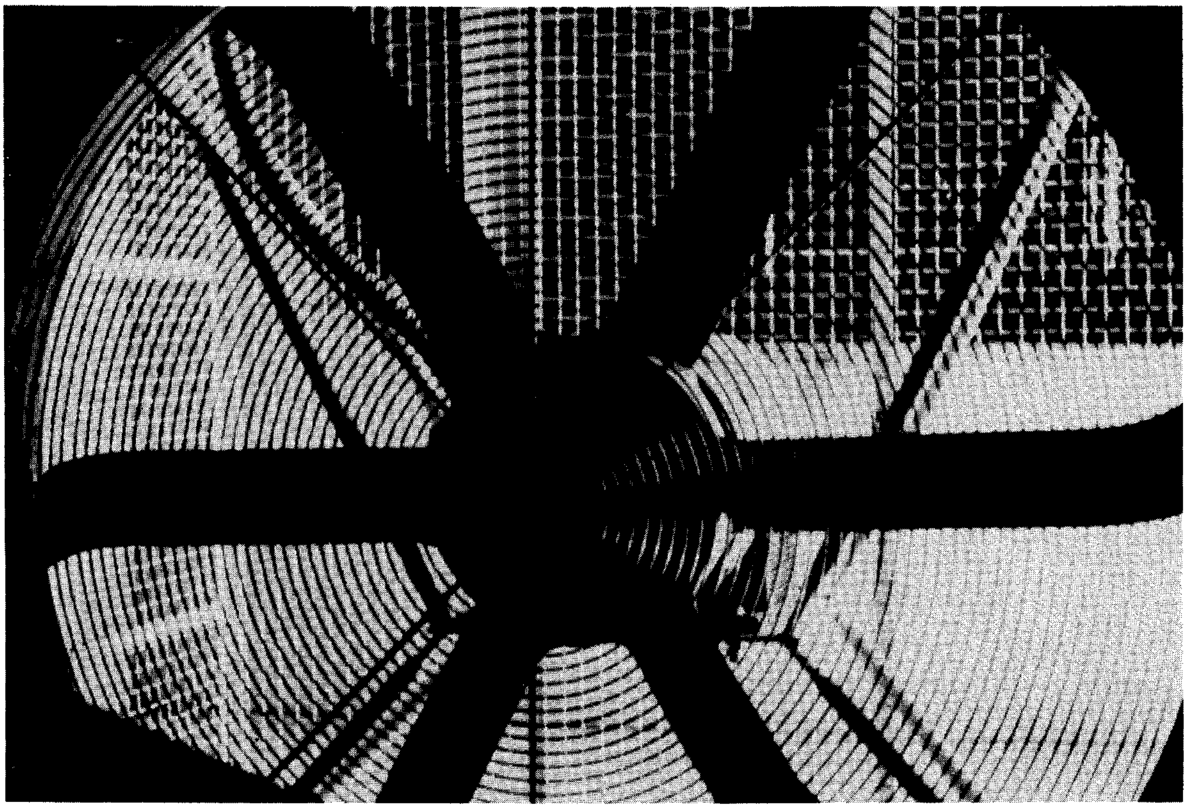
Onion Storage
Guidelines for Commercial Growers



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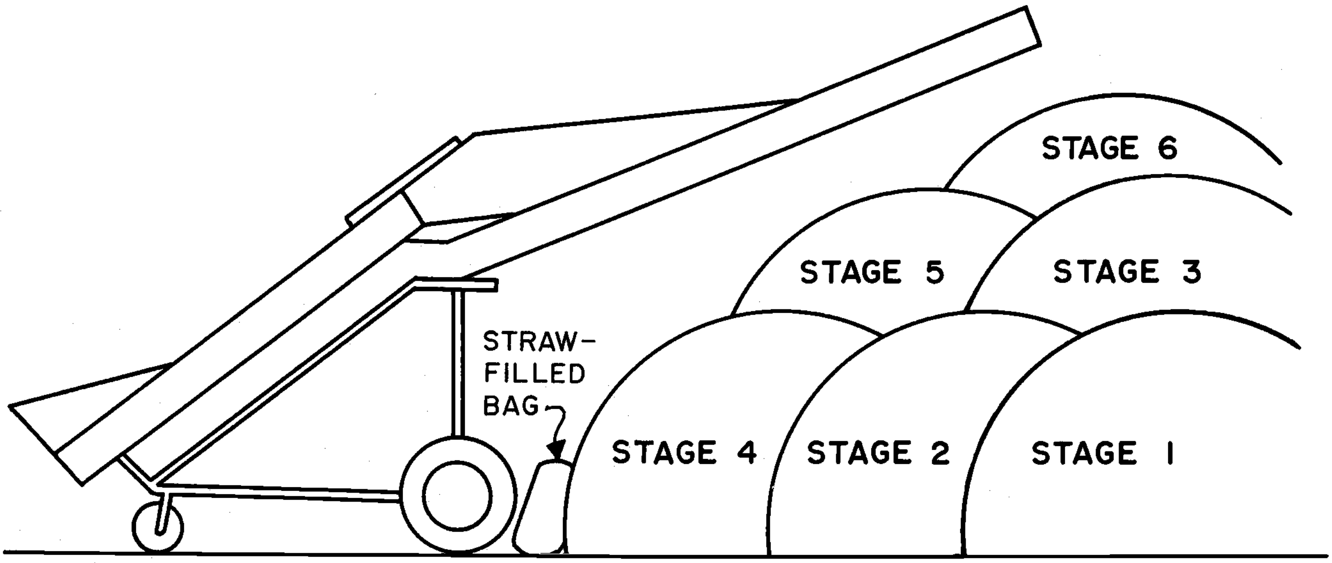


Figure 1.—Load placement with progressive bin filling

This publication is a guide to storing yellow sweet Spanish onions in the Columbia Basin, in the Snake River Valley, and in eastern Oregon, and Yellow Globe Danvers onions in western Oregon. Where storage conditions differ for the various areas, we've included appropriate instructions.

Storage losses of onions depend on preharvest, harvest, and storage conditions. The prestorage phases of onion management have a great influence on the quality of your stored onions.

Preharvest factors include:

1. your choice of variety,
2. the timing and rates of fertilization and irrigation,
3. applying growth regulators to inhibit storage sprouting,
4. curing of tops, and
5. topping.

Harvest date is extremely important. Early season maturity, through use of early varieties or early planting, increases the probability of good field curing and maturing conditions.

Immature onions don't store well in unrefrigerated storages; in most cases, you'll have to sell them quickly to avoid heavy storage losses. Immature onions are more subject to increases in neck rot and other storage disease problems.

Harvest injury occurs for a number of reasons. A major factor is carelessness during harvesting operations. If you use machine topping, consider these important factors: machine speed, conveyor speed, machine setting, and sharpness of onion top-cutting device and its setting (amount of top to be left).

Carefully transport onions to storage, to avoid bruising. Onions bruise if handled roughly when you load them onto trucks or into storage bins.

Handling precautions. Watch these points when you handle onions—starting with field lifting; moving on to bin filling, bulk loading, transport, unloading, and later moving onions from storage; then to processing, packaging, and shipping.

- Operate conveyors at full capacity and slow speeds.
- Be sure that all chain conveyors have rubberized surfaces.
- Pad any metal in contact with onions.
- Reduce right-angle bends.
- Keep all onion drops to less than 18 inches (46 cm) unless you use special canvas drop chutes. It's most desirable to keep all drops below 12 inches (30 cm). This will significantly reduce bruising damage.

In filling all bulk storages:

- Provide a short draper chain conveyor between initial fill hopper and the boom piler to allow dirt, clods, and rocks to sift through before they hit the piler.
- Remove any diseased or injured onions carried from the field by having a sorter work beside the dropper chain conveyor.
- Be sure your boom piler is long enough to provide a wide swing for the piler boom (and thus a more uniform onion pile surface).

Figure 1 shows onion load placement with progressive filling to prevent rolling bruises.

Storage management

The phases of onion storage management are drying, curing, cooling, holding, and conditioning before marketing. We discuss these phases in the sections that follow—in this order, except that we've inserted refrigeration between cooling and holding because refrigeration can be important for both these phases.

Climatic or cultural conditions may prevent complete maturation and/or field drying of onions. If so, you must plan to mature and dry your onions in storage.

Drying

Surface drying of onions is most frequently necessary west of the Cascades. It's occasionally necessary east of the Cascades.

Drying may be needed:

- if you bring your onions into storage green;
- if you need to hasten the maturity of your onions for an early market; or
- if rain or dew periods occur during your harvest.

Your onions should be thoroughly dry before you lift them. Let all dew evaporate before you store them.

If external free moisture is present on onions when you bring them into storage, remove it as quickly as possible—the atmosphere surrounding the onion will be saturated until you remove this moisture.

