New Insights into Natural Aeration Grain Drying

IHARF Soil and Crop Management Seminar

Southey

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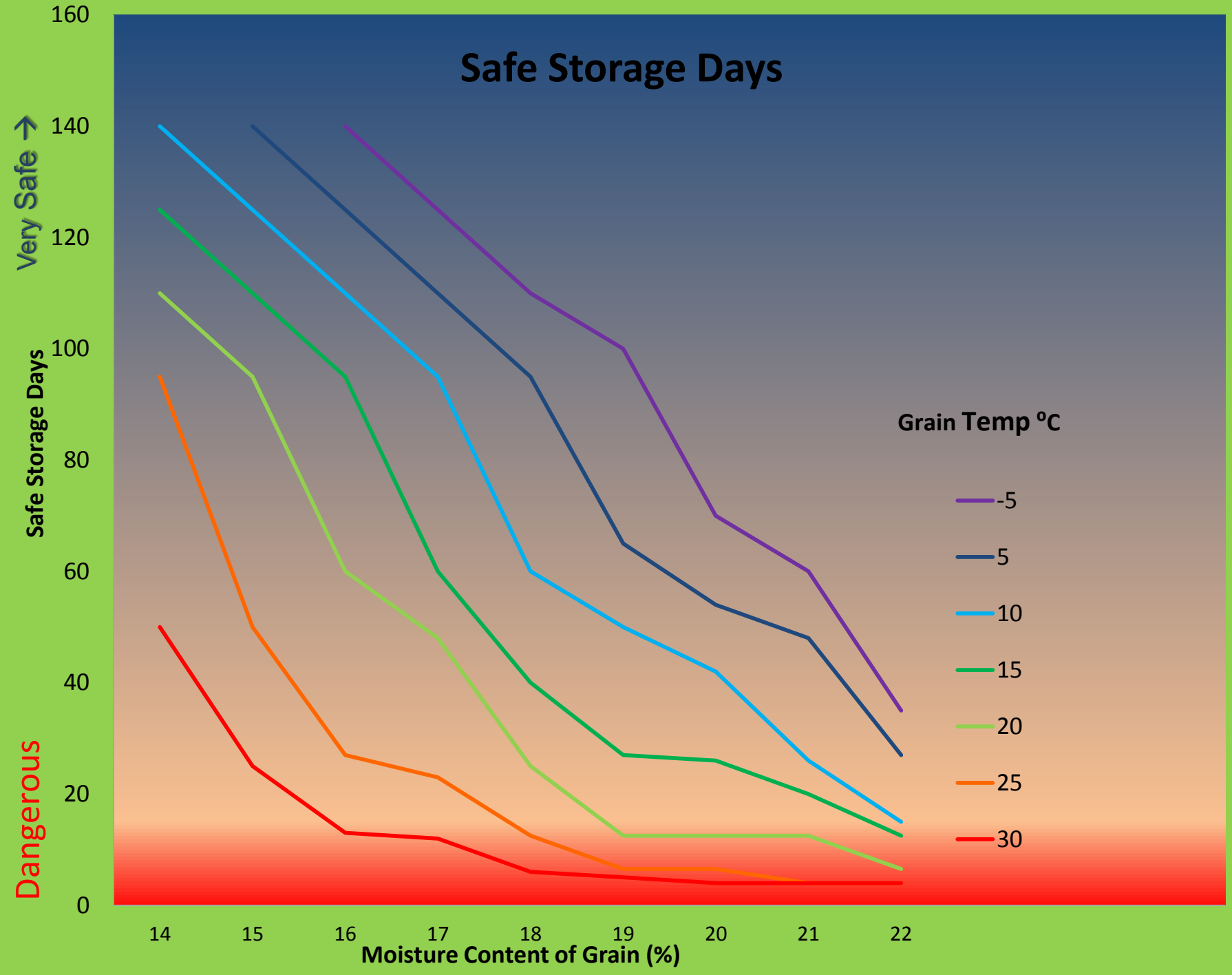
Objective

- To build a fan controller that:
  - is **Efficient** – saves power, fan on only when necessary (if drying, fan on, if not drying, fan off)
  - Provides **Safe** Grain Storage – ie. No spoilage
    - **Cool** grain
    - **Dry** grain

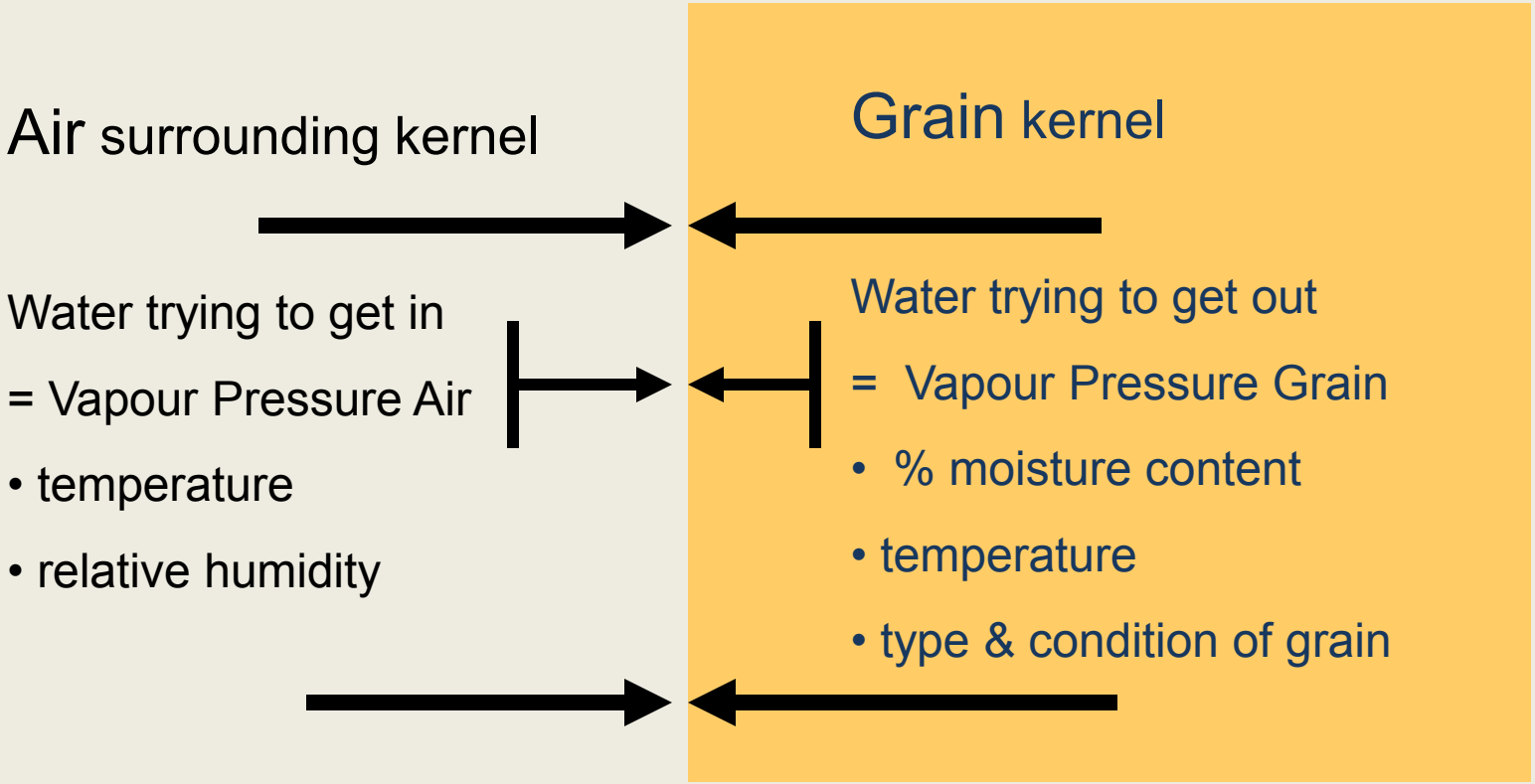
Strategy

Only run the fan when ambient air conditions will result in the drying of the grain;

OR: only run the fan to make the grain as cold as possible??


Safe Storage Days
Very Safe
Dangerous
Safe Storage Days
160
140
120
100
80
60
40
20
0
14
15
16
17
18
19
20
21
22
Moisture Content of Grain (%)
Grain Temp °C
-5
5
10
15
20
25
30

Vapour Pressure



When air vapour pressure is greater than grain vapour pressure, water enters the grain and WETTING occurs. When Vps are equal, → EMC

When grain vapour pressure is greater than the air vapour pressure, water evaporates from the grain into the air and we have DRYING

Controller – Vapour Pressure?

