Comprehensive Natural-Air-Grain-Drying (NAD) Factsheet

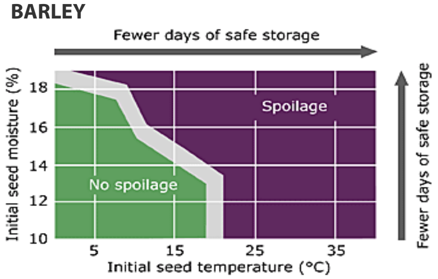
This factsheet is compiled to provide producers with a quick reference guide for grain storage and includes information relating to:

- safe storage conditions;
- management strategies for controlling moisture and temperature;
- airflow rate; and,
- airflow resistance.

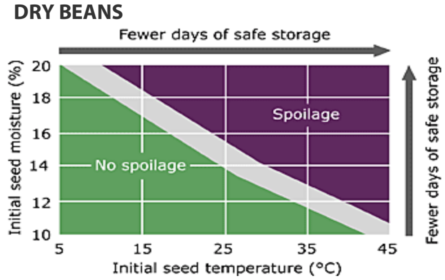
Safe Storage Time and Target Moisture Contents for Common Crops

The main concern when storing grain is to avoid spoilage. Microorganisms responsible for spoilage thrive in hot and moist conditions, so **both temperature and moisture content** must be properly managed. The below charts outline relative safe storage times for several crops, including target temperatures and moisture contents. *Note: "no spoilage" should be interpreted as "reduced risk of spoilage" as these are guidelines only*.

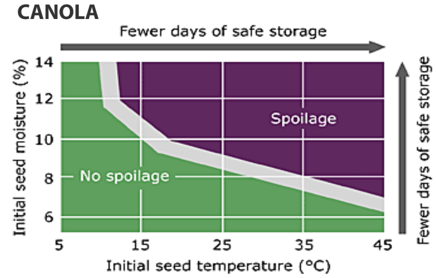
BARLEY



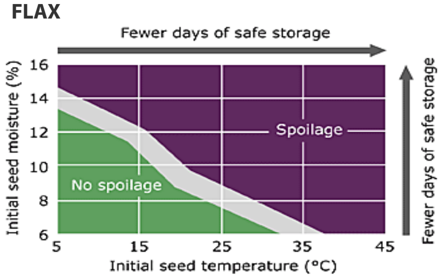
DRY BEANS



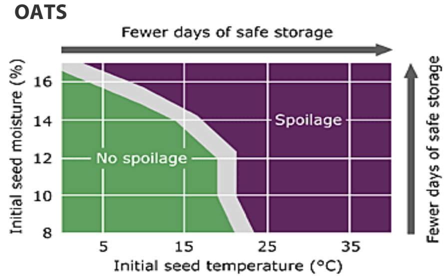
CANOLA



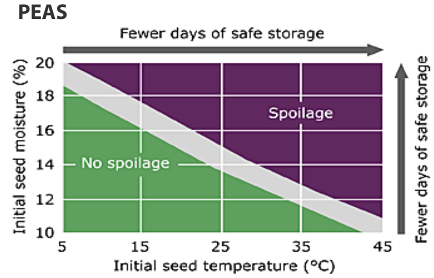
FLAX



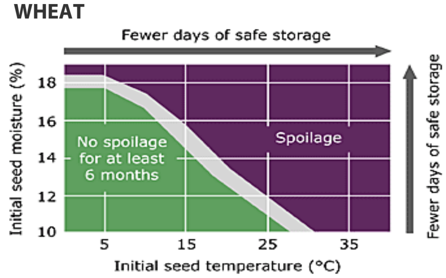
OATS



PEAS



WHEAT



Source: Dr. Noel White, AAFC, as posted on the [Canadian Grain Commission website](#).

Management Strategies for Controlling Temperature and Moisture

There are multiple strategies for controlling temperature and moisture in-bin. The table below will help you determine which management strategy will work best for your operation's needs.

	Description	Pros	Cons
Aeration	▪ Cools and create an even temperature profile ▪ Low airflow rates (0.1 cfm/bu)	▪ Minimal capital investment ▪ "Better than nothing"	▪ No moisture control
Natural Air Drying (NAD)	▪ In-bin moisture and temperature control ▪ Grain will dry if the ambient air has a "capacity to dry" (page 8) ▪ Blows ambient air (5-25 C) through grain ▪ Uses moderate air flow rates (approx. 1 cfm/bu)	▪ Energy savings ▪ Smaller investment ▪ Reduced risk of spoilage ▪ Most suitable when ambient >15 C	▪ Slow (can take weeks) ▪ Requires management ▪ Success dependent on ambient conditions
NAD with Supplemental Heat	▪ Adding heater to a NAD fan to increase the temperature of the air going into the bin	▪ Turns a "poor" drying day into a "good" drying day ▪ Minimal capital investment ▪ Most suitable when ambient >0 C ▪ Reduces drying time to days	▪ Requires management (and grain turning) ▪ Few options for temperature control ▪ Energy cost
Heated Air Drying	▪ Usually a small batch process ▪ Uses hot air (45-85 C) to dry grain ▪ Uses very high air-flow rates (approx. 20 cfm/bu)	▪ Success does not depend on ambient conditions ▪ Dries grain quickly (hours) ▪ Suitable for any ambient condition	▪ Can result in seed damage ▪ Requires cooling cycle ▪ High capital and energy costs

NOTE: cfm/bu = cubic feet per minute per bushel

Airflow rate is the key difference between management strategies

How to Use Airflow Resistance Charts for Managing Stored Grain

Airflow resistance in a grain bin is an important measure as it dictates how much airflow (cubic feet of air per minute, or cfm) your fan is pushing into the grain. The target airflow for aeration (cooling) is 0.1 to 0.25 cfm per bushel while the target airflow for natural air drying is 0.5 to 1 cfm per bushel. Note that airflow rates between 0.25 and 0.50 cfm per bushel will result in faster cooling or conditioning, and may also result in some moisture loss or removal (depending on air and grain conditions).