If your onions are partially topped, you can dry them in bulk storages by forcing 2 cubic feet of air per minute per cubic foot of onions (2 cfm/ft^3) through the pile. Start air flow as soon as onions cover the first air duct. In a saturated atmosphere, rot-causing fungi and bacteria carried on the onion can infect the onion bulb.

To preserve onion quality, air supplied to the storage should not have a relative humidity higher than 75% during the drying period. Exhaust as much air as necessary to keep humidity below this level.

At first, use only outside air that has a humidity below 75%. When you use heated air, keep its temperature below 95°F (35°C). During the drying period, large amounts of air (2 cubic feet per minute per cubic foot of onions or 2 m^3/min/m^3) are needed.

Air without artificial heat is satisfactory when you extend your drying period to 3 days and when ventilating air is well below 75% relative humidity. You can monitor the drying by placing a hygrothermograph at the top of the onion pile.

When the relative humidity of the air above the pile drops suddenly after the initial period of continuously high relative humidity readings, the drying period is completed—providing that you didn't add any heat.

After you remove surface moisture, keep the humidity of the storage area between 60 and 70%. Check the outer scales and neck of the onions for proper moisture content. Excessive drying may result in shucking of the outer scales (this is referred to as *baldness)*.

Wet onions offer a fairly high resistance to air flow. It's a good idea to limit your onion pile depth to 8 feet (2.4 m). This is especially important for some soft-bulbed varieties.

A static pressure of approximately 1¼ inches (32 mm) of water is needed to push air through the onions and the air distribution systems, especially when you leave the tops on the onions.

The pressure drop through dry onions without dirt and trash is almost negligible under normal ventilation rates. In this case, we can attribute the static pressure loss to the design of the air distribution system.

Curing

Onions must be cured to obtain maximum storage life and to retain quality. A properly cured onion has a dried, shrunken neck and dry outer scales free of splits or peeling. Excessive drying causes sloughing off of the outer scales and excessive shrinkage of the onion.

Weight loss of properly stored onions should not exceed 5% during the curing period. The outer scales of the onion provide protection against decay-causing organisms through antifungal compounds they contain. Presence of these compounds is necessary for extended storage.

Immature onions have fewer outer scales and high moisture content; therefore, they require more extensive curing conditions than mature onions do.

Your objectives now are to:

1. allow development of natural dormancy,
2. seal the onion against infection by disease organisms that may be present in the tops,
3. provide for maximum retention of the outer onion scales, and
4. reduce respiration rate of the bulbs.

Protection from disease organisms occurs when:

1. the neck tissue of the onion bulb dries and shrinks, and
2. the damaged areas on the onion skin are healed.

You must complete your curing quickly—to prevent disease and rot organisms from affecting the onion bulb. Field curing normally takes from 6 to 20 days.

Curing requirements

1. Immature or inadequately field-cured bulbs
   - ventilation—up to 2 cubic feet of air per minute for each cubic foot of onions (2 cfm/ft^3), or up to 2 cubic meters of air per minute for each cubic meter of onions (2 m^3/min/m^3);
   - temperature—up to 95°F (35°C); and
   - air moisture content—less than 50% relative humidity.
2. Fully mature and partially field-cured onions
   - ventilation—an air volume of 1 cubic foot per minute per cubic foot of onions (1 cubic meter per minute per cubic meter of onions);
   - temperature—you can use heated air to increase the rate of curing; and
   - air moisture content—less than 50% relative humidity.

Free water on onion bulbs results in an environment that promotes early sprouting and allows disease and rot organisms to develop.

You can prevent condensation during the curing period by:

1. using warm, dry air, and
2. using outside air only when:
   - its dewpoint temperature is at or below the temperature of the coldest onions *or*
   - its air wet bulb temperature is lower than the temperature of the coldest onions.

Use the psychrometric chart to determine the dewpoint temperature (see page 10). Keep a record of daily onion pulp temperatures, taken from various locations within the storage (see table 1 for an example).

Cooling

After drying and curing, lower the temperature of stored onions steadily and evenly to the desired storage temperature. Bring onion temperature down to holding temperature in gradual steps, following the normal seasonal temperature monthly drop unless you use refrigeration.

Table 1.—Example record of temperatures in an onion storage

Date	Time	Storage location	Temperature: Onion tissue	Air dry bulb	Air wet bulb	Air dewpoint
20 Oct.	0900	outside air at intake	——	35°F (1.7°C)	30°F (−1.1°C)	21°F (−6.1°C)
20 Oct.	0900	mixed air entering ducts	——	44°F (6.7°C)	39°F (3.9°C)	33°F (0.6°C)
20 Oct	0910	air over onions	——	47°F (8.3°C)	42°F (5.6°C)	37°F (2.8°C)
20 Oct.	0910	top of pile, position 1	48°F (8.9°C)	——	——	——
20 Oct.	0920	top of pile, positon 2	46°F (7.8°F)	——	——	——
20 Oct.	0925	top of pile, position 3	46°F (7.8°C)	——	——	——

Long term average monthly temperatures serve as a guide (see figure 2 for monthly average temperatures for selected areas in Idaho, Oregon, and Washington). You can also follow shorter range seasonal temperatures; however, you must monitor air humidity and onion temperatures to be sure that condensation will not occur.

If onions are colder than the dewpoint temperature of the ventilating air, condensation will occur.

Keep all onions in a storage within 5°F (3°C) of the same temperature by using cool ventilating air (within 5°F or 3°C of the onion pulp temperature). During freezing weather, you may have to mix inside air and cold outside air to obtain desired ventilating air temperature.

Large variations of temperature within the onion pile can lead to dehydration of those onions nearest the ventilating tubes and to condensation problems on the surface of the cooler onions.

Refrigeration

When you use refrigeration, lower the temperature of the onion storage air slowly to 33°F (0.5°). The onions should not be cooled too rapidly as this could result in damage to some onions from the low humidity and other stress damage.

As a guideline, reduce onion pile temperature at a rate of about 1°F (.5°C) per day. This helps you keep your investment in a refrigeration system down to a reasonable level. Your refrigeration system size should be 5 hp of compressor capacity per 200 tons of onions if you cool primarily by refrigeration.

If you use refrigeration to maintain the holding temperature, and if you primarily use natural outside air for your initial cooling, 3 hp of compressor capacity per 200 tons of onions is adequate.

These capacities are based on the following assumptions:

1. you're using recommended R values of insulation in your walls and ceiling;
2. the onions are mature;
3. the heat of respiration is under 2,000 Btu/ton/24 hours; and
4. outside air temperature is below 90°F (32°C).

To keep your system costs in an affordable range, reduce the temperature of the onions as much as possible when you first place them in storage—before you use refrigeration.

Design your refrigeration system so that you can mix refrigerated air passing through evaporator coils with recirculated warmer return air, so that the ventilated air will not be more than 5°F (2.7°C) cooler than the coolest onions in the storage—and in no case lower than 29°F (−1.7°C).

Air cooling coils for onion storages are normally designed to maintain a storage air temperature near 33°F (.6°C), with a relative humidity of 60 to 70%.

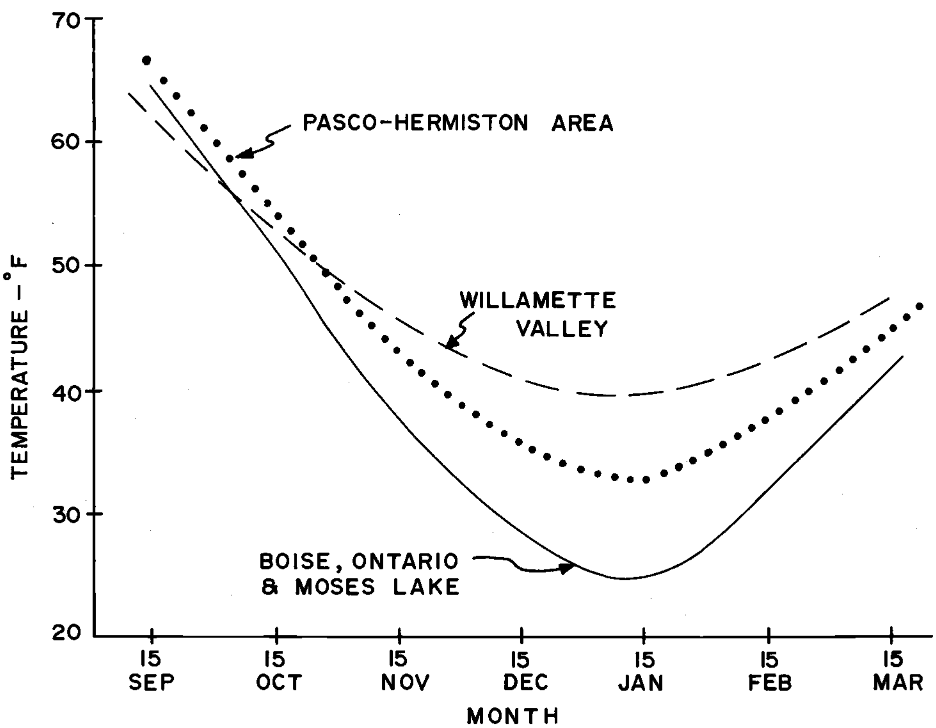


Figure 2.—Monthly average temperatures in selected Oregon, Idaho, and Washington areas

Fin spacing on the coils should not be more than 6 per inch. A wide fin spacing is desirable with the low operating coil temperatures (27 to 28°F; -2.8° to -2.2°C) that are required to maintain both a 33°F (.6°C) storage temperature and 60 to 70% relative humidity.

