Appendix C:
Building Enclosure Calculations

Perm-A-Barrier® Wall Membrane

Self-adhesive, rubberized asphalt/polyethylene waterproofing membrane for air and vapor barrier applications

Advantages

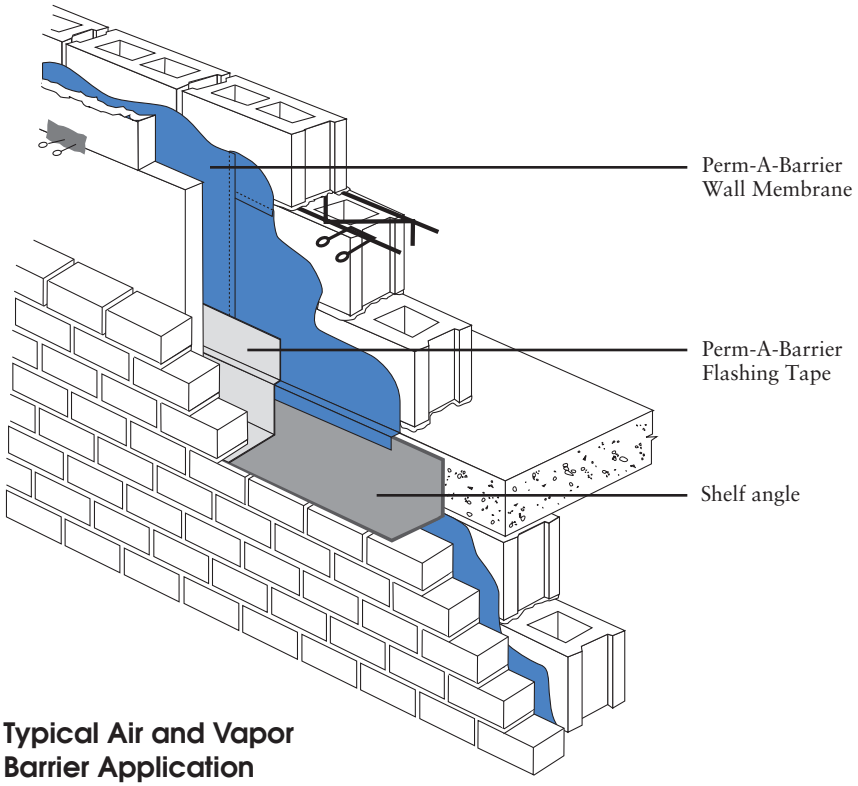
- **Fully bonded** – transmits wind loads directly to the substrate
- **Waterproof and virtually impermeable to moisture** – virtually impermeable to the passage of liquid water and vapor
- **Air tight** – exceeds CCMC requirements for air barrier membranes and complies with Massachusetts State Energy Code
- **Cross laminated film** – provides dimensional stability, high tear strength, puncture and impact resistance
- **Cold applied** – no flame hazard; self-adhesive overlaps ensure continuity
- **Flexible** – accommodates minor settlement and shrinkage movement
- **Controlled thickness** – factory made sheet ensures constant, non-variable site application
- **Aggressive, conformable adhesive** – allows self-sealing around mechanical fasteners
- **Wide application window** –
  - **Perm-A-Barrier® Wall Membrane** surface and ambient temperatures at 5°C (40°F) and above
  - **Perm-A-Barrier System 4000 Wall Membrane** surface and ambient temperatures at -4°C (25°F) and above
  - **Perm-A-Barrier Low Temperature Wall Membrane** surface and ambient temperatures between -4°C (25°F) and 16°C (60°F)

Description

Perm-A-Barrier wall membranes are ideal for protecting the building superstructure from the damaging effects of the elements.

By minimizing air and water vapor flow through the building exterior, Perm-A-Barrier wall membranes:

- Prevent premature deterioration of the building envelope
- Enhance thermal performance of the structure and save energy costs
- Improve comfort for the building occupants



Typical Air and Vapor Barrier Application

GRACE
Construction Products

System Components

- **Perm-A-Barrier System 4000 Wall Membrane –** extended temperature range system for use at all temperatures above -4°C (25°F), conveniently packaged with a unique water-based surface conditioner
- **Perm-A-Barrier Wall Membrane** – standard grade for use at temperatures above 5°C (40°F)
- **Perm-A-Barrier Low Temperature Wall Membrane –** low temperature grade for use at temperatures between -4°C (25°F) and 16°C (60°F)
- **Perm-A-Barrier Surface Conditioner –** water-based surface treatment for use with System 4000 on cementitious substrates
- **Perm-A-Barrier WB Primer –** high tack, water-based primer for use on exterior wallboards
- **Bituthene® Mastic Trowel Grade** – rubberized asphalt mastic for sealing patches, terminations, brick ties, etc.

Installation

Safety

Perm-A-Barrier products must be handled properly. Vapors from the mastic and solvent-based primer are harmful and flammable. For these products, the best available information on safe handling, storage, personal protection, health and environmental considerations has been gathered. Refer to product label and Material Safety Data Sheet before use. All users should acquaint themselves with this information prior to working with the material. Carefully read detailed precaution statements on the product labels and MSDS before use. MSDSs can be obtained from our web site at www.graceconstruction.com or by contacting us toll free at 866-333-3SBM (3726).

Surface Preparation

Surface must be smooth, clean, dry and free of voids, spalled areas, loose aggregate, loose nails, sharp protrusions or other matter that will hinder the adhesion or regularity of the wall membrane installation. Clean loose dust or dirt from the surface to which the wall membrane is to be applied by wiping with a clean, dry cloth or brush.

If the substrate is damp, allow to dry or use Bituthene Primer B2 to prepare the area to receive the membrane.

Temperature

Perm-A-Barrier System 4000 Membrane and Bituthene Surface Conditioner may be applied only in dry weather when air and surface temperatures are above -4°C (25°F). Perm-A-Barrier Low Temperature Membrane may be applied only in dry weather when air and surface temperatures are between -4°C (25°F) and 16°C (60°F). Perm-A-Barrier Wall Membrane may be applied only in dry weather when air and surface temperatures are above 4°C (40°F).

Application

Conditioning and Priming:
Bituthene System 4000 Surface Conditioner is supplied ready to use. It should not be diluted with water or solvent. Mix and apply a light coating with a portable spray unit, brush or roller. Conditioner will cover 7.5 m^2/L (300 ft^2/gal) when applied with a low pressure, portable sprayer. Allow surface conditioner to dry completely before membrane application. The surface conditioner is considered dry when the substrate returns to its original color (minimum 1 hour). To test for dryness, rub small conditioned area by hand. Wet conditioner will ball up under the fingertips. Let dry until conditioner cannot be rubbed off. Condition only areas that can be covered the same day. Conditioned areas not covered the same day should be reconditioned.

Perm-A-Barrier WB Primer is a water-based primer which imparts an aggressive, high tack finish on the treated substrate. It is packaged ready to use and is specifically designed to facilitate tenacious adhesion of Perm-A-Barrier flashing tapes and wall membranes to glass mat surfaces and exterior gypsum boards such as Dens-Glass® Gold. Apply Perm-A-Barrier WB Primer by roller at a coverage rate of 6-7.4 m^2/L (250-300 ft^2 gal). Allow to dry for a minimum of 1 hour (longer at low temperatures).