- Fan ON only if VPgrain > VPair
- This is not practical because:
  - Although VPair is easy to determine from temperature and relative humidity; it varies across the bin
  - VPgrain can not be measured directly, and it too varies across the bin.
  - We need another approach

The Black Box Approach

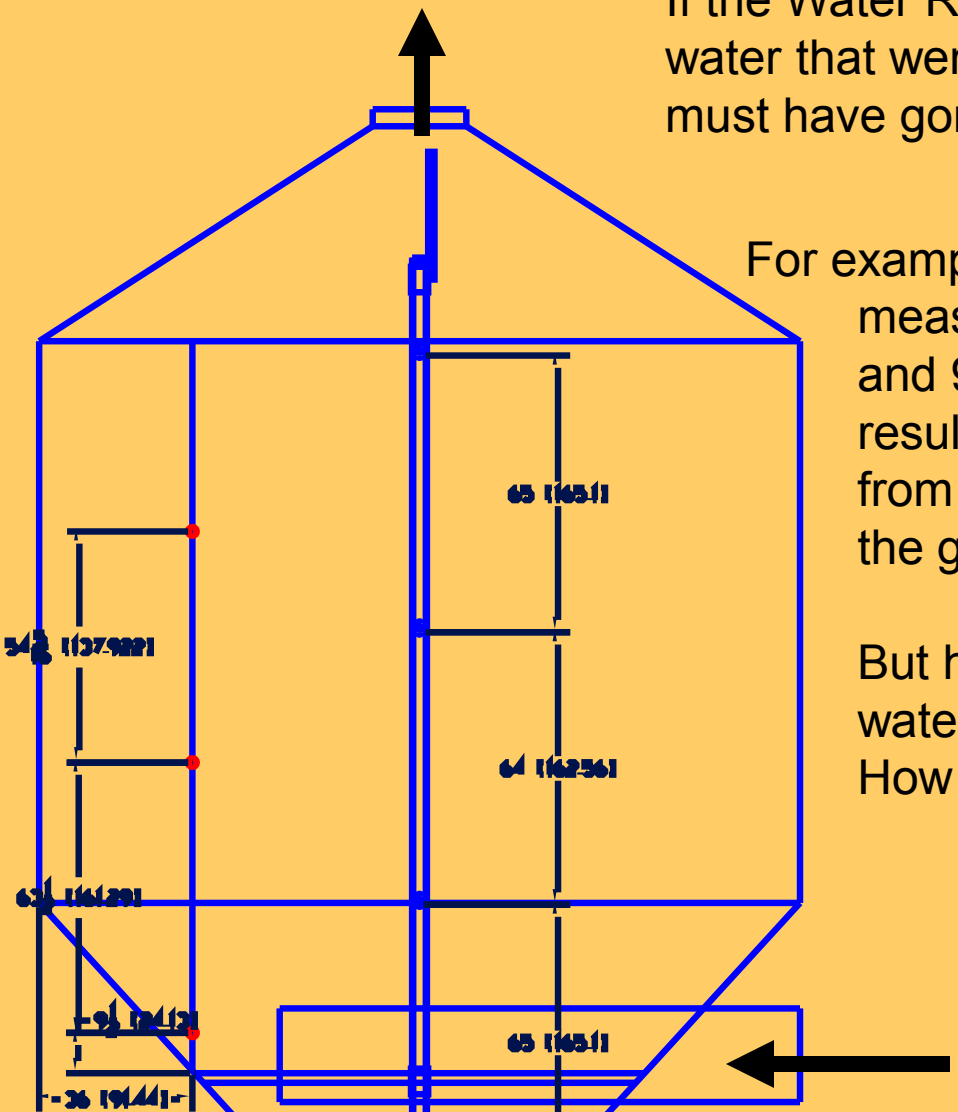
If H_2O OUT > H_2O IN then FAN ON (drying)

If H_2O IN > H_2O OUT then FAN OFF (wetting)

lbs Water OUT – lbs Water IN = Water Removed

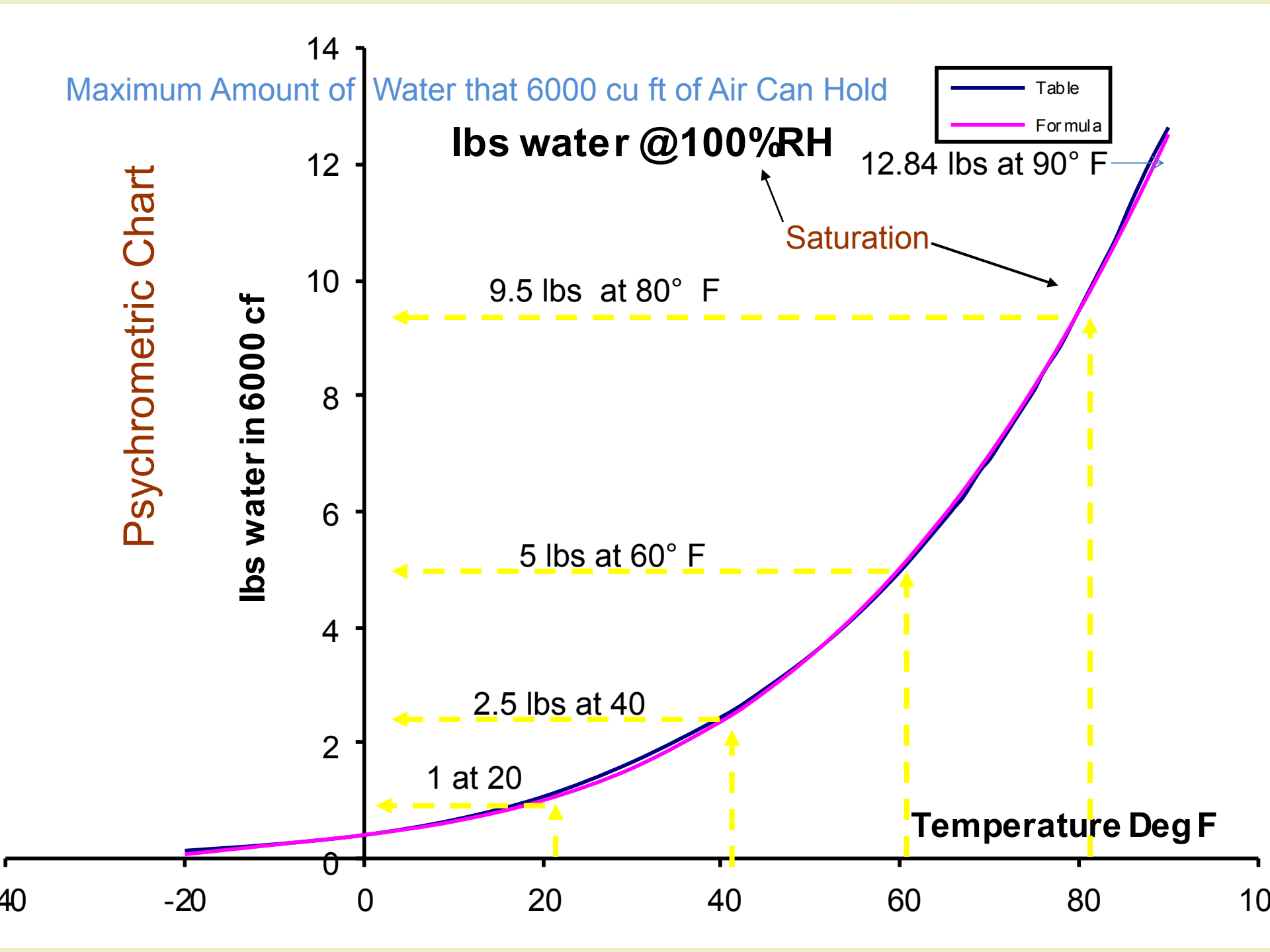
If the Water Removed is positive, then this is the amount of water that must have come from the grain and therefore we are DRYING

If the Water Removed is negative, ie there is more water that went in than came out; then the water must have gone into the grain :: WETTING