At this low temperature, frost and ice tend to build up on coils at a fairly fast rate and to quickly block the flow of air through the coils.

Select refrigerated cooling coils to operate on a maximum of 10°F (3°C) differential between the coil temperature and the room air temperature. These coils need more cooling surface than coils designed to operate at a 15 to 20°F (8.3 to 11.0°C) temperature differential.

Your coils should have an automatic defrost system. The two recommended choices are electric heat or hot gas defrost. In the Northwest, an electric defrost system would likely cost less to install.

Another important point to consider when you use a refrigerated cooling coil is bypassing all or part of the ventilation air around the cooling coils. This would reduce air friction losses when you use cold outside air instead of refrigerated air to cool your onions.

You could also mix this bypass air with cooler refrigerated air from the coils to provide the desired cooling air temperature and humidity. If you dry and cure onions in storages, you could add heat to the ventilation air and then bypass the cooling coils.

Holding

The best holding temperature for onions is at or near 33°F (.6°C), with a relative humidity between 60 and 70%. Adjust louvers to allow air relative humidity to remain below 70% (higher humidity promotes root growth and bulb decay).

The desired temperature and humidity is difficult to maintain without refrigeration. To keep a uniform holding temperature without refrigeration, hold stored onions at 35°F (2°C) east of the Cascade Range and 40°F (4.4°C) west of the Cascades.

These temperatures are recommended to reduce fluctuations in onion holding temperature, and this will minimize sweating and sprouting of stored onions.

After you have lowered temperatures to the desired holding point, operate your ventilating system to prevent condensation from occurring on the onions. During the holding period, reduce ventilation air flow rate to 1 cfm per cubic foot (1 $m^3/min/m^3$) of onions.

Ventilate only when necessary to maintain storage temperature or to exhaust high humidity air (relative humidity above 70%). Normally, you can do this by operating the fans a portion of each day when outside air is cooler than onion bulb temperature.

In some cases, circulating the air within the storage will be necessary to maintain even temperatures throughout the onion pile. Good storage management requires an understanding of the relationship of air temperature and humidity to desired storage conditions. Improper use of the ventilating system during the holding period can spoil dry, well-cured onions.

Every onion storage operator should have either a sling or an aspirating psychrometer—and know to use it. We provide details below in the section, "Moist air and the psychrometric chart," page 10.

Two good rules to remember:

1. It's safe to ventilate whenever the dewpoint temperature of the air to be circulated is at least 1°F (.5°C) lower than the bulb temperature of the coldest onions in the storage.
2. It's also safe to ventilate whenever the dry bulb temperature of the ventilaing air is at least 1°F (.5°C) lower than the onion bulb temperature—but not below 29°F (– 1.7°C), the freezing point of onions.

Study the examples on the use of the psychrometric chart (page 11). Understanding the chart—and learning how to use it—will help you eliminate the danger of condensing moisture from the ventilating air.

A commmon mistake in onion storage management is to ventilate on a sunny and warm winter day, when (first) the onions in storage are cooler than the air being blown into the storage and (second) the dewpoint of the incoming air is higher than the temperature of the onions. The result—moisture condenses on the cooler onions.

Conditioning

You will often need to condition your onions before you package them—either by holding them in a warm packing plant or by conditioning them before you move them into a packing line. During this time, there is danger of water condensing on the onions if the air has a high moisture content.

Air at a temperature of 68°F (20°C), with a relative humidity of 50%, has a dewpoint near 50°F (10°C). If onions at 40°F (4.4°C) are exposed to this air, moisture will condense on the surface of the onions. (See the section on using psychrometric charts, page 10.)

Moisture on the surface of onion bulbs will prevent the removal of loose outer bulb scales (called *shucking*), and it will pose problems in cleaning. When bulbs are wet, it's necessary to dry them to a point where you can do the shucking. During the time required for the additional drying, the packing line can't operate—which can mean a loss of income.

If you remove too much moisture too rapidly when you artificially heat your onions, the result could be *bald* onions (those that have lost too many scales).

You can reduce shucking and balding problems by using separate facilities to control the environmental conditions of those onions that you plan to pack each day. This conditioning facility should handle at least a 2- or 3-day processing line supply. Use this facility to bring the onion temperature up to the packing room temperature—slowly.

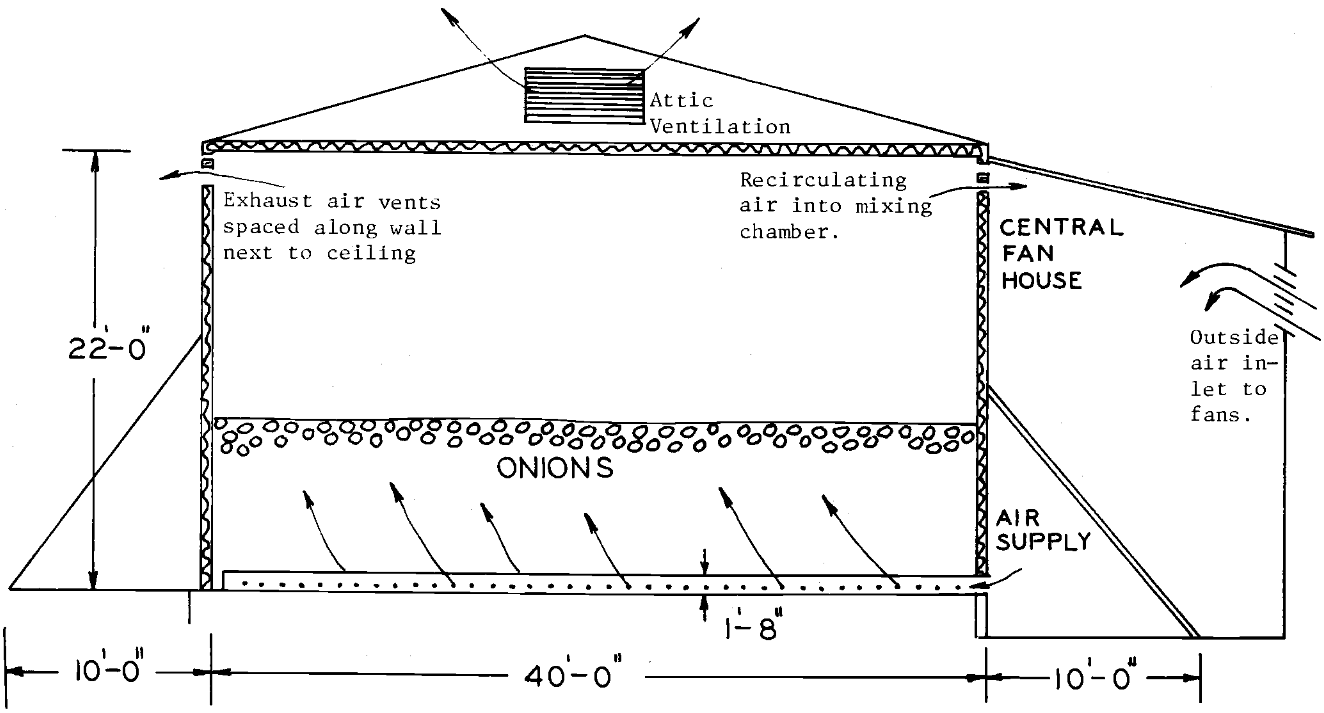


Figure 3.—Elevation view of a bulk onion storage. In this and similar figures, keep in mind that 1 foot = approximately .3 meter.

Storage systems

Bulk storage

Before you can design an environmentally controlled onion storage building, you need to understand the interaction of the building, its fixed equipment design, and the stored product (figure 3).

The building's design must accommodate the bulk and weight of the stored product. For example, if the wall height is 18 feet (5.5 m) with a maximum of 10 feet (3 m) of onions, you'll have to use 2 × 12 studs of No. 2 Douglas-fir or equivalent spaced 16 inches on centers. (See figure 4 for suggestions on stud wall foundation support.)

Use ¾-inch exterior plywood on inside walls. Your walls and ceiling must have adequate insulation to eliminate condensation, to reduce heat losses or heat gains to an economically controllable level, and to prevent the onions from freezing.

The air ducts must be large enough to distribute the air uniformly—and economically. The controls must coordinate air temperature, humidity, and volume to achieve and maintain the conditions you have chosen.

Pallet storage

The major problem with pallet box handling and storage of onions is the difficulty in cooling the onions in boxes and providing uniform air movement through the onions.

