Drying and Storage of Small Grains

Leeds, NY
February 6, 2015

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Recommended Long-Term Storage Moisture Content

EMC @ 70°F & 60% RH

Grain	EMC	Moisture
Barley	11.8%	12%
Canola	8.0%	8%
Corn	12.8%	13%
Flaxseed	8.3%	8%
Soybeans	10.2%	11%
Sunflower		
Non-Oil	9.6%	10%
Oil	7.4%	8%
Wheat	13.3%	13.5%

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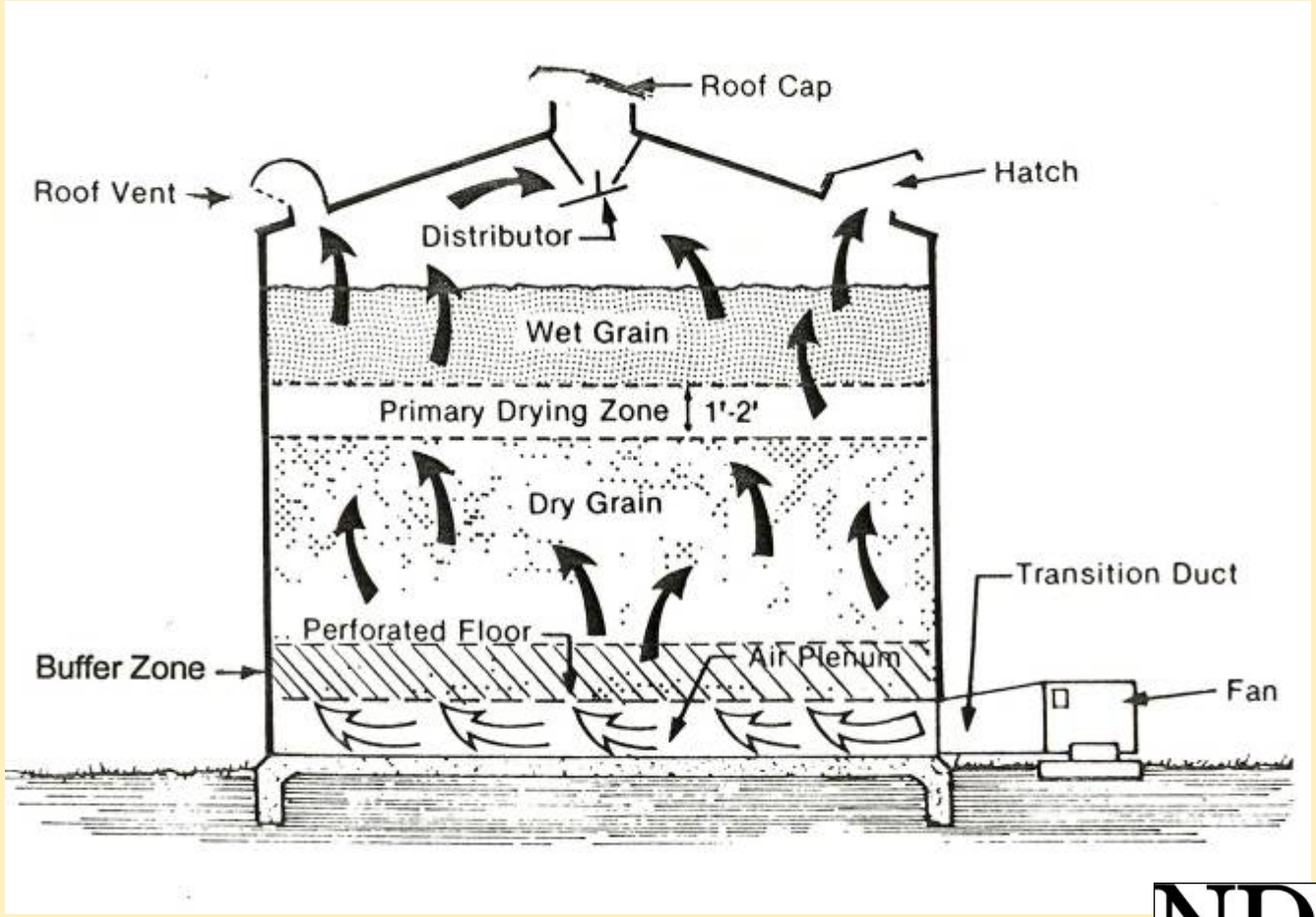
Natural Air Drying



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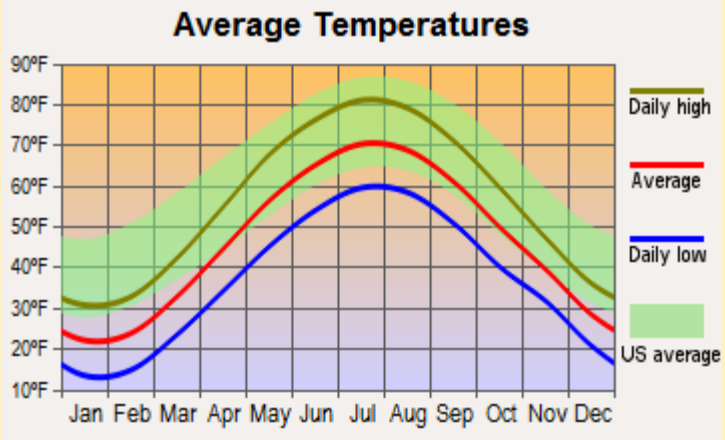
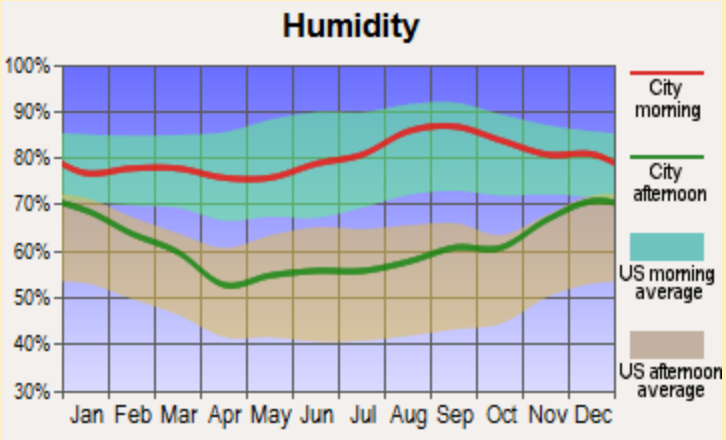
North Dakota Harvest Progression

	Aug			Sep			Oct			Nov
Crop	10	20	30	10	20	30	10	20	30	10
Barley	20	49	77	94	99					
Canola	4	15	36	61	81	92	97			
Corn					2	9	22	43	73	88
Flaxseed		7	20	40	61	79	90	96		
Soybeans					15	46	67	83	93	98
Sunflower						7	21	49	78	90
Wheat	13	34	61	83	94	98	99			
Temperature		69			58			47		27

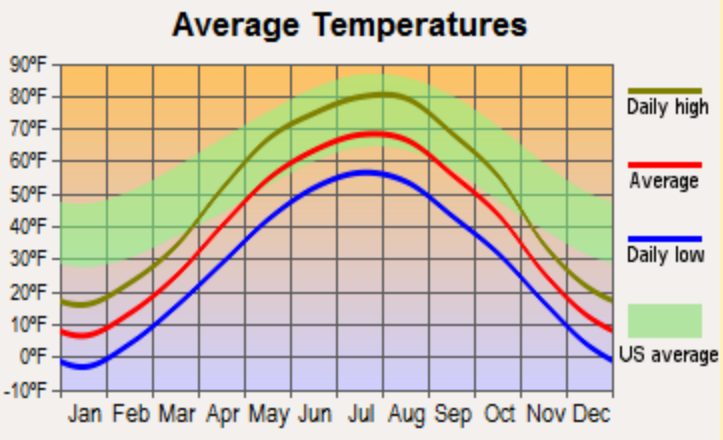
Climate Comparison, NY v. ND

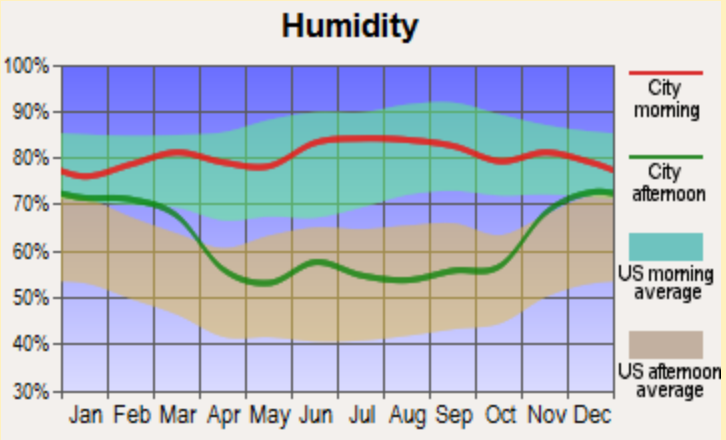
Syracuse, NY





Carrington, ND

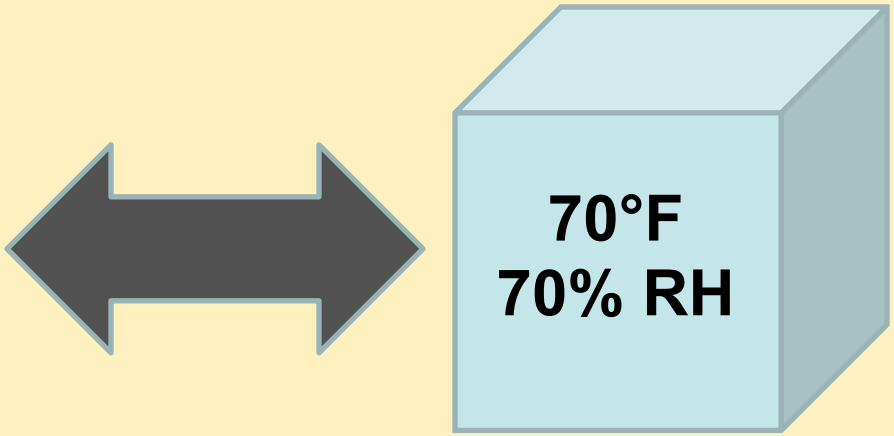




Equilibrium Moisture Content

Barley

Air



EMC = 13.3%

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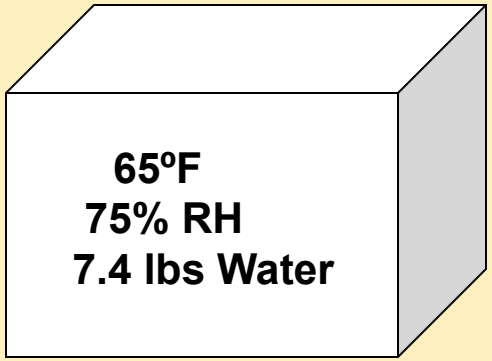
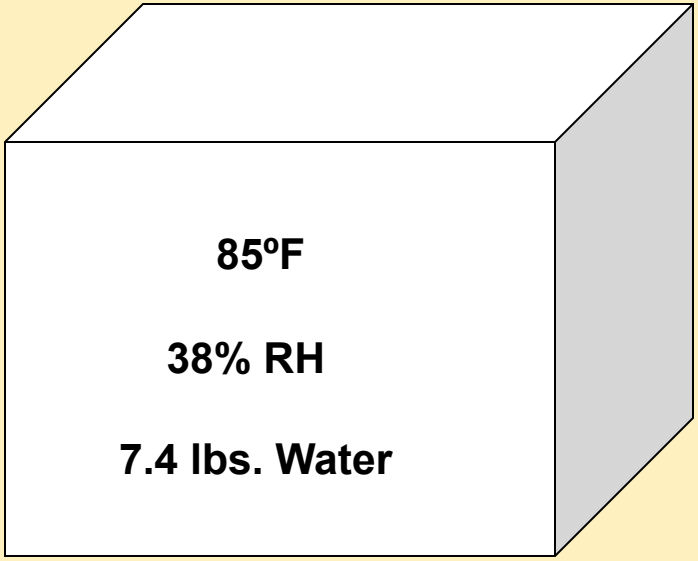
Heat Reduces Air Relative Humidity and Grain Moisture Content



EMC= 15.8%



EMC = 10.0%

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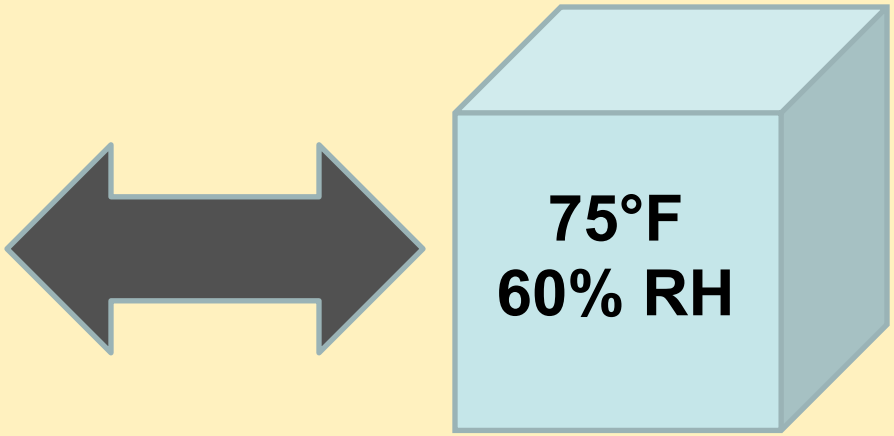
10,000 cubic feet of air

