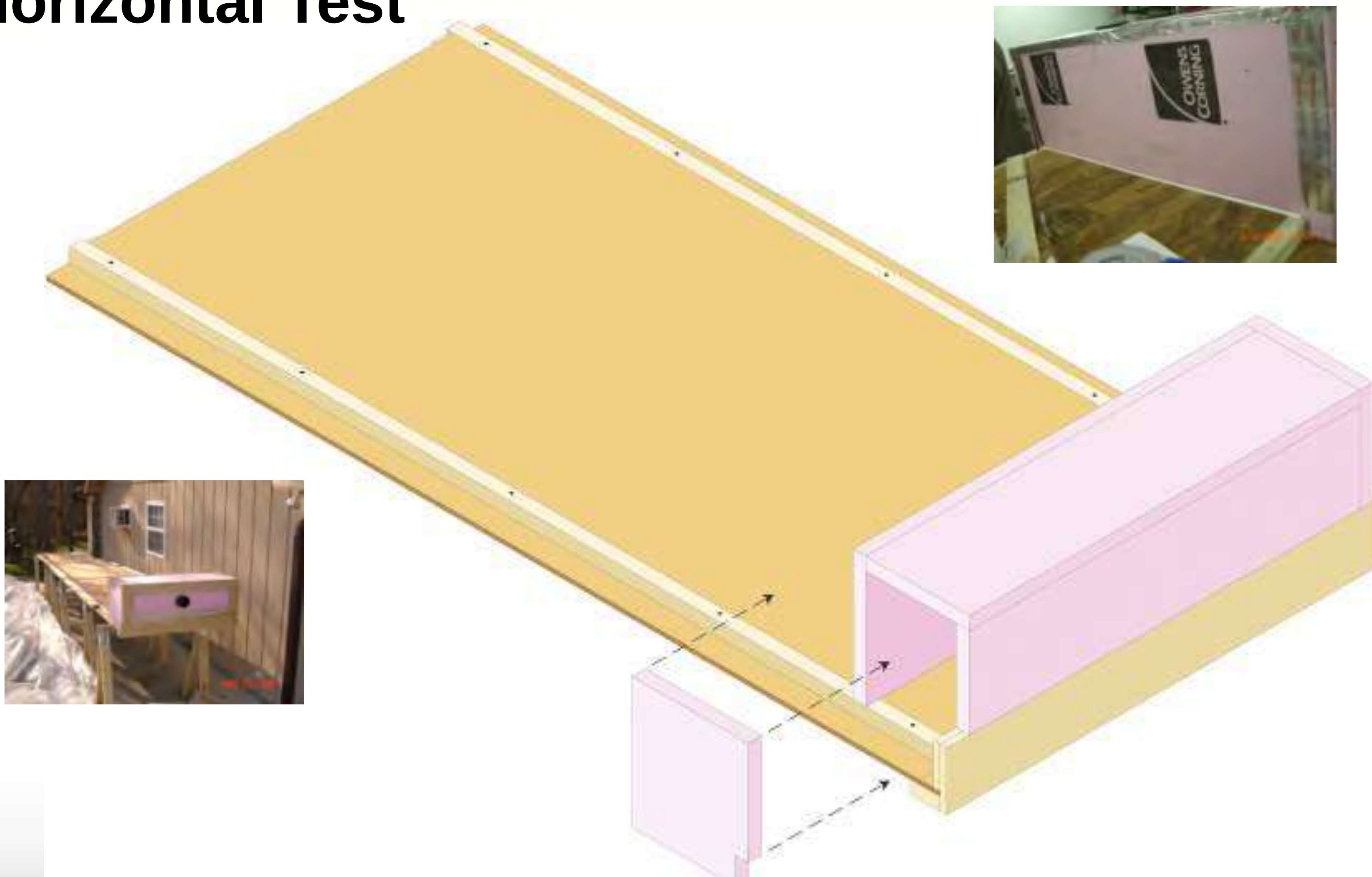
Horizontal Test

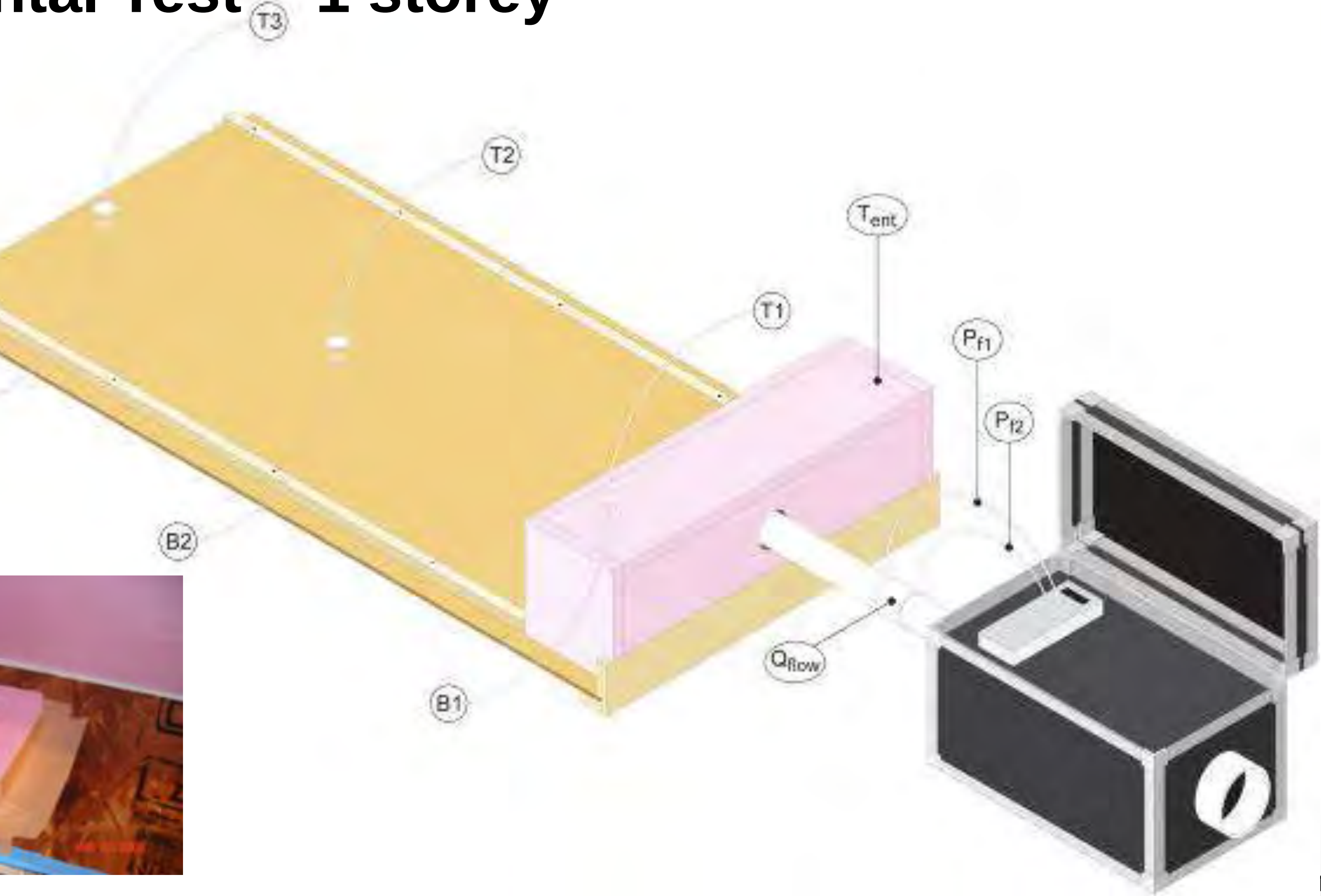


Air Flow Dynamics

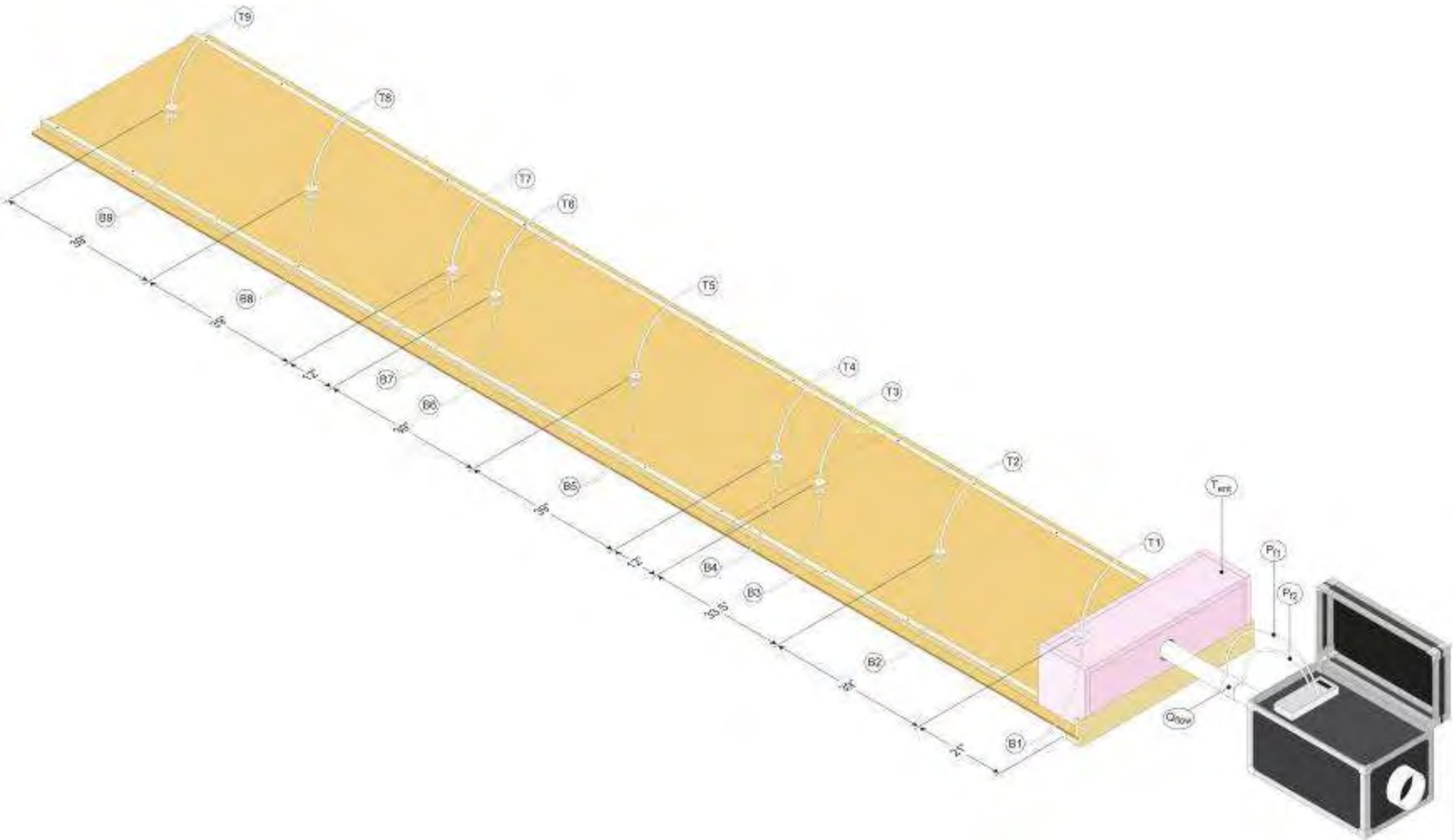
Horizontal Test



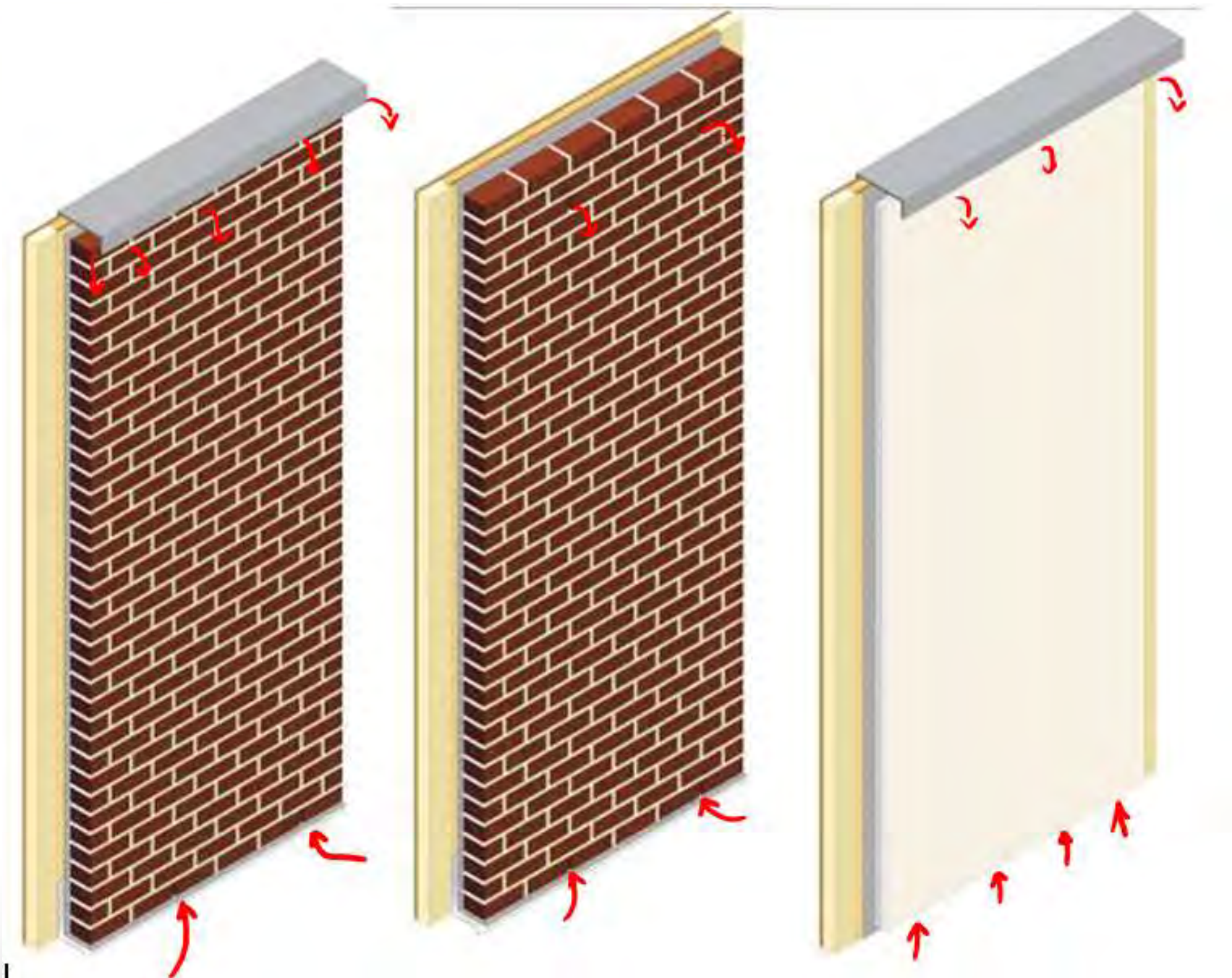
Horizontal Test - 1 storey



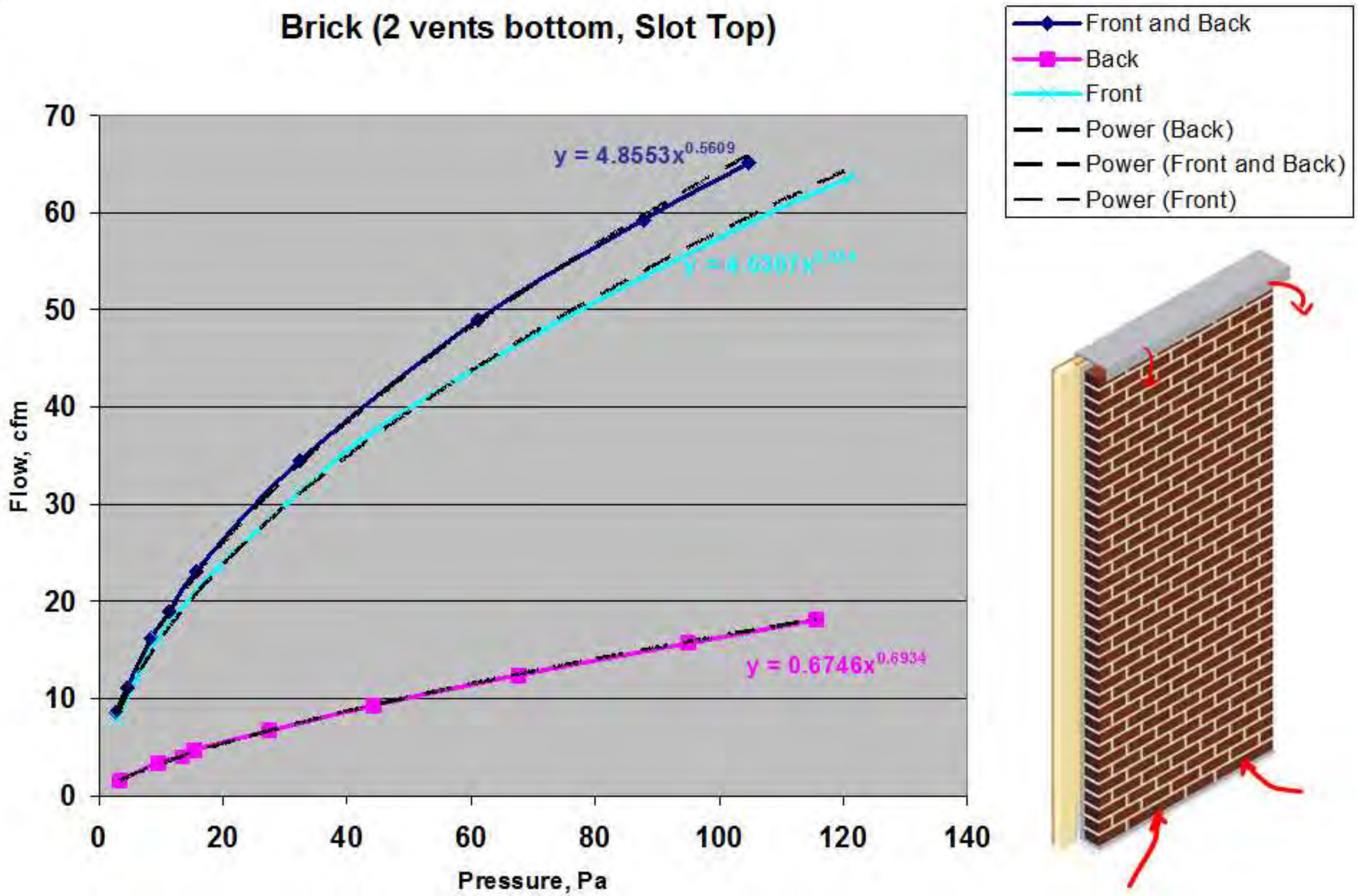
Horizontal Test -3 Storey



