New Insights into Natural Aeration Grain Drying

Agri-ARM Research Update

Saskatoon Inn

Friday Jan 11, 2013 1:45 - 2:30

Ron Palmer P.Eng. Ph.D.

Indian Head Agricultural Research Foundation

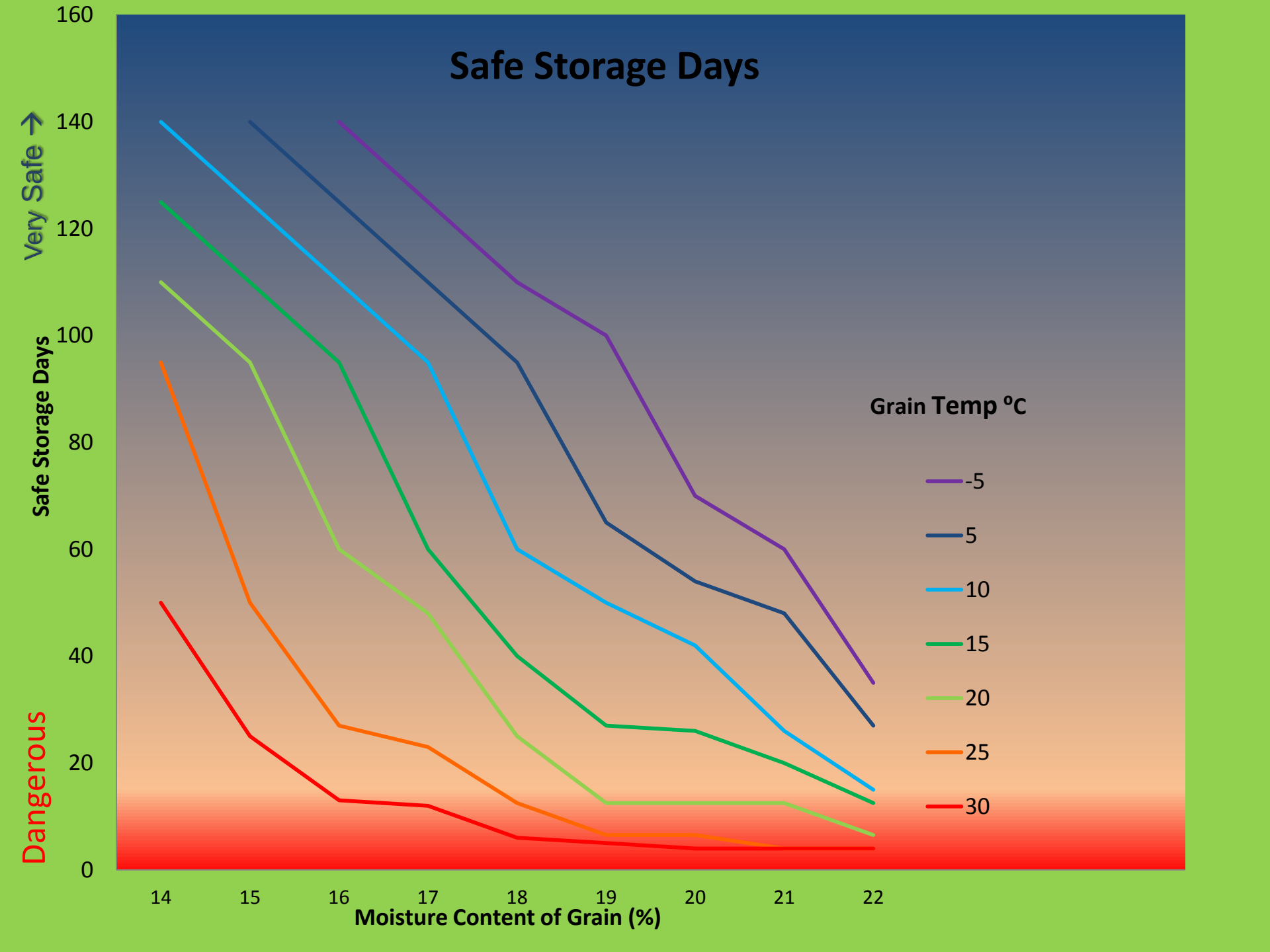
Objective

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

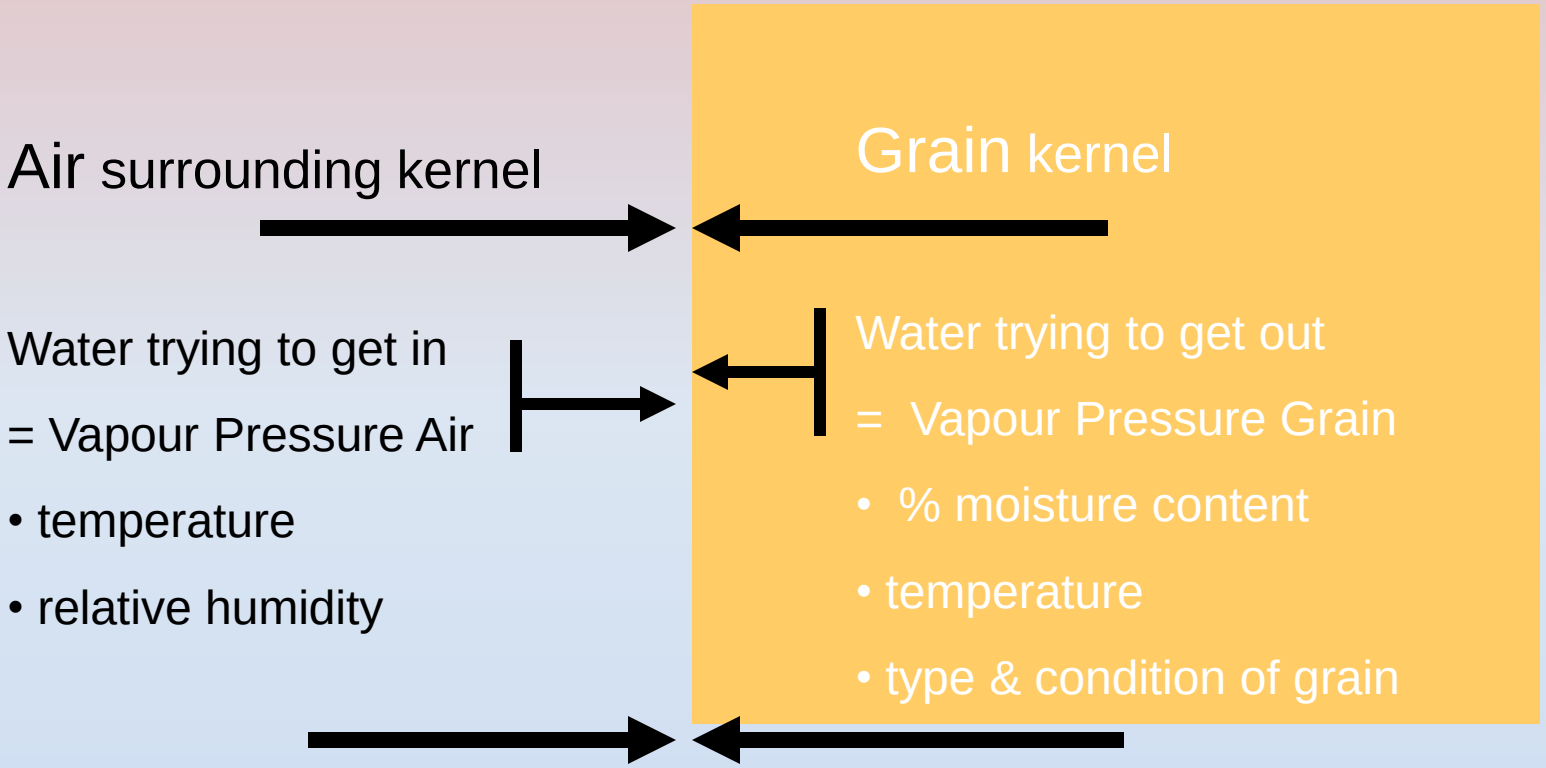
Strategy

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)

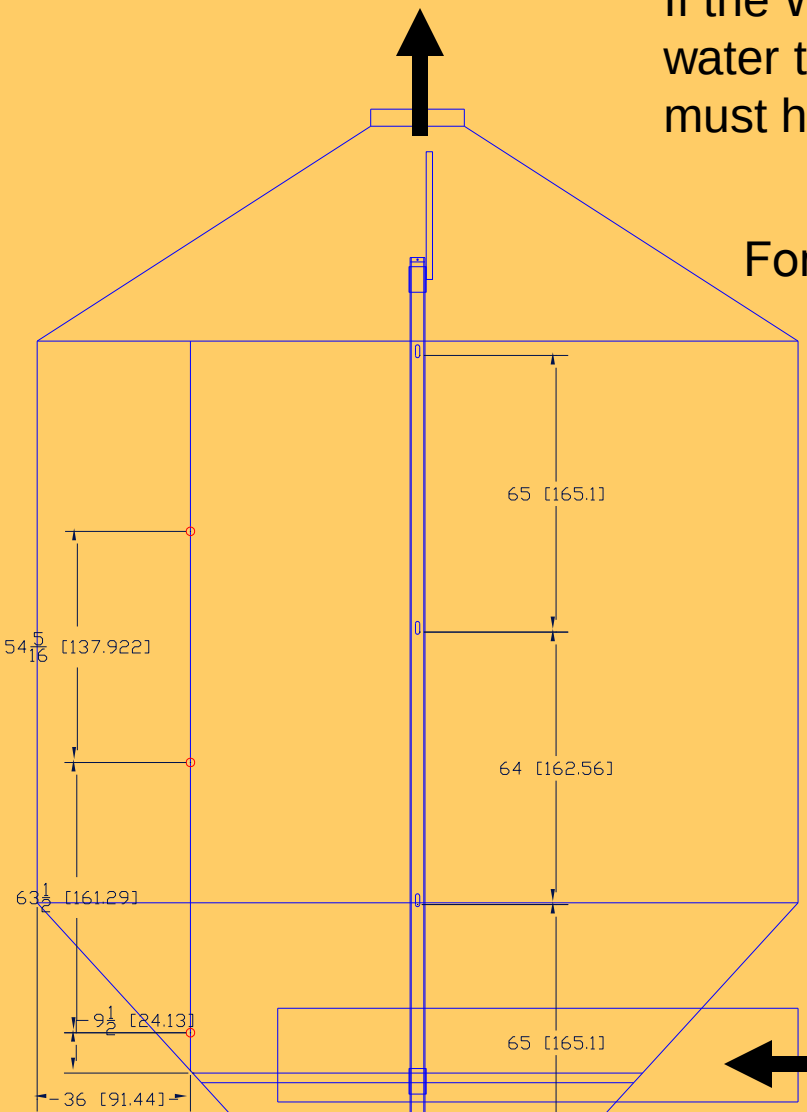
If H_2O IN > H_2O OUT then FAN OFF (wetting)