Equilibrium Moisture Content

Barley

Air



EMC = 11.7%

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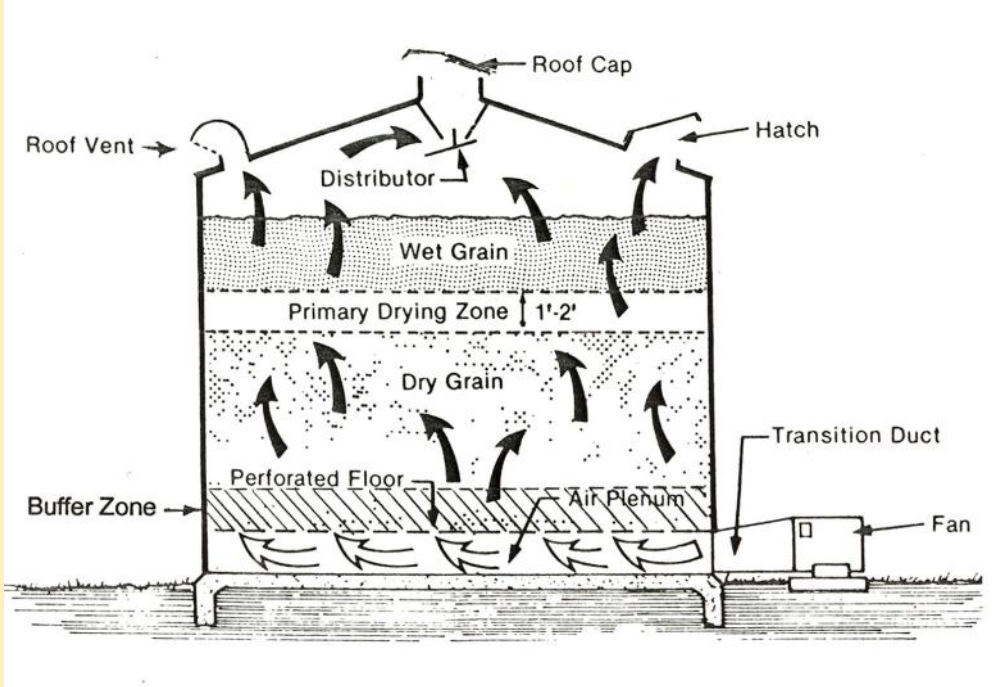
Running Fans at Night



Condition	Temp. (F)	Relative Humidity	E.M.C
Afternoon	80	43%	10.7%
Night	60	85%	17.9%
Average	70	60%	13.3%

Barley Equilibrium Moisture Content

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BARLEY EQUILIBRIUM MOISTURE CONTENT																	
	TEMPERATURE (°F)																
	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°	95°	100°
R.H.	MOISTURE CONTENT (% W.B.)																
5%	3.3	3.3	3.3	3.2	3.2	3.2	3.2	3.2	3.1	3.1	3.1	3.1	3.1	3.0	3.0	3.0	3.0
10%	4.7	4.6	4.6	4.6	4.5	4.5	4.5	4.4	4.4	4.4	4.4	4.3	4.3	4.3	4.3	4.2	4.2
15%	5.7	5.7	5.6	5.6	5.6	5.5	5.5	5.5	5.4	5.4	5.4	5.3	5.3	5.3	5.2	5.2	5.2
20%	6.6	6.6	6.5	6.5	6.5	6.4	6.4	6.3	6.3	6.3	6.2	6.2	6.1	6.1	6.1	6.0	6.0
25%	7.5	7.4	7.4	7.3	7.3	7.2	7.2	7.1	7.1	7.0	7.0	7.0	6.9	6.9	6.8	6.8	6.8
30%	8.2	8.2	8.1	8.1	8.0	8.0	7.9	7.9	7.8	7.8	7.7	7.7	7.6	7.6	7.5	7.5	7.5
35%	9.0	8.9	8.8	8.8	8.7	8.7	8.6	8.6	8.5	8.5	8.4	8.4	8.3	8.3	8.2	8.2	8.1
40%	9.7	9.6	9.6	9.5	9.4	9.4	9.3	9.3	9.2	9.1	9.1	9.0	9.0	8.9	8.9	8.8	8.8
45%	10.4	10.3	10.2	10.2	10.1	10.1	10.0	9.9	9.9	9.8	9.8	9.7	9.7	9.6	9.5	9.5	9.4
50%	11.1	11.0	10.9	10.9	10.8	10.7	10.7	10.6	10.6	10.5	10.4	10.4	10.3	10.3	10.2	10.1	10.1
55%	11.8	11.7	11.6	11.6	11.5	11.4	11.4	11.3	11.2	11.2	11.1	11.0	11.0	10.9	10.9	10.8	10.7
60%	12.5	12.4	12.4	12.3	12.2	12.1	12.1	12.0	11.9	11.9	11.8	11.7	11.7	11.6	11.5	11.5	11.4
65%	13.3	13.2	13.1	13.0	13.0	12.9	12.8	12.7	12.7	12.6	12.5	12.5	12.4	12.3	12.3	12.2	12.1
70%	14.1	14.0	13.9	13.8	13.8	13.7	13.6	13.5	13.4	13.4	13.3	13.2	13.1	13.1	13.0	12.9	12.9
75%	15.0	14.9	14.8	14.7	14.6	14.5	14.4	14.4	14.3	14.2	14.1	14.0	14.0	13.9	13.8	13.7	13.7
80%	15.9	15.8	15.7	15.6	15.6	15.5	15.4	15.3	15.2	15.1	15.0	15.0	14.9	14.8	14.7	14.6	14.6
85%	17.1	17.0	16.9	16.8	16.7	16.6	16.5	16.4	16.3	16.2	16.1	16.0	15.9	15.9	15.8	15.7	15.6
90%	18.5	18.4	18.2	18.1	18.0	17.9	17.8	17.7	17.6	17.5	17.5	17.4	17.3	17.2	17.1	17.0	16.9
95%	20.5	20.4	20.3	20.2	20.1	19.9	19.8	19.7	19.6	19.5	19.4	19.3	19.2	19.1	19.0	18.9	18.9

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Source: ASAE D245.4 Modified Henderson Equation

"Approximate" Allowable Storage Time for Cereal Grains (Days)

Moisture	----- Grain Temperature (°F) -----					
Content	30°	40°	50°	60°	70°	80°
(%)	Approximate Allowable Storage Time (Days)					
14	*	*	*	*	200	140
15	*	*	*	240	125	70
16	*	*	230	120	70	40
17	*	280	130	75	45	20
18	*	200	90	50	30	15
19	*	140	70	35	20	10
20	*	90	50	25	14	7
22	190	60	30	15	8	3
24	130	40	15	10	6	2
26	90	35	12	8	5	2
28	70	30	10	7	4	2
30	60	25	5	5	3	1

* Exceeds 300 days

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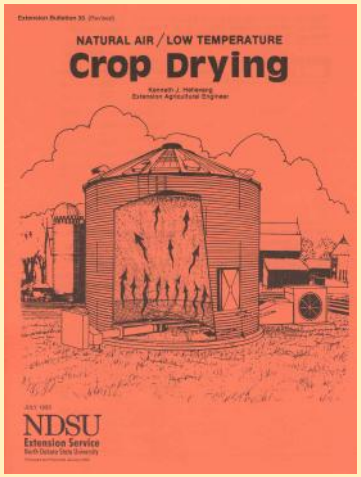
Airflow Rates and Drying Times

natural air drying wheat

air at 69°and 60% relative humidity, average North Dakota condition for August.

Moisture Content	Airflow (cfm/bu)	Fan Time	
		Hours	Days
18%	1.25	480	20
	1.00	600	25
17%	1.00	552	23
	0.75	744	31
16%	1.00	504	21
	0.75	672	28
	0.50	1,008	42
15%	1.00	480	20
	0.75	648	27
	0.50	960	40
14%	1.00	408	17
	0.75	544	23
	0.50	816	34



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Horsepower Required Increases with Airflow Rate			
Cfm/bu.	HP	HP/1,000 bu.	Static Pressure
0.5	4	0.4	3
0.75	9	1.0	5
1.0	17	1.8	7
1.5	44	4.8	12

27 ft. diameter bin with barley 20 ft. deep
9,161 bushels

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Horsepower Required Increases with Grain Depth

Depth (ft.)	HP	HP/1,000 bu.	Static Pressure (inch H_20)
15	3.5	0.5	2.6
17	5.3	0.7	3.4
19	7.5	0.9	4.4
21	10.4	1.1	5.5
23	14.0	1.3	6.8
25	18.5	1.6	8.2

27 ft. diameter bin of barley with 0.75 cfm/bu. airflow rate

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Wheat Drying Time

17% initial M.C., 0.75 cfm/bu, +3°F fan

Month	Temp.	RH	+3° Temp	+3° RH	EMC	Days	%↑
Aug.	69	60%	72	54%	12.6%	26	
Sep/ May	58 56	65% 60%	61	58%	13.5%	31	20%
Oct/ Apr	47 42	65% 65%	50	58%	13.9%	39	50%
Nov/ Mar	27 24	73% 73%	30	63%	15.6%	75	300%

Effect of Supplemental Heat Drying Wheat

17% initial M.C., 0.75 cfm/bu, 10,000 bu Bin, $0.06 electric heat, $7.00 Wheat

	Temp (°F)	RH (%)	EMC (%)	Drying Time (Days)	Shrink Cost	Heat Cost	Overdry Cost
Ave Sep	58	65	14.4	--			
+3° Fan	61	58	13.5	31			
10° + 3°	71	41	10.8	27	$2,119	$940	$3,059
Ave Oct Cold Sep	47	65	15.0	--			
+3° Fan	50	58	13.9	39			
10° + 3°	60	40	11.0	37	$1,966	$1278	$3,244
Humid Sep	58	75	16.1	--			
+3° Fan	61	67	14.6	40			
10° + 3°	71	47	11.6	28	$1505	$968	$2,473
5° + 3°	66	56	12.9	32	$482	$484	$966

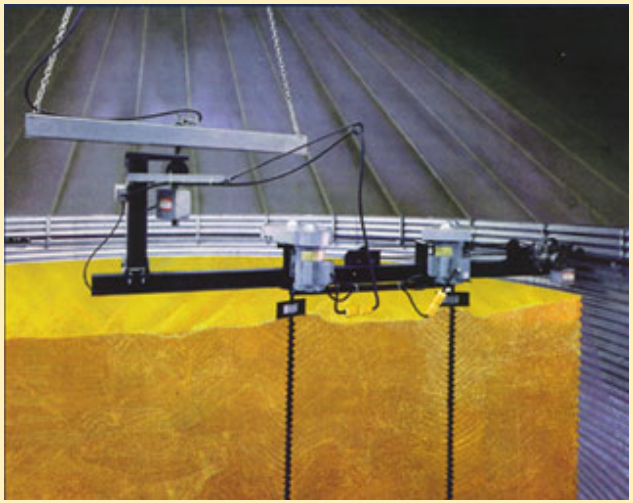
Supplemental Heat

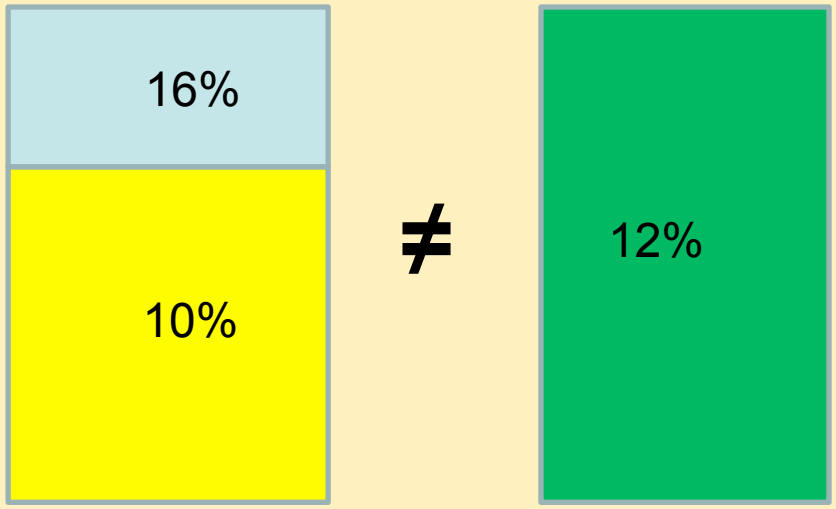
Btu/hr	=	cfm x 1.1 x temperature increase
Btu/hr	=	5,000 x 1.1 x 5
Btu/hr	=	27,500 Btu
1 kW	=	3,413 Btu/hr
	=	8.1 kW

Fan Heat 2-5°F

Wheat Rule of Thumb: 1 Kw heats air 5ºF

Mix Dry Grain with Wet Grain





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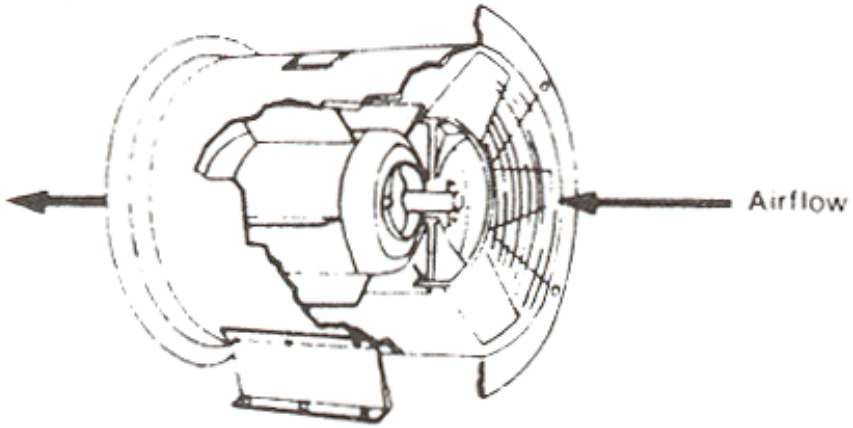
Kernel deterioration?
Equilibration Important!!!
Mechanical damage?

