Update on Natural Air Grain Drying

IHARF Soil and Crop Management Seminar

White City Community Center

Wed Feb 4, 2015 1:45

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Objective

- To build a fan controller that:
  - is **<u>Efficient</u>** – saves power, fan on only when neccesary (if drying, fan on, if not drying, fan off)
  - Provides **<u>Safe</u>** Grain Storage – ie. No spoilage
    - **<u>Cool</u>** grain
    - **<u>Dry</u>** 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 TIME (days) CEREAL GRAINS

$\log_{10}$ (**safe days**) = 6.2 – 0.3 **MC%** - .07 **°C** Fraser & Mu

germination reduced by 5%

14.5% @ 30°C = 38 safe days
14.5% @ 20°C = 128 safe days
14.5% @ 0°C = 1458 safe days

Grain Temp°C	**Grain Moisture Content** 14%	15%	16%	17%	18%	19%	20%	21%	22%	23%	24%
<-5											
5					80-120	40-60	40-60	40-60	20-30	20-30	20-30
10				80-120	0-60	40-60	40-60	20-30	10-15	10-15	10-15
15			80-120	40-60	0-60	20-30	20-30	20-30	10-15	10-15	5-8
20		80-120	40-60	40-60	0-30	10-15	10-15	10-15	5-8	5-8	3-5
25	80-120	40-60	20-30	20-30	0-15	5-8	5-8	3-5	3-5	3-5	3-5
30					5-8	3-5	3-5	3-5	3-5	3-5	3-5

Safe storage > a year

NOT SAFE **VERY DANGEROUS**

Vapour Pressure

Air surrounding kernel

Water trying to get in

= Vapour Pressure Air

- temperature
- relative humidity

Grain kernel

Water trying to get out

= Vapour Pressure Grain

- % moisture content
- temperature
- type & condition of grain

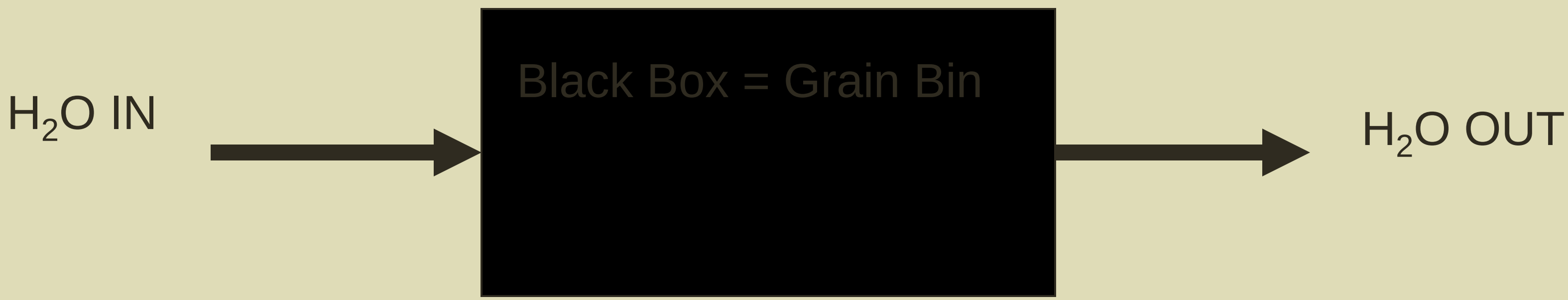
When air vapour pressure is greater than grain vapour pressure, water enters the grain and WETTING occurs. When Vps are equal, → EMC

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

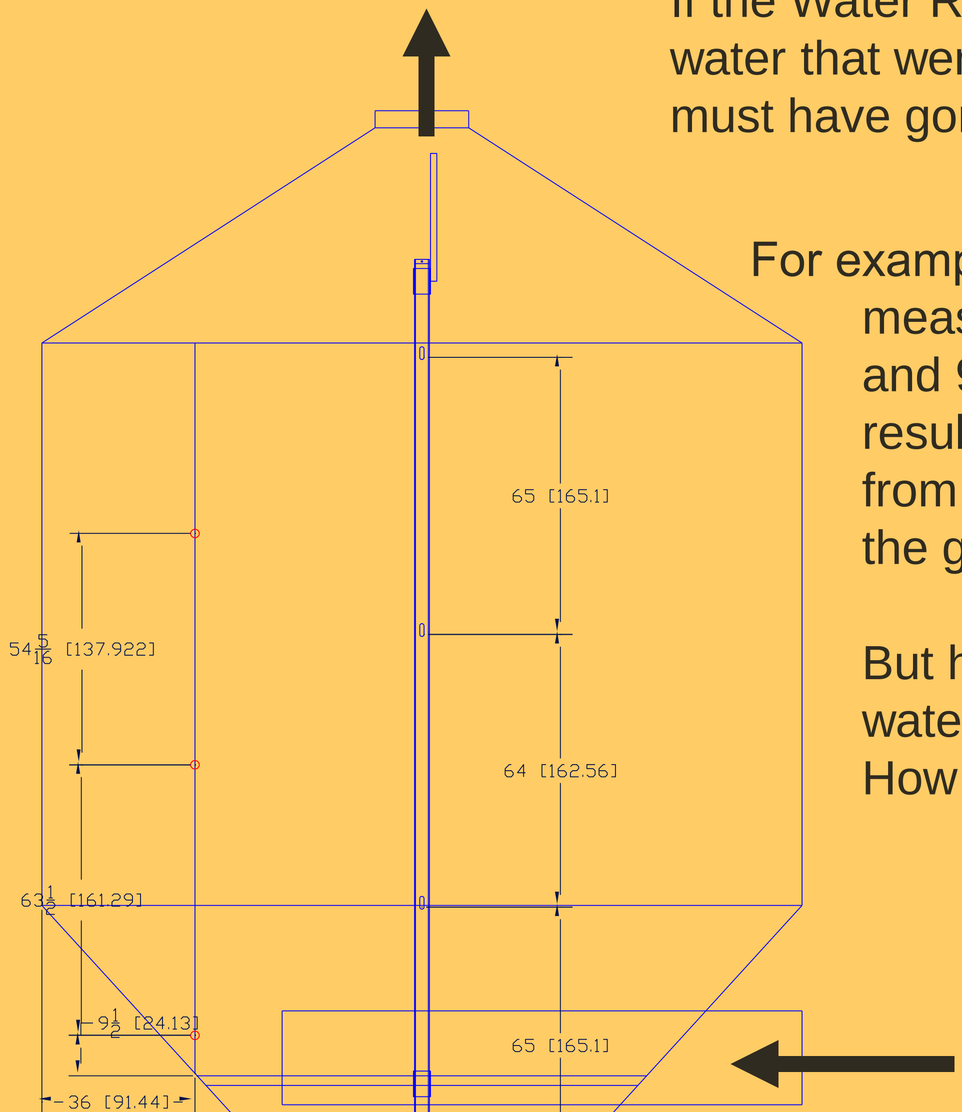
If the Water Removed is positive, then this is the amount of water that must have come from the grain and therefore we are DRYING

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

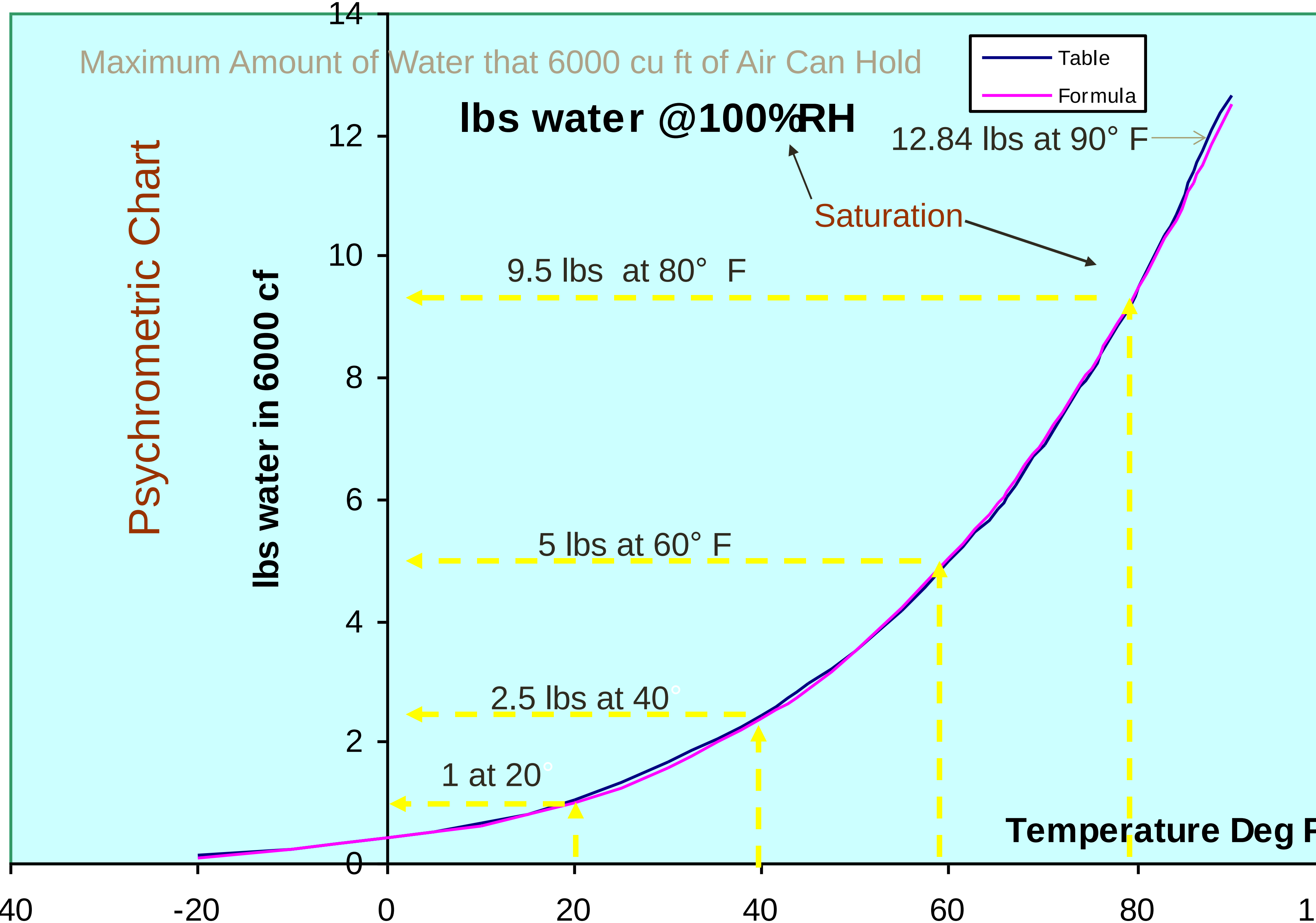
For example: let's say that in one hour we measured 80 lbs of water going into the bin and 90 lbs of water coming out. The net result is 10 lbs of water being removed from the bin. And it must have come from the grain, so we are drying.

