Lab 5
Hygrothermal Physics

Building Physics & Environmental Systems
BC 3014

SLIDES ARE BEING REVISED FOR BUILDINGS XIII BSE UPDATE

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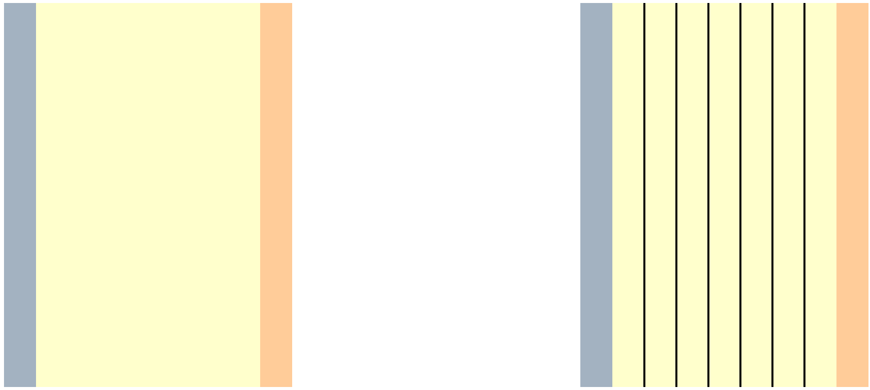
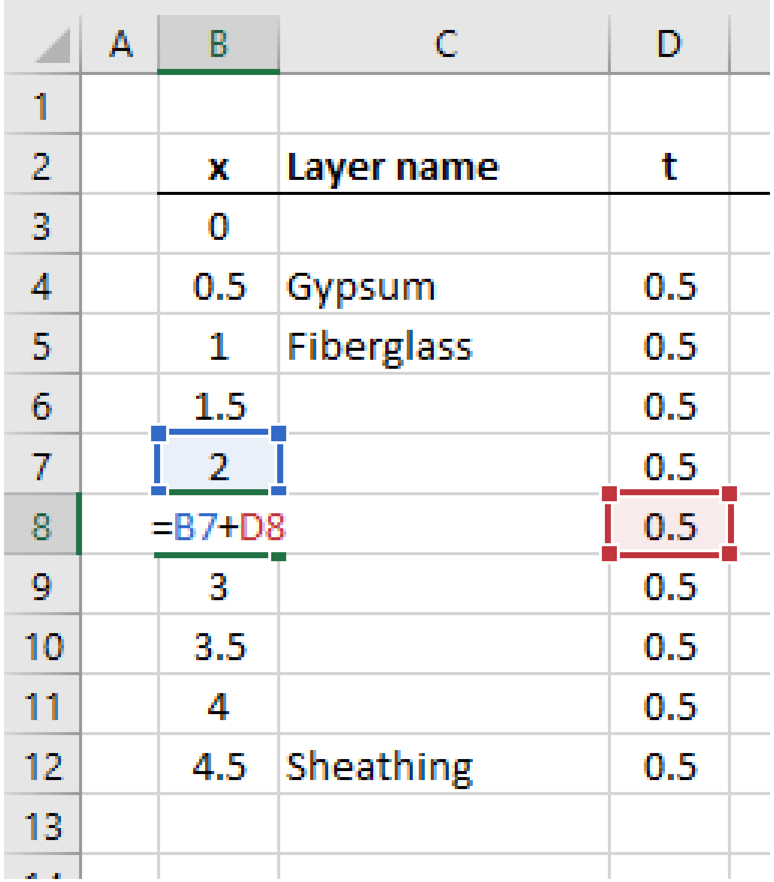
Hygrothermal Profile

- For this exercise building component with the following layer composition is given (from inside to outside):
  - ½″ Gypsum board (drywall)
  - 3½″ Fiberglass batt insulation
  - ½″ Plywood sheathing



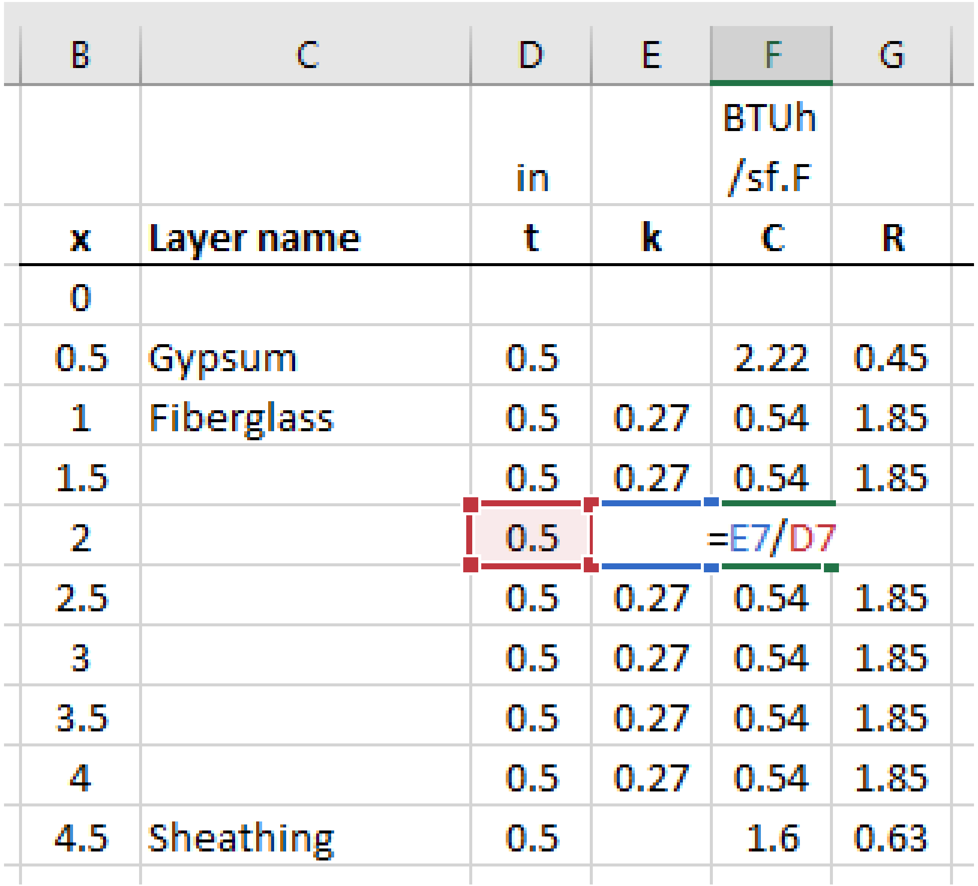
Let's split up our layers in ½" slices



	A	B	C	D
1				
2		**x**	**Layer name**	**t**
3		0		
4		0.5	Gypsum	0.5
5		1	Fiberglass	0.5
6		1.5		0.5
7		2		0.5
8		=B7+D8		0.5
9		3		0.5
10		3.5		0.5
11		4		0.5
12		4.5	Sheathing	0.5
13				

- ☐ We need a column for our running variable x (accumulated thickness as we move through the component)
- ☐ Column for layer material
- ☐ Column for thickness [in]
- ☐ Use formula to calculate x_n from $x_{n-1} + t$

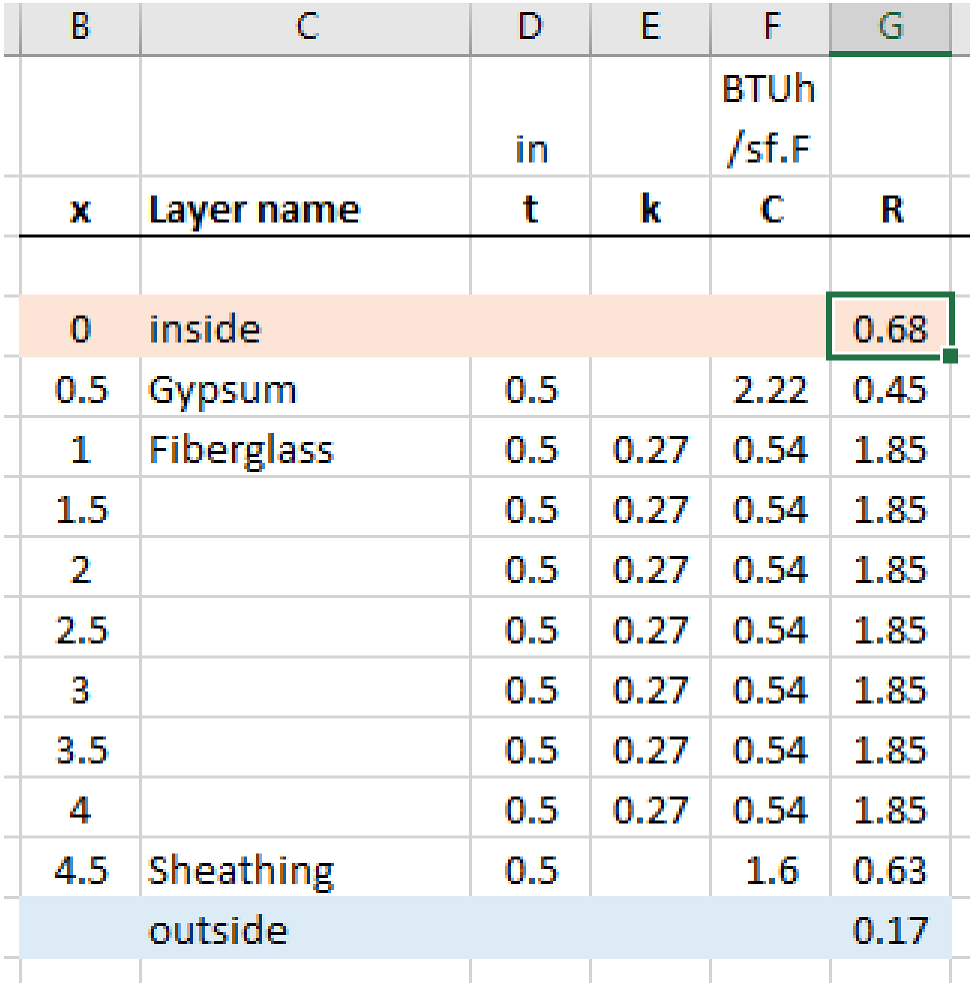
Now let’s add some conductivities …



B	C	D	E	F	G
		in		BTUh /sf.F	
x	**Layer name**	**t**	**k**	**C**	**R**
0					
0.5	Gypsum	0.5		2.22	0.45
1	Fiberglass	0.5	0.27	0.54	1.85
1.5		0.5	0.27	0.54	1.85
2		0.5		=E7/D7	
2.5		0.5	0.27	0.54	1.85
3		0.5	0.27	0.54	1.85
3.5		0.5	0.27	0.54	1.85
4		0.5	0.27	0.54	1.85
4.5	Sheathing	0.5		1.6	0.63

- ☐ E.g. from ASHRAE Fundamentals Handbook
- ☐ Need Conductance C per slice/layer
  - Either directly given (e.g. gypsum boards)
  - Or use conductivity k / t
- ☐ Then convert to resistance
  - Inverse of C

Hey, we forgot our surfaces …



B	C	D	E	F	G
		in		BTUh /sf.F	
x	Layer name	t	k	C	R
0	inside				0.68
0.5	Gypsum	0.5		2.22	0.45
1	Fiberglass	0.5	0.27	0.54	1.85
1.5		0.5	0.27	0.54	1.85
2		0.5	0.27	0.54	1.85
2.5		0.5	0.27	0.54	1.85
3		0.5	0.27	0.54	1.85
3.5		0.5	0.27	0.54	1.85
4		0.5	0.27	0.54	1.85
4.5	Sheathing	0.5		1.6	0.63
	outside				0.17

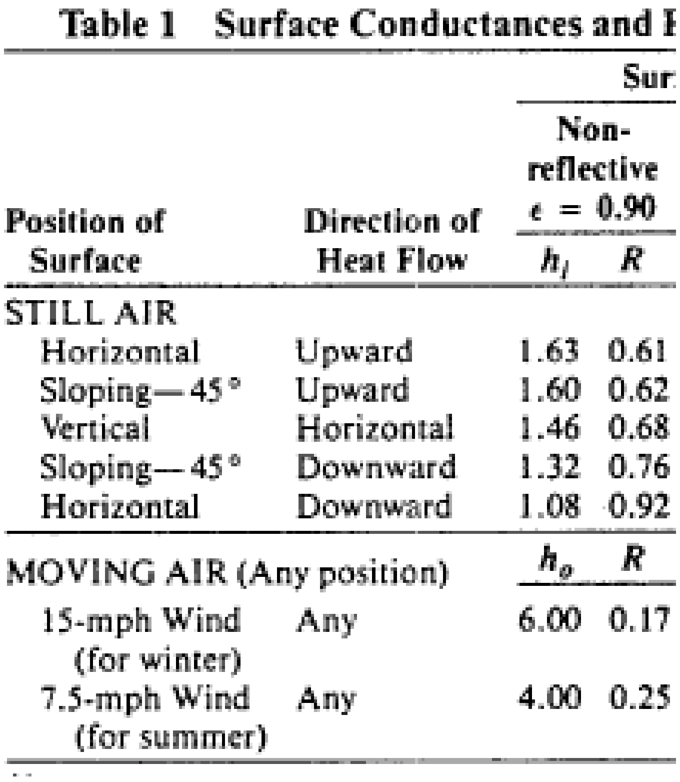
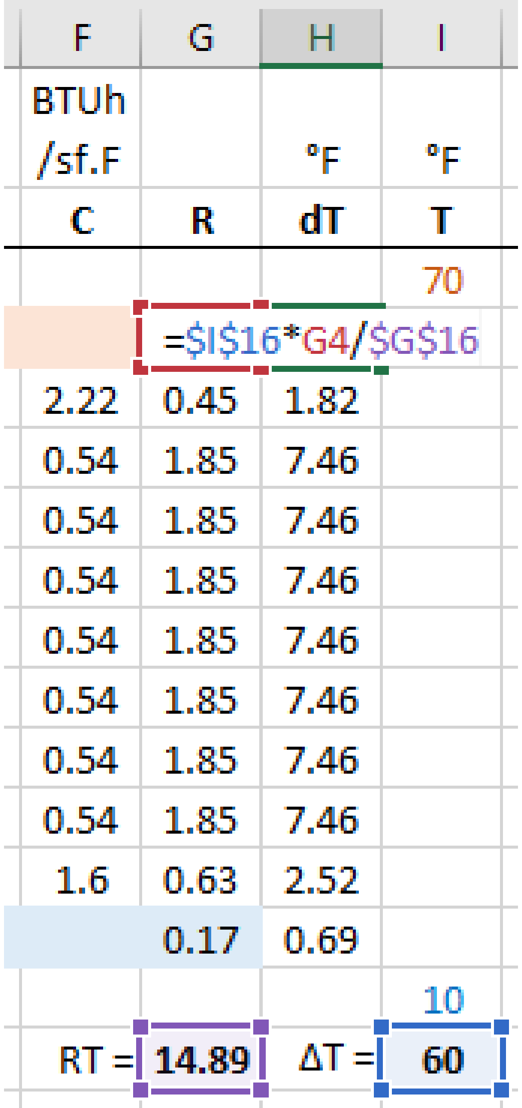