Axial-flow Fans



Axial-flow fans operate most efficiently at static pressures below 3 to 4 inches of water. Noise can be a problem.

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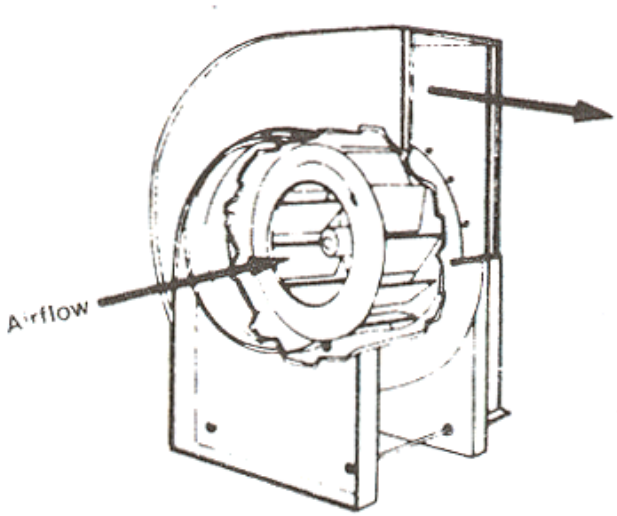
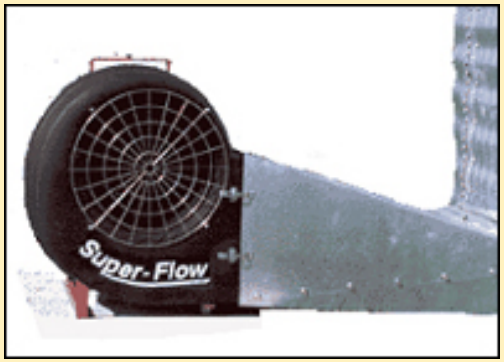
Centrifugal Fans



Centrifugal fans require higher investment than axial-flow fans, but are more efficient at higher static pressures and are quieter. They normally operate at 1,750 or 3,500 rpm.



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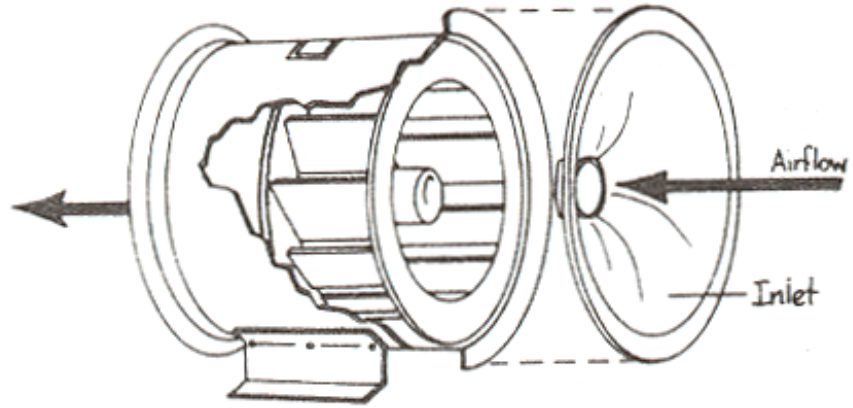
In-line Centrifugal Fans



In-line centrifugal fans develop higher pressures than an axial-fan at a lower cost than a normal centrifugal fan.

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Typical Fan Performance.

	Fan			Static Pressure (Inches of Water)									
Type	Hp	Dia.	RPM	1	2	3	4	5	6	7	8	9	10
		(in.)		Airflow Rate (cfm)									
Axial	3.0	18	3450	5700	4600	2650	1400						
LS Cent.	3.0	24	1750	4580	4230	3820	3350	2550					
HS Cent.	3.0	16	3500		2950		2550		2120		1650		1000
IL Cent.	3.0	18	3450	3800	3600	3400	3000	2500	1900				
IL Cent.	3.0	24	3450	4100	4000	3750	3500	3250	2950	2650			
Axial	5.0	24	3450	10500	9000	7000	4600	2900					
LS Cent.	5.0	24	1750	7800	7000	6250	5550	4600	3300				
HS Cent.	5.0	13	3500		4350		3850		3200		2200		1800
IL Cent.	5.0	24	3450	5500	5000	4400	4100	3900	3600	2800	1800		
Axial	7.5	24	3450	12500	11100	9450	6550	3900					
LS Cent.	7.5	24	1750	10550	9750	8950	8000	7400	6100				
HS Cent.	7.5	15	3500		5700		5100		4500		3800		2900
IL Cent.	7.5	28	3450	6200	6000	5700	5500	5200	4800	4500	4000	3500	3000
Axial	10.0	26	3450	15500	14000	12250	9500	5800	3400				
LS Cent.	10.0	27	1750	13300	12400	11550	10500	9550	8500	7300			
HS Cent.	10.0	18	3500		6800		6300		5750		5100		4450
IL Cent.	10.0	28	3450	7700	7300	6800	6500	6300	6000	5400	5100	4800	4400

LS = Low Speed Centrifugal Fan
HS = High Speed Centrifugal Fan
IL = In-Line Centrifugal Fan

* Consult a comparable table for the actual fan being selected.

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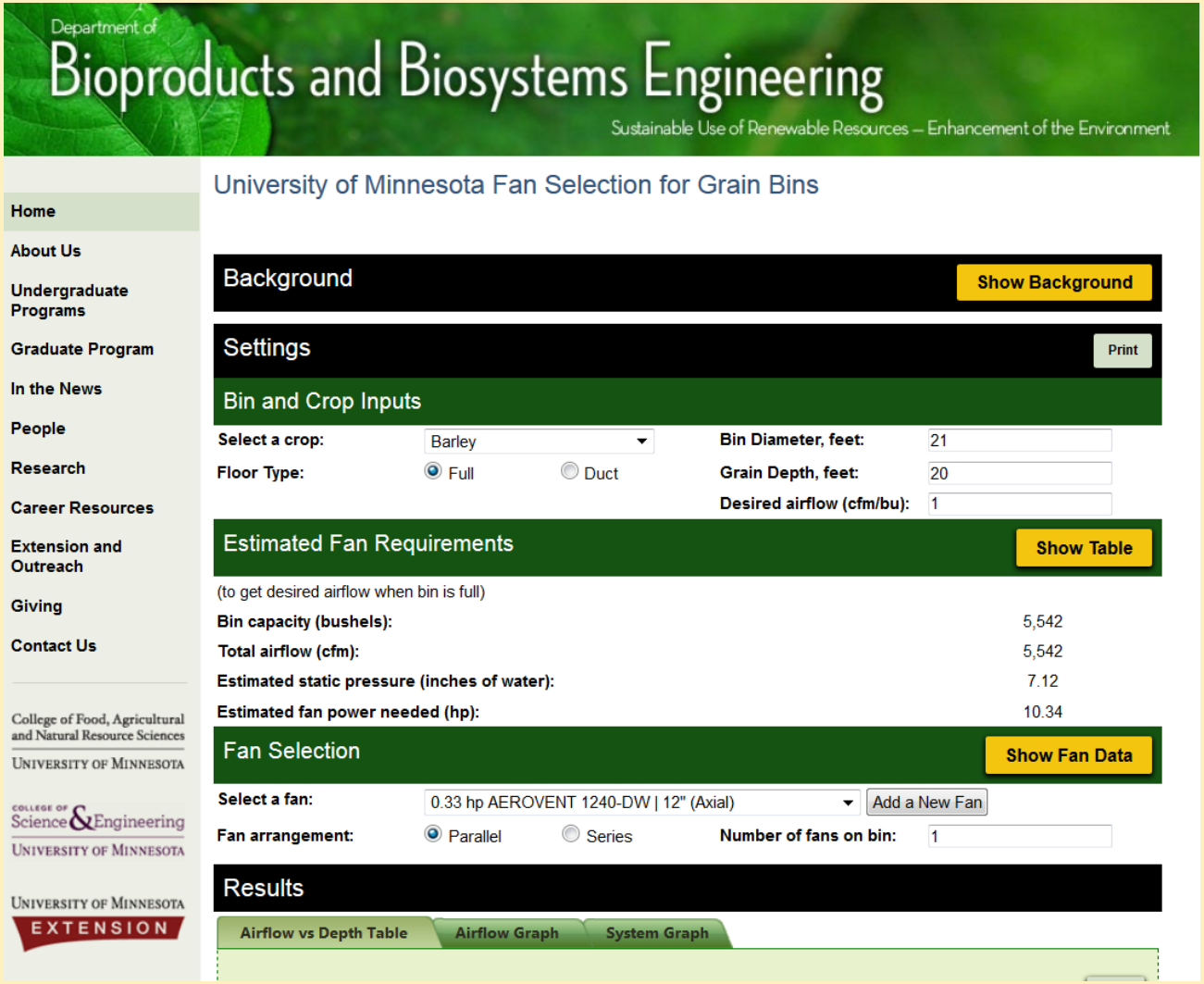
Fan Type Affects Airflow

1 x 7.5 hp LSC = 0.92 cfm/bu
1 x 7.5 hp ILC = 0.97 cfm/bu
1 x 7.5 hp HSC = 0.86 cfm/bu
1 x 7.5 hp Axial = 0.70 cfm/bu

2 x 7.5 hp LSC = 1.40 cfm/bu
2 x 7.5 hp ILC = 1.35 cfm/bu
2 x 7.5 hp HSC = 1.21 cfm/bu
2 x 7.5 hp Axial = 0.80 cfm/bu (in parallel)
2 x 7.5 hp Axial = 1.15 cfm/bu (in series)

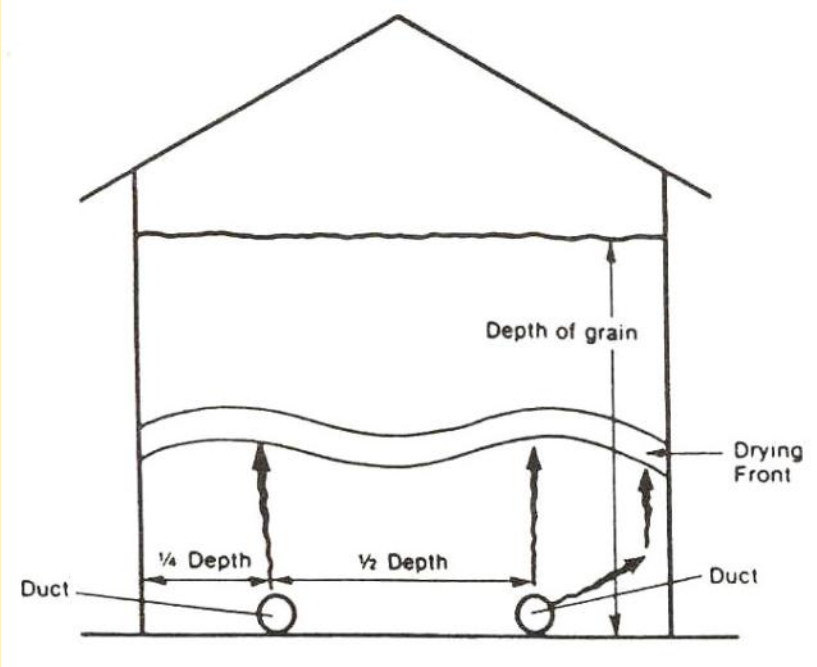
21 ft diameter bin with wheat 17.5 ft deep