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

Water OUT

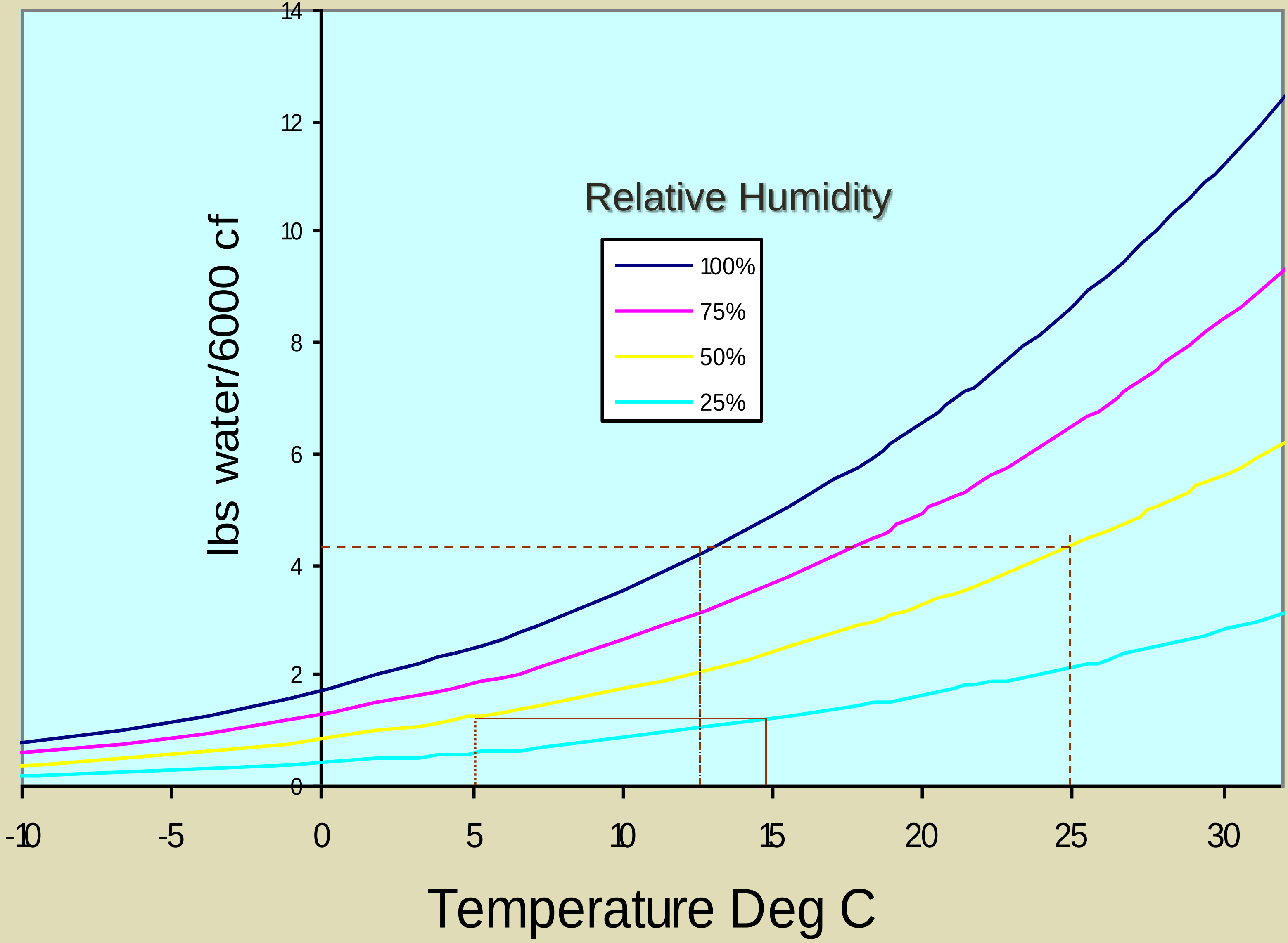


Water IN (carried in by the air)



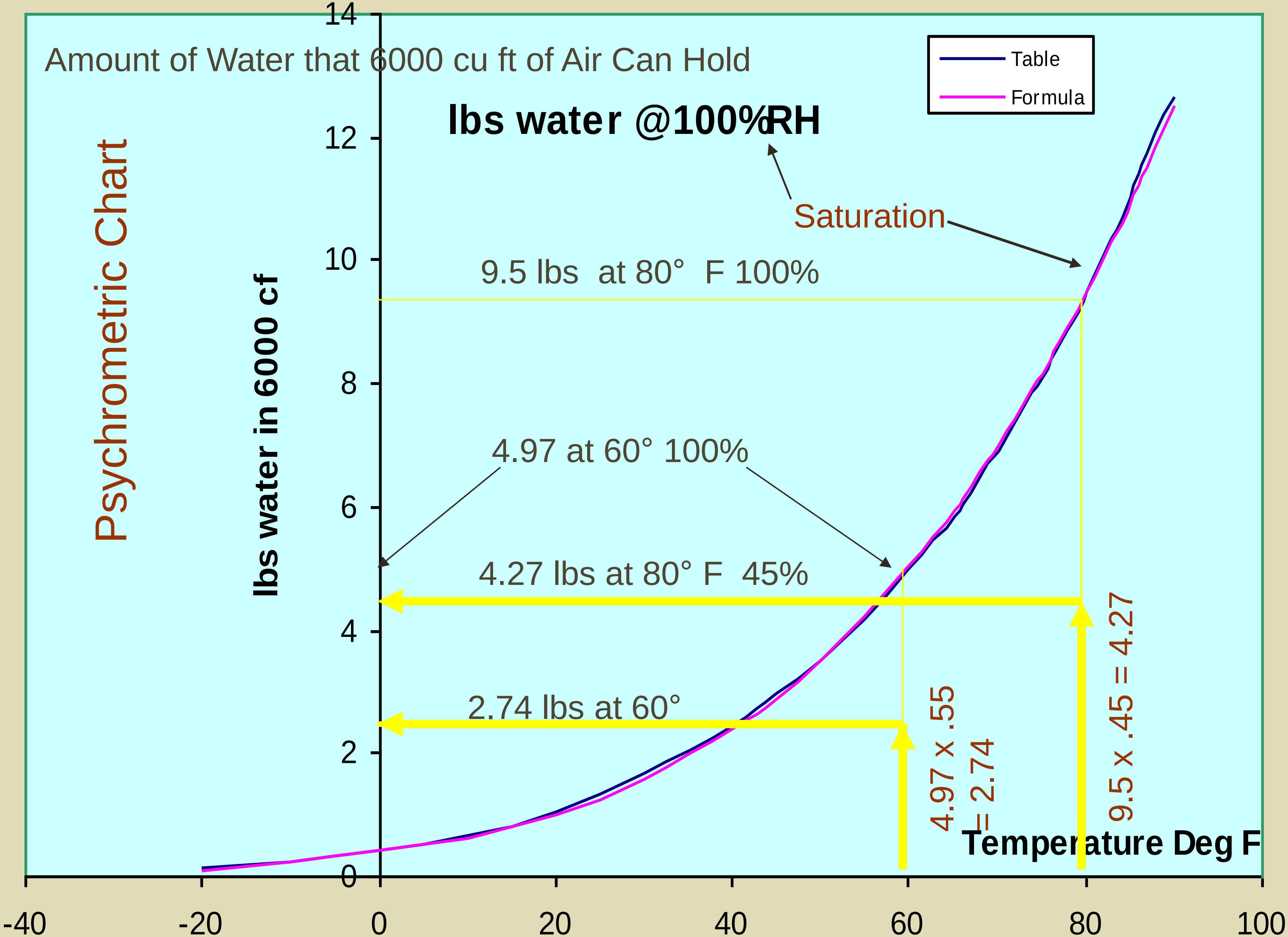
Maximum Amount of Water that 6000 cu ft of Air Can Hold
lbs water @100% RH
Table
Formula
12.84 lbs at 90° F
Saturation
9.5 lbs at 80° F
5 lbs at 60° F
2.5 lbs at 40°
1 at 20°
Psychrometric Chart
lbs water in 6000 cf
Temperature Deg F
14
12
10
8
6
4
2
0
-20
0
20
40
60
80

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 the bin is 60° F @ 55% RH.
  - leaving the bin is 80° F @ 45% RH.
- Are we drying?
- How much?