Membrane Application

Cut membrane into easily handled lengths. Apply wall membranes horizontally to the primed blockwork between projecting masonry reinforcing, beginning at the base of the wall. Each length of the membrane must be installed so that the upper edge runs continuously along the underside of the line of masonry reinforcing. Subsequent sheets applied above must overlap the sheet below by 51 mm (2 in.) immediately below the line of reinforcing. Since the membrane width appropriate for this application of 457 mm (18 in.) is wider than the typical spacing between the lines of reinforcing 406 mm (16 in.), it will be necessary to cut the membrane at the location of the tie wires projecting from the wall to enable the sheet to be laid in place. End laps that occur in subsequent lengths that follow should maintain a minimum overlap of 51 mm (2 in.). See Figures 1 and 2.

The membrane must be pressed firmly into place with a hand roller or the back of a utility knife as soon as possible, ensuring

* Dens-Glass® Gold is a trademark of the Georgia Pacific Corporation

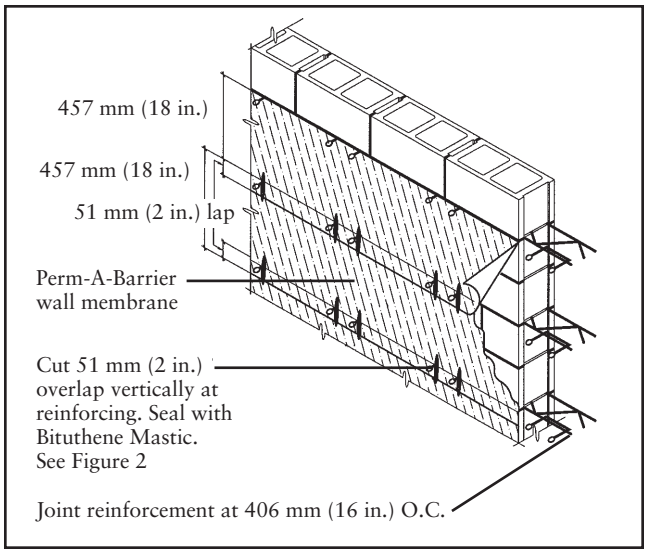


Figure 1: Membrane System Detail

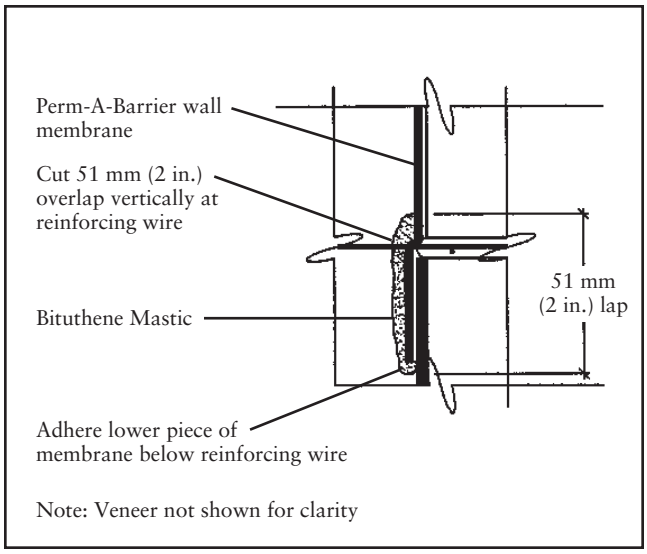


Figure 2: Horizontal Reinforcing

continuous and intimate contact with the substrate to prevent water from migrating under the membrane.

In certain applications such as on soffits, ceilings or substrates such as oriented strand board (OSB), backnail the membrane along the side lap prior to installing the next sheet of membrane to ensure positive contact to the substrate.

Apply Bituthene Mastic to seal around the tie wire projections. Fit the Perm-A-Barrier wall membrane tightly around all penetrations through the membrane and seal using Bituthene Mastic.

Continue the membrane into all openings in the wall area, such as windows, doors, etc., and terminate at points that will prevent interior visibility. The installation must be made continuous at all framed openings. Coordinate installation of the Perm-A-Barrier wall membrane with the roofing trade to ensure continuity with the roofing system at this critical transition area.

At the end of each working day, if the wall has been only partially covered, apply a bead of Bituthene Mastic along the top edge of the membrane at its termination to prevent vertical drainage of precipitation from penetrating the end and undermining the membrane adhesion. Tool the Bituthene Mastic to ensure it is worked into the surface. Inspect the membrane before covering and repair any punctures, damaged areas or inadequately lapped seams.

Membrane Repairs

Repairs must be made using Perm-A-Barrier wall membrane sized to extend 150 mm (6 in.) in all directions from the perimeter of the affected area. If repairs are required, carefully cut out affected areas and replace in similar procedure as outlined above. The repair piece must be pressed into place with a hand roller as soon as possible to ensure continuous and intimate contact with the substrate.

Membrane Protection

Perm-A-Barrier wall membranes must be protected from damage by other trades or construction materials.

Storage and Handling Information

All materials must be protected from rain and physical damage. Pallets of Perm-A-Barrier wall membrane must not be double stacked on the job site. Provide cover on top and all sides, allowing for adequate ventilation. Store membrane where temperatures will not exceed 32°C (90°F) for extended periods. All products must be stored in a dry area away from high heat, flames or sparks. Store only as much material at point of use as is required for each day's work.

Limitations

Perm-A-Barrier wall membrane systems must not be applied in areas where they will be permanently exposed to UV light and must be covered within a reasonable amount of time, not to exceed 30 days.

Warranty

Perm-A-Barrier products are warranted to be free of defects in manufacture for a period of 5 years. Material will be provided at no charge to replace any defective product.

Technical Service

Support is provided by full-time technically trained Grace field sales representatives and technical service personnel, backed by a central research and development technical services staff.

Supply

Product	Unit of Sale	Approximate Coverage	Weight	Palletization
Perm-A-Barrier System 4000 Wall Membrane (includes surface conditioner)	1 roll	20.9 m^2 (225 ft^2) per roll 0.9 x 25 m (3 x 75 ft) roll	73 lbs/roll	25 cartons (25 rolls) per pallet
Perm-A-Barrier Wall Membrane	1 roll	20.9 m^2 (225 ft^2) per roll 0.9 x 25 m (3 x 75 ft) roll	67 lbs/roll	25 cartons (25 rolls) per pallet
Perm-A-Barrier Low Temperature Wall Membrane	1 roll	20.9 m^2 (225 ft^2) per roll 0.9 x 25 m (3 x 75 ft) roll	67 lbs/roll	25 cartons (25 rolls) per pallet
Perm-A-Barrier Wall Flashing				
– 305 mm (12 in.)	3 rolls	83 linear ft per roll	25 lbs/roll	25 cartons (75 rolls) per pallet
– 457 mm (18 in.)	2 rolls	83 linear ft per roll	37.5 lbs/roll	25 cartons (50 rolls) per pallet
– 610 mm (24 in.)	1 roll	83 linear ft per roll	55 lbs/roll	35 cartons (35 rolls) per pallet
– 914 mm (36 in.)	1 roll	83 linear ft per roll	75 lbs/roll	25 cartons (25 rolls) per pallet
Bituthene Mastic – 5 gal pail	1 pail	approx. 120 ft^2 at 60 mils	54 lbs/roll	36 pails per pallet
Bituthene Mastic – 30 oz tube	12 tubes	approx. 30 lin. ft x ¼ in. bead	32 lbs/carton	72 cartons (864 tubes) per pallet
Perm-A-Barrier Surface Conditioner – 1 gal jug	4 jugs	6-7.4 m^2/L (250-300 ft^2/gal)	9 lbs/jug	36 cartons (144 jugs) per pallet
Perm-A-Barrier WB Primer – 5 gal pail	1 pail	7.4 m^2/L (300 ft^2/gal)	45 lbs/pail	24 pails per pallet
Bituthene Primer B2 – 5 gal pail	1 pail	6-8 m^2/L (250-350 ft^2/gal)	44 lbs/pail	48 pails per pallet