<u>lbs Water OUT – lbs Water IN = Water Removed</u>

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

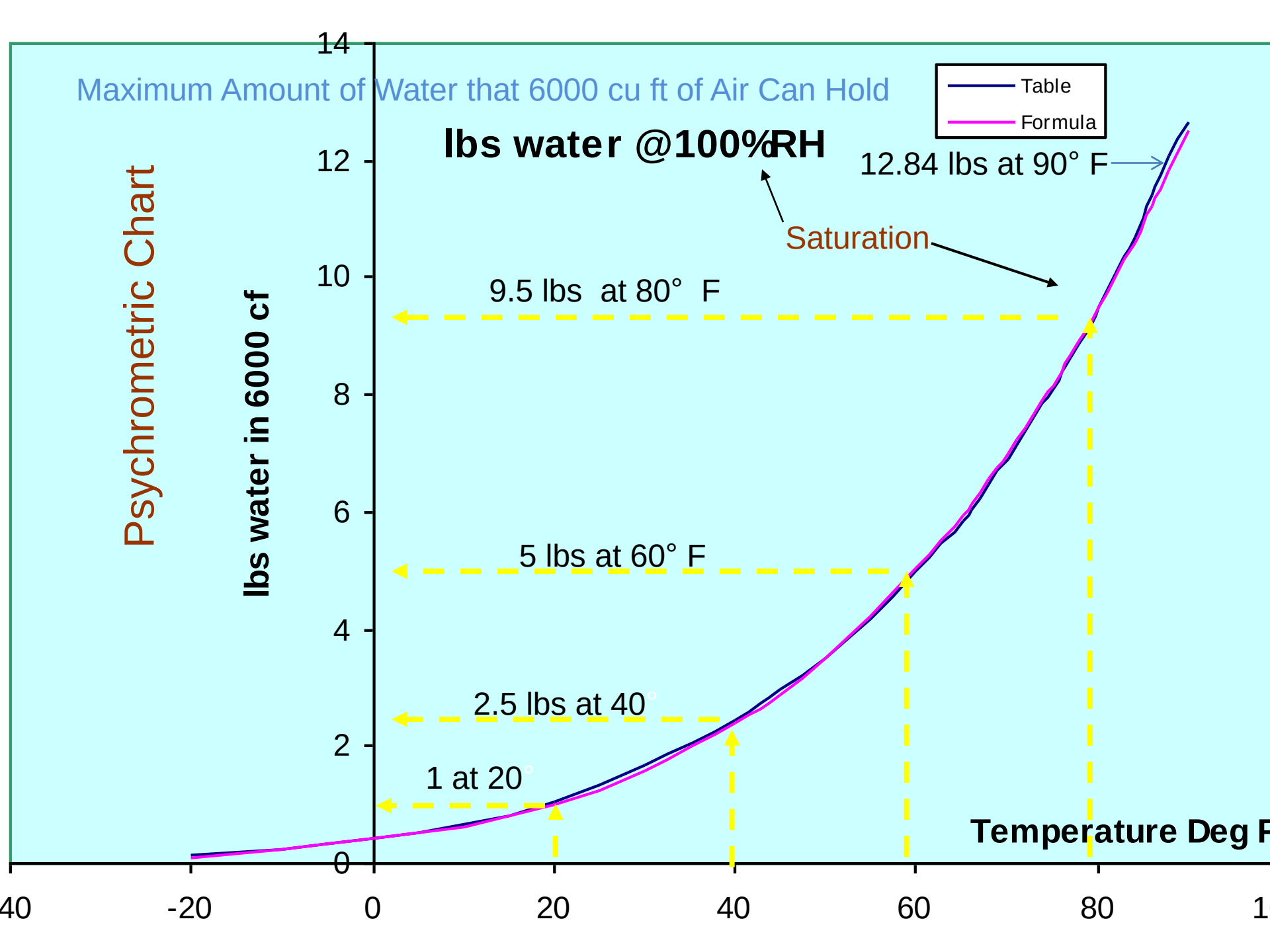
Water OUT



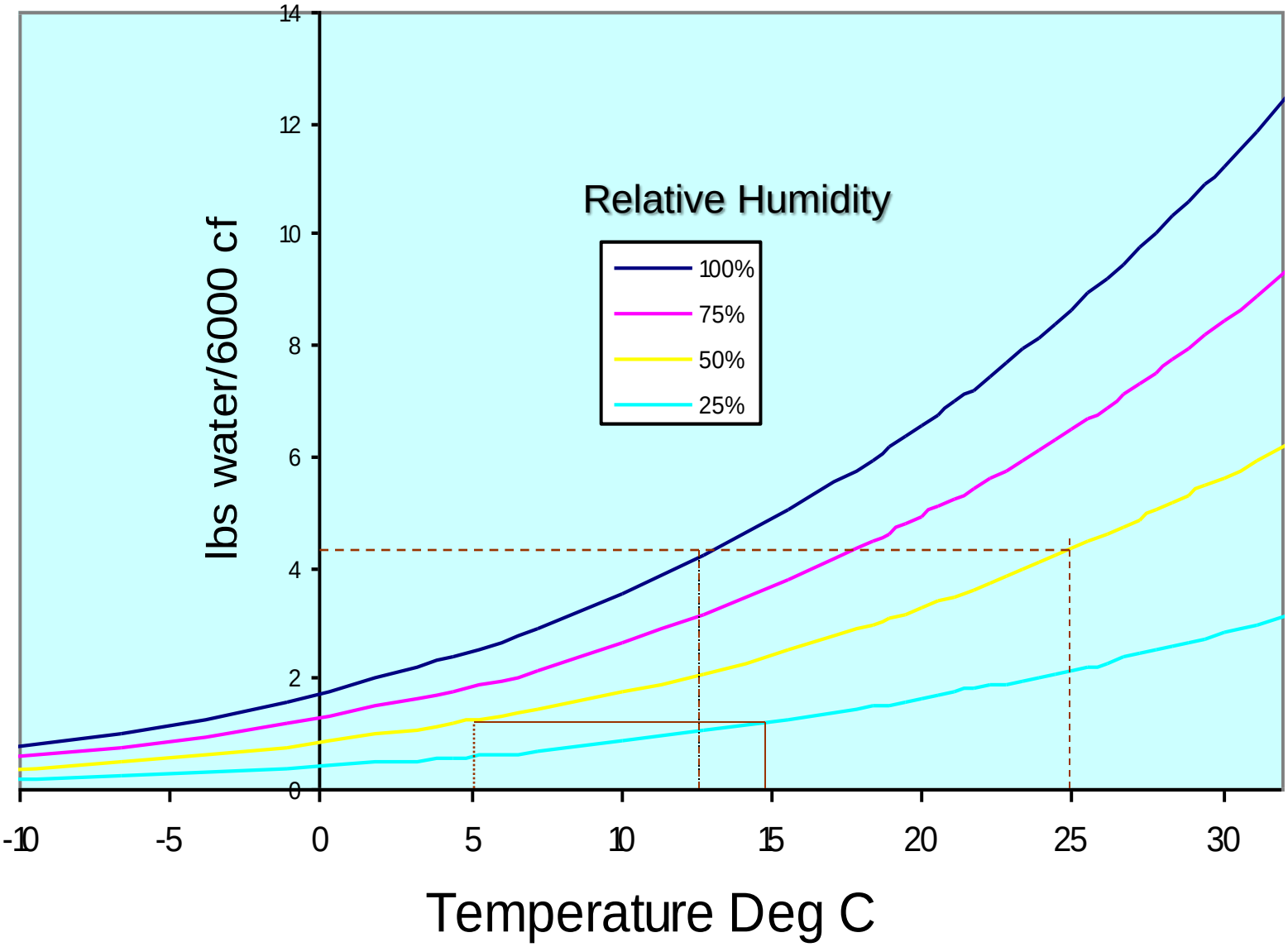
For example: let's say that in one hour we measured 80 lbs of water going into the bin and 90 lbs of water coming out. The net result is 10 lbs of water being removed from the bin. And it must have come from the grain, so we are drying.

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

Water IN (carried in by the air)

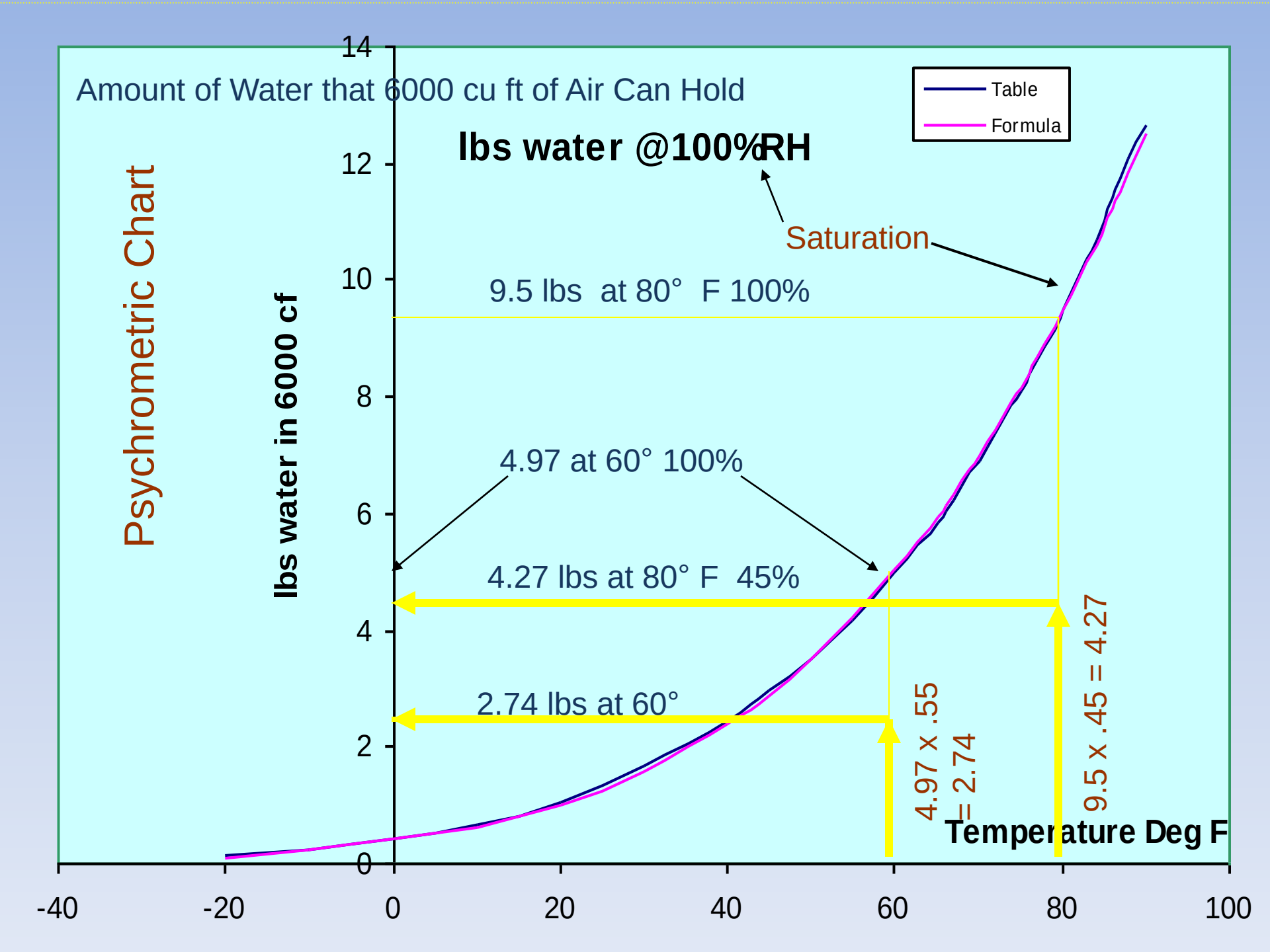

Maximum Amount of Water that 6000 cu ft of Air Can Hold
Psychrometric Chart
lbs water @100%RH
12.84 lbs at 90° F
Saturation
9.5 lbs at 80° F
5 lbs at 60° F
2.5 lbs at 40°
1 at 20°
lbs water in 6000 cf
Temperature Deg F
Table
Formula
14
12
10
8
6
4
2
0
-40
-20
0
20
40
60
80

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 going into the fan and into the bin is 60° F @ 55% RH. The air leaving the bin is 80° F @ 45% RH. Are we drying? How much?
- From the previous psychrometric chart for 6000 cu ft, 80° @ 45% = 4.27 lbs H_20 ->air
  6000 cu ft, 60° @ 55% = 2.74 lbs
- Every 2 min remove 1.53 lbs ::(drying)


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)

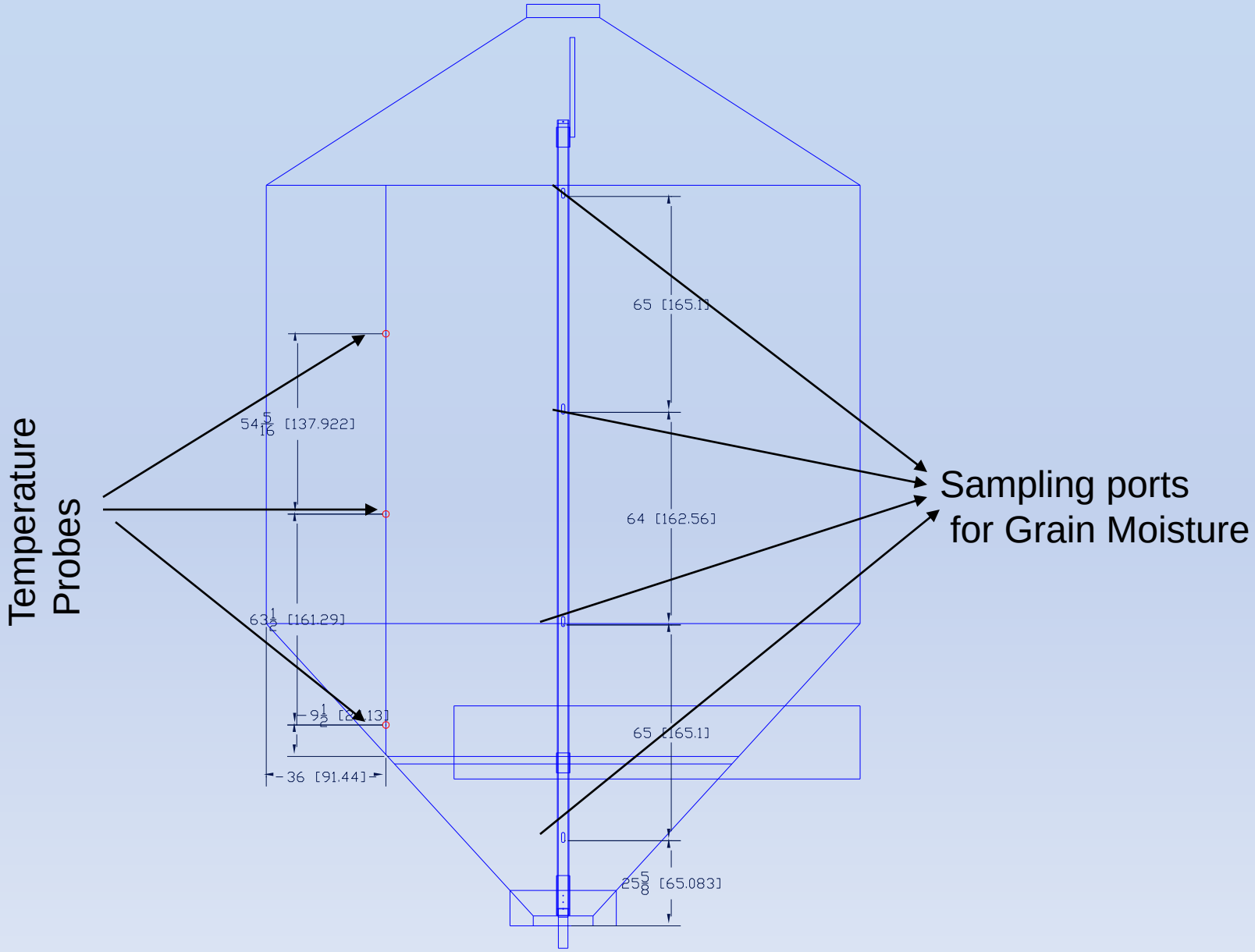
4.27 lbs > 2.74 lbs → FAN On (1.53lbs/6000)

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

What we did

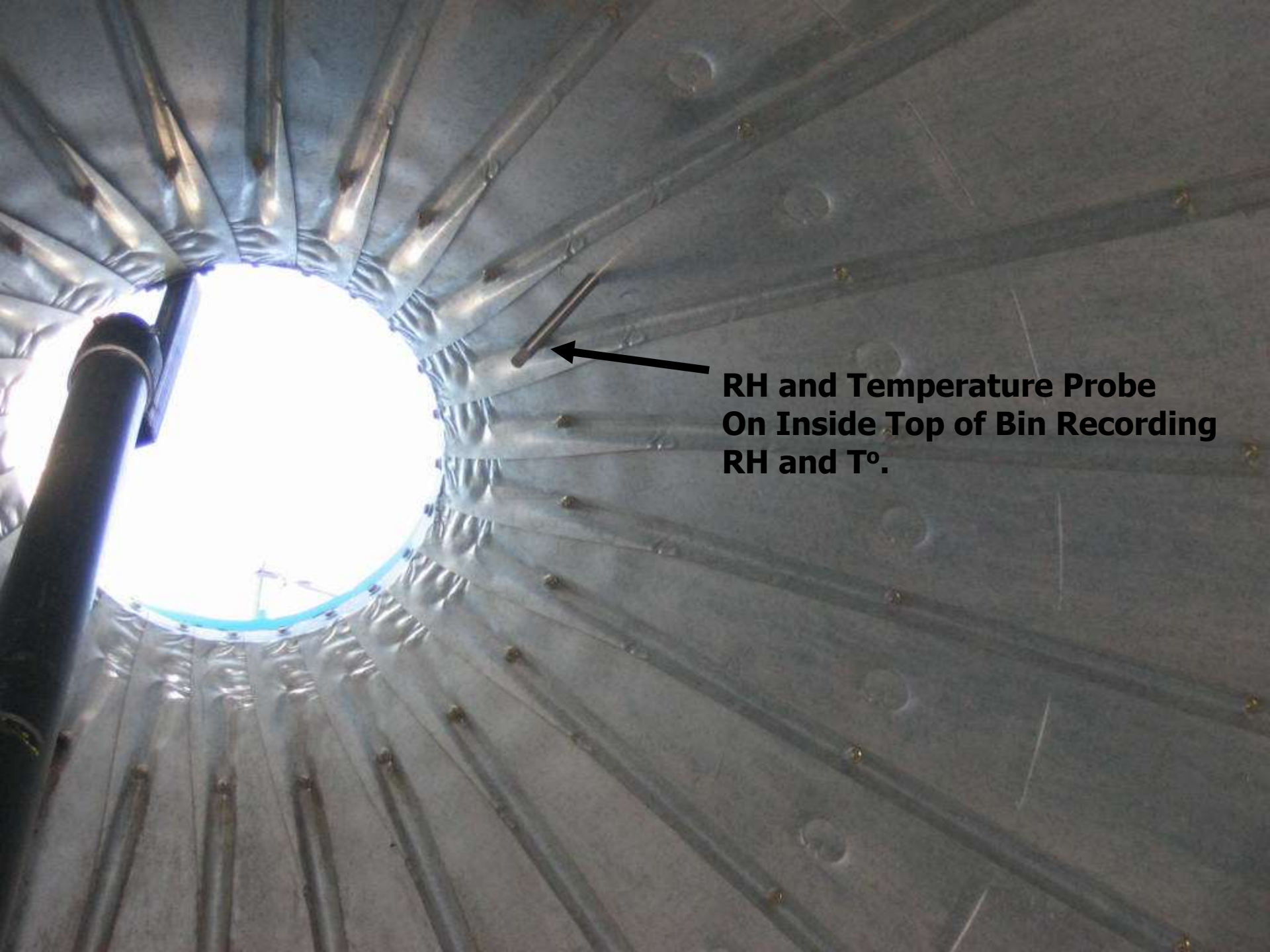
- Instrumented Two Bins and measured on an hourly basis:
  - Temp and Humidity – air in and out
  - Air Flow
  - Temp of Grain at three levels
- On a daily basis measured grain moisture at 4 levels

Have done this for 5 years with 3 different grains – peas, barley, and wheat


Temperature Probes
Sampling ports for Grain Moisture
65 [165.1]
64 [162.56]
65 [165.1]
36 [91.44]