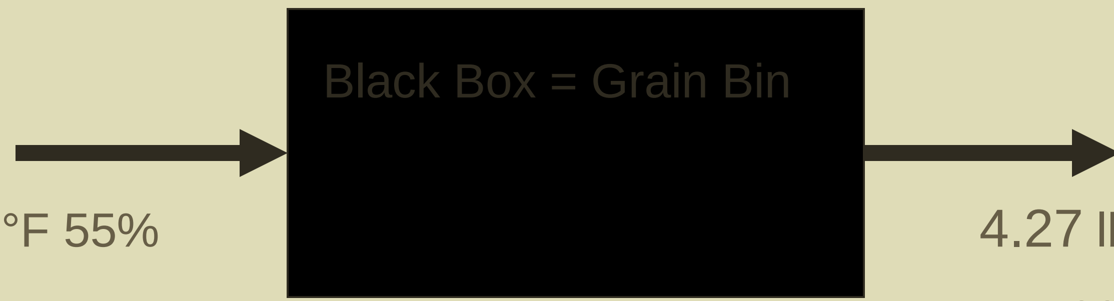

Amount of Water that 6000 cu ft of Air Can Hold
lbs water @100% RH
Psychrometric Chart
lbs water in 6000 cf
Table
Formula
Saturation
9.5 lbs at 80° F 100%
4.97 at 60° 100%
4.27 lbs at 80° F 45%
2.74 lbs at 60°
4.97 x .55 = 2.74
9.5 x .45 = 4.27
Temperature Deg F
14
12
10
8
6
4
2
0
-40
-20
0
20
40
60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

The Black Box Approach

H_2O IN

.2.74 lbs at 60°F 55%

Per 6000 cu ft.



H_2O OUT

4.27 lbs at 80°F 45%

Per 6000 cu ft.

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

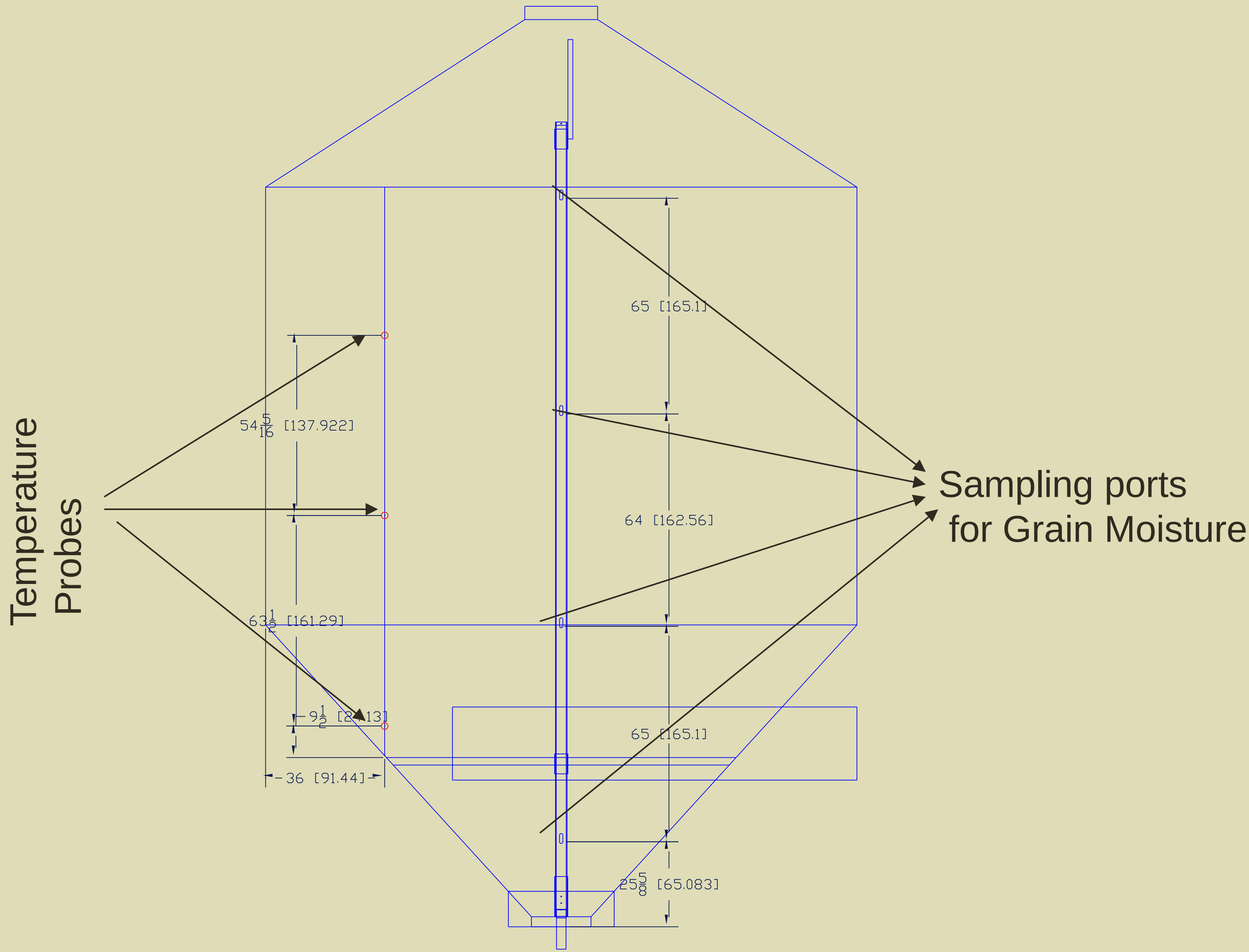
4.27 lbs > 2.74 lbs → FAN On (1.53lbs/6000)

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
65 [165.1]
64 [162.56]
65 [165.1]
25 5/8 [65.083]
54 5/16 [137.922]
63 1/2 [161.29]
36 [91.44]

