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4th IBPC 4th International Building Physics Conference

Istanbul 15-18 June 2009

Istanbul Technical University

MOISTURE MANAGEMENT AND ENERGY ANALYSIS IN BUILDINGS

Part III- *Assessment of Energy Rating of Polyurethane Foam Walls*

Wahid Maref, Hakim Elmahdy, Mike Swinton and Fitsum Tariku

4th IBPC, Istanbul, Turkey, 14 June 2009

Outline

- *Background*
- *Project objectives*
- *Scope*
- *Wall samples*
- *Testing protocol*
- *Interim results*
  - *Air leakage*
  - *Wall R-value*
  - *Material Characterization*
- *Computer modeling*
- *WER calculation*
- *New developments*
- *Closing remarks*

Background Review

- *Canadian Building Code Requirements*
- *Canadian Construction Materials Center (CCMC) Air Barrier Guide 07272 (1996)*
- *Glass fiber and spray polyurethane foam (SPF)*
- *Energy Rating of building components*
- *Focus on Wall Energy Rating (WER)*
- *Joint research project:*
  - *NRC-IRC, foam contractors and material suppliers*

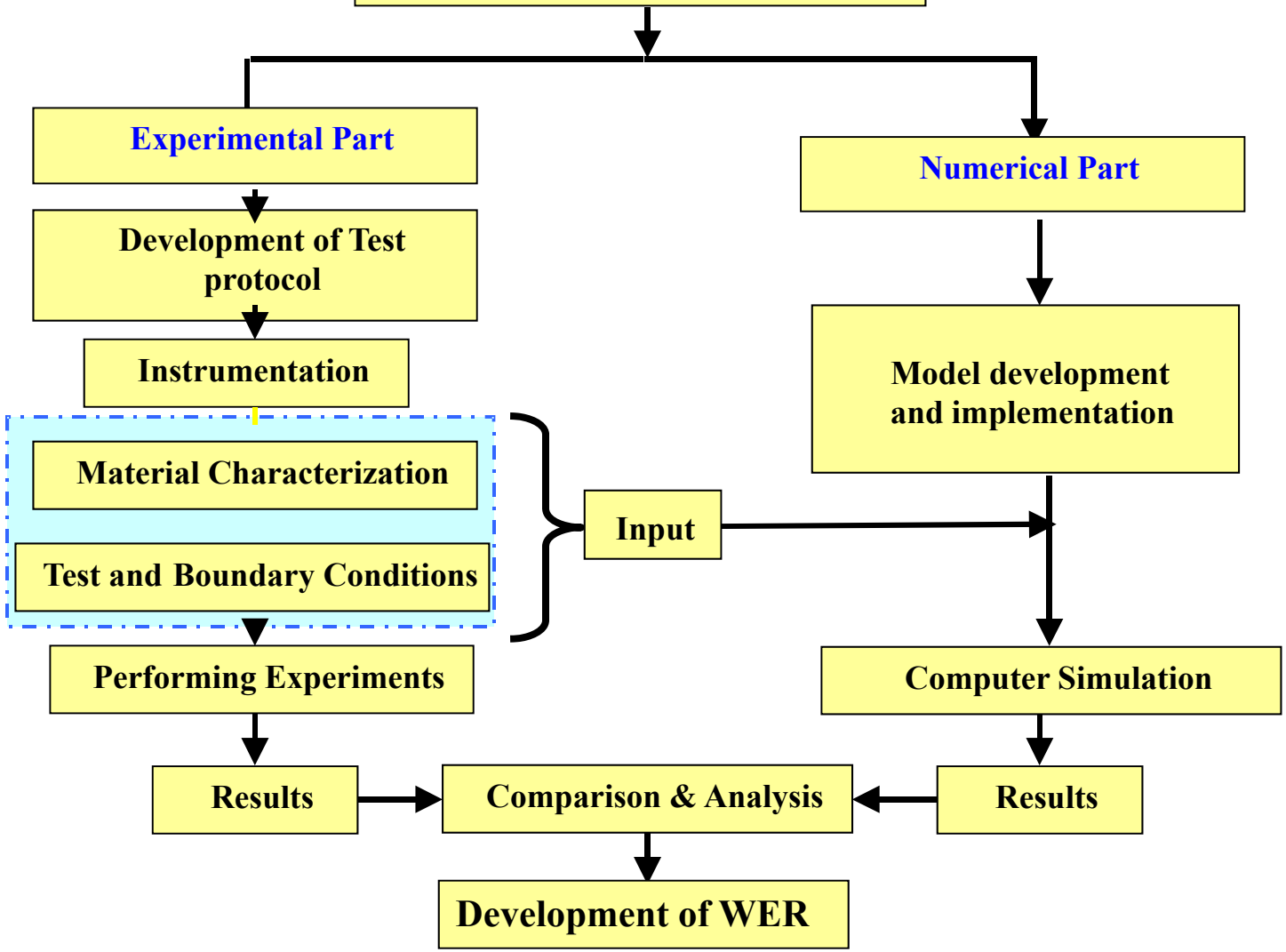
Objective

- ***To determine Wall Energy Rating (WER) of walls constructed according to field practices with spray polyurethane foam insulation, by combining measured heat losses due to conduction and air leakage.***

Scope

- *Define wall test samples and test conditions*
- *Develop the methodology to determine WER*
- *Develop a test method to determine WER (air leakage, R-value, etc.)*
- *Develop a calculation procedure to calculate WER and simulation algorithms*
- *Characterize the materials*
- *Compare test and computer simulation results*
- *Calculate WER for the wall samples*
- *Document the outcome*

Wall Energy Rating (WER) Project overview



Wall Samples: Stage I

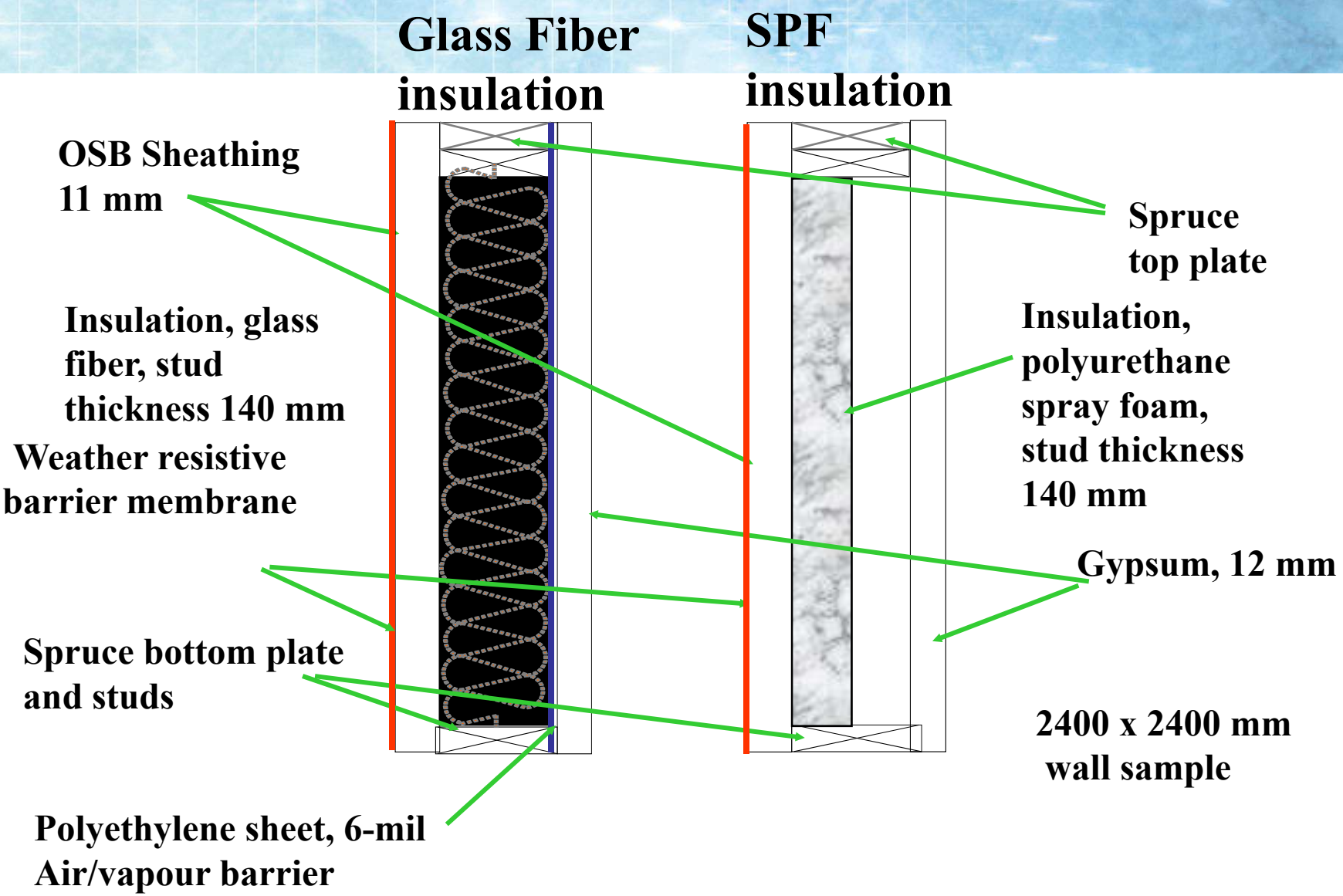
- ***Six 2" x 6" spruce stud walls, 16" spacing (nominal)***
  - ***one sample without penetration, with glass fiber (reference wall sample WER-1)***
  - ***one sample without penetration, with foam (WER-2), HCFC 141b blowing agent***
  - ***one sample without penetration, with spray polyurethane (WER-3a) HFC-245fa blowing agent***
  - ***two samples, with penetration, spray polyurethane foam (WER-3b, HFC-245fa and WER-4, HCFC 141b blowing agent)***
  - ***one sample, with penetration, glass fiber, reference wall (WER-5)***
- ***All foam products are medium density meeting ULC 705.1 2001 standard***