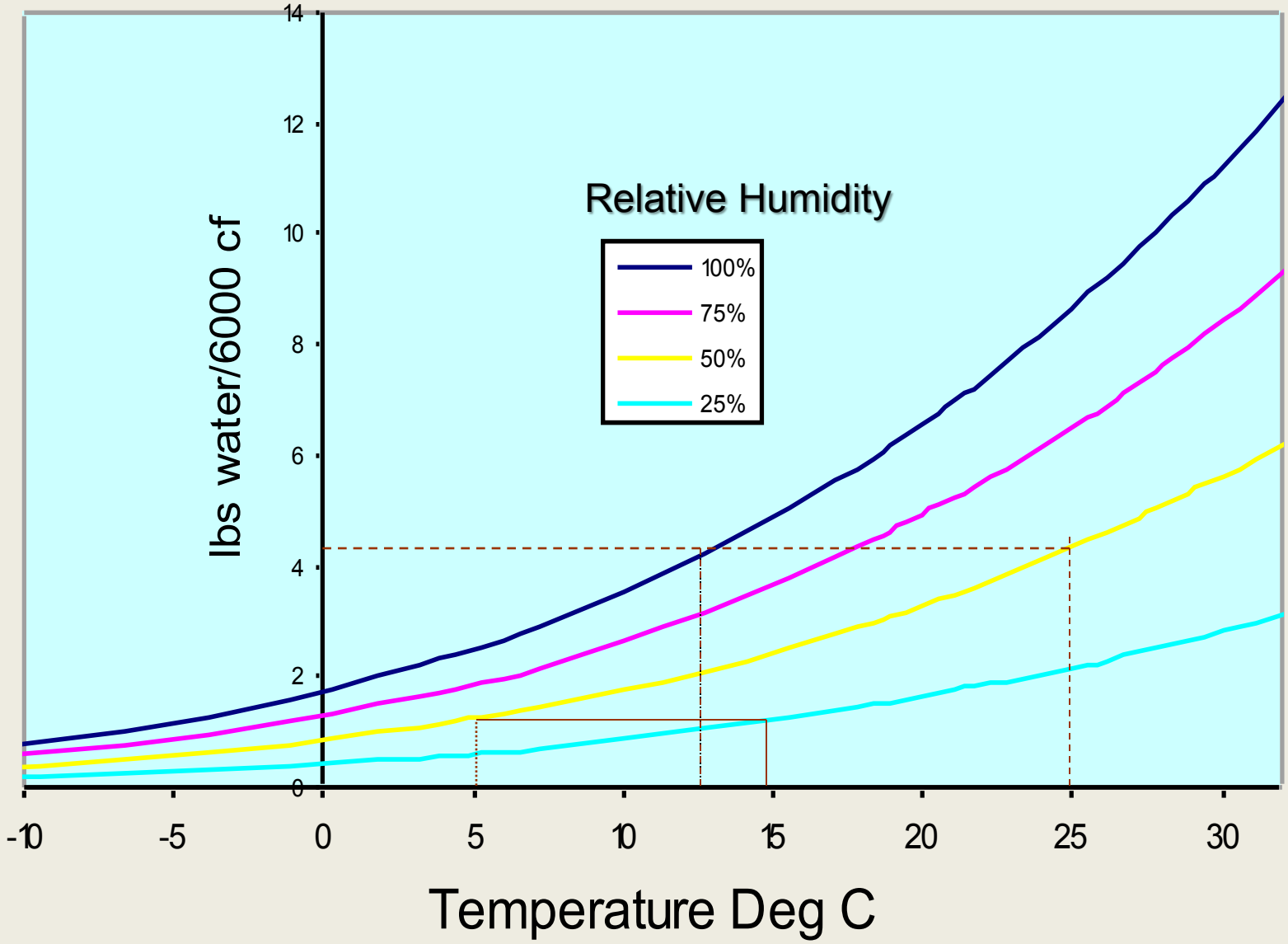


For example: let's say that in one hour we measured 80 lbs of water going into the bin and 90 lbs of water coming out. The net result is 10 lbs of water being removed from the bin. And it must have come from the grain, so we are drying.

But how do we measure the amount of water going in and out?
How much water is the air carrying?

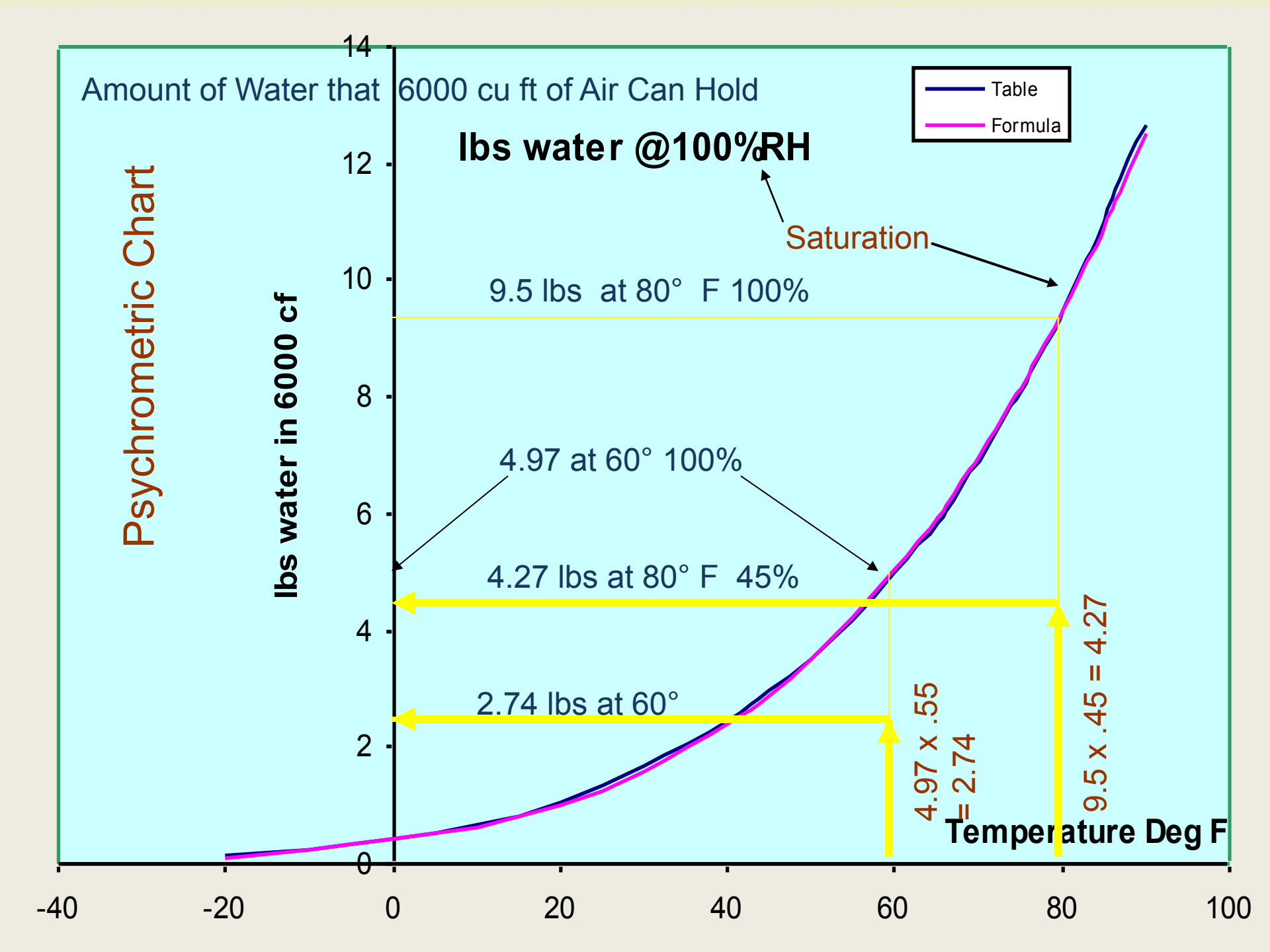

Maximum Amount of Water that 6000 cu ft of Air Can Hold
Psychrometric Chart
lbs water in 6000 cf
lbs water @100%RH
Table
Formula
12.84 lbs at 90° F
Saturation
9.5 lbs at 80° F
5 lbs at 60° F
2.5 lbs at 40
1 at 20
Temperature Deg F
14
12
10
8
6
4
2
0
-40
-20
0
20
40
60
80
100

Water Holding Capacity



H_2O IN/OUT Example

- We have a 2000 bu. Bin with an aeration fan with a flow of 3000 cfm. The air:
  - entering the bin is 60° F @ 55% RH
  - leaving the bin is 80° F @ 45% RH
- Are we drying?
- How much?


Amount of Water that 6000 cu ft of Air Can Hold
Psychrometric Chart
lbs water in 6000 cf
lbs water @100%RH
Table
Formula
Saturation
9.5 lbs at 80° F 100%
4.97 at 60° 100%
4.27 lbs at 80° F 45%
2.74 lbs at 60°
4.97 x .55 = 2.74
9.5 x .45 = 4.27
Temperature Deg F
14
12
10
8
6
4
2
0
-40
-20
0
20
40
60
80
100

The Black Box Approach

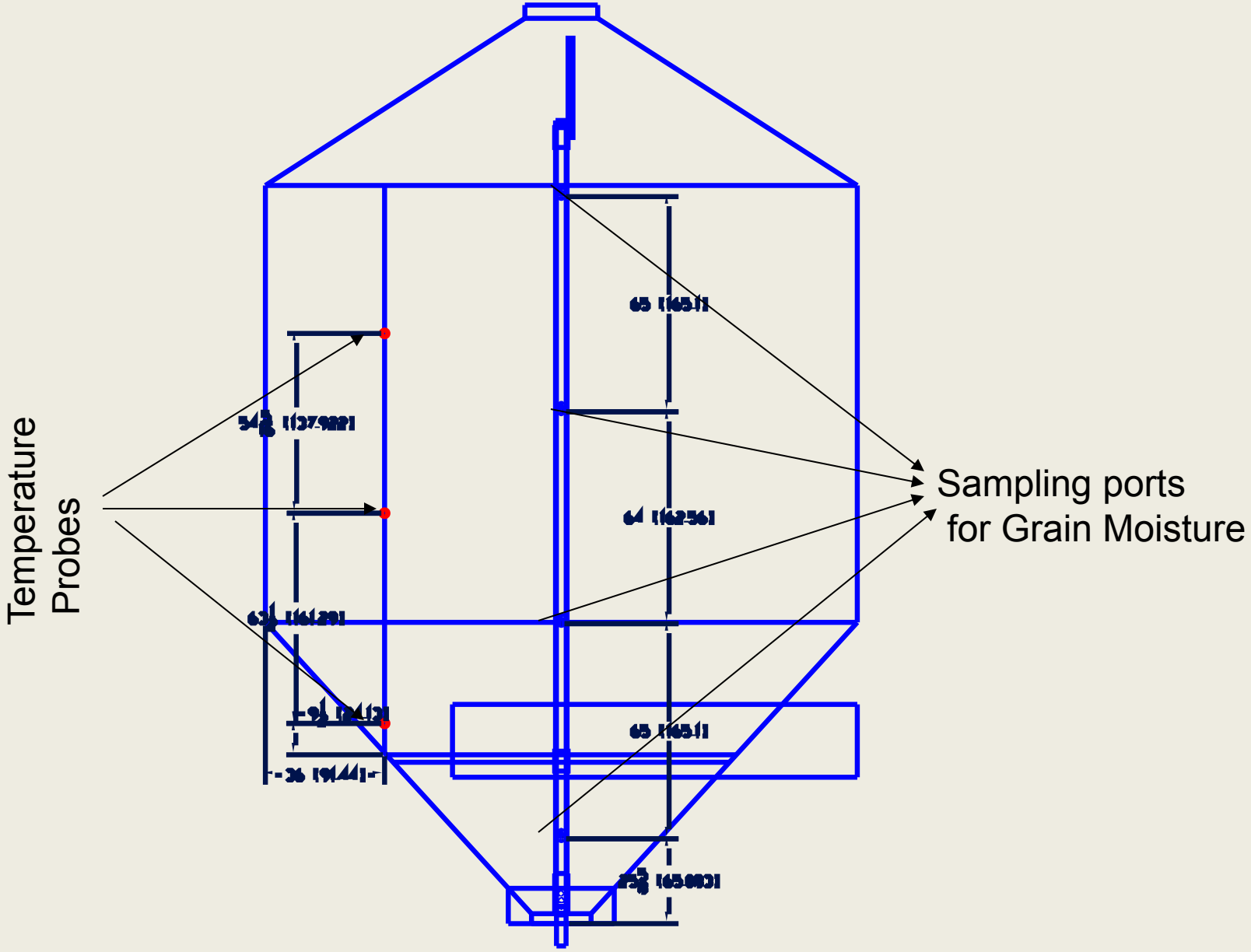
If H_2O OUT > H_2O IN then FAN ON (drying)