Panel with Instruments

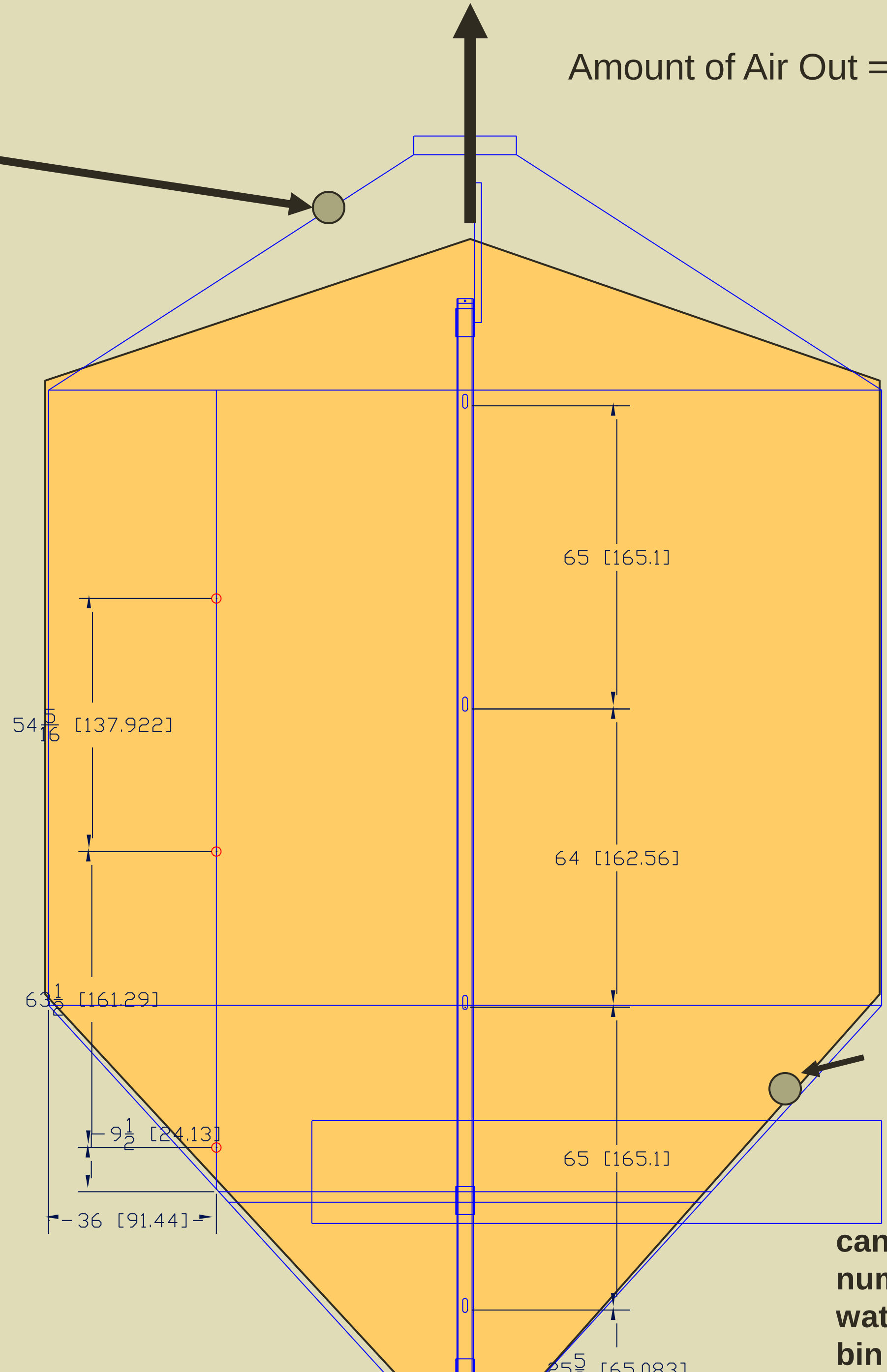

Air Tubes for Recording CFM


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

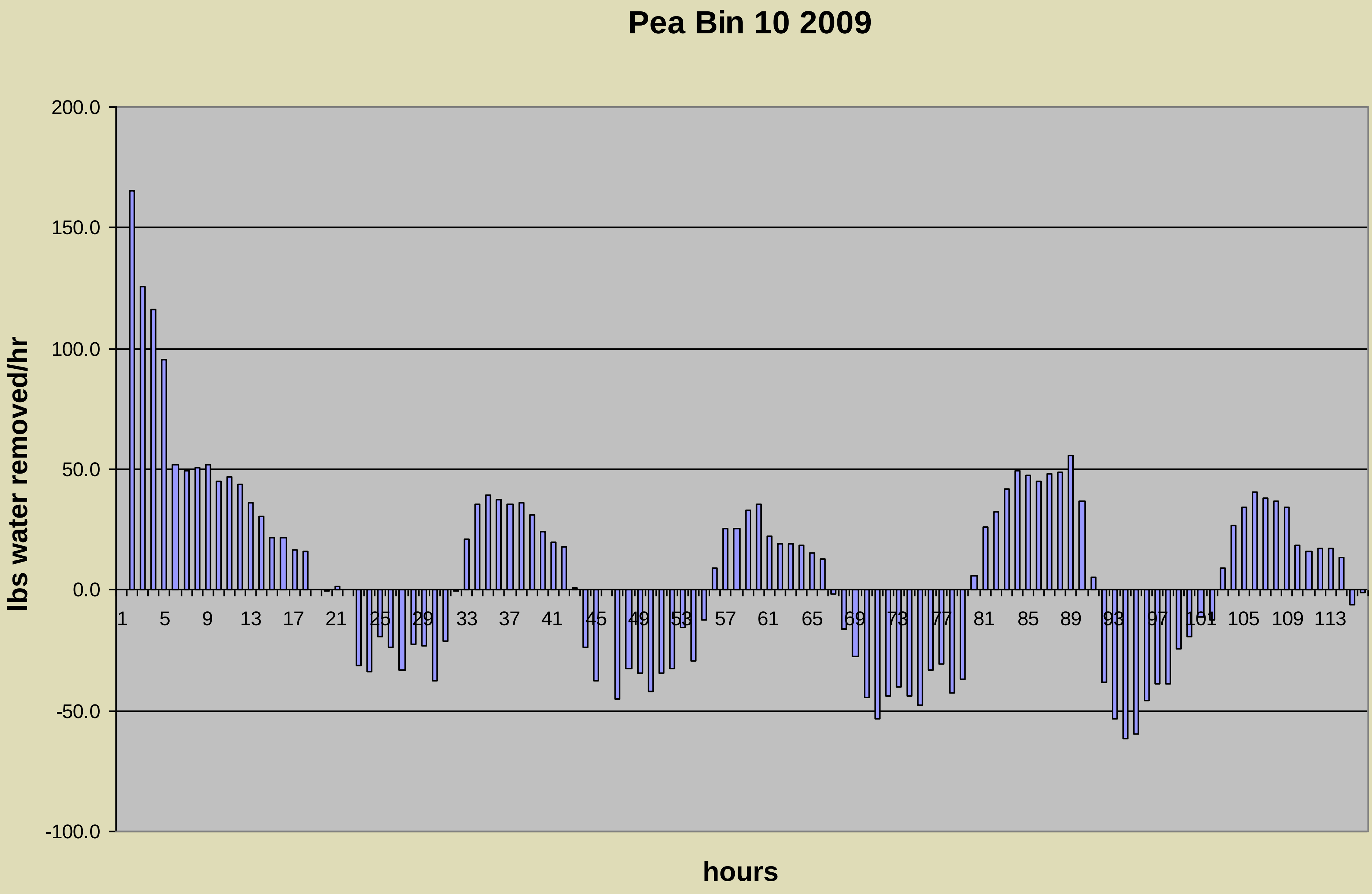


Sensor measuring T and RH of the air entering the bin

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

Data Stored Hourly in Excell

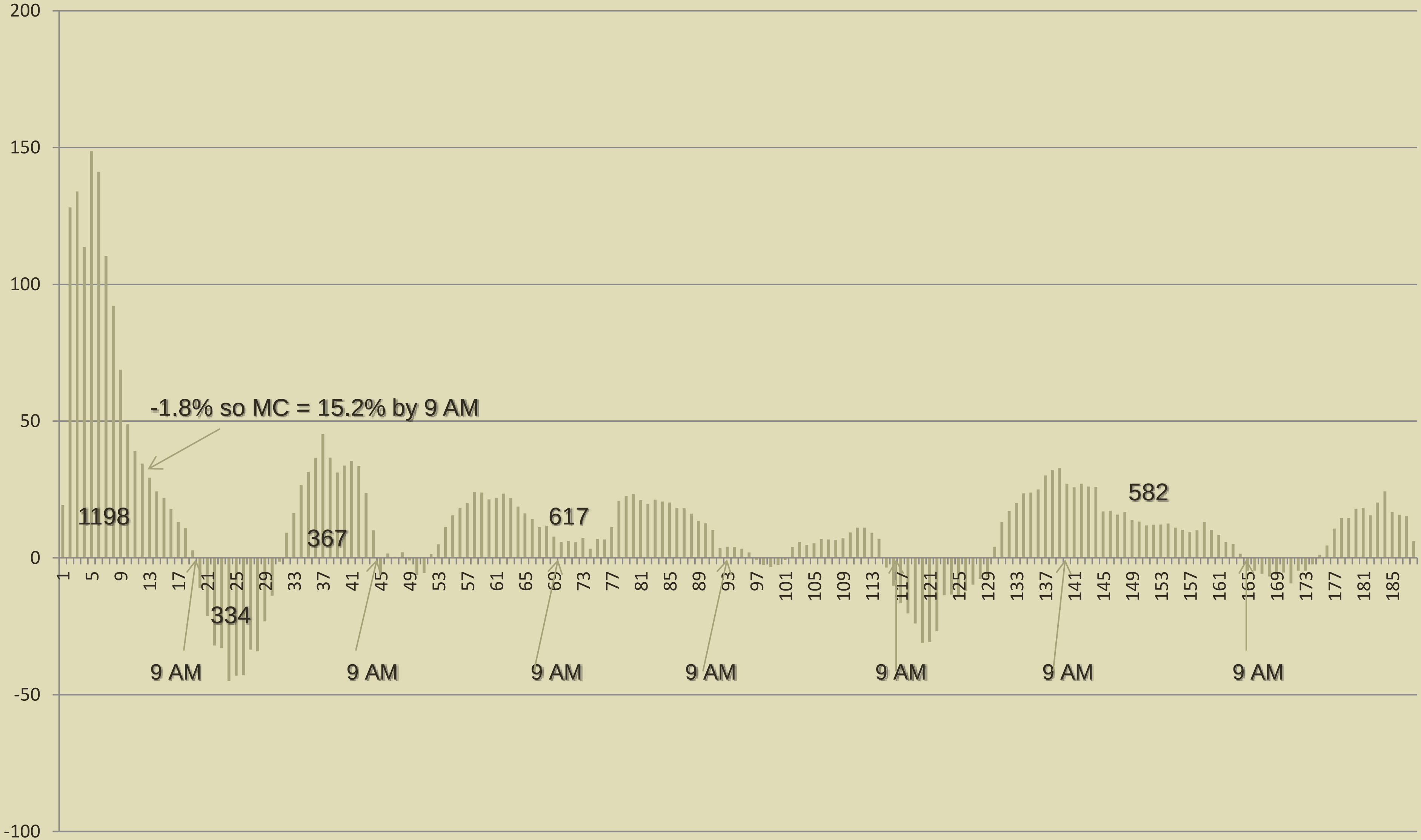
Date / Time	10-LOW LEVEL TEMP	10-MID LEVEL TEMP	10-HI LEVEL TEMP	10-DISCH TEMP	10-DISCH HUMID	10-FAN CFM	Outside T	Outside RH
09/02/2011 9:58	18.13	37.88	30.3	25.41	90.06	2882	14.54	75.38
09/02/2011 10:58	17.64	29.84	31	31.94	86.94	2502	17.25	66.31
09/02/2011 11:58	17.7	22.02	33.06	30.23	85.5	2732	16.75	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