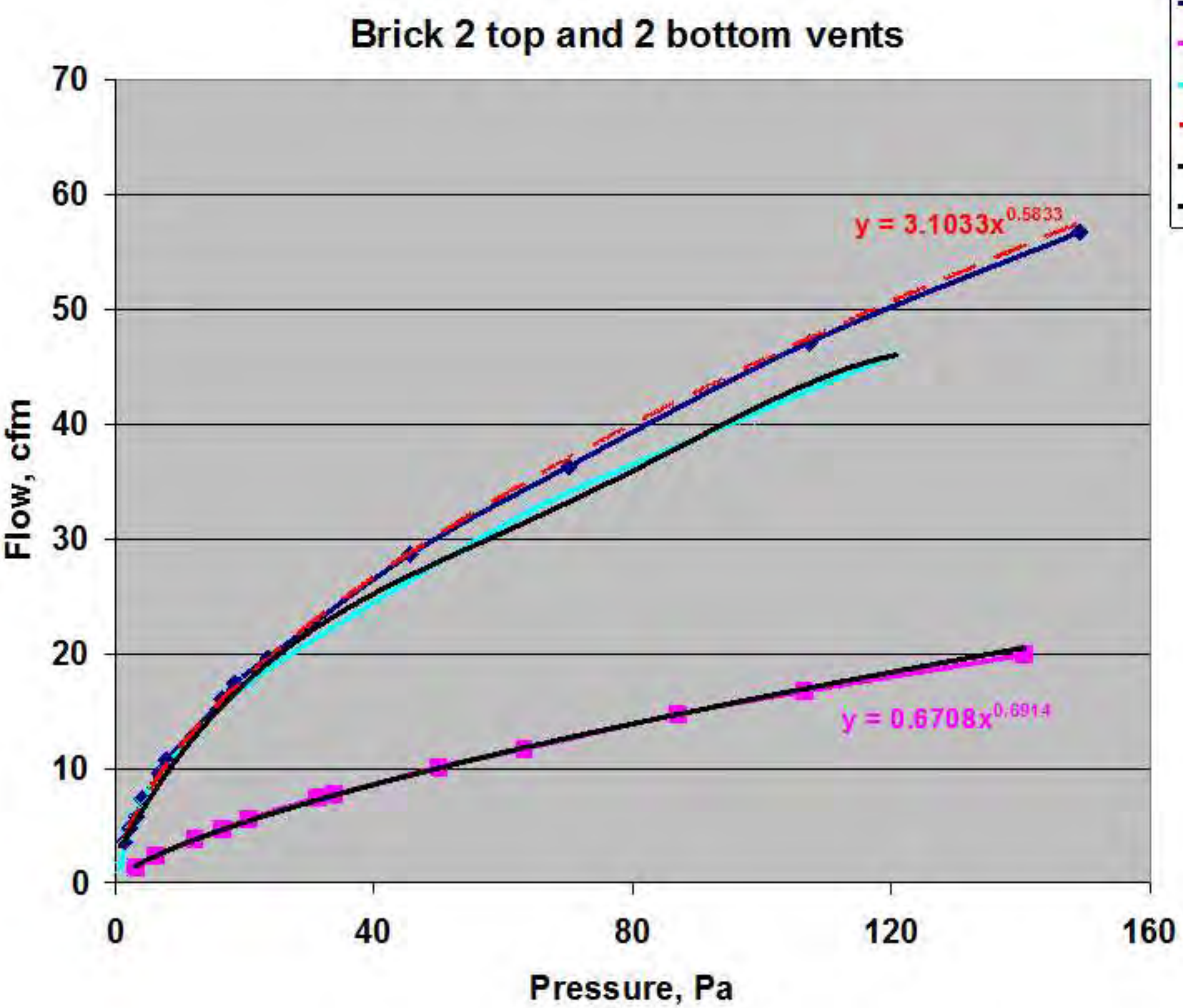
Three Venting Options



Air flow in Front & Back Air Spaces



Air flow in Front & Back Air Spaces



Air flow in Front & Back Air Spaces

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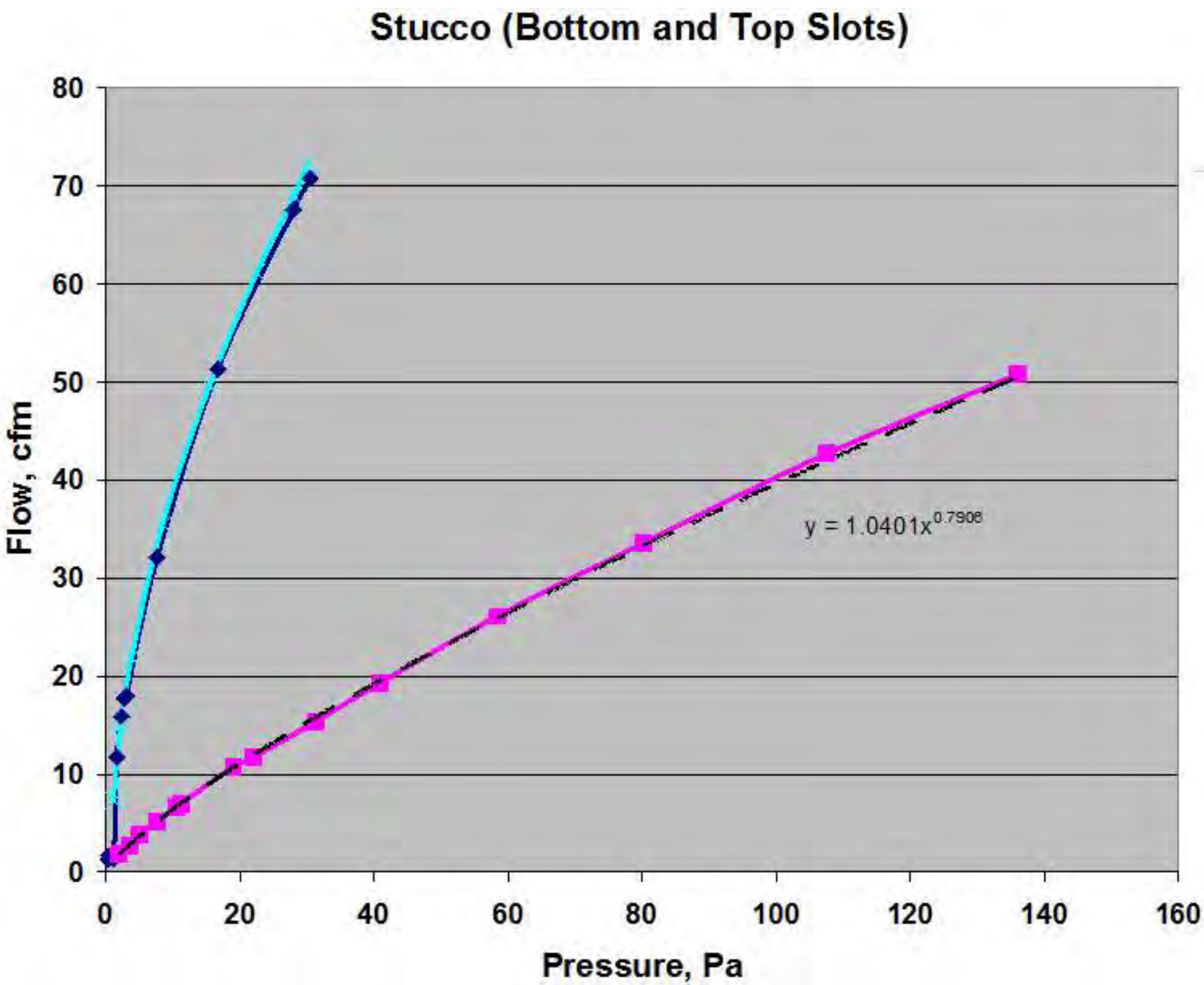
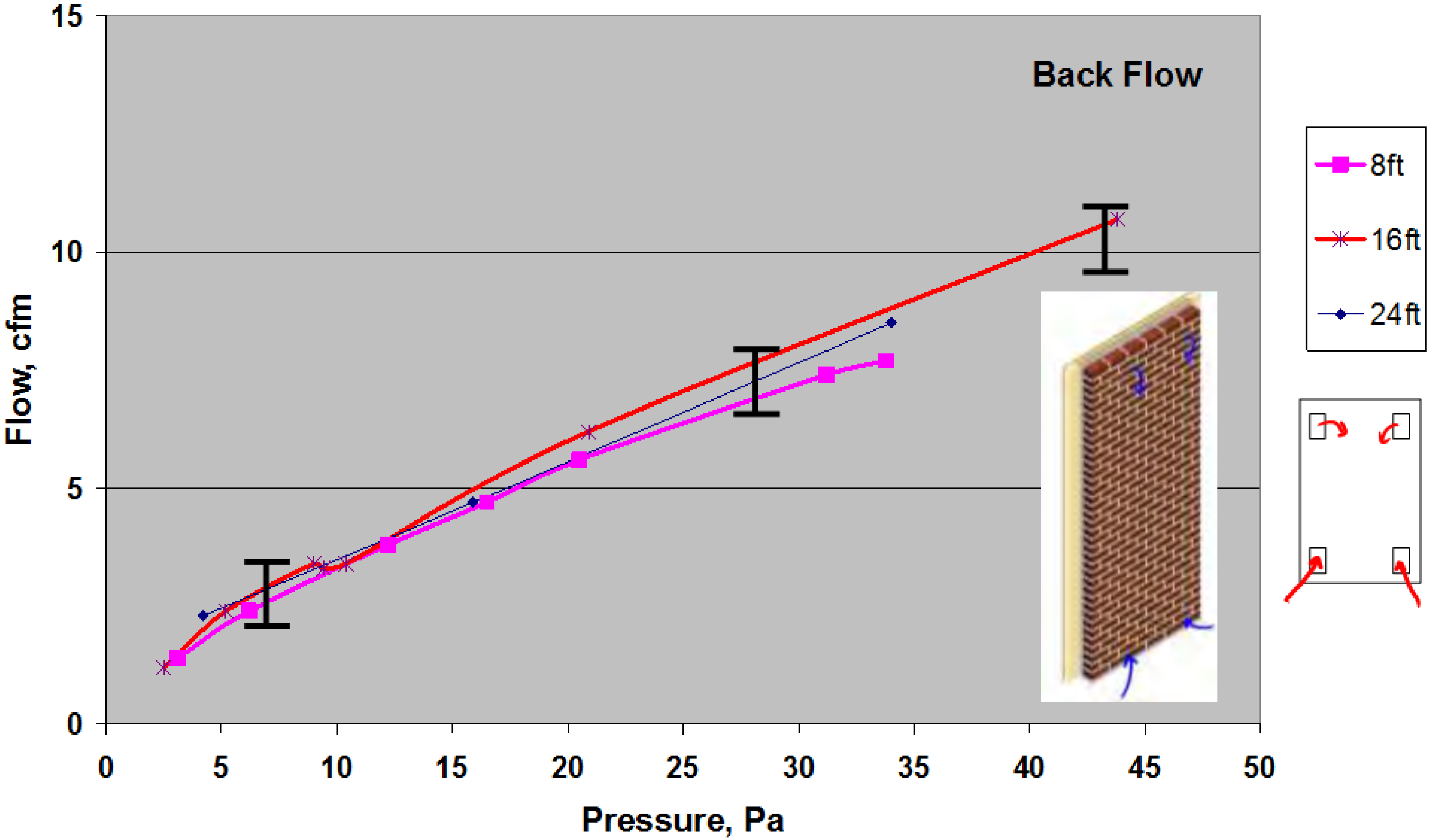
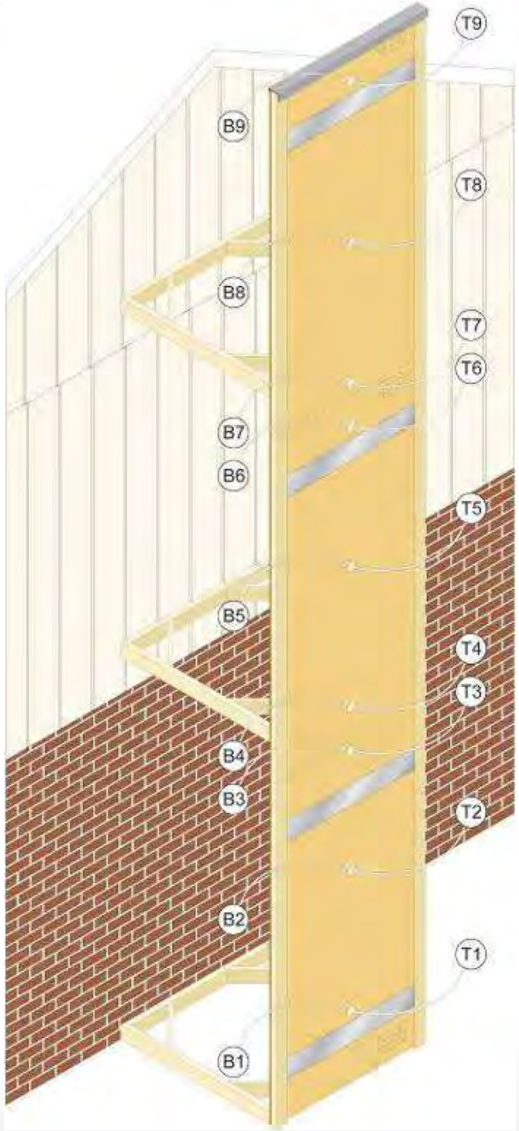