Panel with Instruments


Air Tubes for Recording CFM

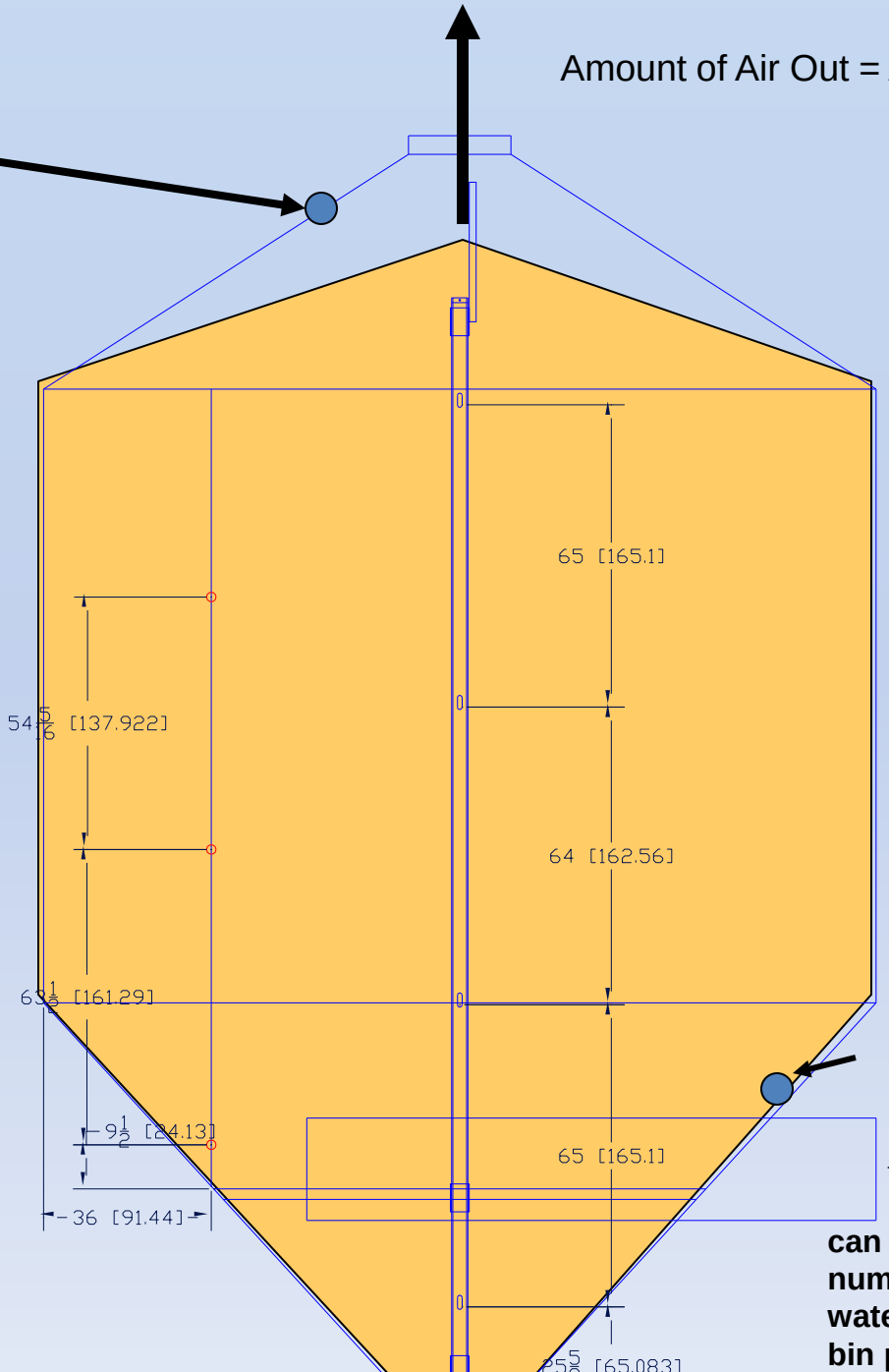

RH and Temperature Probe
On Inside Top of Bin Recording
RH and T°.

Inside the Panel

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



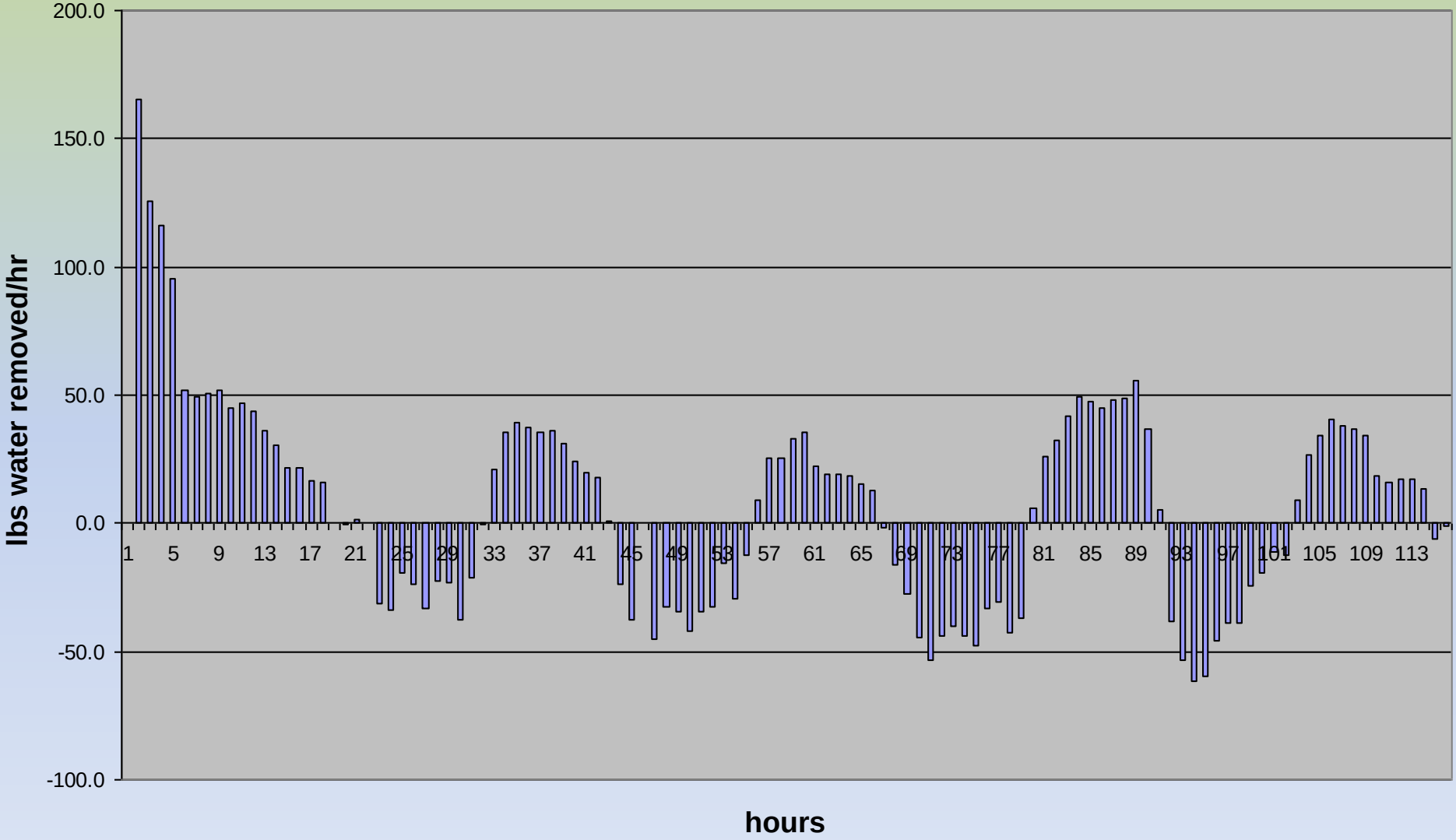
Sensor measuring T and RH of the air entering the bin

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

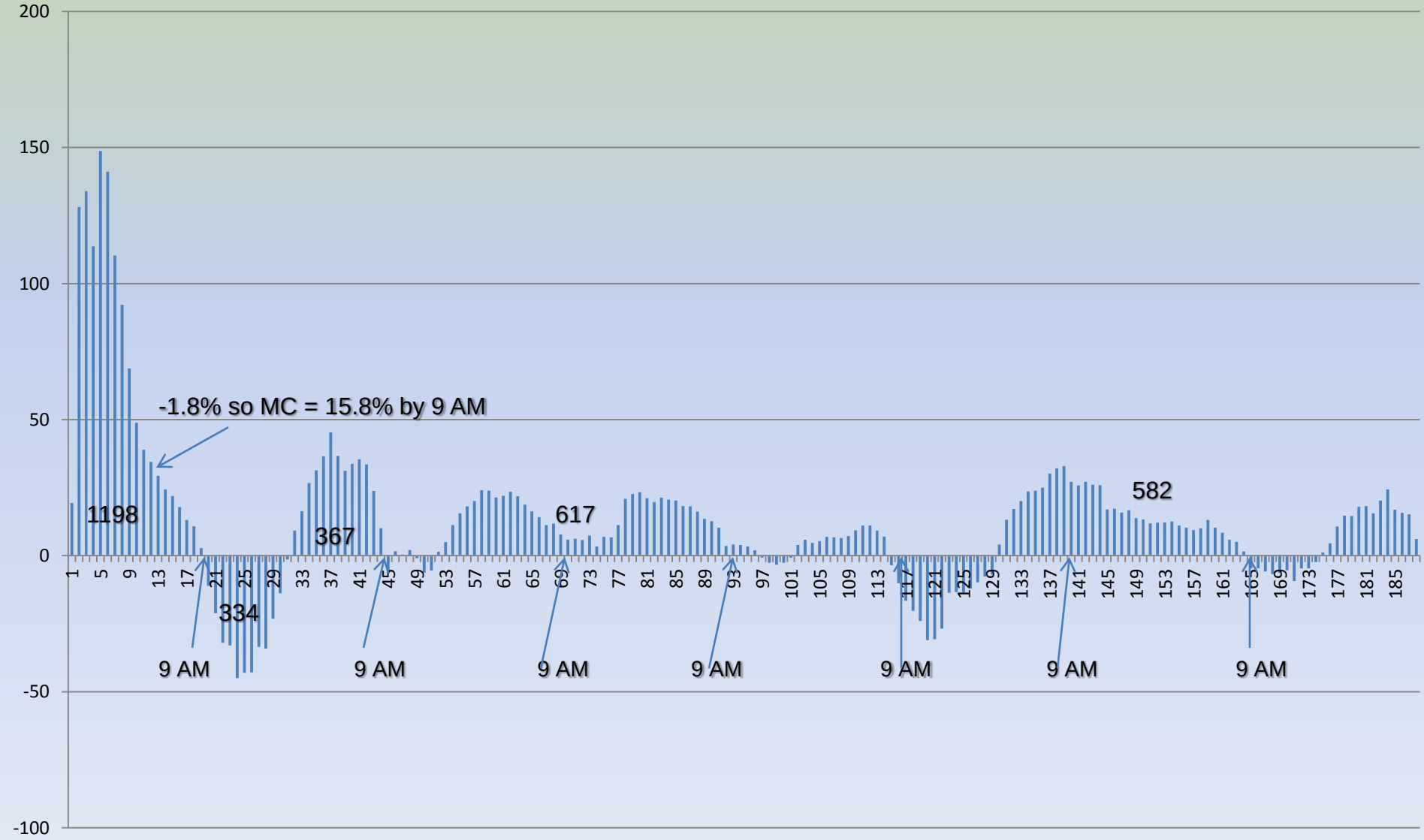
Pea Bin 10 2009



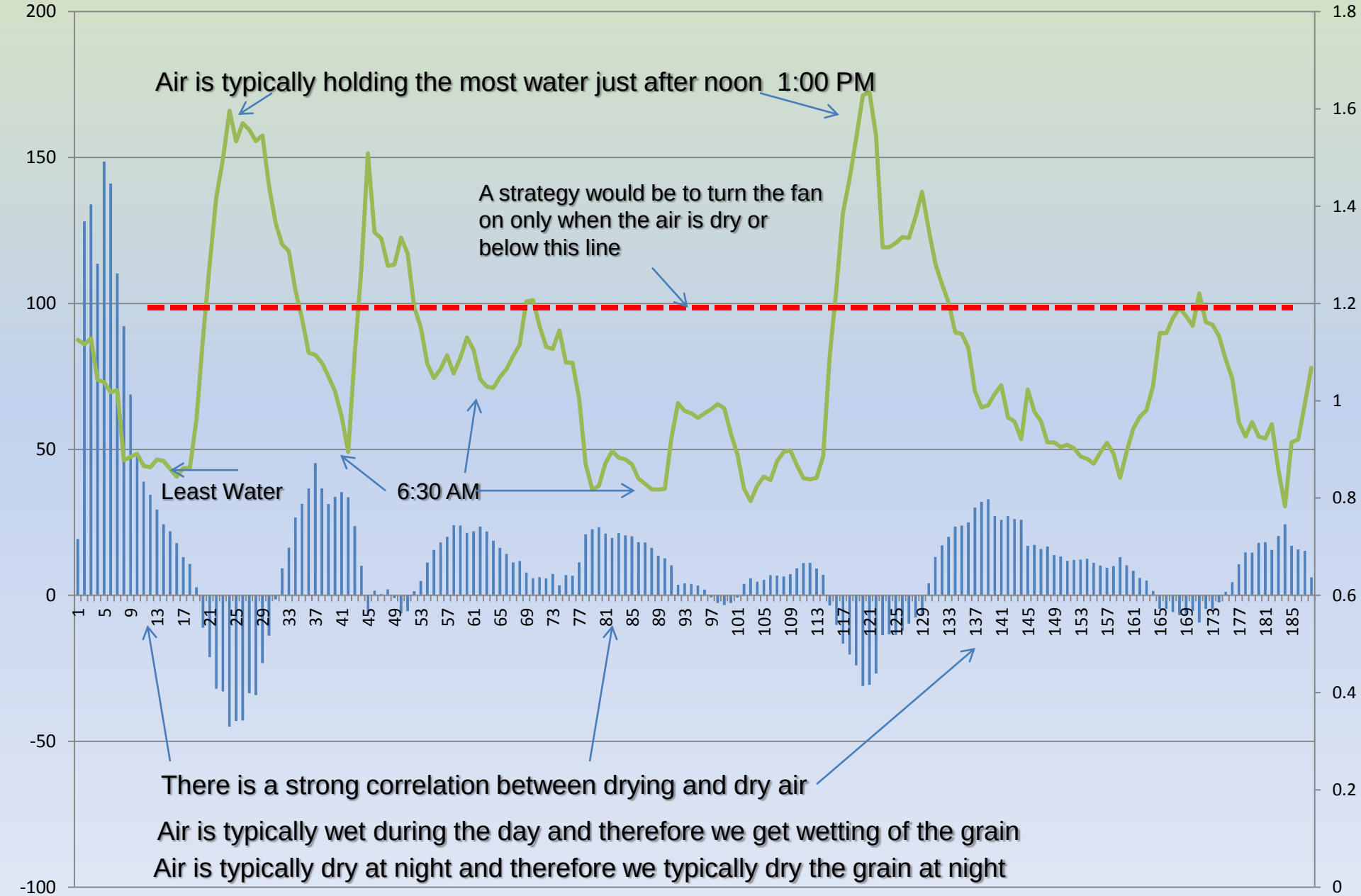
Bin 9 Wheat 17% - 13.5% Start 2:09 PM Sept 9 continuous for 190 hrs (8 days)