Wall Description Stage I

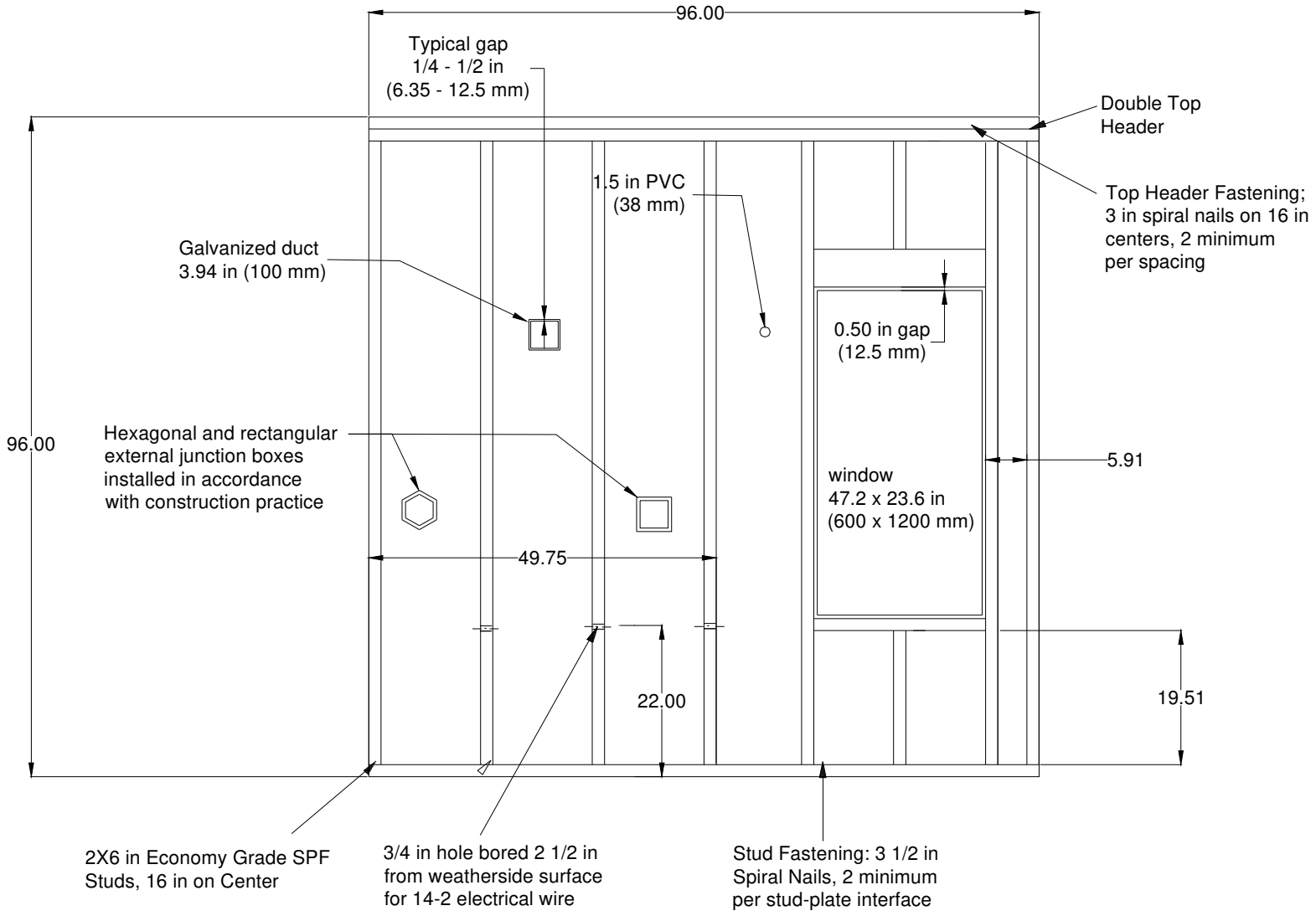
Wall #	Insulation type	Description
WER-1	Glass fiber	Reference wall-blank with interior and exterior electric outlet
WER-2	HCFC-141b Blowing Agent	Reference wall-blank with interior and exterior electric outlet
WER-3a	HFC-245fa Blowing Agent	Foamed wall with penetration
WER-3b	HFC-245fa Blowing Agent	Foamed wall with penetration
WER-4	HCFC-141b Blowing Agent	Foamed wall with penetration
WER-5	Glass fiber	Reference wall with penetration

Wall Samples (Cont.)

- *OSB facing*
- *Weather resistive barrier membrane*
- *Air barrier (poly) in the glass fiber wall sample*
- *No cladding*
- *Wall dimension : ~ 2.4 m x 2.4 m nominal*
- *All penetrations are according the CCMC Guide (CCMC Air Barrier Guide 07272)*