Effect of Height for Brick wall with 2 top and 2 bottom openings



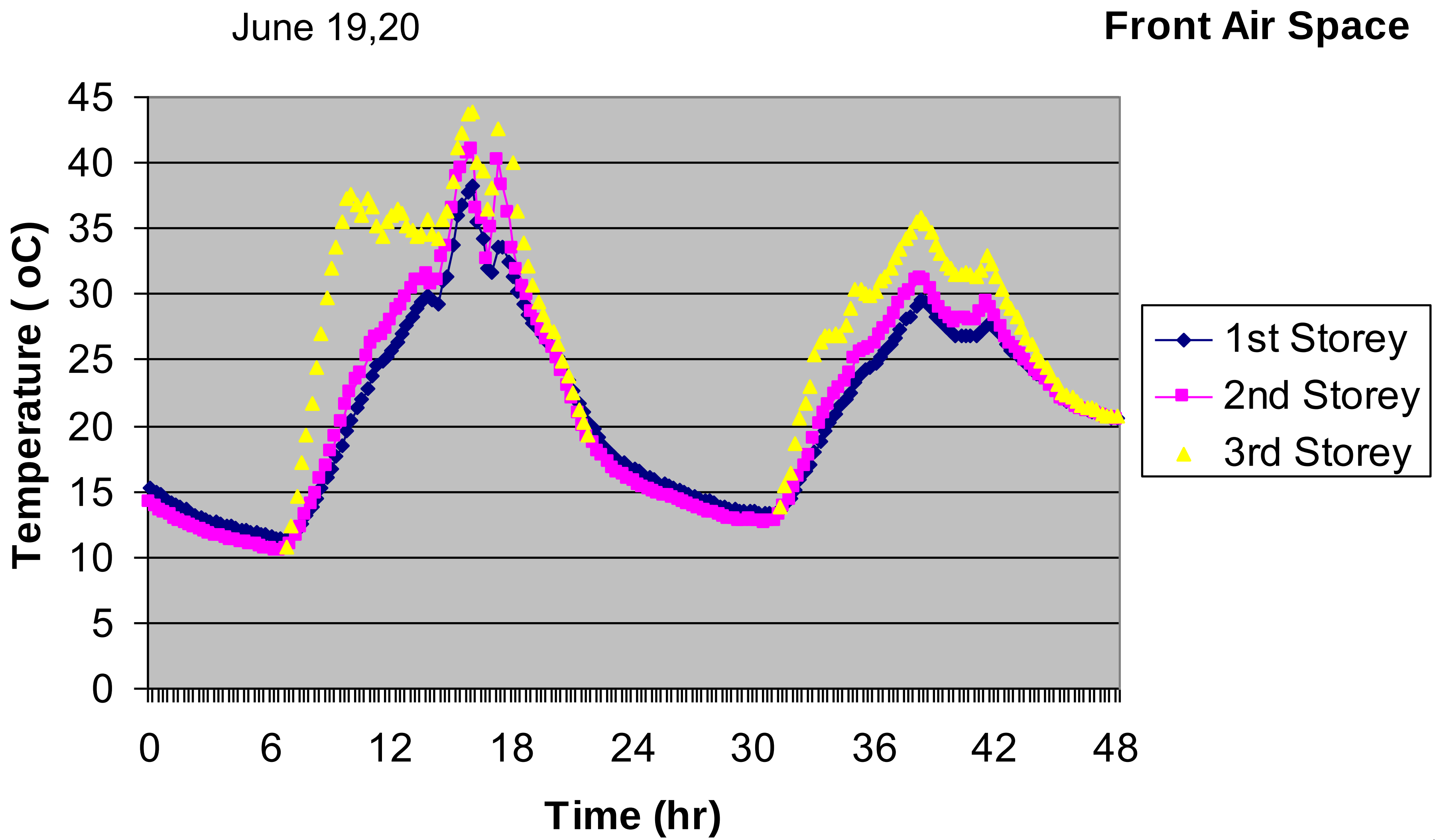
Vertical Test-3 Storey

Measure Solar, Wind speed, Velocity, Tracer gas, T, RH, Pressure



Field Monitoring

6/19/200- 6/20/2008



Field Monitoring

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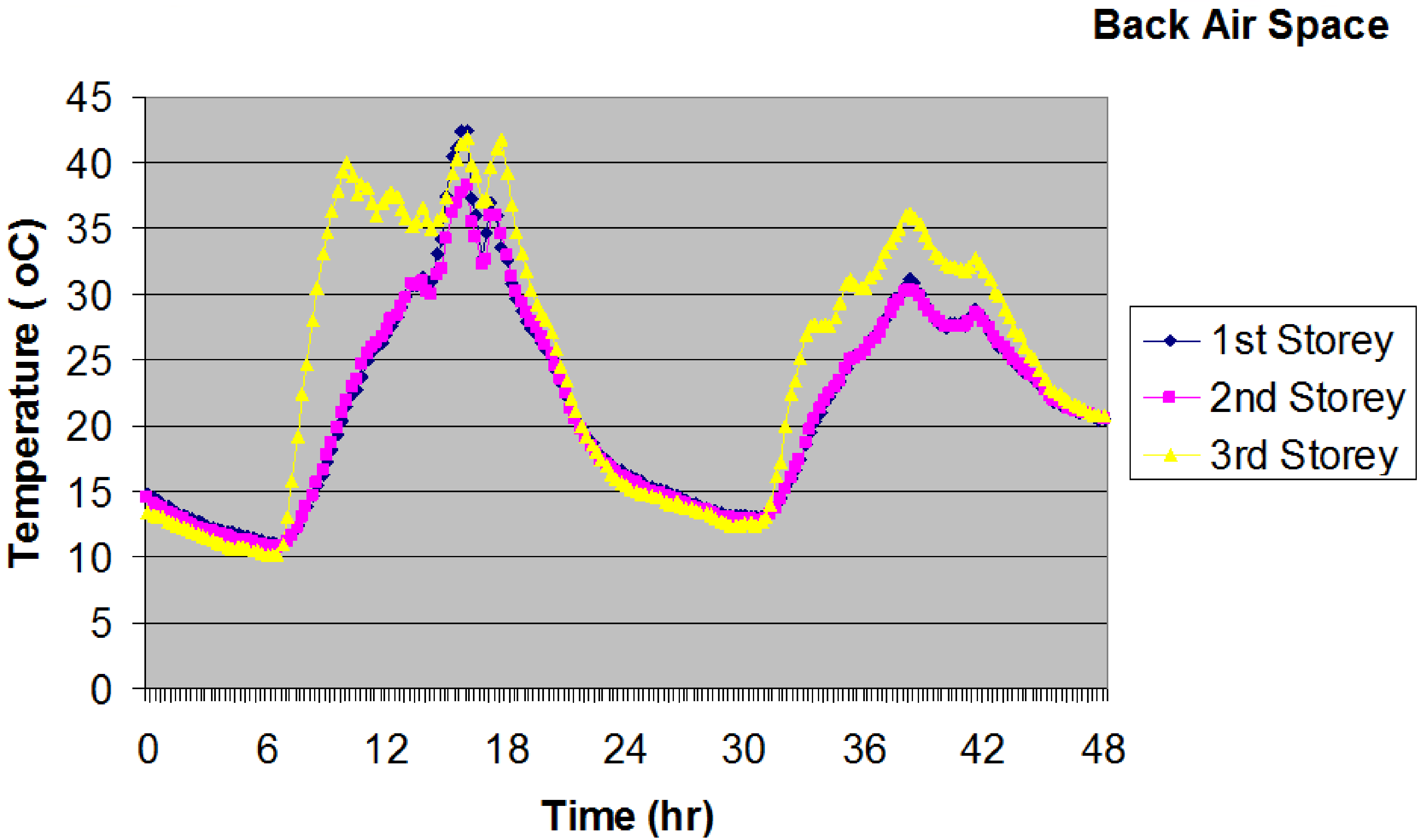
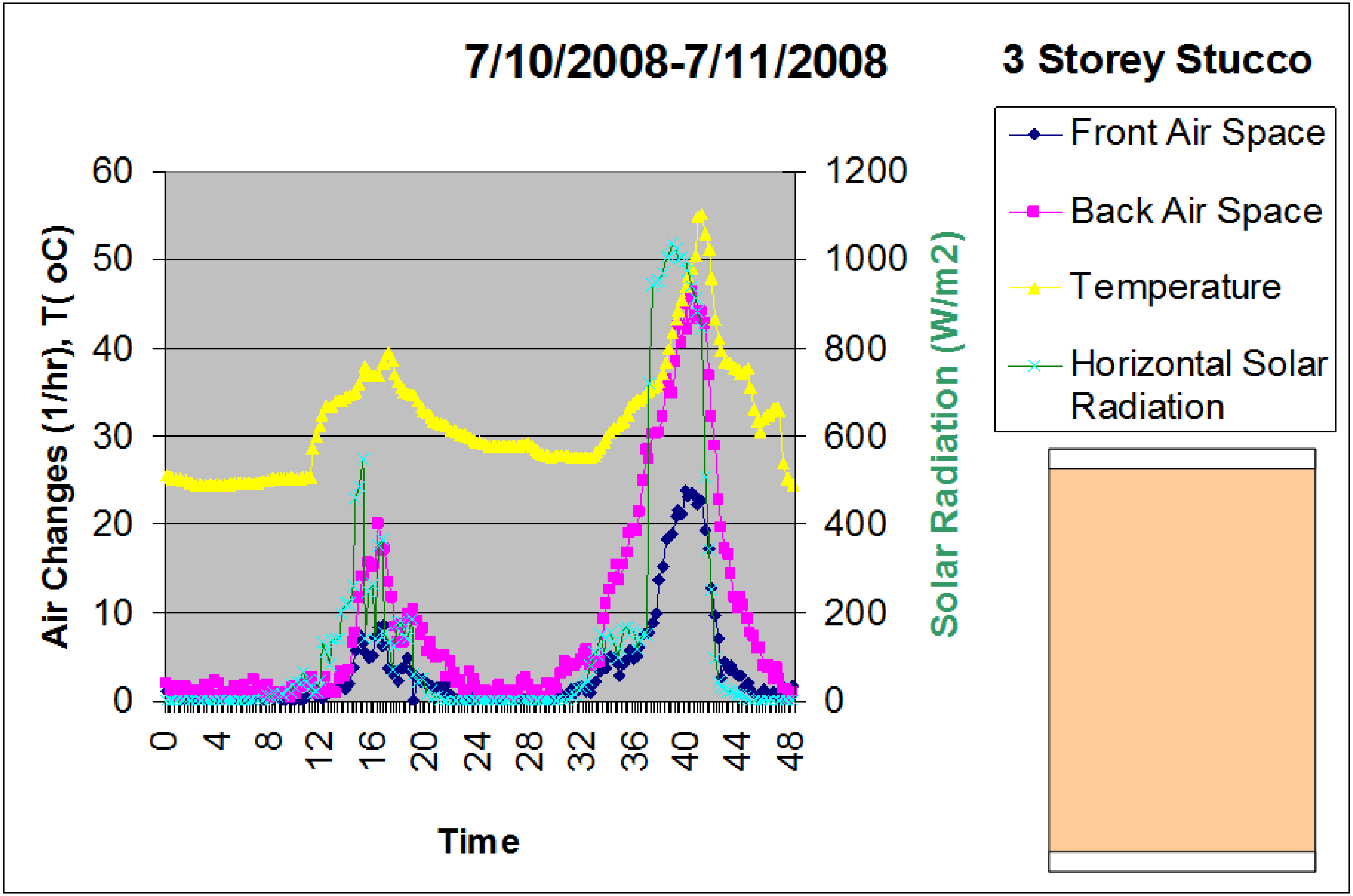
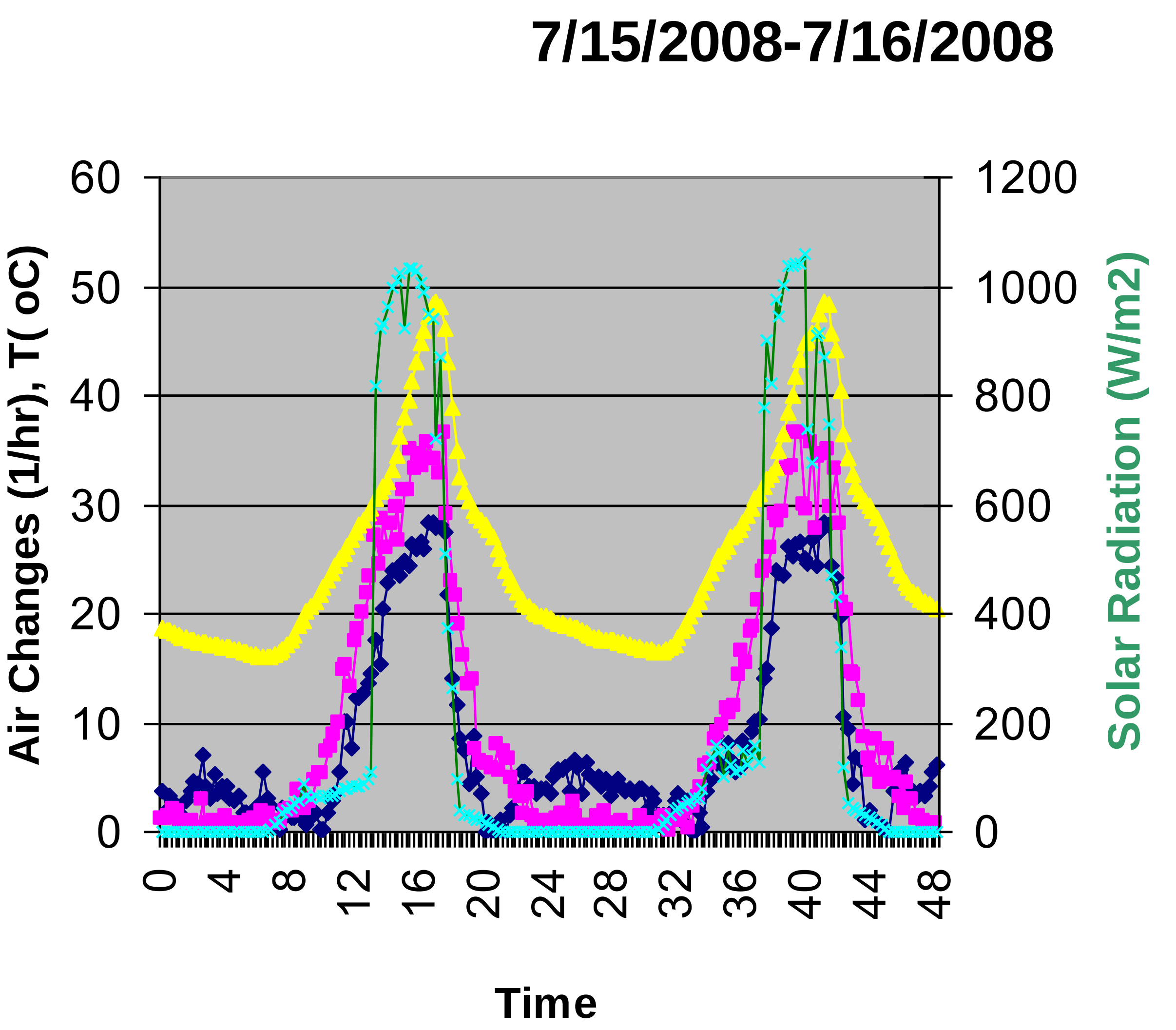
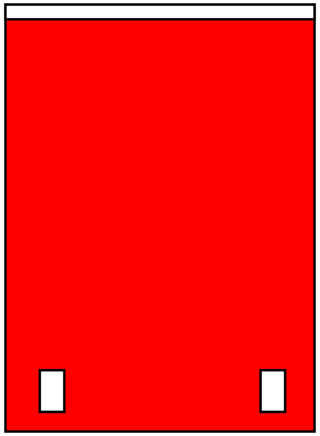


