MANAGING GRAIN STORAGE

New Insight into Natural Aeration Grain Drying

IHARF
INDIAN HEAD AGRICULTURAL RESEARCH FOUNDATION

Prairieland Park Hall A Rm #1

503 Ruth St. W. Saskatoon SK

Thurs January 14, 2016 10:00 AM

Ron Palmer P.Eng. Ph.D.

ron.palmer@uregina.ca

Indian Head Agricultural Research Foundation

Content

- Common Practice: Fan on Continuously
- The Set-up 2007, Data Collected
- Objectives
- Vapour Pressure
- Water Balance-In/Out, Diurnal Cycle, Yard Light Rule
- Cooling is Drying → Fan On if: Grain Temp > Air Temp
- Safe Grain, Number of Safe Days, Spoilage Index
- EMC equilibrium moisture content, the calculator
- Dripping, crusting – why? Prevention
- Comparing Fan Control Strategies: Best to Worst
- Review: Points to Take Home
- Future Work → Questions ??

Current Practice and Common Beliefs:

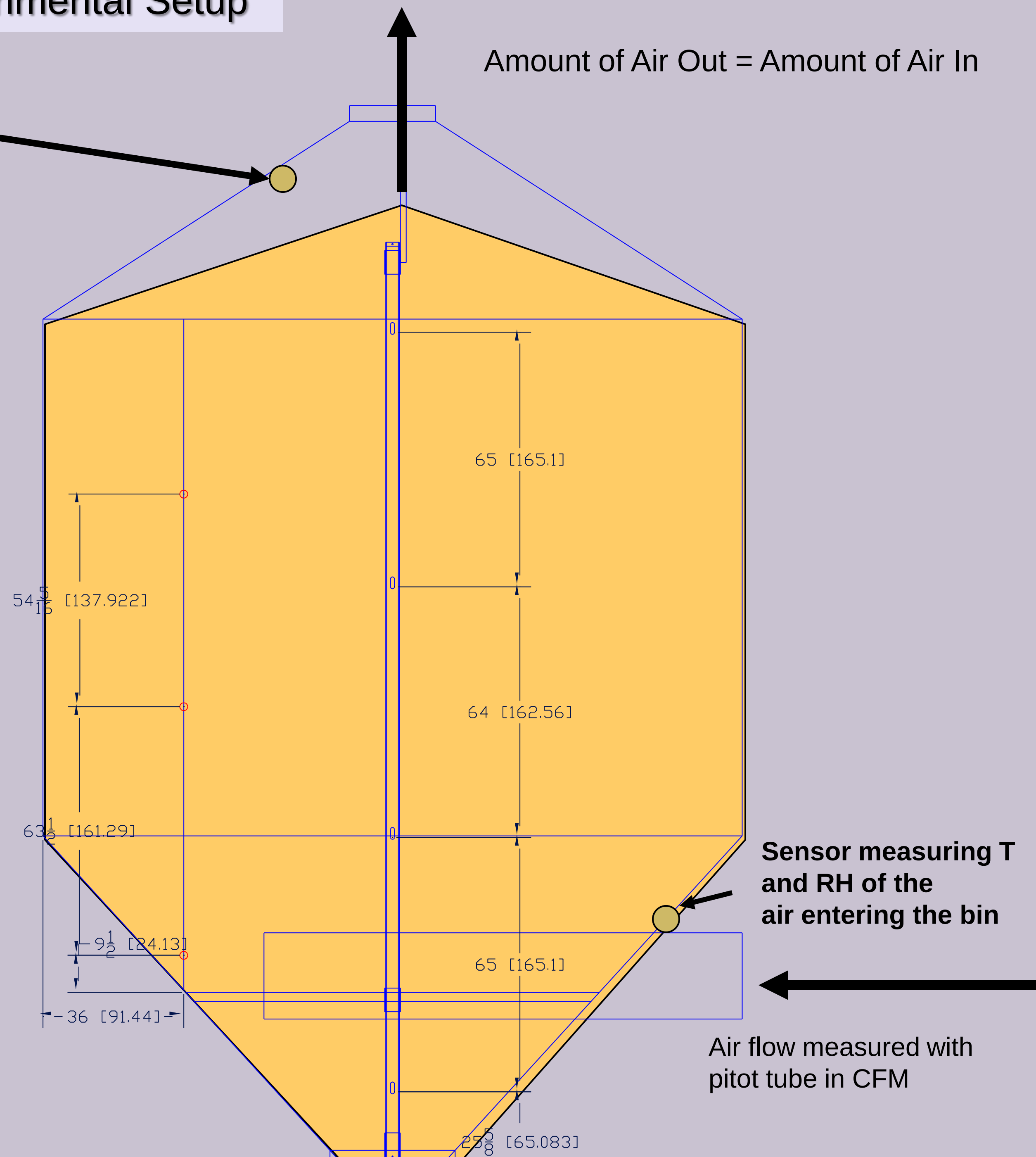
- Fan on ***continuously***.
- Keep that ***drying front*** moving.
- Don't need aeration fans if grain stored "dry".
- Need heat to dry, so maybe only turn on during the hot days?
- Regarding fans: The bigger the better!
- To dry: 1 CFM/bu. To cool: 0.1 CFM/bu.
- Cold air does not dry grain.
- Turn the fan on when conditions are right.

The Experimental Setup

Amount of Air Out = Amount of Air In

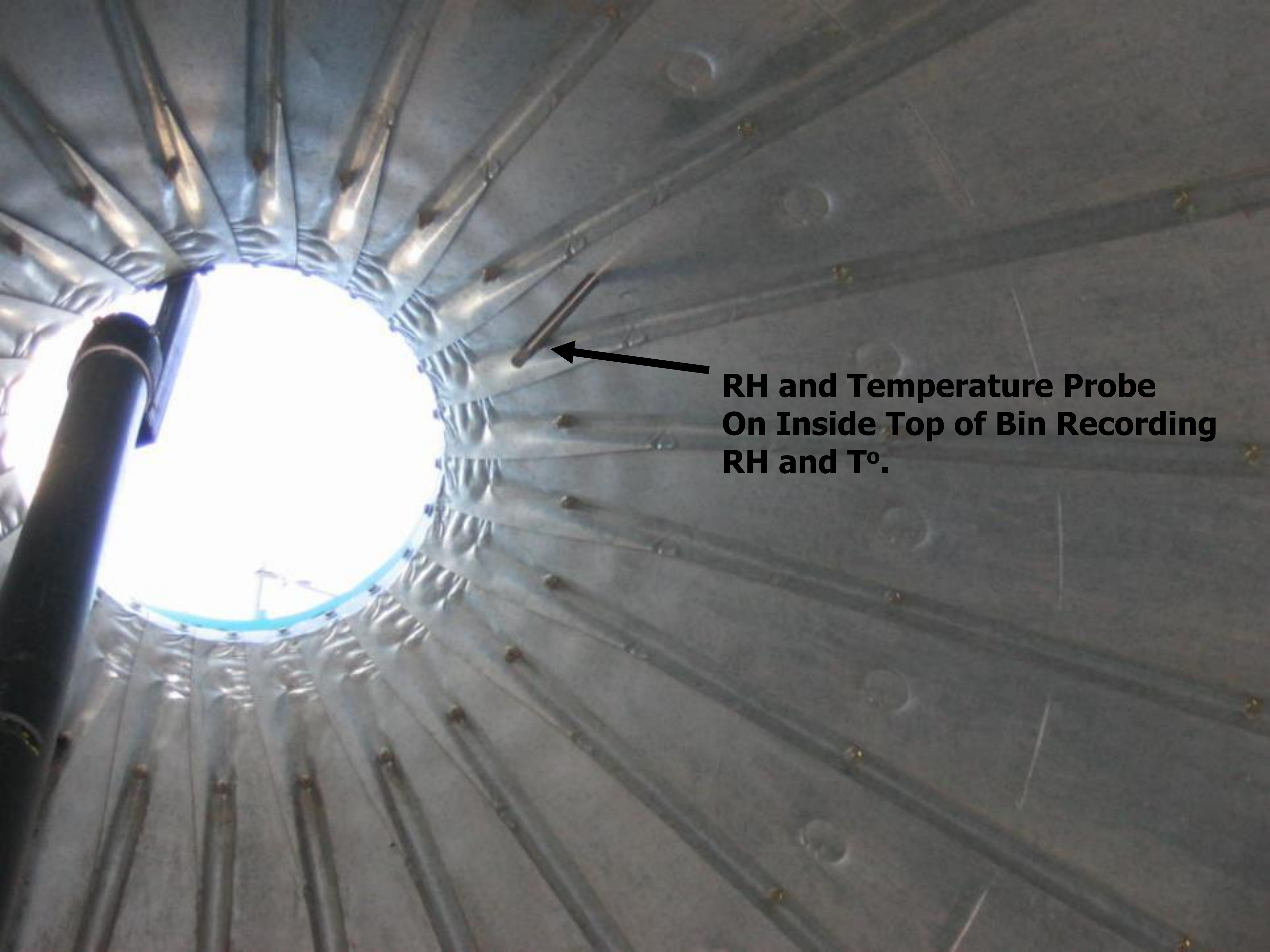
Sensor measuring T and RH of the air leaving the bin