4.27 lbs > 2.74 lbs → FAN On (1.53lbs/6000)

Fan 3000 cfm or 6000 cu ft/2 min → 46 lbs/hr drying

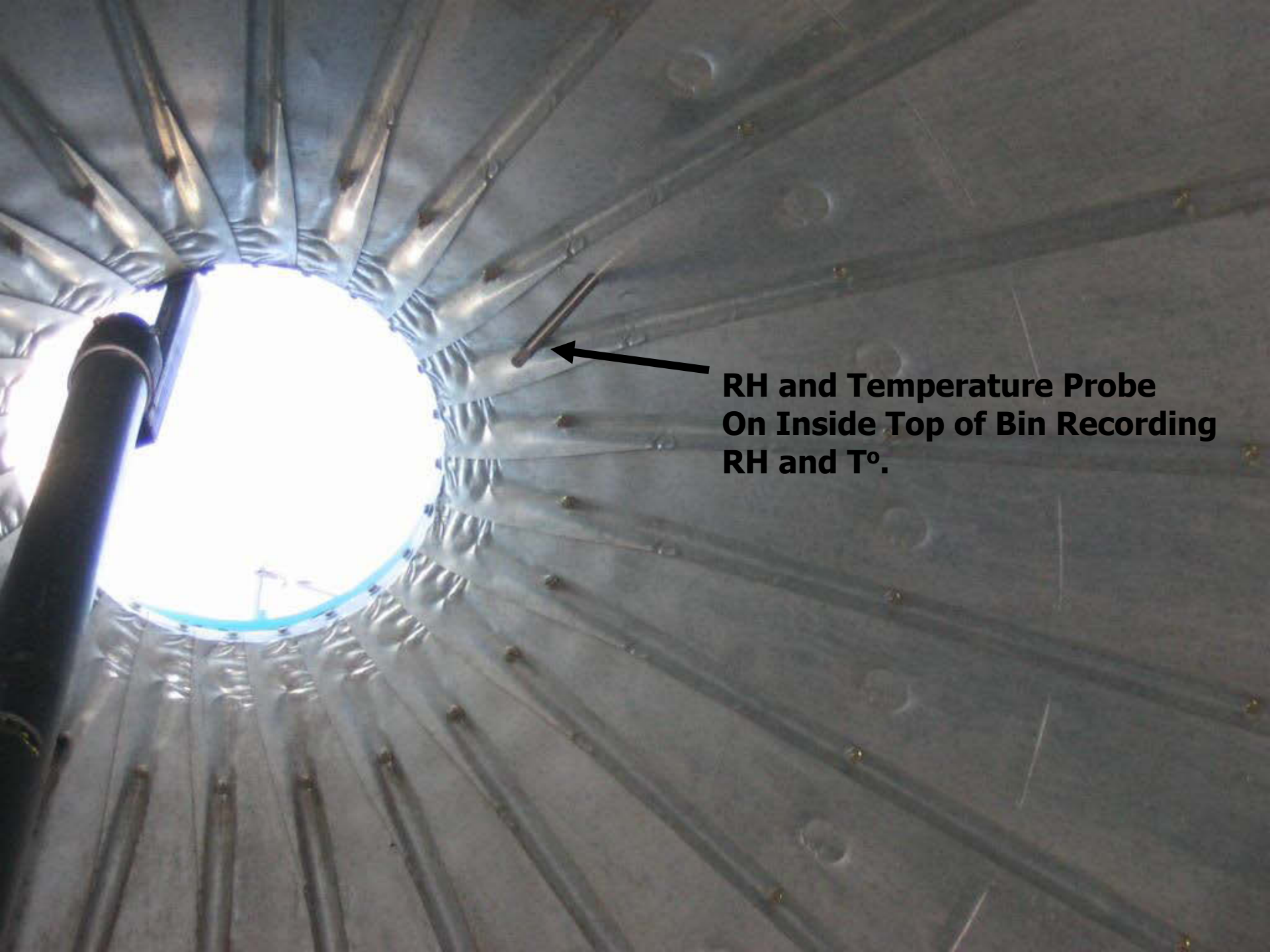
What we did

- Instrumented two bins and measured on an hourly basis:
  - Temp and Humidity – air in and out
  - Air Flow
  - Temp of Grain at three levels
- On a daily basis measured grain moisture at 4 levels
- Have done this for 7 years with 3 different grains:
  - peas, barley, and wheat: 23 runs


Temperature Probes
Sampling ports for Grain Moisture

Panel with Instruments

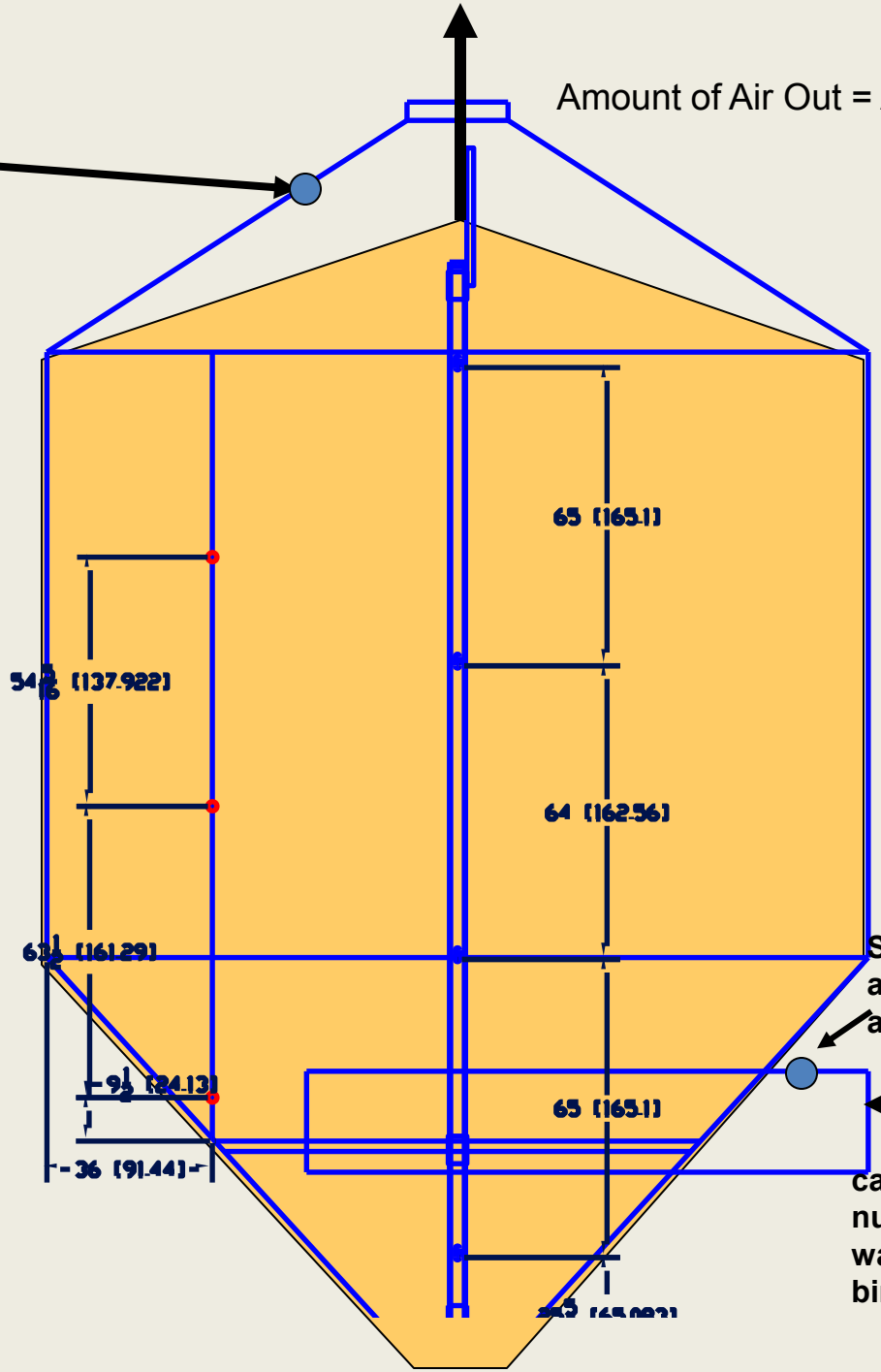

Air Tubes for Recording CFM


RH and Temperature Probe
On Inside Top of Bin Recording
RH and T°.