Field Monitoring

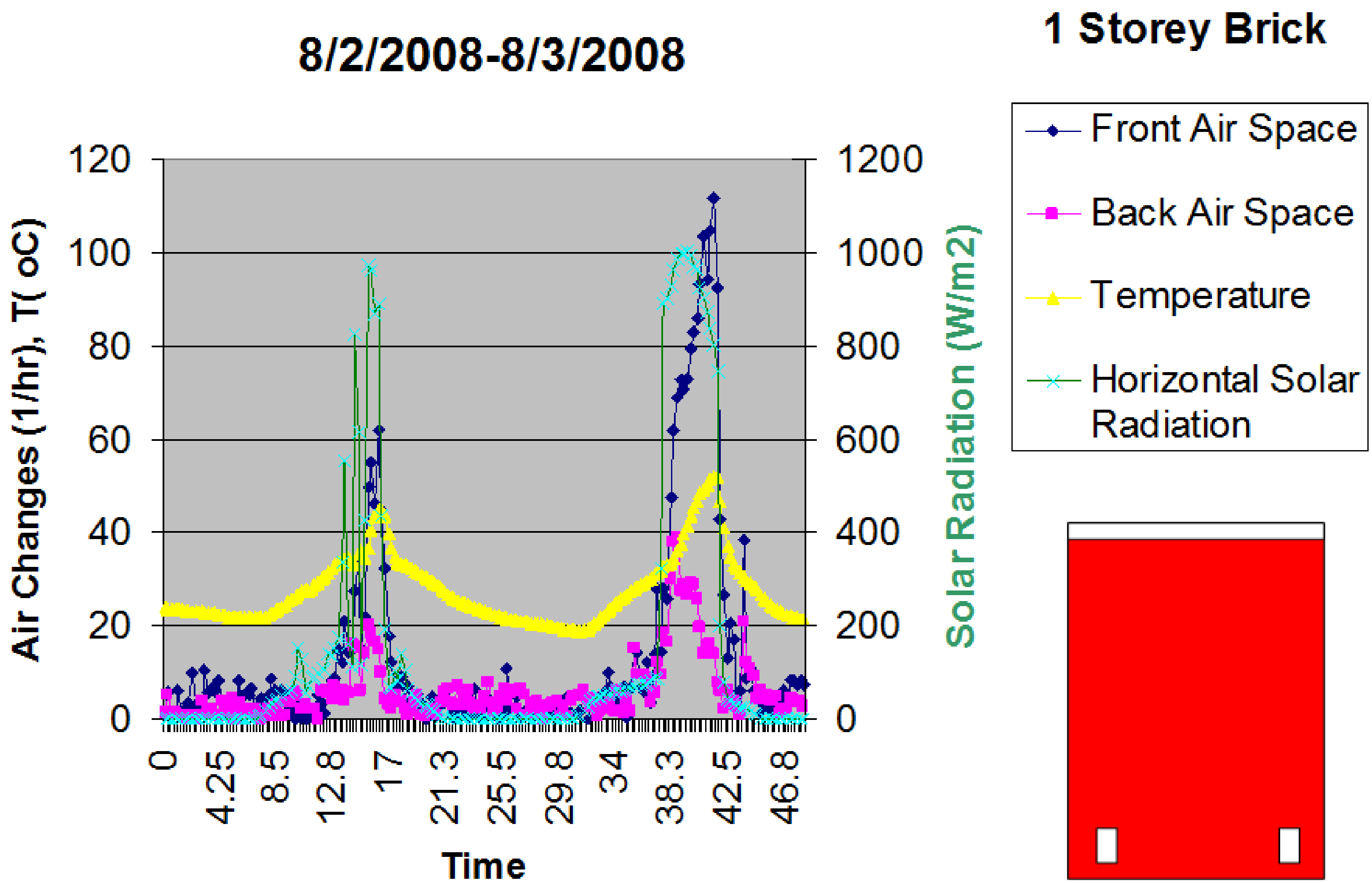


Field Monitoring

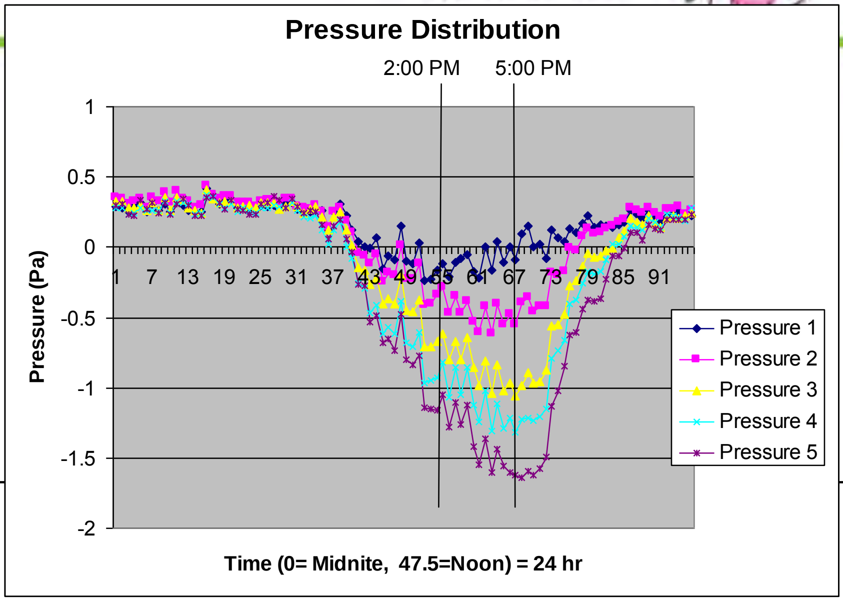


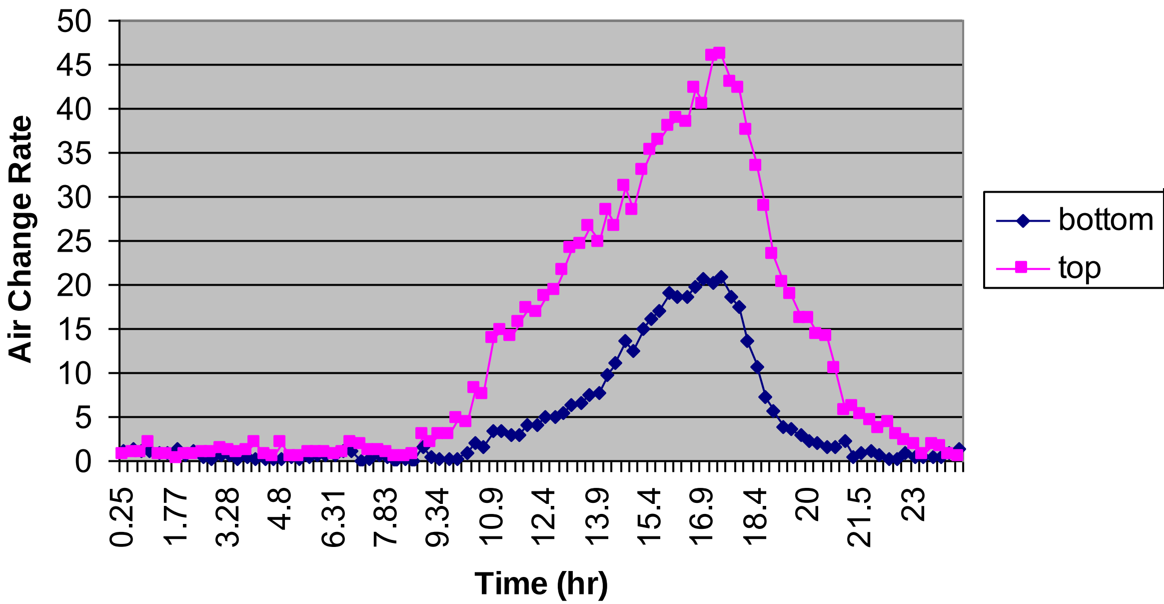


Field Monitoring



Air Changes per hour





Front Air Cavity

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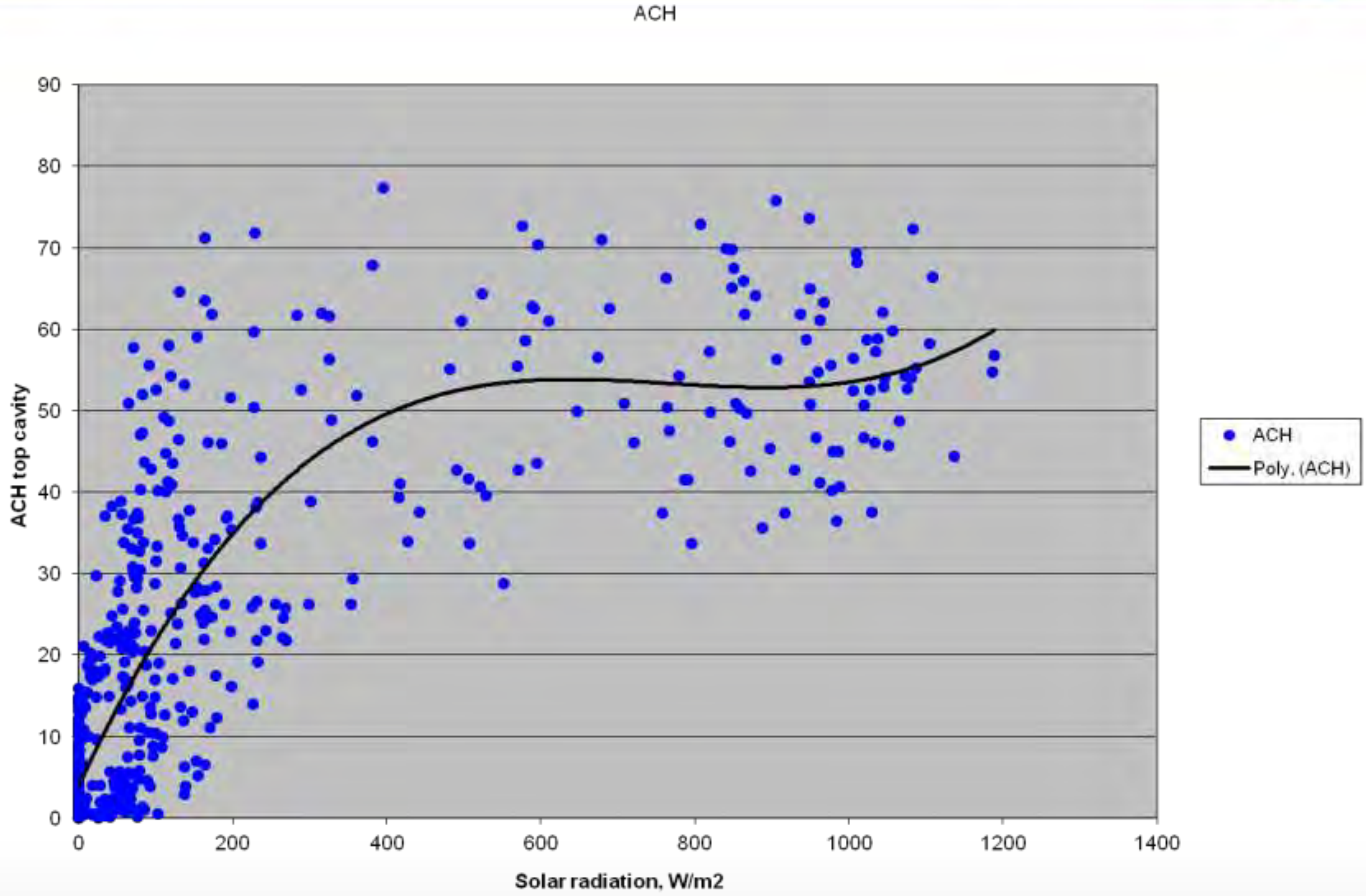

Conclusions

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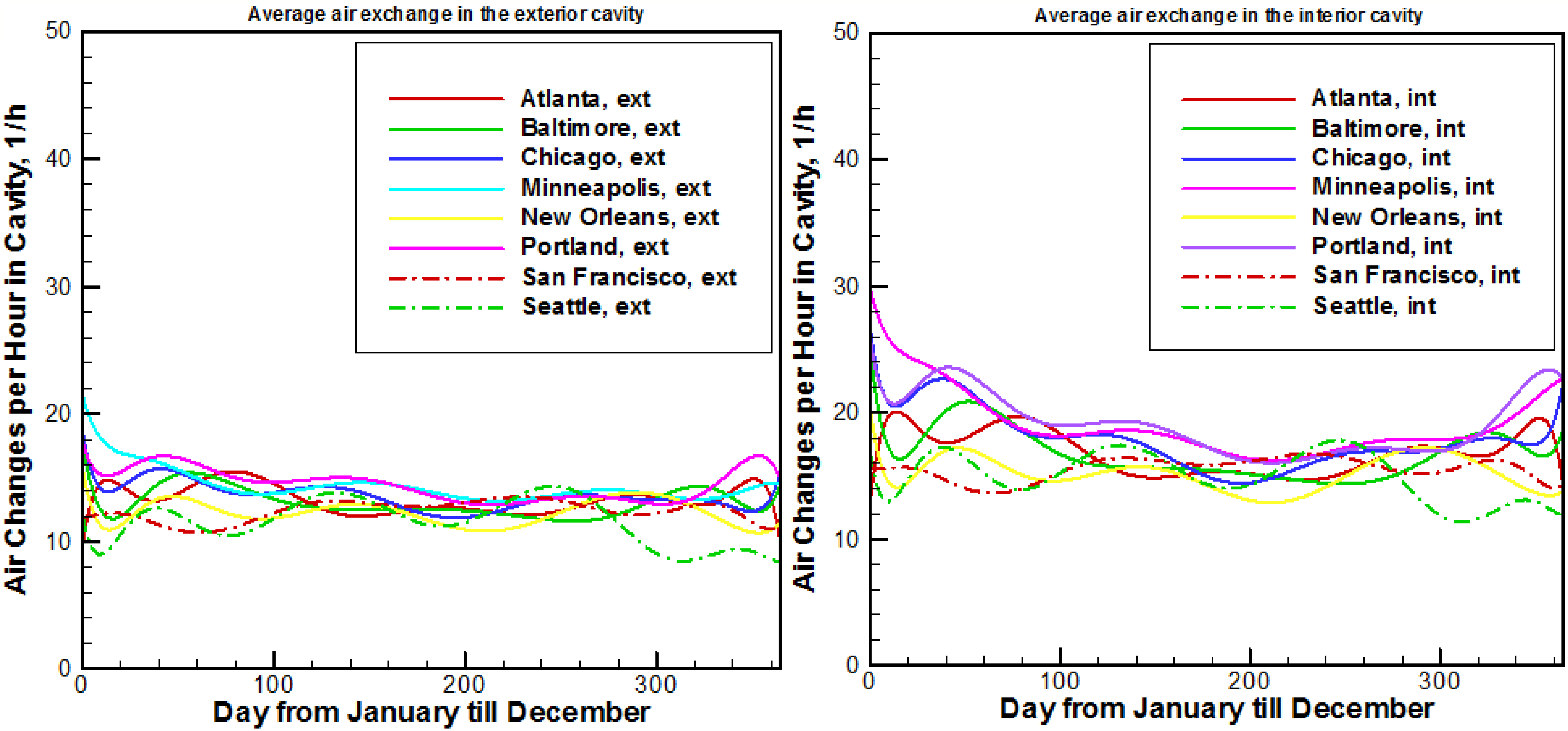
Max (Front 3-ST)	23.84
Average (Front 3-ST)	3.624
Max (Back 3-ST)	46.24
Average (Back 3-ST)	9.712
Max (Front 3-BR)	29.0
Average (Front 3-BR)	7.552
Max (Back 3-BR)	39.7
Average (Back 3-BR)	10.5
Max (Front 2-BR)	36.
Average (Front 2-BR)	5.100
Max (Back 2-BR)	59.2
Average (Back 2-BR)	9.254

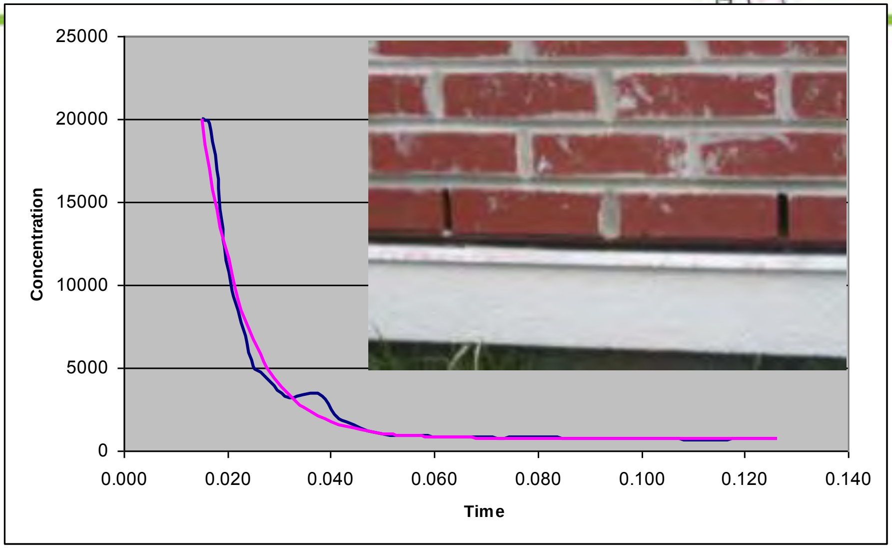
Max (Front 2-ST)	44.6
Average (Front 2-ST)	7.294
Max (Back 2-ST)	44.
Average (Back 2-ST)	7.60
Max (Front 1-ST)	46.9
Average (Front 1-ST)	6.150
Max (Back 1-ST)	33.2
Average (Back 1-ST)	5.79
Max (Front 1-BR)	11
Average (Front 1-BR)	14.44
Max (Back 1-BR)	38.6
Average (Back 1-BR)	5.668

Brick (Interior/Exterior ACH)



CO2 as Tracer Gas

Cladding Ventilation QUANTIFIED



Ventilated Brick
(**20**-120 ACH) for 1 to 4 m/s)

Vented Brick
(**5** - 45 ACH) for 1 to 4 m/s)

Cladding Ventilation QUANTIFIED

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Ventilated
(10 - 20 ACH) for 0 to 2 m/s)

Vented
(1.5 - 10 ACH) for 0 to 2 m/s)

Drainage

Test Conventional Approach

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Test Conventional Approach

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Drainage

Conclusions

- The first series of tests allowed the characterization of the flow in both front and back spaces for the three ventilation strategies.
- The result indicated that the highest resistance is due to the entry and exits in these air cavities at higher velocities.