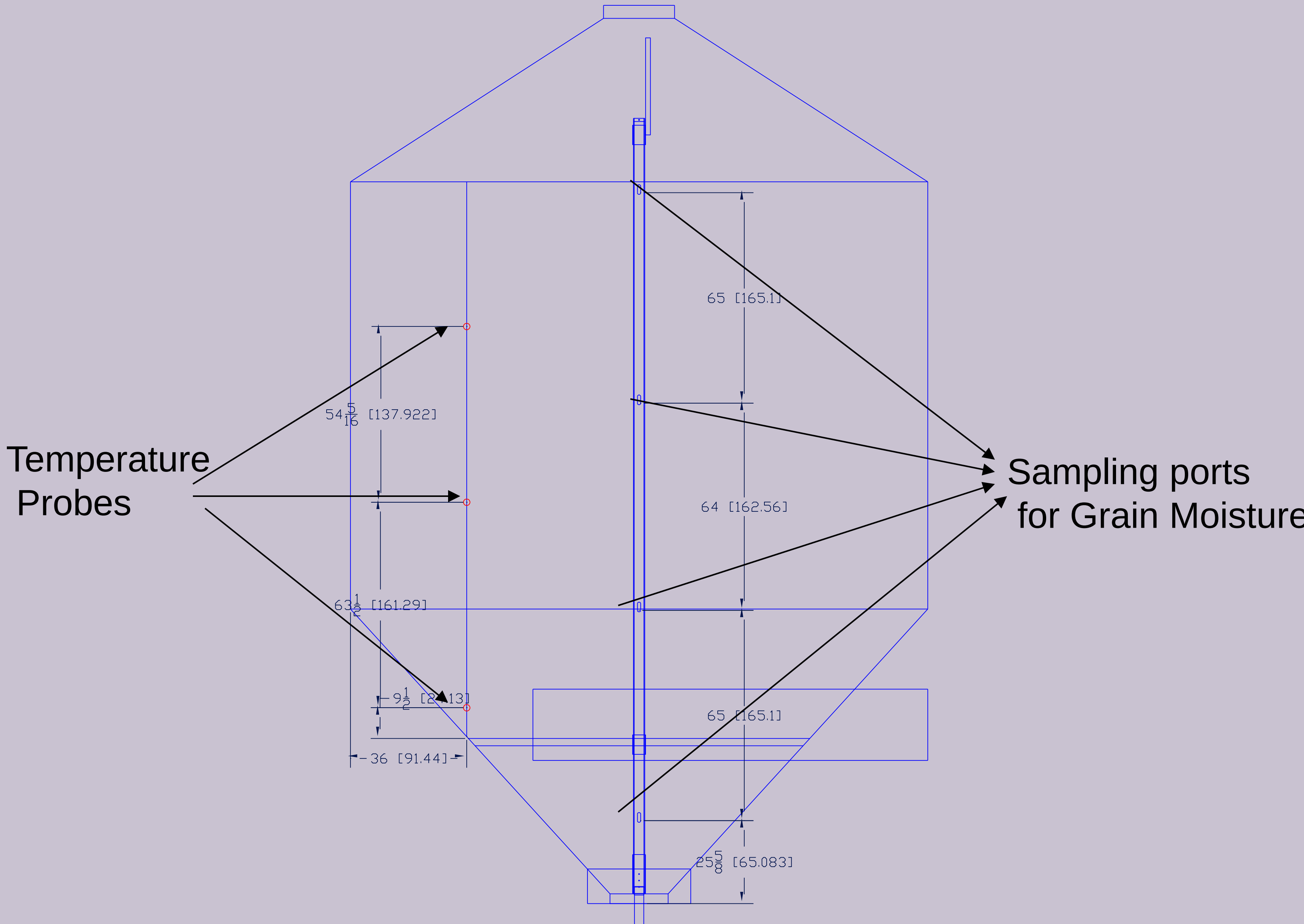
- Each Sensor 's value was recorded every hour.
- Fans were run continuously
- Data has been collected every year since 2007



Sensor measuring T and RH of the air entering the bin

Air flow measured with pitot tube in CFM


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



Temperature Probes
Sampling ports for Grain Moisture
65 [165.1]
54 5/16 [137.922]
64 [162.56]
63 1/2 [161.29]
65 [165.1]
36 [91.44]
25 5/8 [65.083]

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

Objective

- To find out what is going on? When is there drying?
- To design a management practice to control the fan:
  - Dries Grain to market-dry level standards
  - Is efficient – saves power, fan on only when necessary (if drying: fan on -- if not drying: fan off)
  - Provides **Safe** Grain Storage – i.e. No spoilage, no loss of grade, no infestation of molds, fungus, toxins (OTA)
    - Cool grain
    - Dry grain

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

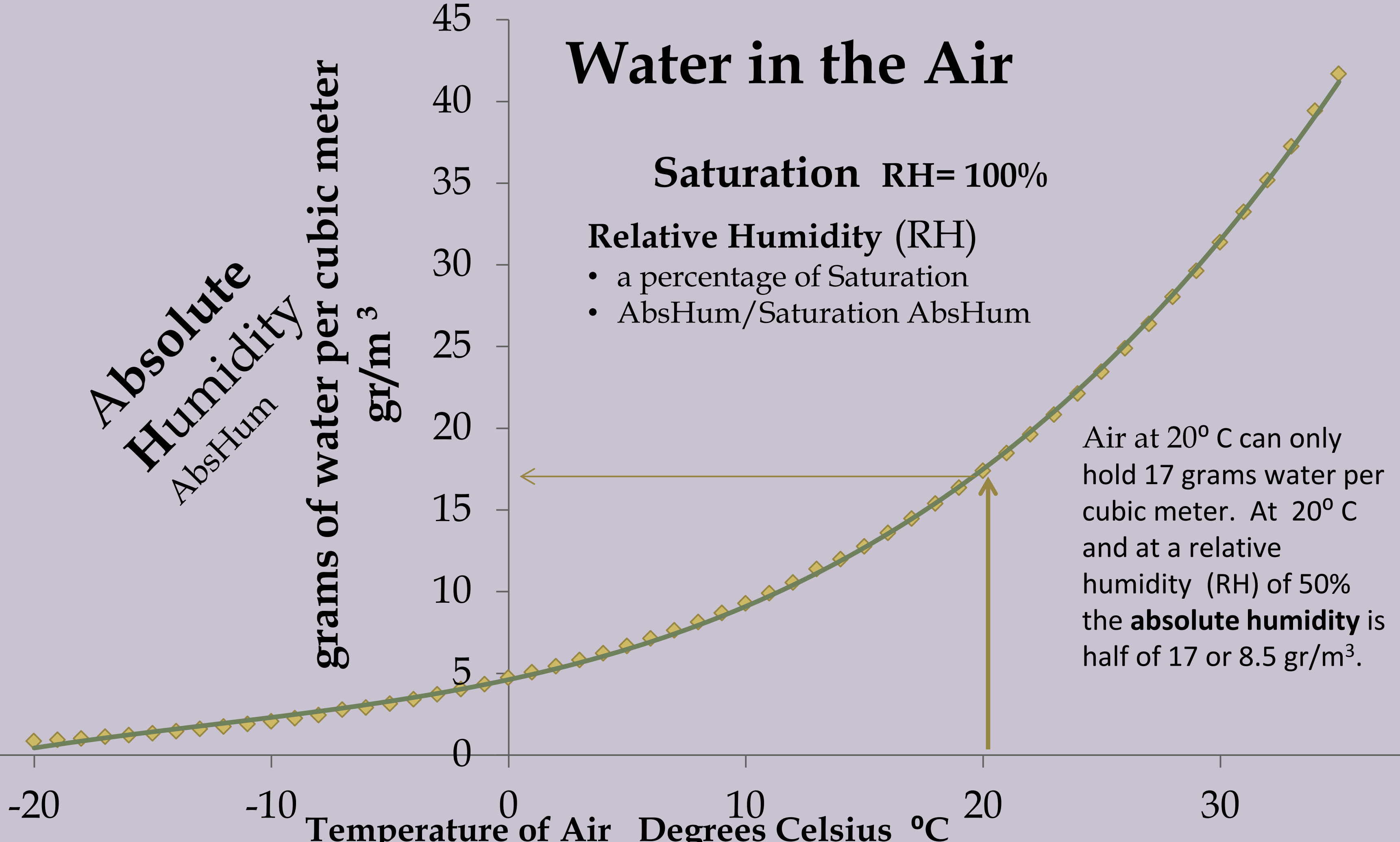
- % moisture content
- temperature
- type & condition of grain