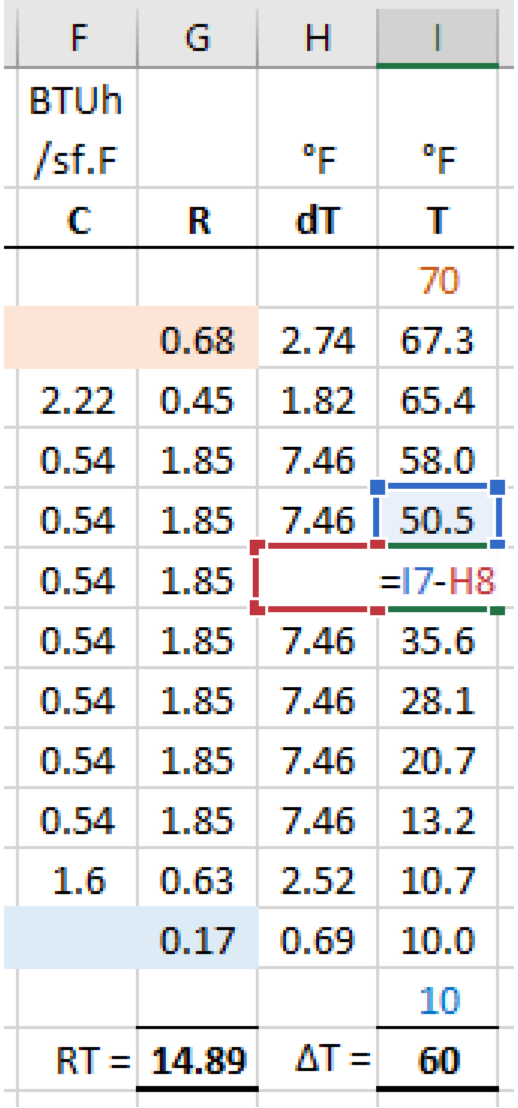
Table 1 Surface Conductances and I

		Sur	
		Non-reflective $\epsilon = 0.90$	
Position of Surface	Direction of Heat Flow	h_i	R
STILL AIR			
Horizontal	Upward	1.63	0.61
Sloping—45°	Upward	1.60	0.62
Vertical	Horizontal	1.46	0.68
Sloping—45°	Downward	1.32	0.76
Horizontal	Downward	1.08	0.92
MOVING AIR (Any position)		h_o	R
15-mph Wind (for winter)	Any	6.00	0.17
7.5-mph Wind (for summer)	Any	4.00	0.25

Temperature Profile



F	G	H	I
BTUh /sf.F		°F	°F
C	**R**	**dT**	**T**
			70
	=$I$16*G4/$G$16		
2.22	0.45	1.82	
0.54	1.85	7.46	
0.54	1.85	7.46	
0.54	1.85	7.46	
0.54	1.85	7.46	
0.54	1.85	7.46	
0.54	1.85	7.46	
0.54	1.85	7.46	
1.6	0.63	2.52	
	0.17	0.69	
			10
RT =	14.89	ΔT =	60



F	G	H	I
BTUh /sf.F		°F	°F
C	**R**	**dT**	**T**
			70
	0.68	2.74	67.3
2.22	0.45	1.82	65.4
0.54	1.85	7.46	58.0
0.54	1.85	7.46	50.5
0.54	1.85		=I7-H8
0.54	1.85	7.46	35.6
0.54	1.85	7.46	28.1
0.54	1.85	7.46	20.7
0.54	1.85	7.46	13.2
1.6	0.63	2.52	10.7
	0.17	0.69	10.0
			10
RT =	**14.89**	ΔT =	**60**

- ☐ Calculate dt_n from

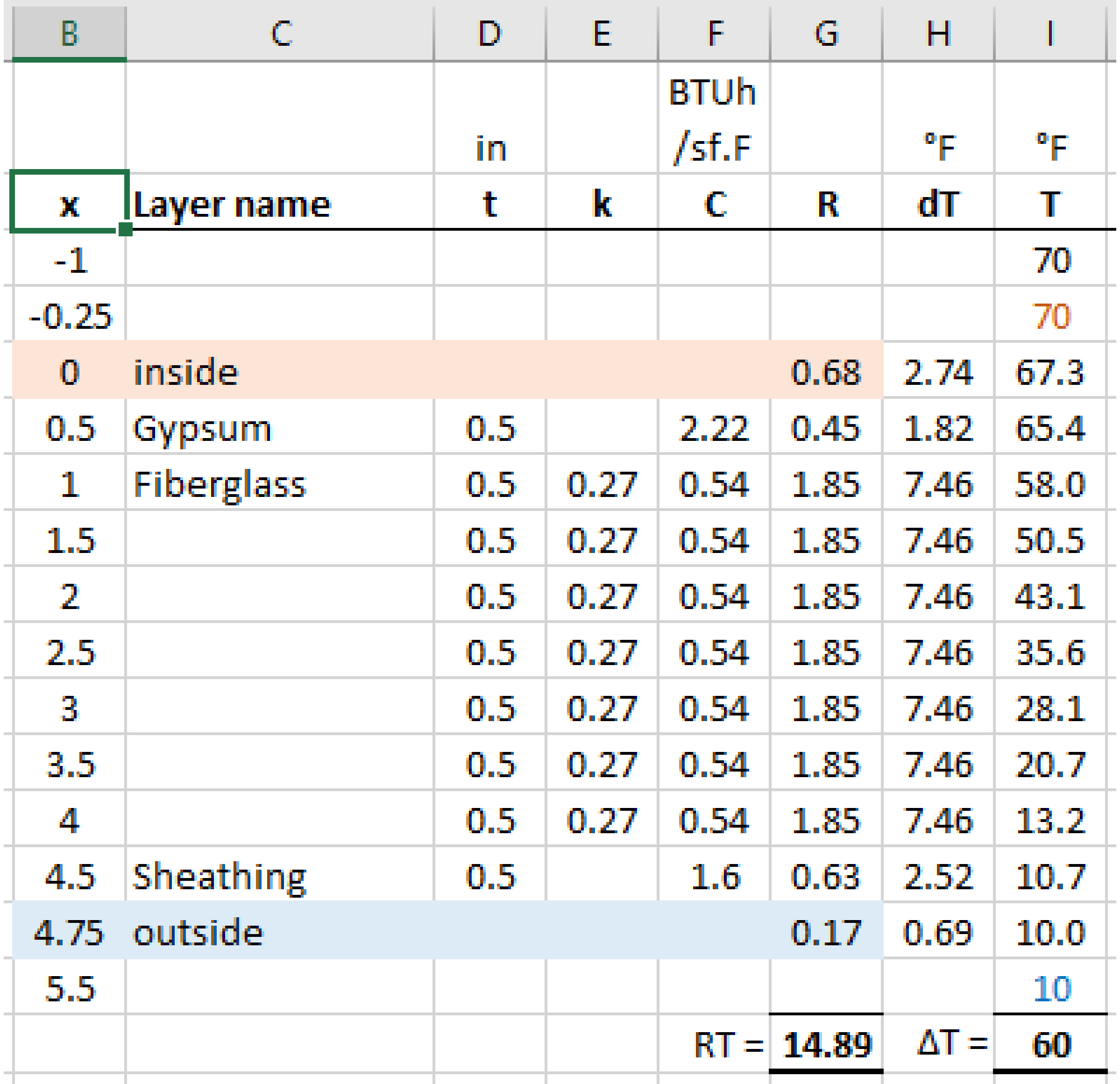
$$\Delta t_n = \Delta T \cdot \frac{R_n}{RT}$$

- ☐ Calculate T_n from

$$T_n = T_{n-1} - dt_n$$

- ☐ Check that you end up at the “correct” temperature at the other side …

Let’s draw the temperature gradient



B	C	D	E	F	G	H	I
		in		BTUh /sf.F		°F	°F
x	**Layer name**	**t**	**k**	**C**	**R**	**dT**	**T**
-1							70
-0.25							70
0	inside				0.68	2.74	67.3
0.5	Gypsum	0.5		2.22	0.45	1.82	65.4
1	Fiberglass	0.5	0.27	0.54	1.85	7.46	58.0
1.5		0.5	0.27	0.54	1.85	7.46	50.5
2		0.5	0.27	0.54	1.85	7.46	43.1
2.5		0.5	0.27	0.54	1.85	7.46	35.6
3		0.5	0.27	0.54	1.85	7.46	28.1
3.5		0.5	0.27	0.54	1.85	7.46	20.7
4		0.5	0.27	0.54	1.85	7.46	13.2
4.5	Sheathing	0.5		1.6	0.63	2.52	10.7
4.75	outside				0.17	0.69	10.0
5.5							10
				RT =	**14.89**	ΔT =	**60**

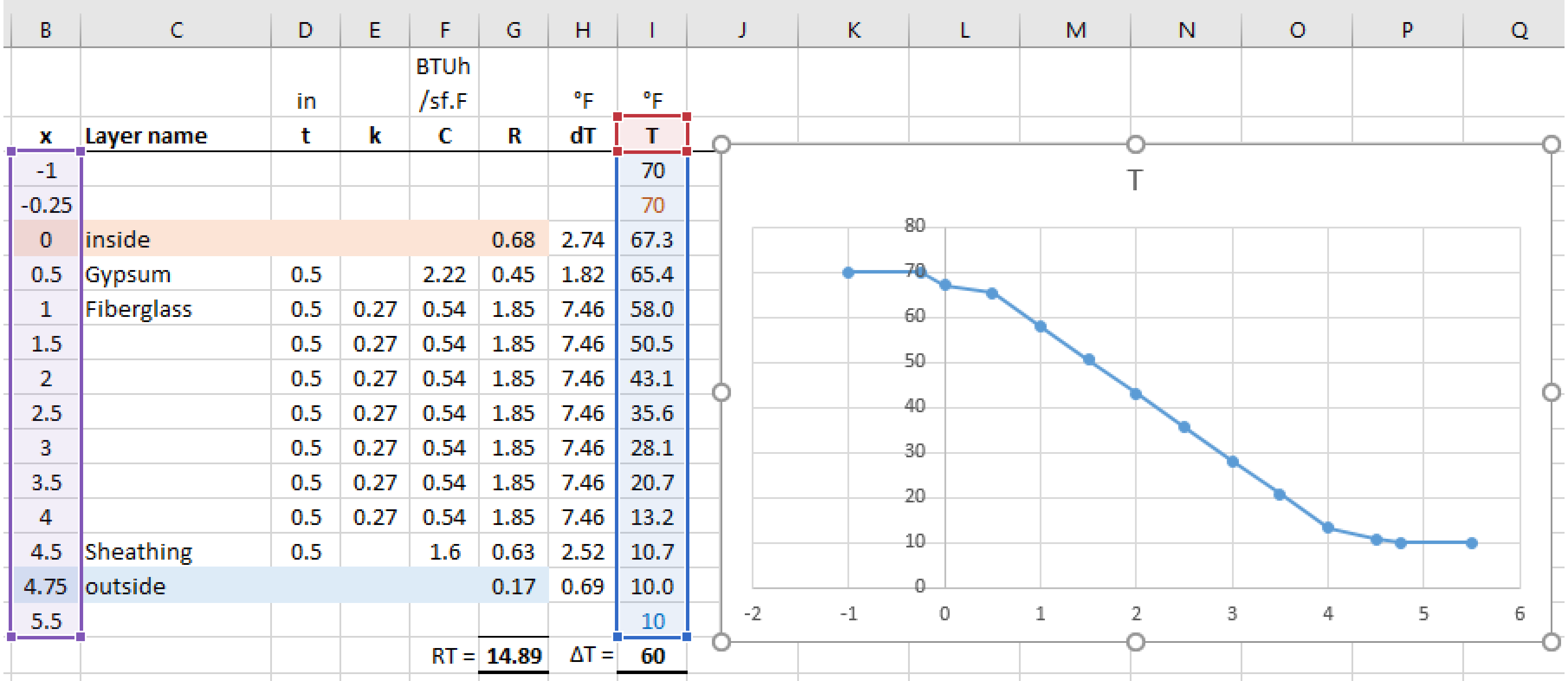
We expand our coordinates to better show interior and exterior temperature

- Set x = -0.25 for line above “inside”
- Add line above
- Set x = -1
- Set T to interior temp

- Set x of “outside” to $x_n + 0.25$
- Add line below outside
- Give it $x = x_n + 1.0$
- Set T to exterior temp

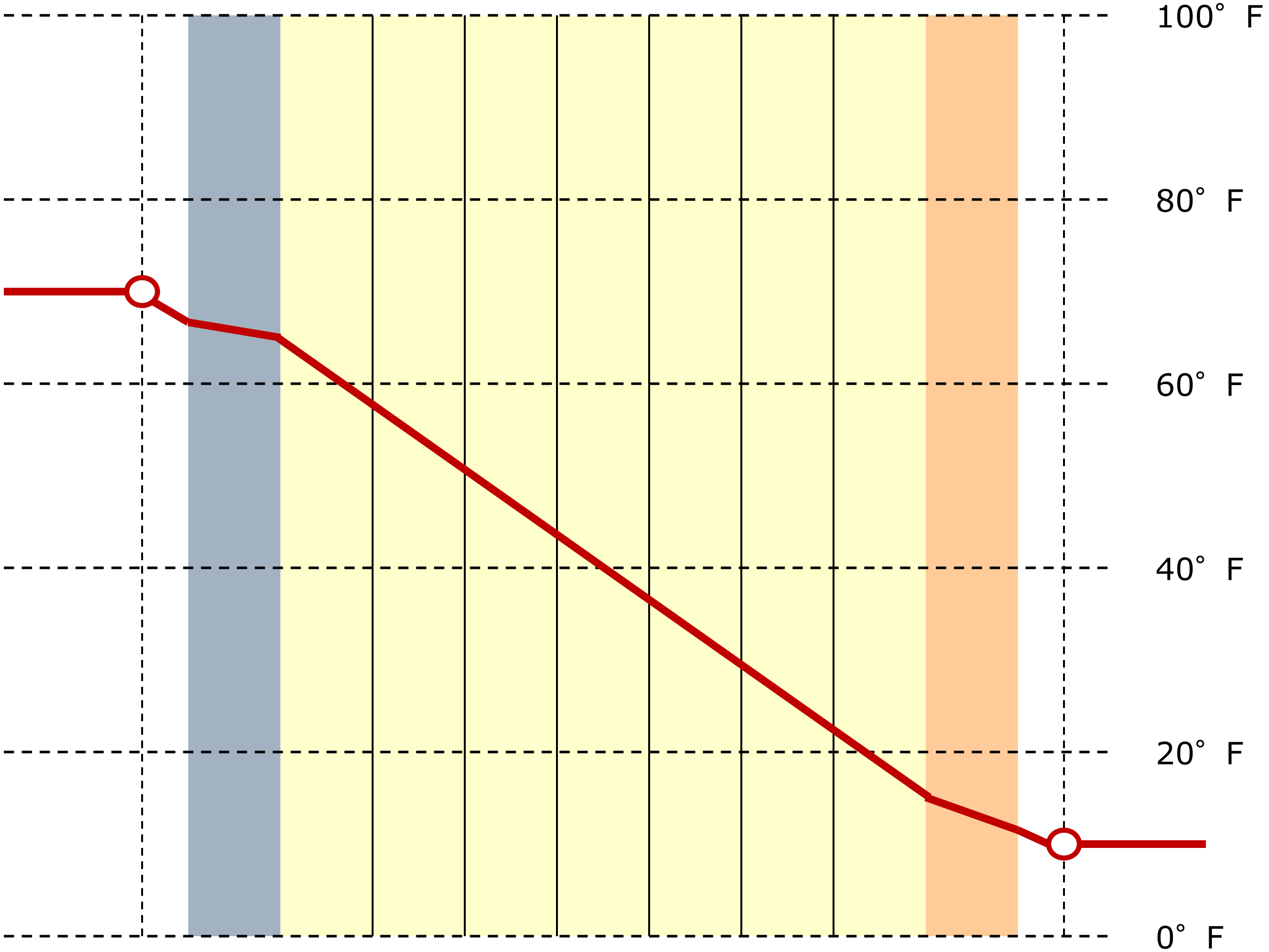
Create the graph

- ☐ Select “x” and “T” column
- ☐ Insert “Scatter Plot” (e.g. with straight lines and markers)



B	C	D	E	F	G	H	I
		in		BTUh /sf.F		°F	°F
x	**Layer name**	**t**	**k**	**C**	**R**	**dT**	**T**
-1							70
-0.25							70
0	inside				0.68	2.74	67.3
0.5	Gypsum	0.5		2.22	0.45	1.82	65.4
1	Fiberglass	0.5	0.27	0.54	1.85	7.46	58.0
1.5		0.5	0.27	0.54	1.85	7.46	50.5
2		0.5	0.27	0.54	1.85	7.46	43.1
2.5		0.5	0.27	0.54	1.85	7.46	35.6
3		0.5	0.27	0.54	1.85	7.46	28.1
3.5		0.5	0.27	0.54	1.85	7.46	20.7
4		0.5	0.27	0.54	1.85	7.46	13.2
4.5	Sheathing	0.5		1.6	0.63	2.52	10.7
4.75	outside				0.17	0.69	10.0
5.5							10
				RT =	**14.89**	ΔT =	**60**

Temperature Gradient



Saturation Pressure from db-Temp?