This happens (first) because designs of many boxes don't provide for adequate bottom slots to assist in ventilation through onions and (second) because pallet boxes are difficult to arrange in a storage area in such a way that you can obtain maximum cooling efficiency of the ventilating air.

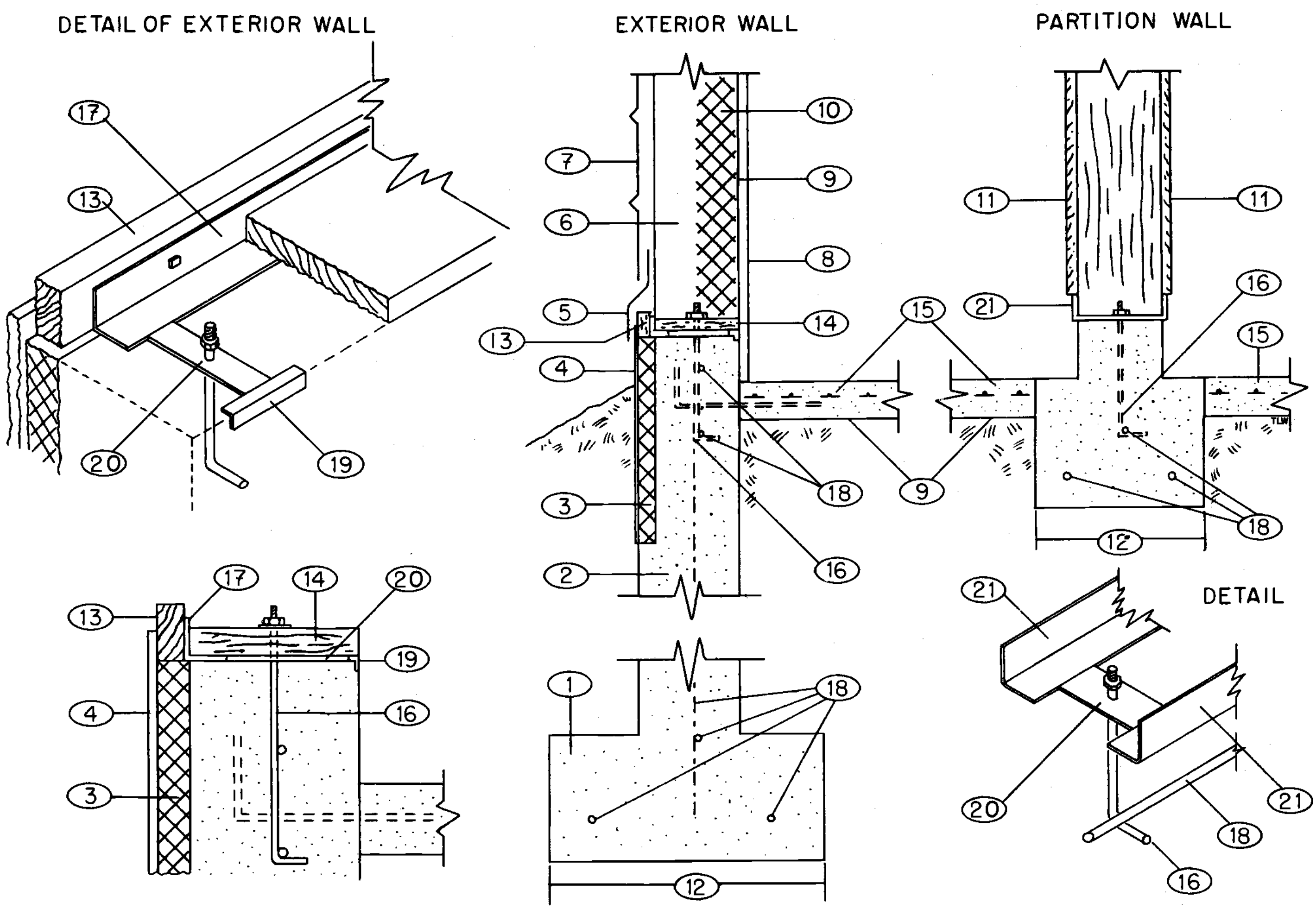
When it's possible to cure onions in the field in boxes, you reduce storage air requirements and you handle your onions fairly efficiently into storage.

If you plan to store onions outside for a short time before shipping, hold them in shaded areas (be sure to allow for good air movement around the bins and through the onions).

Don't store onions on the south side of buildings. Onions stored in direct sunlight can get too warm, and they may show transluscent scales. These scales can cause marketing problems (and serious losses) if you eventually store the onions before shipping.

The following suggestions (illustrated in figures 5 and 6) may be helpful when you stack pallets of onions in a storage area:

1. *Don't place pallets directly against walls.* Heat and cold from walls are readily transmitted to nearby onions, and either one will cause severe problems in the flow of ventilating air past pallets. Stacks should be 8 to 12 inches (20 to 30 cm) from all walls.
2. *Form rows in straight lines* with a 6-to 7-inch (15- to 18-cm) space between rows of pallet boxes.
3. *Stack rows parallel* to the direction of air flow.
4. *Make stack rows of similar pallets,* so that all dimensions are nearly the same. Height, width, and length should not differ between various pallets. Position each column of boxes over an air lateral if you use underfloor laterals. Place boxes along laterals tightly against each other to reduce air leakage.
5. If you place *immature or inadequately field-cured onions* in pallet boxes to complete drying and curing, they may pose a severe problem because they lower the rate of air circulation within the boxes.
6. *Exhaust air at a high point* on the wall, opposite low or underfloor air inlet entrance. Space your exhaust



1. Footing below frost line.
2. Concrete foundation.
3. 2″ × 22″ rigid insulation (perm rating less than 0.8).
4. 3/16″ × 24″ high-density, recompressed, exterior-type cement asbestos board or an acceptable metal protective cover.
5. Galvanized metal flashing.
6. 2″ × 12″ or 4″ × 12″ stud.
7. Metal siding applied horizontally.
8. ¾″ exterior-plywood sheathing.
9. 6-mil polyethylene vapor barrier.
10. Insulation.
11. ¾″ exterior-plywood sheathing.
12. Dimension varies according to soil bearing capacity.
13. 2 × 4 nailer.
14. 2 × 12 pressure-treated sill.
15. 5″ concrete floor reinforced with 6″ × 6″ × 6/6 wire mesh.
16. ½″ diameter × 18″ anchor bolt every 2 feet wired to upper two reinforced horizontal bars.
17. 3″ × 3″ × ¼″ steel angle iron in 4′ lengths; ⅜″ × 1½″ lag screws into 2″ × 4″ nailer (13).
18. #4 reinforcing bars—horizontal bars continuous; vertical bars wired every 4 feet to horizontal bars.
19. 1″ × 1″ × ¼″ × 6″ long steel angle iron.
20. ¼″ × 2″ plate drilled for ½″ anchor bolts welded to (17) and (19) for exterior wall or to (21) for partition wall (coat welds with primer).
21. 3″ × 3″ × ¼″ angle iron in 4′ lengths connected by ¼″ × 2″ plate welded to each side piece & drilled for ½″ anchor bolts (16). A 2 × 12 sill plate can be used for ease of attachment of interior wall studs to foundation as shown in detail of exterior wall.

Figure 4.—Typical exterior and partition wood stud wall construction

outlets along the length of the wall. The outside air intake to the fan should be high on the side of the building, to reduce uptake of high moisture air near ground level.

7. *Continuous circulation of air* in the storage may be necessary to provide enough moist air exhaust from the central portion of the bin. When you bring in outside air to dry, cool, hold, or condition onions in pallet boxes, pay attention to the principles about dewpoint outlined for bulk storage (see page 11).

8. *The total open area between slats* of floor ducts should be about 30% less than the cross-sectional area of the duct opening. Keep the floor-duct depth constant for its entire length. Use slats 3½ inches (9 cm) thick to reduce breakage. Provide a support 2 to 3 inches (5 to 7 cm) wide on each side of the floor duct for slats. Provide approximately 0.6 inch (1 cm) slot width. Not all adjoining slats need open spaces; this depends on required open area compared to duct cross-sectional area.