- At low velocities (low air exchange rates) the inlet and outlet resistances diminish significantly.
- The conventional brick openings recorded a higher resistance than the slotted arrangement

Conclusions

- The flow along the length of the wall in either front or back air space is only slightly reduced by the height of the application of the Delta-Dry weather resistive barrier (8ft versus 16 ft versus 24 ft).
- At lower pressures, both front and bottom cavities became well ventilated (higher than 5 air changes per hour).
- The field tests show that the driving force is primarily due to solar radiation inducing buoyancy in the air space cavities.

Conclusions

- The buoyancy was present while the wall is directly within the solar path and a few hours after the direct sun impinging on the wall.
- The cavity ventilation flow seems to reduce rapidly, and is close to zero for at least 8 to 10 hours per day.
- This observation is true for the summer periods and may be different during other periods of the year, and at other climatic locations, and orientations.
- The effect of wind was not found to be significant driver for air flow through either front or back cavities.

Conclusions

- However, wind pressures may vary a lot on the building shell depending on the building, its design and surrounding structures and therefore definite conclusions can not be made based on this individual study.

- To understand the moisture performance, simulations can be performed using the results generated in this project, to address these issues.

Validation work for Solar Driven Moisture

Brick/Stucco
Air Space-B
SPBO
OSB
FIB
GYP
Vinyl Wall

APPARATUS

- Weighing Cups
- Balance
- Drying Ovens

APPARATUS (CONTINUED)

- Environmental Chambers
  - Temperature and Humidity controlled
  - Use Salt Solutions (ASTM E 104)