Physical Properties

Property and Test Method	Perm-A-Barrier System 4000	Perm-A-Barrier Wall Membrane	Perm-A-Barrier Low Temperature	Test Method
Thickness	1 mm (3⁄64 in.)	1 mm (3⁄64 in.)	1 mm (3⁄64 in.)	ASTM D3767 Method A
Minimum tensile strength, membranes	2.8 MPa (400 psi)	2.8 MPa (400 psi)	2.8 MPa (400 psi)	ASTM D412 Die C Modified
Minimum tensile strength, film	34.5 MPa (5000 psi)	34.5 MPa (5000 psi)	34.5 MPa (5000 psi)	ASTM D412 Die C Modified
Minimum elongation, to failure of rubberized asphalt	200%	200%	200%	ASTM D412 Die C Modified
Pliability, at 180° bend over 25 mm (1 in.) mandrel	Pass at -43°C (-45°F)	Pass at -32°C (-25°F)	Pass at -43°C (-45°F)	ASTM D1970
Crack cycling, 3.2 mm (⅛ in.) at -32°C (-25°F)	Unaffected	Unaffected	Unaffected	ASTM C836
Minimum puncture resistance, membrane	178 N (40 lbs)	178 N (40 lbs)	178 N (40 lbs)	ASTM E154
Lap peel adhesion at minimum application temperature	1100 N/m width (6.3 lbs/in.)	700 N/m width (4 lbs/in.)	875 N/m width (5 lbs/in.)	ASTM D1876 Modified
Maximum permeance to water vapor transmission	2.9 ng (0.05 perms/(Pa.s.m^2))	2.9 ng (0.05 perms/(Pa.s.m^2))	2.9 ng (0.05 perms/(Pa.s.m^2))	ASTM E96 Method B
Air permeance of in-place membrane[1]	$8x10^{-5}$ L/s/m^2 ($4x10^{-6}$ cf/min/ft^2)	$1.7x10^{-4}$ L/s/m^2 ($8.5x10^{-5}$ cf/min/ft^2)	$1.7x10^{-4}$ L/s/m^2 ($8.5x10^{-5}$ cf/min/ft^2)	ASTM E283
Air permeance of in-place membrane[2]	No change in air permeance value	No change in air permeance value	No change in air permeance value	ASTM E330
Water absorption (weight gain at 24 hours)	0.1%	0.1%	0.1%	ASTM D570

Footnote:

1. Air permeance measured at a pressure differential of 68 Pa (1⁄64 in.) Hg.
2. Air permeance measured at a pressure differential of 68 Pa (1⁄64 in.) Hg after wall being subjected to a negative 3014 Pa (57⁄64 in.) Hg pressure difference for 10 seconds.

For Technical Assistance call toll free at 866-333-3SBM (3726).

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GRACE Construction Products

Source: "Comparative Climatic Data", National Climatic Data Center, NOAA, 2001. See: Data Explanations
http://ggweather.com/ccd/avgrh.htm
Average Relative Humidity(%)

Morning (M), Afternoon (A)

DATA THROUGH 2001	YEARS		JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		ANN	
	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A
BRIDGEPORT, CT	35	35	70	59	70	57	70	55	69	53	75	59	78	61	78	60	80	61	82	61	80	59	77	60	74	60	75	5
HARTFORD, CT	42	42	72	57	72	54	72	51	69	45	73	48	77	51	79	51	83	53	86	55	84	51	79	56	76	59	77	5

Hartford, Connecticut

Weather can't be forecast more than a week or so in advance, but weather averages are good indicators of what to expect any month.

Fahrenheit

Month	Average high	Average low	Warmest ever	Coldest ever	Average dew point	Average precipitation
JAN.	34.0	17.0	66.0	-26.0	15.0	3.4
FEB.	37.0	19.0	73.0	-21.0	17.0	3.1
MARCH	46.0	28.0	87.0	-8.0	24.0	3.9
APRIL	60.0	38.0	96.0	9.0	33.0	3.9
MAY	71.0	47.0	97.0	28.0	45.0	3.7
JUNE	80.0	57.0	101.0	37.0	56.0	3.5
JULY	85.0	62.0	102.0	44.0	61.0	3.3
AUG.	82.0	60.0	101.0	36.0	60.0	4.0
SEP.	74.0	52.0	101.0	27.0	53.0	3.8
OCT.	64.0	41.0	91.0	17.0	42.0	3.6
NOV.	51.0	33.0	83.0	1.0	32.0	4.1
DEC.	38.0	22.0	74.0	-14.0	20.0	3.9

Celsius

Average high	Average low	Warmest ever	Coldest ever
1.1	-8.3	18.9	-32.2
2.8	-7.2	22.8	-29.4
7.8	-2.2	30.6	-22.2
15.6	3.3	35.6	-12.8
21.7	8.3	36.1	-2.2
26.7	13.9	38.3	2.8
29.4	16.7	38.9	6.7
27.8	15.6	38.3	2.2
23.3	11.1	38.3	-2.8
17.8	5.0	32.8	-8.3
10.6	0.6	28.3	-17.2
3.3	-5.6	23.3	-25.6

Latitude: 41 degrees, 56 minutes north
Longitude: 72 degrees, 41 minutes west

http://www.usatoday.com/weather/climate/usa/conn/whartfor.htm

0.15 -17.7

Ice Hockey: Interior Temperature=0 C, RH=75%

Winter Ave Low T=-9 degrees C, RH=72%

Interface	Layer	Material	L (mm)	L (m)	ΣL (mm)	k (W/mK)	C (W/m^2K)	RSI (m^2K/W)	ΔT (K)	T (°C)	M (ng/Pa*s*m^2)	RV (Pa*s*m^2/ng)	ΔP (Pa)	Pc (Pa)	Ps (Pa)
a					0					0				458.1	610.8
	1	Interior Film	0				8.3	0.1205	0.334656		0	0.0000	0		
b					0					-0.334655998				458.1	593.0883594
	2	12" fully grouted CMU	295	0.295			1.53	0.6536	1.81545411		15.93	0.0628	32.50628		
c					295					-2.150110106				425.5937	519.0524546
	3	Membrane Waterproofing	1.5	0.0015			0	0.0000	0		2.9	0.3448	178.5603		
d					296.5					-2.150110106				247.0334	519.0524546
	4	Rigid insulation	76.2	0.0762		0.036	0.47244094	2.1167	5.87934813		22.3	0.0448	23.22085		
e					372.7					-8.029458234				223.8125	332.3057741
	5	Air Space	12.7	0.0127			6.25	0.1600	0.44442317		0	0.0000	0		
f					385.4					-8.4738814				223.8125	320.999642
	6	Cedar Plywood	16	0.016		0.1	6.25	0.1600	0.44442317		625	0.0016	0.82852		
g					401.4					-8.918304565				222.984	310.0376492
	7	Exterior Film	0	0			34	0.0294	0.08169543		0	0.0000	0		
h					401.4					-9				222.984	309.7
							ΣRSI =	3.2402			Σ =	0.4540	235.116		