http://webapps.bbe.umn.edu/fans/

Preferred Duct Spacing

Drying



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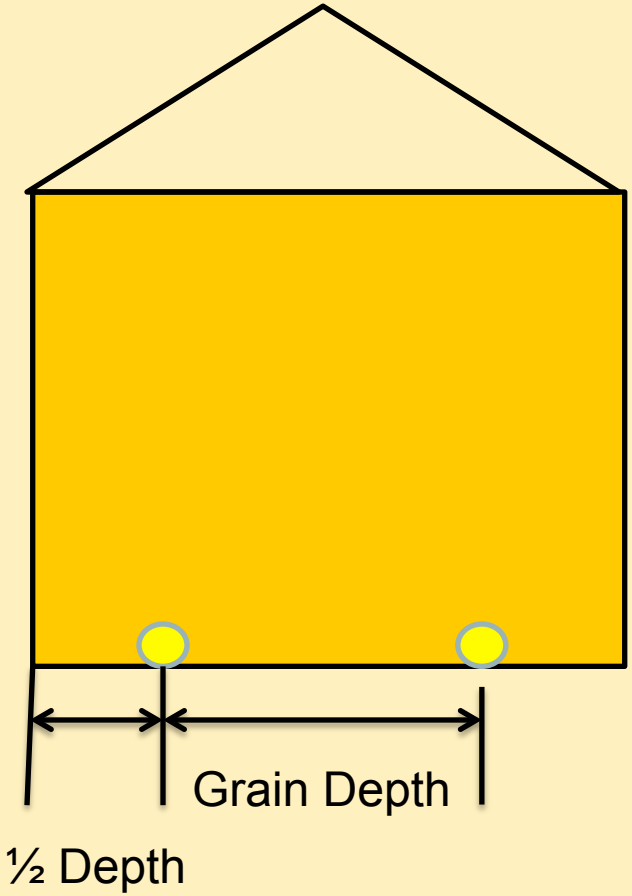
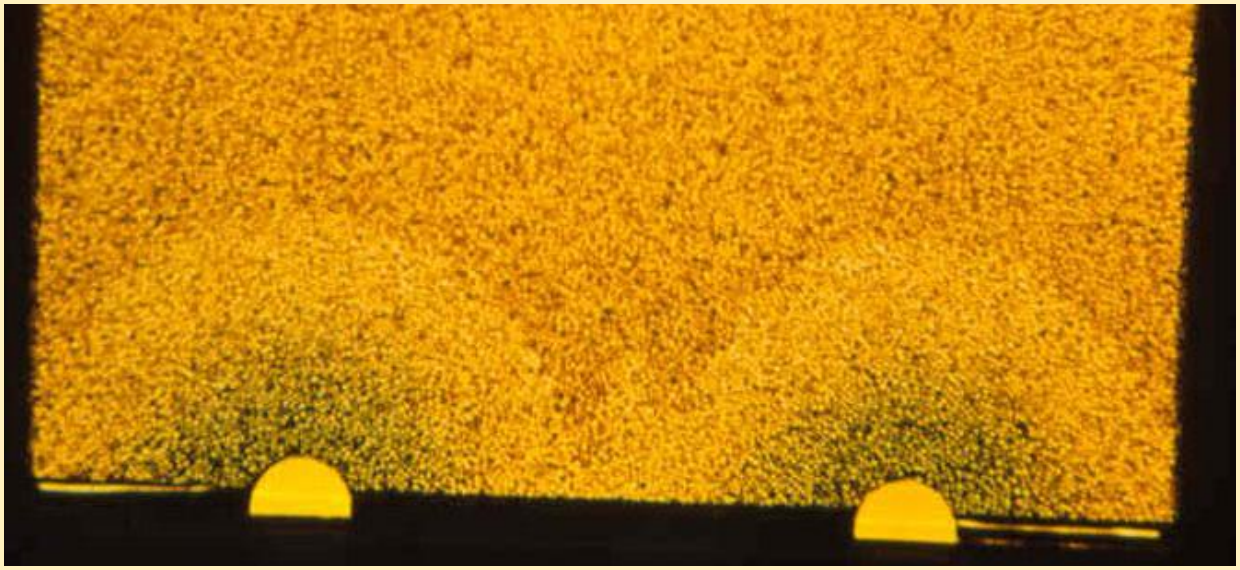
Aeration



Fronts Using Air Ducts



Airflow is not uniform!
Both between and along ducts.

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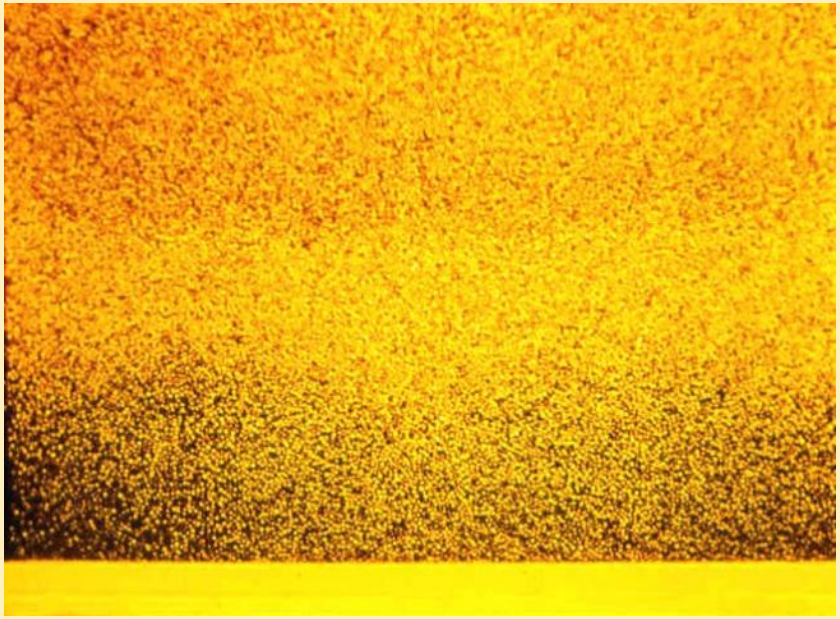
Perforated Floor Preferred



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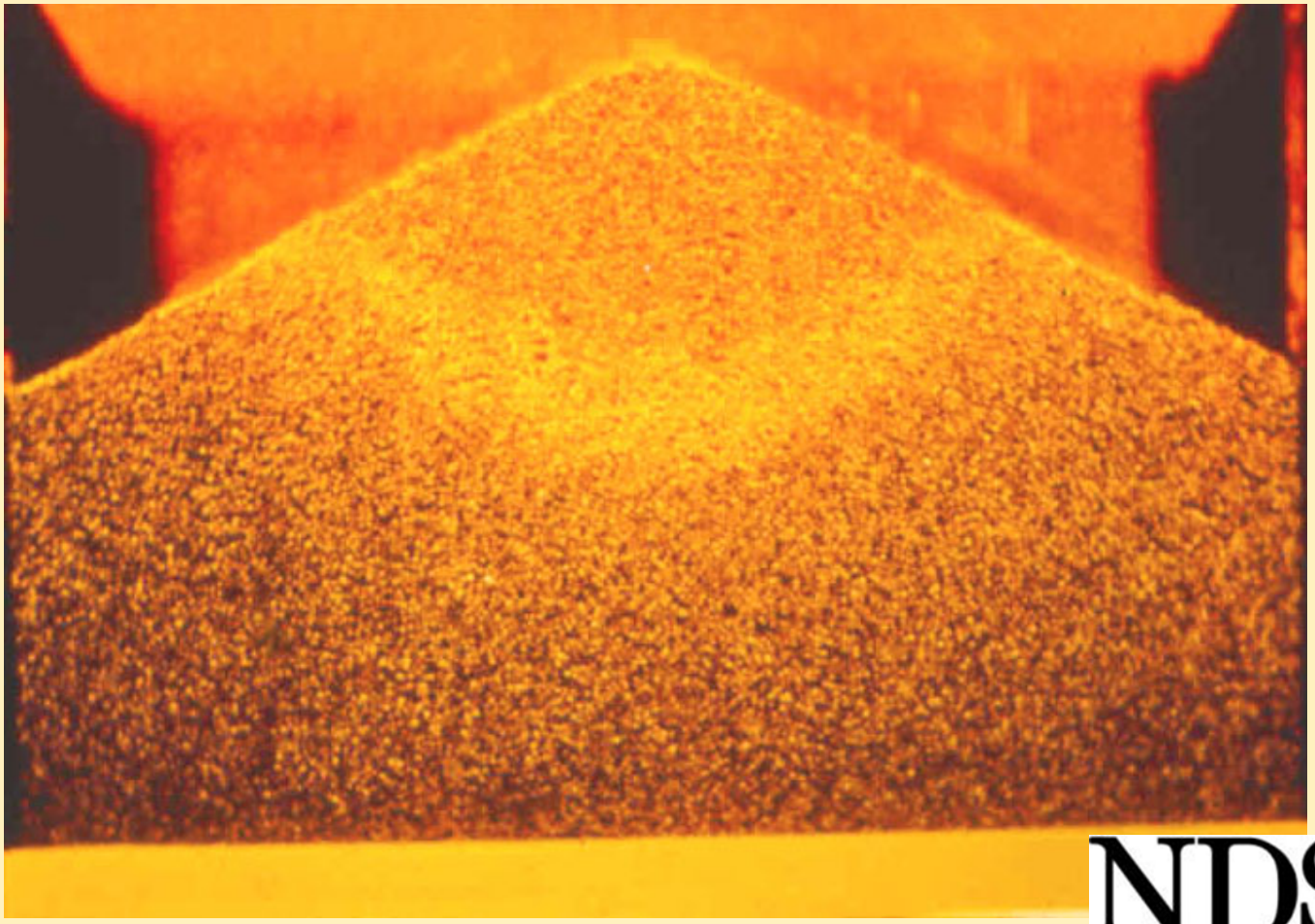
Level Bins for Uniform Airflow



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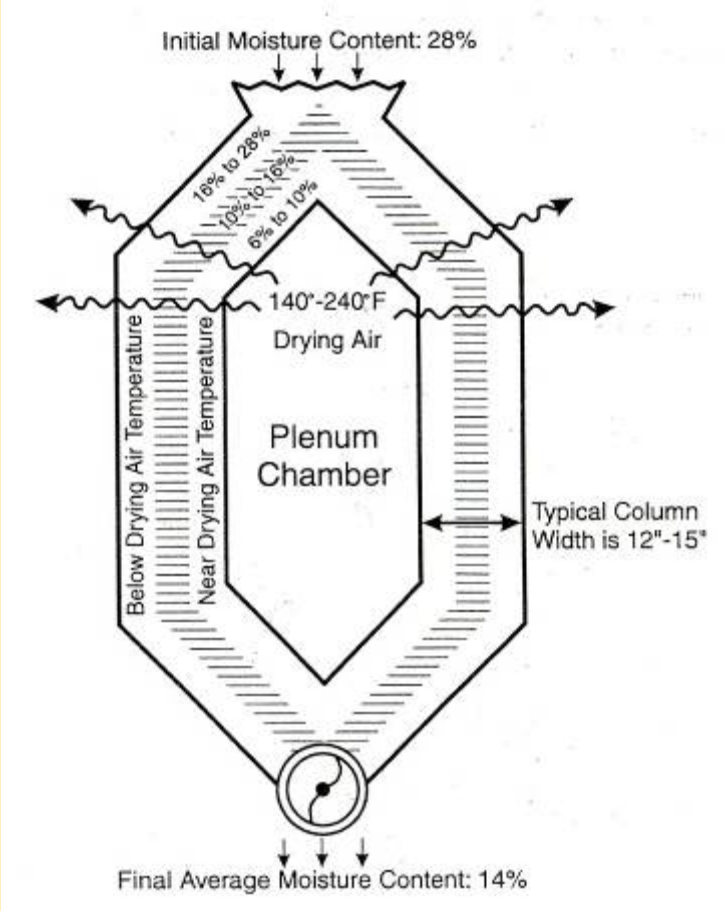
High Temperature Dryer



Maximum temperature to maintain germination ≈110°F

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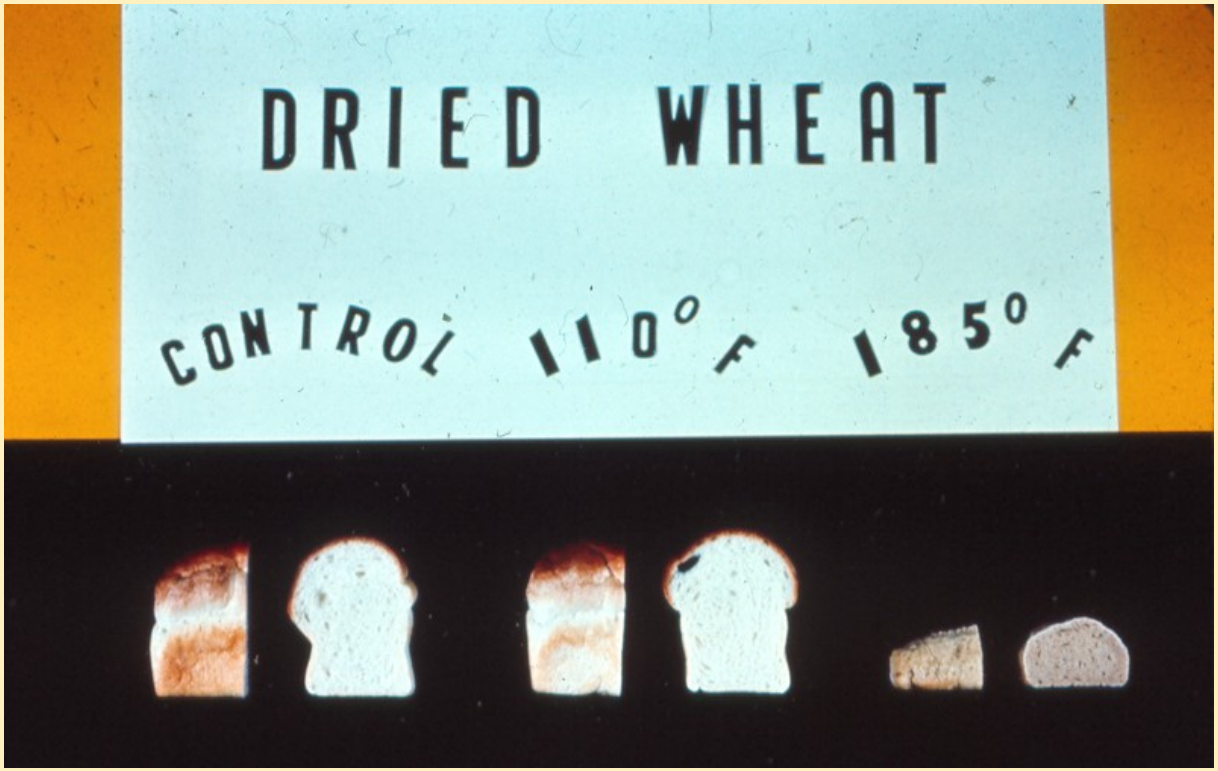
Drying Temperature and Time Affect Quality



Maximum dryer temperature is about 150°F for 16% and 130°F for 20% moisture wheat.