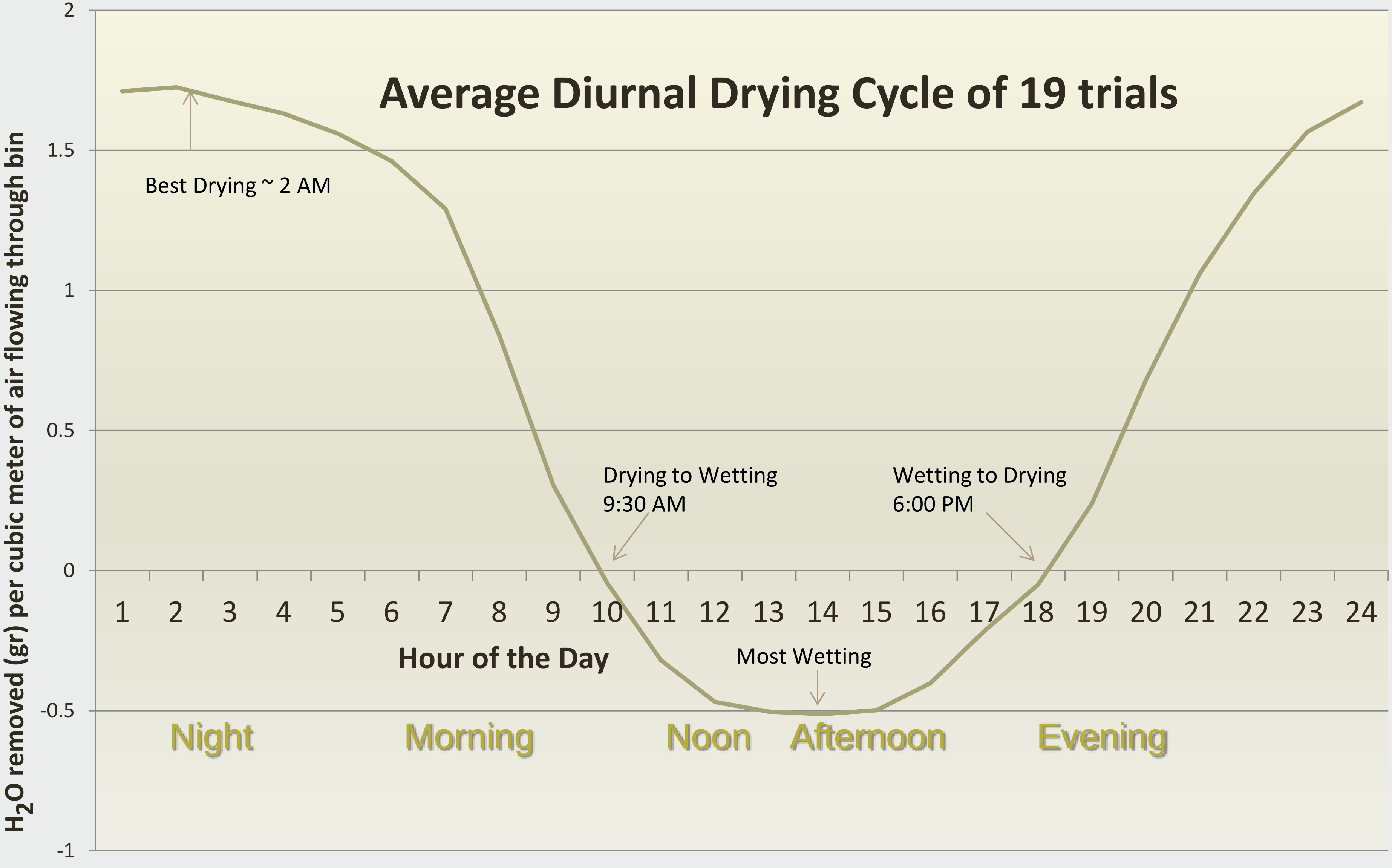

Pea Bin 10 2009
lbs water removed/hr
200.0
150.0
100.0
50.0
0.0
-50.0
-100.0
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
81
85
89
93
97
101
105
109
113
hours

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

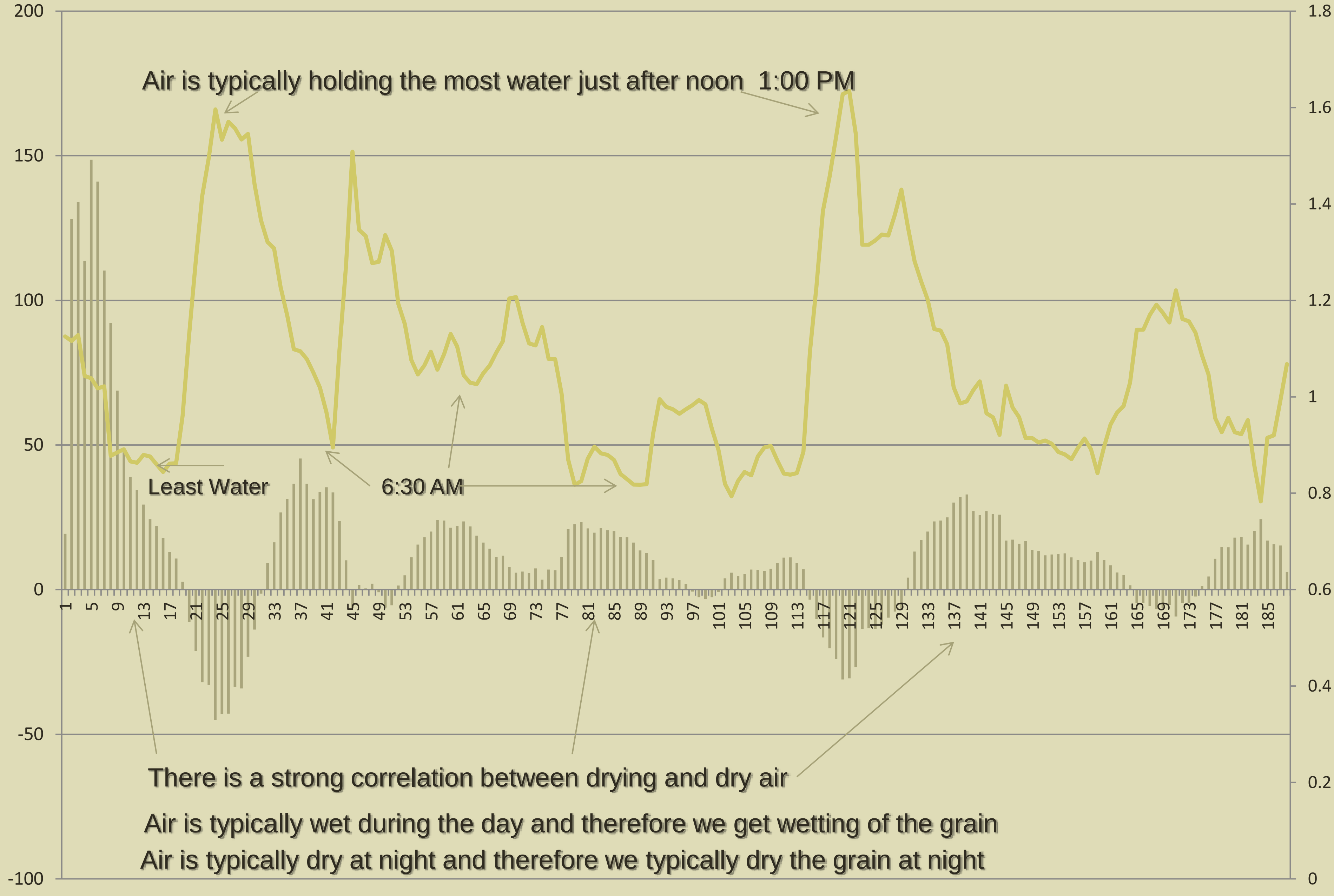
Switch from drying to wetting at 9:30 AM, -- turn the fan off by 9 in the morning