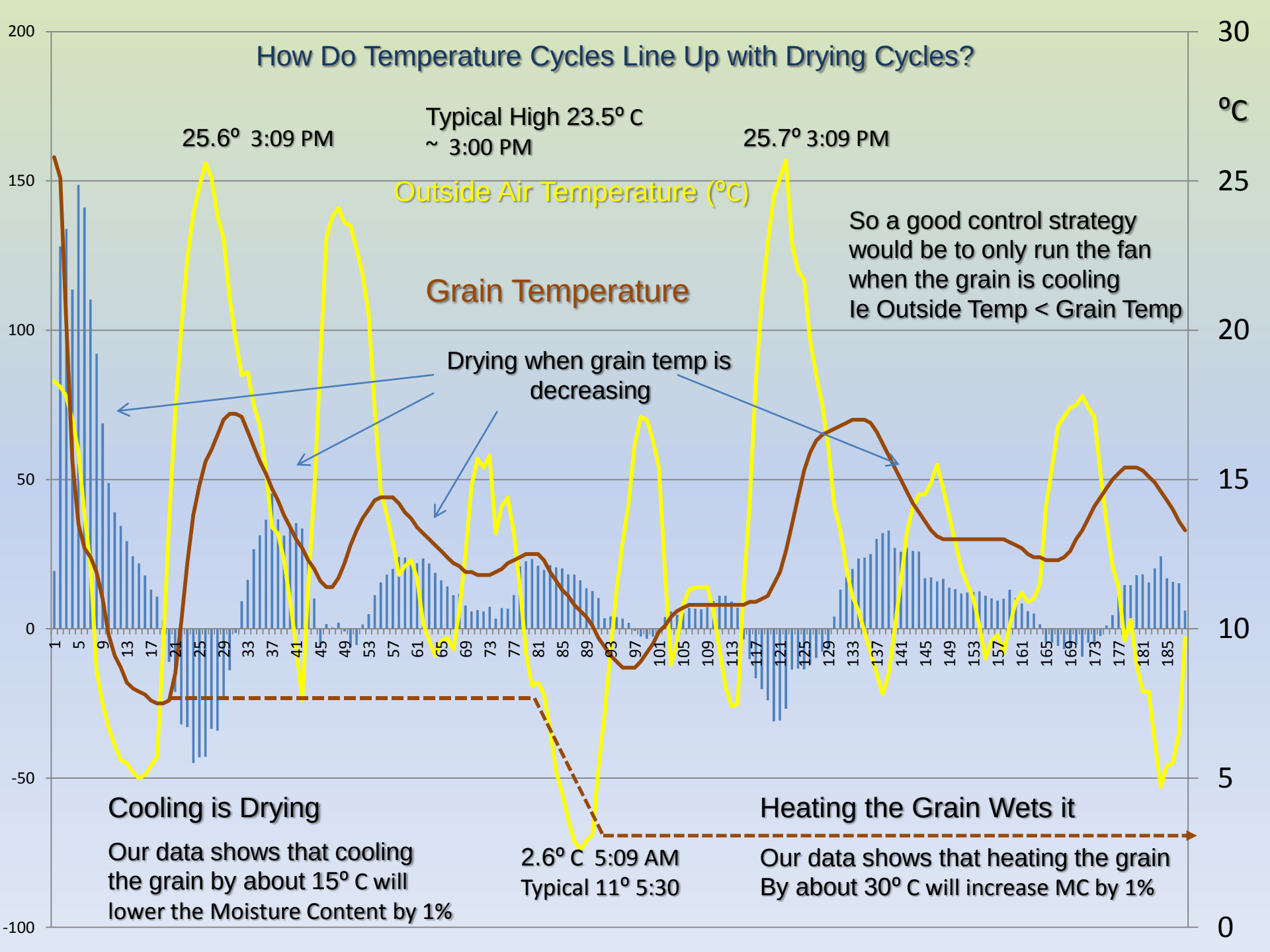
Switch from drying to wetting at 9:00 AM, -- turn the fan off at 9 in the morning

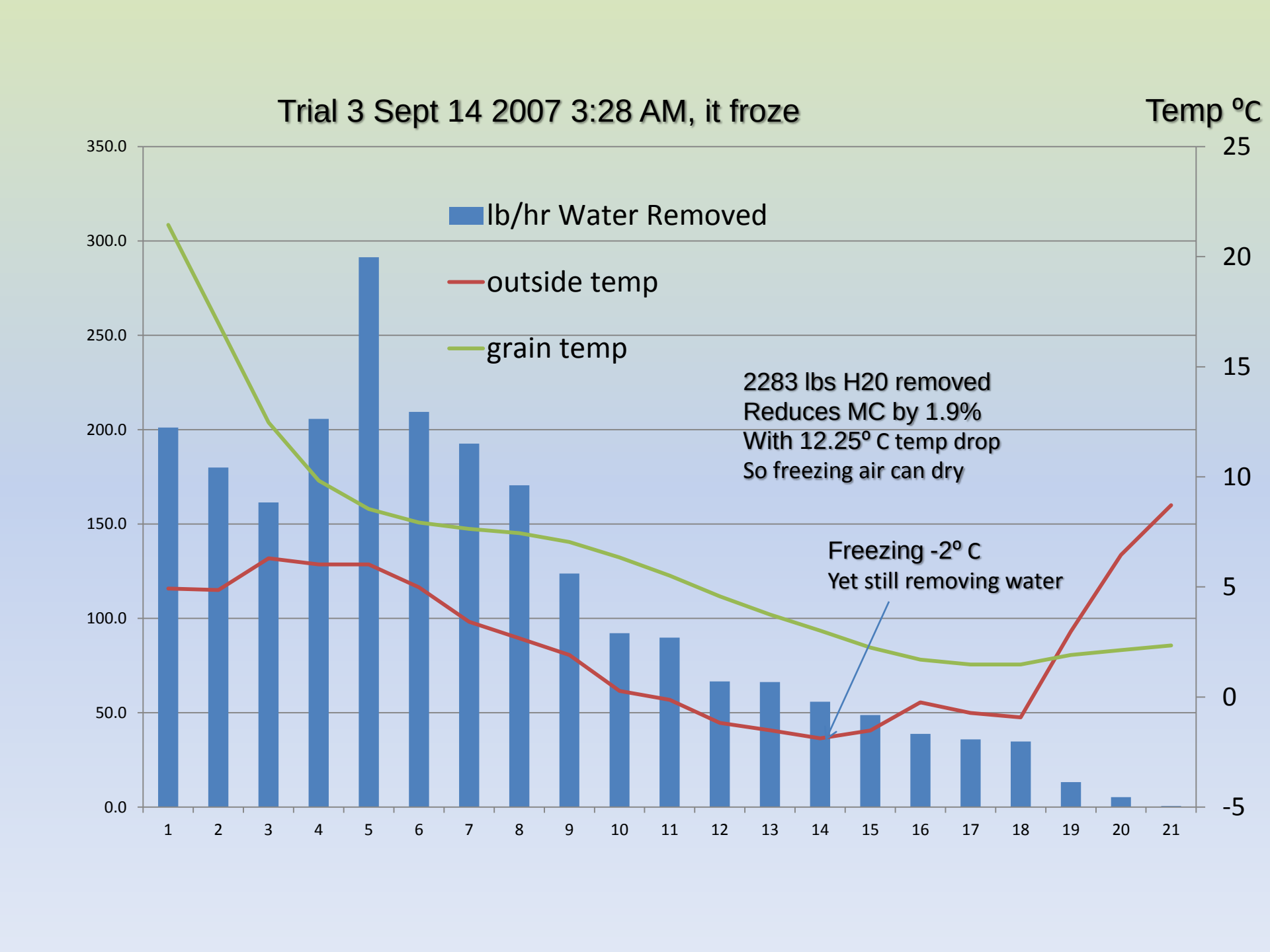
If we turned the fan on only at night for 3 days, would take 20 + 12 + 12 = 44 hrs with MC to 14.2%

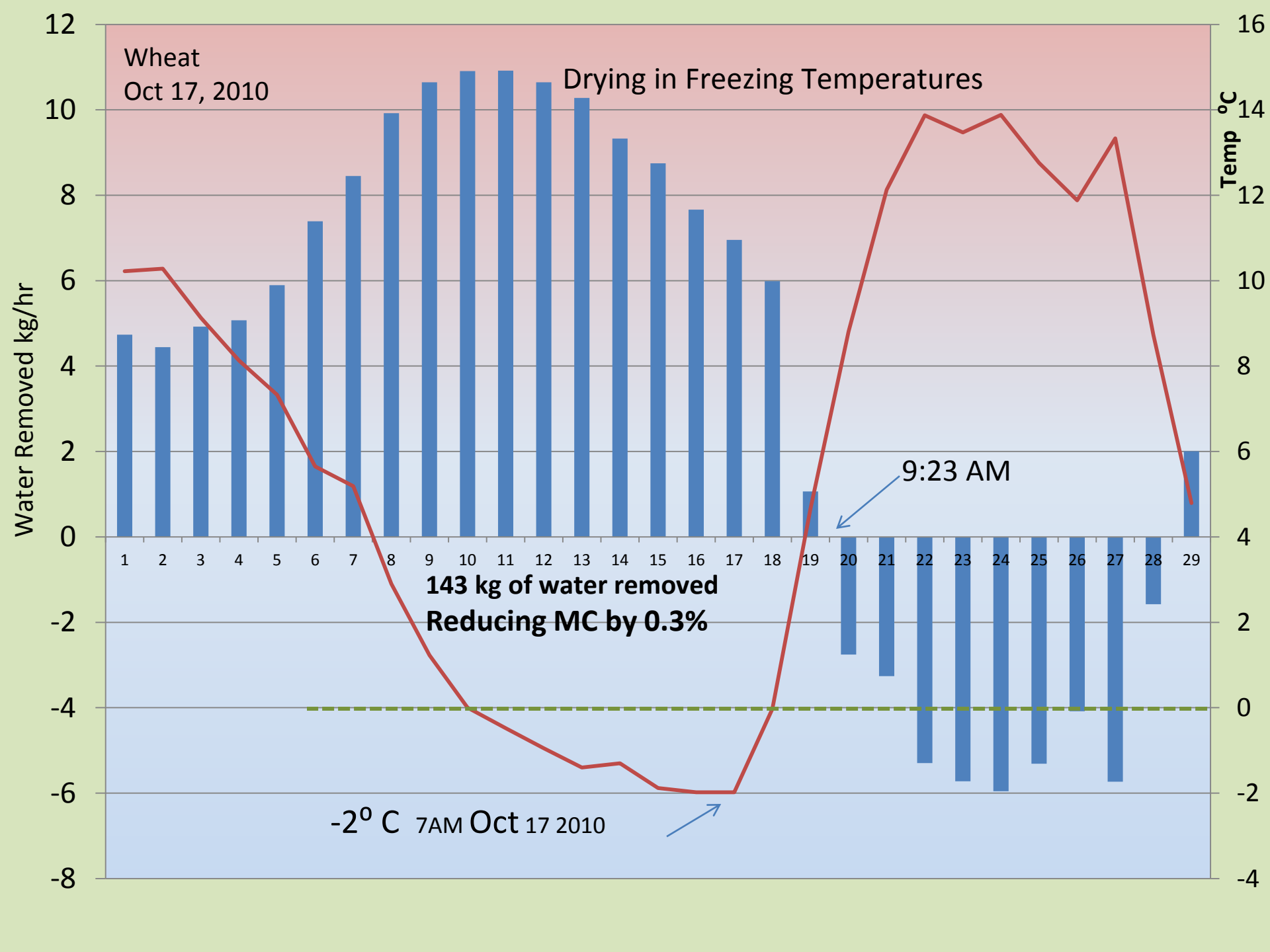


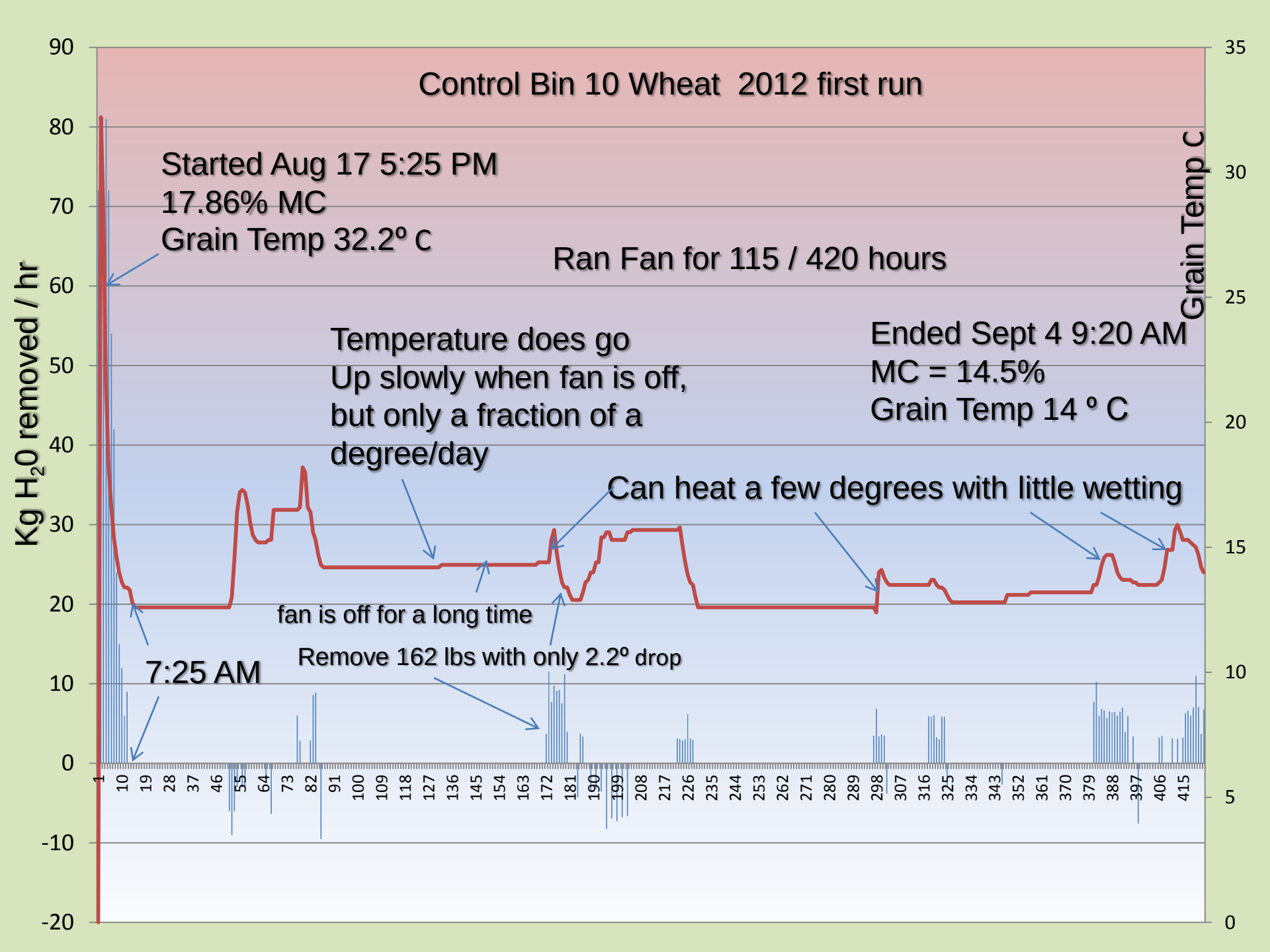
Air Wetness (how much water is in the air)$_{kg/6000cf}$