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Teten's Formula

- ☐ This is an empirical formula that provides sufficiently accurate numbers for liquid water (i.e. above freezing temperatures)

$$e_s = e_0 \cdot exp\left[\frac{b \cdot (T - T_1)}{T - T_2}\right]$$

$$e_s = 6.112 \cdot exp\left[\frac{17.67 \cdot T}{T + 243.5}\right]$$

$$e_s = 6.1121 \cdot exp\left[\frac{17.502 \cdot T}{T + 240.97}\right]$$

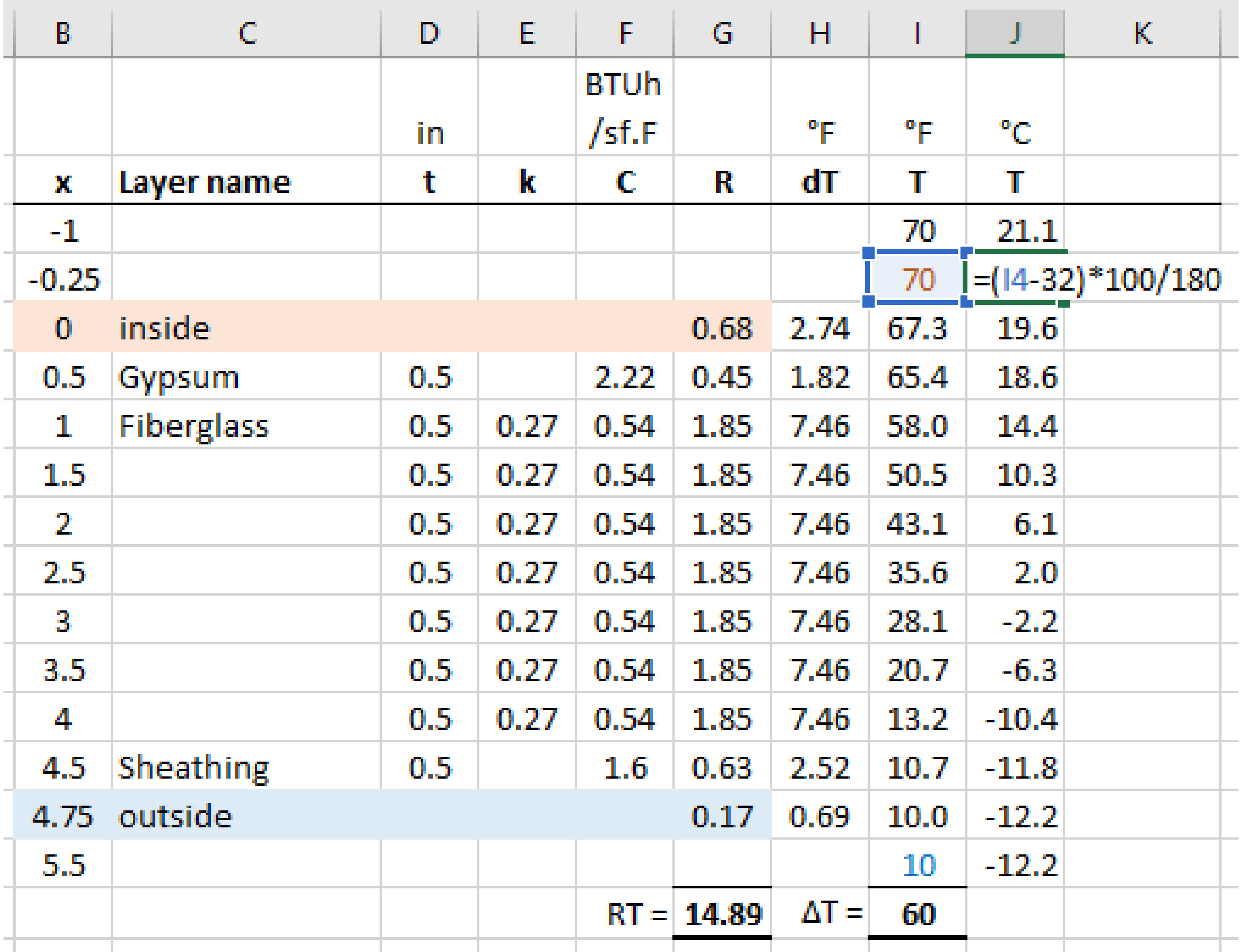
e_s in mbar or hPa from T in ° C

Temperature Conversion

- Converting Fahrenheit to Celsius
  - Check your conversion formula against “known” values
    - Freezing: 32° F = 0° C
    - Boiling: 212° F = 100° C

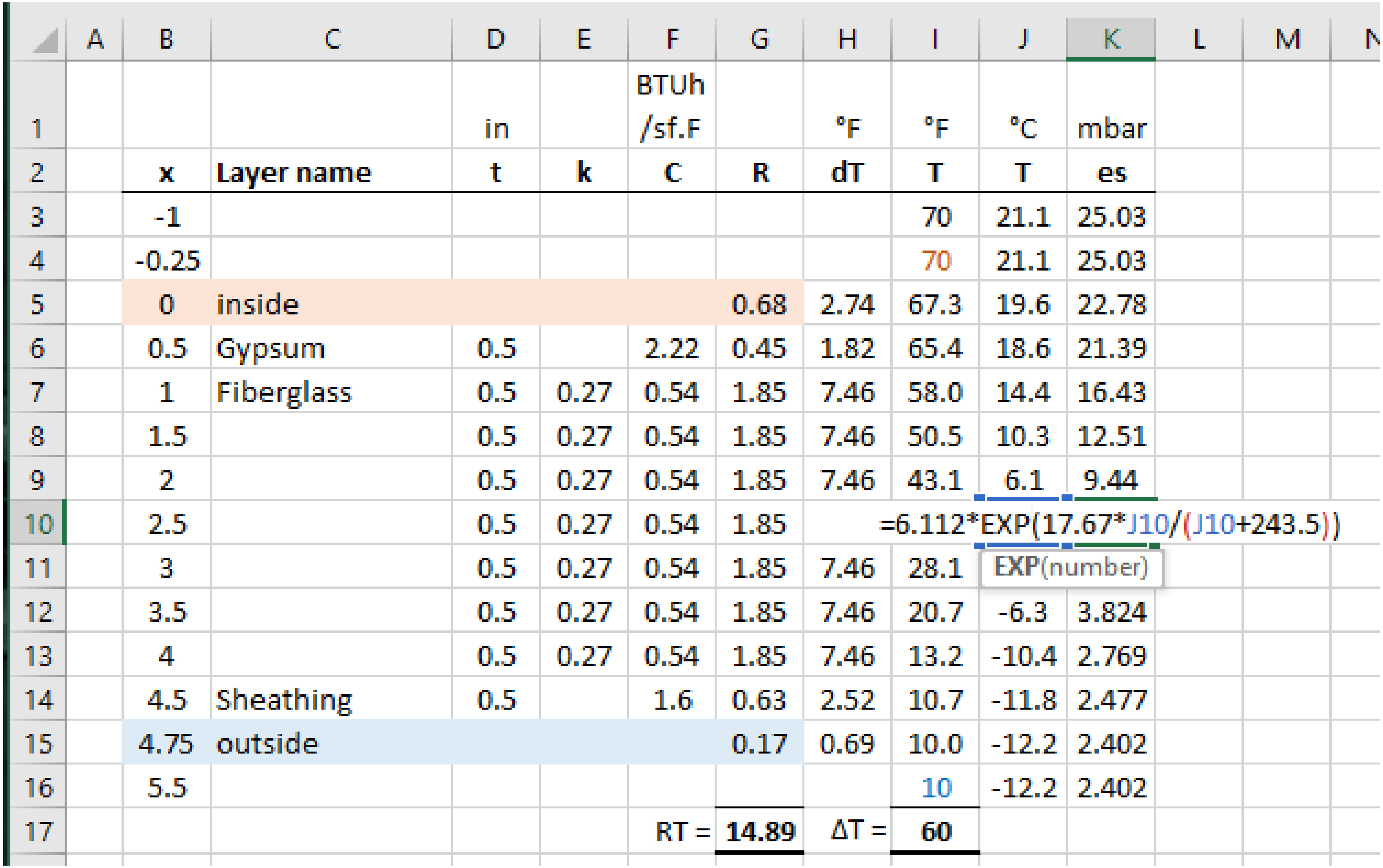
$$T_C = (T_F - 32) \times \frac{100}{180} = (T_F - 32) \times \frac{5}{9}$$

Temperature Conversion: F -> C



B	C	D	E	F	G	H	I	J	K
		in		BTUh /sf.F		°F	°F	°C	
x	**Layer name**	**t**	**k**	**C**	**R**	**dT**	**T**	**T**	
-1							70	21.1	
-0.25							70	=(I4-32)*100/180	
0	inside				0.68	2.74	67.3	19.6	
0.5	Gypsum	0.5		2.22	0.45	1.82	65.4	18.6	
1	Fiberglass	0.5	0.27	0.54	1.85	7.46	58.0	14.4	
1.5		0.5	0.27	0.54	1.85	7.46	50.5	10.3	
2		0.5	0.27	0.54	1.85	7.46	43.1	6.1	
2.5		0.5	0.27	0.54	1.85	7.46	35.6	2.0	
3		0.5	0.27	0.54	1.85	7.46	28.1	-2.2	
3.5		0.5	0.27	0.54	1.85	7.46	20.7	-6.3	
4		0.5	0.27	0.54	1.85	7.46	13.2	-10.4	
4.5	Sheathing	0.5		1.6	0.63	2.52	10.7	-11.8	
4.75	outside				0.17	0.69	10.0	-12.2	
5.5							10	-12.2	
				RT =	**14.89**	ΔT =	**60**		

Calculate saturation pressure (in mbar)



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				in		BTUh /sf.F		°F	°F	°C	mbar			
2		**x**	**Layer name**	**t**	**k**	**C**	**R**	**dT**	**T**	**T**	**es**			
3		-1							70	21.1	25.03			
4		-0.25							70	21.1	25.03			
5		0	inside				0.68	2.74	67.3	19.6	22.78			
6		0.5	Gypsum	0.5		2.22	0.45	1.82	65.4	18.6	21.39			
7		1	Fiberglass	0.5	0.27	0.54	1.85	7.46	58.0	14.4	16.43			
8		1.5		0.5	0.27	0.54	1.85	7.46	50.5	10.3	12.51			
9		2		0.5	0.27	0.54	1.85	7.46	43.1	6.1	9.44			
10		2.5		0.5	0.27	0.54	1.85				=6.112*EXP(17.67*J10/(J10+243.5))			
11		3		0.5	0.27	0.54	1.85	7.46	28.1	EXP(number)				
12		3.5		0.5	0.27	0.54	1.85	7.46	20.7	-6.3	3.824			
13		4		0.5	0.27	0.54	1.85	7.46	13.2	-10.4	2.769			
14		4.5	Sheathing	0.5		1.6	0.63	2.52	10.7	-11.8	2.477			
15		4.75	outside				0.17	0.69	10.0	-12.2	2.402			
16		5.5							10	-12.2	2.402			
17						RT =	**14.89**	ΔT =	**60**					