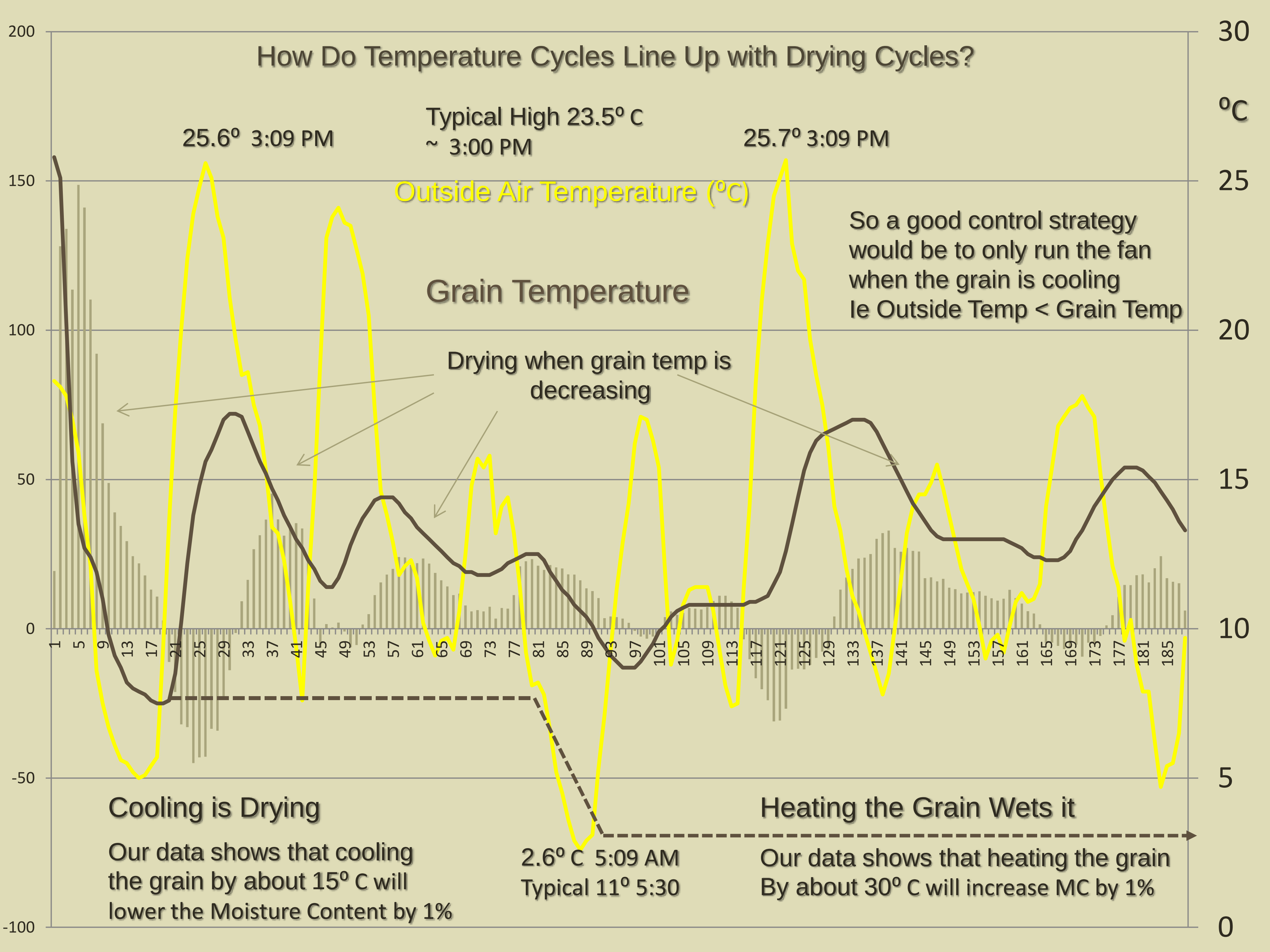
If we turned the fan on only at night for 3 days, would take 20 + 12 + 12 = 44 hrs with MC to 14.2%




Average Diurnal Drying Cycle of 19 trials
Best Drying ~ 2 AM
Drying to Wetting
9:30 AM
Wetting to Drying
6:00 PM
Most Wetting
Hour of the Day
H2O removed (gr) per cubic meter of air flowing through bin
2
1.5
1
0.5
0
-0.5
-1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Night
Morning
Noon
Afternoon
Evening

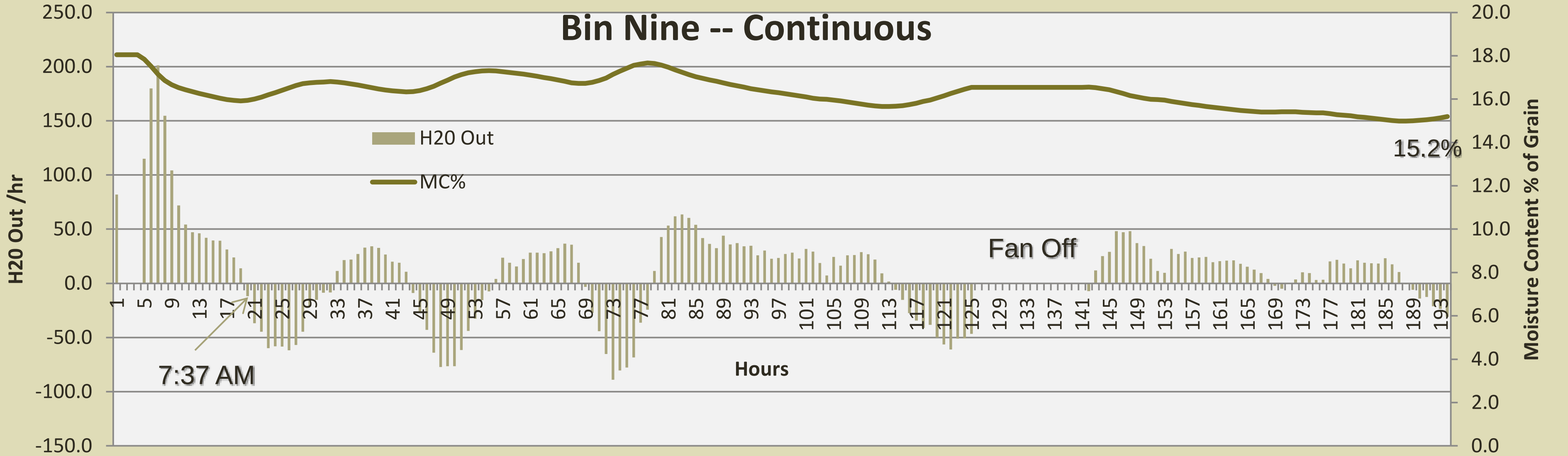
Air Wetness (how much water is in the air)kg/6000cf




How Do Temperature Cycles Line Up with Drying Cycles?
Typical High 23.5º C
~ 3:00 PM
25.6º 3:09 PM
25.7º 3:09 PM
Outside Air Temperature (ºC)
So a good control strategy
would be to only run the fan
when the grain is cooling
Ie Outside Temp < Grain Temp
Grain Temperature
Drying when grain temp is
decreasing
Cooling is Drying
Our data shows that cooling
the grain by about 15º C will
lower the Moisture Content by 1%
2.6º C 5:09 AM
Typical 11º 5:30
Heating the Grain Wets it
Our data shows that heating the grain
By about 30º C will increase MC by 1%
200
150
100
50
0
-50
-100
30
ºC
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

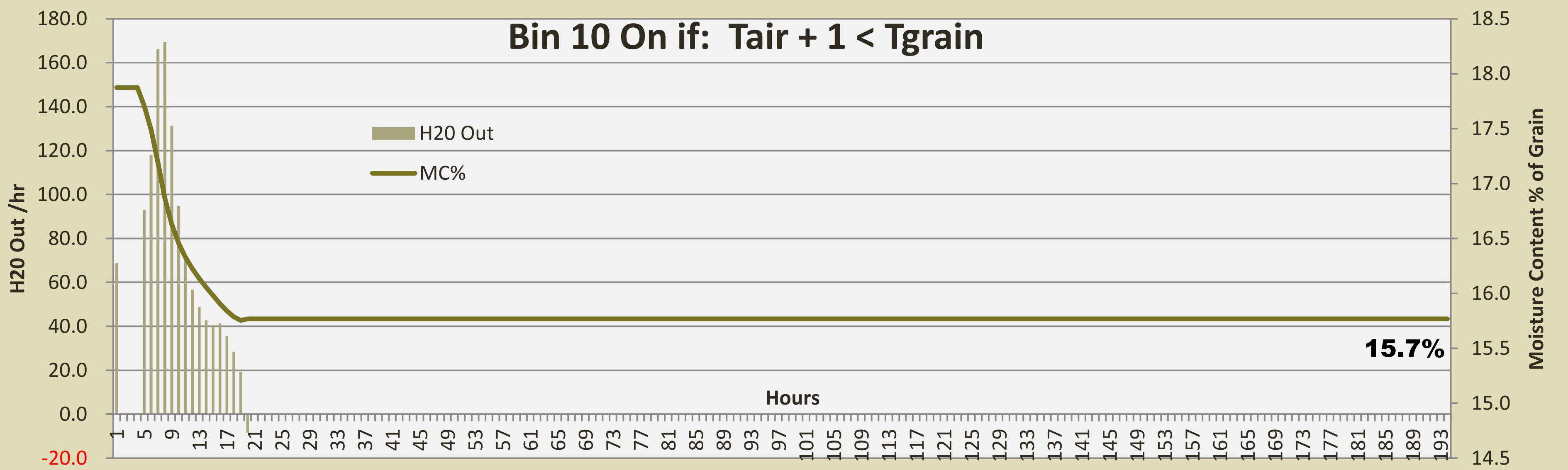
2014 trial – comparing continuous with new control