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

Psychrometric Charts:

$$W_s = 0.000289\,T^3 + 0.010873\,T^2 + 0.311043T + 4.617135$$



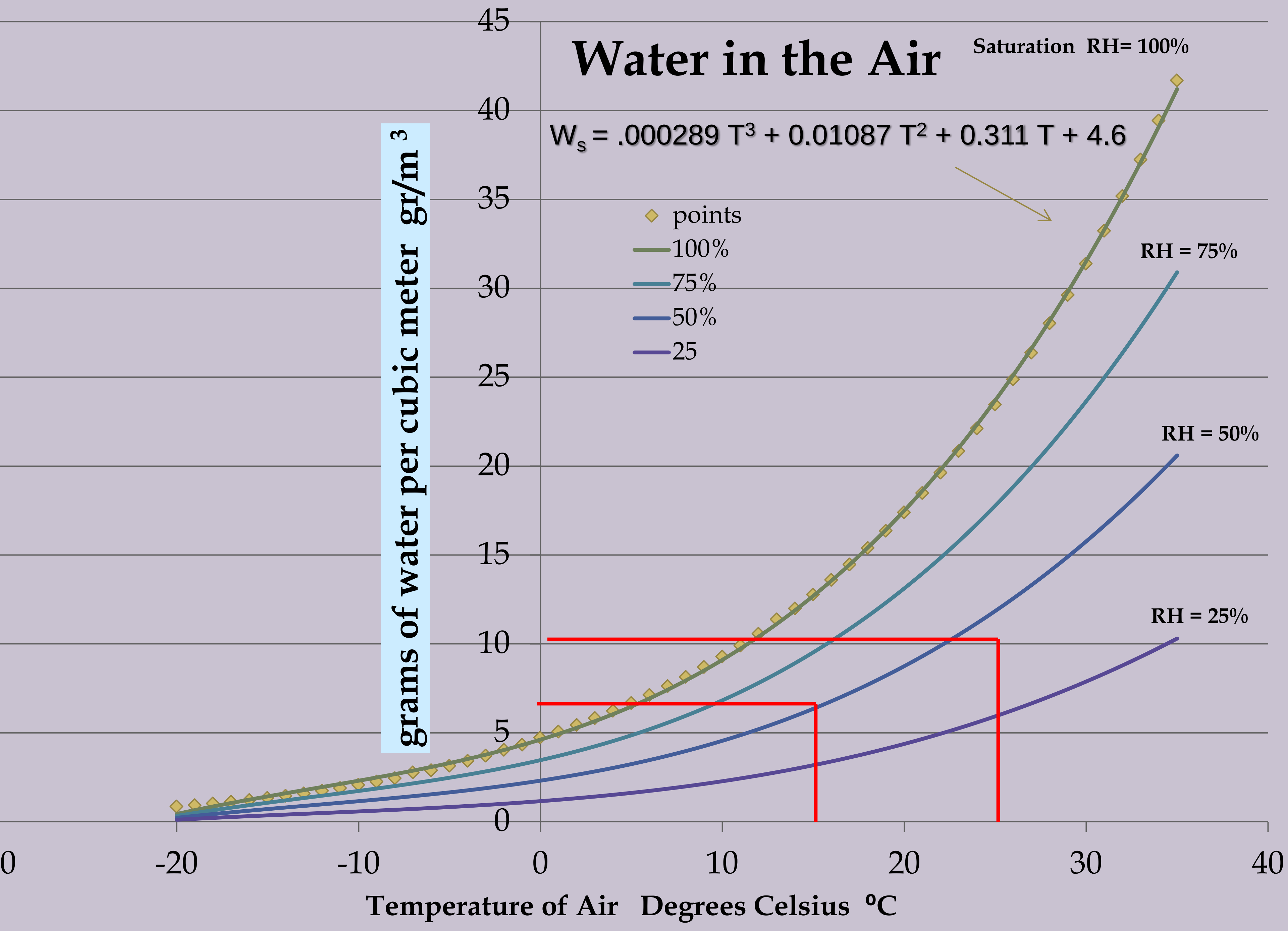
H_2O Balance --IN/OUT Example

- We have a 2000 bu. Bin with an aeration fan with a flow of 3000 CFM.
- The air :
  - entering the bin is 15°C @ 55% RH.

    12.7 gr. X 0.55 = 7 gr/m^3
  - leaving the bin is 25°C @ 45% RH.

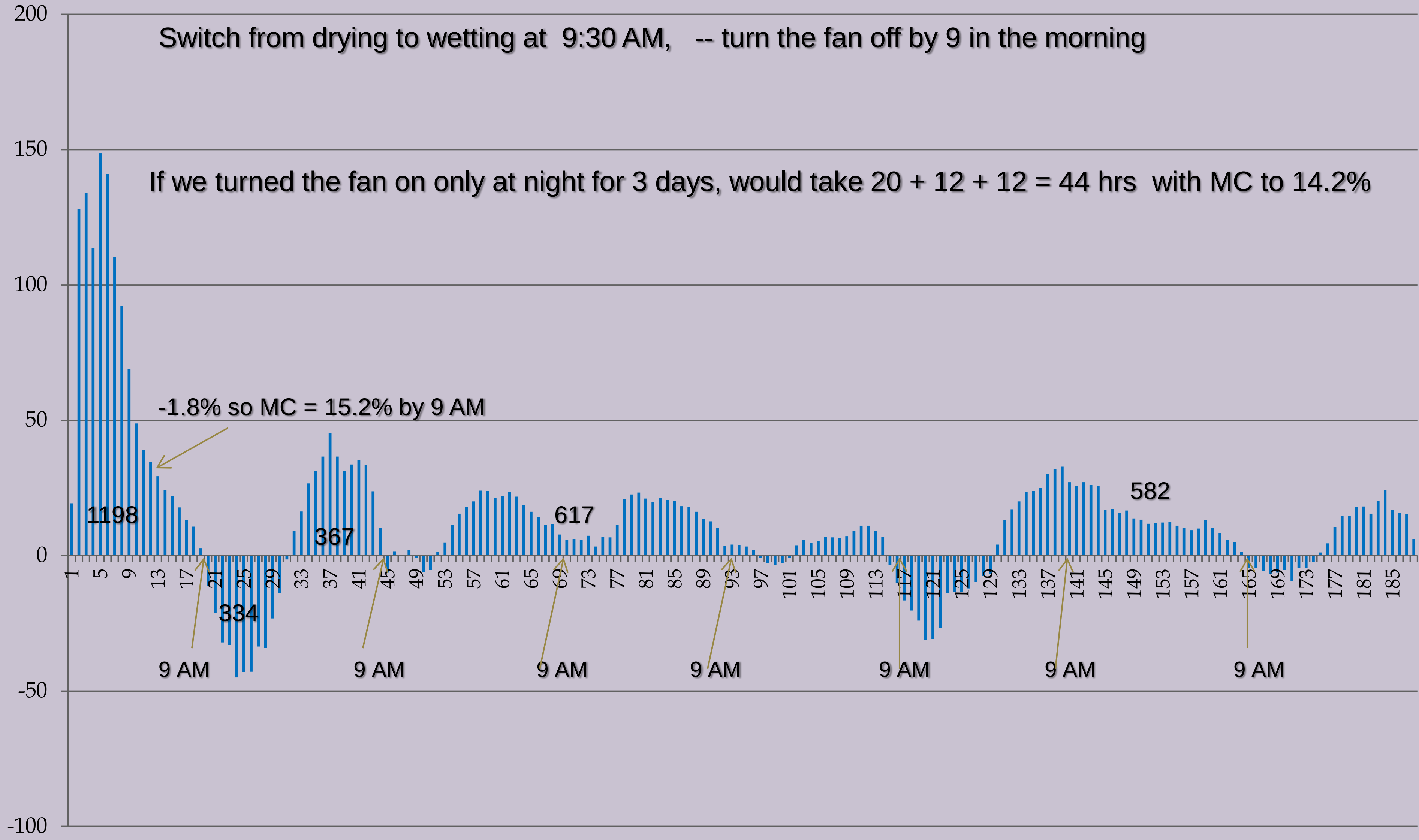
    23.7 gr x 0.45 = 10.67 gr/m^3
- Are we drying? Yes 10.67 – 7 = 3.67 gr/m^3
- How much? 3000 CFM = 180,000 $ft^3/hr.$