Sensor measuring T and RH of the air leaving the bin

Therefore we know the temp & RH of the air leaving the bin, and we can calculate the number of lbs of water leaving the bin per hour

Amount of Air Out = Amount of Air In

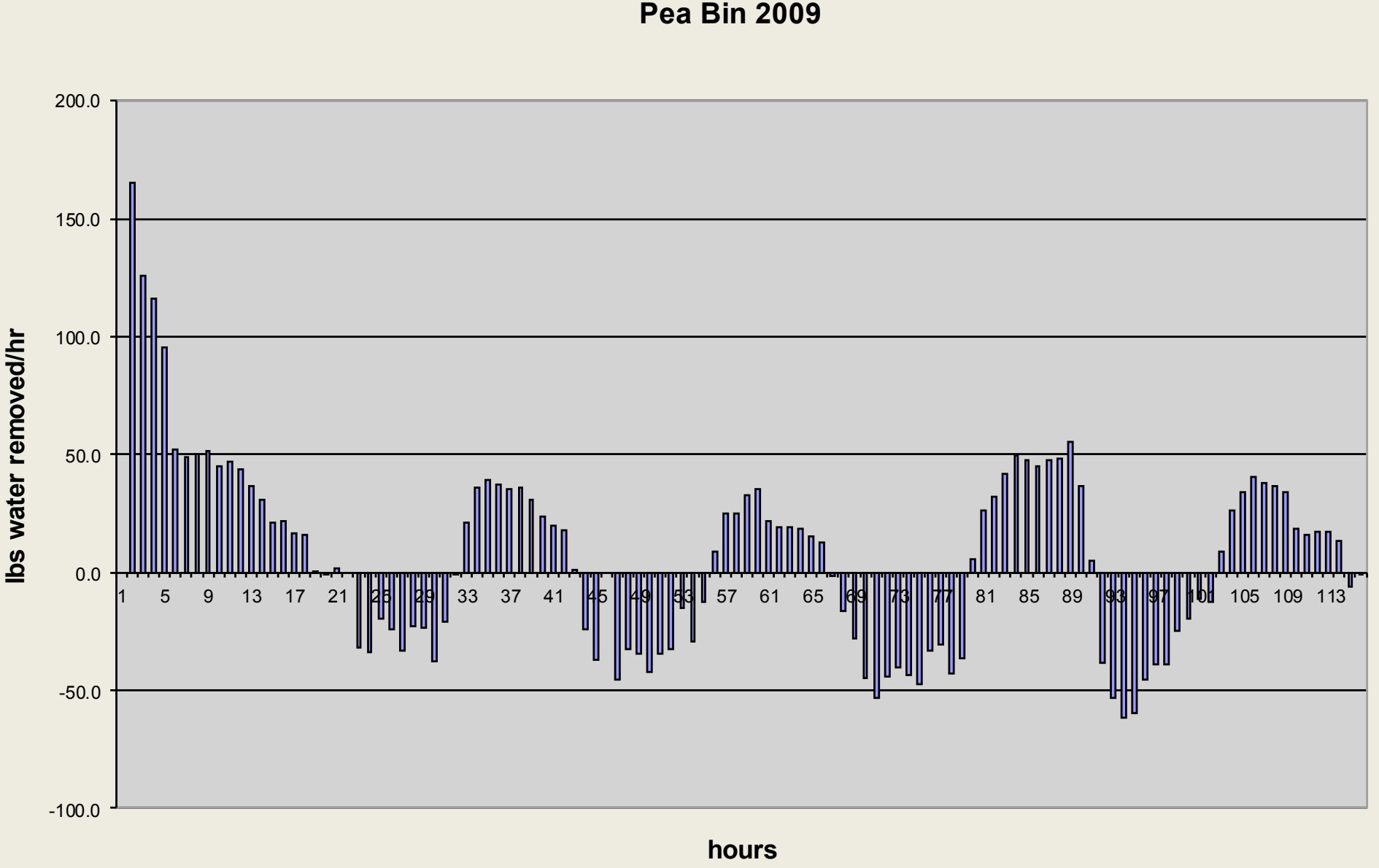


Sensor measuring T and RH of the air entering the bin

can calculate the number of lbs of water entering the bin per hour

Data Stored Hourly in Excel

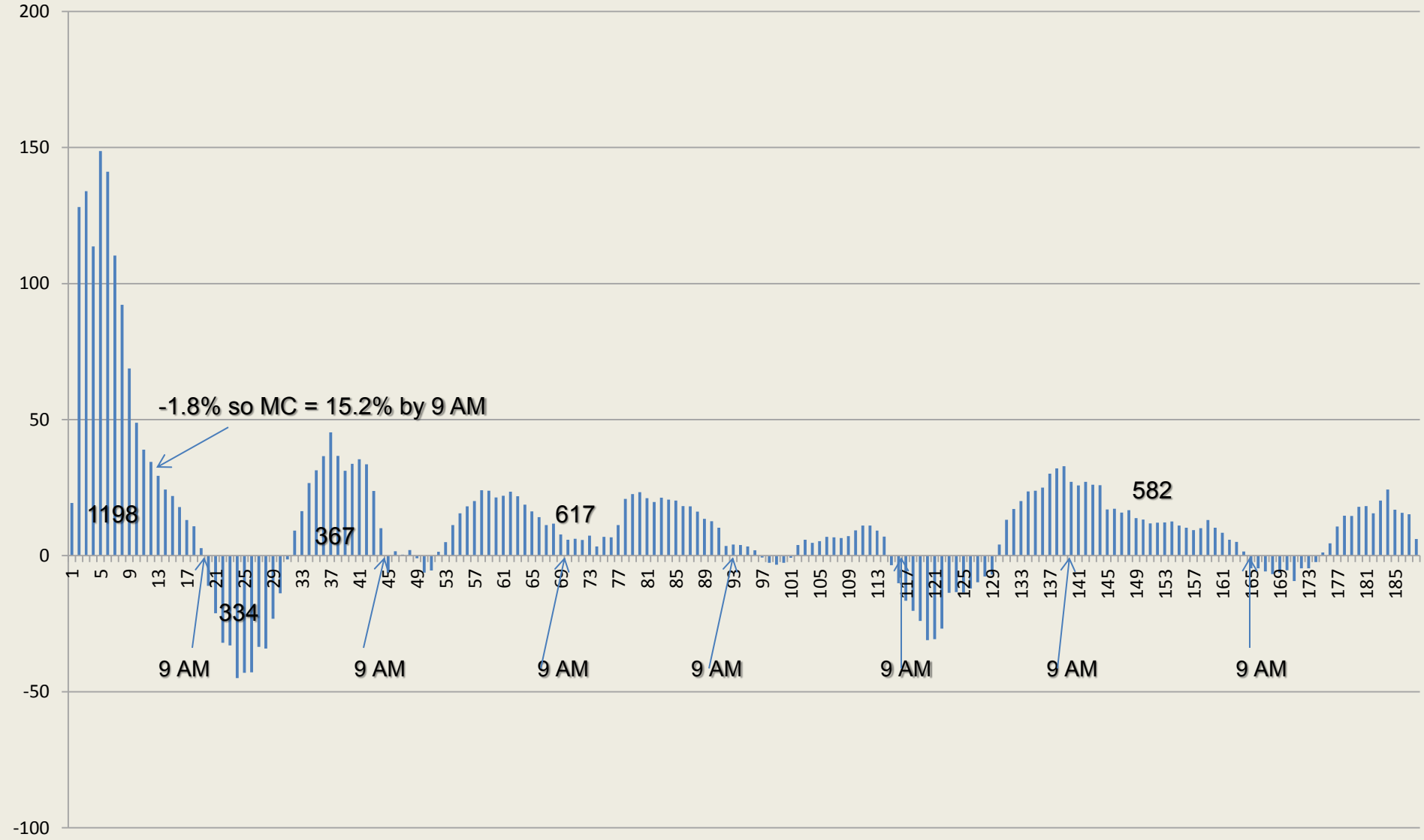
Date / Time	10-LOW LEVEL TEMP	10-MID LEVEL TEMP	10-HI LEVEL TEMP	10-DISCH TEMP	10-DISCH HUMID	10-FAN CFM	Outside T	Outside RH
09/02/2011 9:58	18.13	37.88	30.3	25.41	90.06	2882	14.54	75.38
09/02/2011 10:58	17.64	29.84	31	31.94	86.94	2502	17.25	66.31
09/02/2011 11:58	17.7	22.02	33.06	30.23	85.5	2732	16.75	70.69
09/02/2011 12:58	18.27	17.55	29.94	29.64	87.88	2600	17.14	71.81
09/02/2011 13:58	18.83	15.82	25.78	29.63	87.06	2014	17.22	74
09/02/2011 14:58	19.22	15.73	22.3	27.8	83.38	2504	18.17	68.75
09/02/2011 15:58	19.41	15.78	19.64	26.56	76.44	2780	22.25	53.88
09/02/2011 16:58	19.17	15.97	17.98	23.45	76.56	2994	21.5	50.75
09/02/2011 17:58	18.97	16.06	17.25	20.7	77.56	3456	15.15	67.69
09/02/2011 18:58	18.41	15.82	17.16	19.06	77.31	3154	15.4	65.13
09/02/2011 19:58	17.83	15.34	17.16	17.83	78	3094	14.38	73.06
09/02/2011 20:58	17.73	14.29	17.16	17.34	78	3420	14	78.06
09/02/2011 21:58	17.98	13.72	16.88	16.97	78.69	3118	13.33	86.81
09/02/2011 22:58	18.08	13.71	16.3	16.97	78.06	3106	13.2	84.56
09/02/2011 23:58	18.02	13.96	15.63	16.78	78	3362	12.37	87.94
09/03/2011 0:58	17.25	14.05	15.16	16.11	79.13	3420	10.61	91
09/03/2011 1:58	16.59	14.05	15.05	15.3	80.88	3680	10.61	97.31
09/03/2011 2:58	16.59	13.42	15.05	15.02	79	3580	10.78	94.63
09/03/2011 3:58	16.39	12.95	15.05	15.02	77.63	3486	10.7	93.38
09/03/2011 4:58	16.02	12.95	15.05	15.02	77.75	3552	10.61	91.31