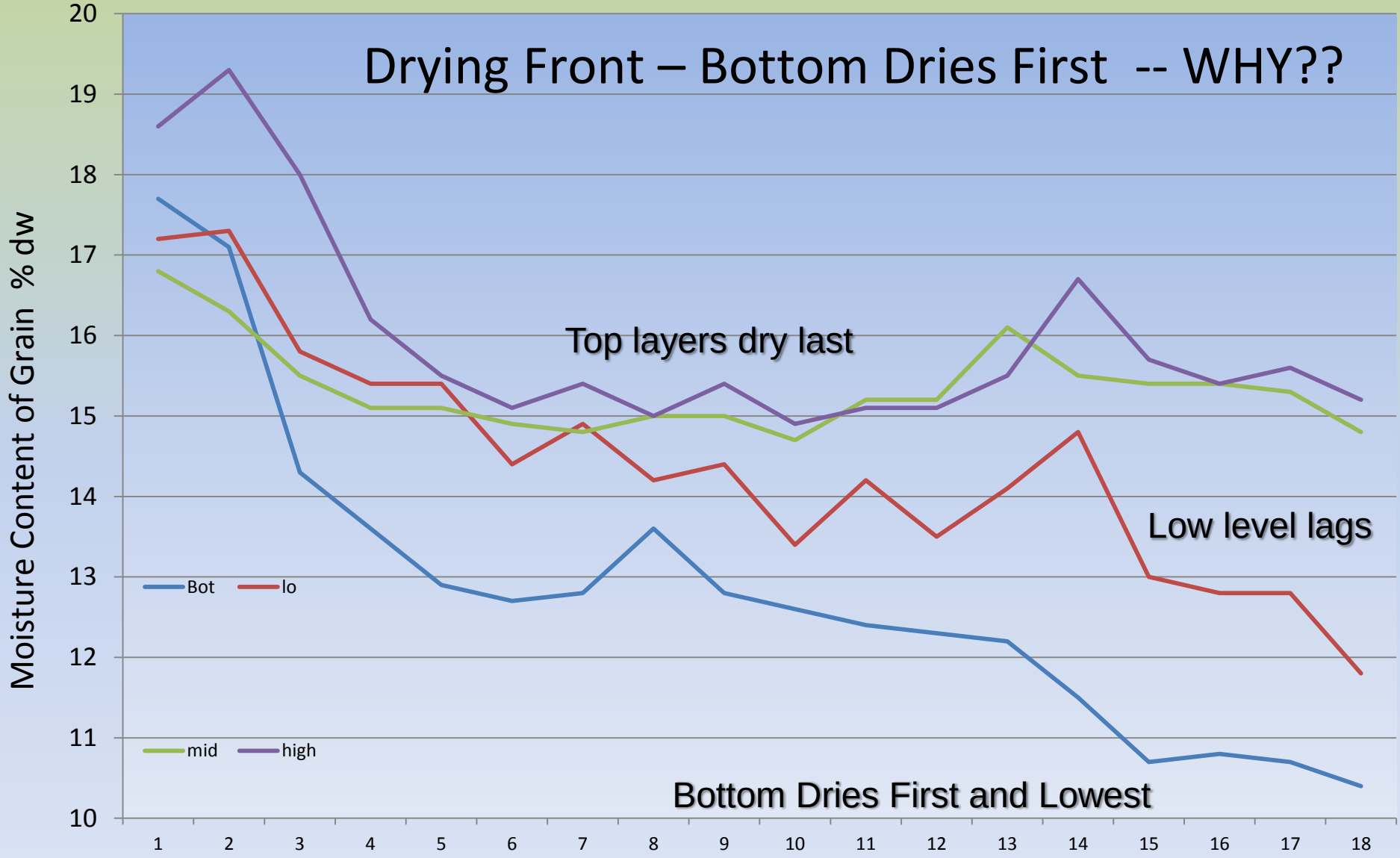



How Do Temperature Cycles Line Up with Drying Cycles?
Typical High 23.5° C
~ 3:00 PM
25.6° 3:09 PM
25.7° 3:09 PM
Outside Air Temperature (°C)
Grain Temperature
So a good control strategy would be to only run the fan when the grain is cooling
Ie Outside Temp < Grain Temp
Drying when grain temp is decreasing
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


Trial 3 Sept 14 2007 3:28 AM, it froze
Temp ºC
lb/hr Water Removed
outside temp
grain temp
2283 lbs H20 removed
Reduces MC by 1.9%
With 12.25º C temp drop
So freezing air can dry
Freezing -2º C
Yet still removing water
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
25
20
15
10
5
0
-5
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21


Wheat
Oct 17, 2010
Drying in Freezing Temperatures
Water Removed kg/hr
Temp °C
12
10
8
6
4
2
0
-2
-4
-6
-8
16
14
12
10
8
6
4
2
0
-2
-4
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
9:23 AM
143 kg of water removed
Reducing MC by 0.3%
-2° C 7AM Oct 17 2010


Control Bin 10 Wheat 2012 first run
Started Aug 17 5:25 PM
17.86% MC
Grain Temp 32.2º C
Ran Fan for 115 / 420 hours
Temperature does go
Up slowly when fan is off,
but only a fraction of a
degree/day
Ended Sept 4 9:20 AM
MC = 14.5%
Grain Temp 14 º C
Can heat a few degrees with little wetting
fan is off for a long time
Remove 162 lbs with only 2.2º drop
7:25 AM
Kg H20 removed / hr
Grain Temp C
90
80
70
60
50
40
30
20
10
0
-10
-20
35
30
25
20
15
10
5
0
1
10
19
28
37
46
55
64
73
82
91
100
109
118
127
136
145
154
163
172
181
190
199
208
217
226
235
244
253
262
271
280
289
298
307
316
325
334
343
352
361
370
379
388
397
406
415


Drying Front – Bottom Dries First -- WHY??
Moisture Content of Grain % dw
20
19
18
17
16
15
14
13
12
11
10
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Top layers dry last
Low level lags
Bottom Dries First and Lowest
Bot
lo
mid
high

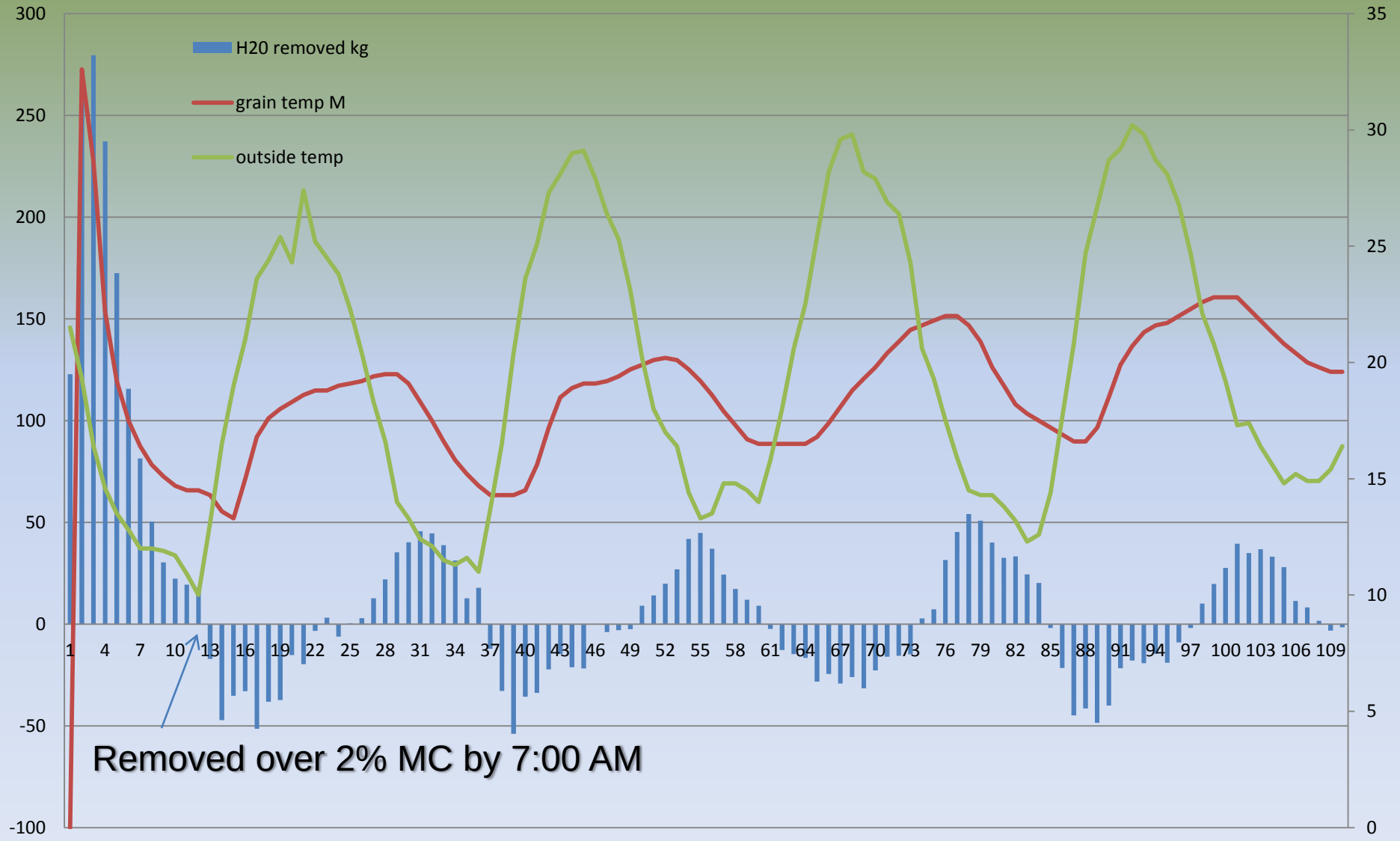
Best Control

- 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 < Grain Temp**
- OR: Drive the temp of the grain down as far as you can.

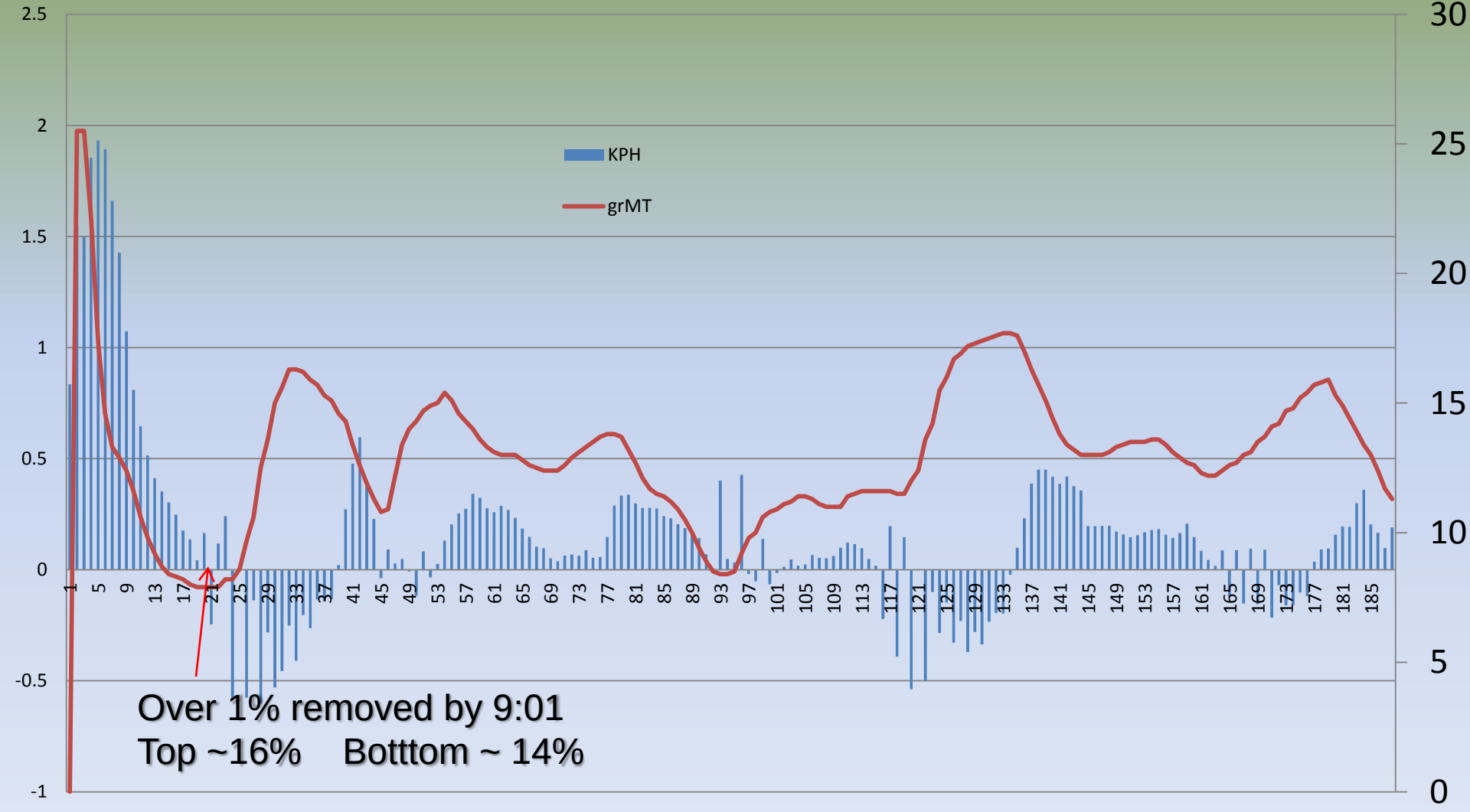
What have we learned from the data!

- 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 1.0%. 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
- 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!