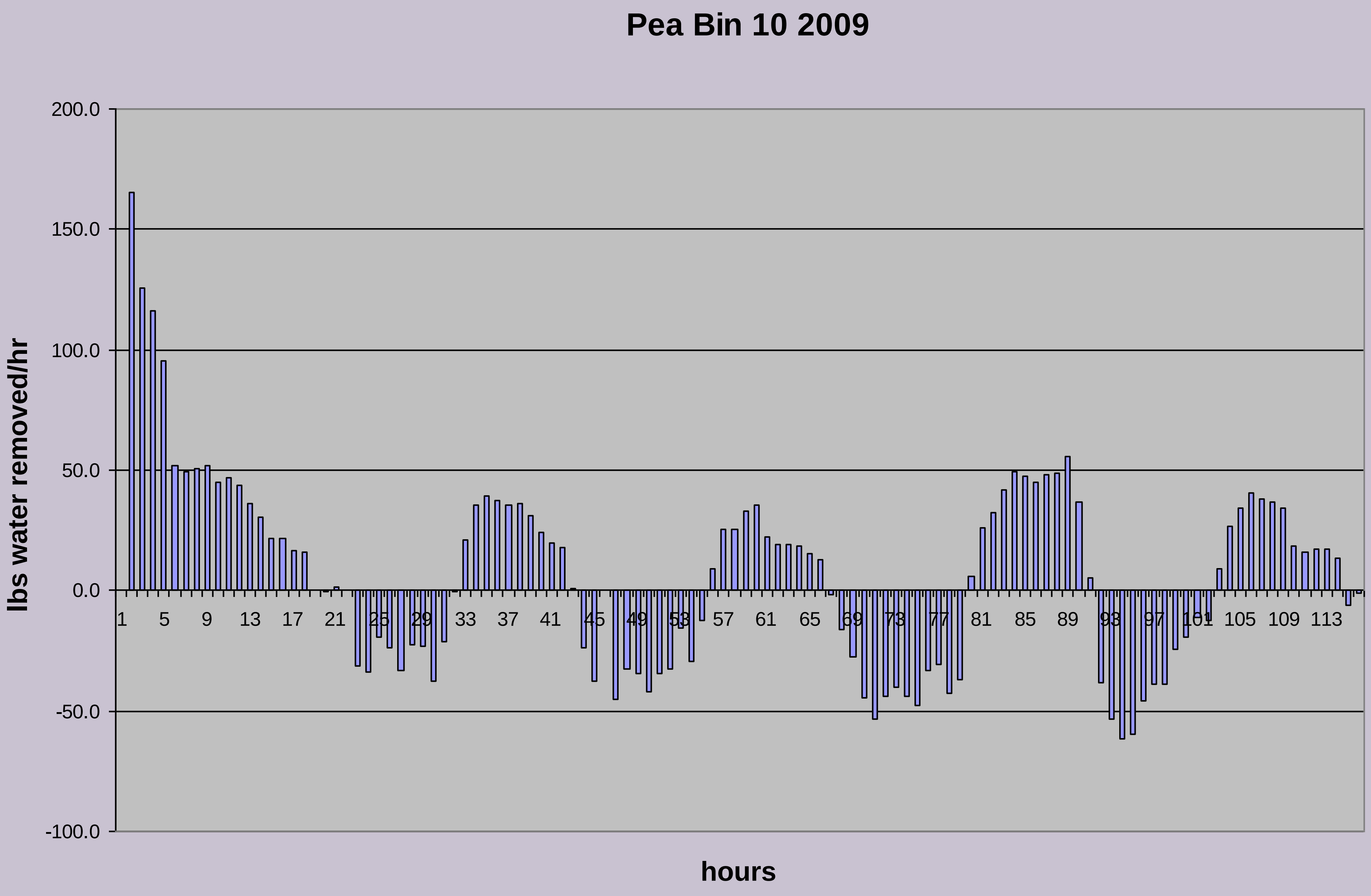
180000/35.41 x 3.67 = **18.6 kg/hr.** water removed



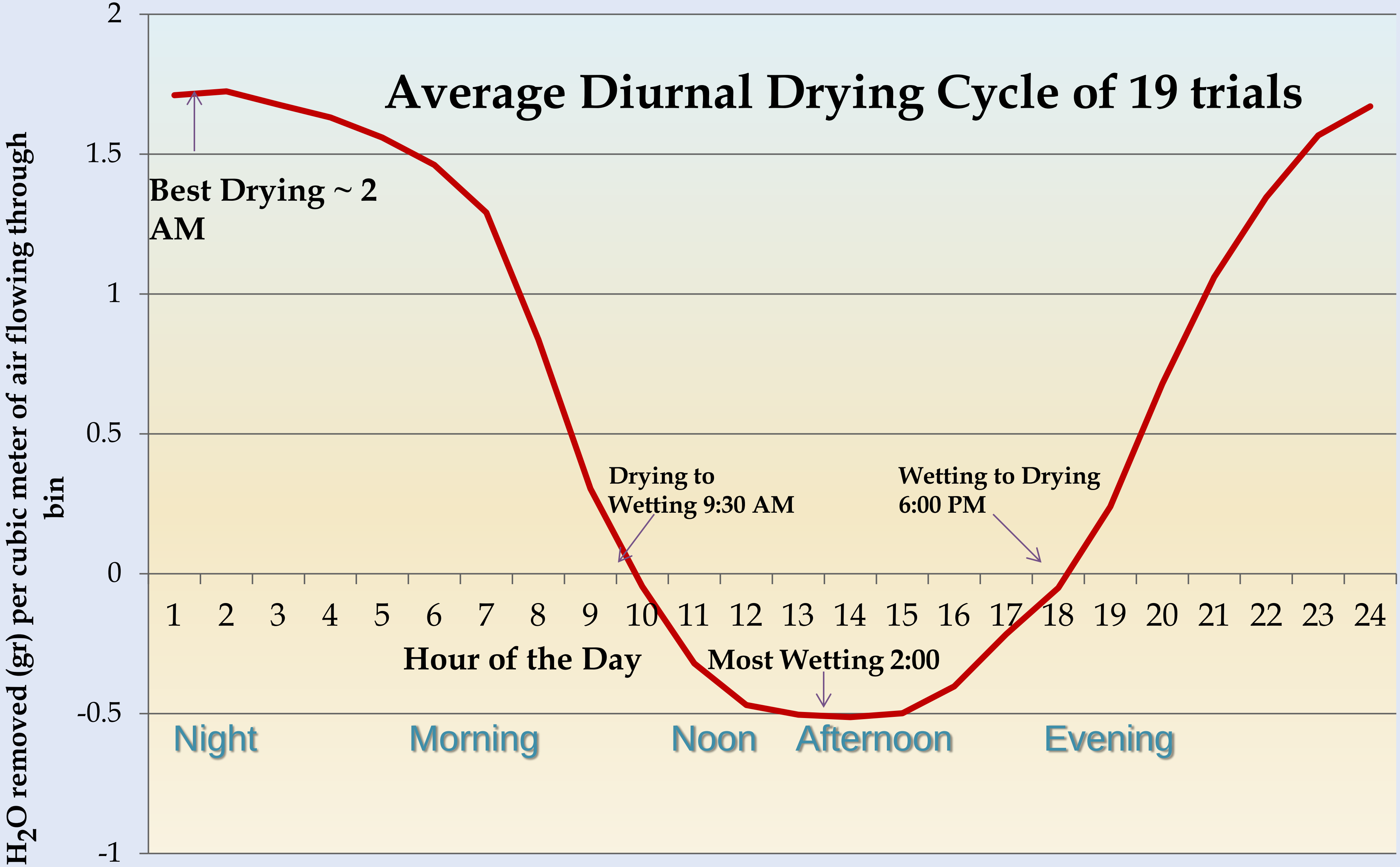
Water in the Air
Saturation RH= 100%
W_s = .000289 T³ + 0.01087 T² + 0.311 T + 4.6
points
100%
75%
50%
25
RH = 75%
RH = 50%
RH = 25%
grams of water per cubic meter gr/m 3
0
5
10
15
20
25
30
35
40
45
0
-20
-10
0
10
20
30
40
Temperature of Air Degrees Celsius ºC