Pressure Conversion

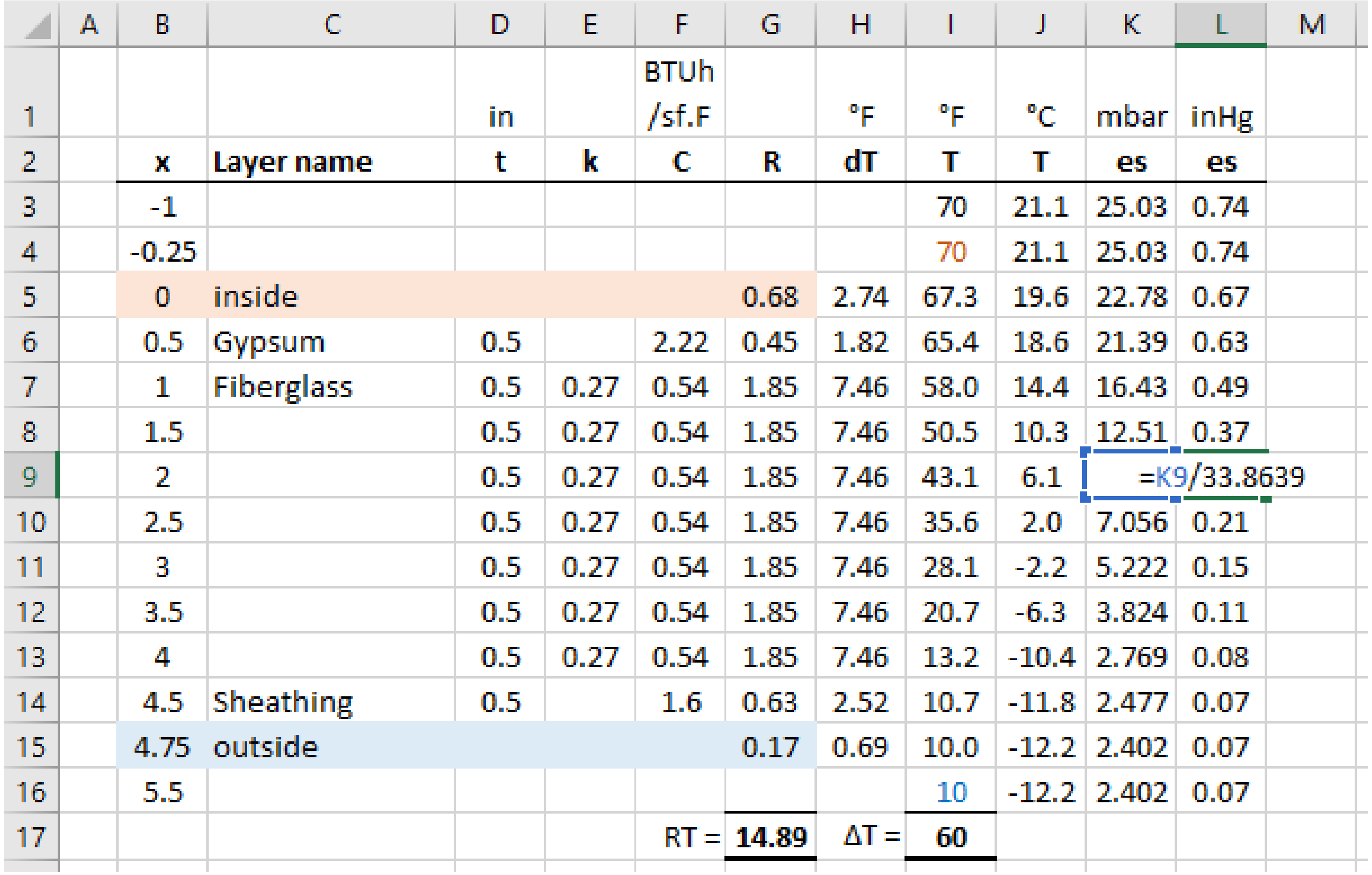
- Converting inches of mercury [inHg]
  - to millibars [mb]
  - or hectopascals [hPa]

$$P_{mb} = 33.8639 \times P_{inHg}$$

$$P_{inHg} = P_{inHg} / 33.8639$$

Convert mbar into inHg

- ☐ Compare values to those you read in psychrometric chart to check your equations are working correctly …



	A	B	C	D	E	F	G	H	I	J	K	L	M
1				in		BTUh /sf.F		°F	°F	°C	mbar	inHg	
2		**x**	**Layer name**	**t**	**k**	**C**	**R**	**dT**	**T**	**T**	**es**	**es**	
3		-1							70	21.1	25.03	0.74	
4		-0.25							70	21.1	25.03	0.74	
5		0	inside				0.68	2.74	67.3	19.6	22.78	0.67	
6		0.5	Gypsum	0.5		2.22	0.45	1.82	65.4	18.6	21.39	0.63	
7		1	Fiberglass	0.5	0.27	0.54	1.85	7.46	58.0	14.4	16.43	0.49	
8		1.5		0.5	0.27	0.54	1.85	7.46	50.5	10.3	12.51	0.37	
9		2		0.5	0.27	0.54	1.85	7.46	43.1	6.1		=K9/33.8639	
10		2.5		0.5	0.27	0.54	1.85	7.46	35.6	2.0	7.056	0.21	
11		3		0.5	0.27	0.54	1.85	7.46	28.1	-2.2	5.222	0.15	
12		3.5		0.5	0.27	0.54	1.85	7.46	20.7	-6.3	3.824	0.11	
13		4		0.5	0.27	0.54	1.85	7.46	13.2	-10.4	2.769	0.08	
14		4.5	Sheathing	0.5		1.6	0.63	2.52	10.7	-11.8	2.477	0.07	
15		4.75	outside				0.17	0.69	10.0	-12.2	2.402	0.07	
16		5.5							10	-12.2	2.402	0.07	
17						RT =	**14.89**	ΔT =	**60**				

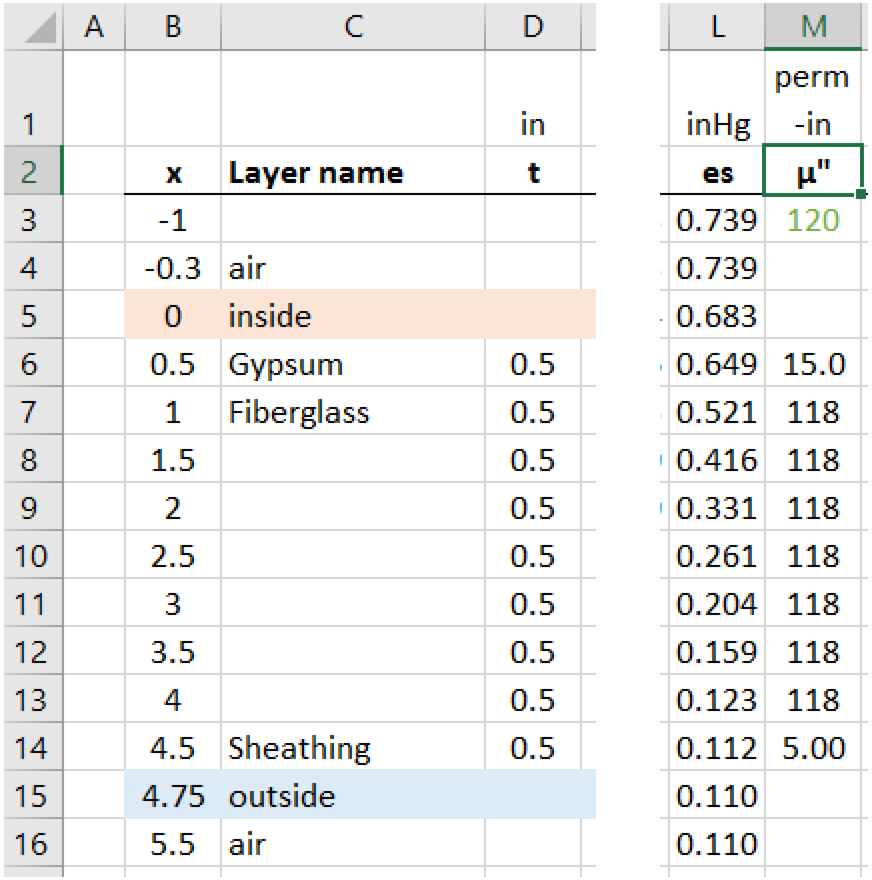
Glaser Method

- Assumptions:
  - steady state boundary conditions
    (i.e. no significant changes in humidity on either side over a longer time)
  - no heat or moisture storage effects
  - no airflow, (initial) wetting, capillary effects (work in opposite)

- So why do it anyway?
  - **Visibility (= supports understanding) of diffusion process**

- Method Approach:
  - If we adjust the thickness of each material (layer) so that their respective permeabilities are the same, we can draw a linear pressure gradient from inside to outside conditions and compare against the saturation pressure in calculated points.
  - The Glaser Method converts permeability of materials to an equivalent thickness of air for visualization of risks

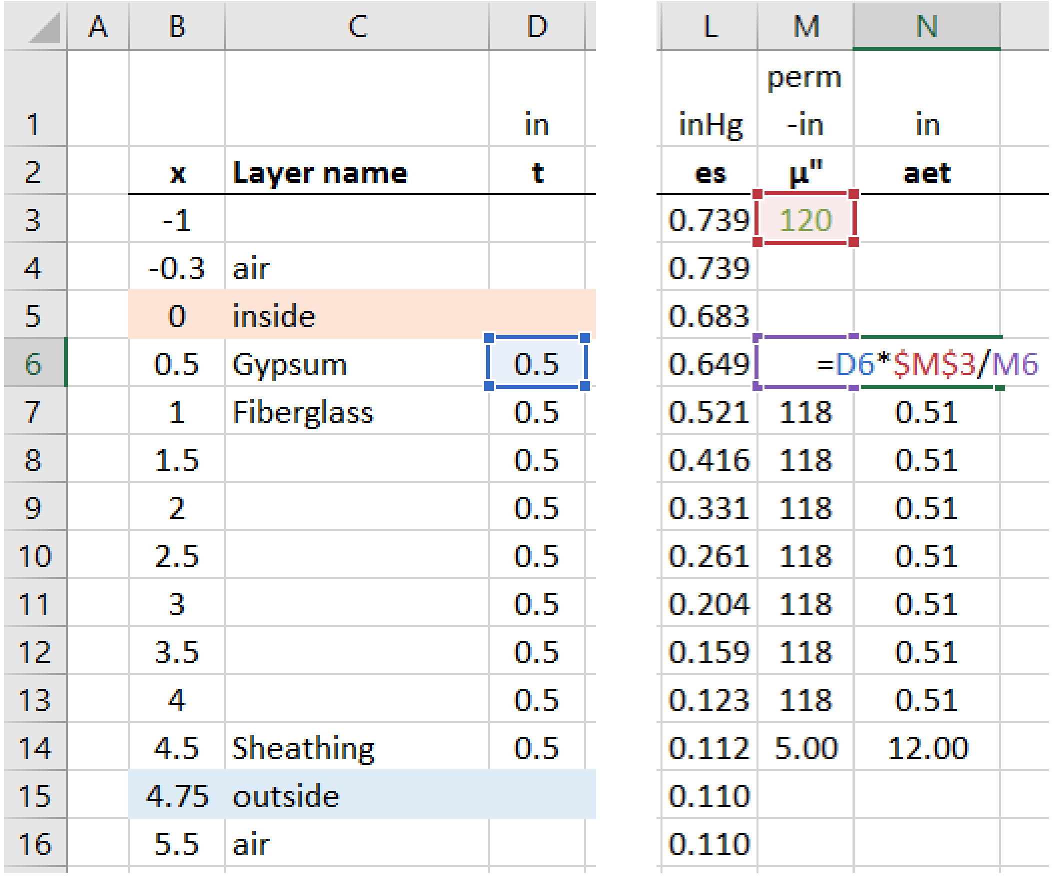
Find vapor permeability/permeance of materials



	A	B	C	D	L	M
1				in	inHg	perm -in
2		x	**Layer name**	**t**	**es**	**μ"**
3		-1			0.739	120
4		-0.3	air		0.739	
5		0	inside		0.683	
6		0.5	Gypsum	0.5	0.649	15.0
7		1	Fiberglass	0.5	0.521	118
8		1.5		0.5	0.416	118
9		2		0.5	0.331	118
10		2.5		0.5	0.261	118
11		3		0.5	0.204	118
12		3.5		0.5	0.159	118
13		4		0.5	0.123	118
14		4.5	Sheathing	0.5	0.112	5.00
15		4.75	outside		0.110	
16		5.5	air		0.110	

- E.g. ASHRAE Fund. Ch 26
- Chapter 25 describes vapor permeability as:
  - $\boldsymbol{\mu_p}$ = water vapor permeability of material in [gr / ft·hr·inHg]
  - Ch 26 gives perm-in and we therefore label in here the permeability column as **μ”**

Now convert to air equivalent thickness

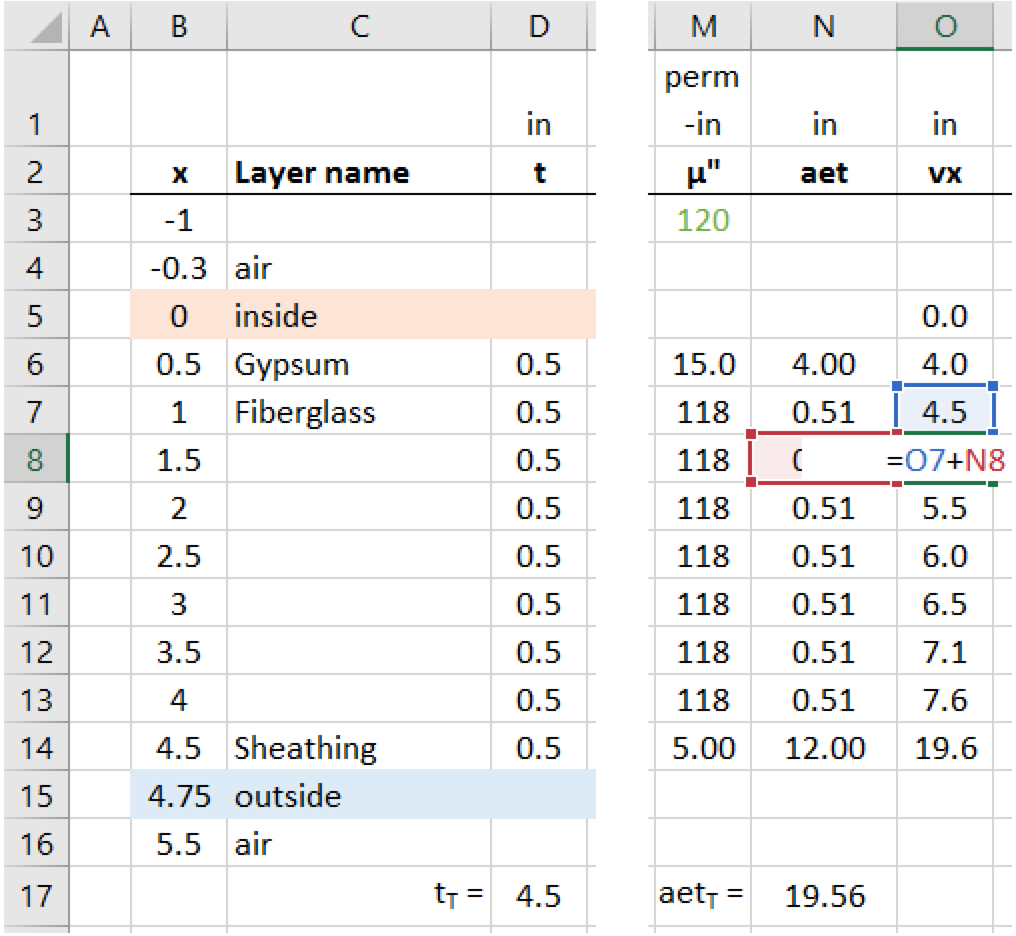


	A	B	C	D	L	M	N
1				in	inHg	perm -in	in
2		**x**	**Layer name**	**t**	**es**	**µ"**	**aet**
3		-1			0.739	120	
4		-0.3	air		0.739		
5		0	inside		0.683		
6		0.5	Gypsum	0.5	0.649		=D6*$M$3/M6
7		1	Fiberglass	0.5	0.521	118	0.51
8		1.5		0.5	0.416	118	0.51
9		2		0.5	0.331	118	0.51
10		2.5		0.5	0.261	118	0.51
11		3		0.5	0.204	118	0.51
12		3.5		0.5	0.159	118	0.51
13		4		0.5	0.123	118	0.51
14		4.5	Sheathing	0.5	0.112	5.00	12.00
15		4.75	outside		0.110		
16		5.5	air		0.110		

- ☐ Comparing permeability to air, which we assume as **120 perm-in**

aet = t · 120 / µ”