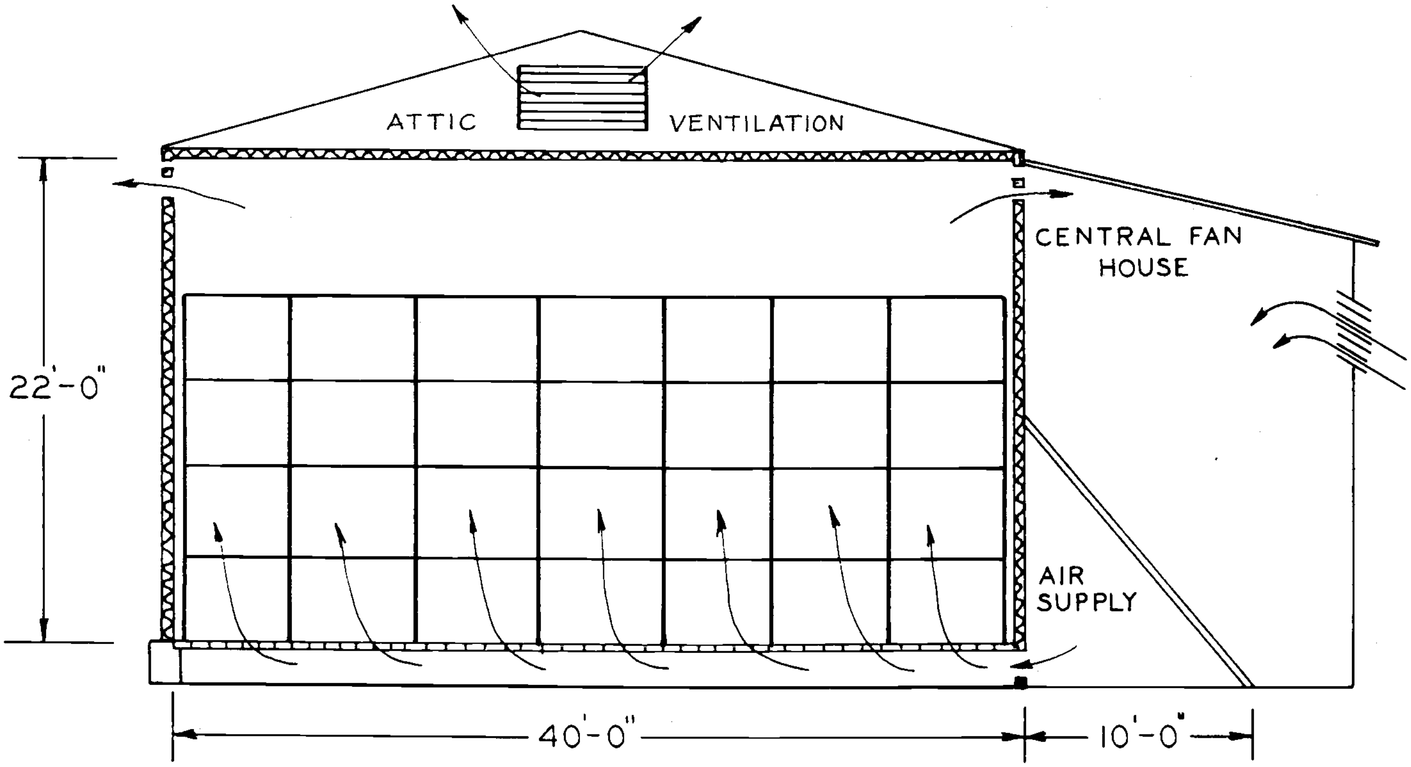


Figure 5.—Elevation view of a palletized onion storage

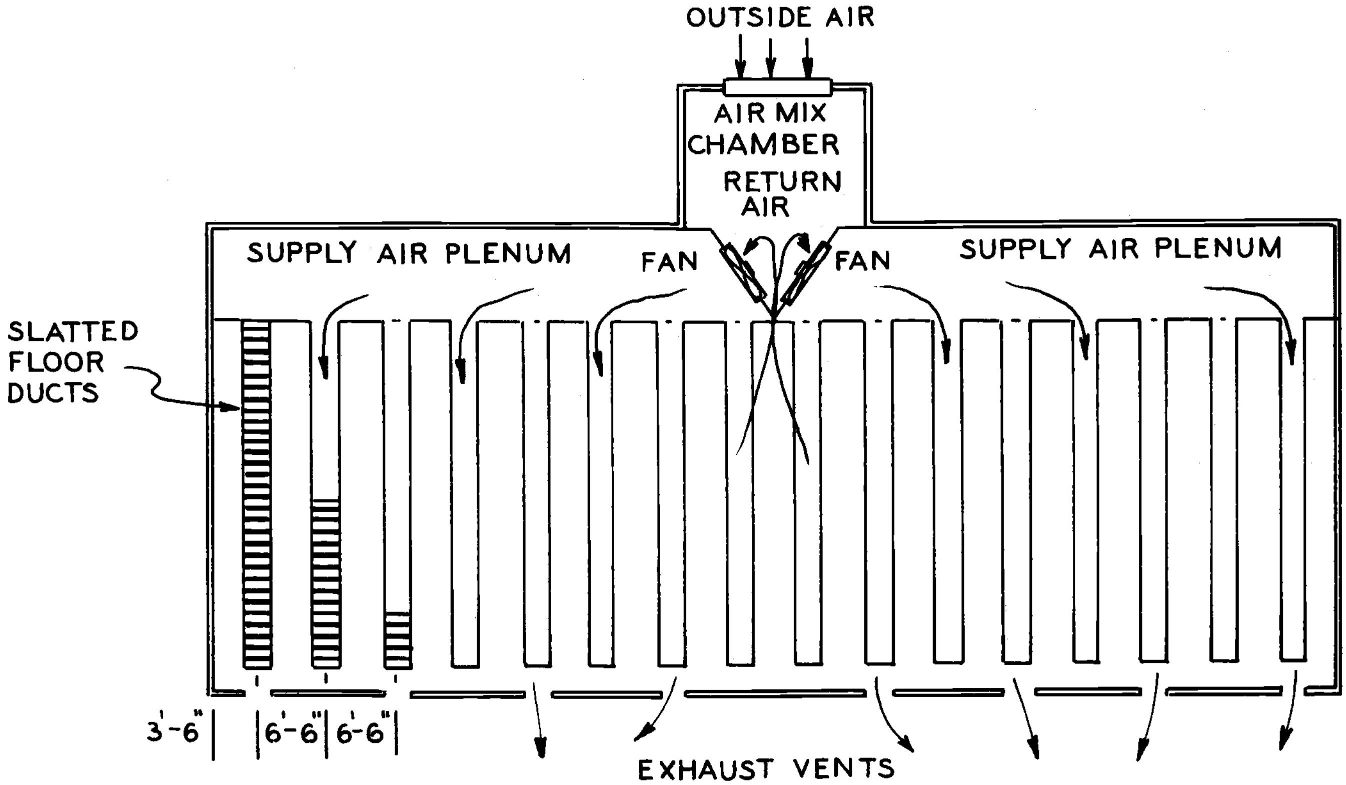


Figure 6.—Floor plan of a palletized onion storage

Insulation

Insulation is important to maintain a uniform holding temperature. Take the time to learn how the R value can help you do this.

The *R* value describes the ability of a material to resist heat flow (the greater the R value, the higher the insulation value). The R value is normally indicated on the insulation material itself or in charts, either per unit of thickness or for the listed thickness of material.

West of the Cascades, the storage walls should have an R value of 11. This means that the walls should have about 3 inches (8 cm) of a fibrous insulation or 2 inches (5 cm) of a plastic foam insulation with an R value of 5 to 6 per inch (2 to 2.4 per cm).

East of the Cascades, walls should have an R-19 insulation value—about 6 inches (15 cm) of fibrous insulation or about 4 inches (10 cm) of plastic foam insulation.

Cover either type of insulation with an interior wall and use a vapor barrier under the inner surface of the interior wall.

In locations *both* east *and* west of the Cascades, a ceiling insulation value of R-30 is desired. This means 7 or 8 inches (18 to 20 cm) of a fibrous insulation, or about 5 inches (12.5 cm) of a plastic foam, with an R value of 5 to 6 per inch (2 to 2.4 per cm) of thickness.

A vapor barrier should face the interior of the building. Be sure that the vapor barrier has no holes and that all joints are sealed to prevent moisture movement into insulation.

Provide a 2- to 6-inch (5- to 15-cm) air space between the insulation and outer surface of the structure. Use a continuous screened air vent along the bottom of outside walls and along the roof ridge, to promote air movement between the outer surface of the structure and the insulation. This will reduce moisture buildup behind the insulation.

Ventilation systems

For bulk storages, design your ventilation system to cover seven basic areas: adequate air pressure, air flow velocity, using fans correctly, laterals and ducts, duct outlet holes, controlling air flow, and using fan controls.

Adequate air pressure

Your system must provide 2 cubic feet per minute of air per cubic foot of onions (2 $m^3/min/m^3$) at 1¼ inches (32 mm) of static pressure—and it must distribute this pressure uniformly through the onions. Additional air pressure is necessary if you use refrigeration.

Air flow velocity

In the lateral ducts, the *velocity* should be no higher than 1,200 feet per minute (6 m per second or 6m/s) at an air *flow* rate of 2 cfm per cubic foot of onions (2 $m^3/min/m^3$)—and no lower than 600 feet per minute (3 m/s) when you reduce the air flow rate during the holding period.

This means that the air volume of the system can vary from 1 to 2 cfm per cubic foot of onions (1 to 2 $m^3/min/m^3$). Air flow rates within this range will maintain a large enough pressure drop through the lateral holes to give good air distribution.