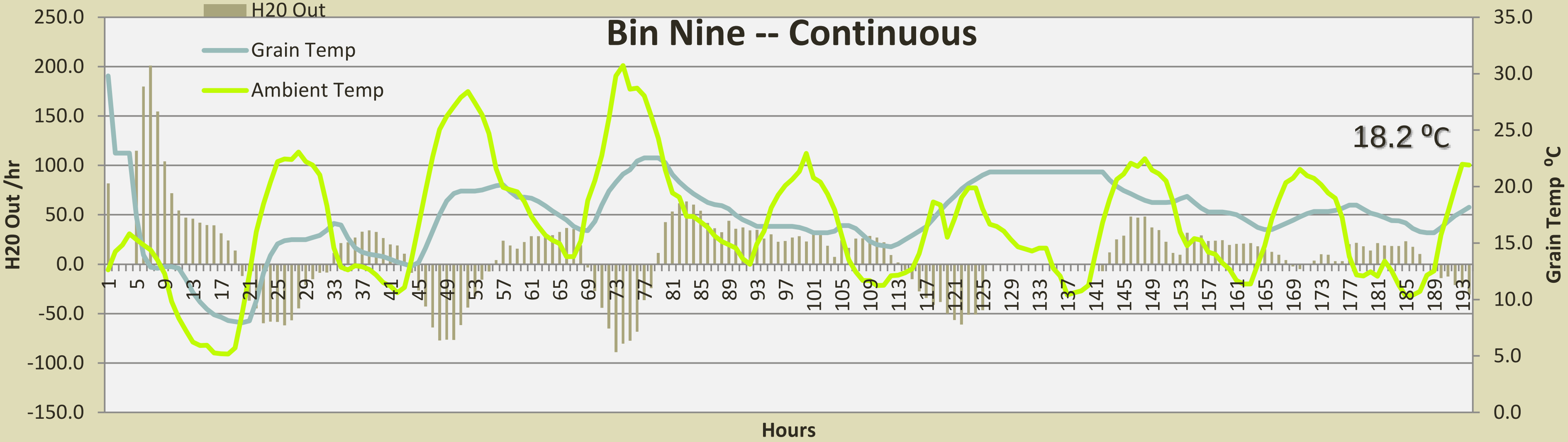
- Start: Aug 19 12:37 PM Nine Ten
- 2200 bu, barley 18.2% 18.0%
- Start Temp of Grain: 29.8º C 29.4º C
- Control Strategy: On Continuous ON iff: AirTemp + 1< GrainTemp
- 5 HP Flaman Fans – 3400 CFM – 7” H_20
- End Sept 2 1:37 PM

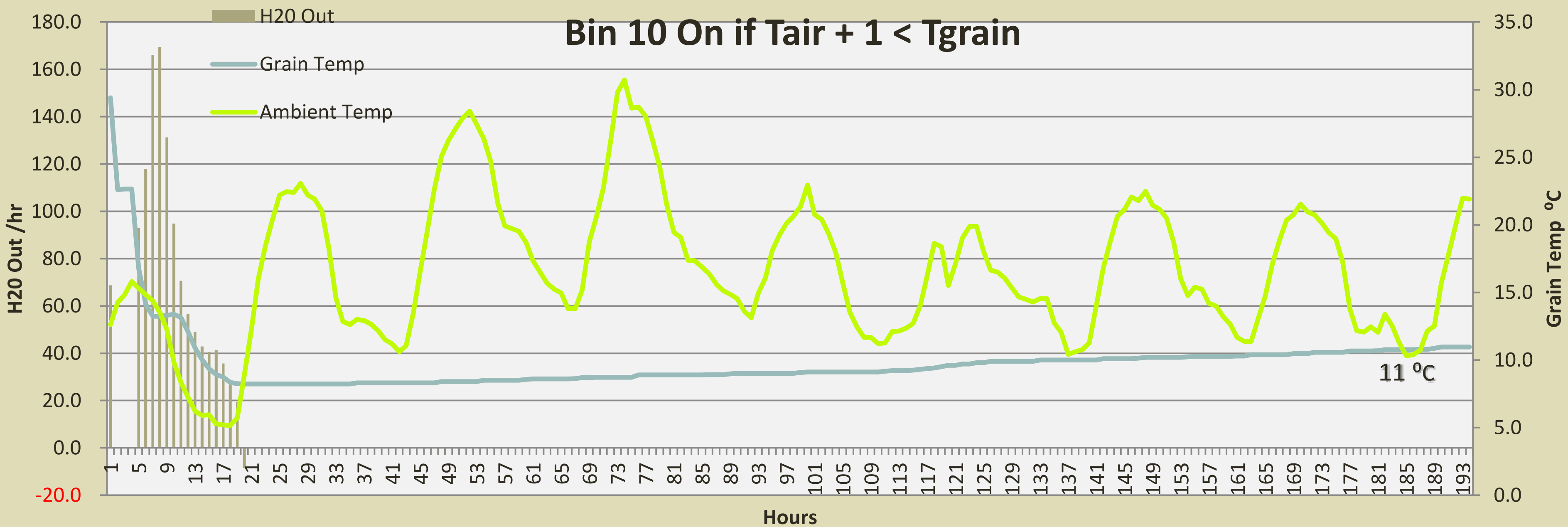


Continuous vs Controlled: 2200 bu of barley, 18% MC, 29.5^{o}C

Started Tue Aug 19, 2014 12:37 – End Tue Sep 2 1:37




Bin Nine -- Continuous
H20 Out
Grain Temp
Ambient Temp
18.2 °C
H20 Out /hr
Grain Temp °C
Hours
250.0
200.0
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0


Bin 10 On if Tair + 1 < Tgrain
H20 Out
Grain Temp
Ambient Temp
11 °C
H20 Out /hr
Grain Temp °C
Hours
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0

Continuous(9) vs Control (10)

- Continuous dried more: (9) 15.2% (10) 15.7%
- Continuous warmer grain: 18.2º 11º C
- Continuous more fan hours: 174 17 hrs
- @0.10/kwh 5HP $64.38 $6.29
- Bot -Top MC spread (9) 5%: 12.9 13.6 16.3 18 whereas control (10) had spread < 1%
- Control gets more into the safe zone, quicker

SAFE STORAGE TIME (days) CEREAL GRAINS

Grain Temp ºC	Grain Moisture Content 14%	15%	16%	17%	18%	19%	20%	21%	22%	23%	24%
<-5											
5					80-120	40-60	40-60	40-60	20-30	20-30	20-30
10				80-120	0-60	40-60	40-60	20-30	10-15	10-15	10-15
15			80 20	40-60	0-60	20-30	20-30	20-30	10-15	10-15	5-8
20		80-12	0-60	-60	0-30	10-15	10-15	10-15	5-8	5-8	3-5
25	80-120	40-60	20-30	2 20	0-15	5-8	5-8	3-5	3-5	3-5	3-5
30	40-60	20-30	10-15	10-15	5-8	3-5	3-5	3-5	3-5	3-5	3-5

Safe storage > a year

NOT SAFE

VERY DANGEROUS

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 + Offset <= Grain Temp
- 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!

First 24 Hours is Critical

Average of 33 Runs 2007 – 2014

	Start	End	Difference
• First 24 Hours:	Start	End	Difference
• Grain Temp ^{o}C	26.2	14.6	11.6
• Moist Cont %	17.65	16.77	0.88
• Safe Days	6	32	26

• Cooling/Drying 11.6/0.88 = 13.18 $^{o}C/\%MC$

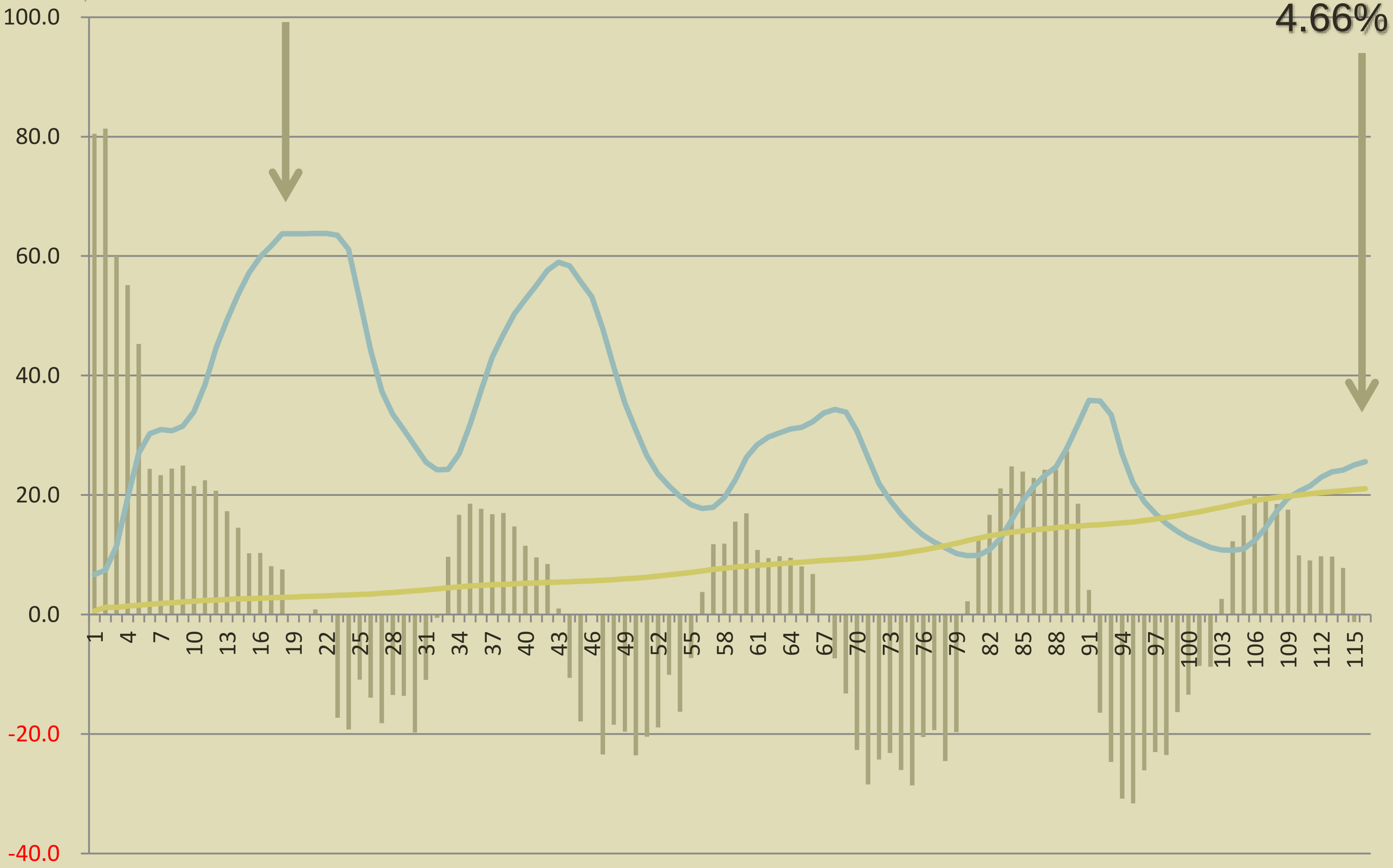
New Definition: Accumulated Deterioration = Σ (1/ safe days) x 100