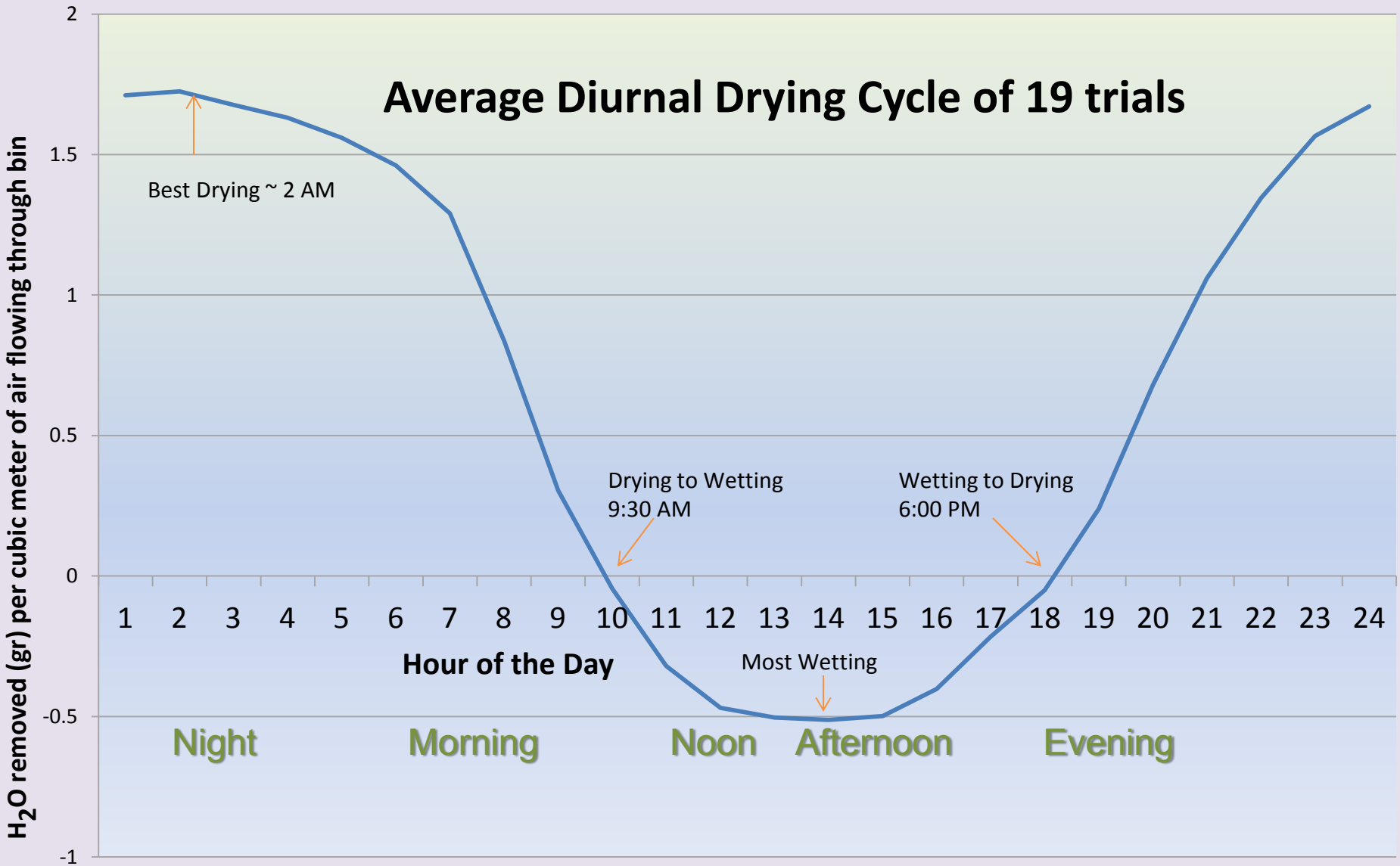

Pea Bin 2009
200.0
150.0
100.0
50.0
0.0
-50.0
-100.0
lbs water removed/hr
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
81
85
89
93
97
101
105
109
113
hours

Bin 9 Wheat 17% - 13.5% Start 2:09 PM Sept 9 continuous for 190 hrs (8 days)

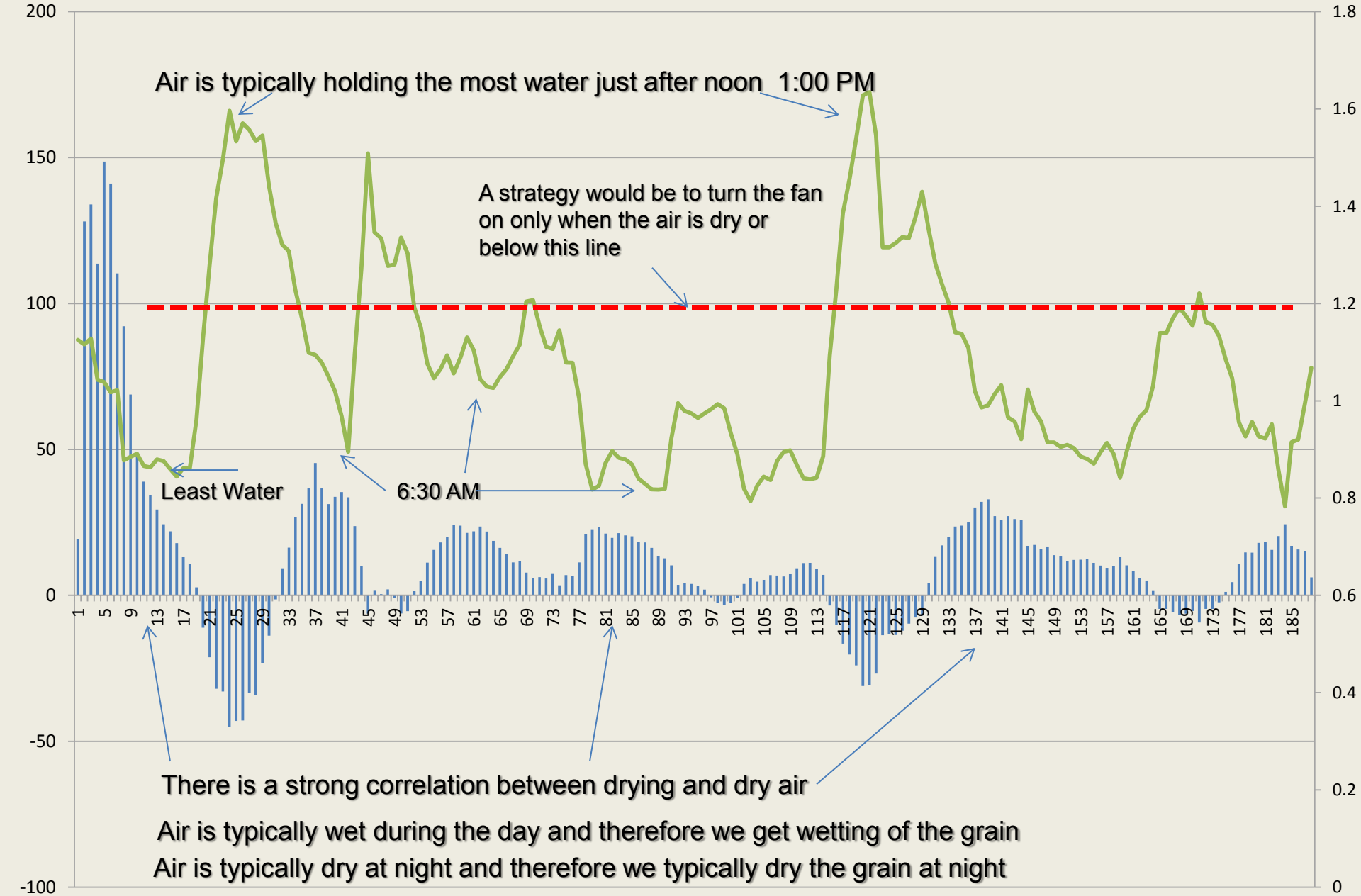
Switch from drying to wetting at 9:30 AM, -- turn the fan off by 9 in the morning