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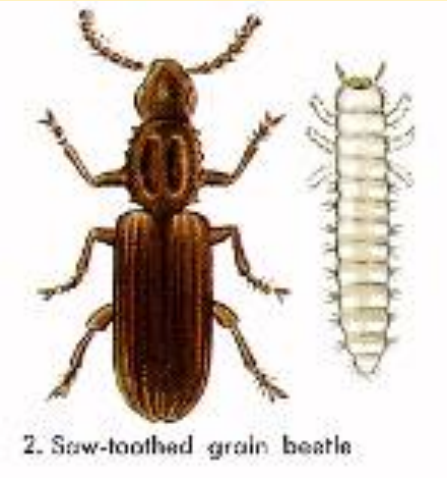
Grain Storage Problems

- Mold
  - Moisture
  - Temperature
- Insects
  - Temperature
  - Cleanliness
  - Grain Protectant
    - Long-term storage



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Grain Storage Steps

- Prepare the structure.
- Prepare the grain.
- Manage the stored grain:
  - Monitoring
  - Aeration

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Clean the Structure

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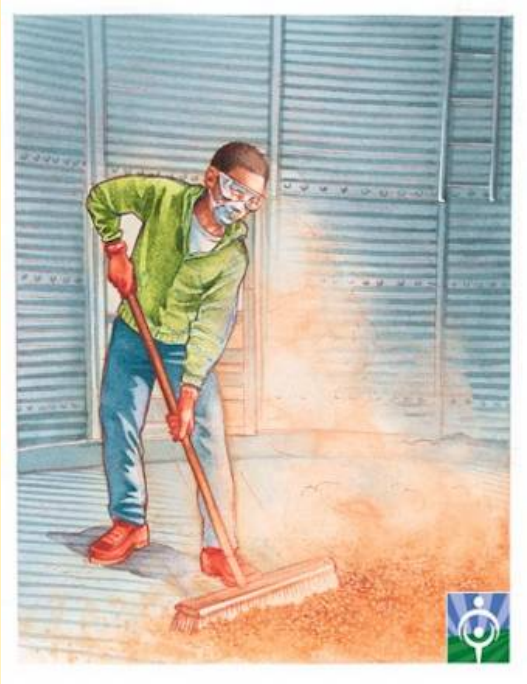

Prepare the Grain

- Grain moisture
- Grain temperature
- Grain condition-kernel damage

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Moisture Measurement

Representative Sample

Follow Instructions

- Adjust for temperature
- May not be accurate <40°F
- Electronic meters more sensitive to outside of kernel
- Meters affected by condensation

- Measure moisture content
- Place sample in sealed container for 6-12 hrs.
- Warm to ~70°F
- Recheck moisture

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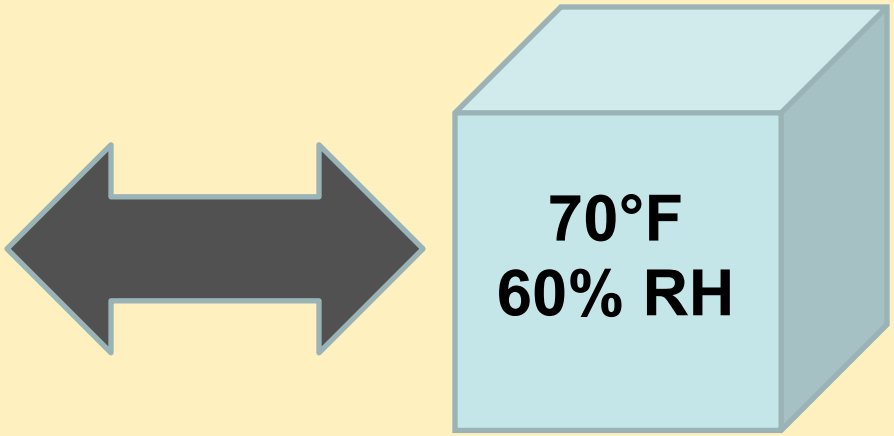
Equilibrium Moisture Content

HRS Wheat

Air



EMC = 13.3%

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Recommended Long-Term Storage Moisture Content

EMC @ 70°F & 60% RH

Grain	EMC	Moisture
Barley	11.8%	12%
Canola	8.0%	8%
Corn	12.8%	13%
Flaxseed	8.3%	8%
Soybeans	10.2%	11%
Sunflower		
Non-Oil	9.6%	10%
Oil	7.4%	8%
Wheat	13.3%	13.5%

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"Approximate" Allowable Storage Time for Cereal Grains (Days)

Moisture	----- Grain Temperature (°F) -----					
Content	30°	40°	50°	60°	70°	80°
(%)	Approximate Allowable Storage Time (Days)					
14	*	*	*	*	200	140
15	*	*	*	240	125	70
16	*	*	230	120	70	40
17	*	280	130	75	45	20
18	*	200	90	50	30	15
19	*	140	70	35	20	10
20	*	90	50	25	14	7
22	190	60	30	15	8	3
24	130	40	15	10	6	2
26	90	35	12	8	5	2
28	70	30	10	7	4	2
30	60	25	5	5	3	1

* Exceeds 300 days

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"Estimated" Allowable Storage Time for Malting Barley (Weeks) (Criterion: Germinability)

		Barley Moisture Content (%w.b.)								
Temperature		11%	12%	13%	14%	15%	16%	17%	18%	19%
(°C)	(°F)	Allowable Storage Time (weeks)								
27	80	32	25	16	10	5	3	1.5	1	1
21	70	80	60	38	25	14	7	3.5	2.5	2
16	60	*	*	94	61	37	18	9	6	3.5
10	50	*	*	*	*	90	50	20	14	8

* Allowable storage time exceeds 100 weeks.

Source: Drying Cereal Grains by Brooker, Bakker-Arkema & Hall

Table developed by Kenneth Hellevang, Ph.D., P.E., 07/16/07

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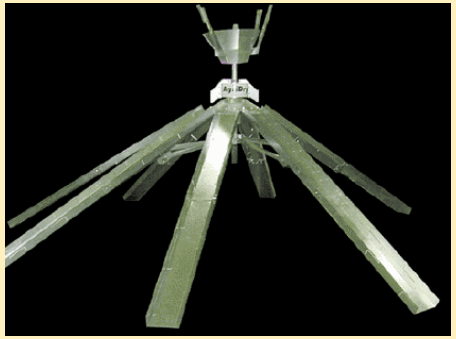
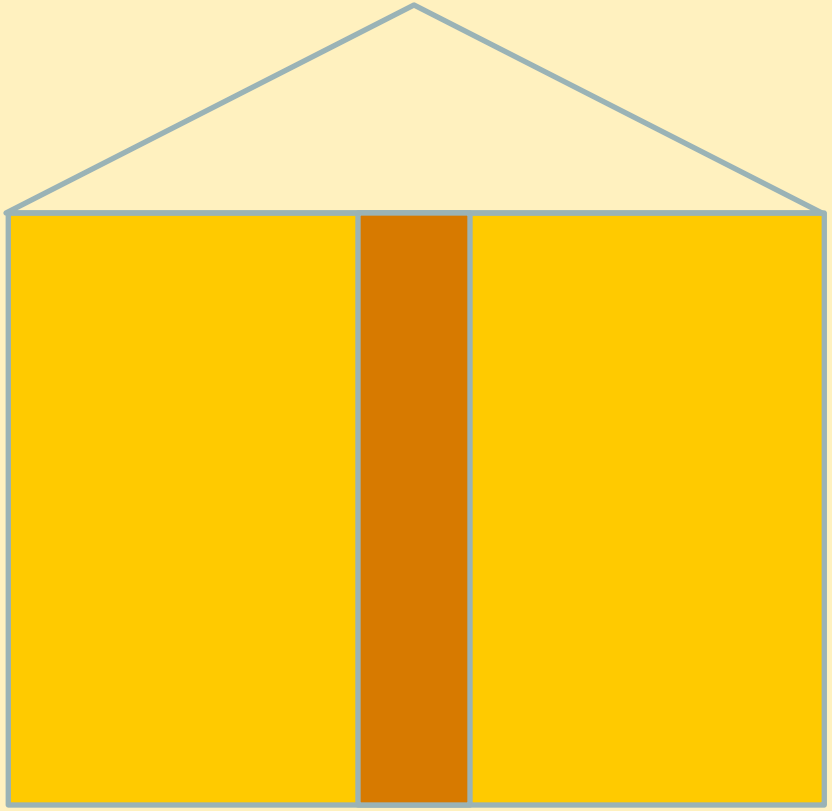
Clean Grain before Storing





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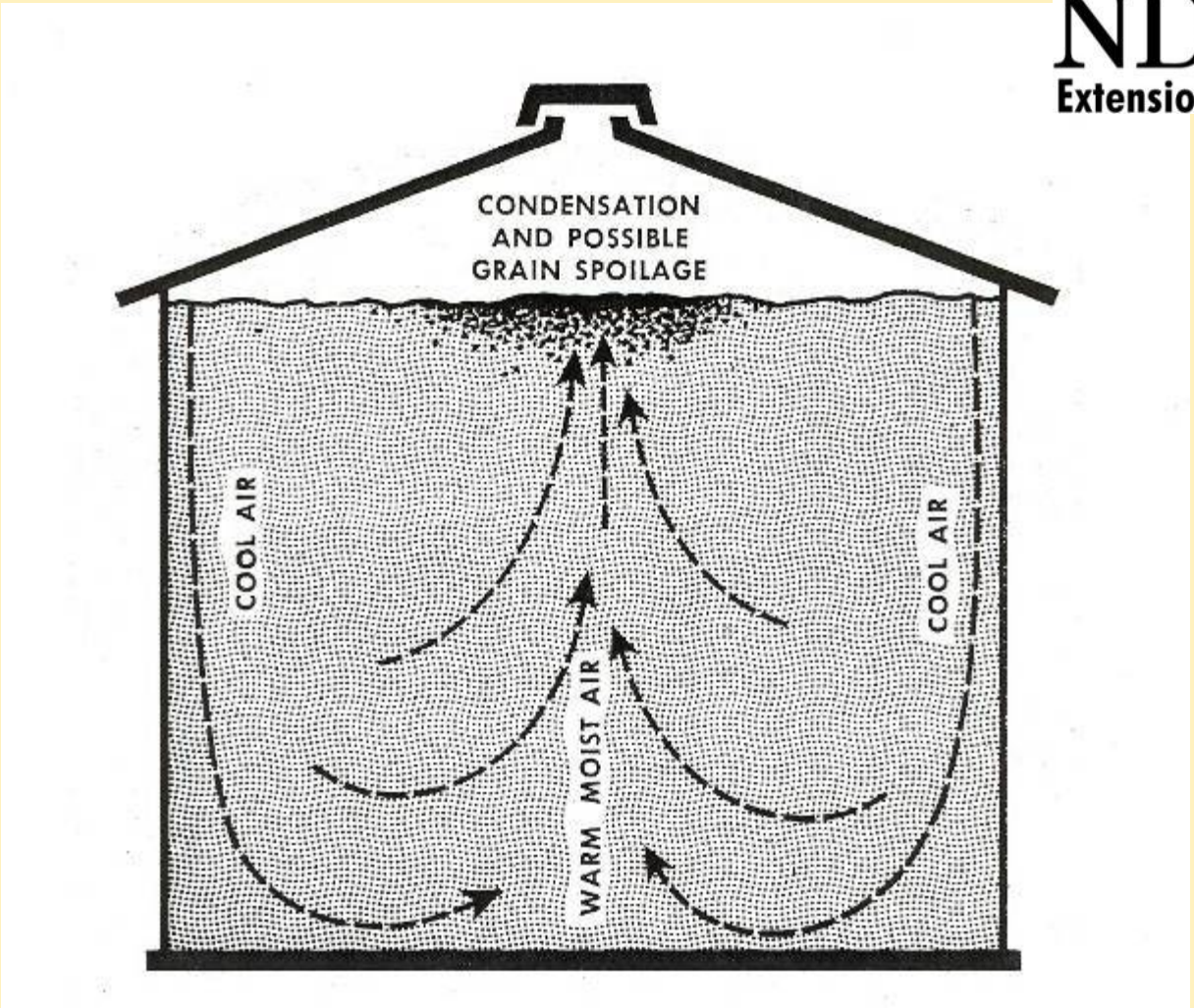