Resistance to airflow depends on:

- Grain Type (size of voids):
  Smaller seeds = smaller voids = increased resistance to airflow
- Depth of the Grain:
  Greater depths = greater resistance to airflow
- Fan Speed:
  The faster the fan tries to push air through grain, the greater the resistance to airflow
- Type of Distribution System (ducting):
  More restrictive ducting systems/plenums may increase the total airflow resistance (data not available for direct comparison).

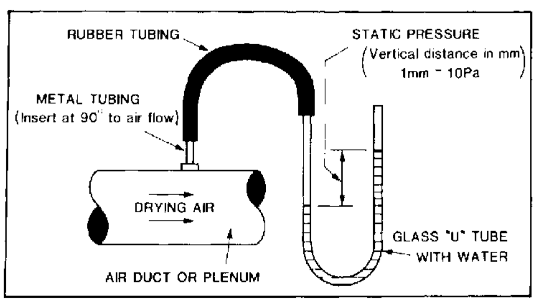
Airflow resistance is measured in static pressure (inches of H_20) and is dependent on grain type and depth. As grain depth increases, airflow resistance increases (and airflow rate decreases).

There are two applications (described later) for using airflow resistance to know or predict airflow rate:

1. For existing fans, use static pressure and fan curves to estimate the airflow rate in the bin.
2. For new bins, use the resistance-to-airflow charts to determine the fan type and size that will achieve the desired airflow rate.

How to Measure Static Pressure:

Use a static pressure gauge (types below) and install at the fan outlet.



Water Manometer:

- Connect a flexible, transparent tube (minimum inside diameter 1/4 in.) to the transition duct.
- End of tube inside – 90 C to airflow.
- End of tube outside – attach to manometer.
- The difference in water height in inches = static pressure (inches H_2O).

Analog manometer (left)

- Specialty gauges will even convert the airflow resistance to an airflow rate for a certain bin/fan size.

Digital manometer (right)

- More expensive, but easier to move from bin to bin.

Estimating Airflow Rate in an Existing Bin

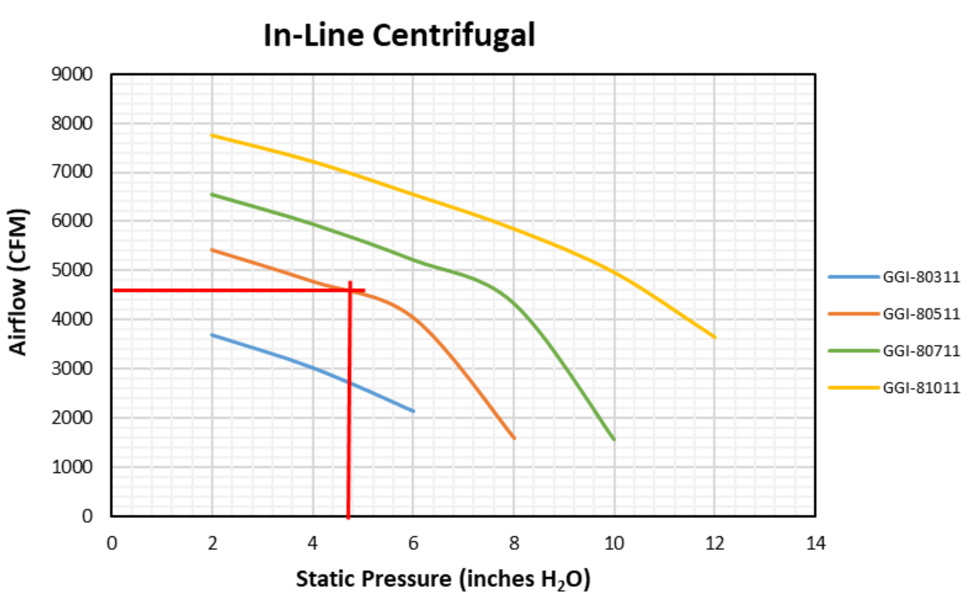
To determine the airflow (cfm) from an existing fan, install a static pressure gauge in the aeration ducting near the fan. With the bin full (or at the target grain level) turn on the fan and take the static pressure reading on the pressure gauge. The static pressure will change based on grain depth and grain type. Use the manufacturer's fan performance tables or curves (examples included below for Grain Guard's in-line centrifugal fans), to estimate the airflow rate based on the static pressure reading.

Example: The static pressure reading is 4.6 inches H_2O for a 5 hp in-line centrifugal grain guard fan (GGI-80511). In Table 1 at 4 inches H_20, the airflow is 4790 cfm and at 6 inches H_20 it is 4050 cfm. From that it is estimated the airflow is likely around 4600 cfm.

Table 1. Estimated airflow rates (cfm) for fan models based on static pressure.

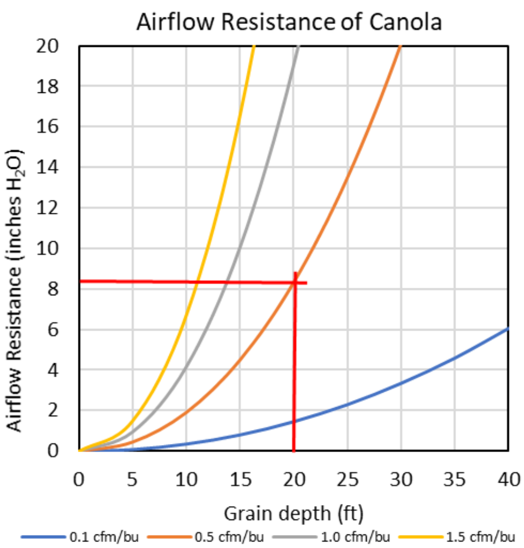
In-Line Centrifugal		Static Pressure (inches H_2O)					
Model	**HP**	**2**	**4**	**6**	**8**	**10**	**12**
GGI-80311	3	3690	3020	2130	0	0	0
GGI-80511	5	5430	4790	4050	1600	0	0
GGI-80711	7	6550	5950	5220	4340	1560	0
GGI-81011	10	7750	7220	6550	5850	4960	3640

Manufacturer-supplied fan information can also be provided in the form of an airflow-static pressure curve (below); these charts make the fan relationships easy to visualize. These charts also show that the airflow rate output is not consistent for all static pressure ranges (ex: GGI-80511).