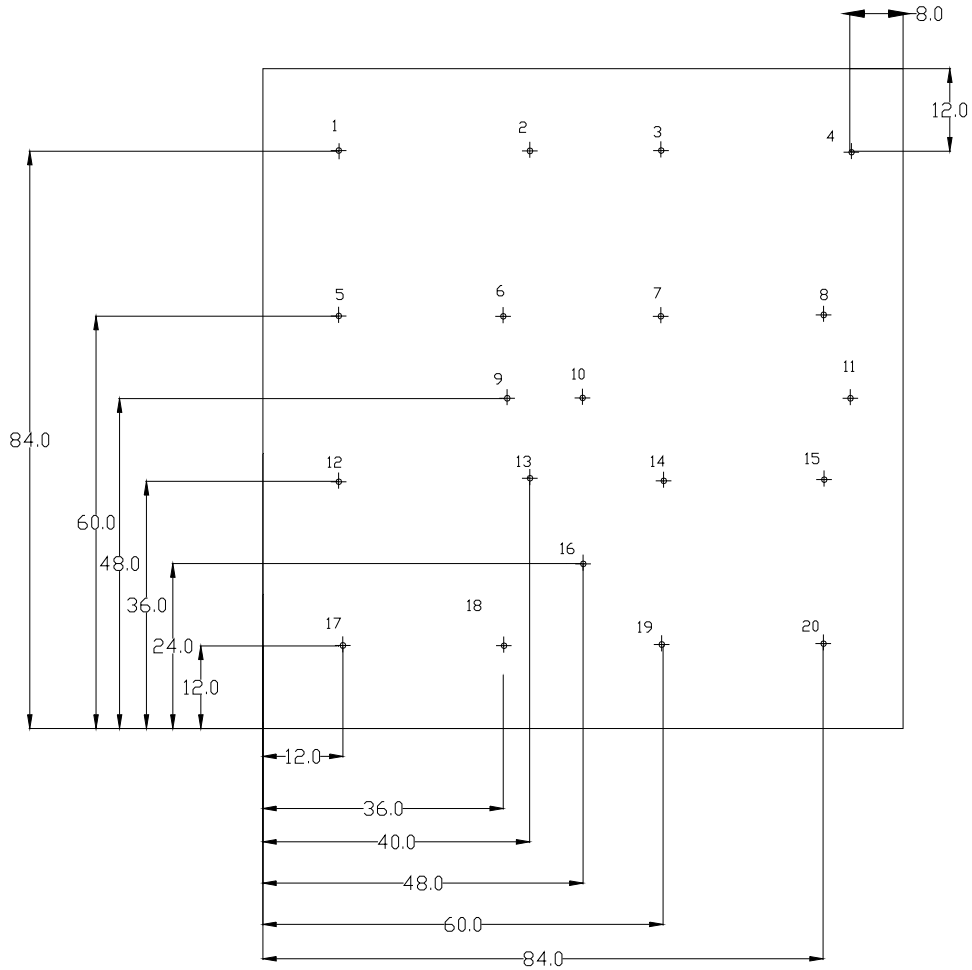


Cross-section of typical wall samples

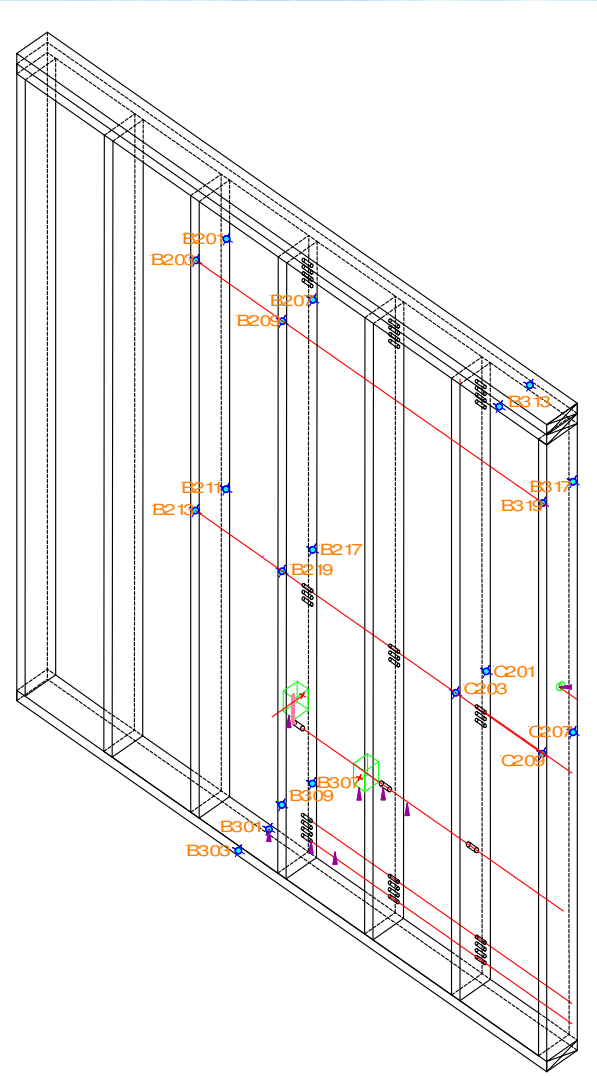


Penetrations layout (CCMC Air Barrier Guide 07272)

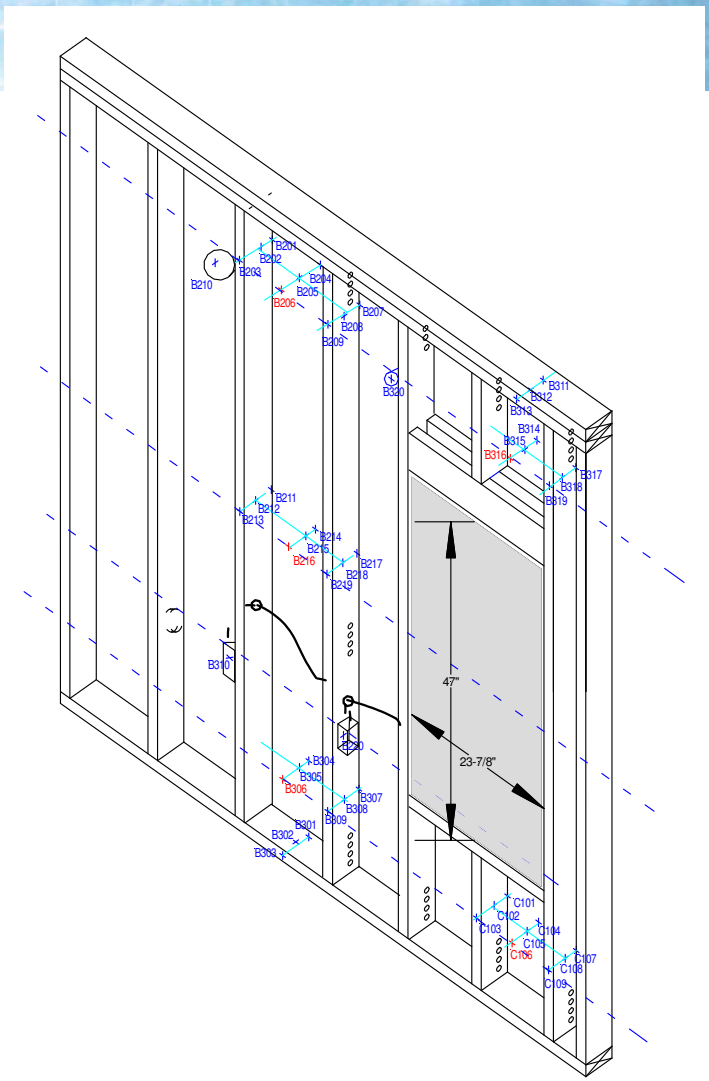
Thermocouple locations for surface temperature measurements



Wall Specimen
(no penetration)



Wall Specimen
(with penetration)

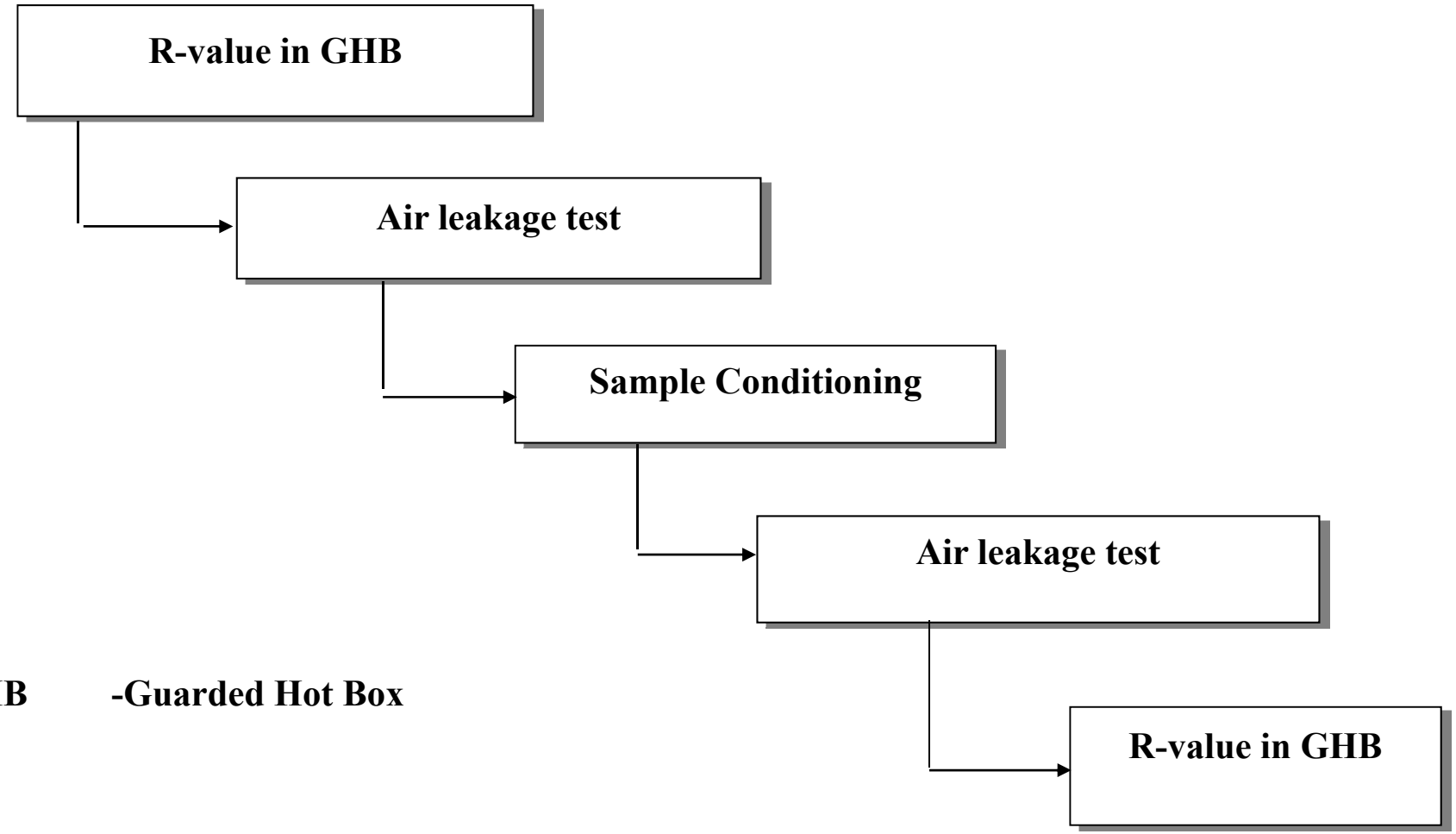


Interstitial thermocouple locations

Test Protocol

- All test procedures were performed according to well established national and/or international standards:
  - Air leakage (ASTM E283)
  - Wall thermal Resistance (ASTM C1199 and ASTM E1423)
  - Material characterization (ASTM C518-98) using heat flow meter
  - Sample conditioning (according to CCMC Technical Guide for Air Barrier Systems for Exterior Walls of Low Rise Buildings (Masterformat Section 07272)