q= ΔT/ΣRSI= 9 / 3.2402 = 2.777645 ωc= ΔP/Rv= 235.116 / 0.4540 = 517.8250125

Rimp= 5.678Rsi = 18.3976 V= 1/ΣRv = 2.202423538

U= 1/Rsi = 0.308627

Summer Ave High T=30 degrees C, RH=86%

Interface	Layer	Material	L (mm)	L (m)	ΣL (mm)	k (W/mK)	C (W/m^2K)	RSI (m^2K/W)	ΔT (K)	T (°C)	M (ng/Pa*s*m^2)	RV (Pa*s*m^2/ng)	ΔP (Pa)	Pc (Pa)	Ps (Pa)	ΔP (Pa)	Pa (Pa)
a					0					0				458.1	610.8	0	458.1
	1	Interior Film	0				8.3	0.1205	-1.11552		0	0.0000	0				
b					0					1.115519994				458.1	658.8034575		-3434.95
	2	12" fully grouted CMU	295	0.295			1.53	0.6536	-6.0515137		15.93	0.0628	-441.159			421.955	
c					295					7.167033687				899.2594	1007.984062		-3012.99
	3	Membrane Waterproofing	1.5	0.0015		0	0	0.0000	0		2.9	0.3448	-2423.33			2317.843	
d					296.5					7.167033687				3322.594	1007.984062		-695.15
	4	Rigid insulation	76.2	0.0762		0.036	0.47244094	2.1167	-19.597827		22.3	0.0448	-315.142			4194.471	
e					372.7					26.76486078				3637.736 >	3499.321265		3499.321
	5	Air Space	12.7	0.0127			6.25	0.1600	-1.4814106		0	0.0000	0			0	
f					385.4					28.24627133				3637.736	3815.911785		3499.321
	6	Cedar Plywood	16	0.016		0.1	6.25	0.1600	-1.4814106		625	0.0016	-11.2443			149.6587	
g					401.4					29.72768188				3648.98	4157.116084		3648.98
	7	Exterior Film	0	0			34	0.0294	-0.2723181		0	0.0000	0			0	
h					401.4					30				3648.98	4243		3648.98
							ΣRSI =	3.2402			ΣRV =	0.4540	-3190.88			7083.928	

q= ΔT/ΣRSI= -30 / 3.2402 = -9.25882 ωc= ΔP/Rv= -3190.88 / 0.4540 = -7027.669219

Rimp= 5.678Rsi = 18.3976 V= 1/ΣRv = 2.202423538

U= 1/Rsi = 0.308627

upstream ωU= ΔP/Rv= 6721.743901 ng/(s*m^2)

= 0.580758673 g/(day*m^2)

first accumulation rate= 7.5008 g/(day*m^2

downstream ωU= ΔP/Rv= 93536.70938 ng/(s*m^2)

= 8.081571691 g/(day*m^2)

Ice Hockey: Interior Temperature=0 C, RH=75%

Winter Extreme Low T=-20 degrees C, RH=72%

Interface	Layer	Material	L (mm)	L (m)	ΣL (mm)	k (W/mK)	C (W/m^2K)	RSI (m^2K/W)	ΔT (K)	T (°C)	M (ng/Pa*s*m^2)	RV (Pa*s*m^2/ng)	ΔP (Pa)	Pc (Pa)	Ps (Pa)
a					0					0				458.1	610.8
	1	Interior Film	0				8.3	0.1205	0.64238619		0	0.0000	0		
b					0					-0.642386187				458.1	579.9156169
	2	12" fully grouted CMU	295	0.295			1.53	0.6536	3.4848401		15.93	0.0628	50.85234		
c					295					-4.127226285				407.2477	447.862304
	3	Membrane Waterproofing	1.5	0.0015			0		0		2.9	0.3448	279.3372		
d					296.5					-4.127226285				127.9105	447.862304
	4	Rigid insulation	76.2	0.0762		0.029	0.38057743	2.6276	14.0097782		22.3	0.0448	36.32636		
e					372.7					-18.13700448				91.58412	146.2412419
	5	Air Space	12.7	0.0127			6.25	0.1600	0.85308886		0	0.0000	0		
f					385.4					-18.99009334				91.58412	135.997048
	6	Cedar Plywood	16	0.016		0.1	6.25	0.1600	0.85308886		625	0.0016	1.296124		
g					401.4					-19.8431822				90.288	126.4013794
	7	Exterior Film	0	0			34	0.0294	0.1568178		0	0.0000	0		
h					401.4					-20				90.288	125.4
							ΣRSI =	3.7511			Σ =	0.4540	367.812		

q= ΔT/ΣRSI= 20 / 3.7511 = 5.331805

ωc= ΔP/Rv= 367.812 / 0.4540 = 810.0778063

Rimp= 5.678Rsi = 21.2986

V= 1/ΣRv = 2.202423538

U= 1/Rsi = 0.26659

Summer Extreme High T=37 degrees C, Tsol=60 C, RH=86%

Interface	Layer	Material	L (mm)	L (m)	ΣL (mm)	k (W/mK)	C (W/m^2K)	RSI (m^2K/W)	ΔT (K)	T (°C)	M (ng/Pa*s*m^2)	RV (Pa*s*m^2/ng)	ΔP (Pa)	Pc (Pa)	Ps (Pa)	ΔP (Pa)	Pa (Pa)
a					0					0				458.1	610.8	0	458.1
	1	Interior Film	0				8.3	0.1205	-1.9271586		0	0.0000	0				
b					0					1.927158561				458.1	698.3305918	2046.387	458.1
	2	12" fully grouted CMU	295	0.295			1.53	0.6536	-10.45452		15.93	0.0628	-2305.16				
c					295					12.38167886				2763.262	1430.616683	11241.01	2504.487
	3	Membrane Waterproofing	1.5	0.0015		0	0		0		2.9	0.3448	-12662.5				
d					296.5					12.38167886				15425.75	1430.616683	1461.836	13745.5
	4	Rigid insulation	76.2	0.0762		0.029	0.38057743	2.6276	-42.029335		22.3	0.0448	-1646.69				
e					372.7					54.41101345				17072.45 >	15207.33569	0	15207.34
	5	Air Space	12.7	0.0127			6.25	0.1600	-2.5592666		0	0.0000	0				
f					385.4					56.97028002				17072.45	17175.58474	1923.864	15207.34
	6	Cedar Plywood	16	0.016		0.1	6.25	0.1600	-2.5592666		625	0.0016	-58.754				
g					401.4					59.52954659				17131.2	19356.46052	0	17131.2
	7	Exterior Film	0	0			34	0.0294	-0.4704534		0	0.0000	0				
h					401.4					60				17131.2	19920	16673.1	17131.2
							ΣRSI =	3.7511			ΣRV =	0.4540	-16673.1				