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



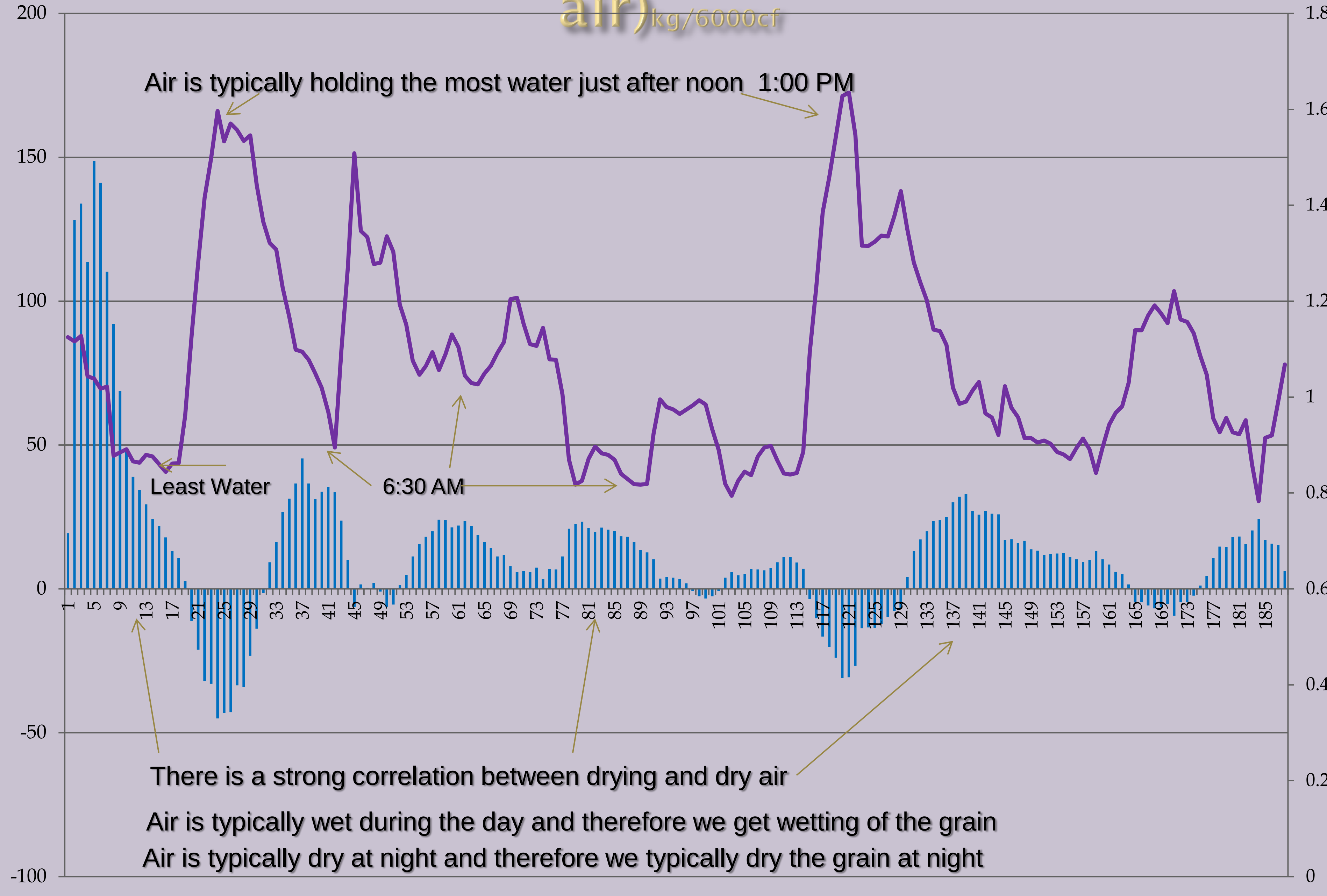


Pea Bin 10 2009
lbs water removed/hr
200.0
150.0
100.0
50.0
0.0
-50.0
-100.0
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
81
85
89
93
97
101
105
109
113
hours



Average Diurnal Drying Cycle of 19 trials
H_2O removed (gr) per cubic meter of air flowing through bin
Hour of the Day
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
Best Drying ~ 2 AM
Drying to Wetting 9:30 AM
Wetting to Drying 6:00 PM
Most Wetting 2:00
Night
Morning
Noon
Afternoon
Evening

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



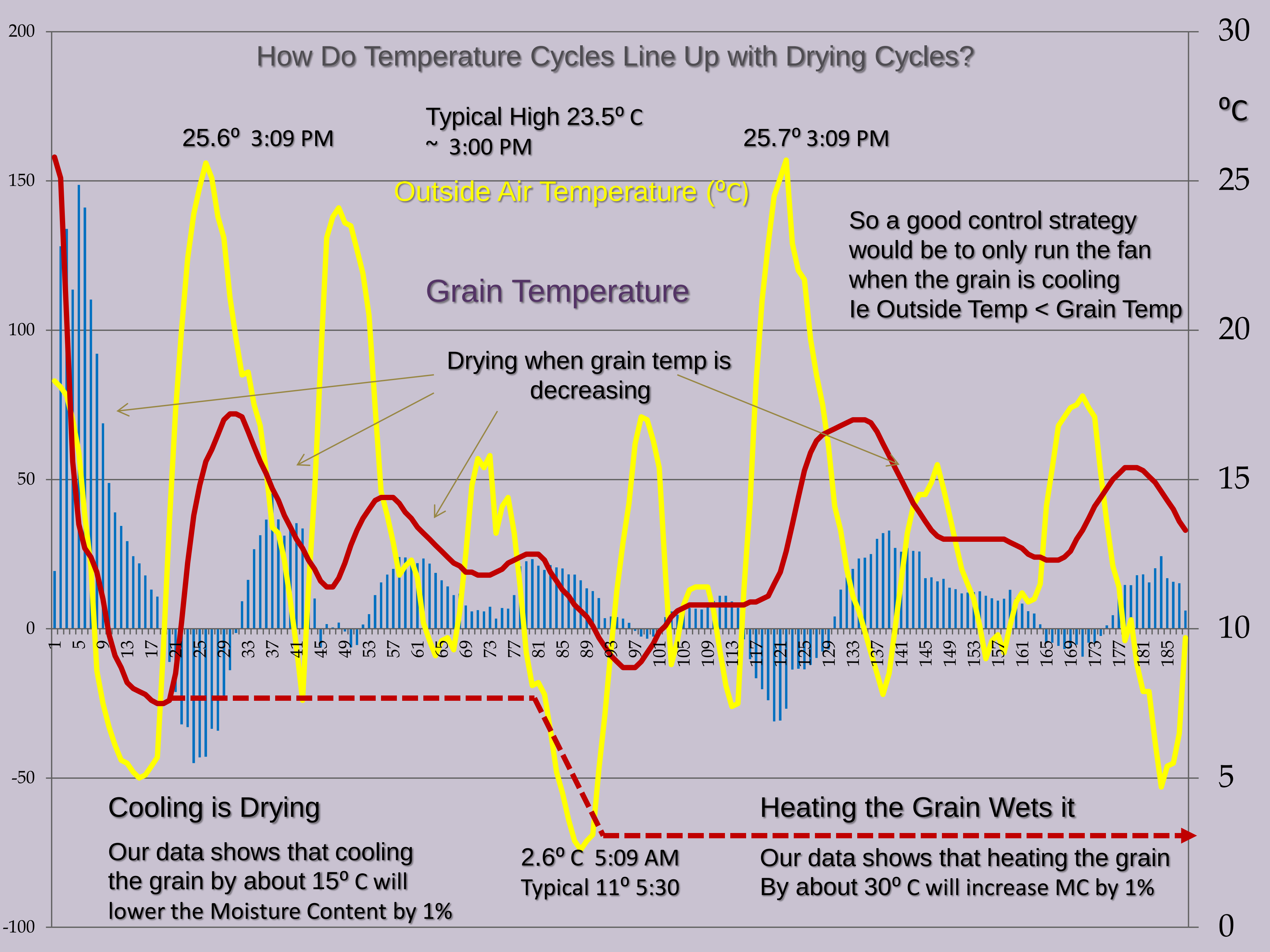
Night Drying Recommendation

- Yard Light Rule (2010):

On at night, you are bright

On during the day, you will pay.