Selecting the Correct Fan Size for a Desired Airflow Rate

Airflow resistance charts and fan performance tables/charts can be used to estimate the size of fan needed to achieve the desired airflow per volume (0.1 to 0.25 cfm/bu. for aeration and 0.5 to 1 cfm/bu. for natural air drying).



Example: 5000 bushels of canola resulting in a grain depth of 20 ft. The desired airflow is at least 0.5 cfm/bu.

1. Calculate the airflow (cfm) required to achieve 0.5 cfm/bu. *0.5 cfm/bu. x 5000 bu. = 2500 cfm*
2. Estimate the airflow resistance using the chart shown (left) for canola. *The static pressure on the 0.5 cfm/bu. curve is about 8 inches H_20.*
3. Use the fan tables or charts to select the appropriate fan. *At 8 inches H_20, the 5 hp in-line centrifugal fan (GGI-80511) is only producing 1600 cfm, which is less than desired. The 7 hp in-line centrifugal fan (GGI-80711) however, is estimated to produce 4340 cfm which achieves the desired result with airflow of about 0.85 cfm/bu.*

Note: These fans are examples only. There may be other fan models or types that are more suitable for this application.

Fan Types

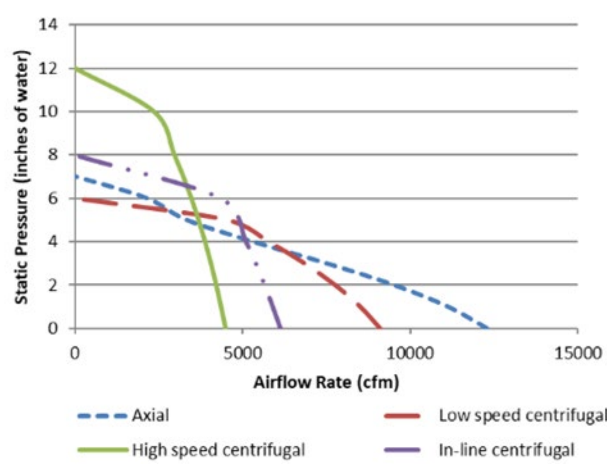
Individual fan models and types have unique airflow ratings, providing the ability to achieve a variety of airflow ranges for different depths of grain. Fan type and size must be selected carefully based on expected static pressure, so make sure you are using the static pressure charts specifically for the type and size of fan you are investigating.

Axial-Flow Fans: air moves in straight line through the fan parallel to the impeller shaft (supply higher airflows at lower pressures

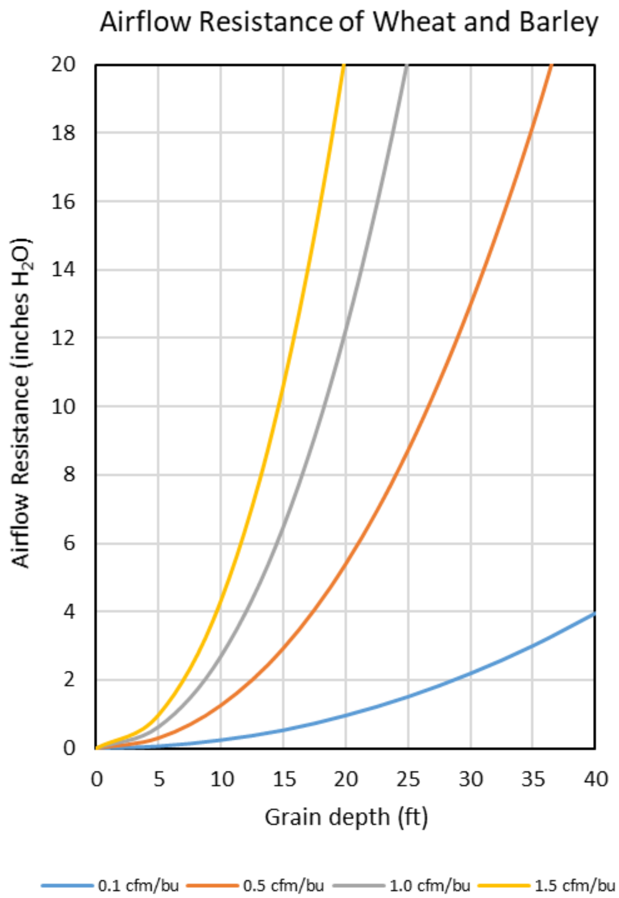
Centrifugal Fans: air enters parallel to the impeller shaft and exits one side perpendicular to the shaft

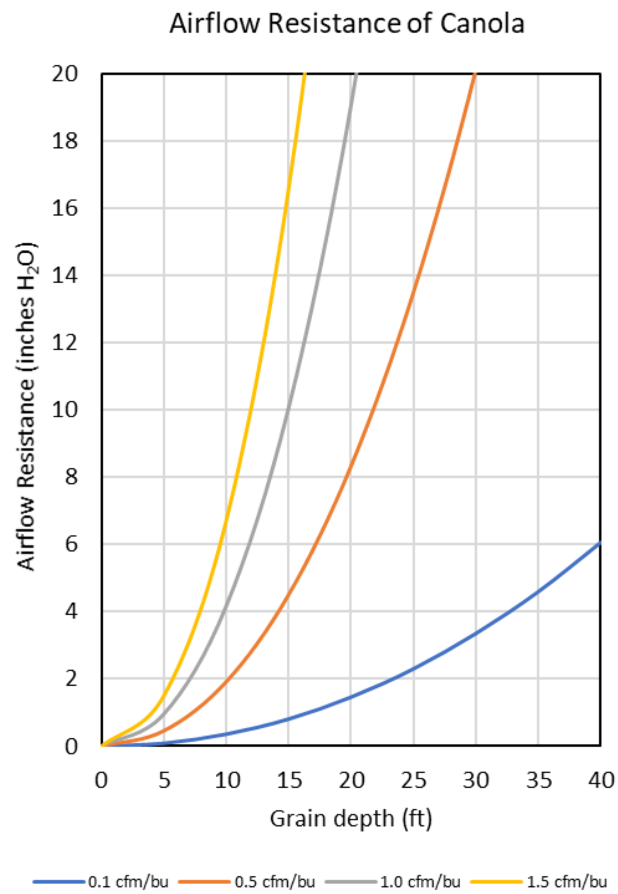
- Low-speed Centrifugal: supply higher airflows at lower pressures
- High-Speed Centrifugal: supply lower airflows at higher pressures