q= ΔT/ΣRSI= -60 / 3.7511 = -15.9954

ωc= ΔP/Rv= -16673.1 / 0.4540 = -36721.22789

Rimp= 5.678Rsi = 21.2986

V= 1/ΣRv = 2.202423538

U= 1/Rsi = 0.26659

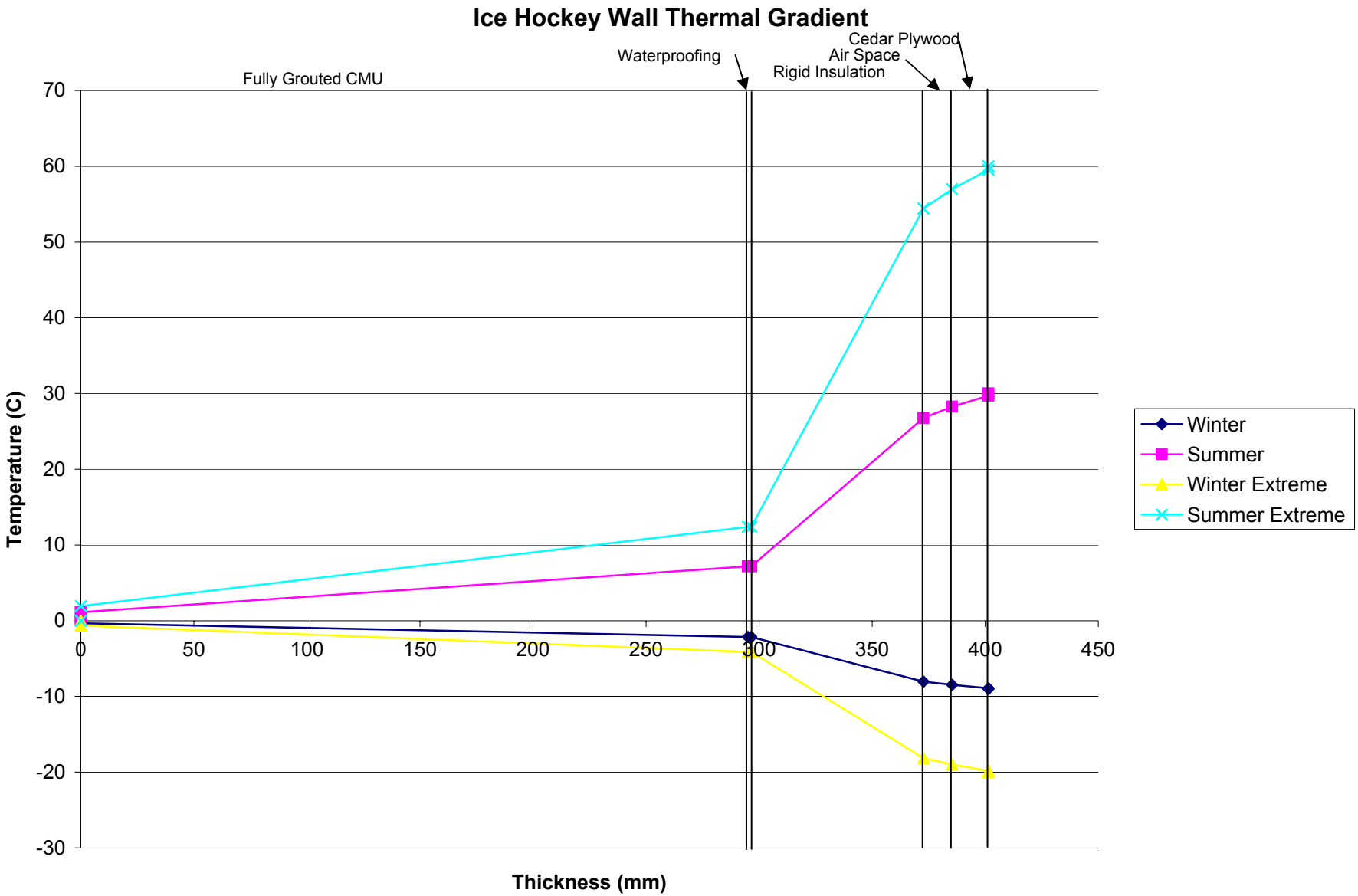
upstream ωU= ΔP/Rv= 32598.93852 ng/(s*m^2)

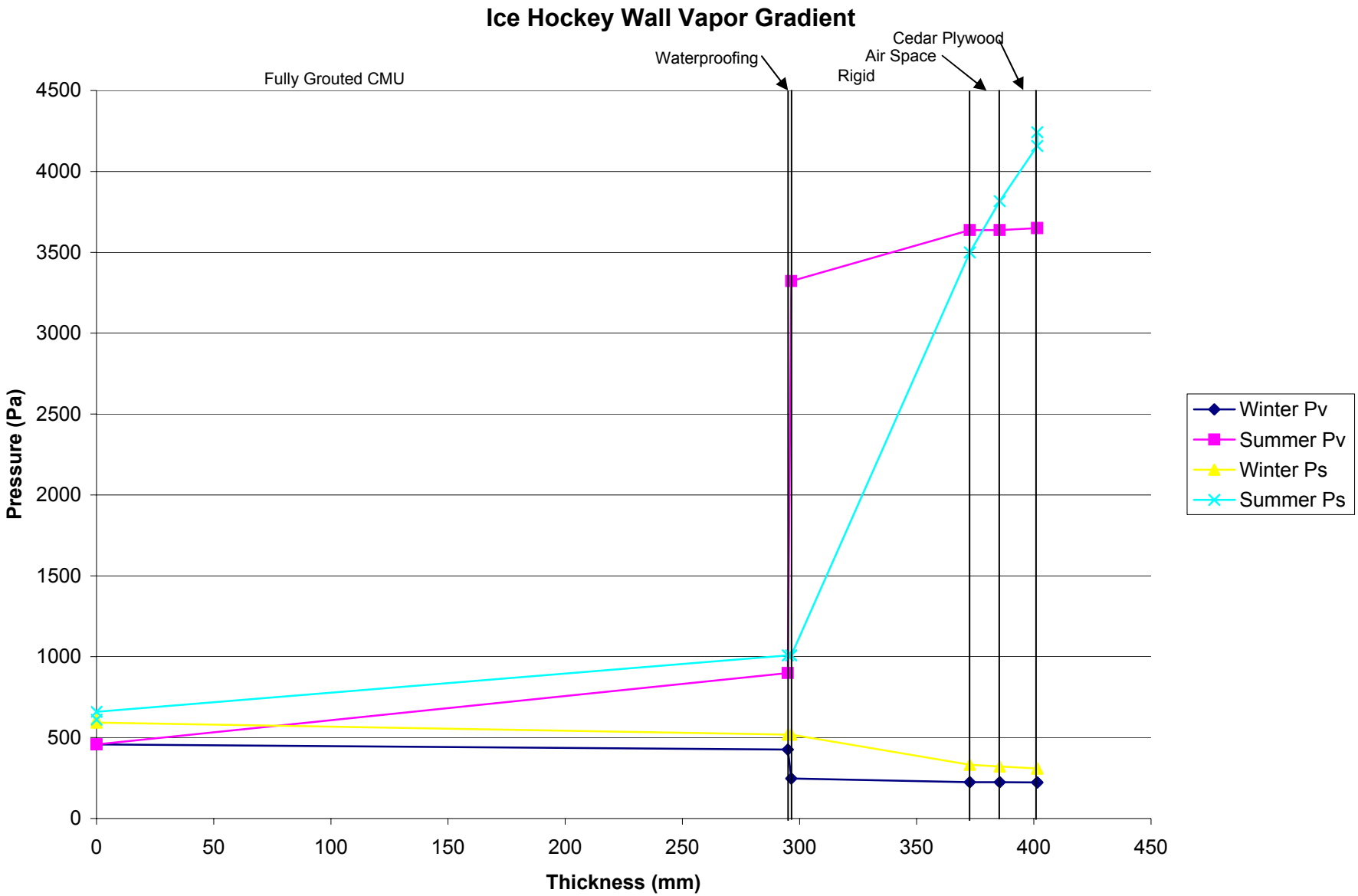
= 2.816548288 g/(day*m^2)

first accumulation rate= 101.0721 g/(day*m^2

downstream ωU= ΔP/Rv= 1202415.193 ng/(s*m^2)

= 103.8886727 g/(day*m^2)


Ice Hockey Wall Thermal Gradient
Fully Grouted CMU
Waterproofing
Rigid Insulation
Air Space
Cedar Plywood
Temperature (C)
70
60
50
40
30
20
10
0
-10
-20
-30
0
50
100
150
200
250
300
350
400
450
Thickness (mm)
Winter
Summer
Winter Extreme
Summer Extreme