Test Sequence



GHB -Guarded Hot Box

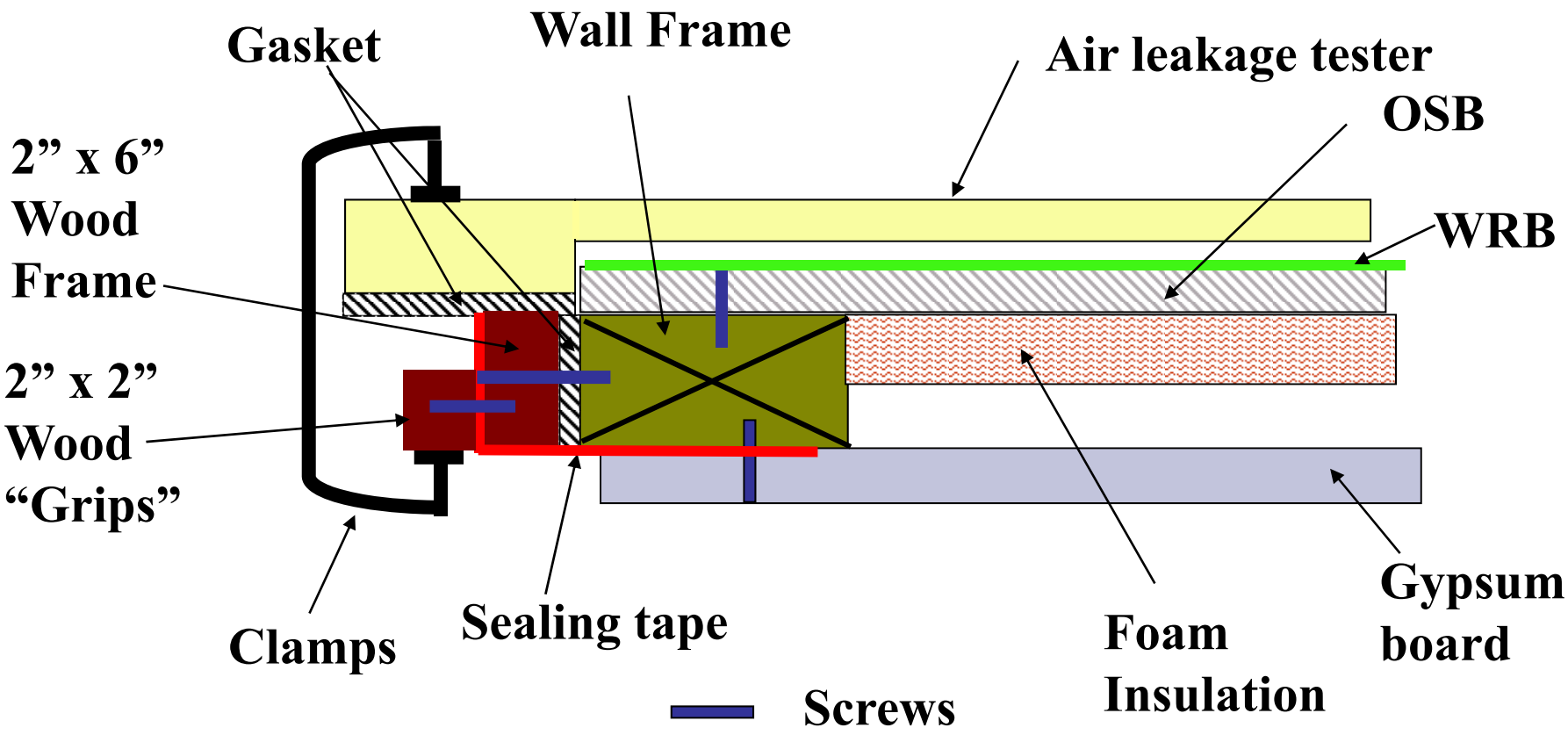
Interim Results

Air leakage test results

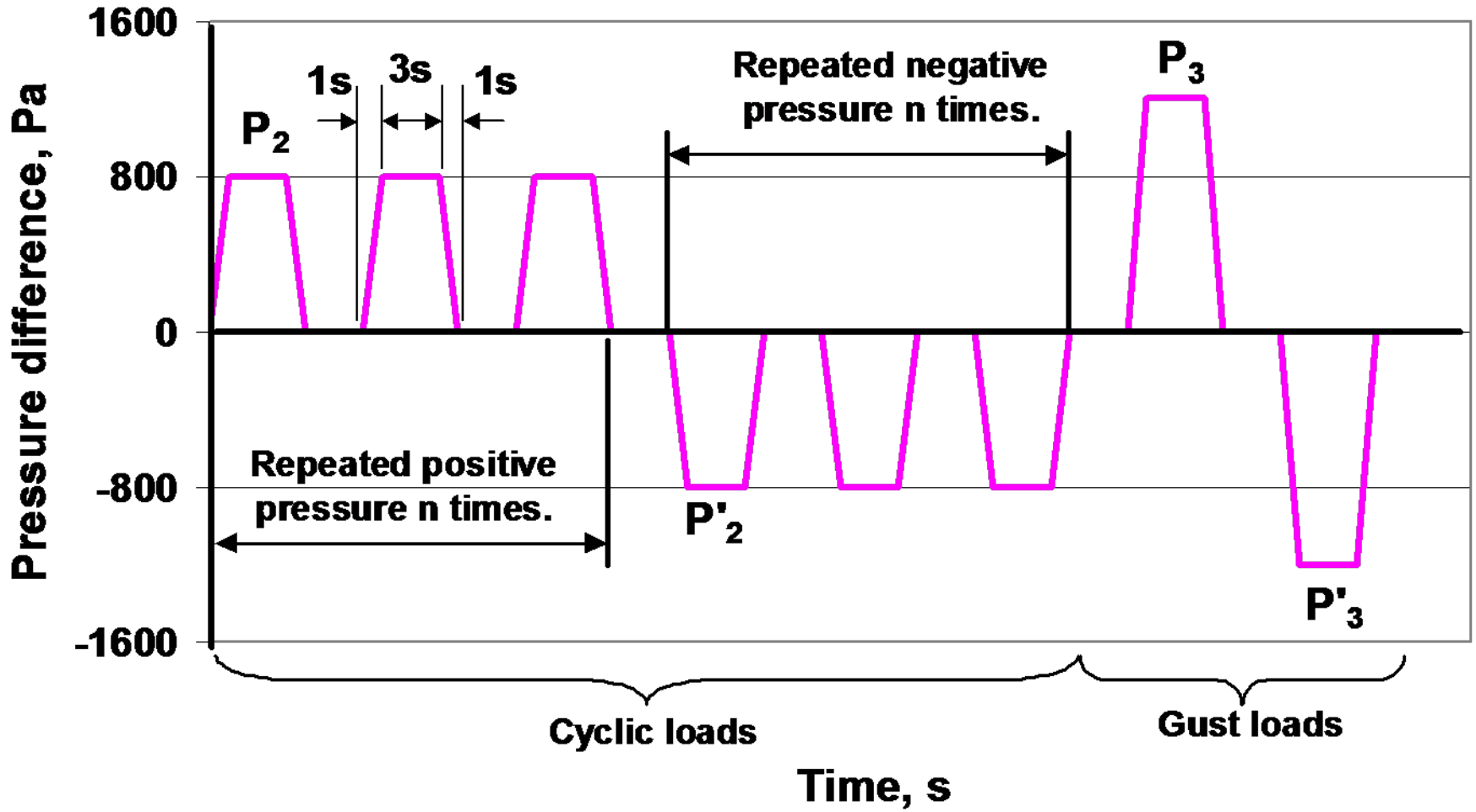
- Infiltration results are reported here
- Comparison test results of the six walls
- Note: For WER-1 and WER-5 (glass fibre walls), the poly was lapped and NOT sealed.