9Sep4 2012 Start Aug 17 19:35 16.86% 32°C
Stop Aug22 13.63% 19.6°C



10wheat2100 start Sep13 14:25 16.25% 25.5°C
stop Sep21 9:01 13.6% 11.2°C



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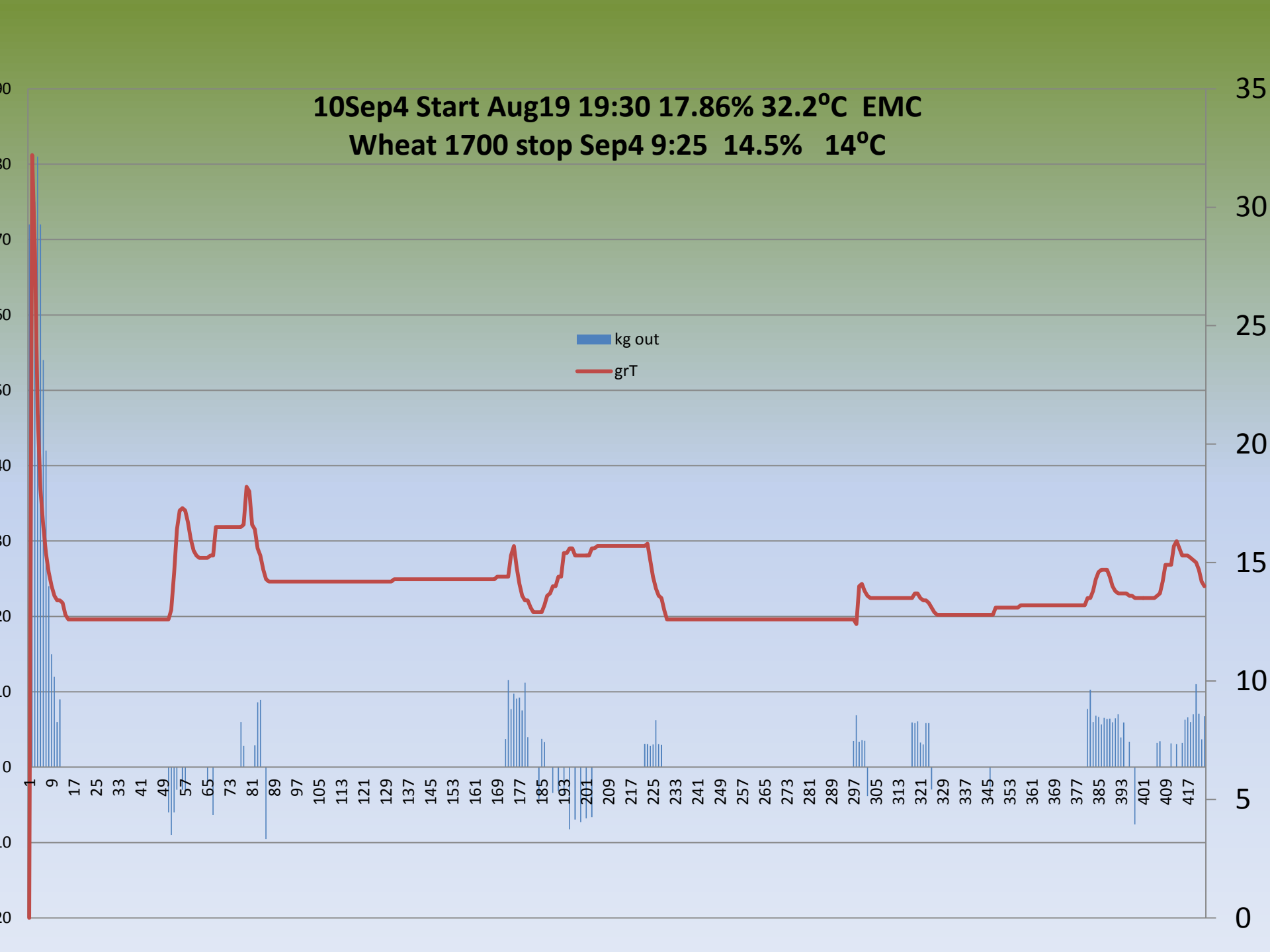
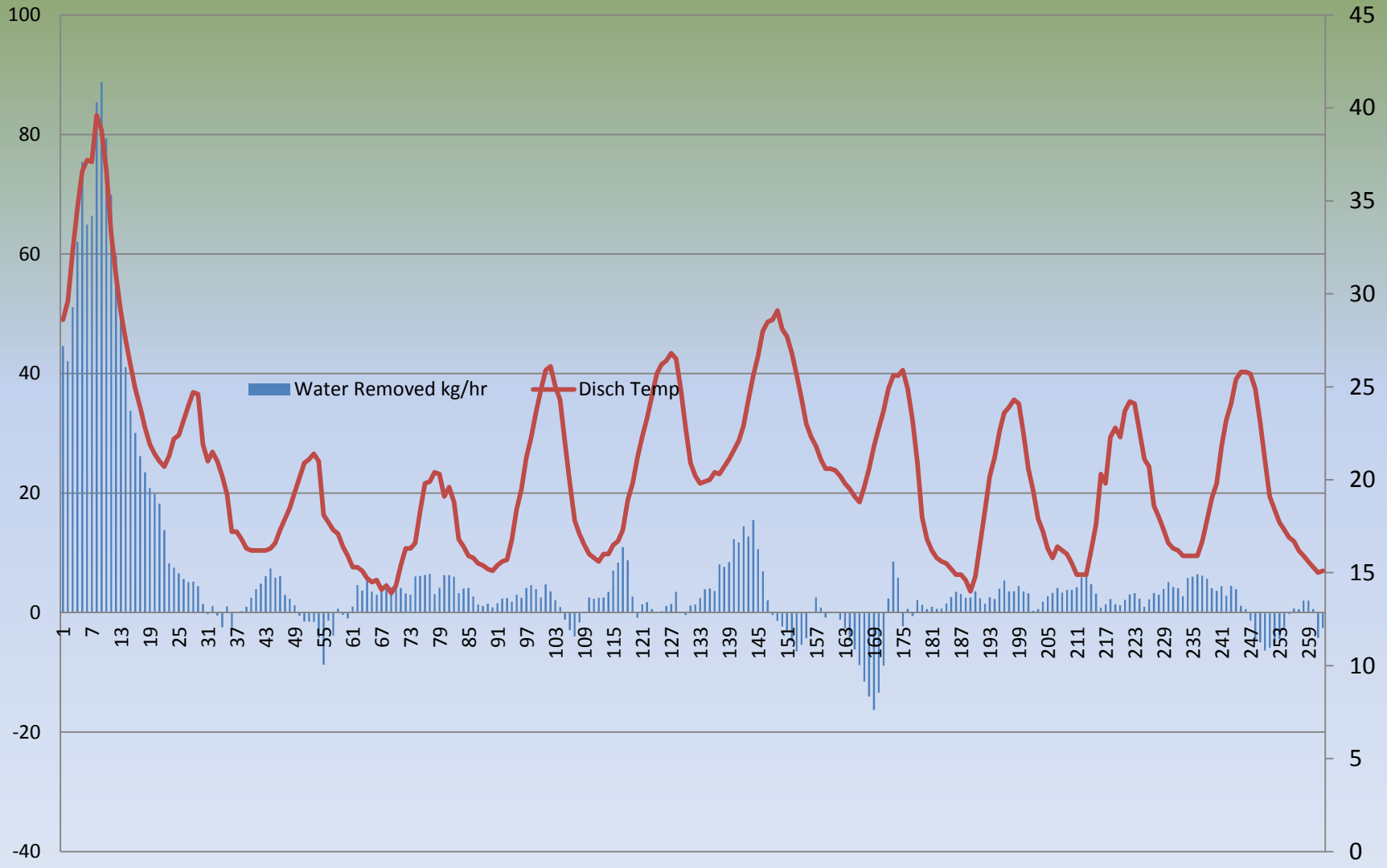
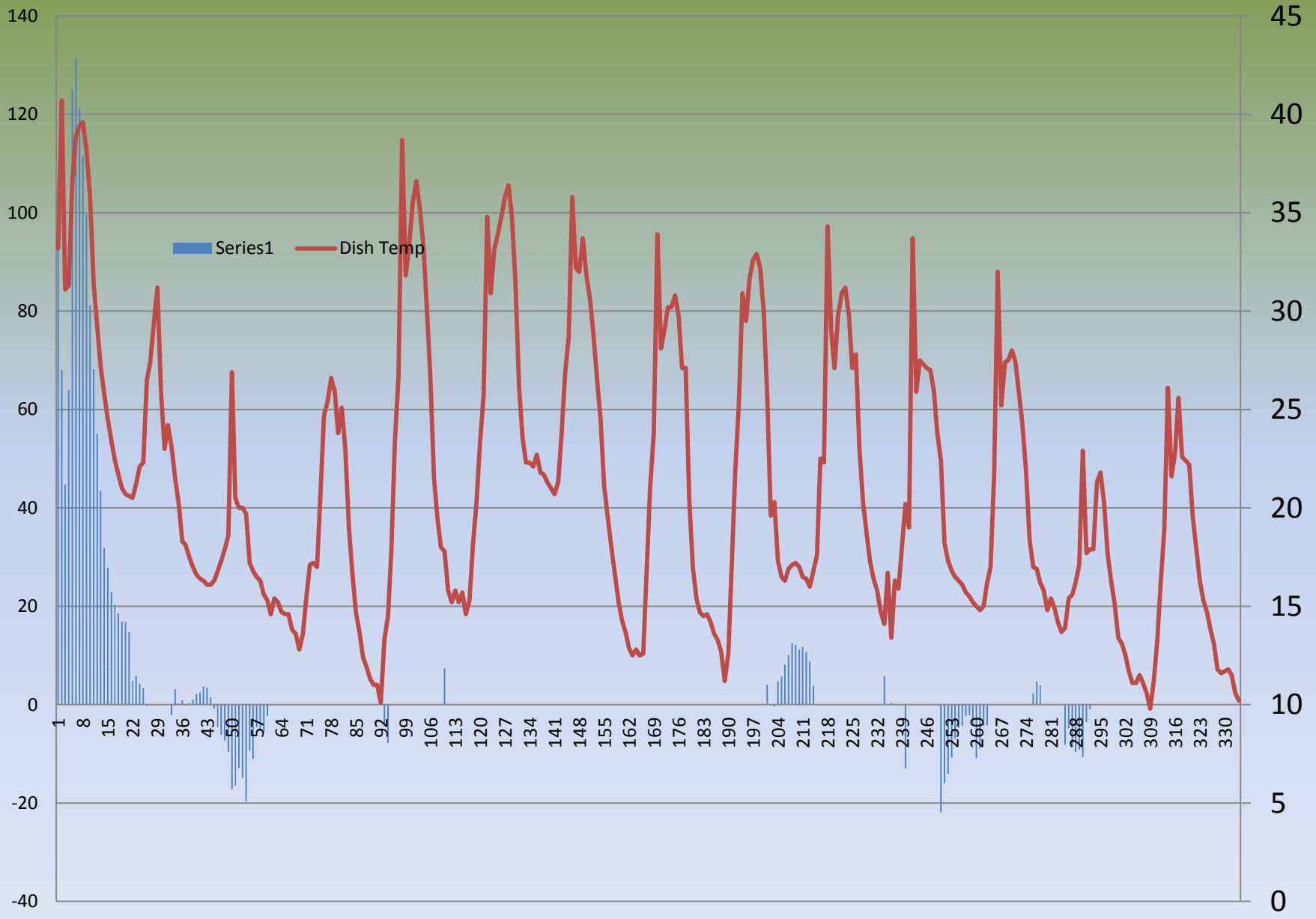
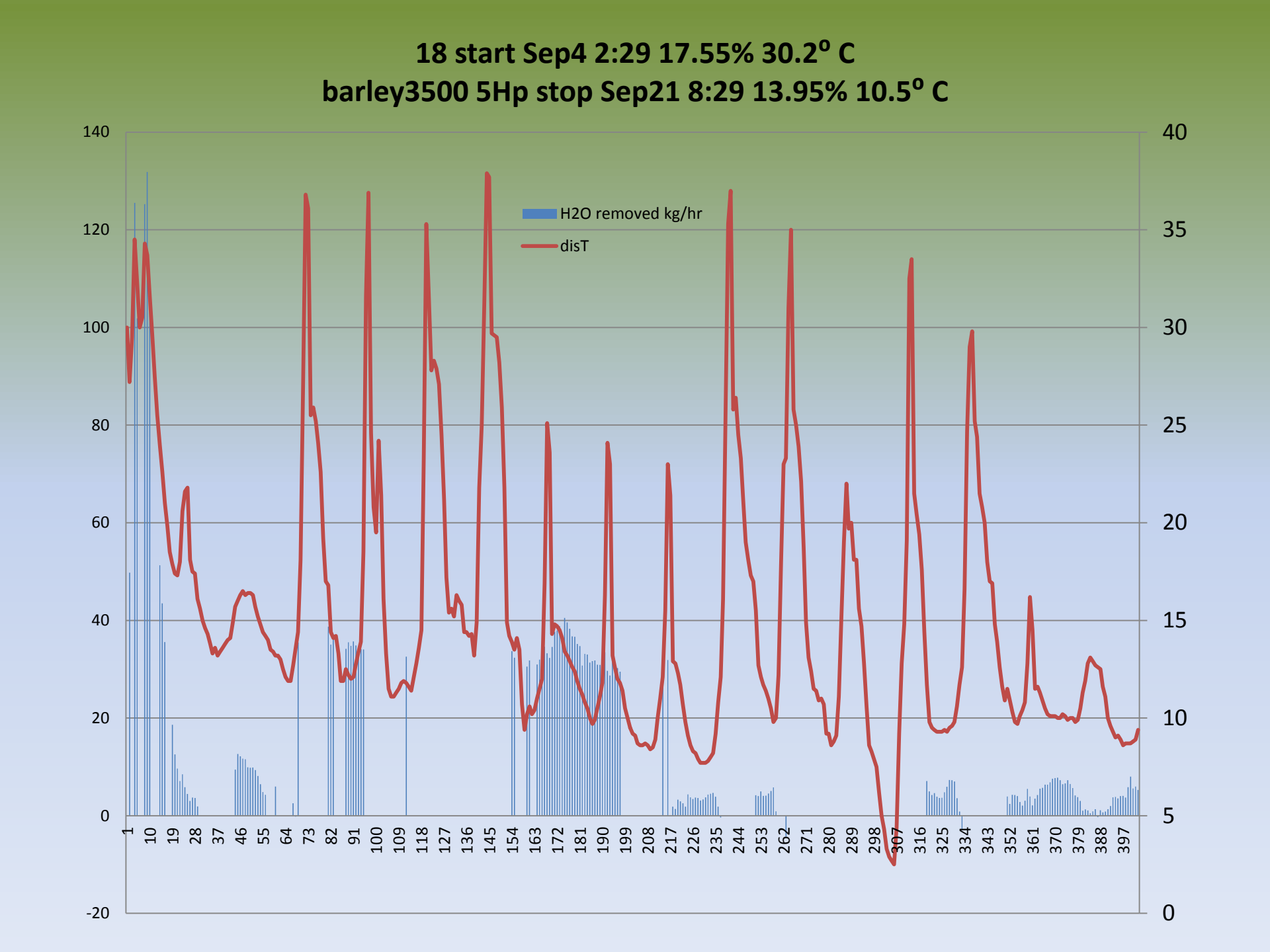

10Sep4 Start Aug19 19:30 17.86% 32.2°C EMC
Wheat 1700 stop Sep4 9:25 14.5% 14°C
kg out
grT
35
30
25
20
15
10
5
0
1
9
17
25
33
41
49
57
65
73
81
89
97
105
113
121
129
137
145
153
161
169
177
185
193
201
209
217
225
233
241
249
257
265
273
281
289
297
305
313
321
329
337
345
353
361
369
377
385
393
401
409
417

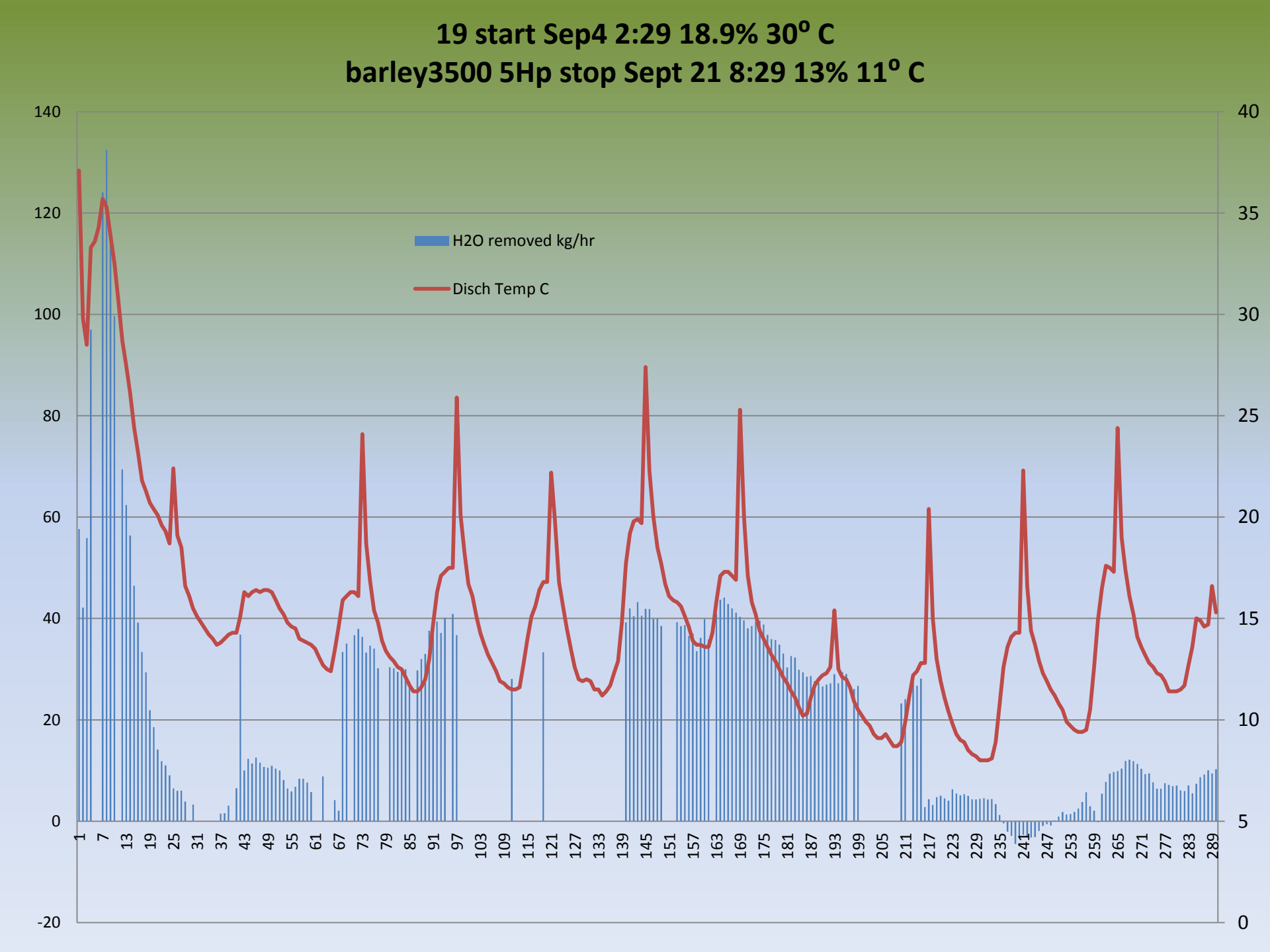
16 start Aug23 10:05 17.5% 29°C
barley3500 stop Sep3 7:30 12.56% 15°C