The general recommendation for duct design is to keep air duct velocities under 1,200 feet per minute (6 m/s), to minimize high-pressure losses, and to provide uniform air distribution.

Because you'll need high volumes of air during drying and curing and relatively low air flow rates during the holding period, you must use a *range* of air velocities that will provide uniform air flow out to laterals during all use conditions.

The arrangement and size of air outlet holes along the lateral ducts greatly affects the uniformity of air distribution. You can check this by adding up the cross-sectional areas of the discharge holes of the laterals; your total should be less than the cross-sectional area of the lateral ducts.

This ratio should be about 1 to 1.3 (assuming that discharge holes are free of obstructions).

Using fans correctly

To obtain a wide range of air volume options, use two or more fans. Then you can obtain a high volume of air when you use all the fans during drying and curing, and a lower volume will be available when you use fewer fans for the holding-period ventilation needs.

All fans should have louvers that you can fully close when the fan is not in operation.

When you select your fans, consider those that will provide the necessary rated air flow at 1¼ inches (32 mm) of static pressure (see also "Selecting your fans," page 13).

This is desirable in case onions get wet from condensation or damp from rain in the field before storage—or if sprouting occurs during late storage (then they'll have a higher resistance to air flow than dry or unsprouted onions). Damp onions with tops can have high resistance to air flow.

Laterals and ducts

Don't space these more than 5 feet (1.5 m) apart on centers. Researchers tell us that air in a bulk onion pile doesn't travel horizontally into the onion pile very far from the duct, even at fairly high discharge pressures through duct outlet holes.

The maximum duct length is 40 feet (12 m). See figure 3 for additional ideas for bulk storage.

Duct outlet holes

These must have protection from possible plugging of holes by onions. In round ducts, locate the holes along a horizontal line on the lower quarter of the duct circumference.

Controlling air flow

You can use sliding panels at each entrance to control the air flow into each lateral.

Using fan controls

Fans have automatic controls that will:

- turn them on and off to maintain a desired onion pulp temperature;
- protect the onions from freezing; and
- reduce sweating with differential temperature controls that maintain the inlet air temperature below onion pulp temperature during the holding phase of storage.

During drying, curing, and conditioning, the storage manager must supervise heating of the inlet air to desired conditions. In the early spring, automatic control of onion pulp temperature is vital. Manual control usually won't give 100% use of the available night cooling hours.

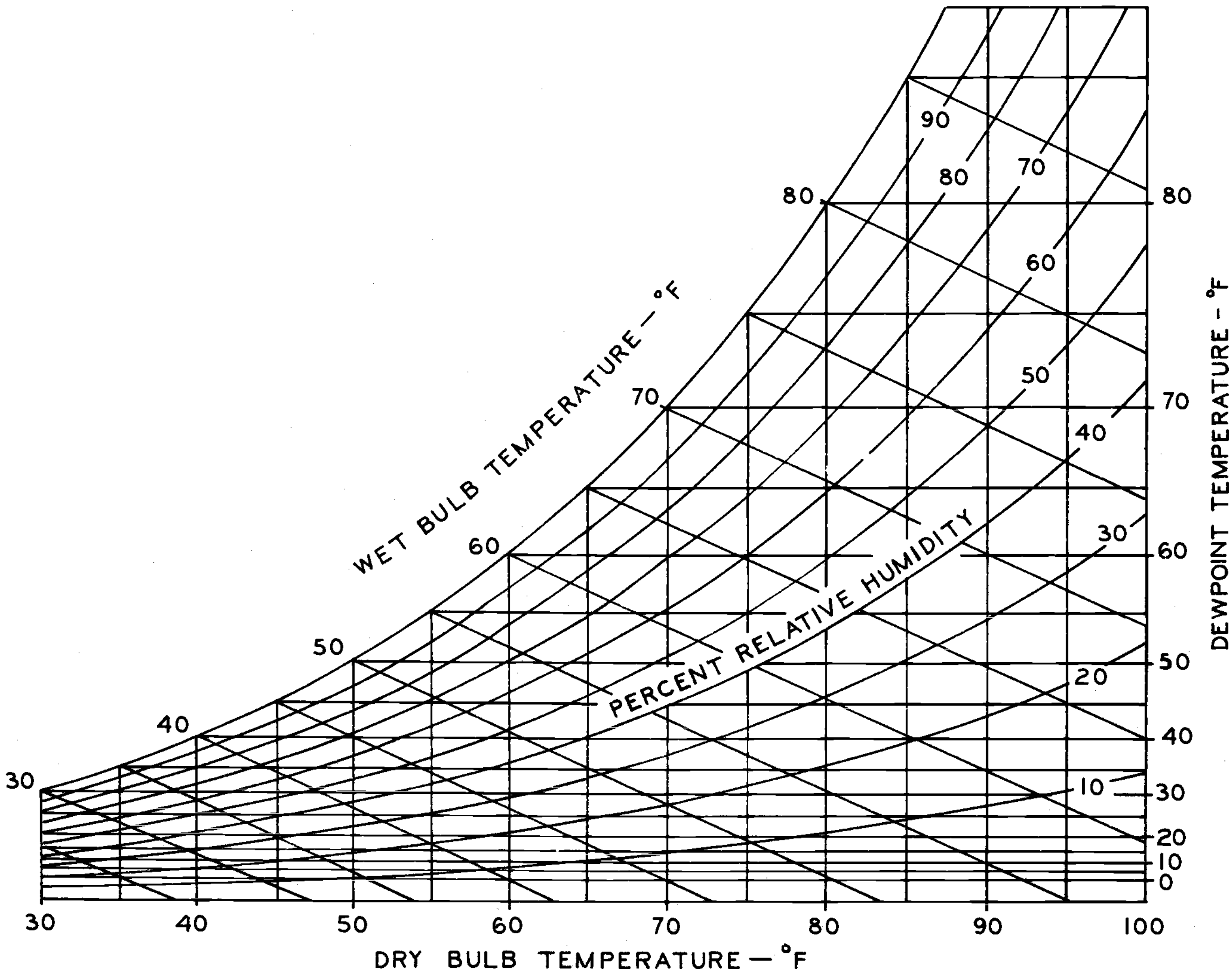


Figure 7.—Simplified version of a psychrometric chart

Moist air and the psychrometric chart

You can use the psychrometric chart to help determine moist air properties. It's one of the most useful tools available to people involved with the drying, curing, and storing onions. Understanding how to use it is necessary to properly operate an onion storage.

The simplified version of a psychrometric chart shown in figure 7 presents the relationship between moist air properties.

Using the chart

Dry bulb temperature (vertical lines). This is the air temperature as taken with a standard thermometer.

Wet bulb temperature (diagonal lines). This is the temperature of the air as influenced by the rate of evaporation of water. Evaporation has a cooling effect, and the rate at which evaporation occurs depends on the amount of moisture in the air.

For air that is relatively dry, the wet bulb temperature is considerably lower than the dry bulb temperature. For air that is saturated with water vapor (100% relative humidity), wet bulb and dry bulb temperatures are the same.

Relative humidity (curved lines). Percent relative humidity is an expression of the amount of water vapor in the air at any given temperature compared to the amount of water vapor there would be if the air were saturated.

Saturated air has a relative humidity of 100%. Air that is carrying only half the water vapor it could carry at a given temperature has a relative humidity of 50%.

Dewpoint temperature (horizontal lines). This is the temperature at which a cooling air mass reaches its saturation point without additional water vapor. Warm air can hold more water vapor than cool air.