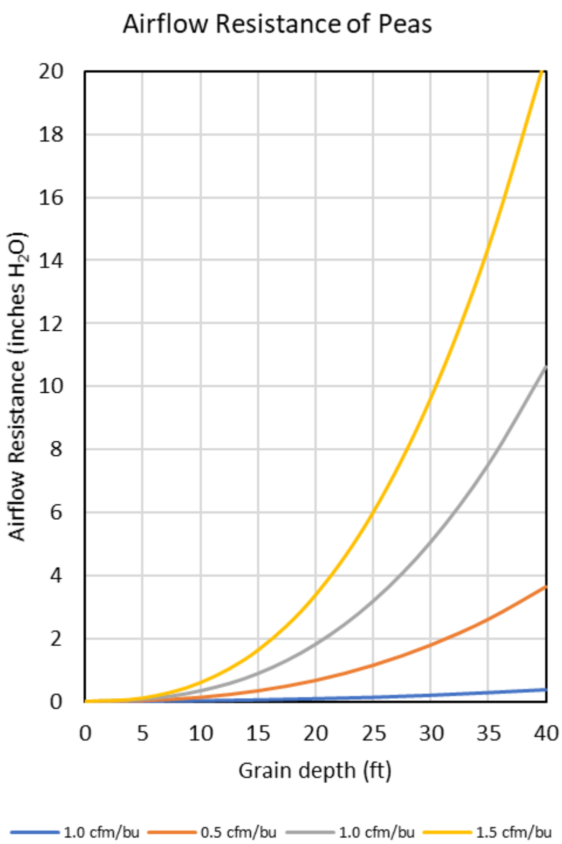
In-Line Centrifugal Fans: have axial flow but use a centrifugal type impeller (supply lower airflows at higher pressures)

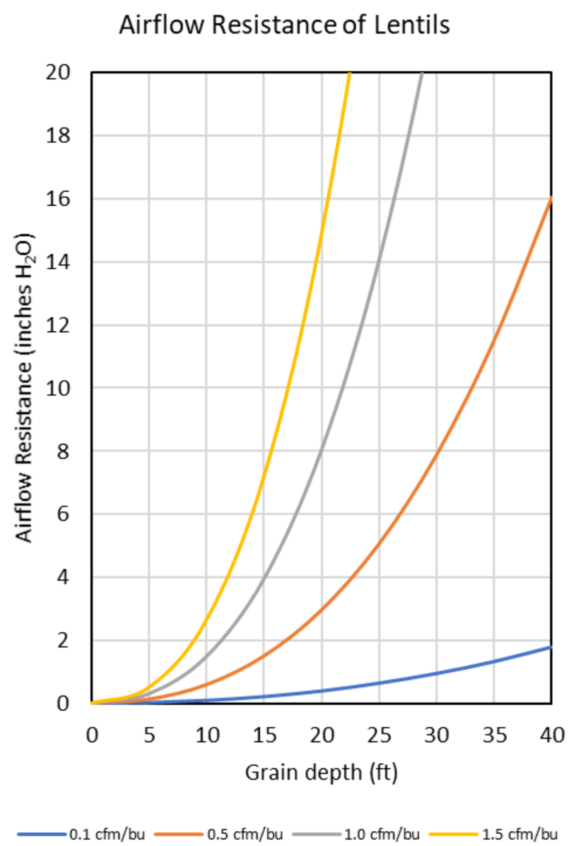


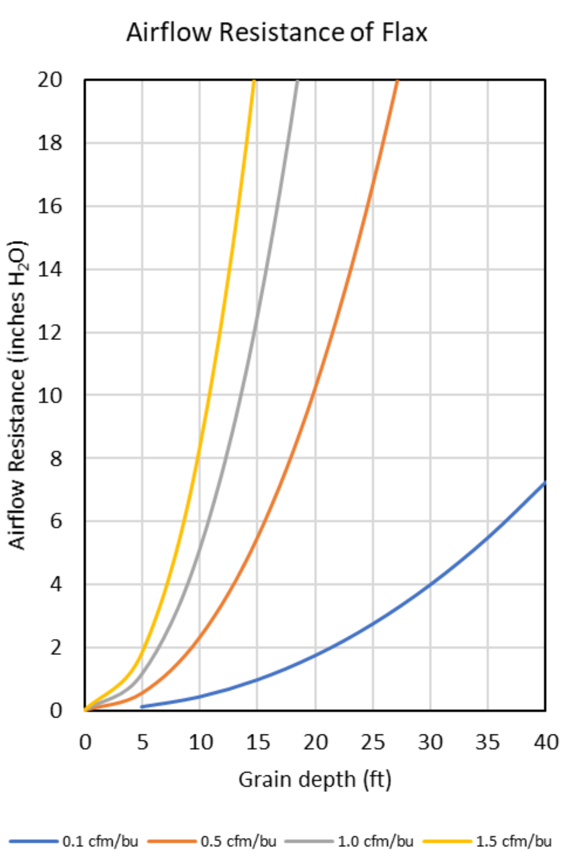
These airflow resistance charts can be used to estimate the expected static pressure based on grain depth, grain type, and target airflow rate (cfm/bu). Shedd's model was used to create the charts using experimental data. These charts account for the airflow resistance of the grain only and do not account for added resistance due to chaff, fines, ductwork, or filling method (e.g., grain spreader).