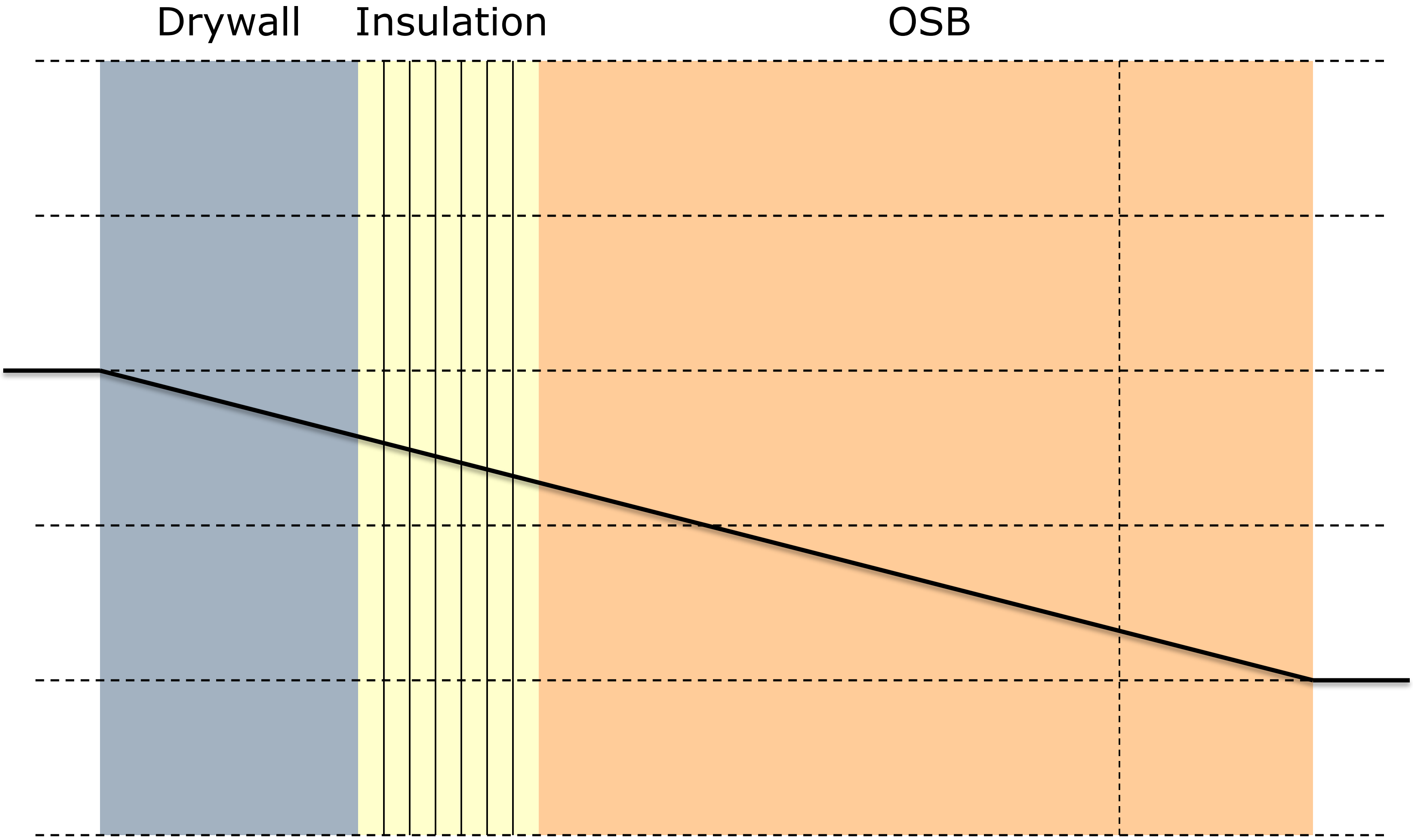
New running variable for depth



	A	B	C	D	M	N	O
1				in	perm -in	in	in
2		x	**Layer name**	t	µ"	aet	vx
3		-1			120		
4		-0.3	air				
5		0	inside				0.0
6		0.5	Gypsum	0.5	15.0	4.00	4.0
7		1	Fiberglass	0.5	118	0.51	4.5
8		1.5		0.5	118	(	=O7+N8
9		2		0.5	118	0.51	5.5
10		2.5		0.5	118	0.51	6.0
11		3		0.5	118	0.51	6.5
12		3.5		0.5	118	0.51	7.1
13		4		0.5	118	0.51	7.6
14		4.5	Sheathing	0.5	5.00	12.00	19.6
15		4.75	outside				
16		5.5	air				
17			t_T =	4.5	aet_T =	19.56	

- We need a new running variable for the depth x as we progress through layers
  - Start at 0
  - Add individual equivalent thicknesses (aet_i)
  - End should be the same as total air equivalent thickness aet_T

Vapor pressure gradient through permeability equivalent thickness



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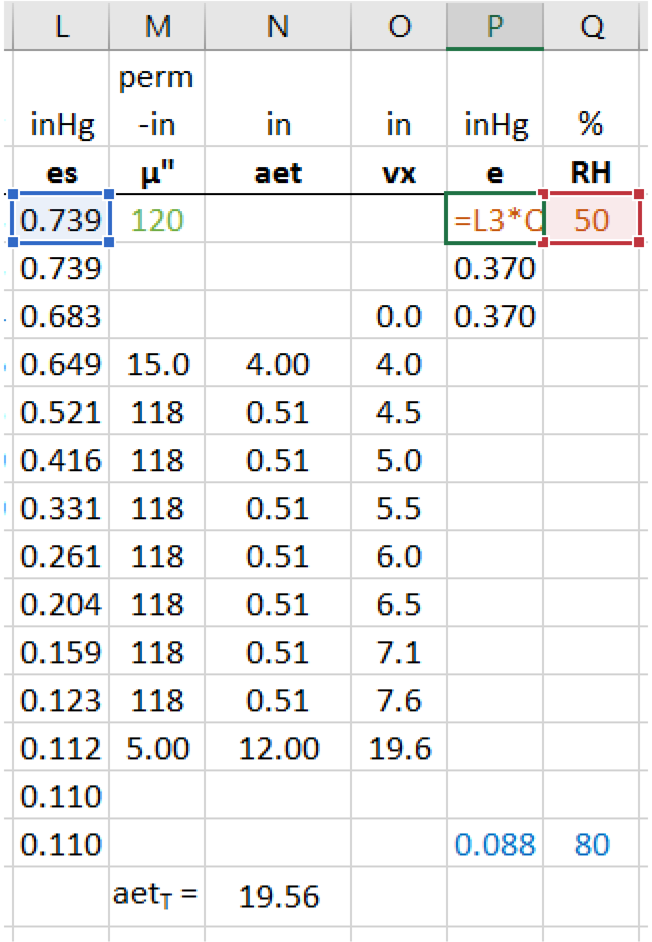
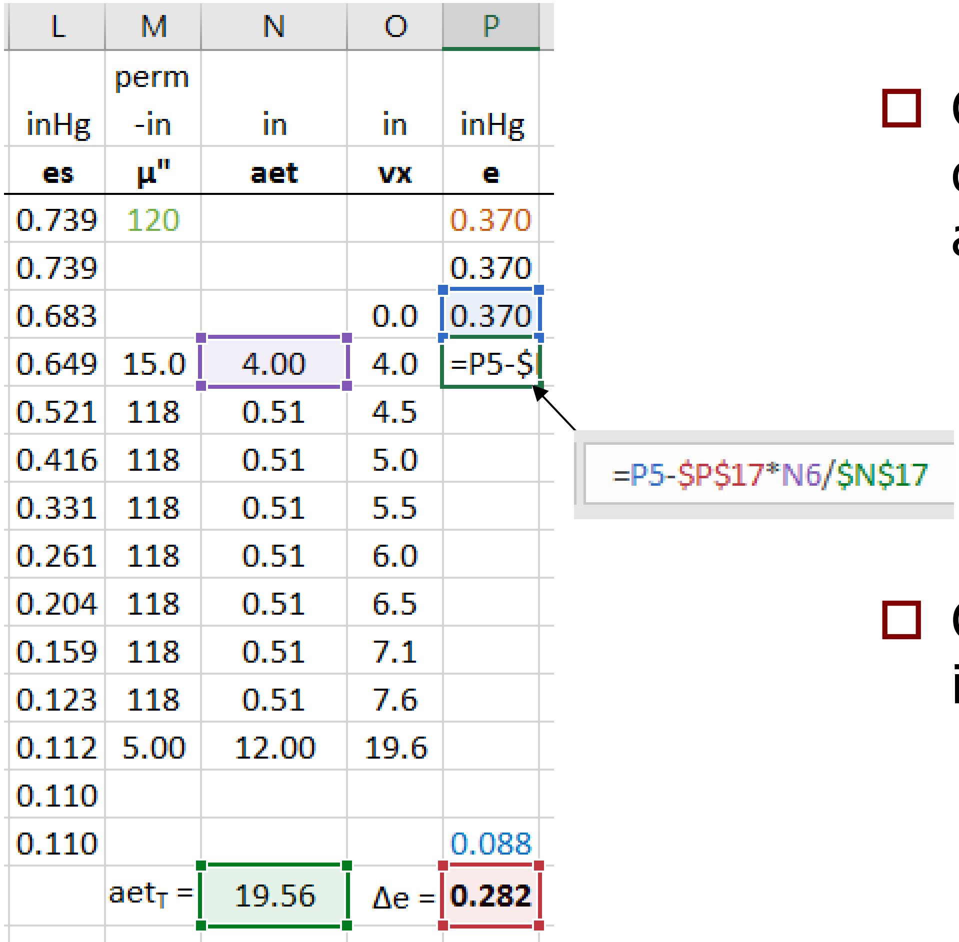
Calculate “real” pressure int/ext



L	M	N	O	P	Q
inHg	perm-in	in	in	inHg	%
es	**µ"**	**aet**	**vx**	**e**	**RH**
0.739	120			=L3*C	50
0.739				0.370	
0.683			0.0	0.370	
0.649	15.0	4.00	4.0		
0.521	118	0.51	4.5		
0.416	118	0.51	5.0		
0.331	118	0.51	5.5		
0.261	118	0.51	6.0		
0.204	118	0.51	6.5		
0.159	118	0.51	7.1		
0.123	118	0.51	7.6		
0.112	5.00	12.00	19.6		
0.110					
0.110				0.088	80
	aet$_T$ =	19.56			

- ☐ Add column for vapor pressure **e** [inHg]
- ☐ Add column for **RH**
  - Set first row to interior RH
  - Set last row to exterior RH
- ☐ Calculate **e** from **es** and **RH**
- ☐ “**e**” is same until we hit a surface …
  - we may want to leave the exterior surface for now and check if we end up correctly

Calculate “real” vapor gradient



L	M	N	O	P
inHg	perm-in	in	in	inHg
es	**μ"**	**aet**	**vx**	**e**
0.739	120			0.370
0.739				0.370
0.683			0.0	0.370
0.649	15.0	4.00	4.0	=P5-$
0.521	118	0.51	4.5	
0.416	118	0.51	5.0	
0.331	118	0.51	5.5	
0.261	118	0.51	6.0	
0.204	118	0.51	6.5	
0.159	118	0.51	7.1	
0.123	118	0.51	7.6	
0.112	5.00	12.00	19.6	
0.110				
0.110				0.088
	aet_T =	19.56	Δe =	**0.282**

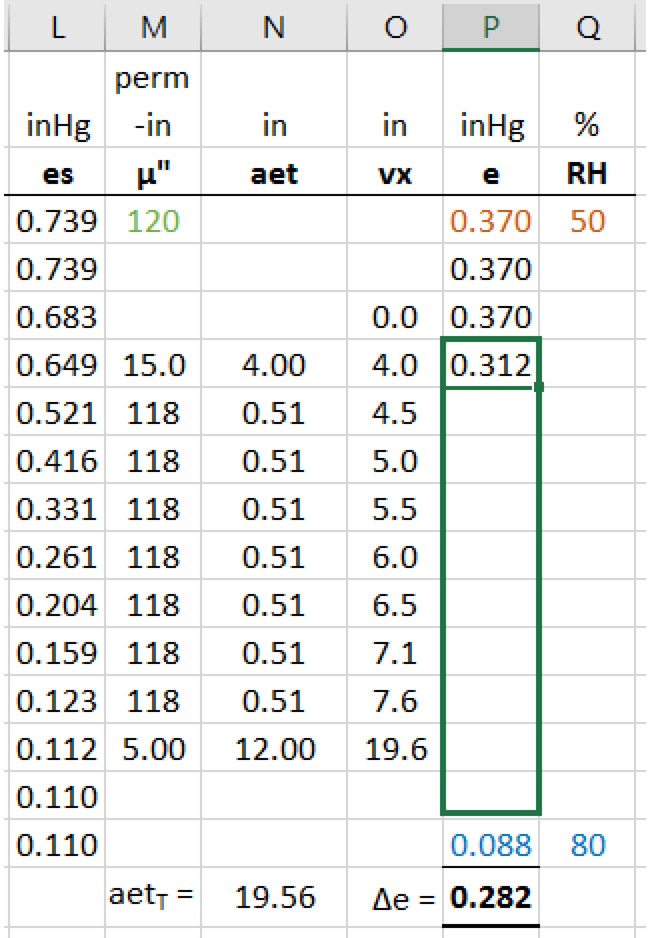
```
=P5-$P$17*N6/$N$17
```

- ☐ Calculate total pressure difference between interior and exterior (P17)
- ☐ Calculate pressure at individual points

$$e_n = e_{n-1} - \Delta e * aet_n / aet_T$$

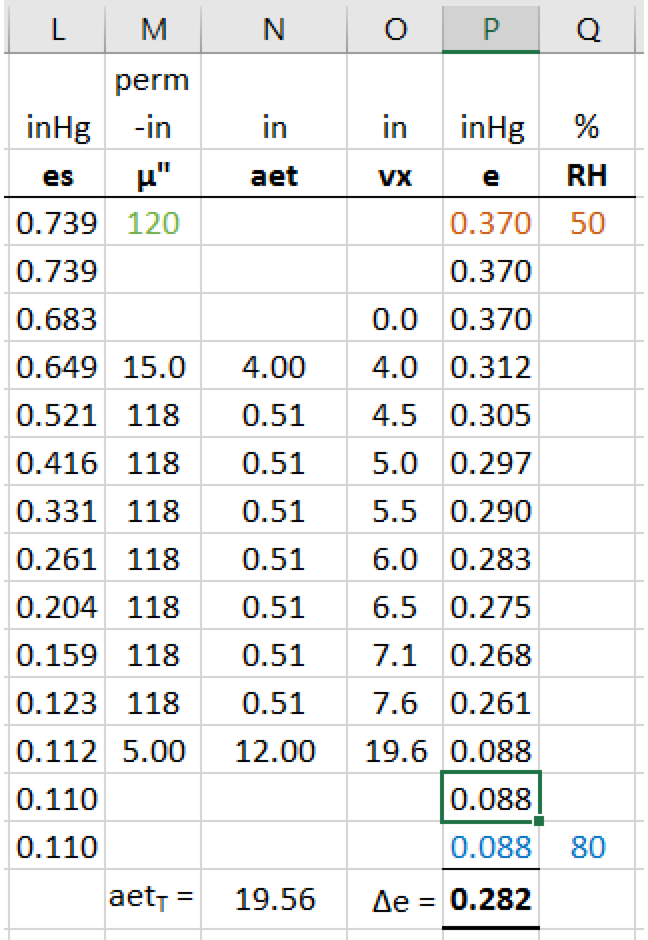
“real” vapor gradient … continued

- ☐ Now “drag it down”