Example, if safe days is six, then after 3 days we will have an accumulated deterioration of: (1/6 + 1/6 + 1/6) x 100 = 50%,
after 6 days : (6 x 1/6) x 100 = 100% accum. deterioration, 95% germination

Time	1:36 PM	9:36 AM	8:36 AM
Grain Temp	27.5 ºC	12.7 ºC	18.7 º C
MC%	16%	15.2%	15.5%
Safe Days	6.7	63.8	25.6
Accum Det	0	3.1 %	21.1%
Fan Hours	0	18 hr	114 hr

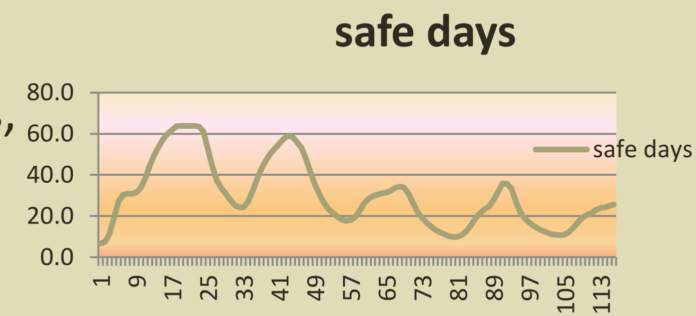
09 10P

If fan turned off here, safe days constant @ 63.8 Accum Deterioration 4.66%



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 nite, 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 iff: 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.

More to Learn

- Proper Offset: On if $T_{air} + Offset < T_{grain}$
- Mitigate MC content difference Top to Bottom
- Smaller Fans?
- Reversing Fans
- More sensors to get clarification "drying front"
- Larger bins > 10,000 bu
- More crops: oilseeds,
- Longer term studies: what happens in spring?

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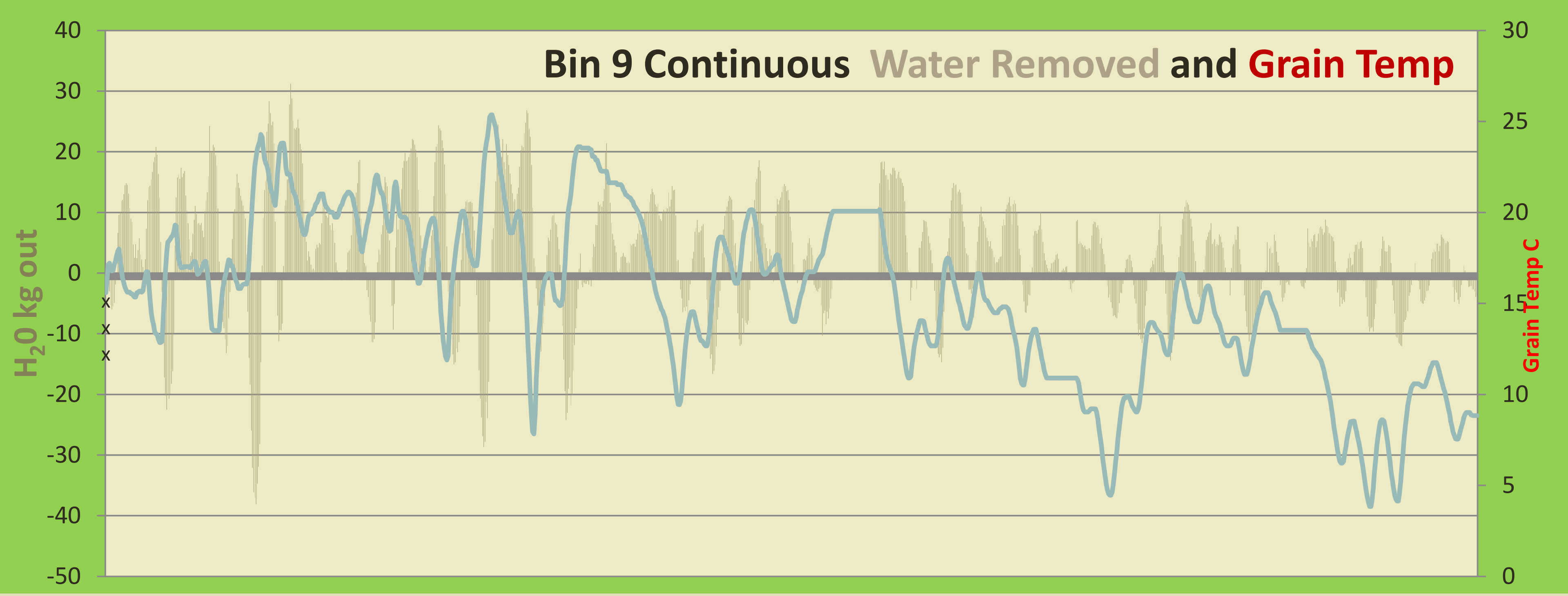
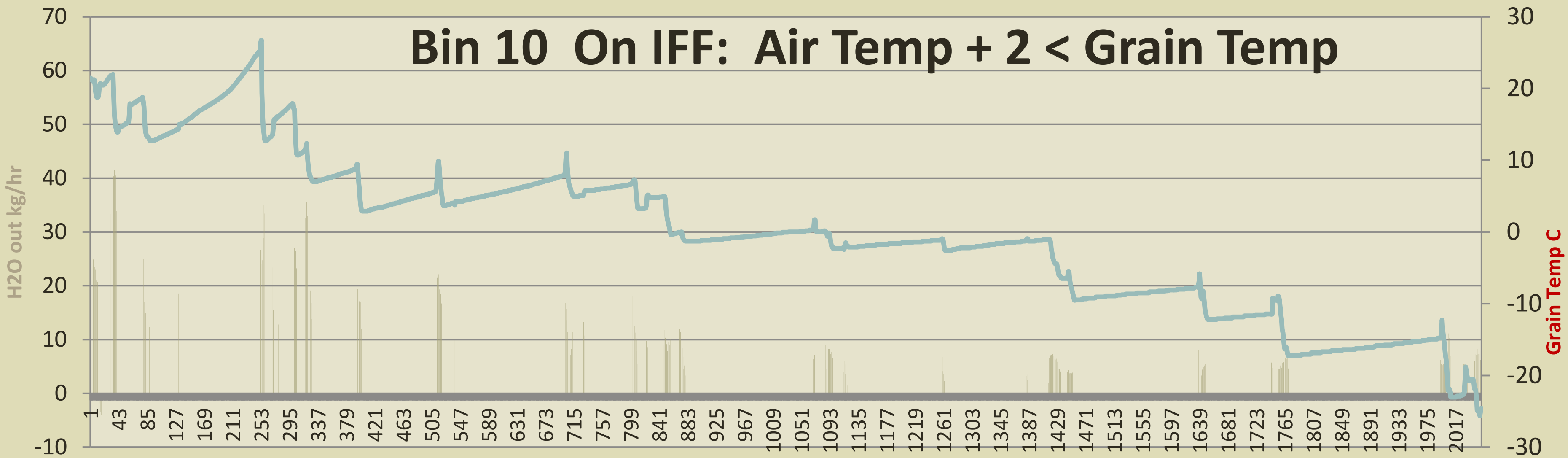
- **Agriculture and Agri-Food Canada (AAFC)**
- **Indian Head Agricultural Research Foundation(IHARF)**
- **Great West Controls - Saskatoon**



- 1200 hrs fan on -- $533 @ $0.10/kwhr
- 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 14.1° C 15.6°C/%
- Final Grain Temp: 3° 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