Ice Hockey Wall Vapor Gradient
Fully Grouted CMU
Waterproofing
Rigid
Air Space
Cedar Plywood
Pressure (Pa)
Thickness (mm)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
0
50
100
150
200
250
300
350
400
450
Winter Pv
Summer Pv
Winter Ps
Summer Ps

Basketball — Interior Temperature=22 C, RH=65%

Winter — Ave Low T=-9 degrees C, RH=72%

Interface	Layer	Material	L (mm)	L (m)	ΣL (mm)	k (W/mK)	C (W/m^2K)	RSI (m^2K/W)	ΔT (K)	T (°C)	M (ng/Pa*s*m^2)	RV (Pa*s*m^2/ng)	ΔP (Pa)	Pc (Pa)	Ps (Pa)
a					0					22				1717.95	2643
	1	Interior Film	0				8.3	0.1205	1.15270399		0	0.0000	0		
b					0					20.84729601				1717.95	2451.332042
	2	12" fully grouted CMU	295	0.295			1.53	0.6536	6.25323082		15.93	0.0628	206.6885		
c					295					14.59406519				1511.261	1652.553178
	3	Membrane Waterproofing	1.5	0.0015			0		0		2.9	0.3448	1135.361		
d					296.5					14.59406519				375.9	1652.553178
	4	Rigid insulation	76.2	0.0762		0.036	0.47244094	2.1167	20.251088		22.3	0.0448	147.6479		
e					372.7					-5.657022806				228.2521	398.8789053
	5	Air Space	12.7	0.0127			6.25	0.1600	1.5307909		0	0.0000	0		
f					385.4					-7.18781371				228.2521	354.6936167
	6	Cedar Plywood	16	0.016		0.1	6.25	0.1600	1.5307909		625	0.0016	5.268077		
g					401.4					-8.718604613				222.984	314.9213946
	7	Exterior Film	0	0			34	0.0294	0.28139539		0		0		
h					401.4					-9				222.984	309.7
							ΣRSI =	3.2402			Σ =	0.4540	1494.966		

q= ΔT/ΣRSI= 31 / 3.2402 = 9.567443

ωc= ΔP/Rv= 1494.966 / 0.4540 = 3292.548307

Rimp= 5.678Rsi = 18.3976

V= 1/ΣRv = 2.202423538

U= 1/Rsi = 0.308627

Summer — Ave High T=30 degrees C, RH=86%

Interface	Layer	Material	L (mm)	L (m)	ΣL (mm)	k (W/mK)	C (W/m^2K)	RSI (m^2K/W)	ΔT (K)	T (°C)	M (ng/Pa*s*m^2)	RV (Pa*s*m^2/ng)	ΔP (Pa)	Pc (Pa)	Ps (Pa)	ΔP (Pa)	Pa (Pa)
a					0					22				1717.95	2643		1717.95
	1	Interior Film	0				8.3	0.1205	-0.297472		0		0			0	
b					0					22.297472				1717.95	2678.787889		1717.95
	2	12" fully grouted CMU	295	0.295			1.53	0.6536	-1.613737		15.93	0.0628	-266.977			190.2654	
c					295					23.91120898				1984.927	2953.362901		1908.215
	3	Membrane Waterproofing	1.5	0.0015		0	0		0		2.9	0.3448	-1466.53			1045.148	
d					296.5					23.91120898				3451.46 >	2953.362901		2953.363
	4	Rigid insulation	76.2	0.0762		0.036	0.47244094	2.1167	-5.2260872		22.3	0.0448	-190.715			671.6525	
e					372.7					29.13729621				3642.175	4018.086907		3625.015
	5	Air Space	12.7	0.0127			6.25	0.1600	-0.3950428		0	0.0000	0			0	
f					385.4					29.53233902				3642.175	4110.659664		3625.015
	6	Cedar Plywood	16	0.016		0.1	6.25	0.1600	-0.3950428		625	0.0016	-6.80471			23.96456	
g					401.4					29.92738184				3648.98	4205.079377		3648.98
	7	Exterior Film	0	0			34	0.0294	-0.0726182		0		0			0	
h					401.4					30				3648.98	4243		3648.98
							ΣRSI =	3.2402			ΣRV =	0.4540	-1931.03			1931.03	

q= ΔT/ΣRSI= -8 / 3.2402 = -2.46902

ωc= ΔP/Rv= -1931.03 / 0.4540 = -4252.945924

Rimp= 5.678Rsi = 18.3976

V= 1/ΣRv = 2.202423538

U= 1/Rsi = 0.308627

upstream ωU= ΔP/Rv= 3030.927763 ng/(s*m^2)

= 0.261872159 g/(day*m^2)

first accumulation rate= 1.0322 g/(day*m^2

downstream ωU= ΔP/Rv= 14977.85157 ng/(s*m^2)

= 1.294086376 g/(day*m^2)

Basketball Interior Temperature=22 C, RH=65%
Winter Extreme Low T=-20 degrees C, RH=72%

Interface	Layer	Material	L (mm)	L (m)	ΣL (mm)	k (W/mK)	C (W/m^2K)	RSI (m^2K/W)	ΔT (K)	T (°C)	M (ng/Pa*s*m^2)	RV (Pa*s*m^2/ng)	ΔP (Pa)	Pc (Pa)	Ps (Pa)
a					0					22				1717.95	2643
	1	Interior Film	0				8.3	0.1205	1.34901099		0	0.0000	0		
b					0					20.65098901				1717.95	2421.877956
	2	12" fully grouted CMU	295	0.295			1.53	0.6536	7.31816421		15.93	0.0628	225.0346		
c					295					13.3328248				1492.915	1522.595665
	3	Membrane Waterproofing	1.5	0.0015			0		0		2.9	0.3448	1236.138		
d					296.5					13.3328248				256.7771	1522.595665
	4	Rigid insulation	76.2	0.0762		0.029	0.38057743	2.6276	29.4205342		22.3	0.0448	160.7534		
e					372.7					-16.08770941				96.02368	173.7326298
	5	Air Space	12.7	0.0127			6.25	0.1600	1.7914866		0	0.0000	0		
f					385.4					-17.87919601				96.02368	149.4704145
	6	Cedar Plywood	16	0.016		0.1	6.25	0.1600	1.7914866		625	0.0016	5.735682		
g					401.4					-19.67068261				90.288	128.2911516
	7	Exterior Film	0	0			34	0.0294	0.32931739		0		0		
h					401.4					-20				90.288	125.4
							ΣRSI =	3.7511			Σ =	0.4540	1627.662		

q= ΔT/ΣRSI= 42 / 3.7511 = 11.19679 ωc= ΔP/Rv= 1627.662 / 0.4540 = 3584.801101

Rimp= 5.678Rsi = 21.2986 V= 1/ΣRv = 2.202423538

U= 1/Rsi = 0.26659

Summer Extreme High T=37 degrees C, Tsol=60 C, RH=86%

Interface	Layer	Material	L (mm)	L (m)	ΣL (mm)	k (W/mK)	C (W/m^2K)	RSI (m^2K/W)	ΔT (K)	T (°C)	M (ng/Pa*s*m^2)	RV (Pa*s*m^2/ng)	ΔP (Pa)	Pc (Pa)	Ps (Pa)	ΔP (Pa)	Pa (Pa)
a					0					22				1717.95	2643	0	1717.95
	1	Interior Film	0				8.3	0.1205	-1.2205338		0	0.0000	0				
b					0					23.22053376				1717.95	2832.979209	2087.981	1717.95
	2	12" fully grouted CMU	295	0.295			1.53	0.6536	-6.6211962		15.93	0.0628	-2130.98				
c					295					29.84172994				3848.93	4184.44925	11469.5	3805.931
	3	Membrane Waterproofing	1.5	0.0015		0	0		0		2.9	0.3448	-11705.7				
d					296.5					29.84172994				15554.62	4184.44925	1491.549	15275.43
	4	Rigid insulation	76.2	0.0762		0.029	0.38057743	2.6276	-26.618579		22.3	0.0448	-1522.26				
e					372.7					56.46030852				17076.89 >	16766.97677	0	16766.98
	5	Air Space	12.7	0.0127			6.25	0.1600	-1.6208688		0	0.0000	0				
f					385.4					58.08117734				17076.89	18095.08184	364.2232	16766.98
	6	Cedar Plywood	16	0.016		0.1	6.25	0.1600	-1.6208688		625	0.0016	-54.3144				
g					401.4					59.70204617				17131.2	19511.54622	0	17131.2
	7	Exterior Film	0	0			34	0.0294	-0.2979538		0		0				
h					401.4					60				17131.2	19920	15413.25	17131.2
							ΣRSI =	3.7511			ΣRV =	0.4540	-15413.3				