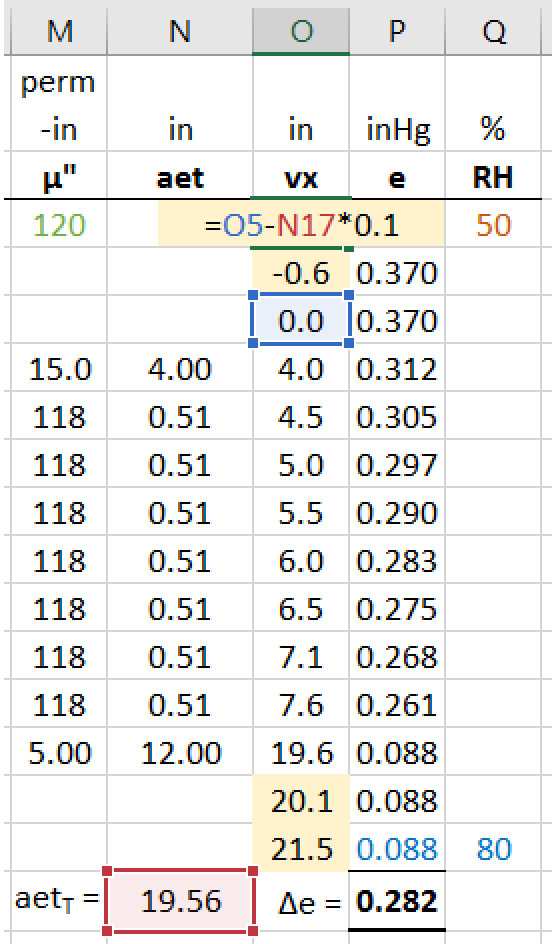
L	M	N	O	P	Q
inHg	perm -in	in	in	inHg	%
es	**µ"**	**aet**	**vx**	**e**	**RH**
0.739	120			0.370	50
0.739				0.370	
0.683			0.0	0.370	
0.649	15.0	4.00	4.0	0.312	
0.521	118	0.51	4.5		
0.416	118	0.51	5.0		
0.331	118	0.51	5.5		
0.261	118	0.51	6.0		
0.204	118	0.51	6.5		
0.159	118	0.51	7.1		
0.123	118	0.51	7.6		
0.112	5.00	12.00	19.6		
0.110					
0.110				0.088	80
	aet_T =	19.56	Δe =	**0.282**	

- ☐ Check if end matches ext



L	M	N	O	P	Q
inHg	perm -in	in	in	inHg	%
es	**µ"**	**aet**	**vx**	**e**	**RH**
0.739	120			0.370	50
0.739				0.370	
0.683			0.0	0.370	
0.649	15.0	4.00	4.0	0.312	
0.521	118	0.51	4.5	0.305	
0.416	118	0.51	5.0	0.297	
0.331	118	0.51	5.5	0.290	
0.261	118	0.51	6.0	0.283	
0.204	118	0.51	6.5	0.275	
0.159	118	0.51	7.1	0.268	
0.123	118	0.51	7.6	0.261	
0.112	5.00	12.00	19.6	0.088	
0.110				0.088	
0.110				0.088	80
	aet_T =	19.56	Δe =	**0.282**	

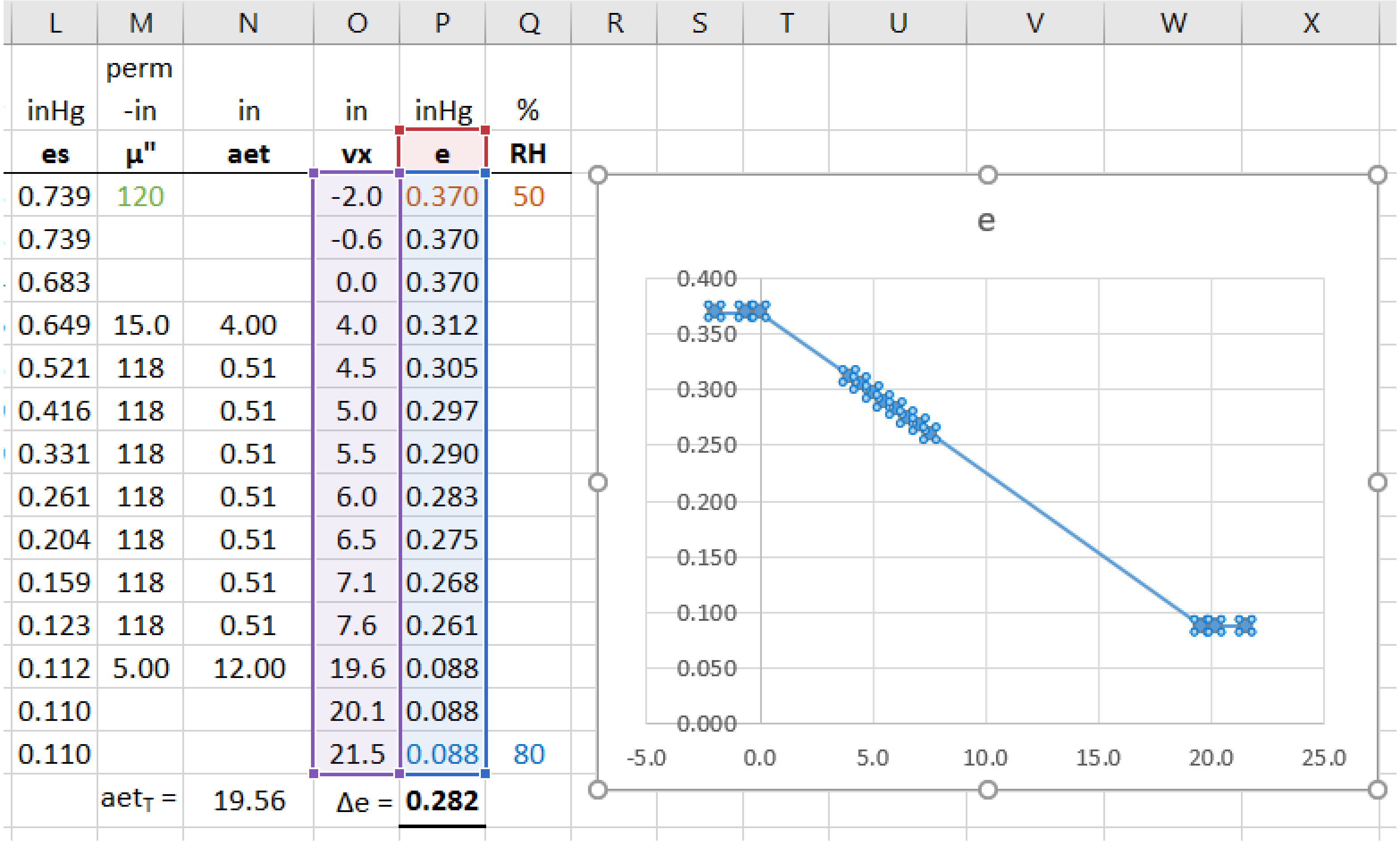
Expand graph on both sides



M	N	O	P	Q
perm -in µ"	in aet	in vx	inHg e	% RH
120		=O5-N17*0.1		50
		-0.6	0.370	
		0.0	0.370	
15.0	4.00	4.0	0.312	
118	0.51	4.5	0.305	
118	0.51	5.0	0.297	
118	0.51	5.5	0.290	
118	0.51	6.0	0.283	
118	0.51	6.5	0.275	
118	0.51	7.1	0.268	
118	0.51	7.6	0.261	
5.00	12.00	19.6	0.088	
		20.1	0.088	
		21.5	0.088	80
aet_T =	19.56	Δe =	**0.282**	

- ☐ We add some x-coordinates to show interior and exterior conditions
- ☐ Make them dependent on scale:
  - interior
    - ☐ subtract 10% of aet_T
  - interior before air film
    - ☐ subtract 3% of aet_T
  - exterior after air film
    - ☐ add 3% of aet_T
  - exterior
    - ☐ add 10% of aet_T

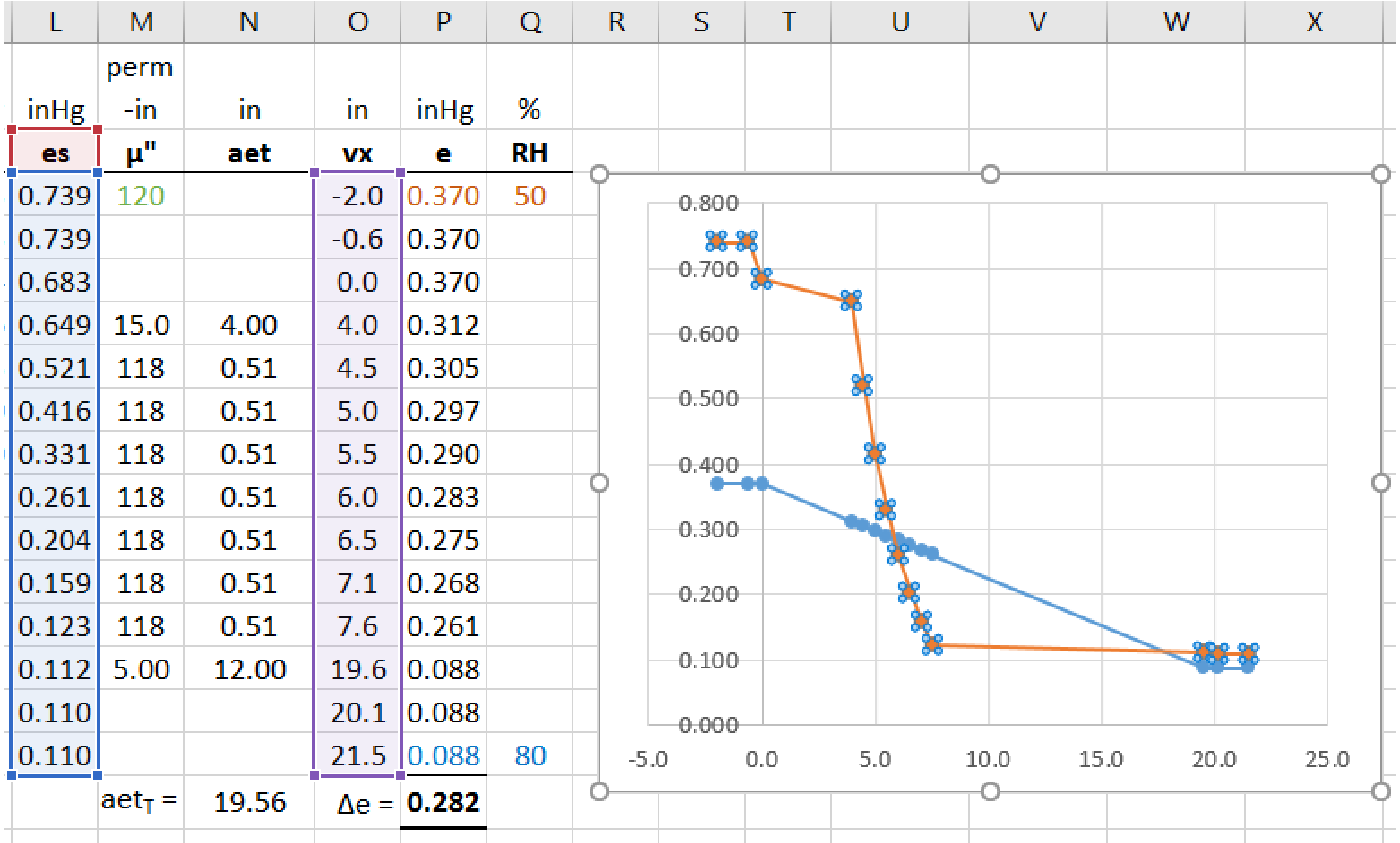
Draw graph as scatter plot



L	M	N	O	P	Q
inHg	perm -in	in	in	inHg	%
es	**μ"**	**aet**	**vx**	**e**	**RH**
0.739	120		-2.0	0.370	50
0.739			-0.6	0.370	
0.683			0.0	0.370	
0.649	15.0	4.00	4.0	0.312	
0.521	118	0.51	4.5	0.305	
0.416	118	0.51	5.0	0.297	
0.331	118	0.51	5.5	0.290	
0.261	118	0.51	6.0	0.283	
0.204	118	0.51	6.5	0.275	
0.159	118	0.51	7.1	0.268	
0.123	118	0.51	7.6	0.261	
0.112	5.00	12.00	19.6	0.088	
0.110			20.1	0.088	
0.110			21.5	0.088	80
	aet_T =	19.56	Δe =	**0.282**	

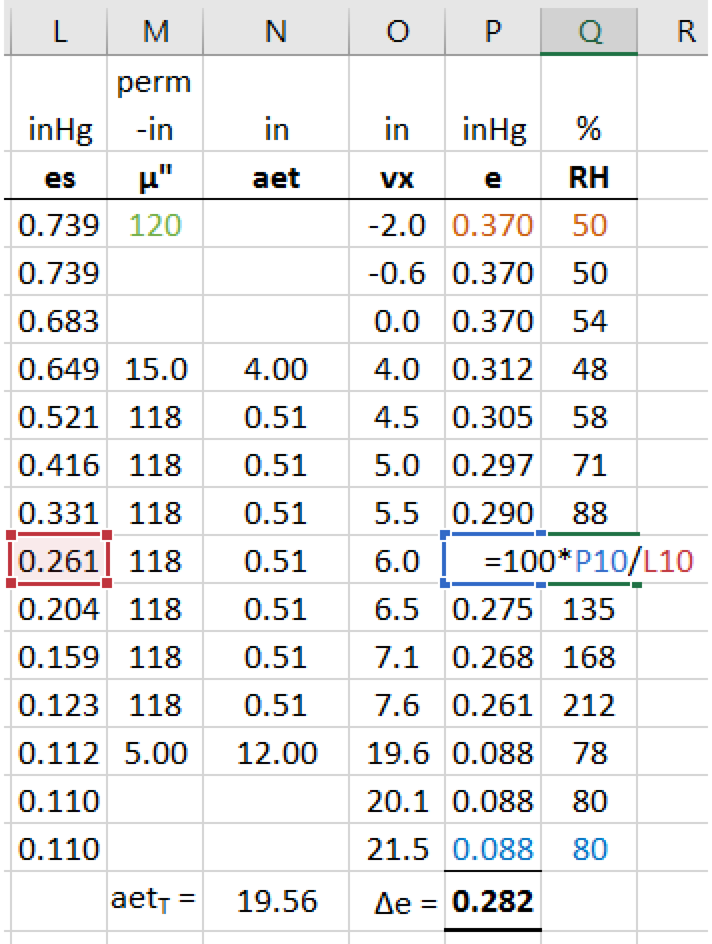
Add saturation pressure curve

- ☐ Theoretical vapor pressure vs saturation pressure



L	M	N	O	P	Q
inHg	perm -in	in	in	inHg	%
es	**μ"**	**aet**	**vx**	**e**	**RH**
0.739	120		-2.0	0.370	50
0.739			-0.6	0.370	
0.683			0.0	0.370	
0.649	15.0	4.00	4.0	0.312	
0.521	118	0.51	4.5	0.305	
0.416	118	0.51	5.0	0.297	
0.331	118	0.51	5.5	0.290	
0.261	118	0.51	6.0	0.283	
0.204	118	0.51	6.5	0.275	
0.159	118	0.51	7.1	0.268	
0.123	118	0.51	7.6	0.261	
0.112	5.00	12.00	19.6	0.088	
0.110			20.1	0.088	
0.110			21.5	0.088	80
	aet_T =	19.56	Δe =	**0.282**	