Fall and Winter Moisture Migration

Grain Stays Warm without Aeration

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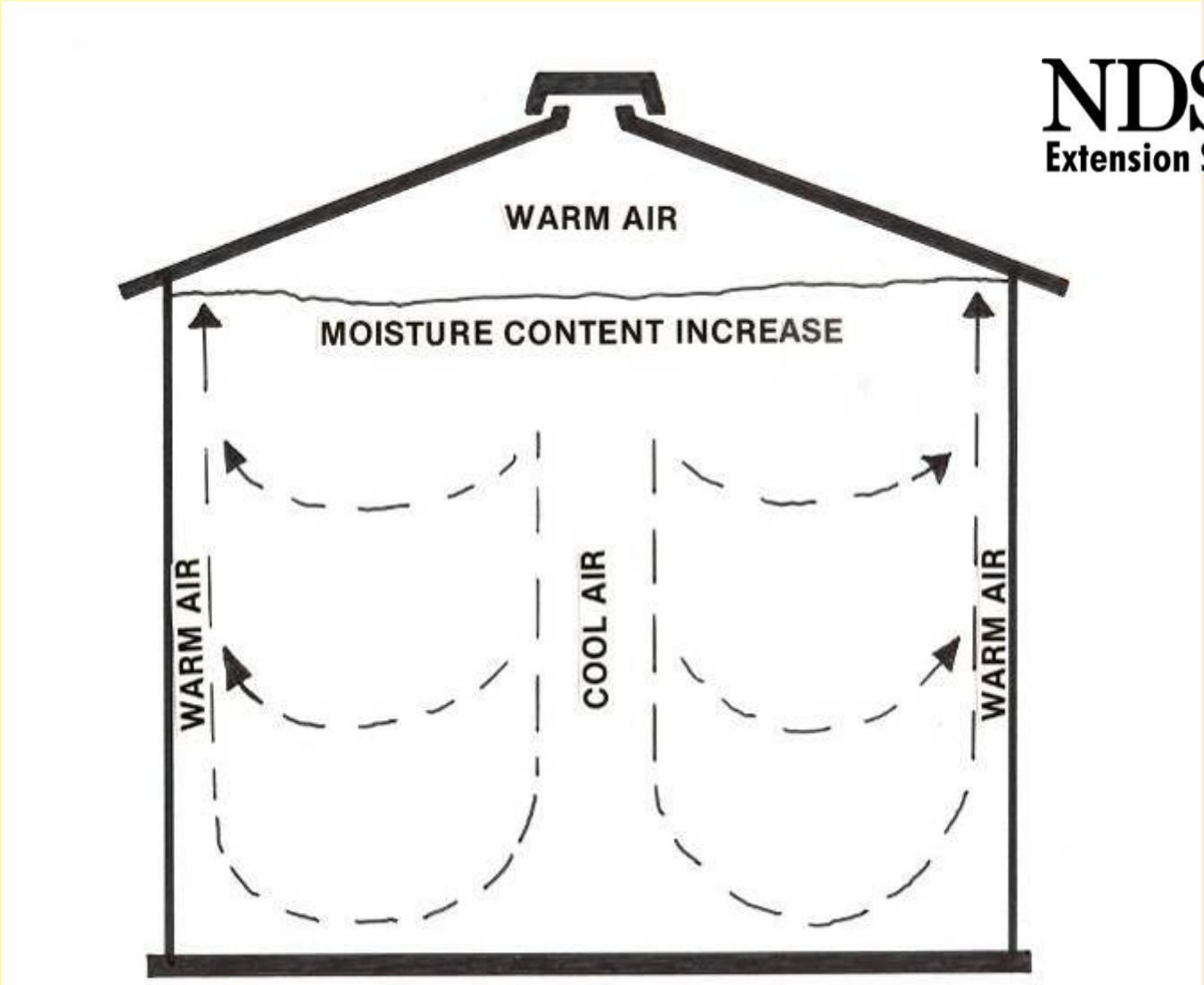
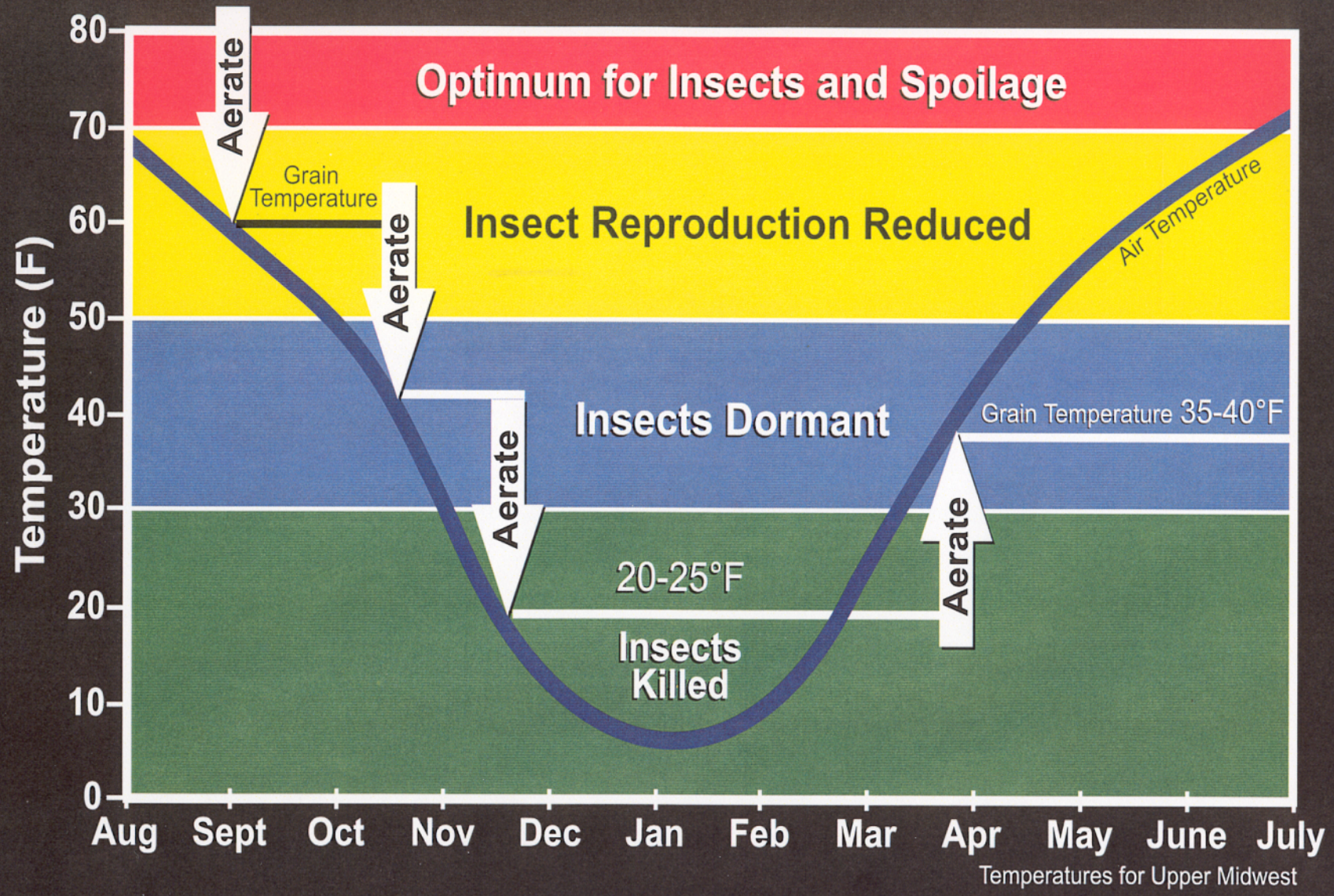


Spring and Summer Moisture Migration

Cool Grain to Prevent Storage Problems



* Prevent crusting due to moisture migration by cooling grain to within 15°F of average outdoor temperatures.
* Cooling grain by 10°F doubles its allowable storage time

Dr. Kenneth J. Hellevang, PE
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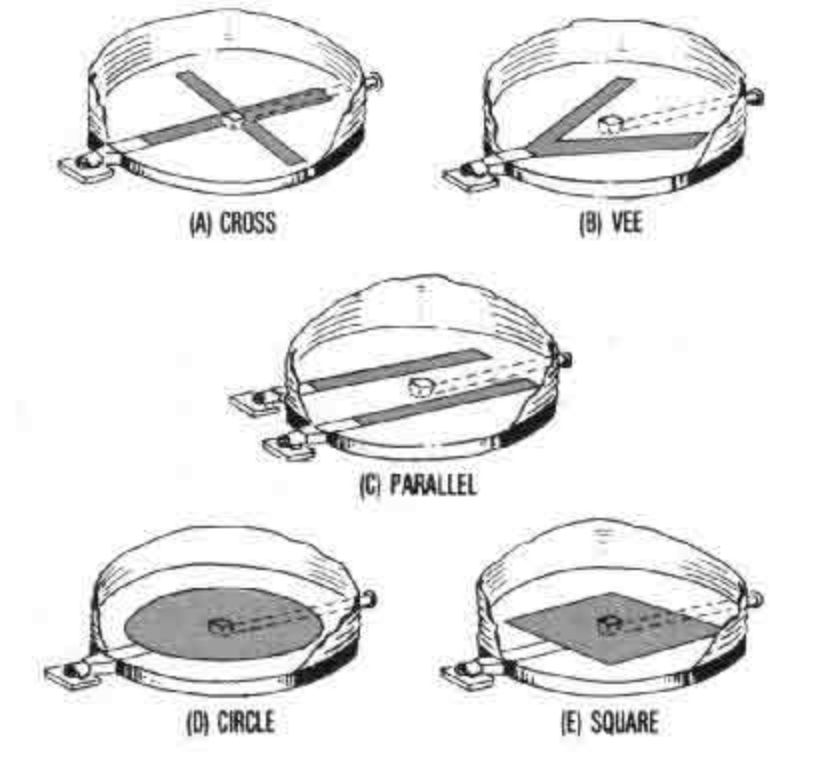
Aeration Used to Control Grain Temperature



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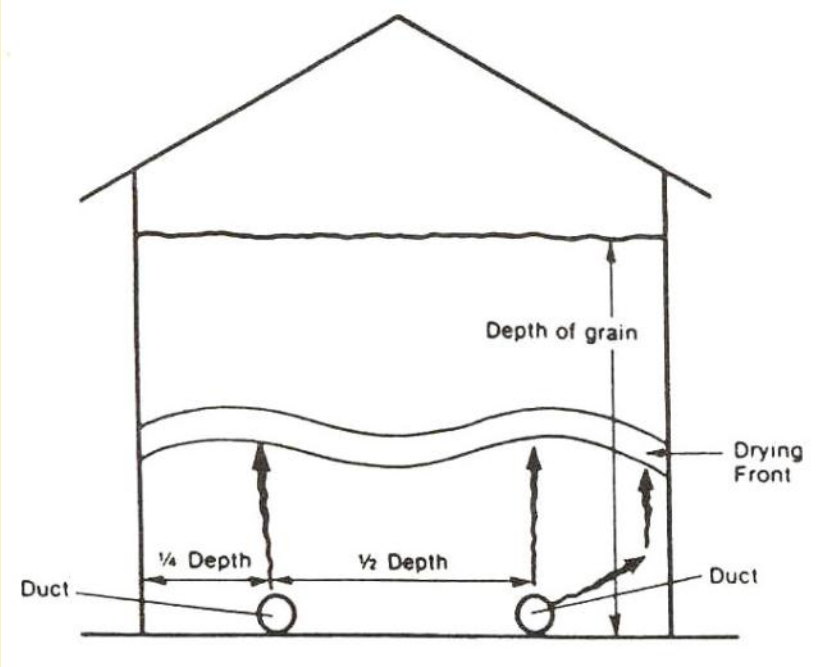
Preferred Duct Spacing