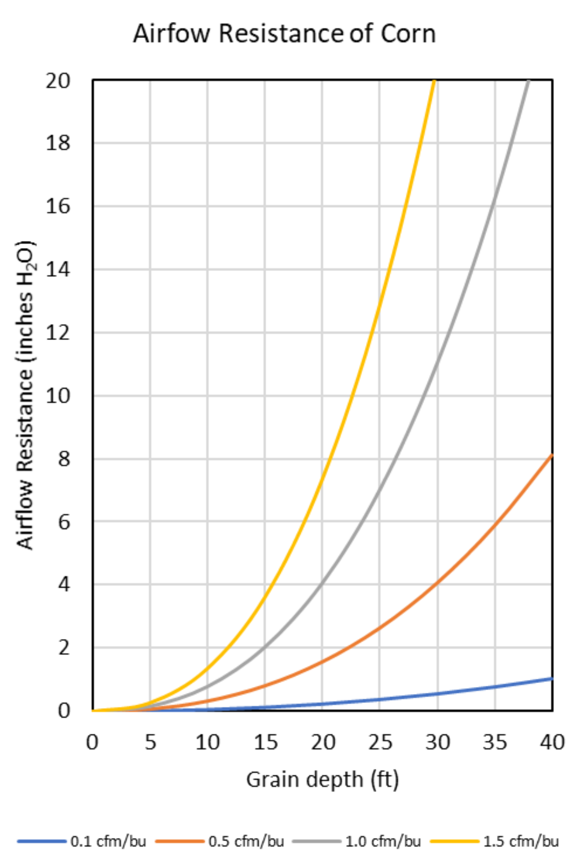





Airflow Resistance of Peas
Airflow Resistance (inches H_2O)
Grain depth (ft)
1.0 cfm/bu
0.5 cfm/bu
1.0 cfm/bu
1.5 cfm/bu


Airflow Resistance of Lentils
Airflow Resistance (inches H_2O)
Grain depth (ft)
0.1 cfm/bu
0.5 cfm/bu
1.0 cfm/bu
1.5 cfm/bu


Airflow Resistance of Flax
Airflow Resistance (inches H_2O)
Grain depth (ft)
0.1 cfm/bu
0.5 cfm/bu
1.0 cfm/bu
1.5 cfm/bu


Airfow Resistance of Corn
Airflow Resistance (inches H_2O)
Grain depth (ft)
0.1 cfm/bu
0.5 cfm/bu
1.0 cfm/bu
1.5 cfm/bu

Equilibrium Moisture Content and Grain Storage Management

The equilibrium moisture content (EMC) of air can be used to predict how the ambient air used for natural air drying (NAD) will affect the moisture content of grain. The EMC of the air depends on its temperature and relative humidity (RH) as well as the grain type. The EMC represents the moisture content that the grain will eventually equilibrate to if the air conditions remain constant for a length of time. The air has a "capacity to dry" when the EMC of the ambient air is less than the moisture of the grain. Although air conditions are rarely constant for longer than an hour, the EMC information can still be used to determine the air temperature and relative humidity ranges that will achieve drying.

Example: If the ambient air has a temperature of 10 C and a RH of 60 per cent, the EMC of the air for WHEAT is 13.6 per cent (refer to EMC chart below). That means that if the air conditions stay constant at 10 C and 60 per cent RH, wheat would eventually equilibrate to 13.6 per cent moisture content (and 10 C). If the goal is to dry wheat to 14.4 per cent, the most effective time to run the fan would be when the EMC of air is less than 14.4 per cent Those conditions (air temperature and RH) are highlighted in red in the chart below.

Temp	Relative Humidity (%)							HARD RED SPRING WHEAT			
(°C)	35	40	45	50	55	60	65	70	75	80	85
-2	10.7	11.4	12.0	12.7	13.5	14.2	15.0	15.9	16.9	18.0	19.3
2	10.4	11.1	11.8	12.5	13.3	14.0	14.8	15.7	16.7	17.8	19.1
5	10.3	11.0	11.7	12.4	13.1	13.9	14.7	15.5	16.5	17.6	19.0
8	10.1	10.8	11.5	12.2	13.0	13.7	14.5	15.4	16.4	17.5	18.9
10	10.0	10.7	11.4	12.1	12.9	13.6	14.4	15.3	16.3	17.4	18.8
13	9.9	10.6	11.3	12.0	12.7	13.5	14.3	15.2	16.2	17.3	18.7
15	9.8	10.5	11.2	11.9	12.6	13.4	14.2	15.1	16.1	17.2	18.6
18	9.6	10.3	11.0	11.8	12.5	13.3	14.1	15.0	16.0	17.1	18.5
22	9.4	10.2	10.9	11.6	12.3	13.1	13.9	14.8	15.8	16.9	18.3
26	9.3	10.0	10.7	11.4	12.2	12.9	13.8	14.6	15.6	16.8	18.2
28	9.2	9.9	10.6	11.3	12.1	12.8	13.7	14.6	15.6	16.7	18.1

It is also important to manage grain temperature as well as moisture content to help prevent spoilage. If you are using warm air (temperature greater than 15 C) to help dry grain, the grain will also warm to that temperature. Once the target moisture content has been reached, aerate with cool air to bring the average grain temperature below 15 C. Due to the effect of grain temperature on the air's ability to remove moisture, this cooling period will also result in some moisture loss, so cooling can start once the grain is within approximately half a percent of the target moisture content.

Also note that if the grain temperature is considerably different than the air temperature, the EMC of the air will be difficult to determine until the temperature of the air and grain equalizes (usually within 6 to 24 hours of fan operation, depending on airflow rate).

The EMC of air depends on the grain type as well as the air temperature and R

Equilibrium Moisture Content Charts for Grain Storage Management

These charts are based on the moisture isotherm data summarized in the ASABE Standard D245.5 (Moisture Relationships of Plant-based Agricultural Products) and various published studies (listed after the charts). Much of the information in ASABE Standard D245.5 is based on research conducted in the 1980's and 1990's. Since that time, plant breeding has resulted in different starch and oil contents of grains and oilseeds which may affect the EMC values. Therefore, these charts should be used as a guideline only.