q= ΔT/ΣRSI= -38 / 3.7511 = -10.1304 ωc= ΔP/Rv= -15413.25 / 0.4540 = -33946.5046

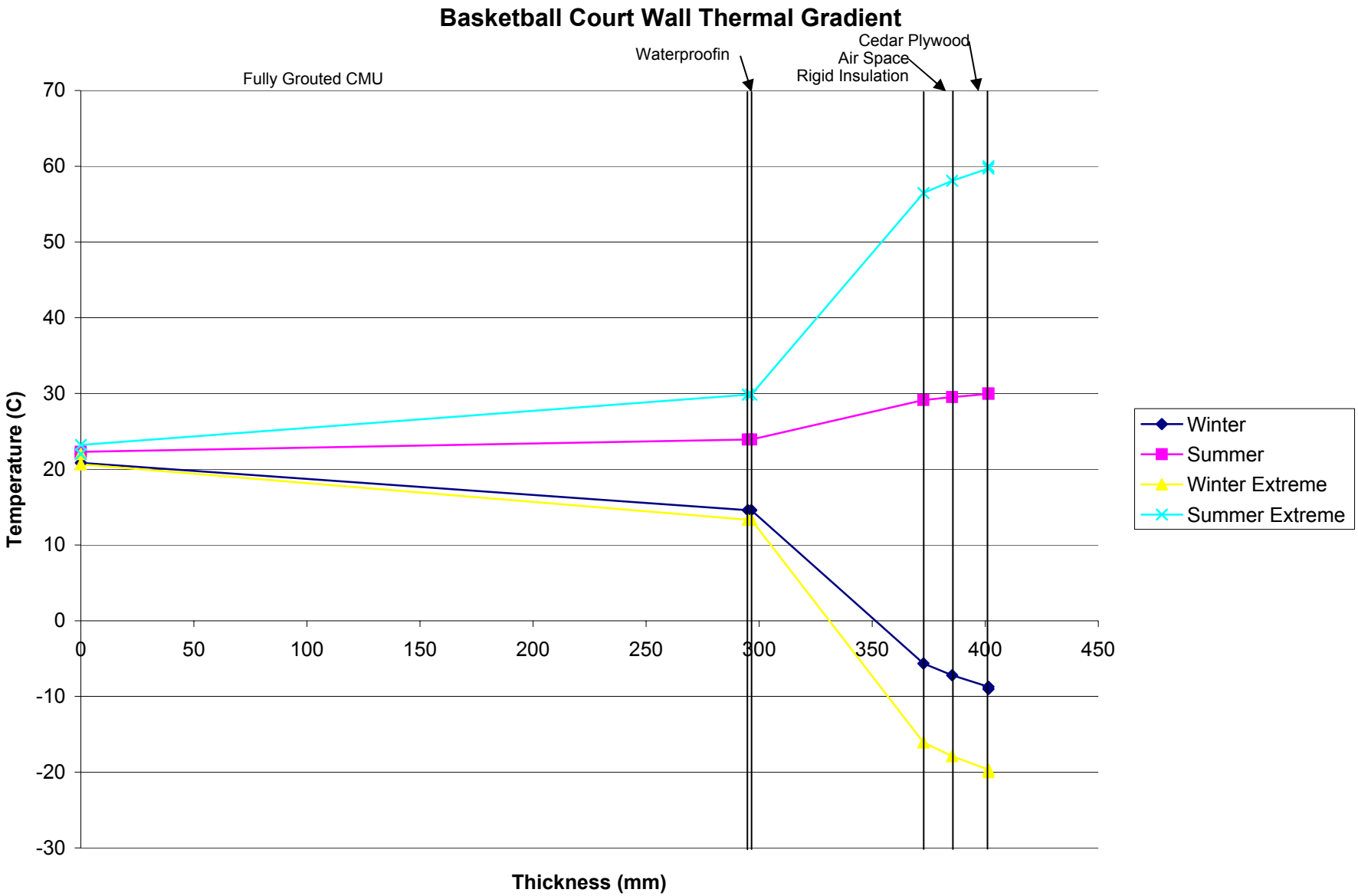
Rimp= 5.678Rsi = 21.2986 V= 1/ΣRv = 2.202423538