Relative Humidity Curve

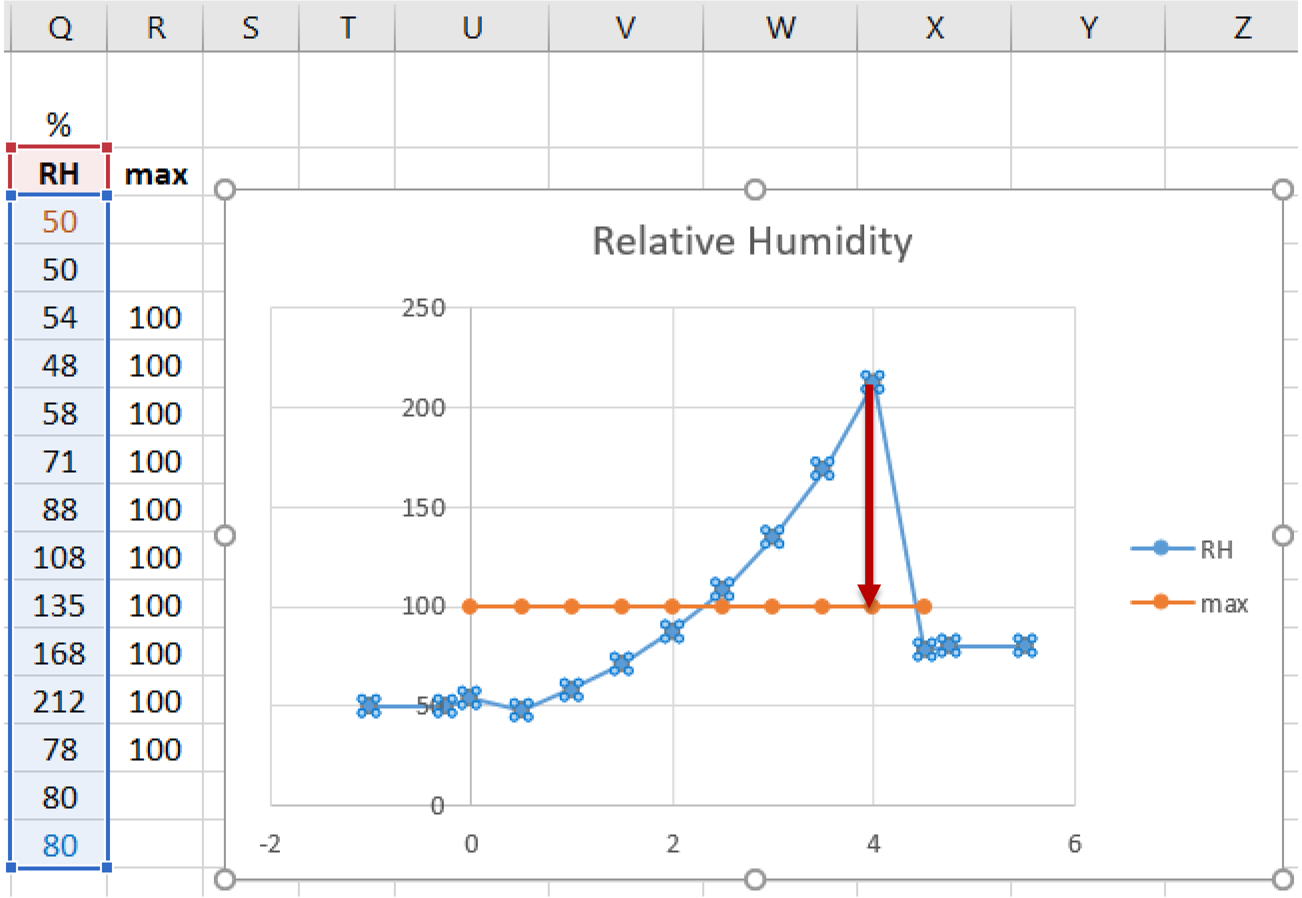


L	M	N	O	P	Q	R
inHg	perm -in	in	in	inHg	%	
es	µ"	aet	vx	e	RH	
0.739	120		-2.0	0.370	50	
0.739			-0.6	0.370	50	
0.683			0.0	0.370	54	
0.649	15.0	4.00	4.0	0.312	48	
0.521	118	0.51	4.5	0.305	58	
0.416	118	0.51	5.0	0.297	71	
0.331	118	0.51	5.5	0.290	88	
0.261	118	0.51	6.0		=100*P10/L10	
0.204	118	0.51	6.5	0.275	135	
0.159	118	0.51	7.1	0.268	168	
0.123	118	0.51	7.6	0.261	212	
0.112	5.00	12.00	19.6	0.088	78	
0.110			20.1	0.088	80	
0.110			21.5	0.088	80	
	aet_T =	19.56	Δe =	**0.282**		

- ☐ Calculate RH at each point from e / e_s

Theoretical Relative Humidity

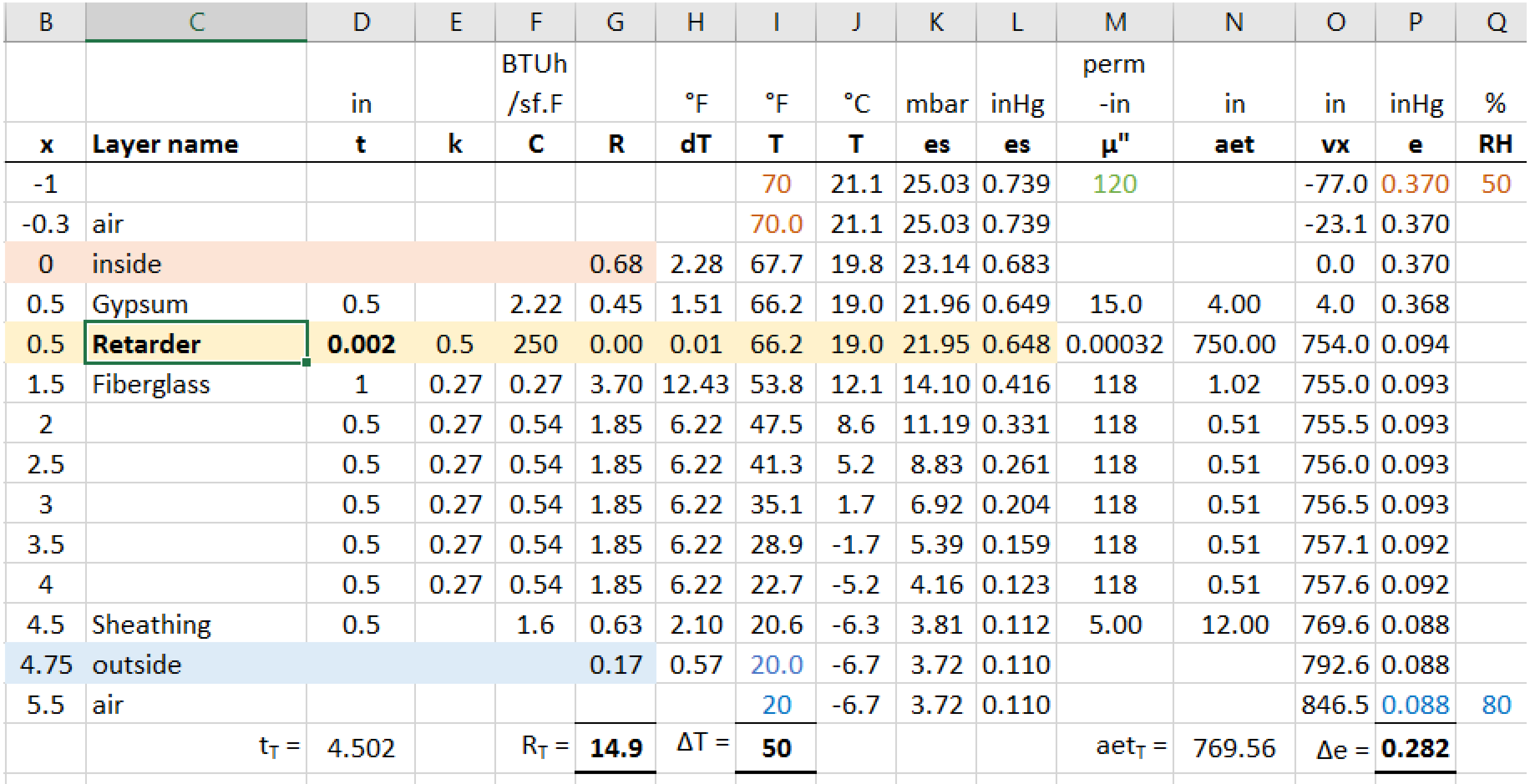
- ☐ Needs some work, as condensation would occur … and thus change real vapor pressure distribution



Q	R
%	
RH	max
50	
50	
54	100
48	100
58	100
71	100
88	100
108	100
135	100
168	100
212	100
78	100
80	
80	

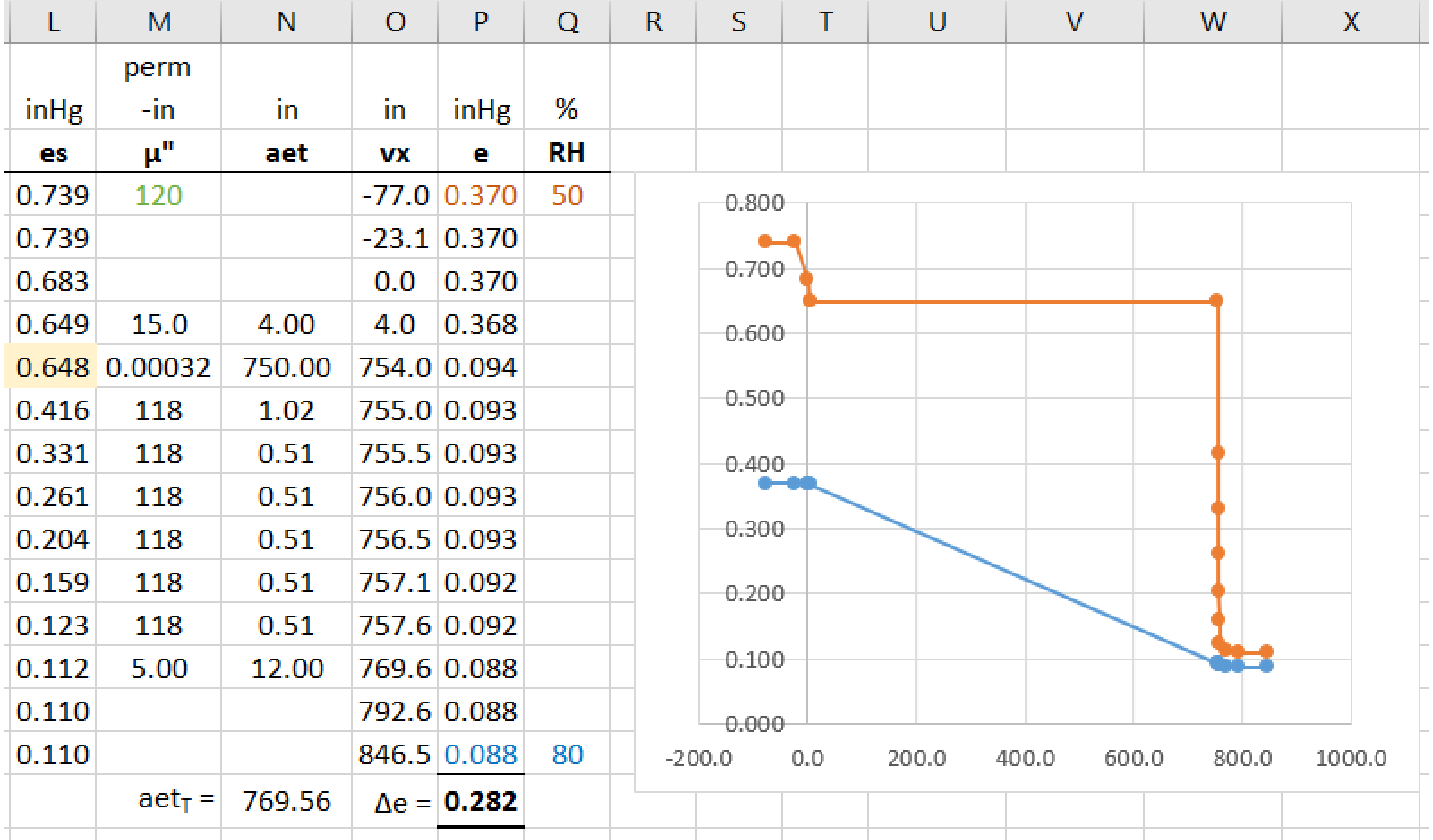
Let’s introduce a vapor retarder

- ☐ We “borrow” the first ½” of fiberglass, and add the lost thickness of insulation to the second slice (½” –> 1”)