Temp	Relative Humidity (%)					**HARD RED WINTER WHEAT** (Modified Oswin)					
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	10.0	11.0	12.0	13.2	14.3	15.6	17.1	18.8	20.8	23.2	26.5
5	9.9	10.8	11.9	13.0	14.1	15.4	16.9	18.5	20.5	23.0	26.2
8	9.7	10.7	11.7	12.8	14.0	15.2	16.7	18.3	20.3	22.7	25.9
10	9.6	10.6	11.6	12.7	13.8	15.1	16.5	18.1	20.1	22.5	25.7
13	9.5	10.4	11.4	12.5	13.6	14.9	16.3	17.9	19.8	22.2	25.4
15	9.4	10.3	11.3	12.4	13.5	14.7	16.1	17.7	19.6	22.0	25.1
18	9.2	10.2	11.2	12.2	13.3	14.5	15.9	17.5	19.4	21.7	24.8
22	9.0	10.0	10.9	11.9	13.0	14.2	15.6	17.2	19.0	21.3	24.4
26	8.9	9.8	10.7	11.7	12.8	14.0	15.3	16.8	18.7	20.9	24.0
28	8.8	9.7	10.6	11.6	12.6	13.8	15.1	16.7	18.5	20.7	23.7

Temp	Relative Humidity (%)						**DURUM WHEAT** (Modified Oswin)				
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	8.7	9.6	10.5	11.5	12.6	13.7	15.0	16.6	18.4	20.6	23.6
5	8.6	9.5	10.4	11.4	12.4	13.6	14.9	16.4	18.2	20.4	23.4
8	8.5	9.4	10.3	11.3	12.3	13.4	14.7	16.2	18.0	20.2	23.2
10	8.4	9.3	10.2	11.2	12.2	13.3	14.6	16.1	17.9	20.1	23.0
13	8.4	9.2	10.1	11.0	12.1	13.2	14.5	15.9	17.7	19.9	22.8
15	8.3	9.1	10.0	11.0	12.0	13.1	14.4	15.8	17.6	19.8	22.7
18	8.2	9.0	9.9	10.8	11.8	13.0	14.2	15.7	17.4	19.6	22.4
22	8.1	8.9	9.7	10.7	11.7	12.8	14.0	15.4	17.1	19.3	22.1
26	7.9	8.7	9.6	10.5	11.5	12.6	13.8	15.2	16.9	19.0	21.8
28	7.9	8.7	9.5	10.4	11.4	12.5	13.7	15.1	16.8	18.9	21.7

Temp	Relative Humidity (%)						**BARLEY** (Modified Chung-Pfost)				
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	10.9	11.6	12.3	13.0	13.8	14.6	15.4	16.3	17.3	18.5	19.9
5	10.7	11.4	12.1	12.8	13.6	14.4	15.2	16.1	17.1	18.3	19.7
8	10.5	11.2	11.9	12.6	13.4	14.2	15.0	15.9	16.9	18.1	19.5
10	10.3	11.1	11.8	12.5	13.3	14.1	14.9	15.8	16.8	18.0	19.4
13	10.1	10.9	11.6	12.3	13.1	13.9	14.7	15.6	16.7	17.8	19.2
15	10.0	10.7	11.5	12.2	13.0	13.8	14.6	15.5	16.5	17.7	19.1
18	9.8	10.6	11.3	12.0	12.8	13.6	14.4	15.4	16.4	17.6	19.0
22	9.6	10.3	11.1	11.8	12.6	13.4	14.2	15.2	16.2	17.4	18.8
26	9.3	10.1	10.8	11.6	12.4	13.2	14.0	15.0	16.0	17.2	18.6
28	9.2	10.0	10.7	11.5	12.3	13.1	13.9	14.9	15.9	17.1	18.5

Temp	Relative Humidity (%)							**PEAS** (Modified Henderson)			
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	9.2	10.2	11.3	12.4	13.5	14.7	15.9	17.3	18.8	20.4	22.4
5	9.0	10.1	11.1	12.2	13.3	14.5	15.7	17.1	18.5	20.2	22.2
8	8.9	9.9	11.0	12.1	13.2	14.3	15.6	16.9	18.3	20.0	21.9
10	8.8	9.9	10.9	12.0	13.1	14.2	15.4	16.8	18.2	19.8	21.8
13	8.7	9.7	10.8	11.8	12.9	14.1	15.3	16.6	18.0	19.6	21.5
15	8.7	9.7	10.7	11.7	12.8	13.9	15.1	16.4	17.9	19.5	21.4
18	8.6	9.6	10.6	11.6	12.7	13.8	15.0	16.3	17.7	19.3	21.2
22	8.4	9.4	10.4	11.4	12.5	13.6	14.8	16.0	17.4	19.0	20.9
26	8.3	9.3	10.2	11.3	12.3	13.4	14.5	15.8	17.2	18.7	20.6
28	8.2	9.2	10.2	11.2	12.2	13.3	14.4	15.7	17.1	18.6	20.5

Temp	Relative Humidity (%)								**OATS** (Modified Oswin)		
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	9.8	10.3	10.9	11.4	11.9	12.5	13.1	13.7	14.5	15.3	16.4
5	9.6	10.1	10.6	11.1	11.7	12.2	12.8	13.5	14.2	15.1	16.2
8	9.3	9.8	10.3	10.9	11.4	12.0	12.6	13.3	14.0	14.9	15.9
10	9.1	9.7	10.2	10.7	11.3	11.8	12.4	13.1	13.9	14.7	15.8
13	8.9	9.4	10.0	10.5	11.0	11.6	12.2	12.9	13.7	14.5	15.6
15	8.8	9.3	9.8	10.3	10.9	11.5	12.1	12.8	13.5	14.4	15.5
18	8.5	9.1	9.6	10.1	10.7	11.3	11.9	12.6	13.3	14.2	15.3
22	8.3	8.8	9.3	9.9	10.4	11.0	11.6	12.3	13.1	14.0	15.1
26	8.0	8.6	9.1	9.6	10.2	10.8	11.4	12.1	12.9	13.8	14.8
28	7.9	8.4	9.0	9.5	10.1	10.7	11.3	12.0	12.8	13.7	14.7