WVP of some materials

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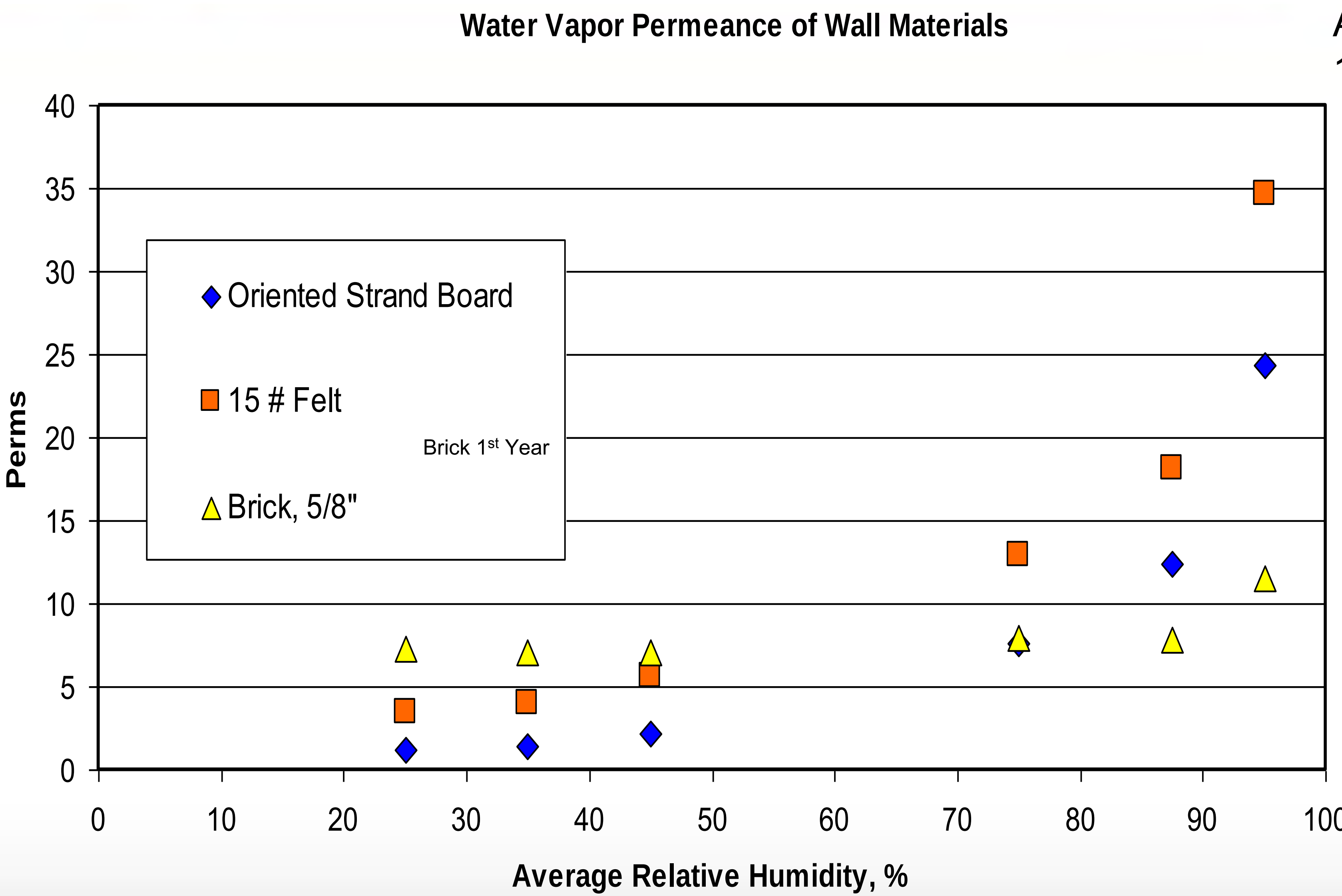
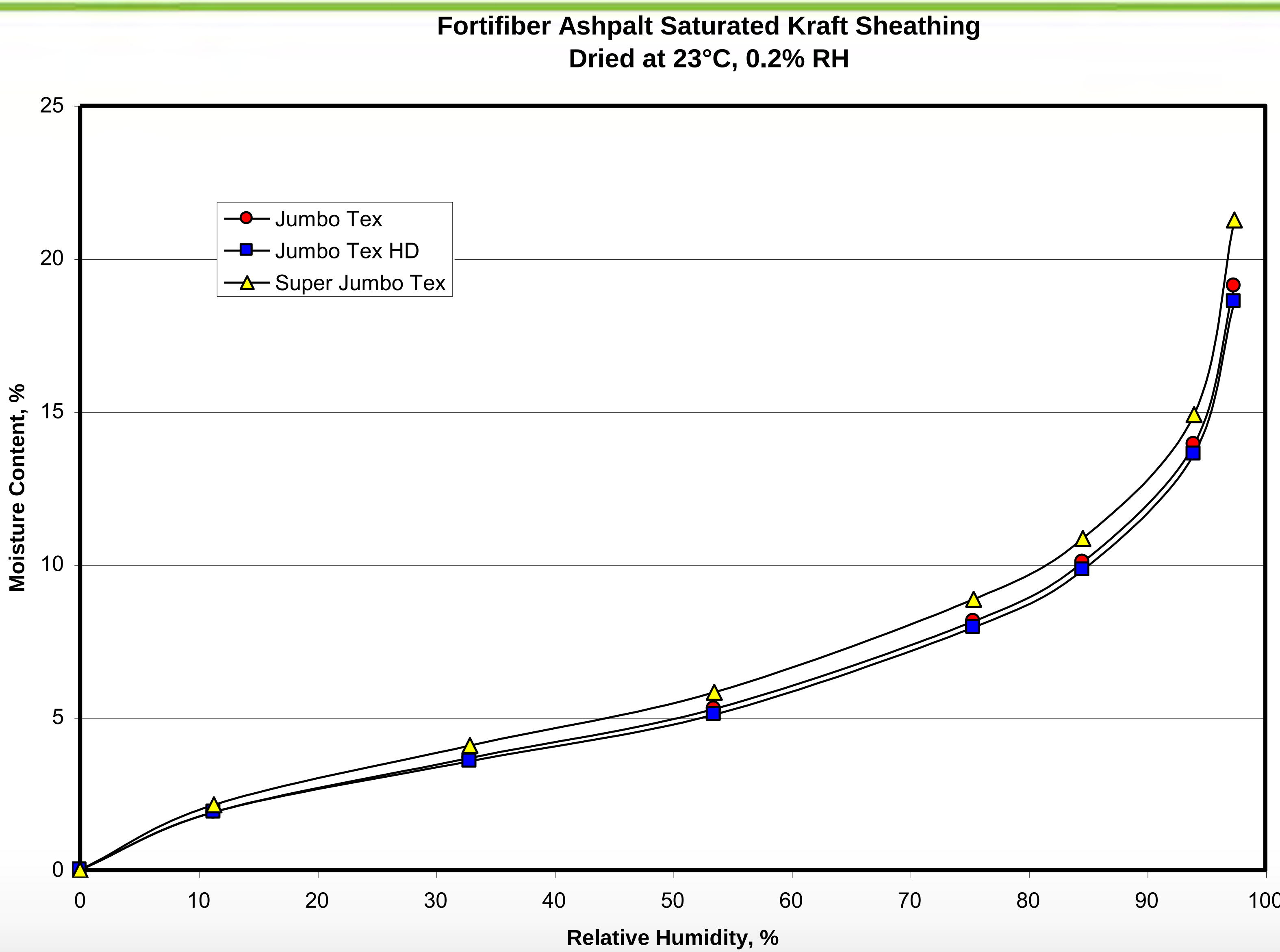
ASHRAE 1325



Sorption Isotherm of some materials



ASHRAE 1325

Liquid Uptake

- Avalue Old Brick (2005-2006)   A= 0.1 kg/m2
- Avalue New Brick (2006-2007)   A= 0.8 kg/m2

New Results

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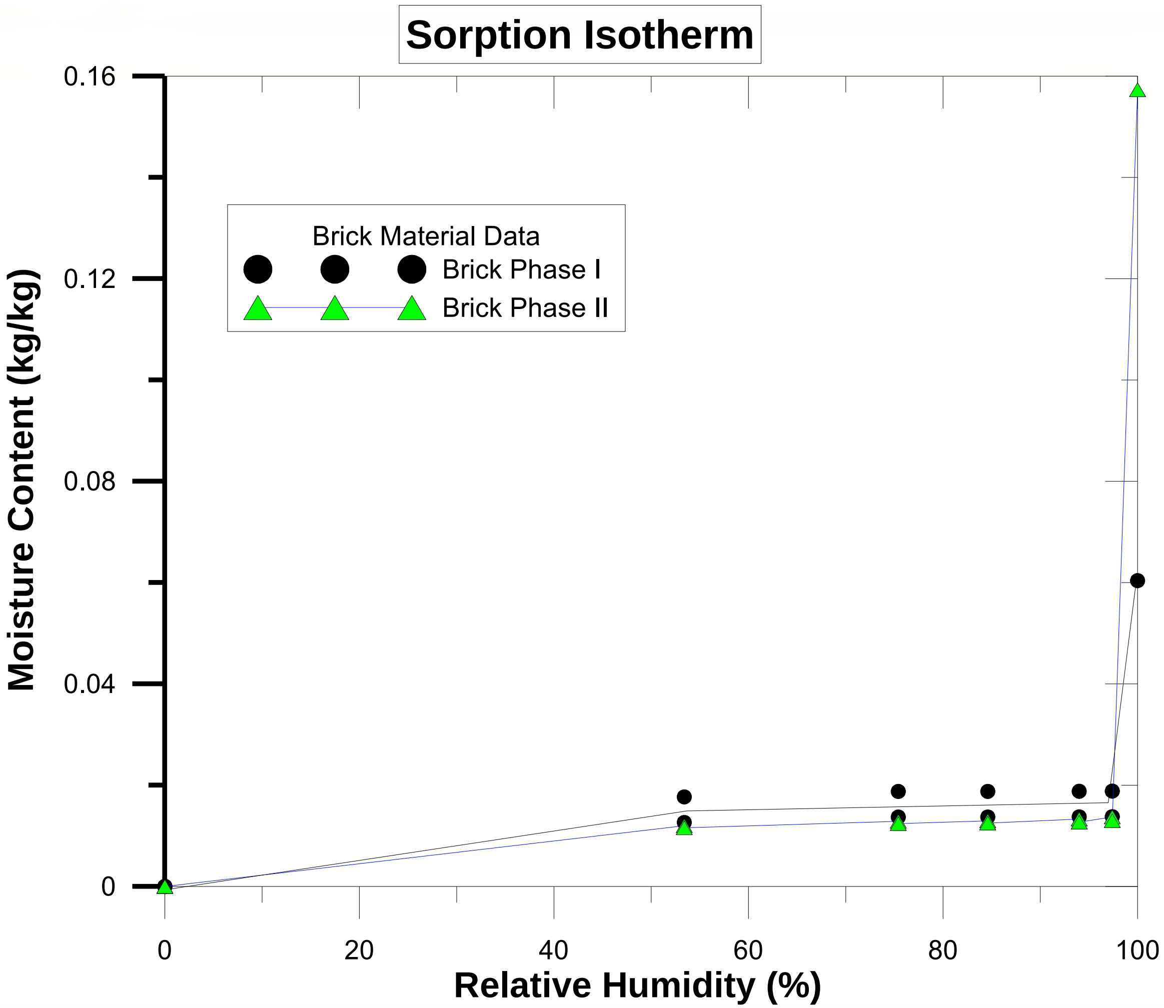
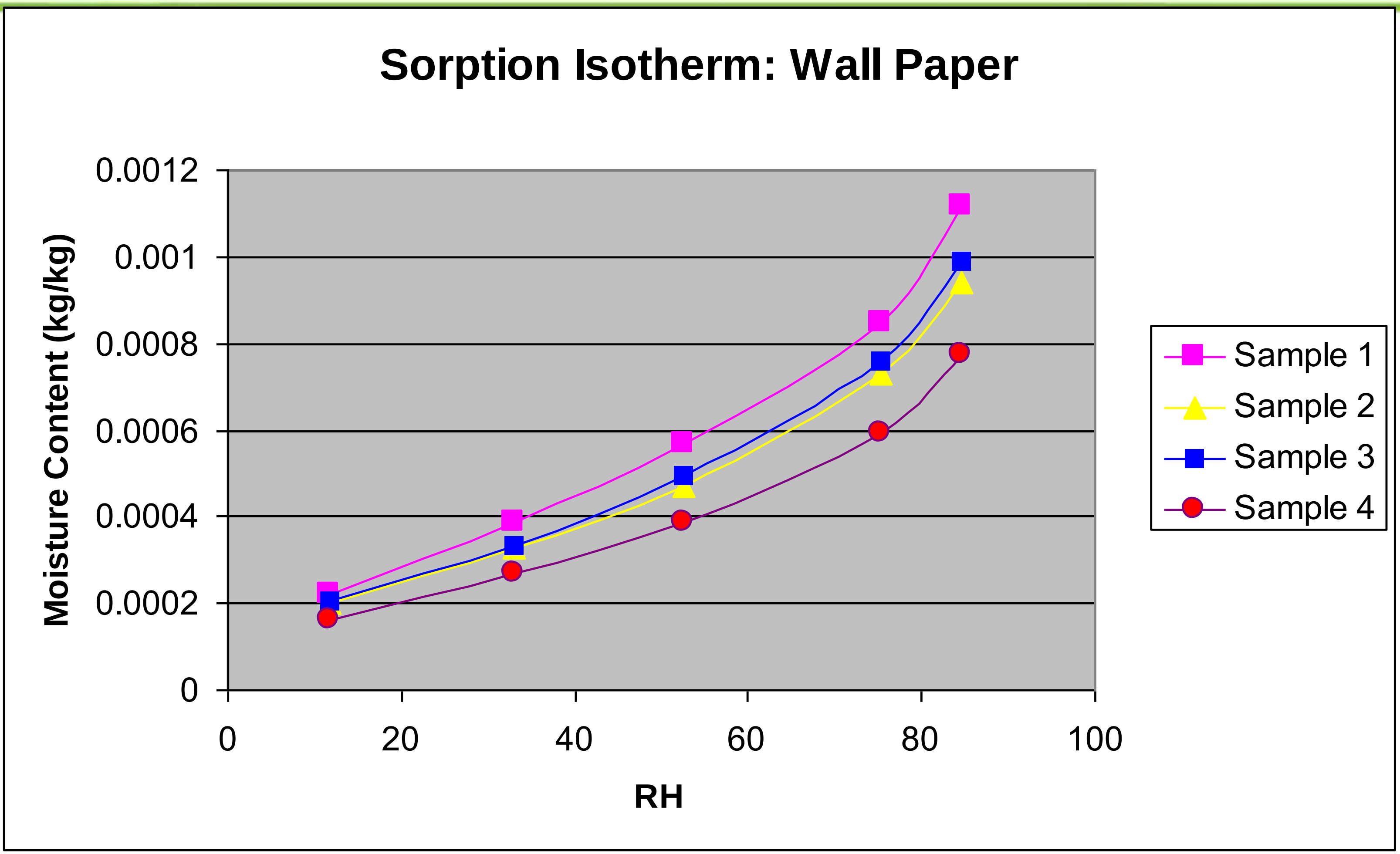
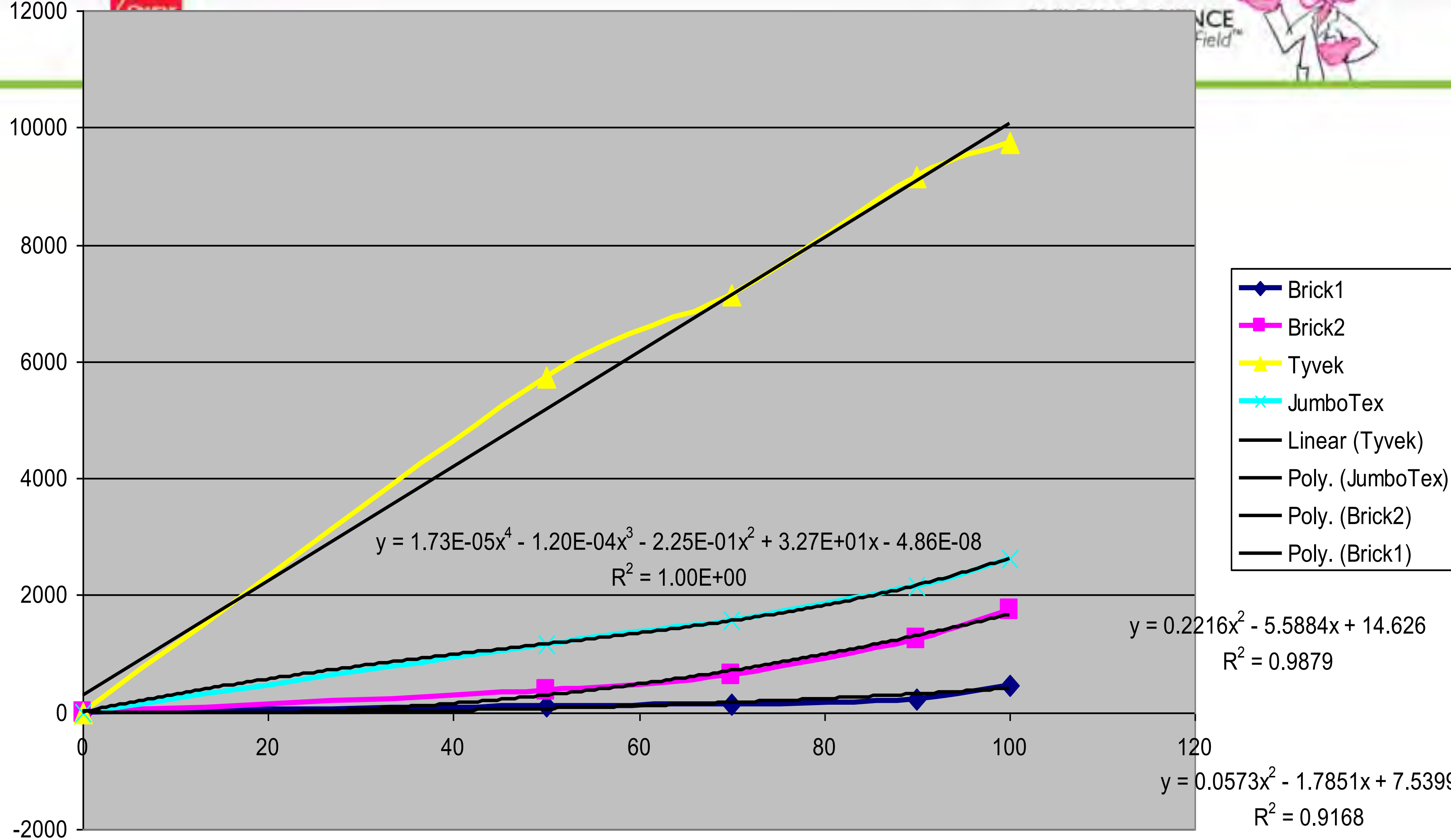