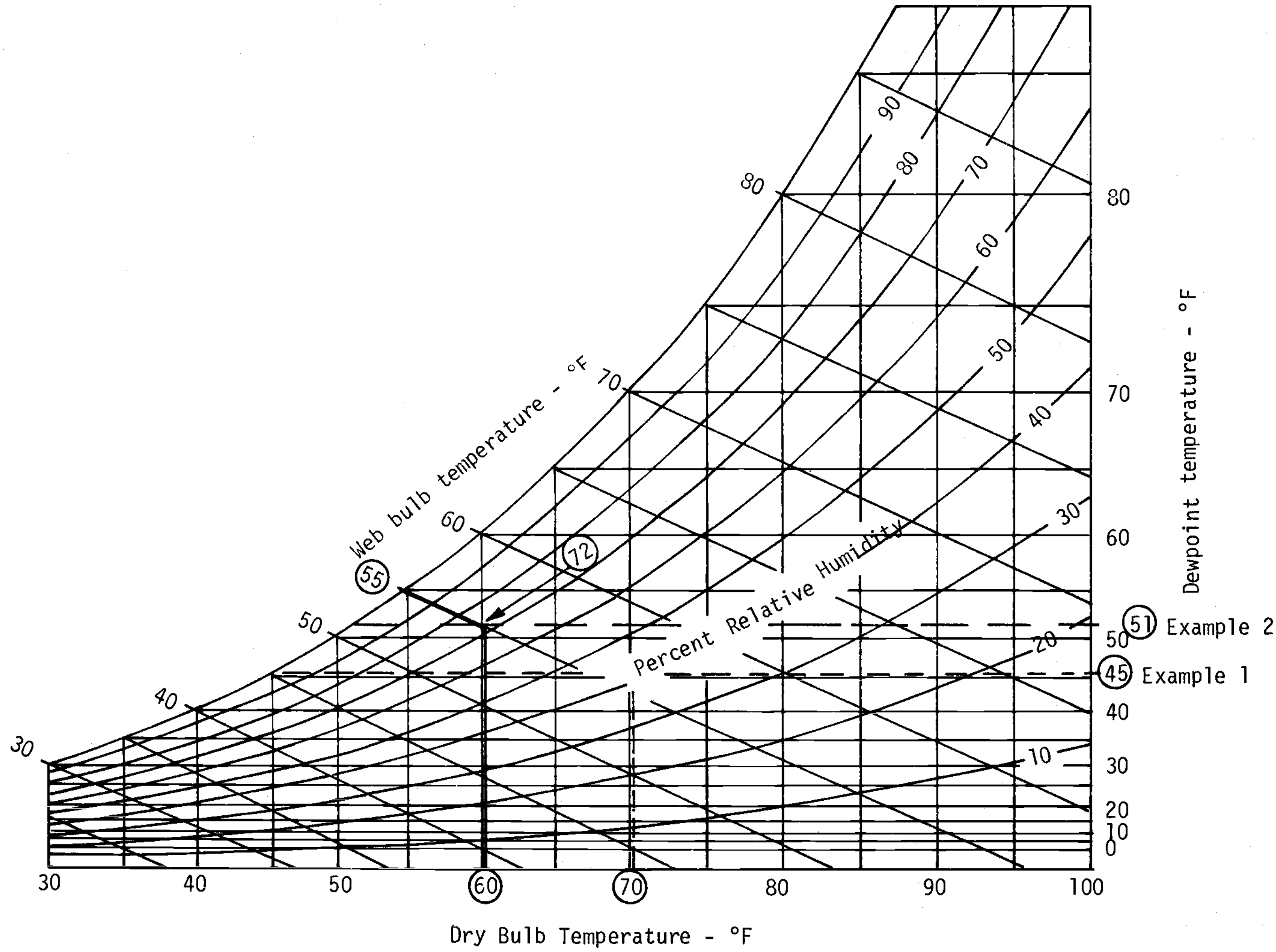


Figure 8.—Psychrometric chart solution to examples 1 and 2

Example 1 (see figure 8). Air with a dry bulb temperature of 70°F (21.1°C) and a relative humidity of 40% is completely saturated when its dry bulb temperature is lowered to 45°F (7.2°C). This is, therefore, the dewpoint temperature for air with a dry bulb temperature of 70°F (21.1°C) and a relative humidity of 40%.

Example 2. This air mass has a dry bulb temperature of 60°F or 15.6°C (vertical line) and a wet bulb temperature of 55°F or 12.8°C (diagonal line). The relative humidity (curved line) is 72%. The dewpoint temperature (100% relative humidity—horizontal line) is 51°F (10.6°C).

A handy rule of thumb

Don't use outside air to ventilate stored onions unless the air's dewpoint temperature is at least 1°F (.5°C) below the temperature of the coldest onions (figure 9).

Example 3. This situation could exist during the curing period. Assume that the onion temperature is 65°F (18.3°C), the dry bulb temperature of outside air is 78°F (25.6°C), and its wet bulb temperature is 70°F (21.1°C).

From the horizontal line, you can see the dewpoint temperature is about 67°F (19.4°C). To bring this air in contact with 65°F (18.3°C) onions would cause instant condensation (100% relative humidity) on the onion surfaces.

Example 4 is a situation that could exist during the last part of the storage period. The onion temperature is 38°F (3.3°C), and moisture is condensing on the ceiling of the storage structure because of increasing humidity.

Outside air has a dry bulb temperature of 48°F (8.9°C), and its wet bulb temperature is 46°F (7.8°C). The horizontal line indicates a dewpoint temperature of 44°F (6.7°C).

Circulating this air through the onion storage would not remove the moisture on the ceiling, but it would cause instant condensation of free water on the 38°F (3.3°C) onion surfaces.

If the outside air had a 48°F (8.9°C) dry bulb temperature at 60% relative humidity, the dewpoint temperature would be 35°F (1.7°C). You could use this air safely and effectively to dry off the storage ceiling.

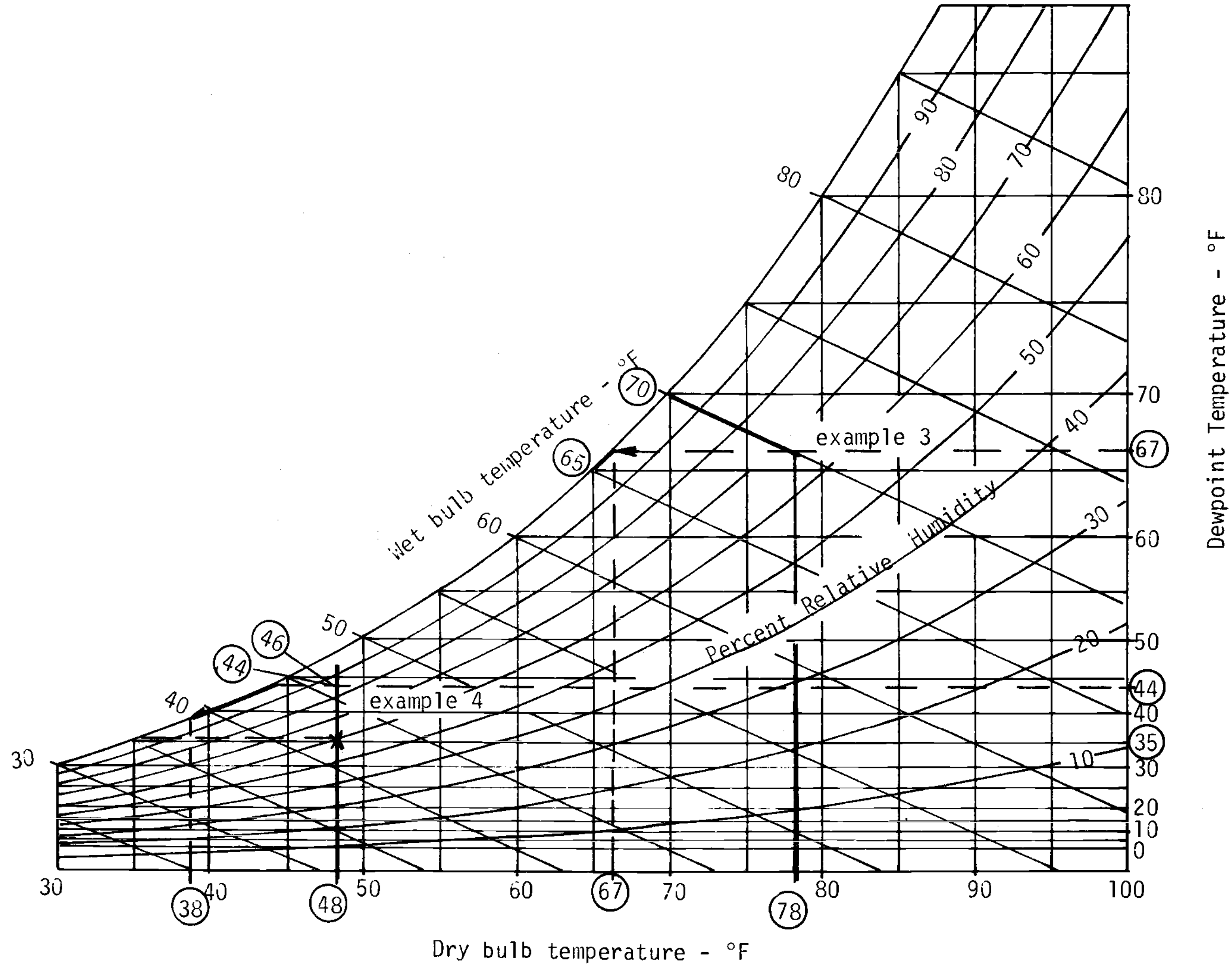


Figure 9.—Psychrometric chart solution to examples 3 and 4

Heating can increase the wet bulb temperature and lower the relative humidity of air, but it doesn't change the dewpoint temperature. Heating will certainly help to "dry out" a storage—but it will, of course, contribute to increased onion temperature. When this situation persists, market the onions before sprouting and/or deterioration occur.

Measuring wet and dry bulb air temperatures

You can read the dry bulb temperature directly from a standard thermometer that has been checked for accuracy. You can obtain both dry bulb and wet bulb temperatures with a psychrometer that provides air movement across the thermometer bulbs.

The sling psychrometer mounts two identical mercury thermometers together, and one of the thermometer bulbs is fitted with a cotton wick. The two thermometers are mounted in such a way as to allow them to spin in the air.