Temp	Relative Humidity (%)								**CANOLA/RAPESEED** (Modified Henderson)		
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	6.4	7.0	7.7	8.4	9.1	9.9	10.7	11.6	12.5	13.6	14.9
5	6.1	6.8	7.4	8.1	8.8	9.5	10.3	11.1	12.0	13.1	14.3
8	5.9	6.5	7.1	7.8	8.5	9.2	9.9	10.7	11.6	12.6	13.8
10	5.7	6.3	7.0	7.6	8.3	8.9	9.7	10.5	11.3	12.3	13.5
13	5.5	6.1	6.7	7.3	8.0	8.6	9.4	10.1	11.0	11.9	13.1
15	5.4	6.0	6.6	7.2	7.8	8.5	9.2	9.9	10.7	11.7	12.8
18	5.2	5.8	6.4	7.0	7.6	8.2	8.9	9.6	10.4	11.3	12.4
22	5.0	5.6	6.1	6.7	7.3	7.9	8.5	9.3	10.0	10.9	12.0
26	4.8	5.4	5.9	6.5	7.0	7.6	8.2	8.9	9.7	10.5	11.6
28	4.8	5.3	5.8	6.3	6.9	7.5	8.1	8.8	9.5	10.4	11.4

Temp	Relative Humidity (%)								**LENTILS** (Modified Oswin)		
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	9.1	10.0	11.0	12.0	13.1	14.3	15.7	17.3	19.1	21.5	24.5
5	9.0	9.9	10.8	11.8	12.9	14.1	15.4	17.0	18.8	21.1	24.2
8	8.8	9.7	10.6	11.6	12.7	13.9	15.2	16.7	18.5	20.8	23.8
10	8.7	9.6	10.5	11.5	12.5	13.7	15.0	16.5	18.3	20.6	23.6
13	8.5	9.4	10.3	11.3	12.3	13.5	14.8	16.3	18.0	20.3	23.2
15	8.4	9.3	10.2	11.1	12.2	13.3	14.6	16.1	17.8	20.1	23.0
18	8.3	9.1	10.0	10.9	12.0	13.1	14.3	15.8	17.5	19.7	22.6
22	8.1	8.9	9.7	10.7	11.7	12.8	14.0	15.4	17.1	19.3	22.1
26	7.8	8.6	9.5	10.4	11.4	12.4	13.6	15.0	16.7	18.8	21.6
28	7.7	8.5	9.4	10.3	11.2	12.3	13.5	14.9	16.5	18.6	21.4

Temp	Relative Humidity (%)								**RED LENTILS** (Modified Halsey)		
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	8.8	9.3	9.8	10.4	11.0	11.8	12.6	13.5	14.7	16.2	18.3
5	8.7	9.2	9.7	10.3	10.9	11.6	12.4	13.4	14.5	16.0	18.0
8	8.5	9.0	9.6	10.1	10.7	11.4	12.2	13.2	14.3	15.8	17.8
10	8.5	8.9	9.5	10.0	10.6	11.3	12.1	13.1	14.2	15.7	17.7
13	8.3	8.8	9.3	9.9	10.5	11.2	12.0	12.9	14.0	15.5	17.4
15	8.3	8.7	9.3	9.8	10.4	11.1	11.9	12.8	13.9	15.3	17.3
18	8.2	8.6	9.1	9.7	10.3	10.9	11.7	12.6	13.7	15.1	17.1
22	8.0	8.5	9.0	9.5	10.1	10.7	11.5	12.4	13.5	14.9	16.8
26	7.9	8.3	8.8	9.3	9.9	10.6	11.3	12.2	13.3	14.6	16.5
28	7.8	8.2	8.7	9.2	9.8	10.5	11.2	12.1	13.1	14.5	16.4

Temp	Relative Humidity (%)								**SOYBEANS** (Modified Halsey)		
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	6.9	7.5	8.2	8.9	9.8	10.8	12.0	13.5	15.3	17.7	21.1
5	6.8	7.4	8.1	8.9	9.7	10.7	11.9	13.3	15.1	17.5	20.9
8	6.7	7.3	8.0	8.8	9.6	10.6	11.8	13.2	15.0	17.4	20.8
10	6.7	7.3	8.0	8.7	9.6	10.5	11.7	13.1	14.9	17.3	20.6
13	6.6	7.2	7.9	8.6	9.5	10.4	11.6	13.0	14.8	17.1	20.5
15	6.6	7.2	7.8	8.6	9.4	10.4	11.5	12.9	14.7	17.0	20.3
18	6.5	7.1	7.7	8.5	9.3	10.3	11.4	12.8	14.5	16.9	20.2
22	6.4	7.0	7.6	8.4	9.2	10.1	11.2	12.6	14.3	16.6	19.9
26	6.3	6.9	7.5	8.2	9.0	10.0	11.1	12.5	14.2	16.4	19.7
28	6.3	6.8	7.5	8.2	9.0	9.9	11.0	12.4	14.1	16.3	19.6

Temp	Relative Humidity (%)								**FLAX** (Modified Henderson/Chung-Pfost)		
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	7.1	7.6	8.1	8.6	9.1	9.7	10.2	10.8	11.5	12.3	13.2
5	6.9	7.4	7.9	8.4	8.9	9.4	10.0	10.6	11.2	12.0	12.9
8	6.7	7.2	7.7	8.2	8.7	9.2	9.7	10.3	11.0	11.8	12.7
10	6.6	7.1	7.5	8.0	8.5	9.0	9.6	10.2	10.8	11.6	12.5
13	6.4	6.9	7.3	7.8	8.3	8.8	9.4	10.0	10.6	11.4	12.3
15	6.3	6.7	7.2	7.7	8.2	8.7	9.3	9.8	10.5	11.2	12.1
18	6.1	6.6	7.0	7.5	8.0	8.5	9.1	9.6	10.3	11.0	11.9
22	5.9	6.4	6.8	7.3	7.8	8.3	8.8	9.4	10.0	10.8	11.7
26	5.7	6.2	6.6	7.1	7.6	8.1	8.6	9.2	9.8	10.5	11.4
28	5.6	6.1	6.5	7.0	7.5	8.0	8.5	9.1	9.7	10.4	11.3

Using Supplemental Heat with Natural Air Drying

Rain, snow, and cool temperatures at harvest time mean producers must manage grain in the bin as carefully as they manage it in the field. Adding supplemental heat to natural air drying (NAD) can be an efficient and effective way to dry grain in bins if done correctly. It is also a way to extend the drying season.