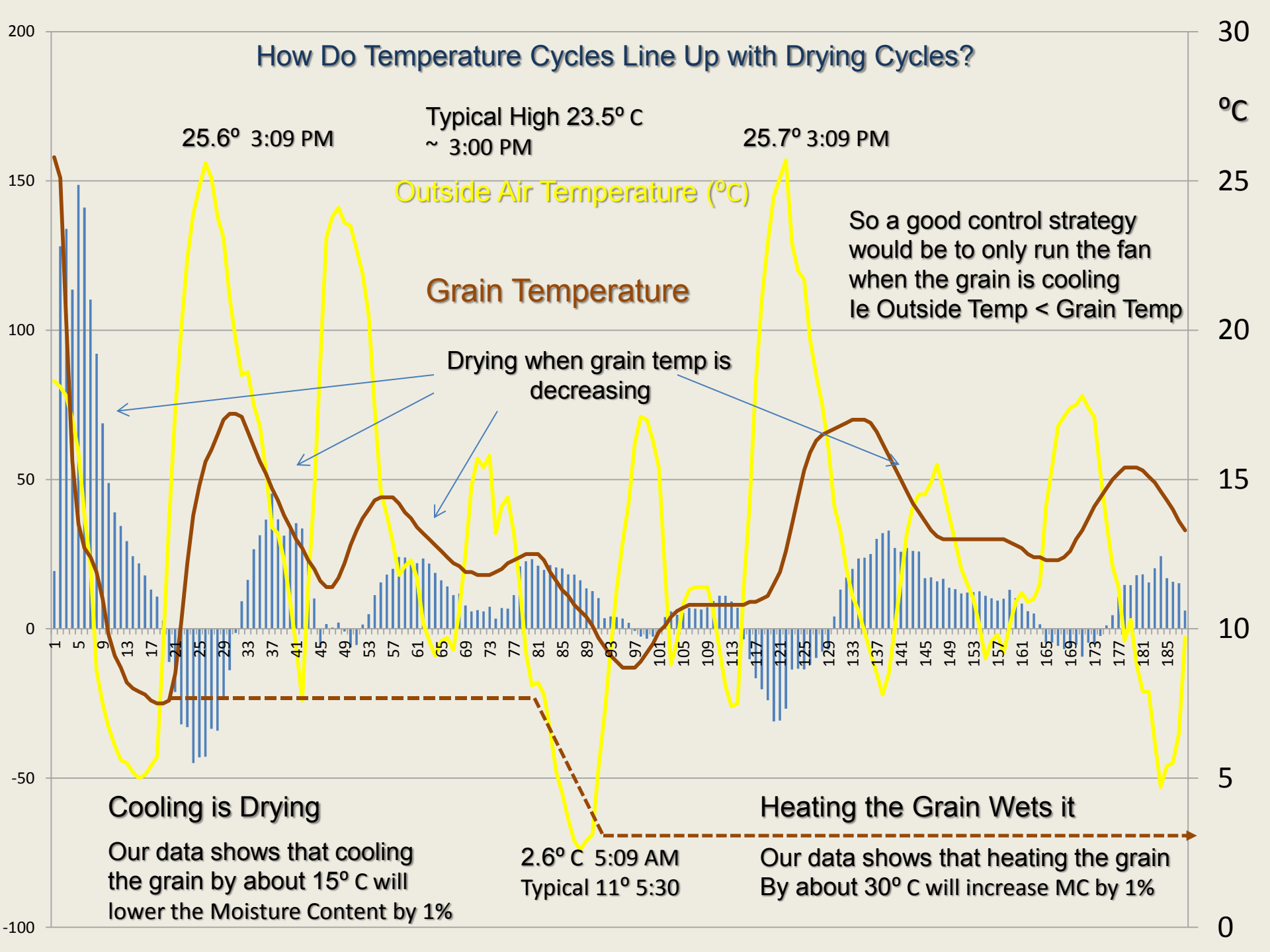
If we turned the fan on only at night for 3 days, would take 20 + 12 + 12 = 44 hrs with MC to 14.2%




Average Diurnal Drying Cycle of 19 trials
H_2O removed (gr) per cubic meter of air flowing through bin
2
1.5
1
0.5
0
-0.5
-1
Best Drying ~ 2 AM
Drying to Wetting
9:30 AM
Wetting to Drying
6:00 PM
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of the Day
Most Wetting
Night
Morning
Noon
Afternoon
Evening

Air Wetness (how much water is in the air)$_{kg/6000cf}$




How Do Temperature Cycles Line Up with Drying Cycles?
Typical High 23.5° C
~ 3:00 PM
25.6° 3:09 PM
25.7° 3:09 PM
Outside Air Temperature (°C)
Grain Temperature
So a good control strategy would be to only run the fan when the grain is cooling
Ie Outside Temp < Grain Temp
Drying when grain temp is decreasing
Cooling is Drying
Our data shows that cooling the grain by about 15° C will lower the Moisture Content by 1%
2.6° C 5:09 AM
Typical 11° 5:30
Heating the Grain Wets it
Our data shows that heating the grain By about 30° C will increase MC by 1%
200
150
100
50
0
-50
-100
30
°C
25
20
15
10
5
0
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
81
85
89
93
97
101
105
109
113
117
121
125
129
133
137
141
145
149
153
157
161
165
169
173
177
181
185

Fie	Na	Gr	Start	Finish	Overall Hrs	Hrs. Fan On	% 1st loss	Low Temp	Mid Grain Temp	High Grain	MC% start	CFM	Transition Dry-Wet	kg net loss	kg wet	kg dry	mid °C dec / %MC	top dec °C /%MC	MC% loss measured	MC loss calculated	°C Grain End of Run	Ave Temp Amb Air °C
07	1	Fir	W	A29 16:28	S7 23: 28	225	210	0.5	20.1	19.1	17.5	15.6	3318	8:45	1445	574	2018	12.0	7.6	3	3.1	16.6	18.3
07	2		W	S13 13:28	S25 23:28	300	250	1.3	14.0	13.4	11.9	16.3	3168	9:15	1690	487	2177	10.9	9.4	3.8	3.6	14.3	11.9
07	3		W	S27 12:28	O12 12:2	362	345	0.7	10.8	10.5	9.5		3129	9:15	1357	394	1751	9.8	10.1	3.2	2.9	10.8	8.25
08	10B		Ba	A29 17:18	S10 18:18	291	283	1.1	14.3	13.7	13.1	17.2	3632	7:45	1514	322	1837	10.6	8.5	3.57	3.3	18.0	12.4
08	09P		Pe	A20 10:28	A22 14:28	54	52	2.9	21.9	21.9	22.7	14.5	8703		1421	0	1421	3.7	6.3	3.95	3.1	15.0	21.1
08	09W		W	S12 15:28	S24 13:28	288	286	2.4	16.1	15.6	14.7	16.0	4997	9:55	2729	1092	3821	7.8	7.0	3.33	3.5	12.0	14.2
08	10W		W	O8 10:18	O10 7:18	215	212	0.9	13.6	13.2	12.0	17.2	3499	8:48	1087	207	1295	12.8	8.6	3.3	2.3	7.9	11.8
09	9B	E	Ba	S6 10:36	S12 15:36	151	149	2.2	19.1	18.7	17.0	15.4	5183	8:15	1153	397	1550	12.0	8.5	1.73	2.5	20.0	17
09	10B		Ba	S6 10:36	S25 13:36	461	458	1.7	20.3	19.8	18.8	17.0	3113	8:03	1813	845	2658	14.3	11.0	4.45	3.9	20.4	18.3
09	10P		Pe	A29 13:36	S3 8:36	117	113	1.2	19.1	18.7	18.1	15.6	4888	7:24	373	845	1218	16.8	7.9	1.4	0.8	18.8	19.3
09	09W		W	S14 12:36	S25 13:36	267	265	1.7	20.9	19.5	18.2	17.3	4772	8:45	2094	1117	3211	7.4	6.0	4.4	4.5	20.3	19.1
10	10		W	S23 14:23	O24 14:2	746	650	0.5	13.9	12.6	10.8	20.5	3004	10:30	3107	1471	4578	15.0	11.6	6.8	6.7	9.5	12
10	09		W	S26 12:23	O24 14:2	676	572	1.1	14.2	13.0	12.1	18.5	3270	9:29	2717	1652	4369	13.9	11.6	6.18	5.9	9.4	11.9
11	09		Ur	S2 9:51	S12 6:51	239	173	Run ruined because of faulty discharge relative humidity sensor --															
11	10		Ur	S2 9:58	S12 6:58	239	231	2	20.0	16.5	15.9	18.4	2953	9:13	1585	571	2156	11.7	9.4	3.83	3.4	19.0	18.8
12	09	1	W	A17 19:29	A27 7:29	230	162	1.4	20.6	19.0	18.4	16.9	4077	6:30	733	554	2120	13.1	13.5	2.98	2.1	19.1	18.9
12	09	2	W	S13 14:09	S21 9:09	189	188	1.7	14.2	12.9	12.2	17.1	3867	9:09	1540	421	1960	7.4	6.6	4.55	3.3	13.3	13.1
12	10	1	W	A17 19:29	A27 6:29	229	62	1.1	16.6	14.6	16.2	17.9	3042		639	98	737	18.7	18.0	2.36	1.8	13.0	11.9
12	10	2	W	S13 14:01	S21 9:01	189	187	1.1	14.3	13.0	11.4	16.3	2830	12:00	892	268	1160	12.0	14.6	2.7	1.9	11.0	13.1
12	16		Ba	A23 10:05	S3 7:05	263	262					17.5	2054	11:30	1538	204	1742			4.93	1.9	15.0	20
12	17		Ba	A23 10:05	S6 7: 05	335	98					18.3	3053	9:05	1092	380	1472			4.75	1.3	10.0	19.9
12	18		Ba	S4 1:29	S21 8:29	417	190					17.6	3113		2268	7	2274			3.6	2.8	10.0	13.2
12	19		Ba	S4 14:29	S21 8:29	402	327					18.9	2959	9:15	4206	227	4433			5.98	5.2	9.0	13.2
				Averages		**299**	**249**	**1.4**	**16.9**	**15.9**	**15.0**	**17.1**			**1681**	**552**	**2271**	**11.6**	**9.8**	**4.19**	**3.2**	**13.6**	**15.3**
					12 day	10da	%MC	°C	°C	°C	%MC	CFM		kg	kg	kg	**Drying Rat Mass Balance**					
														for every 3 kg out, we put 1 in								