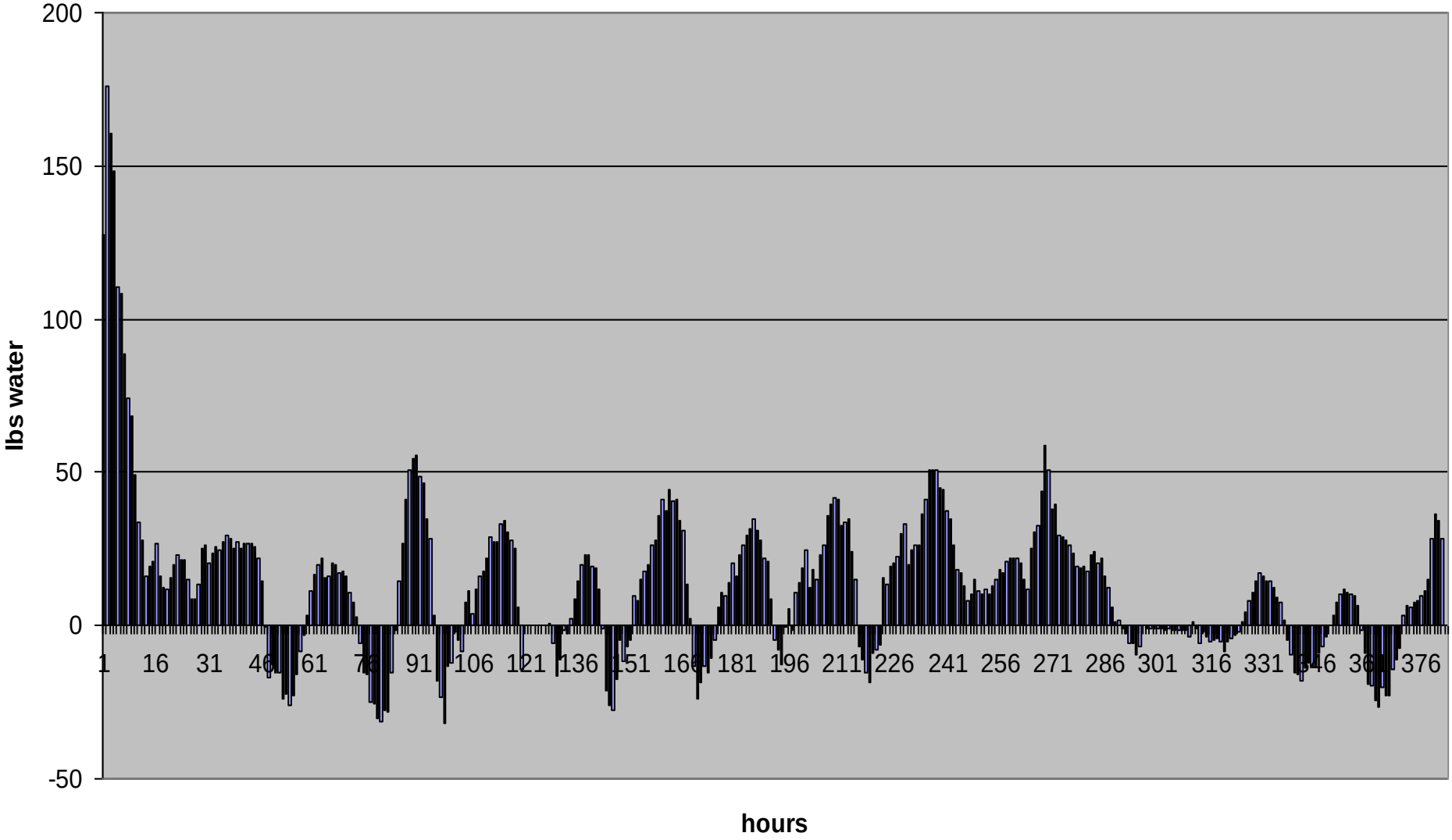


17 start Aug 23 10:05 18.8% 33.2° C
Barley3500 stop Sep7 7:05 14.1% 10.2°C

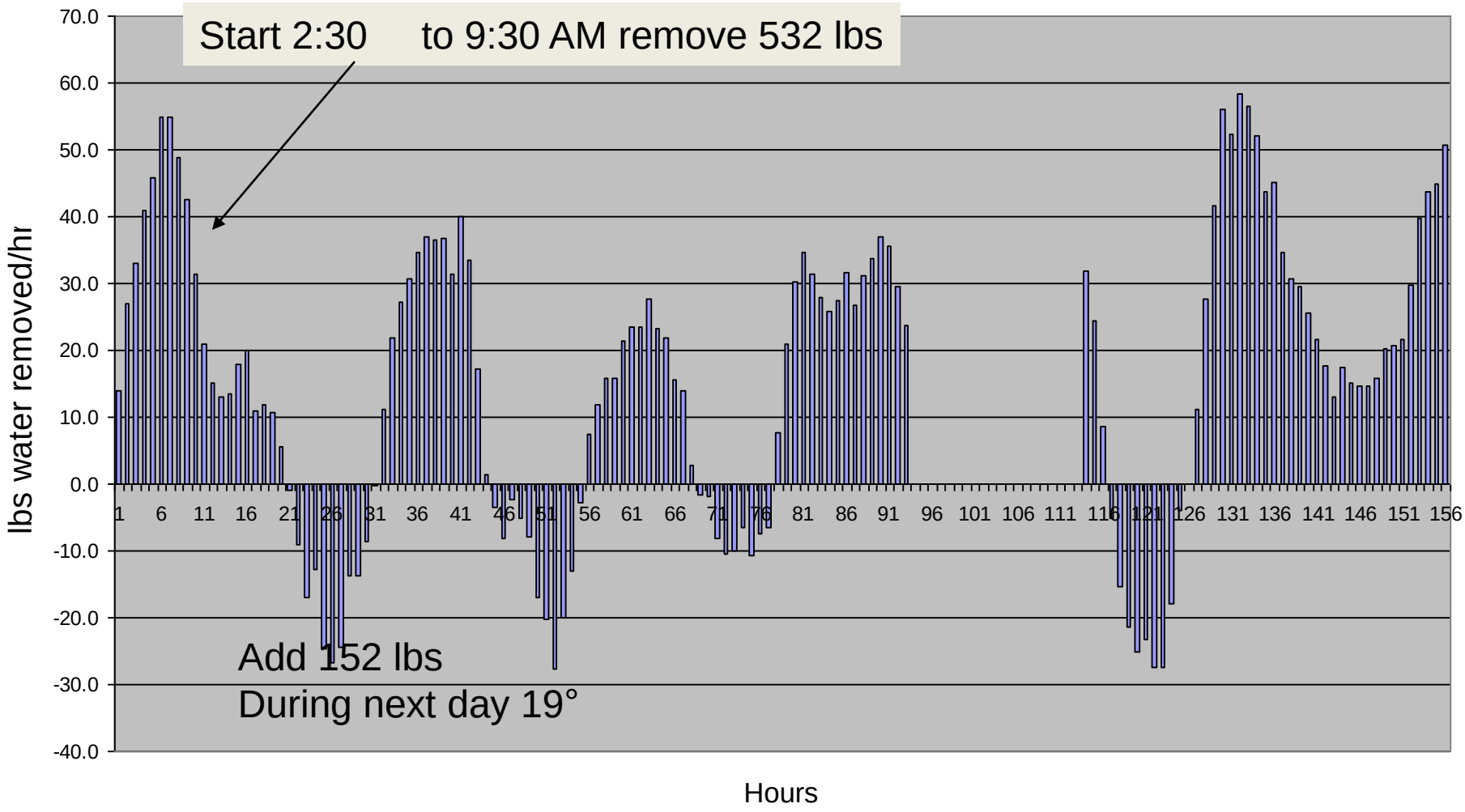



18 start Sep4 2:29 17.55% 30.2° C
barley3500 5Hp stop Sep21 8:29 13.95% 10.5° C
H2O removed kg/hr
disT
140
120
100
80
60
40
20
0
-20
40
35
30
25
20
15
10
5
0
1
10
19
28
37
46
55
64
73
82
91
100
109
118
127
136
145
154
163
172
181
190
199
208
217
226
235
244
253
262
271
280
289
298
307
316
325
334
343
352
361
370
379
388
397

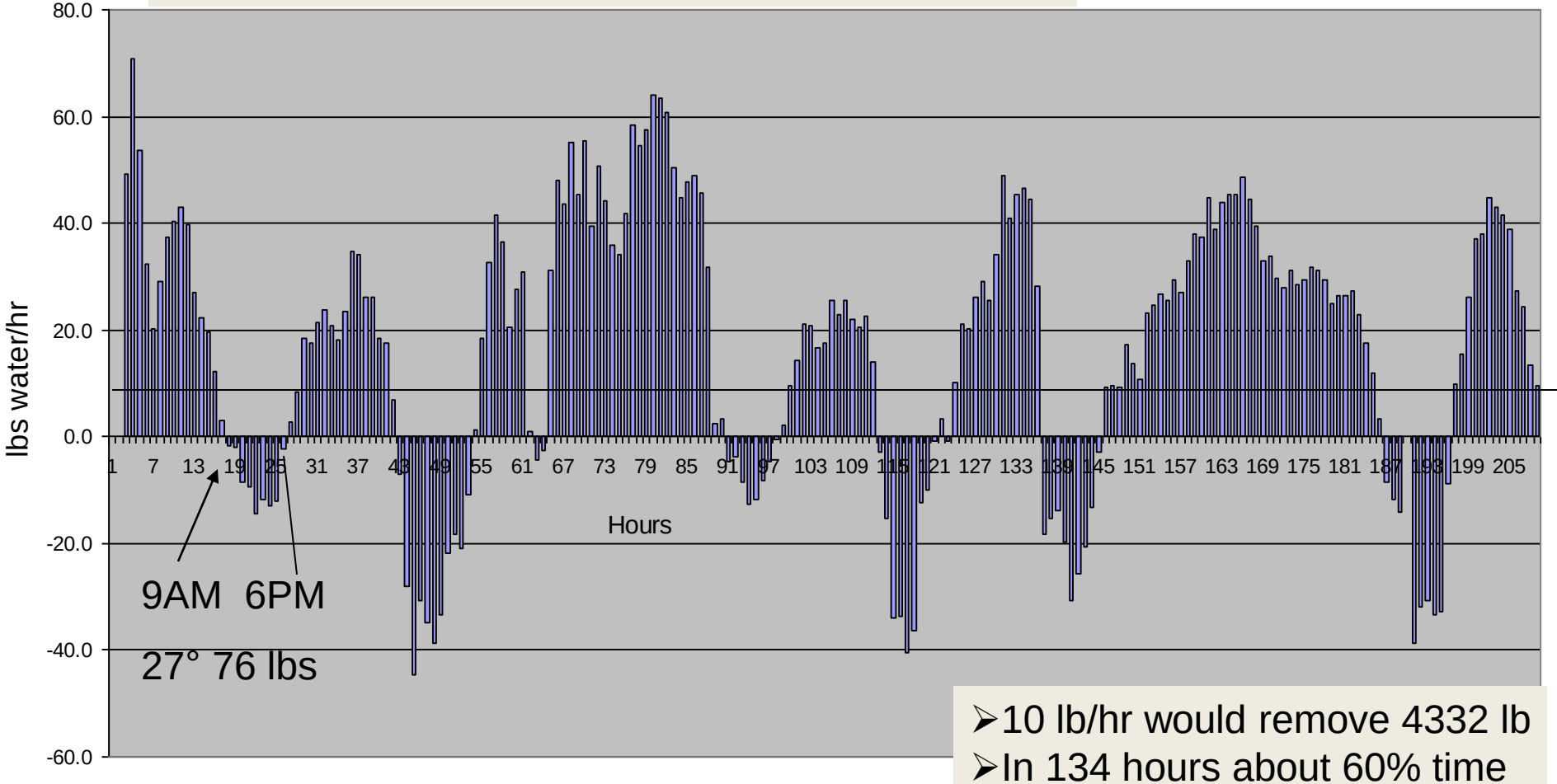

19 start Sep4 2:29 18.9% 30° C
barley3500 5Hp stop Sept 21 8:29 13% 11° C
H2O removed kg/hr
Disch Temp C
140
120
100
80
60
40
20
0
-20
40
35
30
25
20
15
10
5
0
1
7
13
19
25
31
37
43
49
55
61
67
73
79
85
91
97
103
109
115
121
127
133
139
145
151
157
163
169
175
181
187
193
199
205
211
217
223
229
235
241
247
253
259
265
271
277
283
289


Bin 10 2011
200
150
100
50
0
-50
lbs water
1
16
31
46
61
91
106
121
136
151
166
181
196
211
226
241
256
271
286
301
316
331
376
hours