- NBC 2005: 9.25.3.3 Sealed OR Lapped not less than 100 mm and clamped

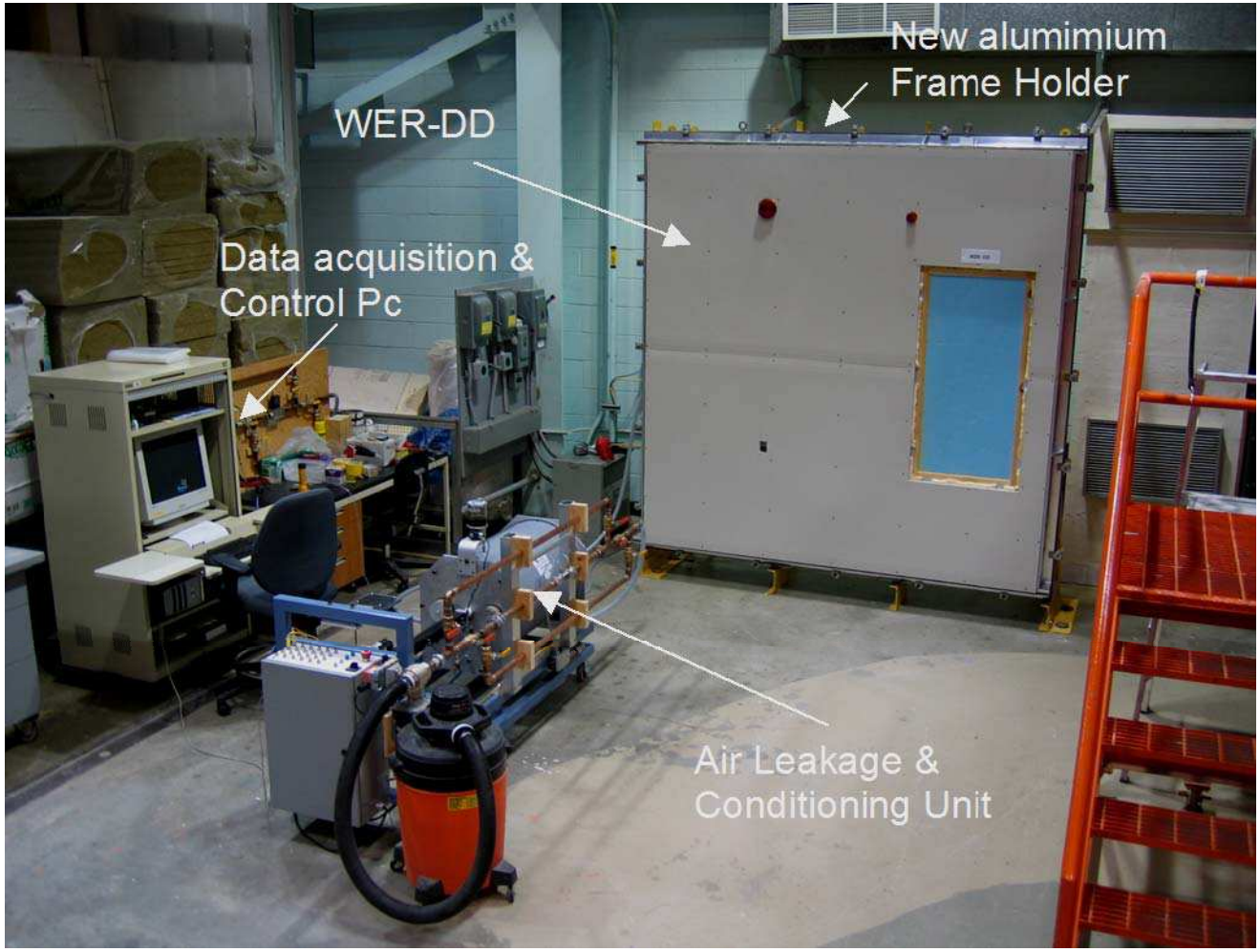
Sample mounting for air leakage test



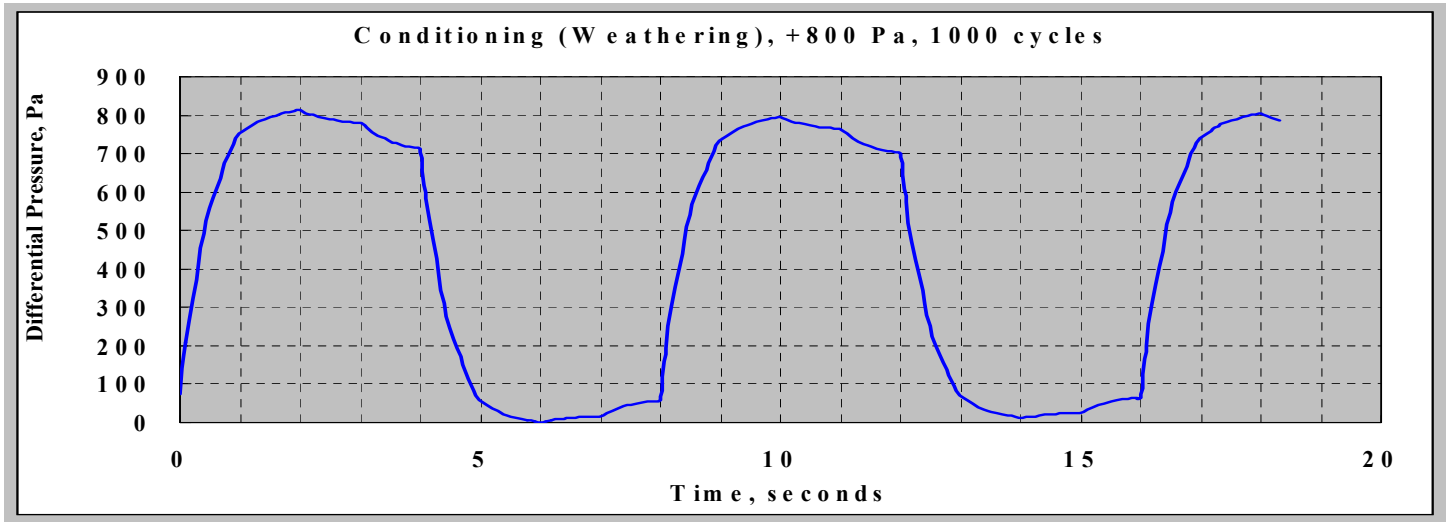
Pressure cycle for sample conditioning

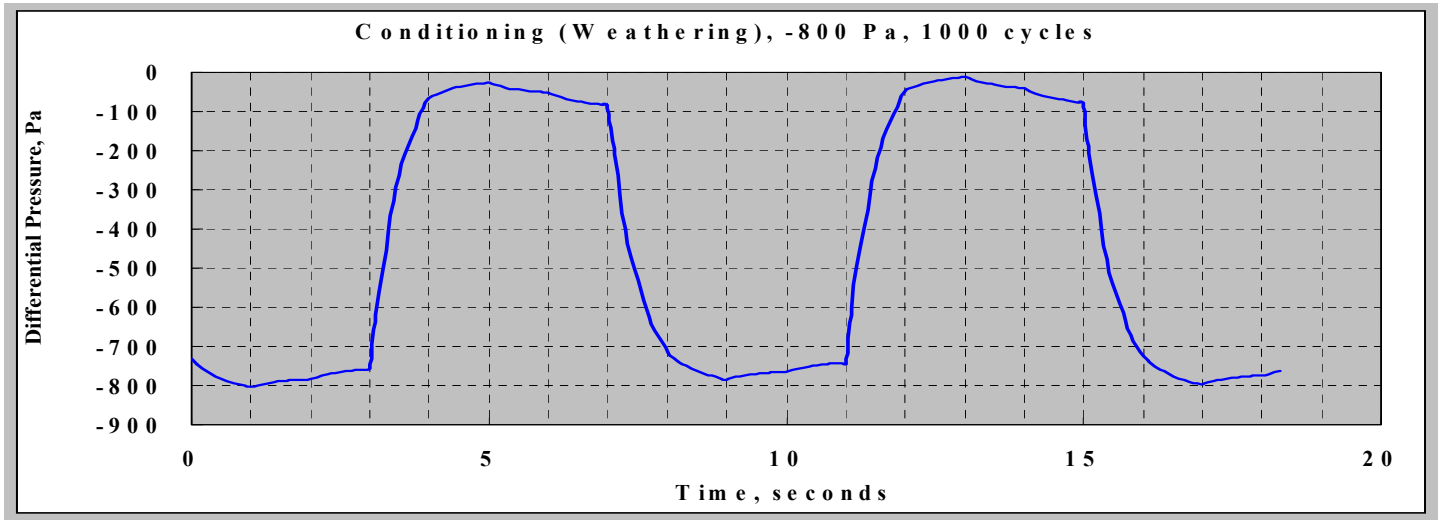


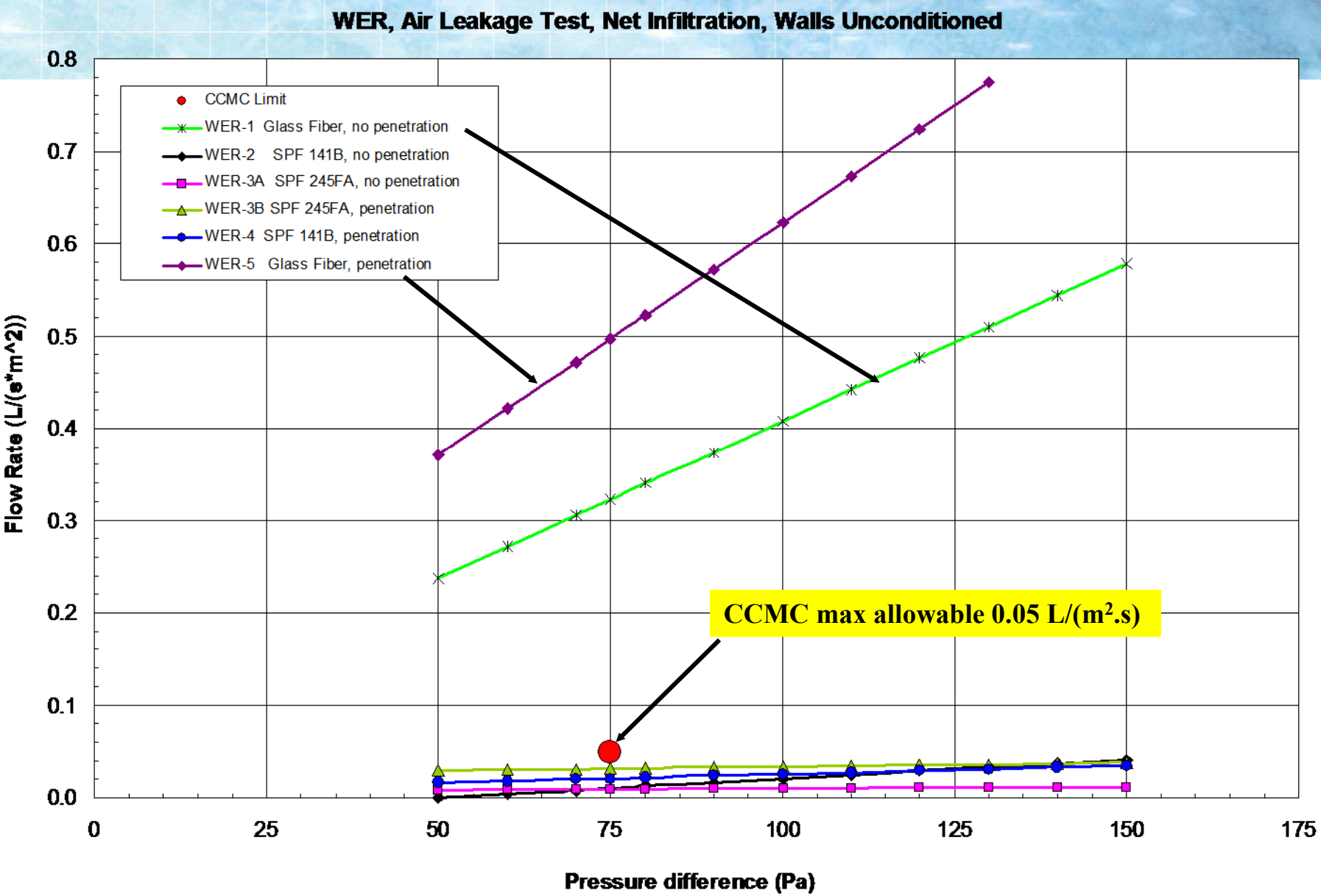
Air Leakage & Conditioning Test Apparatus



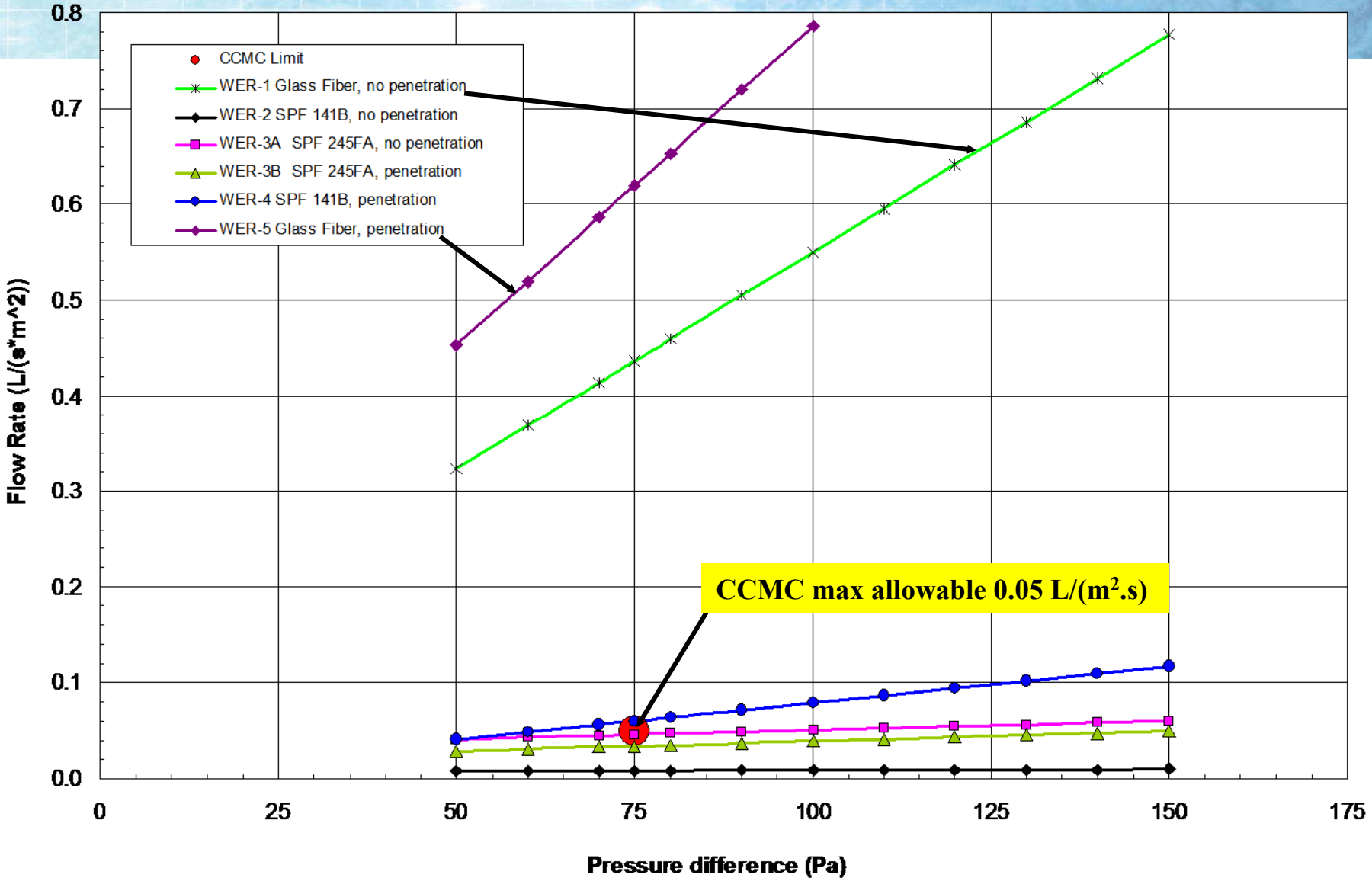
Air Leakage Test Apparatus and Procedure: Conditioning Profile






WER, Air Leakage Test, Net Infiltration, Walls Unconditioned
CCMC Limit
WER-1 Glass Fiber, no penetration
WER-2 SPF 141B, no penetration
WER-3A SPF 245FA, no penetration
WER-3B SPF 245FA, penetration
WER-4 SPF 141B, penetration
WER-5 Glass Fiber, penetration
CCMC max allowable 0.05 L/(m².s)
Flow Rate (L/(s*m^2))
Pressure difference (Pa)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
25
50
75
100
125
150
175