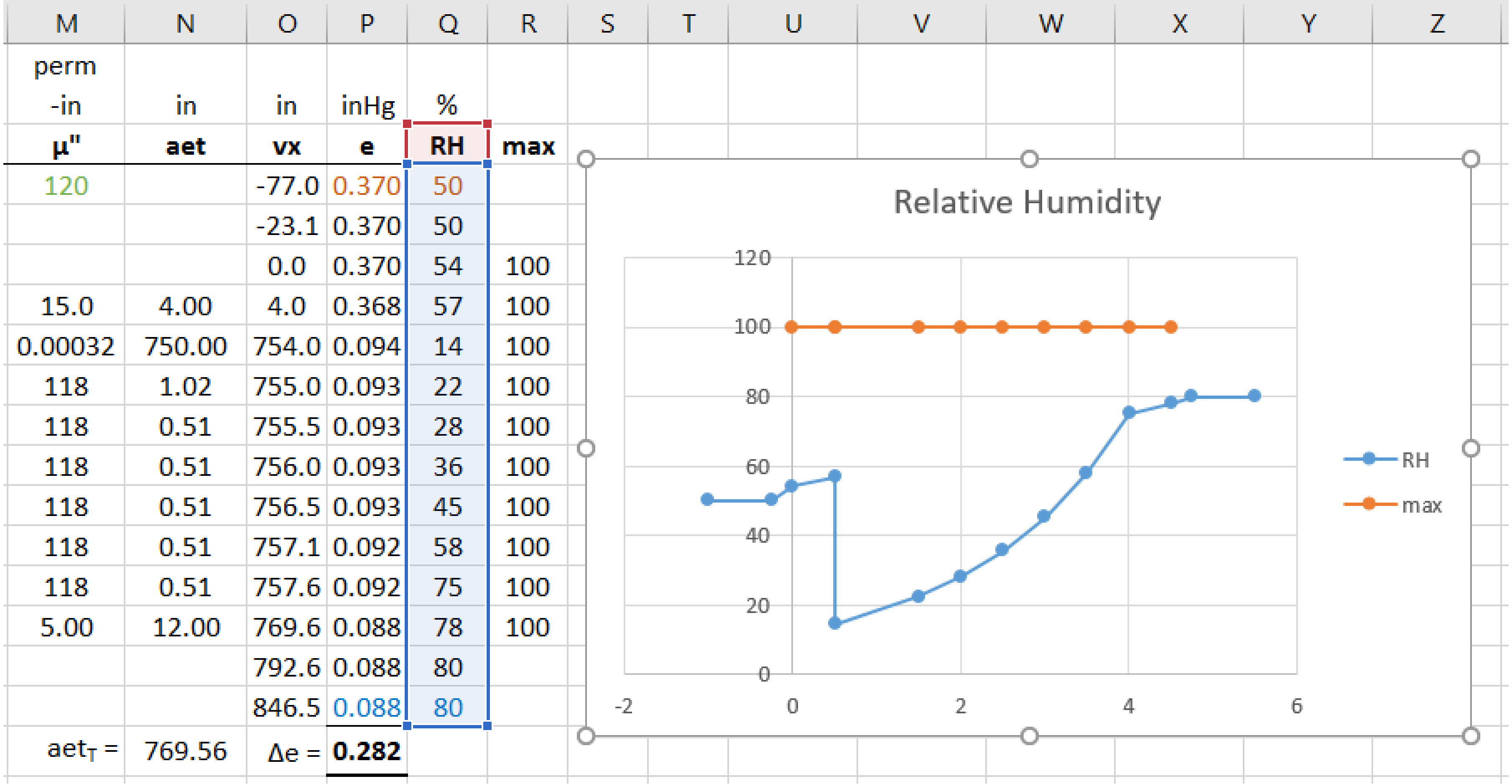
B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
		in		BTUh /sf.F		°F	°F	°C	mbar	inHg	perm -in	in	in	inHg	%
x	**Layer name**	**t**	**k**	**C**	**R**	**dT**	**T**	**T**	**es**	**es**	**μ"**	**aet**	**vx**	**e**	**RH**
-1							70	21.1	25.03	0.739	120		-77.0	0.370	50
-0.3	air						70.0	21.1	25.03	0.739			-23.1	0.370	
0	inside				0.68	2.28	67.7	19.8	23.14	0.683			0.0	0.370	
0.5	Gypsum	0.5		2.22	0.45	1.51	66.2	19.0	21.96	0.649	15.0	4.00	4.0	0.368	
0.5	**Retarder**	**0.002**	0.5	250	0.00	0.01	66.2	19.0	21.95	0.648	0.00032	750.00	754.0	0.094	
1.5	Fiberglass	1	0.27	0.27	3.70	12.43	53.8	12.1	14.10	0.416	118	1.02	755.0	0.093	
2		0.5	0.27	0.54	1.85	6.22	47.5	8.6	11.19	0.331	118	0.51	755.5	0.093	
2.5		0.5	0.27	0.54	1.85	6.22	41.3	5.2	8.83	0.261	118	0.51	756.0	0.093	
3		0.5	0.27	0.54	1.85	6.22	35.1	1.7	6.92	0.204	118	0.51	756.5	0.093	
3.5		0.5	0.27	0.54	1.85	6.22	28.9	-1.7	5.39	0.159	118	0.51	757.1	0.092	
4		0.5	0.27	0.54	1.85	6.22	22.7	-5.2	4.16	0.123	118	0.51	757.6	0.092	
4.5	Sheathing	0.5		1.6	0.63	2.10	20.6	-6.3	3.81	0.112	5.00	12.00	769.6	0.088	
4.75	outside				0.17	0.57	20.0	-6.7	3.72	0.110			792.6	0.088	
5.5	air						20	-6.7	3.72	0.110			846.5	0.088	80
	t_T =	4.502		R_T =	**14.9**	ΔT =	**50**				aet_T =	769.56	Δe =	**0.282**	

Updated equivalent thickness chart



L	M	N	O	P	Q
	perm				
inHg	-in	in	in	inHg	%
es	**μ"**	**aet**	**vx**	**e**	**RH**
0.739	120		-77.0	0.370	50
0.739			-23.1	0.370	
0.683			0.0	0.370	
0.649	15.0	4.00	4.0	0.368	
0.648	0.00032	750.00	754.0	0.094	
0.416	118	1.02	755.0	0.093	
0.331	118	0.51	755.5	0.093	
0.261	118	0.51	756.0	0.093	
0.204	118	0.51	756.5	0.093	
0.159	118	0.51	757.1	0.092	
0.123	118	0.51	757.6	0.092	
0.112	5.00	12.00	769.6	0.088	
0.110			792.6	0.088	
0.110			846.5	0.088	80
	aet_T =	769.56	Δe =	**0.282**	

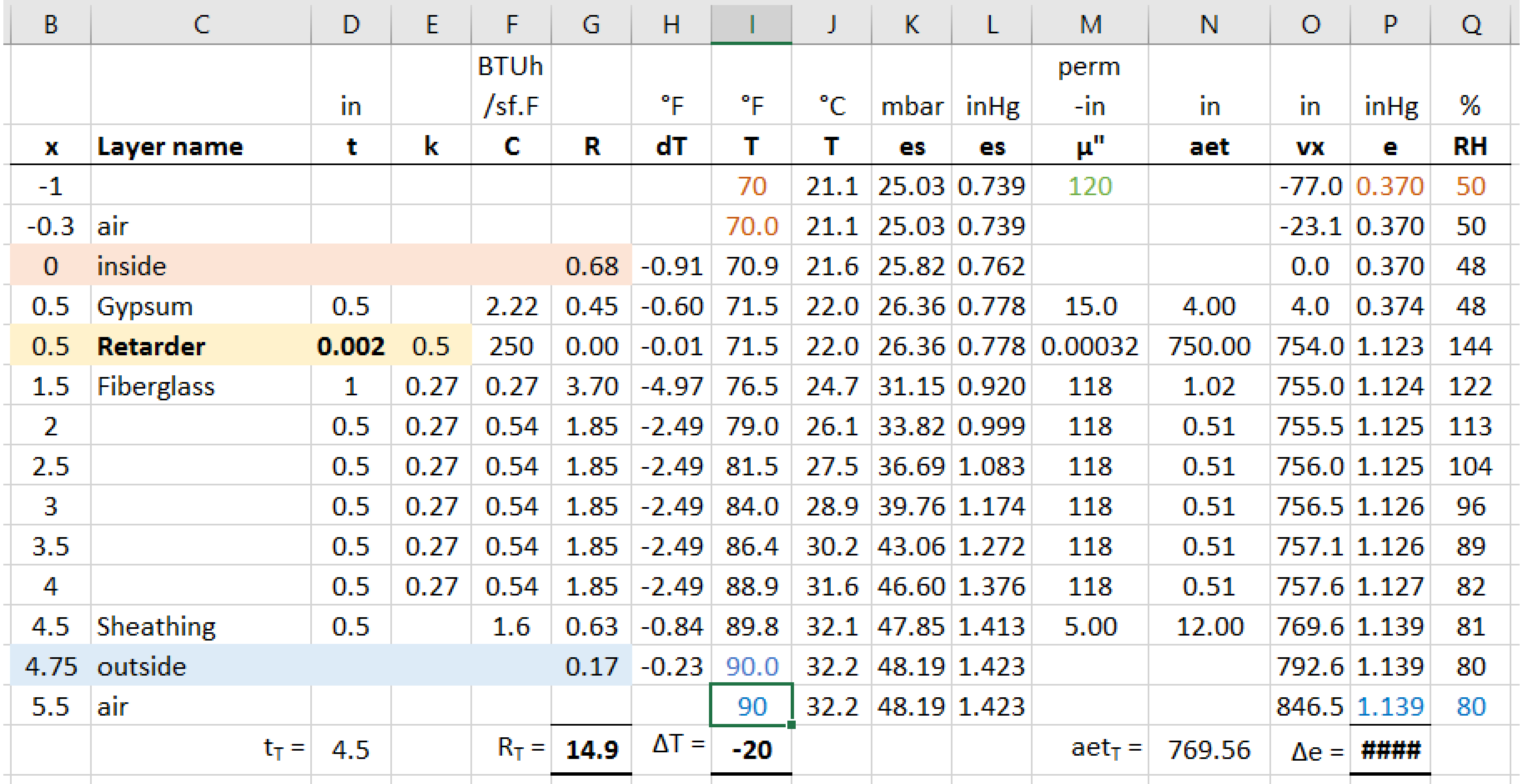
Updated RH Distribution



M	N	O	P	Q	R
perm -in	in	in	inHg	%	
μ"	aet	vx	e	RH	max
120		-77.0	0.370	50	
		-23.1	0.370	50	
		0.0	0.370	54	100
15.0	4.00	4.0	0.368	57	100
0.00032	750.00	754.0	0.094	14	100
118	1.02	755.0	0.093	22	100
118	0.51	755.5	0.093	28	100
118	0.51	756.0	0.093	36	100
118	0.51	756.5	0.093	45	100
118	0.51	757.1	0.092	58	100
118	0.51	757.6	0.092	75	100
5.00	12.00	769.6	0.088	78	100
		792.6	0.088	80	
		846.5	0.088	80	
aet_T =	769.56	Δe =	**0.282**		

Now let’s look at summer …

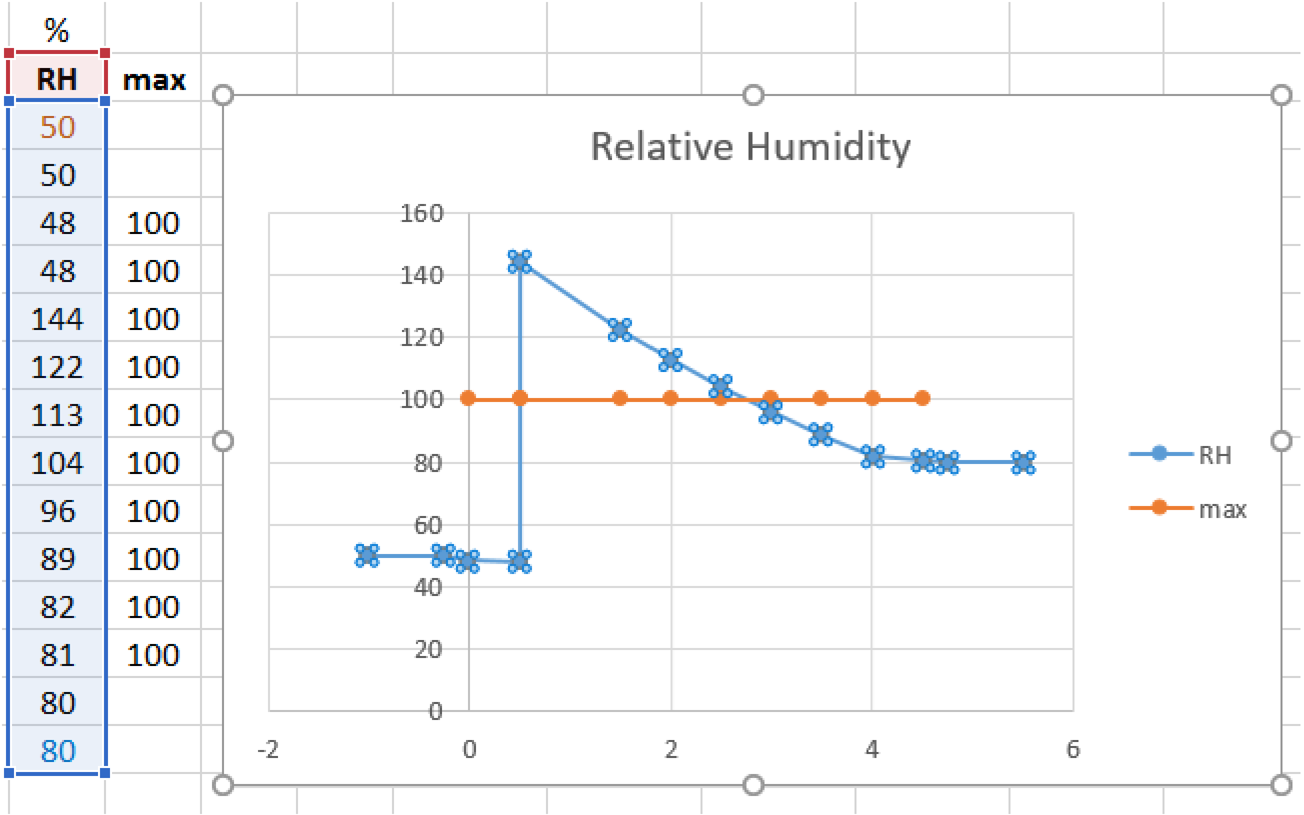
- ☐ Careful – we typically do not have longer intervals of same boundary conditions … for discussion of principles only !



B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
		in		BTUh /sf.F		°F	°F	°C	mbar	inHg	perm -in	in	in	inHg	%
x	**Layer name**	**t**	**k**	**C**	**R**	**dT**	**T**	**T**	**es**	**es**	**μ"**	**aet**	**vx**	**e**	**RH**
-1							70	21.1	25.03	0.739	120		-77.0	0.370	50
-0.3	air						70.0	21.1	25.03	0.739			-23.1	0.370	50
0	inside				0.68	-0.91	70.9	21.6	25.82	0.762			0.0	0.370	48
0.5	Gypsum	0.5		2.22	0.45	-0.60	71.5	22.0	26.36	0.778	15.0	4.00	4.0	0.374	48
0.5	**Retarder**	**0.002**	0.5	250	0.00	-0.01	71.5	22.0	26.36	0.778	0.00032	750.00	754.0	1.123	144
1.5	Fiberglass	1	0.27	0.27	3.70	-4.97	76.5	24.7	31.15	0.920	118	1.02	755.0	1.124	122
2		0.5	0.27	0.54	1.85	-2.49	79.0	26.1	33.82	0.999	118	0.51	755.5	1.125	113
2.5		0.5	0.27	0.54	1.85	-2.49	81.5	27.5	36.69	1.083	118	0.51	756.0	1.125	104
3		0.5	0.27	0.54	1.85	-2.49	84.0	28.9	39.76	1.174	118	0.51	756.5	1.126	96
3.5		0.5	0.27	0.54	1.85	-2.49	86.4	30.2	43.06	1.272	118	0.51	757.1	1.126	89
4		0.5	0.27	0.54	1.85	-2.49	88.9	31.6	46.60	1.376	118	0.51	757.6	1.127	82
4.5	Sheathing	0.5		1.6	0.63	-0.84	89.8	32.1	47.85	1.413	5.00	12.00	769.6	1.139	81
4.75	outside				0.17	-0.23	90.0	32.2	48.19	1.423			792.6	1.139	80
5.5	air						90	32.2	48.19	1.423			846.5	1.139	80
	t_T =	4.5		R_T =	**14.9**	ΔT =	**-20**				aet_T =	769.56	Δe =	**####**	

Once again updated RH distribution

- ☐ Just traded one problem for another …



%	
RH	max
50	
50	
48	100
48	100
144	100
122	100
113	100
104	100
96	100
89	100
82	100
81	100
80	
80	

- ☐ In the end we have to compare condensation amounts and evaporation potential to make a call