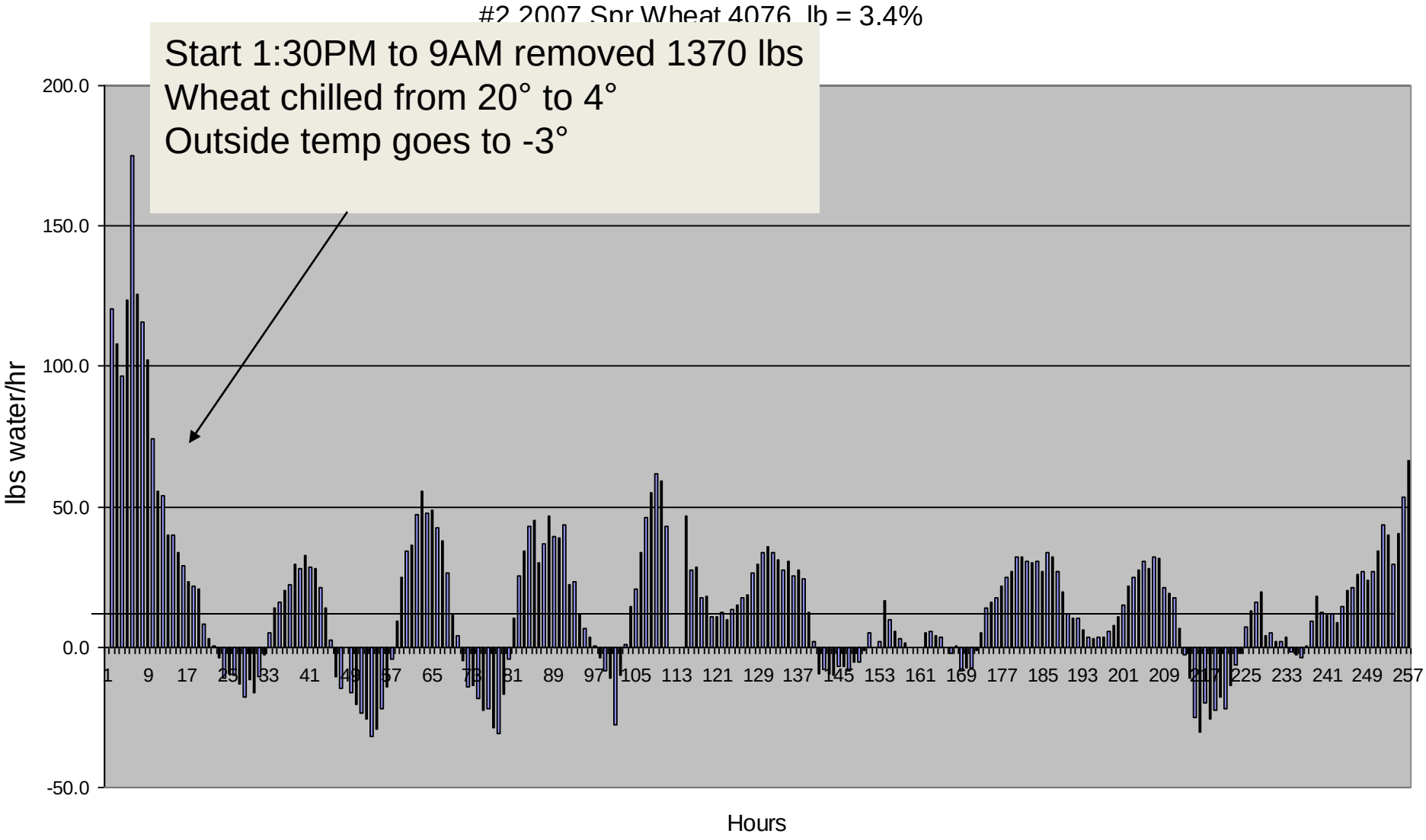
Sept 23 shrt2010 Bin 10

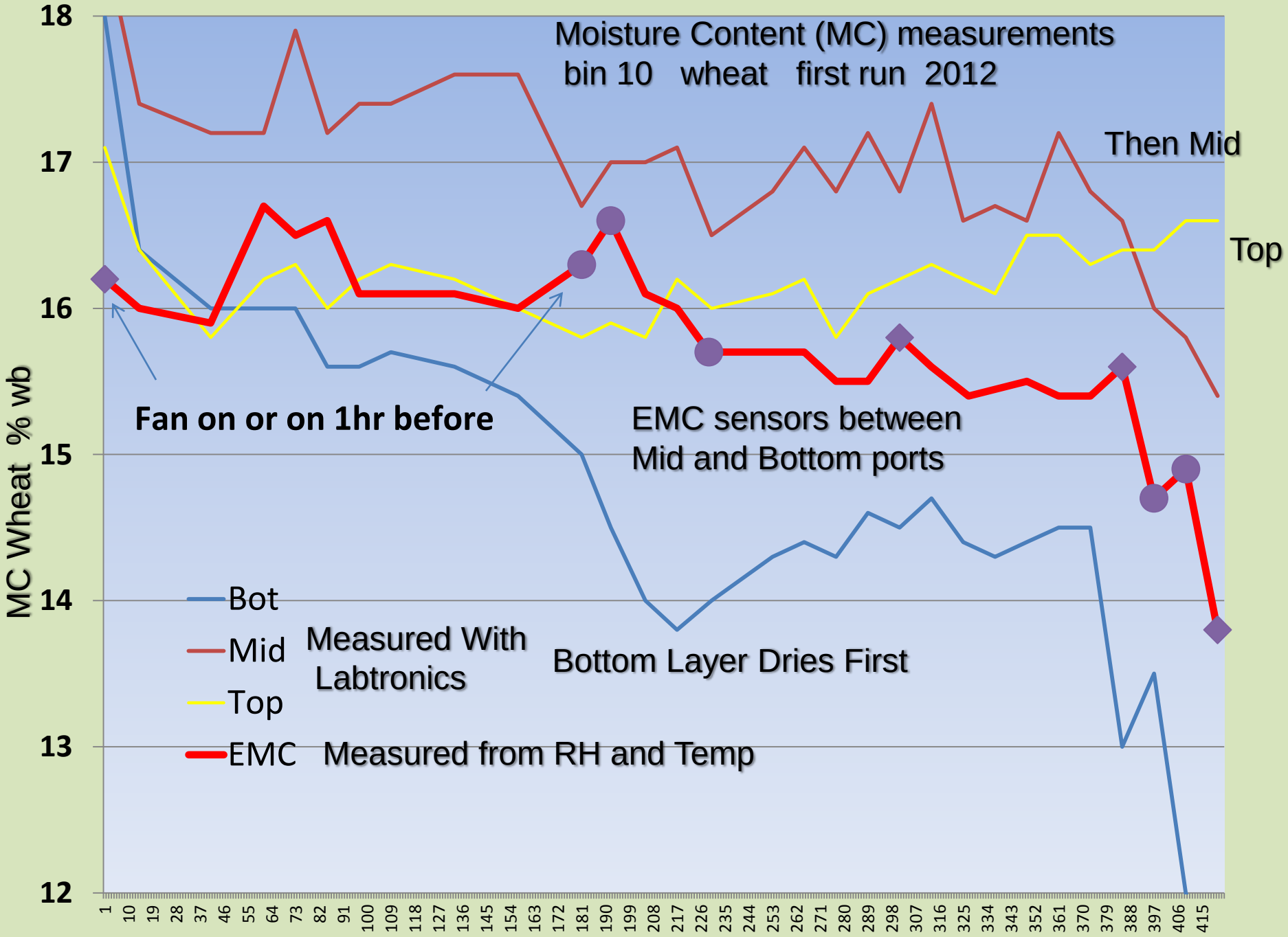


Start 5PM 25°C Wheat 15.6%
First Night 500 lbs removed grain cooled 23° to 16°



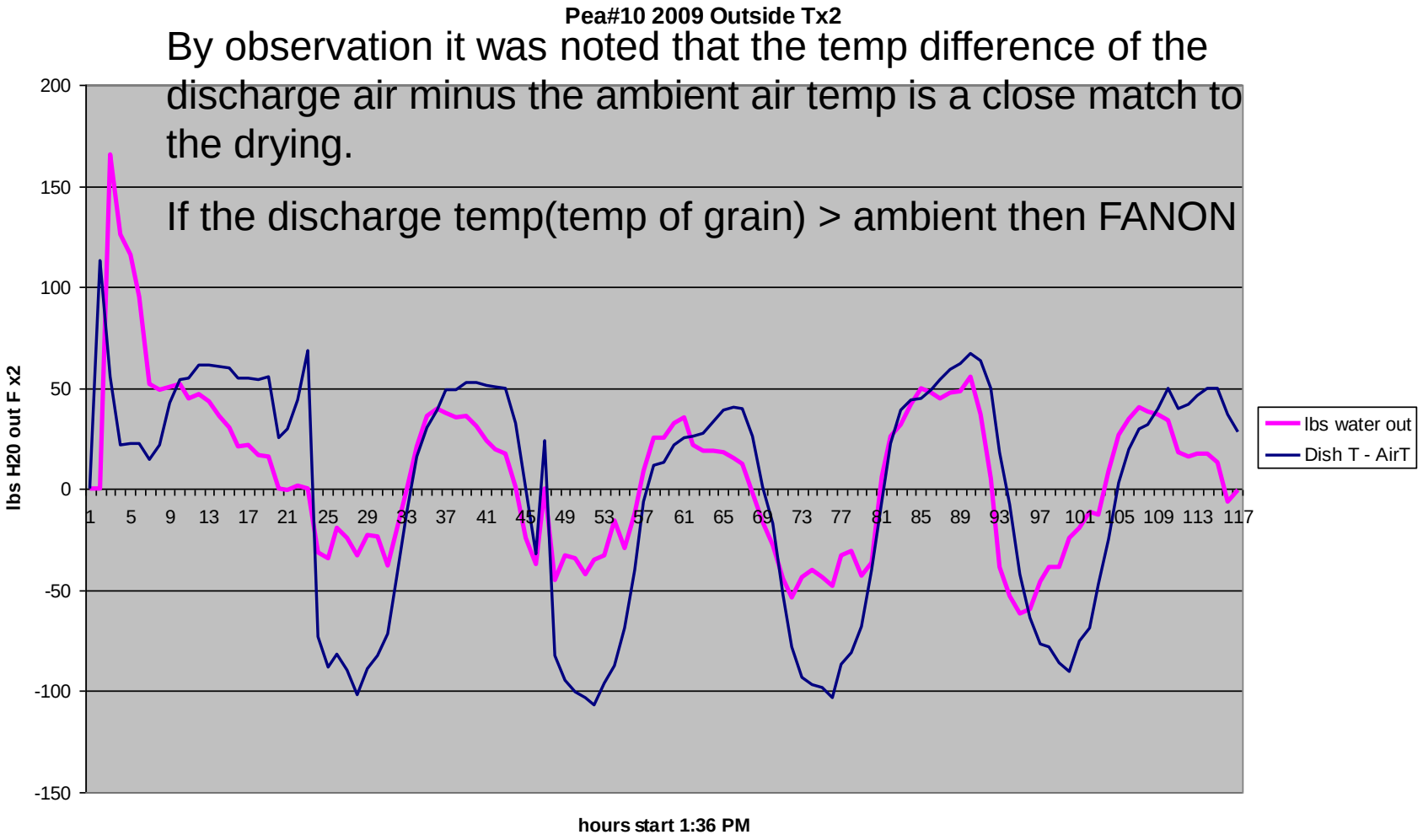
- 10 lb/hr would remove 4332 lb
- In 134 hours about 60% time


#2 2007 Spr Wheat 4076 lb = 3.4%
Start 1:30PM to 9AM removed 1370 lbs
Wheat chilled from 20° to 4°
Outside temp goes to -3°
200.0
150.0
100.0
50.0
0.0
-50.0
lbs water/hr
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145 153 161 169 177 185 193 201 209 217 225 233 241 249 257
Hours

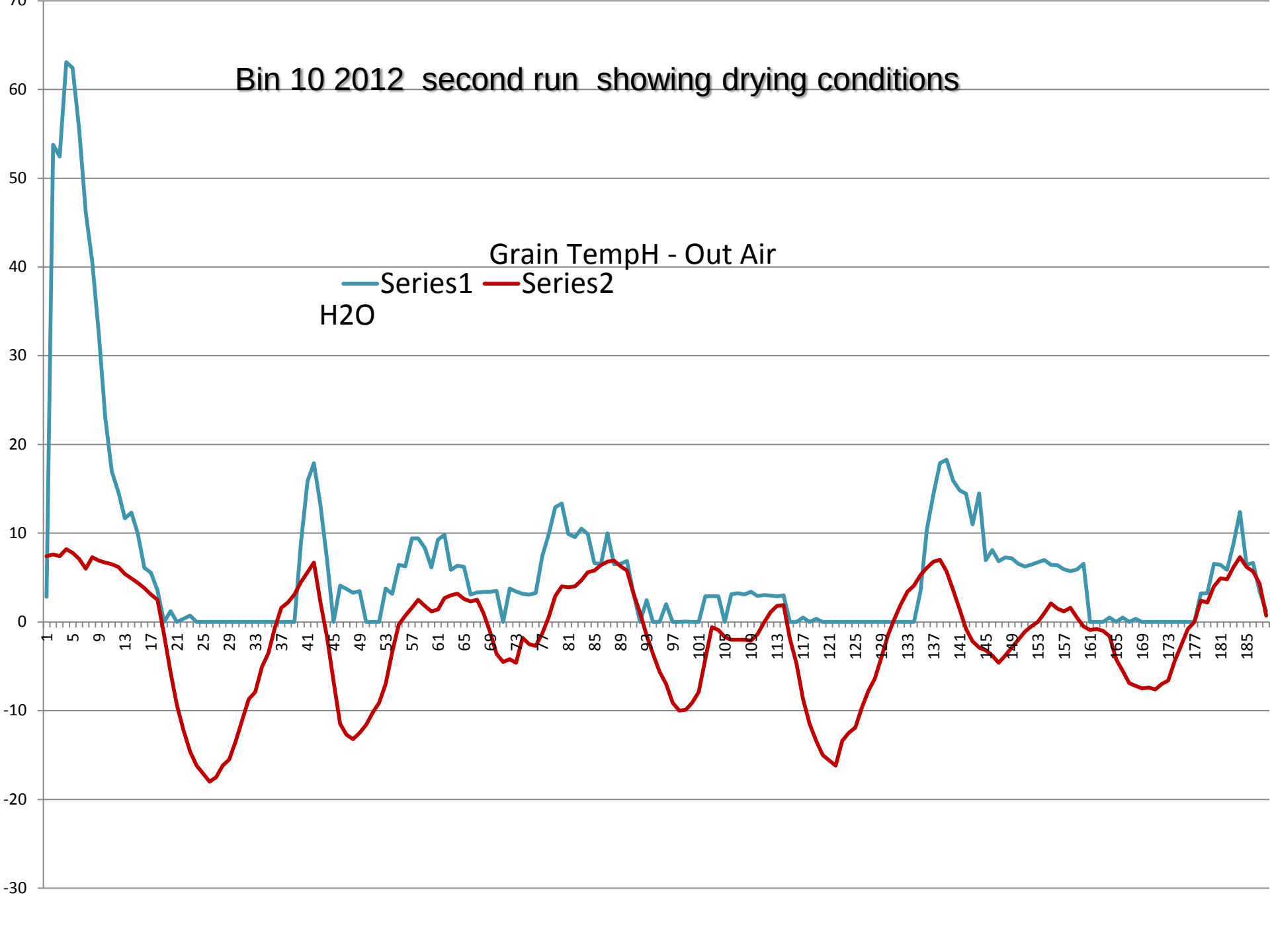

Moisture Content (MC) measurements
bin 10 wheat first run 2012
Then Mid
Top
Fan on or on 1hr before
EMC sensors between
Mid and Bottom ports
Bot
Mid
Top
EMC
Measured With
Labtronics
Measured from RH and Temp
Bottom Layer Dries First
MC Wheat % wb
18
17
16
15
14
13
12
1
10
19
28
37
46
55
64
73
82
91
100
109
118
127
136
145
154
163
172
181
190
199
208
217
226
235
244
253
262
271
280
289
298
307
316
325
334
343
352
361
370
379
388
397
406
415

What's going on here??

- First day, warm air hits the warm grain and plenty of drying takes place.
- First night, cool dry air hits the warm grain. The air is warmed by the grain, lowering its RH – so it can hold more water, and so it does by drying the grain.
- The next day, the warm moist air hits the cool grain, cooling the air. Moisture is released into the grain.



If the temperature of the grain is greater than the outside air temp, then we are in a drying conditon and the fan should be turned on. If the grain temp is < outside air temp, then turn the fan off. The controller only needs to monitor these temps.


Bin 10 2012 second run showing drying conditions
Grain TempH - Out Air
Series1
Series2
H2O
70
60
50
40
30
20
10
0
-10
-20
-30
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

Controller Strategy

- A controller based on the black box approach of "water-out minus water-in" can and did work, but it has a couple of drawbacks:
  - Awkward in knowing when to start the fan
  - Humidity sensors are not reliable.
- I think a better controller is based on temp:

  Temp difference: If $T_{Grain} > T_{Air}$ then Drying
  - Simpler: very few components, -> Low cost & Reliable
  - Safer: Keeps grain as cold as possible and maximizes the energy gathering, (solar collector) effect of the bin.

Other Observations

- The controlled bin had a less distinct drying front. (MC content, top to bottom –closer)
- Provided that we can cool the grain to a safe temp. the first day; there might be an advantage in using a smaller fan to conserve the energy in the grain??
- Change our way of thinking: we must cool the grain before it spoils, rather than dry the grain before it spoils.

It Works!

- Chad Skinner has tried this with side by side trials and found the on-night/off-day was as effective as the continuous-fan-on.
- Lentils 18% to 14% in 5 days (3hp 2000 & 3300)
- Wheat 17% to 13% in 7 days (7.5hp 5000bu)
- Canola

Conclusion: Only need to run the fan a fraction of the time and your grain will be **cooler** and **safer**

Conclusions

- Best drying conditions are when the air is cold and the grain is hot.
- Its not a race *to dry the grain before it spoils*, it is a race *to cool the grain before it spoils*.
- For the best grain storage, keep the grain as cold as possible. < spoilage, < OTA, < mold
- Only need to run the fan half the time (night), 50% saving in electricity.
- Best strategy is to run the fan only if we are drying the grain.
- Adding supplemental heat is not required, and can increase the risk of spoilage.