WER, Air Leakage Test, Net Infiltration, Walls Conditioned



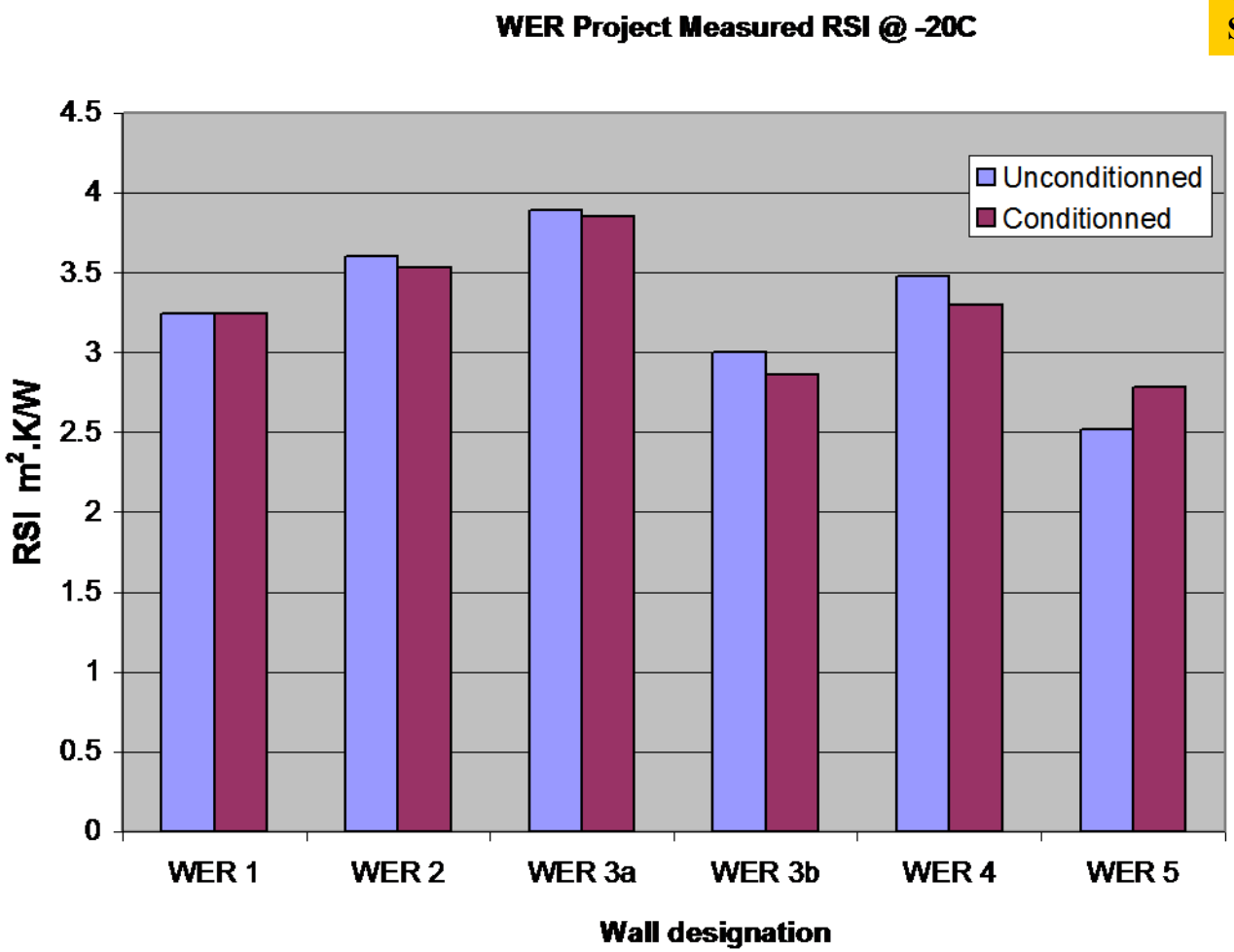
Experimental R-value

- Use of guarded hot box
- Well established test procedures: ASTM E1423 and C1199
- Testing was performed before and after wall sample conditioning
- Testing was performed at two temperature settings

Guarded Hot Box

Test Results: R-value

Glass fiber batts: 150 mm (nominal)
SPF: 75 mm (nominal)



Test Results: R-value

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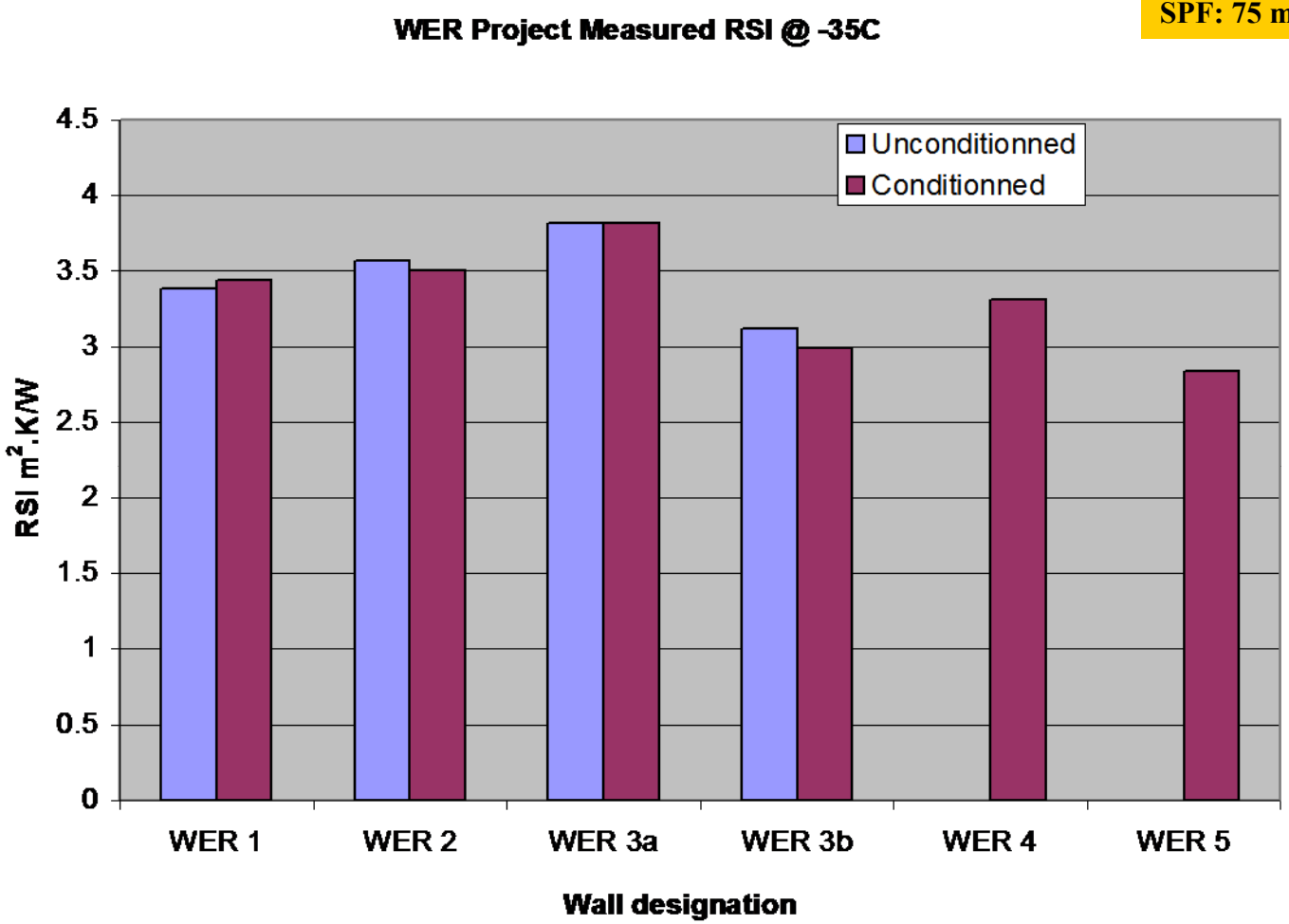
Glass fiber batts: 150 mm (nominal)
SPF: 75 mm (nominal)