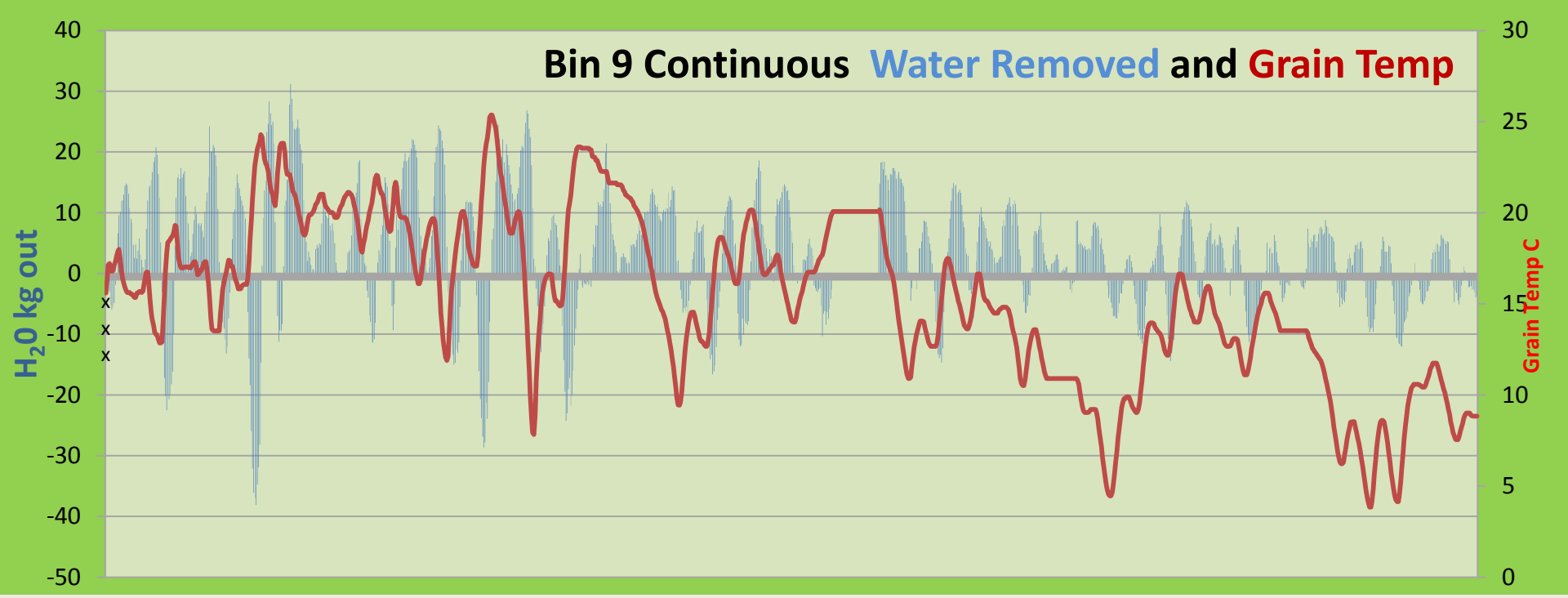
What have we learned from the data!

- The *black-box* approach accurately measures the amount of drying/wetting. Verified with mass-balance.
- There is clearly a daily cycle of drying and wetting of grain.
- Wetting never occurs at night. Drying to wetting ~ 9:00 AM
- Drying occurs at night and occasionally during the day if dry.
- Cooling the grain – dries the grain (15^{o}C/%). The first night typically lowered the temp by 10^{o} C. This lowered MC by 0.5% to 1.5%. Driest air and best drying conditions are typically at night; wettest air and wetting conditions typically occur during the day.
- Cold air, even freezing air, can dry grain
- Not a drying 'front' but a drying 'gradient'– cause→(compression)
- A simple, effective and safe control strategy would be to only have the fan ON when Outside Air Temp <= Grain Temp + Offset
- Could use smaller fans ie: less than one cfm/bu
- Following this control strategy will result in the least fan time and the SAFEST storage. (dry, cold grain) It's best to work with Mother Nature!

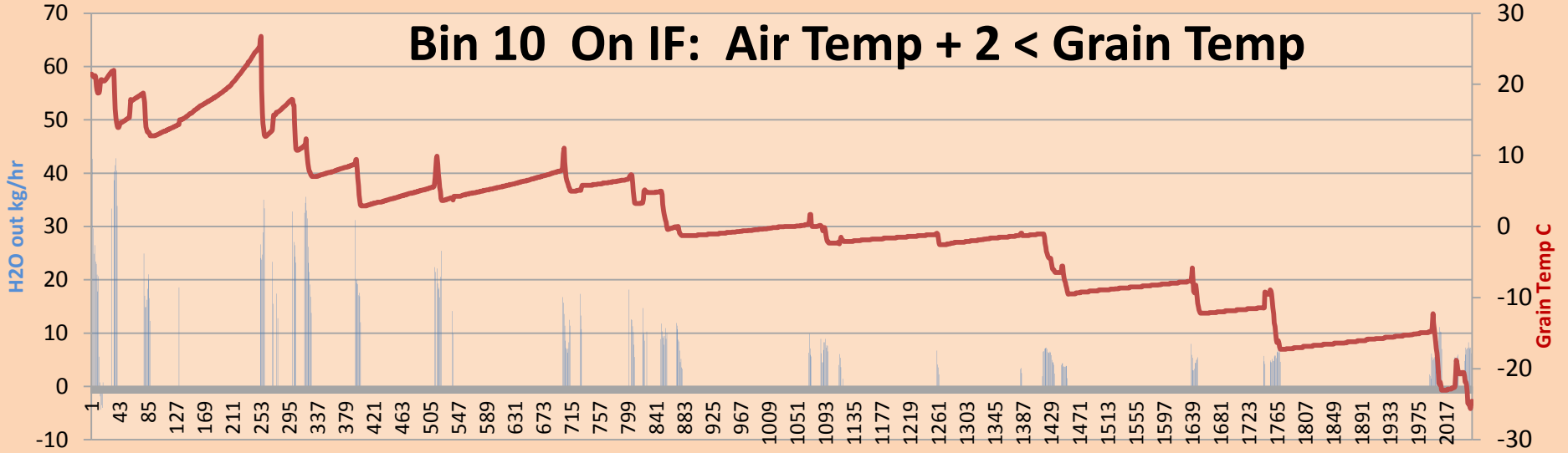
2013 trial – comparing continuous with new control

	Nine	Ten
• Start: Aug 29 10:00 AM		
• 2000 bu of barley (mc)	24.5%	25.4%
• Start Temp of Grain:	43.5º C	43.25º C
• Control Strategy:	On Continuous	ON if: Air Temp < Grain Temp

- 5 HP Flaman Fans – 3400 CFM – 7” H_20



- 1200 hrs fan on -- $533 @ $0.10/kw hr
- Removed 5114 kg (11271 lbs) H_2O 24.5% to 16.67% removed 7.83%
- First 48 hours removed 1609 kg H_2O to 22.3%
  - MC lowered by 2.2%
  - Grain temp lowered 48.5 to 14.1º C 15.6ºC/%
- Final Grain Temp: 3º C



- 251 hrs fan on -- $93 @ $0.10/kwh (21% of continuous)
- Removed 3690 kg (8132 lbs) H_2O 25.4% to 20% lowering the MC by 5.4%
- First 24 hours removed 987 kg H_2O lowered MC 1.4%
  - Grain temp lowered 43.25 to 20.5º C 16ºC/%
  - Fan Stopped at 9:30
- Warming: no fan 40 hr/deg > 0 88 hr/deg < 0
- Nov 22 -20.5 to -24.5 removing 80.5 kg H_2O 34º /%
- Final Grain Temp: -24.5º C

The Good, the Bad, and the Ugly: Guide for NAD

- UGLY – do nothing – get to it later. The first day is critical, get the temp down, even if the grain is dry – could even use a small 1 HP
- BAD: ON hot days, OFF at night. It does work, but Hot Wet grain – could end up badly. This is risky.
- OK: ON Continuous. This also works, but not good to heat and wet the grain during the day; and we are running the fan needlessly.
- GOOD: ON only at night. Yard Light rule: On at night, you are bright; on during the day, you will pay. Turn off at 9 AM.
- BETTER: On only on cold nights. More efficient, less fan time and colder, safer grain storage.
- BEST: ON if: Air Temp + Offset < Grain Temp
  Strategy: Keep the grain as cold as possible and it will result in the least fan time & safest storage. Electronic control simple.

Best Control

- Turn the fan on immediately upon filling the bin with grain that is hot from the field, with more moist grain at the bottom
- Leave fan on until 9 AM next day.
- Keep the grain as cold as possible by following this simple rule:
- **Fan ON if: Outside Temp + Offs< Grain Temp**
- OR: Drive the temp of the grain down as far as you can.

SPONSORS

- Western Grains Research Foundation (WGRF)
- Advancing Canada's Agriculture and Agri-Food Saskatchewan (ACAAFS)
- Agriculture and Agri-Food Canada (AAFC)
- Indian Head Agricultural Research Foundation(IHARF)
- Great West Controls - Saskatoon