- Requires no sensors, or calculations, or knowledge of grain type, temp, RH etc.
- Turn off at 9 AM
- Does not account for MC, air T or RH, nor grain T and therefore may not be the best.


How Do Temperature Cycles Line Up with Drying Cycles?
25.6º 3:09 PM
Typical High 23.5º C
~ 3:00 PM
25.7º 3:09 PM
Outside Air Temperature (ºC)
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 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%
ºC
200
150
100
50
0
-50
-100
30
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

Cooling is Drying

- Can only make the grain colder by using air that is colder than the grain
- Turn the Fan on if:

(Air Temperature + Offset) < Grain Temperature

This is a simple control strategy: no math, no calculations, and can be automated with simple electronics, but; the MC of the grain, and outside air RH are not accounted for, so again we could question: Is this the best? Can we incorporate the MC and RH?

Safe Days

Number of days until germination capacity is reduced to 95% (Fraser & Muir 1981)

Safe Days = 10^(6.234 -0.2118 **MC** – 0.0527 **T**) wheat and cereals

= 10^(6.224 - 0.302 **MC** – 0.069 **T**) canola and oilseeds

The objective for safe storage, is to maximize the number of safe days by lowering the temperature T, and the moisture content, MC. Look at how the number of safe days varies with temperature for 'dry' wheat:

- 14.5% @ 30ºC = 38 safe days
- 14.5% @ 20ºC = 128 safe days
- 14.5% @ 0ºC = 1458 safe days
- New Definition: Spoilage Index = 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% of the way to 95% germination

SAFE STORAGE TIME (days) CEREAL GRAINS

Consider freshly harvested wheat
30º C, MC is 18%, have only 7 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	[illegible]-60	40-60	40-60	20-30	10-15	10-15	10-15
15			80-120	40-60	[illegible]-60	20-30	20-30	20-30	10-15	10-15	5-8
20		80-120	40-60	40-60	[illegible]-30	10-15	10-15	10-15	5-8	5-8	3-5
25	80-120	40-60	20-30	20-30	[illegible]-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

cooled to 10º C
81 safe days

If dried to 14.5%
39

NOT SAFE

VERY DANGEROUS

SAFE STORAGE TIME (days) CEREAL GRAINS

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	[illegible]-60	40-60	40-60	20-30	10-15	10-15	10-15
15			80[illegible]20	40-60	[illegible]-60	20-30	20-30	20-30	10-15	10-15	5-8
20		80-12[illegible]	[illegible]0-60	[illegible]-60	[illegible]-30	10-15	10-15	10-15	5-8	5-8	3-5
25	80-120	40-60	20-30	2[illegible]30	[illegible]-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

81

220

103

39

NOT SAFE **VERY DANGEROUS**

First 24 Hours is Critical

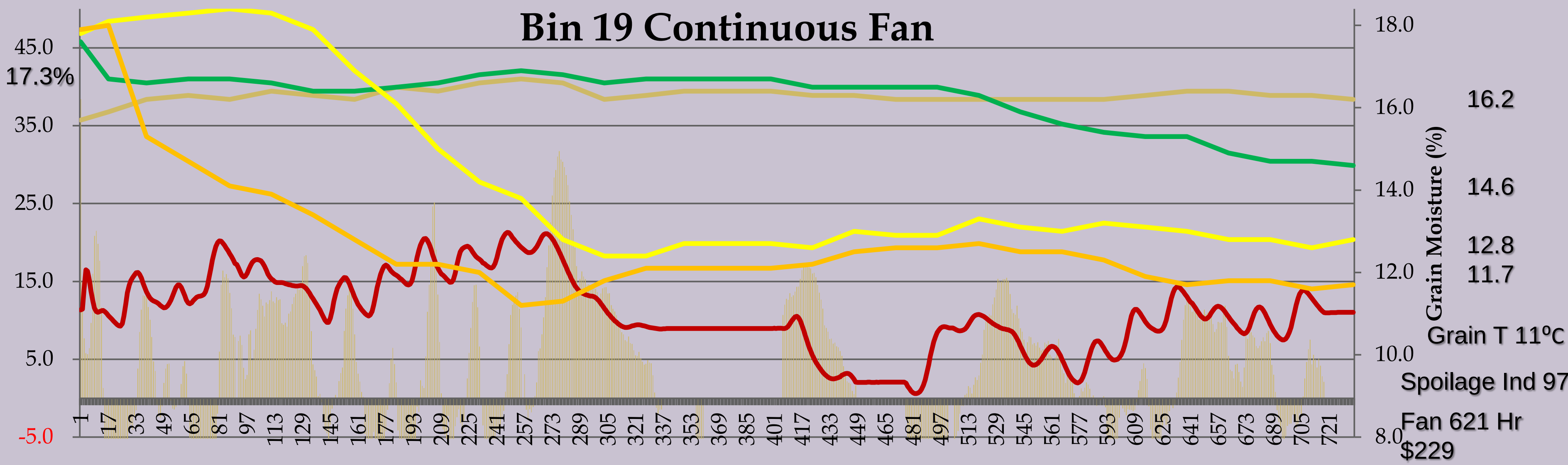
Average of 33 Runs 2007 – 2014

First 24 Hours:	Start	End	Difference
Grain Temp ºC	26.2	14.6	11.6
Moist Content %	17.65	16.77	0.88
Safe Days	13	87	74

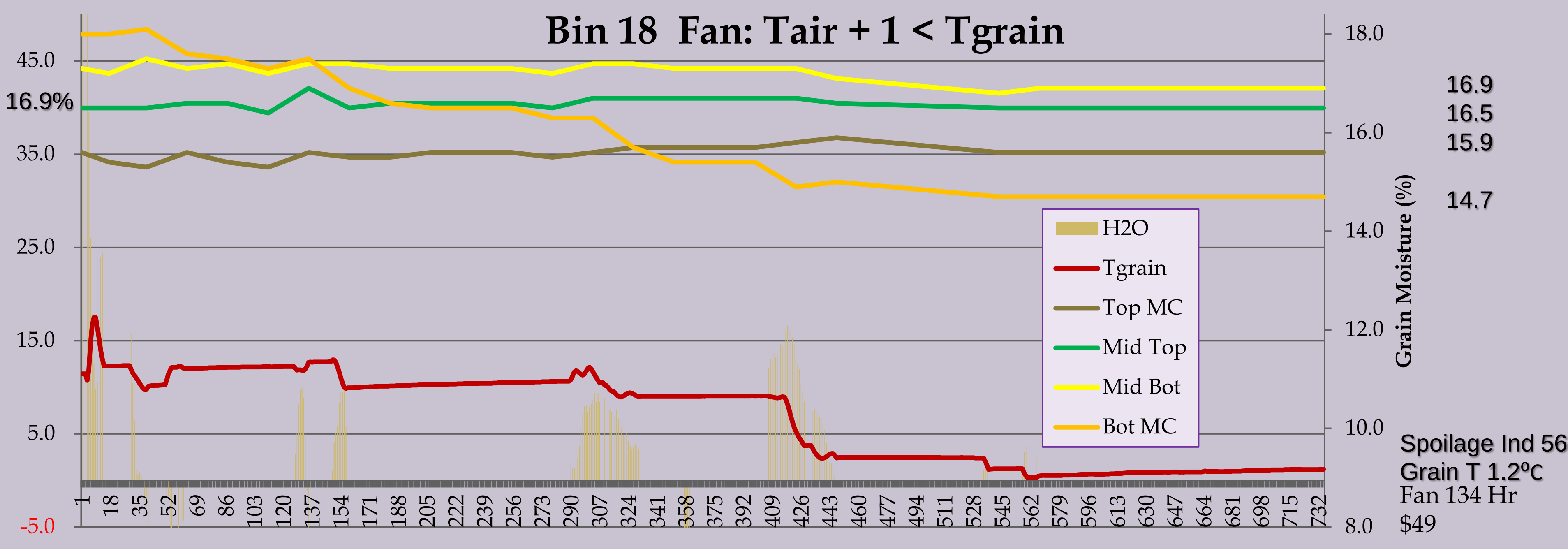
- Cooling/Drying 11.6/0.88 = 13.18 ^{0}C/ %MC

Start Sept 15
2014 7:43

End Oct 16 9:43



Tair = 15.8ºC



EMC Equilibrium Moisture Content

- EMC is the Moisture Content (**MC**) of a grain after it has been exposed to an environment for a long time.
- If one puts barley into a sealed container. The moisture content MC of the barley is 14% and the temperature is 20º C. We wait a long time – several hours. The RH of the air is measured and it is 63%. It was found that the MC and RH were related and EMC equations were formulated.
- **MC ~ RH , T or $\mathbf{RH_{emc}}$ ~ MC, T**
- Done by trial & error, slightly different equations, Henderson, Chung, Pfost
- Back to our Barley Bin --- rather than measure the RH of the air, we could have used an EMC equation to calculate the RH given the MC and T. And then knowing that the RH is 63% and that saturated air at 20 C can hold 17.5gr/m^3 -- the **absolute humidity** in the bin is 11 gr/m^3.
- Now if we blow in outside air that has an **absolute humidity** less than 11gr/m^3 the grain will dry.