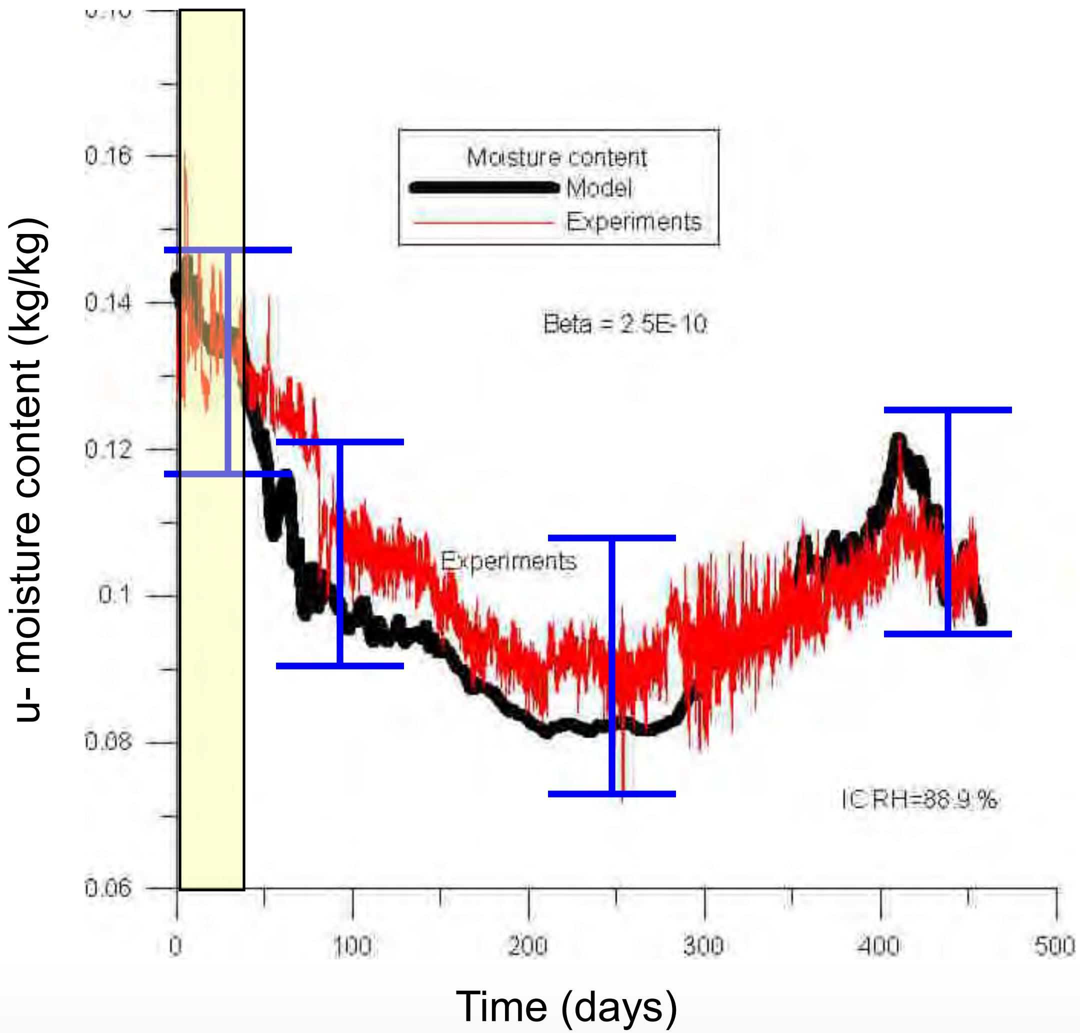
New Data


Sorption Isotherm: Wall Paper
Moisture Content (kg/kg)
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
0
20
40
60
80
100
RH
Sample 1
Sample 2
Sample 3
Sample 4

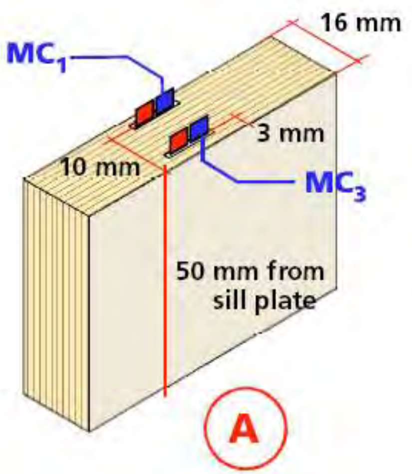
Kirchoff's Potential for Vapor Flux Analysis



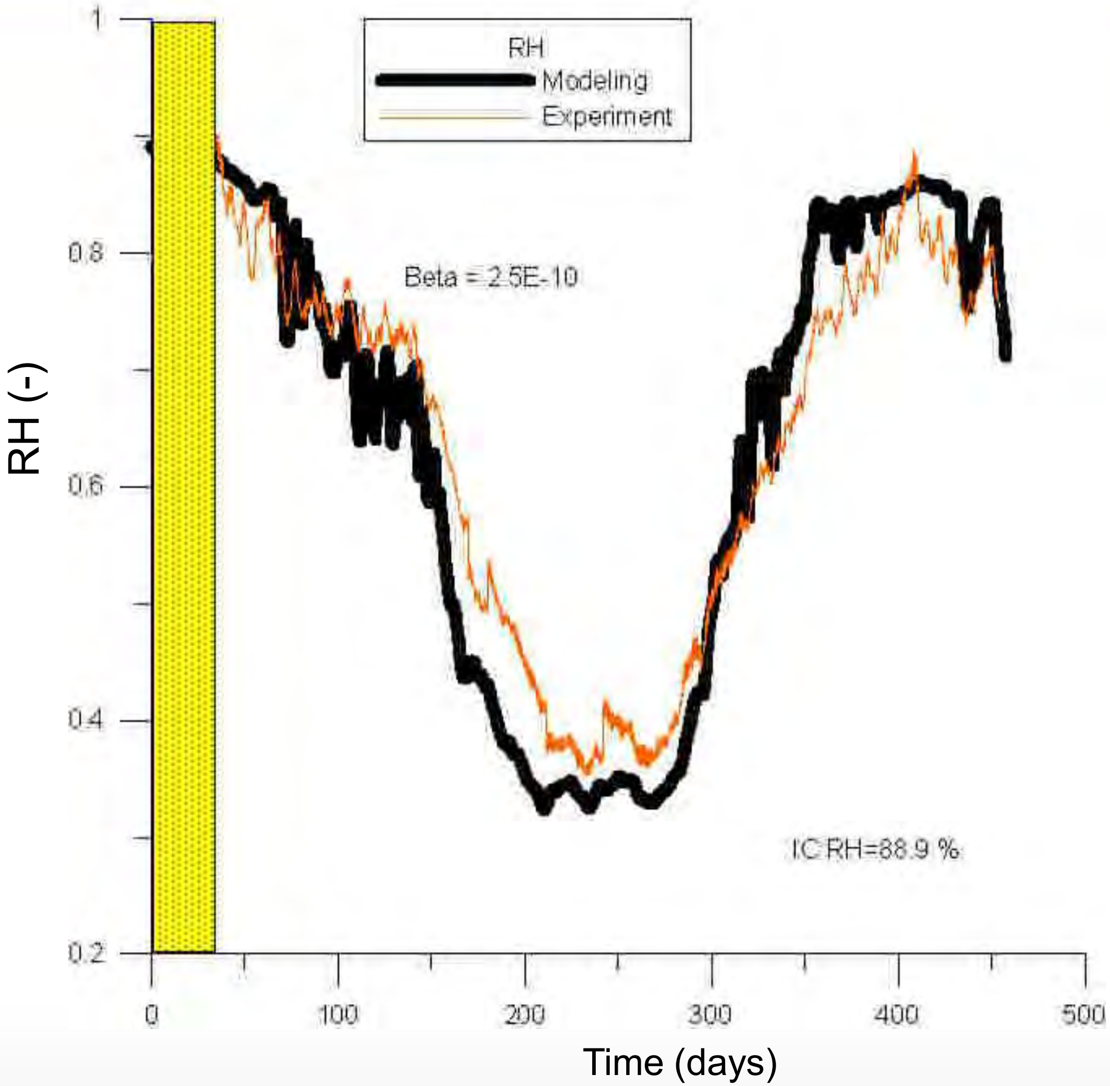
Validation Data: Moisture Content MC1



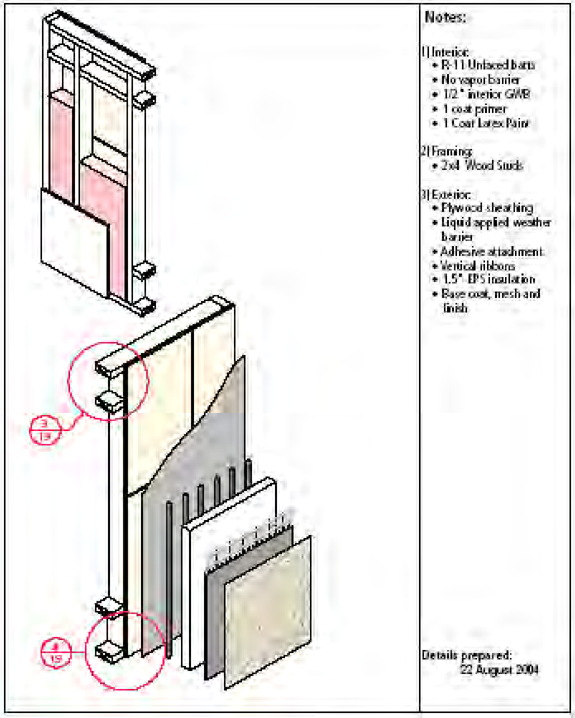
MC 1: 10 mm depth



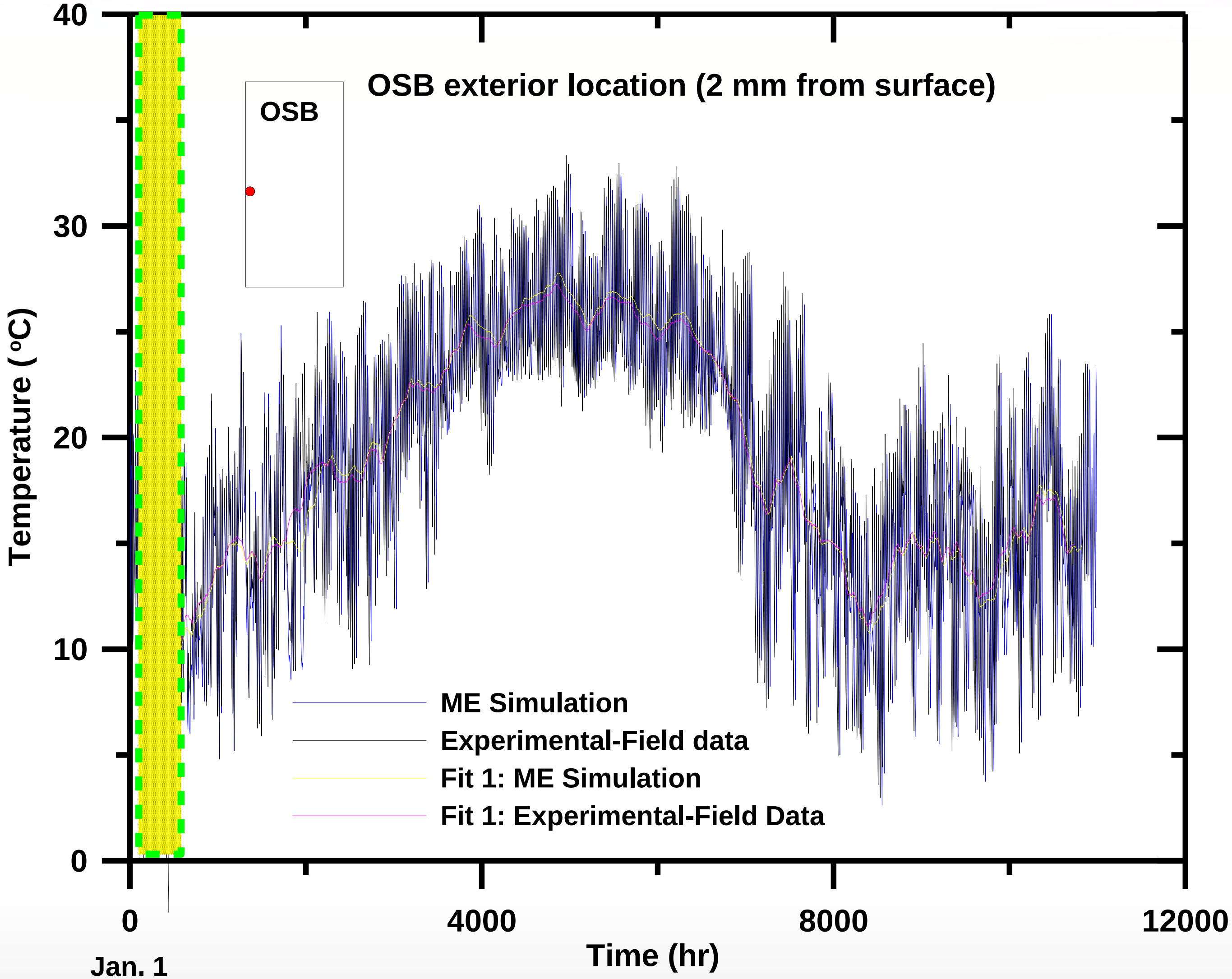
Validation Data: Moisture Content RH3



Plywood RH3



Validation Data: Temperature T11



Observations from Modeling vs Field

- Good agreement (ME and Field)
- Agreement with RH, T and Moisture Content
- Validation requires full material properties
- Needed to include effects of cladding venting potential
- Solar radiation important
- Wind driven rain important

New Validation: ASHRAE 1235

- **Wall 1: Validation**

Brick Cladding

Brick Cladding Validation

- Material Properties were measured
- Issues with rain loads + Weather data completeness + testing
- Water Penetration ?