Note: WER-4 and WER-5 were not tested at this condition

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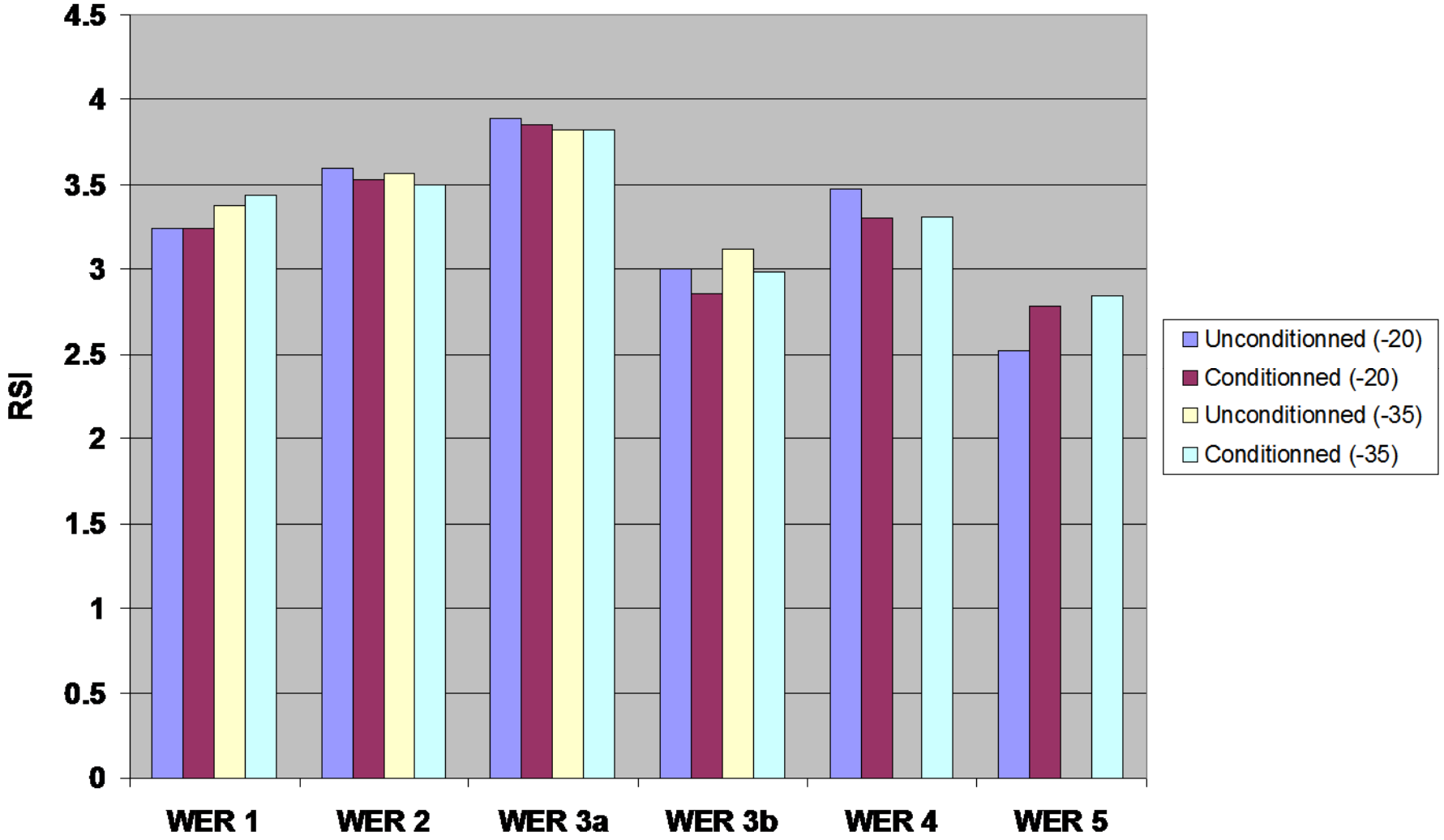
WER Project Measured RSI @ -20 & -35 C



Summary of material characterization

- ***Slabs (and sections) of materials were tested for their thermal properties using guarded hot plate (or HFM)***
- ***This includes:***
  - ***Spray polyurethane without facing (samples are prepared at the same time the walls are foamed)***
  - ***For the glass fiber without facing, data was used from the standard material data base***

Notes on the material R-values

- The foam samples were tested NOT at the same day they were foamed
- The intent is NOT to compare the R-value from one foam to the other, but to have values to use in the simulation
- The R-value is expected to decrease by time (this is a well established characteristics of the foam)
- Wall R-value is also determined for use in the simulation, and NOT to compare products

Material characterization

Wall → / Parameter ↓	Symbol	Units	WER-2	WER-3a	WER-3b	WER-4
Mean temperature of the ASTM test	Tm	°C	24.3	24.1	24.1	24.2
Material density	ρ	Kg/m3	34.9	46.3	43.9	34.3
Thermal conductivity, SI units	λ	W/(m.K)	0.019	0.0224	0.0214	0.0187

Determination of WER: Theoretical Approach

- **Wall Energy Rating (WER):**
  - heat loss due to conduction
  - heat loss due to air leakage

- $WER = Q_c + Q_a$
- $Q_c = U \cdot A \cdot \Delta T_1$
- $Q_a = m \cdot C_p \cdot \Delta T_2$, at a specific ΔP, Pa

  - U is determined at standard conditions using the ASHRAE/ASTM testing and calculation methods
  - Adopt CSA A440.2 methodology for ER

RSI Calculation with Air Leakage

- RSI calculation for cases with air leakage

$$RSI = A\frac{\Delta T}{\left(Q_{cond} + Q_{air}\right)}$$

Q_{cond} : Heat flow due to conduction

Q_{air} : Heat flow due to air leakage

Factor of interaction f_i

$$RSI_{wer} = A \frac{\Delta T}{\left(Q_{cond} + Q_{air} - f_i \bullet Q_{air}\right)}$$

ΔT Temperature difference

RSI Calculation with Air Leakage

- **RSI calculation based on *hygl*RC 2-D results, and f_i**

$$RSI_{wer} = \frac{1}{((1/RSI_{ghb40}) + (1 - f_i)\ \ q_{p75} \times 1.21)}$$

RSI_{ghb40} = **measured RSI of the conditioned wall specimen using the guarded hot box test result at ΔT = 40 K**

f_i = **factor of interaction**

q_{p75} = **air leakage rate from the airtightness test, evaluated at 75 Pa, 1/(s.m^2)**

WER Calculation

$$WER = 50 - \Delta T\left(\underbrace{(1/RSI_{ghb40})}_{\text{Conduction Loss Term}} + \underbrace{(1-f_i)\ \ q_{p75} \times 1.21}_{\text{Air leakage Loss Term}}\right)$$

WER = is the wall energy rating, W/m^2

ΔT = standard temperature difference for evaluating WER, 40º K

50 = arbitrary positive number to make WER positive, W/m^2

RSI_{ghb40} = measured RSI of the conditioned wall specimen using the guarded hot box test result at ΔT = 40 K

f_i = factor of interaction

q_{p75} = air leakage rate from the airtightness test, evaluated at 75 Pa, 1/(s.m^2)

WER Calculation Using CSA A440.2 Approach

$$WER = 50 - \Delta T\left(\underbrace{(1/RSI_{ghb40})}_{\text{Conduction Loss Term}} + \underbrace{(1-f_i)\ \ q_{p75} \times 1.21}_{\text{Air leakage Loss Term}}\right)$$

$$WER = 50 - \frac{\Delta T}{RSI_{wer}}$$

Summary of WER results

Wall ID (1)	Measured RSI of the Assembly at ΔT =40°C,	Measured Air leakage rate (L/s.m^2) @	Derived Factor of Interaction f_i	RSI_{wer} (m^2.K/W)	WER (W/m2)
	(m^2 K/W) (2)	ΔP = 75 Pa (3)	(4)	(5)	(6)
WER 1	3.25	0.369	0.55	1.97	29.7
WER 2	3.53	0.013	0.07	3.42	38.3
WER 3a	3.85	0.046	0.36	3.25	37.7
WER 3b	2.86	0.034	0.45	2.81	35.8
WER 4	3.3	0.059	0.32	2.98	36.6
WER 5	2.78	0.62	0.41	1.25	18

Comments on the factor of interaction, f_i

- **Could not generalize the relationship between f_i and q_{p75}**

- **A large number of walls needs to be tested**

- **Solution**
  - Perform hygIRC simulation
  - Perform a 3-D modelling to obtain more accurate results and better correlation

Sample computer modelling

- A 2-D computer model was used to predict the wall R-value
- Results of two walls (WER-1 and WER-2) showed remarkable agreement between the experimental and predicted R-value
- More refinements are needed to generalize the factor of interaction

WALL ID	RSI, m^2.K/W @ ΔT= 40 K		
	Experiment	Modelling	
	(apparent R-value)		
	ΔP, Pa	ΔP, Pa	
	0	0	75
WER 1	3.24	3.29	1.99
WER 2	3.6	3.58	3.4

New developments

- Use of advanced 3-D hygIRC-C model to correlate the results
- Testing of 4 more walls constructed with open cell foam
- Revise the procedure to determine WER using the new correlation
- Better prediction of WER

Closing Remarks

- A new procedure was developed to determine the energy rating of wall systems
- Although the factor of interaction did not produce final correlation for the determination of WER, it showed that the introduction of air leakage does impact the "effective R-value" of the wall system
- More walls have been tested and 3-D model was used for future study and reporting
- Finally, the intention is to draft a "guideline" or a standard for wall energy rating

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