Drying



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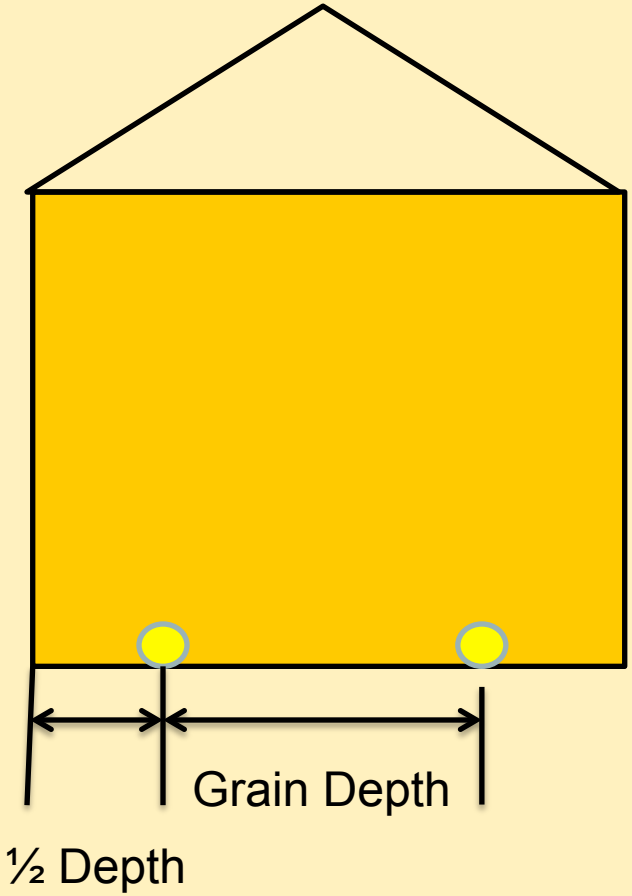
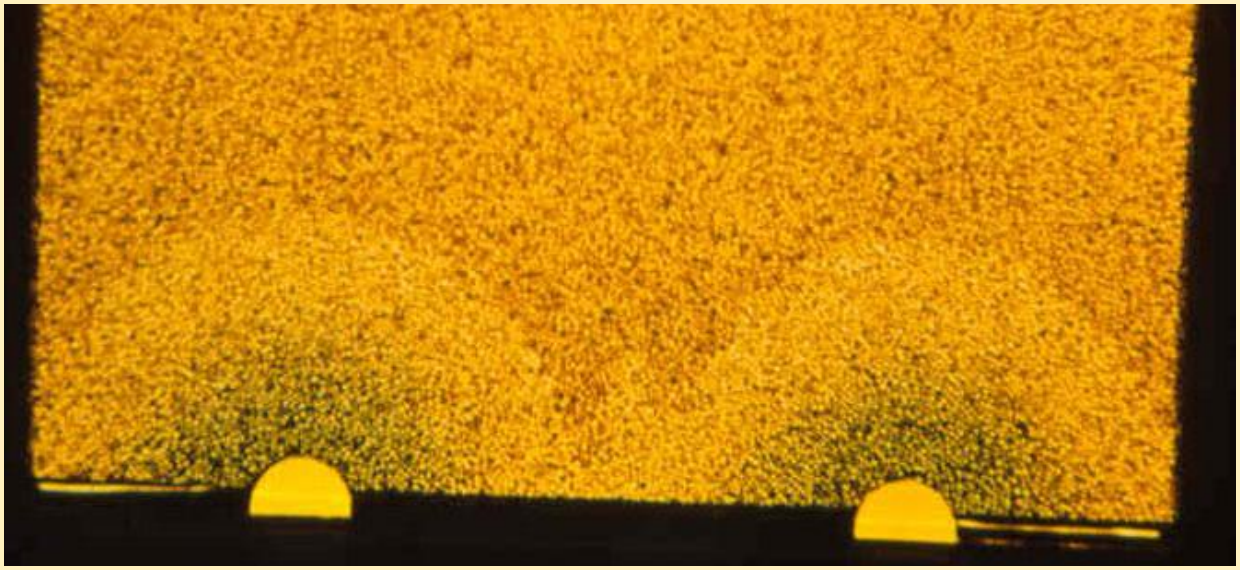
Aeration



Fronts Using Air Ducts



Airflow is not uniform!
Both between and along ducts.

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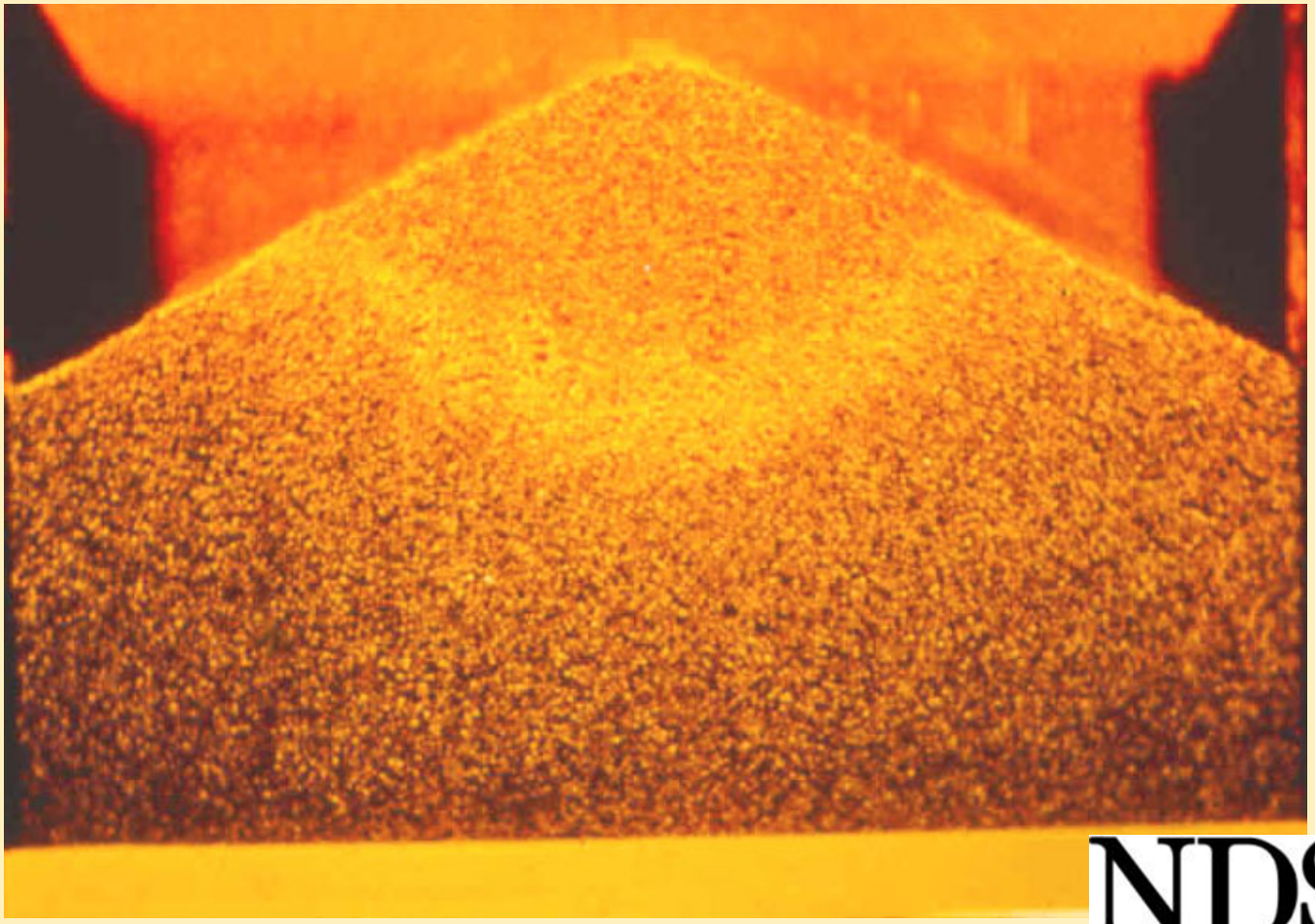
Level Bins



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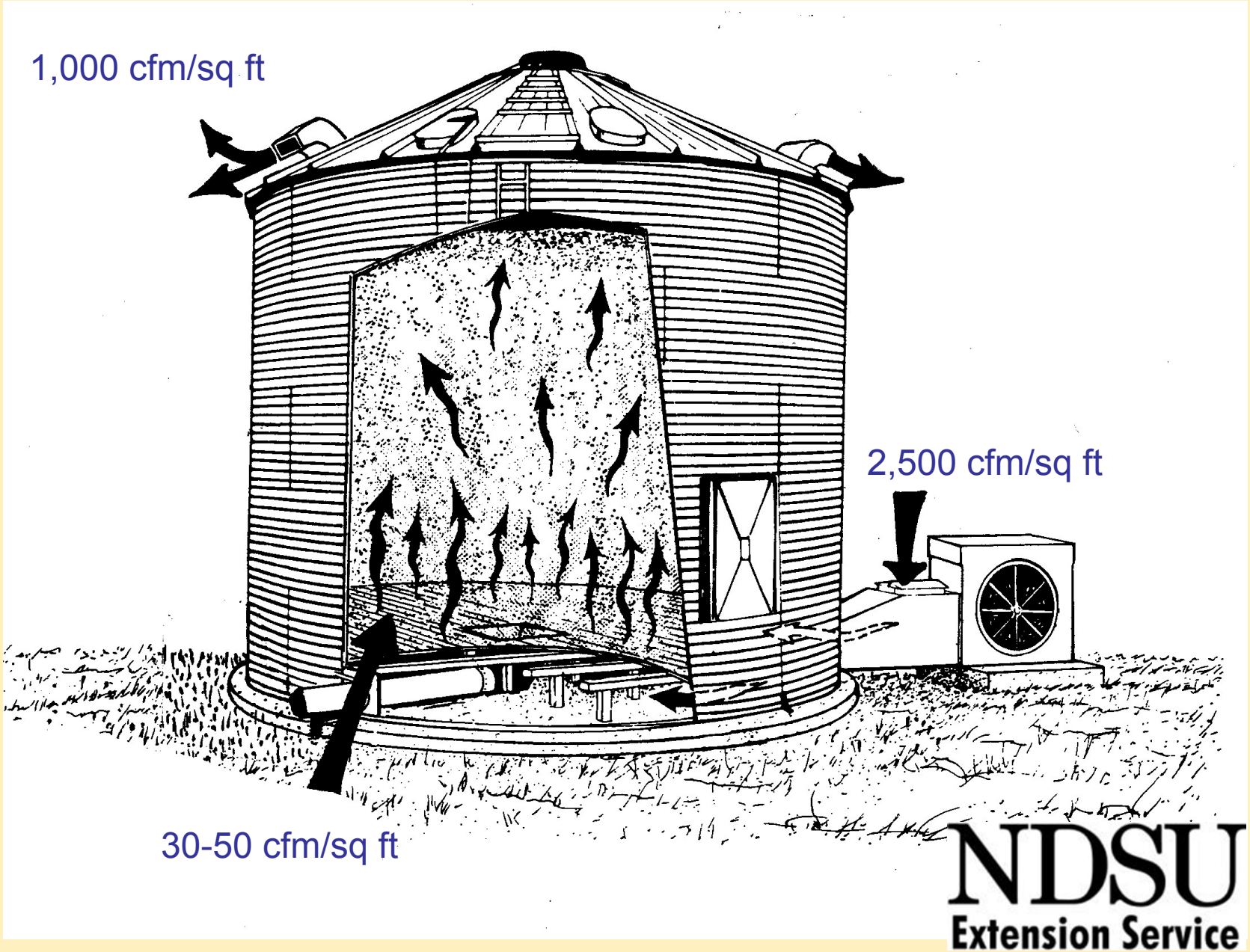
1,000 cfm/sq ft
2,500 cfm/sq ft
30-50 cfm/sq ft
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Aeration Cycle Time

Cooling Time (Barley)

$$15/cfm/bu \ x \ Test\ Weight/56 = hrs$$

15 / 0.2 cfm/bu x 48 /56 = 65 hrs

Barley - 42 ft diameter, 24 ft depth

3.0 hp, 18-inch axial fan, 0.19 cfm/bu

Cooling time = 68 hrs.

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Aeration Investment

42 ft diameter, 26 ft deep, 28,800 bu Barley level full

At 0.17 cfm/bu Cooling time = 76 hrs/cycle

3.0 hp 18-inch Axial Fan, 3 hp fan uses 3.45 kWh/hr

12 cycles x 76 hrs = 912 hrs total/yr

3.45 kWh/hr x 912 hrs = 3,164 kWh

3,164 x $0.10 kwh = $314.64

$314.64 / 28,800 bu = $0.011/bu

≤1¢/bu – yr for insect and mold protection

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Fans Off During Snow/Rain/Fog

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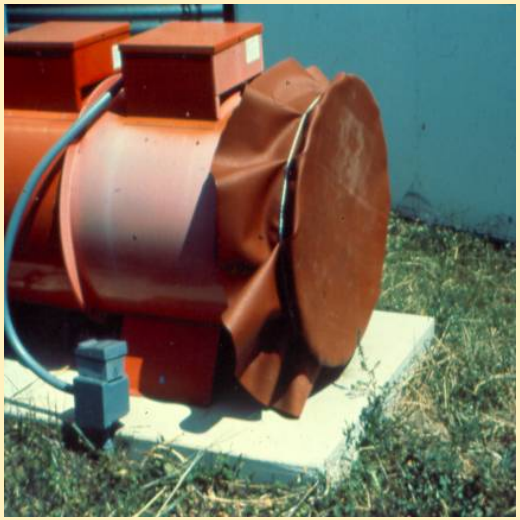
Cover Fans When Not Operating



- Prevents spring warm-up
- Keep snow & pests out
- Keep damp air out

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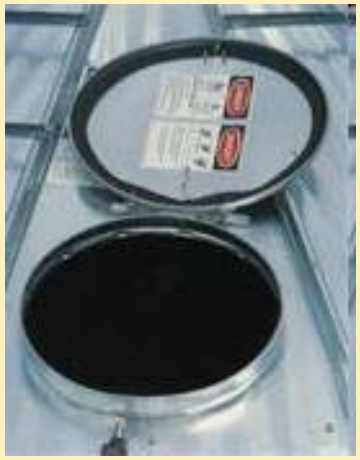
WARNING

Condensation may freeze over vents when outside air temperatures are near or below freezing