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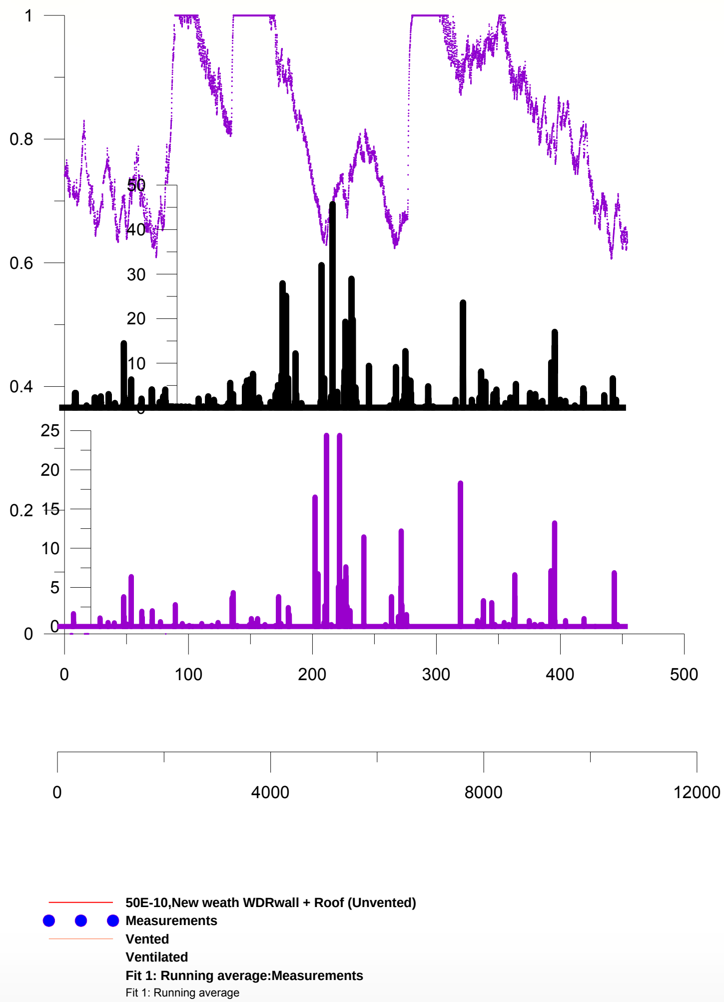
No Water Penetration

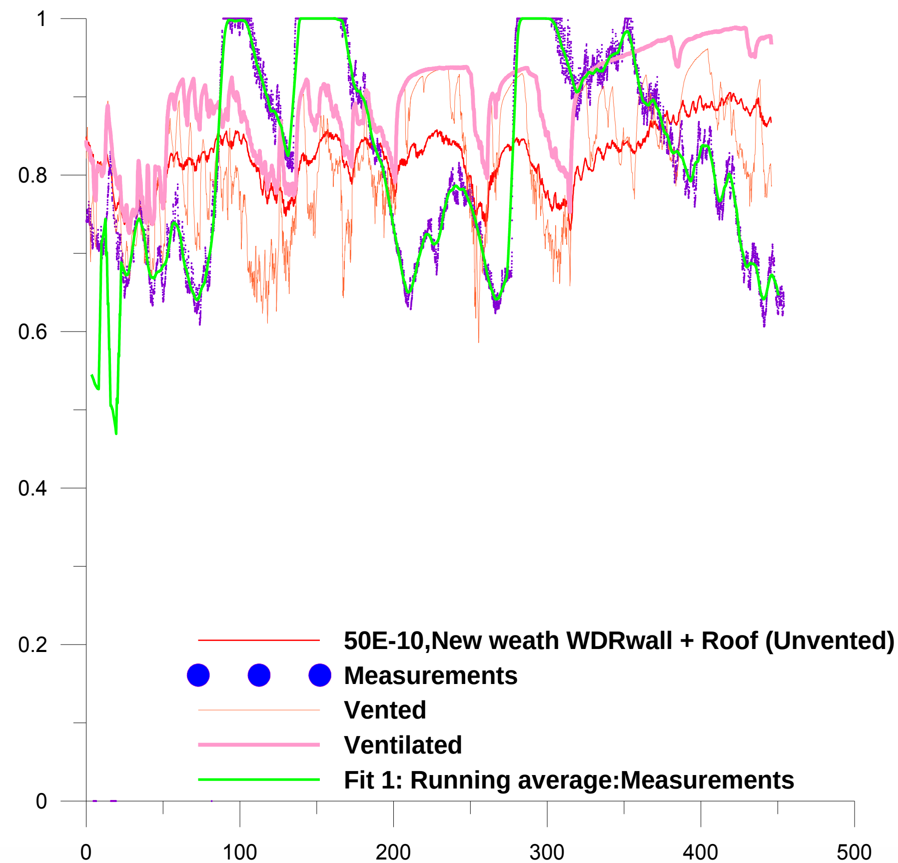
No Water Penetration Very Permeable inside 50E-10

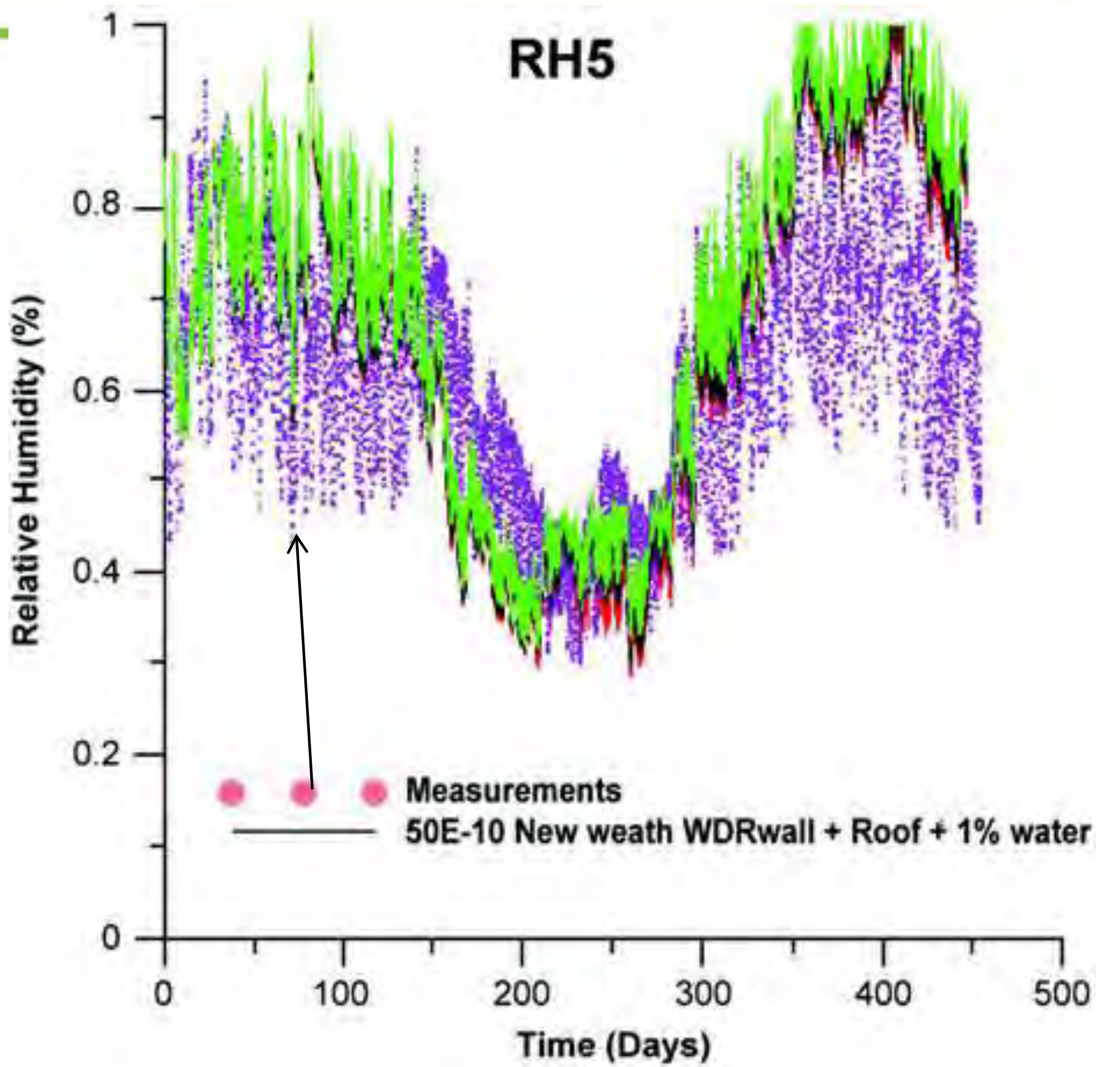
RH1



Very Permeable inside 50E-10

RH3

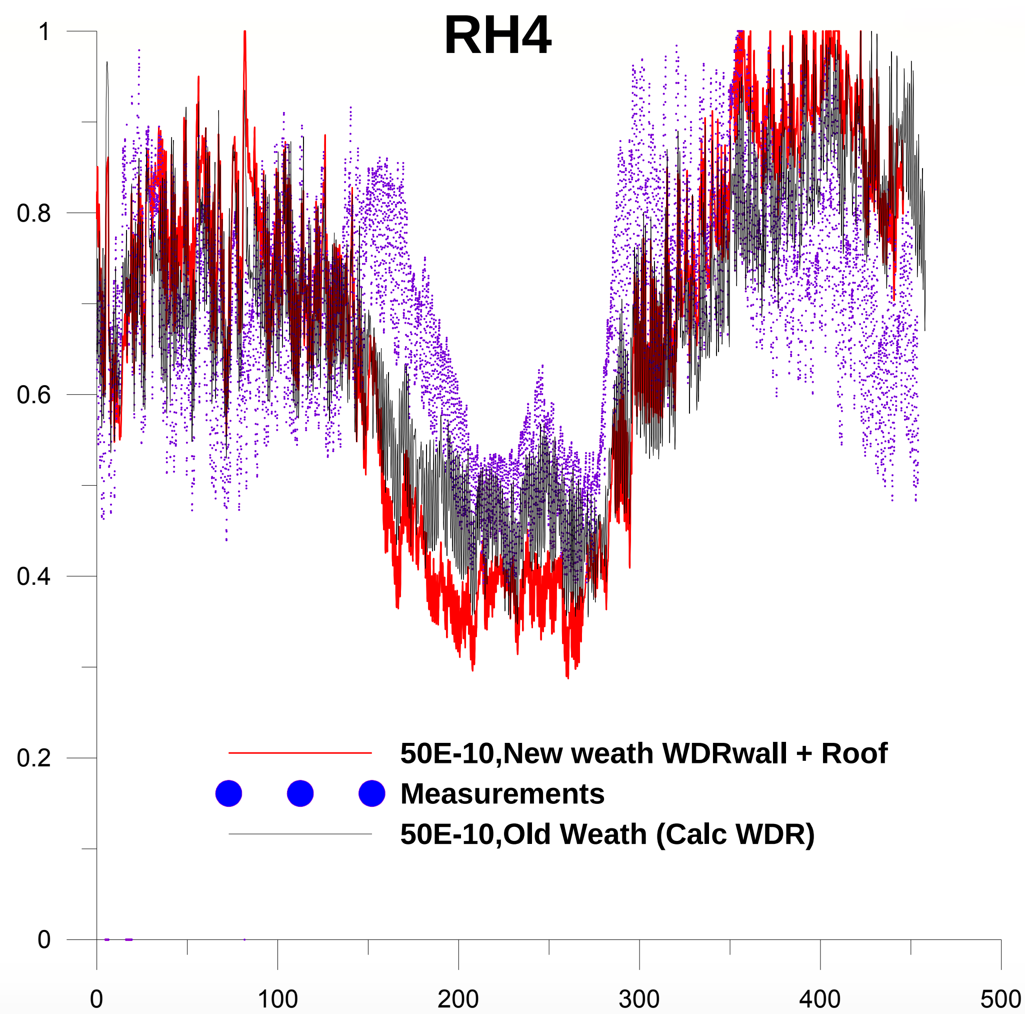



RH5
Relative Humidity (%)
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
Time (Days)
Measurements
50E-10 New weath WDRwall + Roof + 1% water

No Water Penetration

Very Permeable inside 50E-10

No VCVENT



Deconstruction

The issues

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The issues

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The issues

The issues

Conclusion

- Workmanship in buildings can alter the performance in a major way. Critical to the validation of models.
- Measured material properties are very important in validation analysis.
- Low absorptive claddings are favorable in wet and hot climates.
- Results demonstrate confidence in hygrothermal models for simulations.

Another BIG CONCLUSION

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- Leave the **model validation to the EXPERTS- developers… Very few of you can even use a model correctly.**

- Do **not** say you validated a model…. By using material properties from the database, weather data from the database, and ASHRAE SPC 160 interior conditions…..

- You may say you calibrated your model…

Thank you

Questions ?