How to Use EMC to determine drying conditions

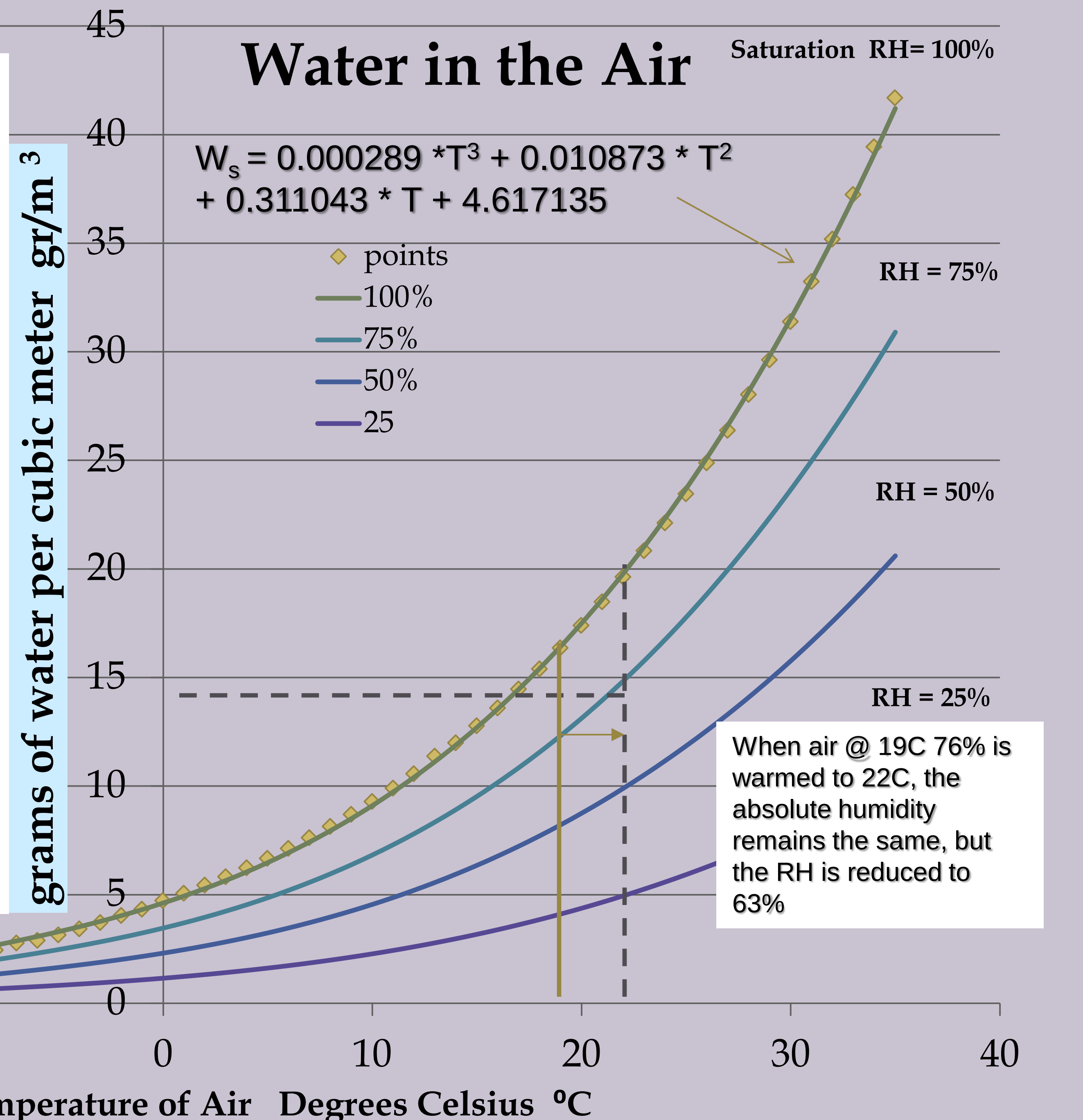
1. Find the RH of the air inside the bin using EMC eq. for grain at T and MC or if you have moisture cables, use the RH value directly.
2. Calculate the saturation absolute humidity for air that is the same T as the grain.
3. Find the **absolute humidity** of the air inside the bin by multiplying 1. x 2.
4. Calculate the saturation absolute humidity of the outside air at its T
5. Determine the threshold RH, RH_{thres} by dividing 3. by 4. If the outside air has a RH that is less than RH_{thres}, we have drying conditions. It is the same as: $AbsHum_{air} < AbsHum_{bin}$
6. Fortunately all this math is done with the grain drying calculator. Simply enter the MC of the grain, its T and the outside temperature. The calculator will calculate the RH_{thres} for a number of grains using the steps above. Find the grain in question, and its RH_{thres}. If the outside air has an RH that is lower than this RH_{thres} , the air will dry your grain. The bigger the difference, the more the drying.

EMC used to check for drying Conditions

- Barley @ MC 15.5%, 22ºC
- Outside Air 19º C RH 76% -- Is this drying air?
- Plug the above into the calculator and it gives: RH_{thres} 82.8% (Ward) ; the outside air has a RH 76% therefore we have pretty good drying conditions

Barley 22 C ,15.5% MC
→ EMC → RHemc is 71%
* Sat humidity @22C 19.88
* $AbsHum_{bin}$ is 19.88 x .71
= 14.2 gr/m^3
What RH would the outside air be to have the same humidity of 14.2?
Sat humidity @ 19 C is 16.4 gr/m^3
RHthres 14.2/16.4 =86.4%

Since the actual outside air has a lower RH, 76%, than Rhthres, 86%, we have good drying conditions
12.5 gr/m^3 < 14.2 gr/m^3



Dripping and Crusting

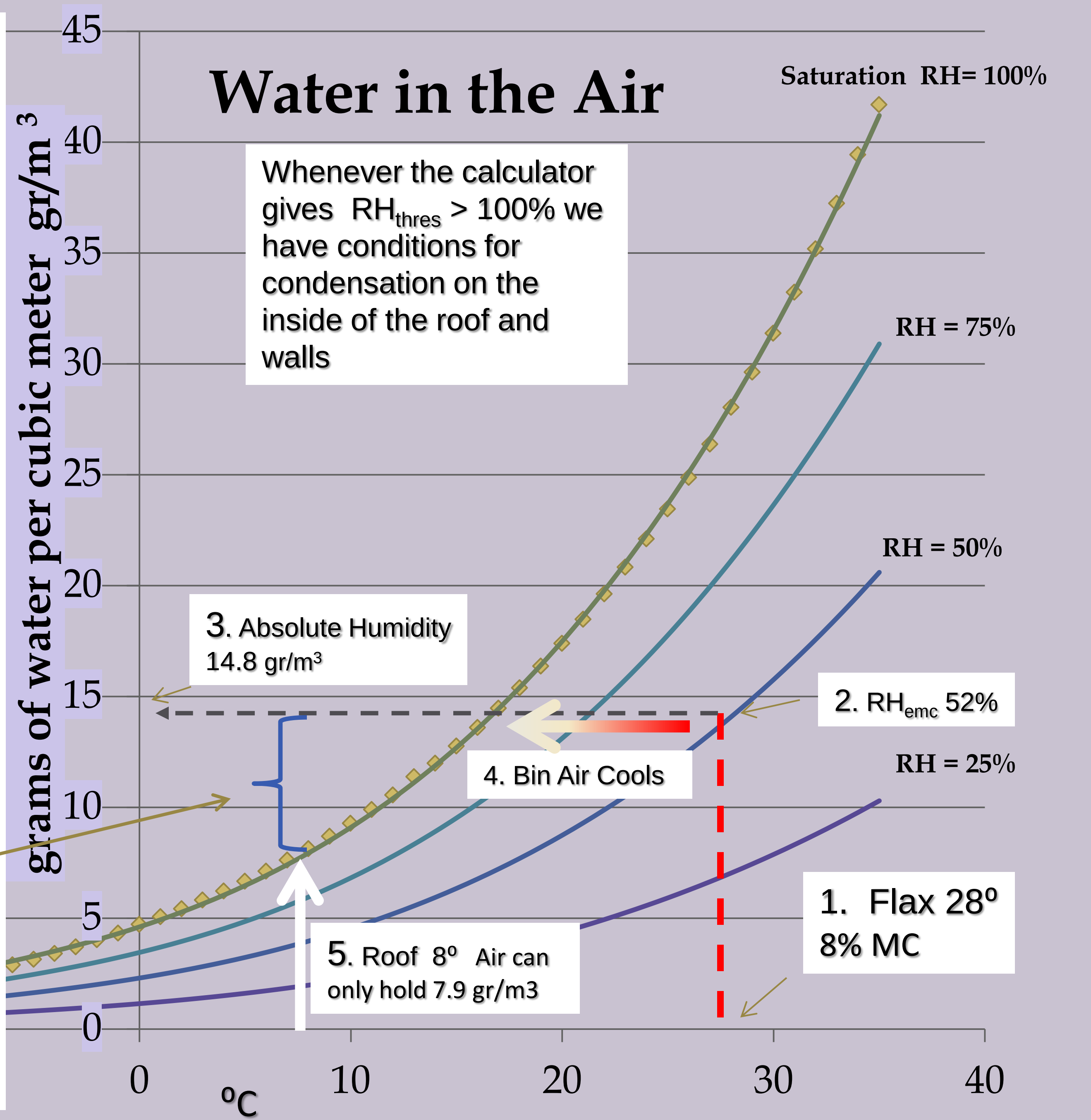
Email from farmer near Moose Jaw:

Flax harvested dry 8% MC, but it is warm 28º C

Nothing is done for a month, but then decides to cool it down, by using night drying: yard light rule. Nights are getting cooler and going down to 8ºC. Next morning lots of condensation on the inside roof. Did drying at night add water? Or, where did the water come from? The flax was dry?

Plug numbers into calculator, 8% 28 C 8 C and we get 186% for TH_{thres}. What's going on here? How can an RH be greater than 100% ??

1. Flax 28 C , 8 % MC
2.→ EMC → RHemc 52%
3. Sat humidity @ 28C 28.2 absolute humidity in the bin: 28.2 x .52 = 14.8 gr/m^3
4. The air in the bin is 28º RH is 52%, and absolute humidity is 14.8. When this air hits the roof, which it cools to 8º C but keeps the same water 14.8.
5. But air at 8º can't hold that much water, the most it can hold is 7.9.
6. For every cubic meter of air flowing through the bin almost 7 grams of water will be dripping on the flax. (80 lbs/hr. @ 3000 CFM)



Control Strategies: The ultimate, the good, the bad and the ugly

RH on, Water Balance Off (compare absolute humidity of air in and out)

- This is the **ultimate** controller, but it requires a moisture cable strung from the center roof collar, with the highest **RH/T** sensor being in the discharge air.
- The lower **T/RH** sensors would be in the grain. For each of these sensor nodes, the absolute humidity can be calculated and compared to the absolute humidity of the outside air. If the absolute humidity of the outside air is less than the grain air, the fan is activated.
- Once the fan is on, a water balance calculation is done to determine the net amount of water leaving the bin. When the calculation indicates that there is no longer a net flow of water out of the bin, the fan is turned off and in an hour we return to comparing the absolute humidity of outside air, and grain air.
- This strategy depends on the installation of a more expensive moisture cable, it avoids the inaccuracies of the **EMC** equations , or even the knowledge of the grain type.
- Terminate the process when the average **MC** of the grain from top to bottom is dry. The grain should still be monitored, and maybe once a month the grain could be cooled to keep it as cold as possible.

Control Strategies: The ultimate, the good, the bad and the ugly

- **EMC Calculator Control**
- The calculator is used to find the conditions in which drying will occur and thus be used to turn the fan on and off.
- Requires the grain's **T** ,**MC**, and type as well as the outside air's **T** and **RH**.
- It could easily be configured to turn the fan on and off automatically, but it also could be used to control the fan manually. For those that have temperature sensors and are not keen on changing to moisture sensors, this may be the way to go.
- The disadvantage with this method is that calculations must be made and that are subject to the inaccuracies of the **EMC** equations. Also if we have an obscure grain, it may not be listed on the calculator.
- The fan should not be turned on if dripping or condensation will occur -- that is if: $\mathbf{RH}_{thres} > 100$
- The advantage with this method is that moisture cables are not required. The only critical sensor is the temperature of the grain which can be obtained with existing temperature cables, or with a temperature probe. The outside air T and RH can easily be obtained from the weather station.
- This control could be improved by adding RH and T in the discharge air to use the Water Balance Method as the criteria to turn the fan off.

Control Strategies: The ultimate, the good, the bad and the ugly

Temp Difference Control: Tair < Tgrain

- This requires only two simple temperature sensors, one in the grain and the other in the outside air.
- No math or calculations are required, and the comparison can easily be done manually or with very simple electronics.
- This would be a simple technique that could be used for automatic control. It should be started as soon as the bin is filled, and end when the average of the grain is dry, after a cold night.
- It is lacking in that it does not take into account either the **MC** of the grain or the **RH** of the outside air. It is not perfect, but it is simple.
- Fine tuning this Method will ensure that no wetting will occur by adding an offset and only turning the fan on if the outside air has an RH < 80% Fan On IFF Tair + 2 < Tgrain and RH < 80% This will ensure no wetting, but it is at the expensive of missing drying opportunities, albeit weak drying opportunities.
- This method keeps the grain as cold as possible and is therefore a very safe method.

Control Strategies: The ultimate, the good, the bad and the ugly

Water Balance , Water In/Out Control

- This requires **T** and **RH** sensors on the air entering and leaving the bins.
- It also involves some calculations to determine the net amount of water leaving the bin.
- However the exhaust **T** and **RH** sensor are only effective when the air is moving or when the fan is on. When there is no air flow, the fan is off, the sensor are in stagnant air and do not represent the true readings of the exhaust air.
- So this is a great mechanism to determine when to turn the fan off (no or little drying is occurring) but it is useless when in determining when to turn it on. The ultimate controller uses this method to turn the fan off – indeed you really can't beat it because it does all the averaging etc. and therefore looks at the bin as a whole and can truly shut the fan off when drying ceases – no guess work, no assumptions.

Control Strategies: The ultimate, the good, the bad and the ugly

On at Night

- One requires no sensors, and only a little attention to turn the fan on at night and off by 9 the next morning.
- The fan should be turned on immediately, even while the bin is being filled.
- When the average grain moisture is dry, the process should stop after a cold night of running.
- The grain will warm up slowly by maybe a degree a week, and once a month the grain should be cooled by running the fan on a very cold dry night.
- This technique does not check for dripping or condensation conditions. It could be automated with a simple timer controlling the fan’s actuator.

Control Strategies: The ultimate, the good, the bad and the ugly

Continuous Method

- The absolute worst situation is doing nothing with hot tough grain.
- This requires no attention, no sensors, but has a very high risk for spoilage.
- The number of safe days is small, and the grain is deteriorating quickly.
- It still may work; it may dry the grain, but is very risky with the potential for the most spoilage.
- The next worst thing is to leave the hot tough grain for a week or so before turning it on only during the day. Or, leave it for a week or two, and then turn it on continuously, and finally turn it off after a hot day of running, leaving the grain hot, but somewhat dried.
- It is better to run the fan continuously right from the start, and quitting after a cold night, leaving the grain cold. Leaving the grain hot could be ugly.

Review: What We Learned – Take Home Points

- Best Drying at Night – Diurnal Drying Cycle
- Net Water Out Absolute Humidity Out – Absolute Humidity In
- Cooling is Drying: simple control Tair < Tgrain
- Safe Grain is dry and cool
- EMC can be used to calculate absolute humidity :: control
- Dripping occurs when we don't cool grain immediately
- Run the fan immediately, get it cool, get it safe
- There is a control management strategy for you:
  - On at night
  - Tair < Tgrain
  - EMC calculator
  - The ultimate: absolute humidity bin_{air} > absolute humidity outside_{air}

Possible Future Work

- Bigger bins
- Oil seeds
- Verify ultimate Controller
- Mitigate drying difference top/bottom
- Smaller Fans
- Air Delivery -- Rocket? Side Vents
- Long term storage studies -- years

Contact   Questions?

Email: Ron.Palmer@uregina.ca

IHARF: www.iharf.ca

EMC calculator: http://planetcalc.com/4959/

Absolute Humidity: http://planetcalc.com/2167/

Blog: http://grain-aeration.com/

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)**