Leave fill and access open

Iced over vents will damage bin

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Management

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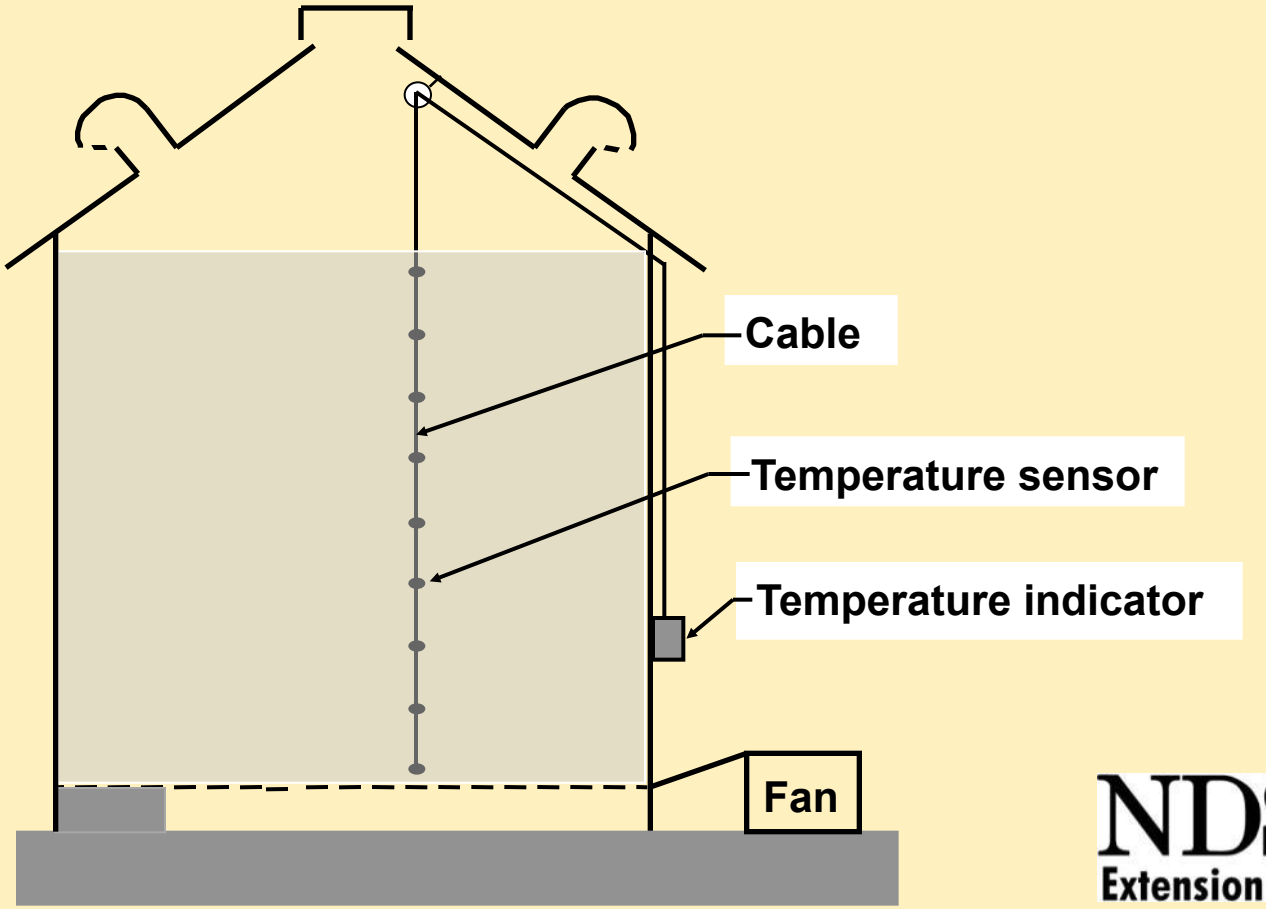
Monitor:

- Temperature
- Moisture
- Insects

How often should I check my grain?

- 2-weeks until cooled
- 2-4 weeks during winter
- 2-weeks spring & summer

Senses only grain near cable



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Grain Temperature

<u>Average Maximum Air Temp.</u>
February 1 - 15°
March 1 - 27°
April 1 - 45°
May 1 - 65°

Solar Radiation (Btu/ft^2-day)

	Wall	Roof
Feb. 21	1725	1800
Jun. 21	800	2425

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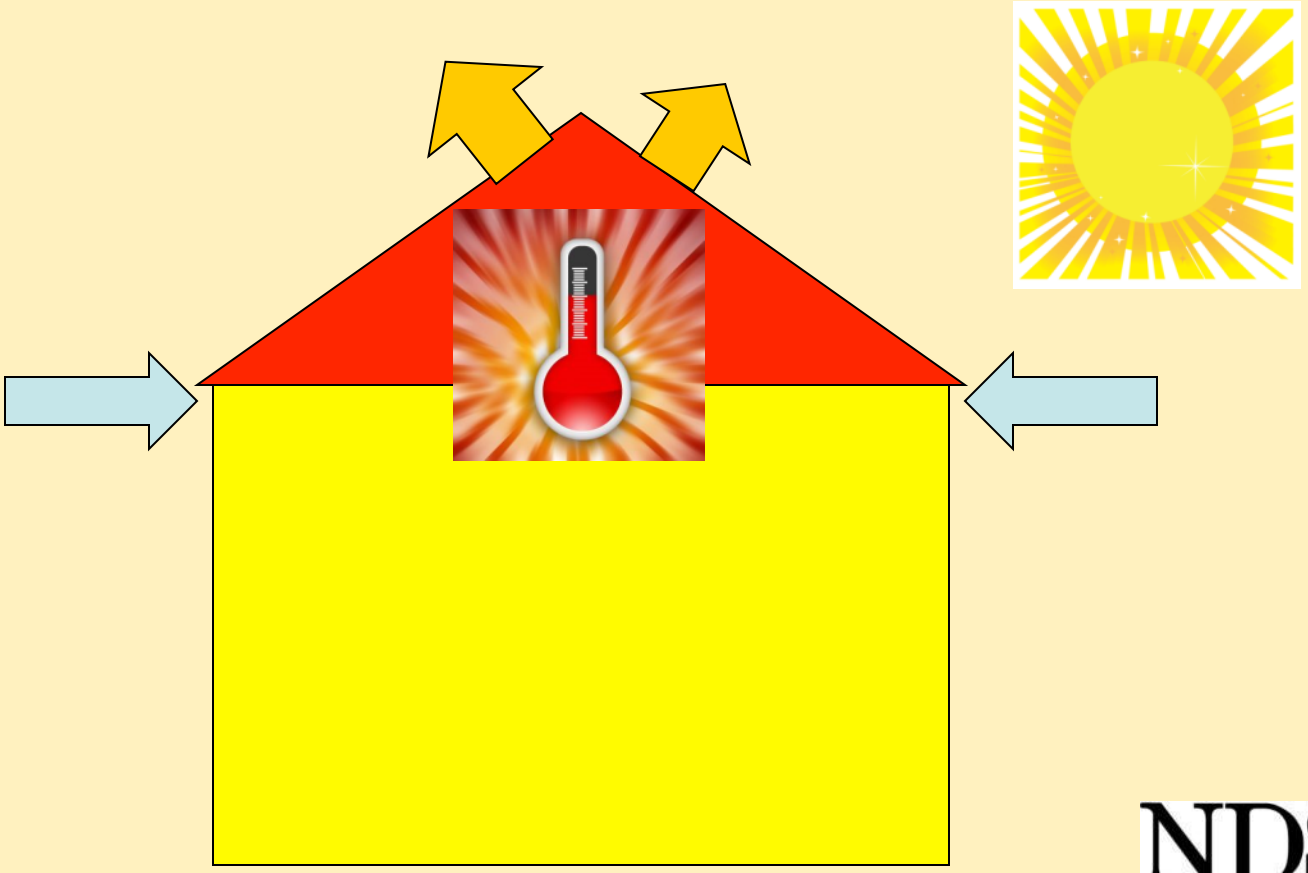
Periodically Cool

Ventilate Bin Headspace



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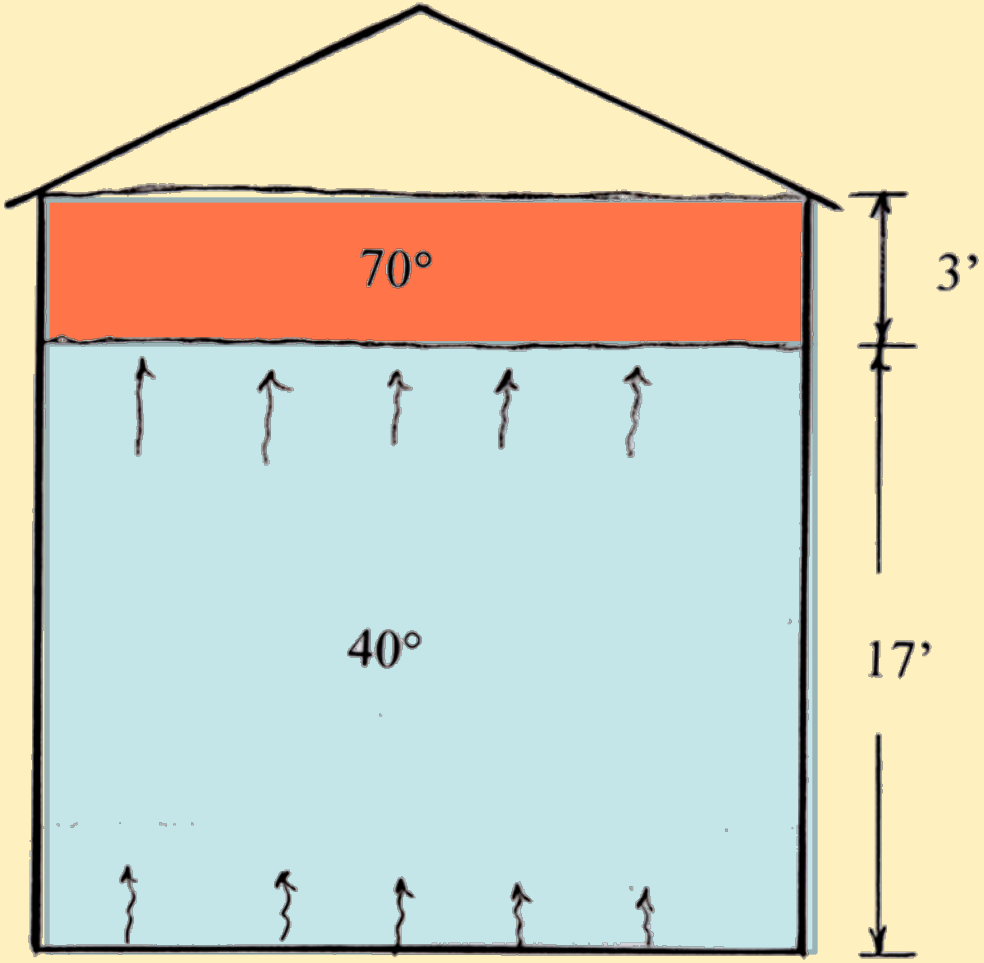
Spring & Summer Cooling

Cooling Time

15 / 0.2 cfm/bu = 75 hrs

3/20 = 0.15 ≈ 11 hrs

Coolest at sunrise



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Grain Hazards

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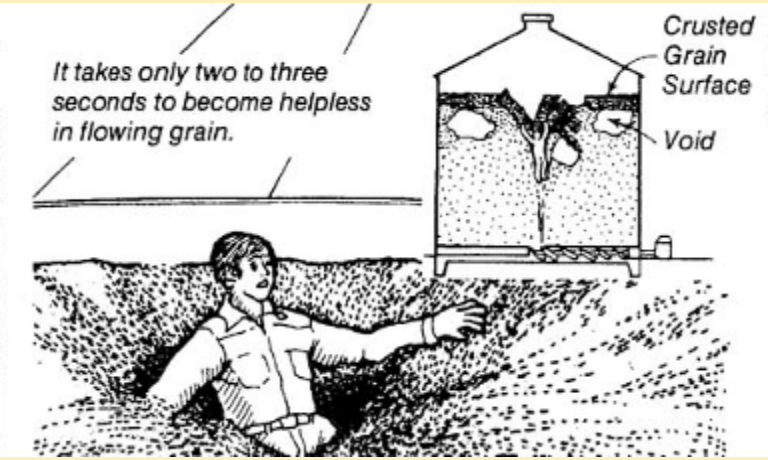
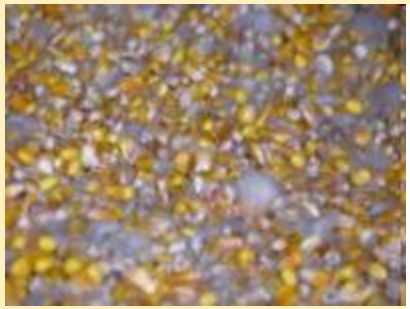
Bridging transfers load to the bin wall

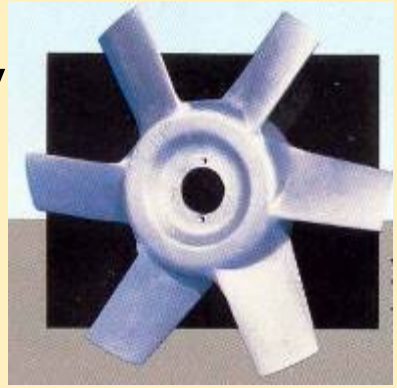


CAUGHT IN THE GRAIN!
AE-1102



Moldy Grain Health Hazard

Ice on blade may cause it to disintegrate



For More Information

Internet Search: NDSU Grain Drying & Storage

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