Adding Heat Affects the Capacity of Air to Dry Grain

For every 10 C increase in the temperature of the air going into the bin, the relative humidity (RH) of the air is cut in half. With added heat, a cold, drizzly fall day can be turned into a beautiful drying day.

Example: Target moisture content of wheat for safe storage is 14.4 per cent. When ambient air conditions are 5 C and 70 per cent RH, the EMC for wheat (chart below) is 16.1 per cent; as such, the air does not have the capacity to dry under those conditions. However, by increasing the air temperature to 15 C using some heat, the resulting RH will be cut in half, to about 35 per cent, and the air will have capacity to dry since its EMC for wheat will now be 10.3 per cent.

Supplemental heating is not the same as heated air drying

Heat/temperature draws moisture out of the kernel

Airflow rate moves moisture out of the grain

The key is to match the moisture removal rate from the kernel with the removal rate from the bin

Determining Heater Size and Type Required

The size of heater you need depends on two things:

1. The air flow rate (cfm) from your fan, and
2. Your desired temperature increases.

Heater capacity = temp. increase x air flow rate x 2.05

(btu/hr = C x cfm x 2.05)

Example 1: To raise the air temperature by 10 C for a bin/fan that is pushing 5000 cfm, the required heater capacity is 10 x 5000 x 2.05 = 102,500 btu/hr.

Example 2: If you have a 100,000 btu/hr heater and you attach it to a bin/fan that is pushing 7500 cfm, the expected temperature increase will be 100,000/7500/2.05 = 6.5 C.

Keep in mind these equations assume a highly efficient heat transfer setup meaning all of the heat generated by the heater ends up in the air. The overall efficiency of some systems may be as low as 50 per cent, so estimate the required size of your heater accordingly.

Temp	Relative Humidity (%)								
°C	35	40	45	50	55	60	65	70	75
-2	11.5	12.2	13.0	13.7	14.5	15.3	16.0	16.9	17.7
2	11.1	11.9	12.6	13.4	14.1	14.9	15.6	16.4	17.3
5	10.9	11.7	12.4	13.1	13.8	14.6	15.3	16.1	17.0
8	10.7	11.5	12.2	12.9	13.6	14.3	15.1	15.8	16.7
10	10.6	11.3	12.0	12.7	13.4	14.2	14.9	15.7	16.5
13	10.4	11.1	11.8	12.5	13.2	13.9	14.6	15.4	16.2
15	10.3	11.0	11.7	12.4	13.1	13.8	14.5	15.2	16.1
18	10.1	10.8	11.5	12.2	12.9	13.6	14.3	15.0	15.8
22	9.9	10.6	11.3	11.9	12.6	13.3	14.0	14.7	15.5

Indirect or Direct-fired Heating Systems?

Combustion of fuels like propane or natural gas does generate water, but the amount of water added to air is negligible compared to the amount of water being removed from the bin. For example, the amount of water added to the air using a propane heater (assuming 10 C increase for 5,000 cfm) is approximately 10 lb/hr. The amount of water being removed from the bin is approximately 120-200 lb/hr depending on the rate of drying.

Fuel Type

The total fuel cost theoretically depends on its cost ($/L) AND its energy density. The cost will fluctuate from month to month and region to region, but the energy density is constant. Propane and natural gas are considered "clean burning" fuels, so they can be used to directly heat the air entering the fan or bin. Diesel should only be used as an indirect source of heat.

Fuel	Fuel Cost* (variable)		Energy Density (fixed)		Fuel Cost (variable)		Fuel Cost (variable)
Diesel	$1.25/L	DIVIDED BY	38.6 MJ/L	EQUALS	$0.032/MJ	X 1056	$34.20 per million btu
Natural Gas*	$0.0998/m^3		37.0 MJ/m^3		$0.0027/MJ		$2.85 per million btu
Propane	$ 0.60/L		25.3 MJ/L		$0.023 /MJ		$25.04 per million btu

* SK rates as of January 2020

General Management Practices for NAD Systems with Supplemental Heat

1. Only use a CSA certified heater that is designed for use with grain storage fans for safety and grain quality reasons. Follow manufacturer's instructions for installation and operation.
2. Ensure adequate air flow rate (minimum 1 cfm/bu) or there is a risk of overheating the grain.
   - Low air flow rates may not have enough energy to fully remove moisture from the bin.
3. Aim for a plenum temperature of 15-25 C, but limit air temperature increase to 15 C or less.
   - Higher temperature increases result in high fuel costs, reduced heat transfer efficiency, increased chance of over drying, and increased chance of condensing and freezing at edge of bin.
4. Do not exceed a plenum (after heater) temperature of 30 C.
   - Even though higher temp = more drying capacity, you do not want to overheat the grain.
   - Air flow rates of 0.75 to 1 cfm/bu can "keep up" with moderate drying rates, but not with high drying rates associated with high temperatures (>30 C).
5. As much as possible, maintain a CONSISTENT air temperature going into the bin.
   - Thermostatic controllers are becoming more common and will help achieve a consistent temperature going into the bin. This will help minimize day-to-night variations in temperature.
6. Ensure adequate ventilation in the headspace since condensation on a cold bin roof can cause moisture problems in the stored grain.
   - A minimum of one square foot of vent space for every 1000 cfm of air flow is required.
   - Consider the use of "active" ventilation in the headspace to expel moist air more effectively.
7. Consider turning the bottom grain once the average bin moisture is dry to distribute over-dry grain.
8. Grain MUST BE cooled to less than 15 C after drying
   - Cooling will also remove some moisture, so drying may be complete when moisture is within 0.5 per cent of target.
9. Monitor grain conditions with in-bin cables and/or samples during drying.

More information on PAMI research projects is available on their website.