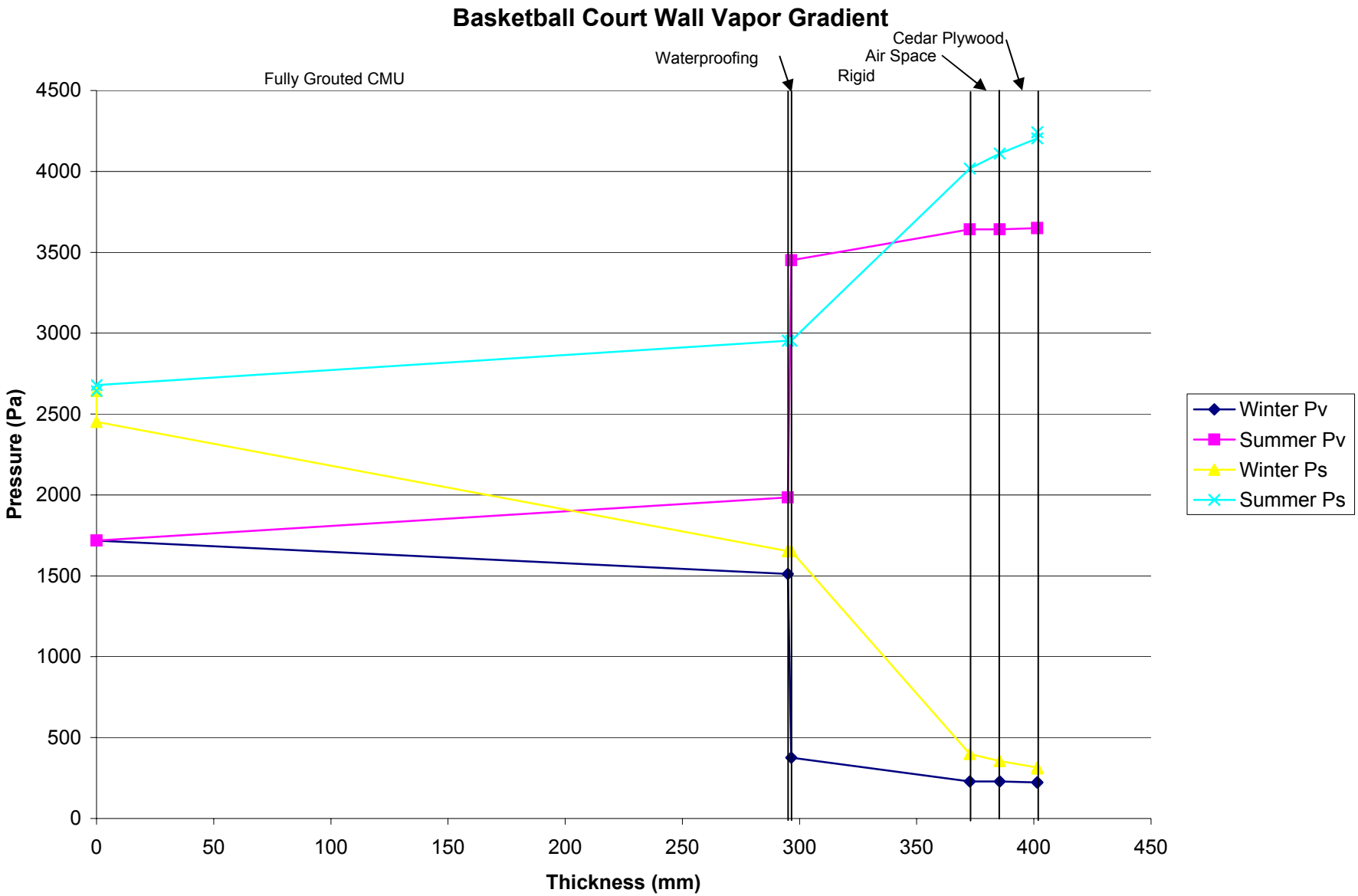
U= 1/Rsi = 0.26659

upstream ωu= ΔP/Rv= 33261.54038 ng/(s*m^2)
= 2.873797088 g/(day*m^2)

first accumulation rate= 16.7943 g/(day*m^2

downstream ωu= ΔP/Rv= 227639.52 ng/(s*m^2)
= 19.66805453 g/(day*m^2)


Basketball Court Wall Thermal Gradient
Fully Grouted CMU
Waterproofin
Air Space
Rigid Insulation
Cedar Plywood
Temperature (C)
70
60
50
40
30
20
10
0
-10
-20
-30
0
50
100
150
200
250
300
350
400
450
Thickness (mm)
Winter
Summer
Winter Extreme
Summer Extreme


Basketball Court Wall Vapor Gradient
Fully Grouted CMU
Waterproofing
Rigid
Air Space
Cedar Plywood
Pressure (Pa)
Thickness (mm)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
50
100
150
200
250
300
350
400
450
Winter Pv
Summer Pv
Winter Ps
Summer Ps

Ice Hockey: Interior Temperature=0 C, RH=75%

Winter Ave Low T=-9 degrees C, RH=72%

Interface	Layer	Material	L (mm)	L (m)	ΣL (mm)	k (W/mK)	C (W/m^2K)	RSI (m^2K/W)	ΔT (K)	T (°C)	M (ng/Pa*s*m^2)	RV (Pa*s*m^2/ng)	ΔP (Pa)	Pc (Pa)	Ps (Pa)
a					0					0				458.1	610.8
	1	Interior Film	0				8.3	0.1205	0.25161975		0	0.0000	0		
b					0					-0.251619749				458.1	596.6879673
	2	12" fully grouted CMU	295	0.295			1.53	0.6536	1.36499602		15.93	0.0628	32.50628		
c					295					-1.61661577				425.5937	539.9068185
	3	Membrane Waterproofing	1.5	0.0015			0	0.0000	0		2.9	0.3448	178.5603		
d					296.5					-1.61661577				247.0334	539.9068185
	4	Rigid insulation	114.3	0.1143		0.036	0.31496063	3.1750	6.63080942		22.3	0.0448	23.22085		
e					410.8					-8.247425193				223.8125	326.7171068
	5	Air Space	38	0.038			5.85	0.1709	0.35699896		0	0.0000	0		
f					448.8					-8.604424153				223.8125	317.7444343
	6	Cedar Plywood	16	0.016		0.1	6.25	0.1600	0.33415103		625	0.0016	0.82852		
g					464.8					-8.938575179				222.984	309.5457178
	7	Exterior Film	0	0			34	0.0294	0.06142482		0	0.0000	0		
h					464.8					-9				222.984	309.7
							ΣRSI =	4.3094			Σ =	0.4540	235.116		

q= ΔT/ΣRSI= 9 / 4.3094 = 2.088444

ωc= ΔP/Rv= 235.116 / 0.4540 = 517.8250125

Rimp= 5.678Rsi = 24.46894

V= 1/ΣRv = 2.202423538

U= 1/Rsi = 0.232049

Summer Ave High T=30 degrees C, RH=86%

Interface	Layer	Material	L (mm)	L (m)	ΣL (mm)	k (W/mK)	C (W/m^2K)	RSI (m^2K/W)	ΔT (K)	T (°C)	M (ng/Pa*s*m^2)	RV (Pa*s*m^2/ng)	ΔP (Pa)	Pc (Pa)	Ps (Pa)	ΔP (Pa)	Pa (Pa)
a					0					0				458.1	610.8	0	458.1
	1	Interior Film	0				8.3	0.1205	-0.8387325		0	0.0000	0				
b					0					0.838732495				458.1	645.7843757	66.7468	458.1
	2	12" fully grouted CMU	295	0.295			1.53	0.6536	-4.5499867		15.93	0.0628	-441.159				
c					295					5.388719233				899.2594	891.493871	366.6471	524.8468
	3	Membrane Waterproofing	1.5	0.0015		0	0	0.0000	0		2.9	0.3448	-2423.33				
d					296.5					5.388719233				3322.594 >	891.493871	2662.489	891.4939
	4	Rigid insulation	114.3	0.1143		0.036	0.31496063	3.1750	-22.102698		22.3	0.0448	-315.142				
e					410.8					27.49141731				3637.736	3651.613417	0	3553.982
	5	Air Space	38	0.038			5.85	0.1709	-1.1899965		0	0.0000	0				
f					448.8					28.68141384				3637.736	3913.513281	94.99759	3553.982
	6	Cedar Plywood	16	0.016		0.1	6.25	0.1600	-1.1138368		625	0.0016	-11.2443				
g					464.8					29.7952506				3648.98	4173.29106	0	3648.98
	7	Exterior Film	0	0			34	0.0294	-0.2047494		0	0.0000	0				
h					464.8					30				3648.98	4243	3190.88	3648.98
							ΣRSI =	4.3094			ΣRV =	0.4540	-3190.88				

q= ΔT/ΣRSI= -30 / 4.3094 = -6.96148

ωc= ΔP/Rv= -3190.88 / 0.4540 = -7027.669219

Rimp= 5.678Rsi = 24.46894

V= 1/ΣRv = 2.202423538

U= 1/Rsi = 0.232049

upstream ωU= ΔP/Rv= 1063.276509 ng/(s*m^2)

= 0.09186709 g/(day*m^2)

first accumulation rate= 5.0380 g/(day*m^2

downstream ωU= ΔP/Rv= 59373.4944 ng/(s*m^2)

= 5.129869916 g/(day*m^2)

CMU SHRINKAGE & THERMAL EXPANSION

SHRINKAGE:

INTERMEDIATE HUMIDITY (SEE WEATHER STATS)

0.045% OVER 20' WALL

$\Delta L = 20(12)(0.00045)$
$= 0.108$

THERMAL EXPANSION

$\Delta L = \alpha L \Delta T$ $\alpha = 0.52$ in/100Ft/100°T

PER 20' WALL OVER 50°F (SEE THERAL GRADIENT)

$\Delta L = 0.52\,(20/100)(50/100)$
$= 0.052$

MAX MOV'T PER 20' = 0.16"

ALLOW FOR 1/4"