Before you spin the thermometers, saturate the cloth wick with distilled water. Then spin them around for about 1 minute.

The thermometer with the wick (wet bulb) will have a lower reading, because of the evaporating moisture, than the dry bulb temperature (without the wick).

Figure 10 shows two types of psychrometers. By using a reference chart and the readings from the wet and dry bulb thermometers, you can determine the air's relative humidity and dewpoint values.

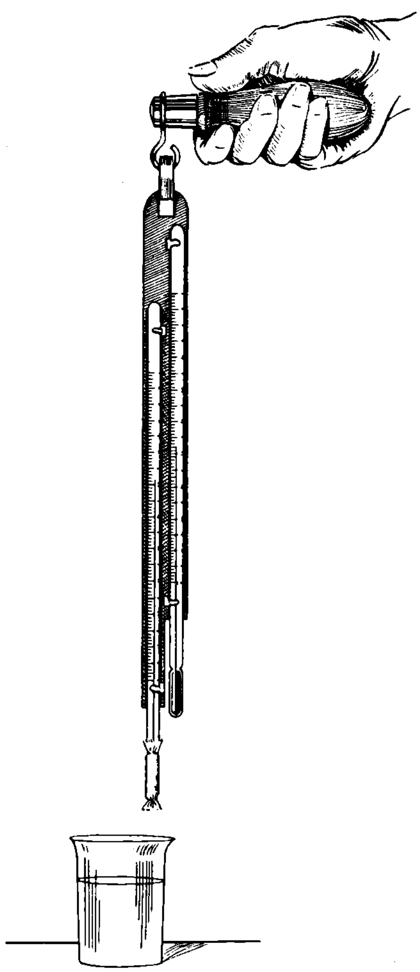
Sling psychrometers require considerable unrestricted space to operate and are subject to breakage, but they do give accurate readings. They cost from $30 to $50.

Electric psychrometers cost from $90 to $120, can be operated in restricted areas, are less subject to breakage, and are the most accurate available.

There is also an aspirator type of psychrometer. You squeeze a rubber bulb to provide the air passed by the dry bulb and wet bulb thermometers. This type can be used in restricted spaces and costs $50 to $60.

You can buy psychrometers from laboratory equipment supply houses or through ventilation and air conditioning distributors. Obtain one that accurately measures dry bulb and wet bulb temperatures within 0.5°F (.3°C).

Tack a psychrometer chart on the wall by the entryway to your onion



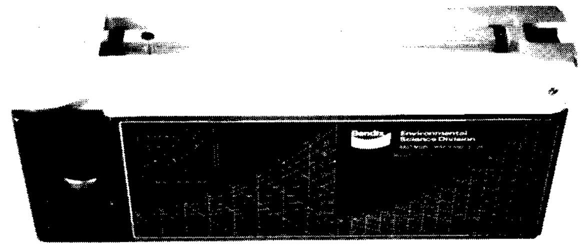


Figure 10.—*Left,* sling psychrometer; *above,* electric-operated psychrometer. The sling type is reproduced, with permission, from *Trane Air Conditioning Manual* (La Crosse, WI: The Trane Co., 1961).

storage building, or keep it at some other convenient place for reference.

When you take onion tissue temperature, remember to take several readings at various locations in the storage. This will provide information on *variations* in tissue temperatures—and it could prevent losses of onions because of freezing or high onion temperature.

Maintain a log of onion tissue temperatures and storage air temperatures (table 1). Indicate date, time, and recorded values for the wet bulb and dry bulb temperatures of the air entering and leaving the stored onions and for the calculated dewpoint temperatures. This will be an important tool for you as a manager of a storage facility.

When you want to survey the variations in onion tissue temperatures, place dial-type meat or fruit thermometers in onions at various locations in the storage. Attach brightly colored tags to these thermometers and identify each by a number.

Record the onion temperatures frequently during the storage period.

Selecting your fans

Two types of fans are normally used to ventilate onion storage areas, *centrifugal* and *propeller* (figures 11 and 12).

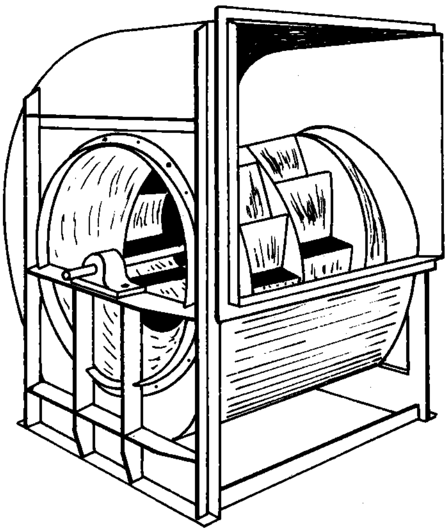


Figure 11.—Double-inlet, backward-curve centrifugal fan

Centrifugal fans

These can be classified three ways, according to blade: *radial, forward-curve,* and *backward-curve.*

Radial-blade fans are generally used only for pneumatic conveying of materials.

Forward-curve-blade fans. Be cautious when using these for onion storage, for three reasons:

1. If the fan was designed to operate near 70% of maximum head of water static pressure and if this static head has been reduced, the horsepower requirements increase sharply. Unless you anticipate variations in static head, the fan's motor could easily become overloaded (figure 13).
2. A small change in static pressure head causes a large change in the air flow volume because the static pressure curve is relatively flat compared to the operating range of the static pressure curve for a backward-curve fan (figure 14).
3. Forward-curve fans tend to be noisier than backward-curve fans in wheel diameters above 2 feet (50 cm).

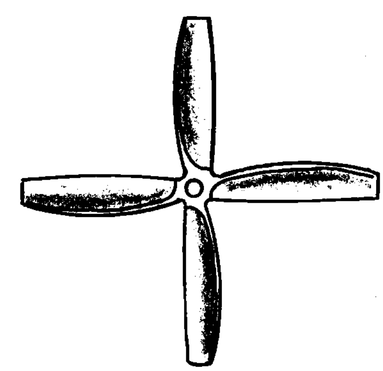


Figure 12.—High-volume, low-static head propeller fan

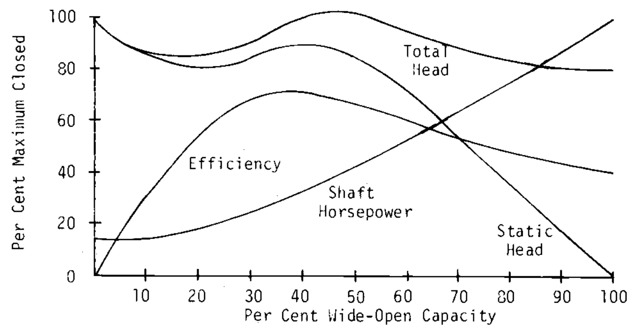


Figure 13.—Performance curves for a forward-curve centrifugal fan

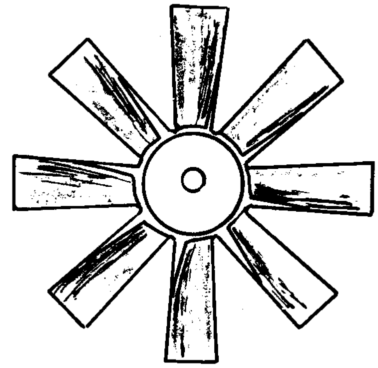


Figure 15.—Multiblade propeller fan

Backward-curve fans are better suited for onion storage ventilation systems, for two primary reasons:

1. This fan's wheel develops a high portion of its energy directly as pressure and avoids much of the conversion loss of the forward-curve type. This makes the backward-curve fan fundamentally more efficient for ventilating onions.
2. The horsepower curve has a flat peak that shows a maximum value not much higher than the horsepower at the point of maximum mechanical efficiency (figure 14).

Under these conditions, you can size your fan motor economically, so that you can use its complete range of operation—from high-static pressure to wide open, low-static pressure—without causing motor overload. This is extremely valuable when you're doubtful about your pressure calculations or when your system requirements will be variable.

The shaded area of the characteristic performance curve (figure 14) is the suggested operation span. Within this span, the fan is operating at or near maximum efficiency, at its rated horsepower, at a steeper slope on its static pressure curve, and at its lowest sound level.

Since the pressure curve of the backward-curve fan is steeper than that of a forward-curve fan, any variation in the system pressure will result in a smaller variation in air volume. Note in figure 14 that the point of maximum efficiency is to the right of the static pressure peak (this means that it allows efficient fan selection with a built-in static pressure reserve).

Dusty air will not cause serious problems with backward-curve fans (unlike a forward-curve fan, where the blades' curved pockets can quickly fill with dirt and cause the fan to loose efficiency).

For your onion storage ventilation system, select a backward-blade centrifugal fan that will operate with a fan outlet velocity range of 1,200 to 1,600 feet per minute (6 to 8 m/s). This range provides quiet operation with maximum efficiency (note that it's within the shaded area of figure 14). Note, too, that the sound level is at a minimum.

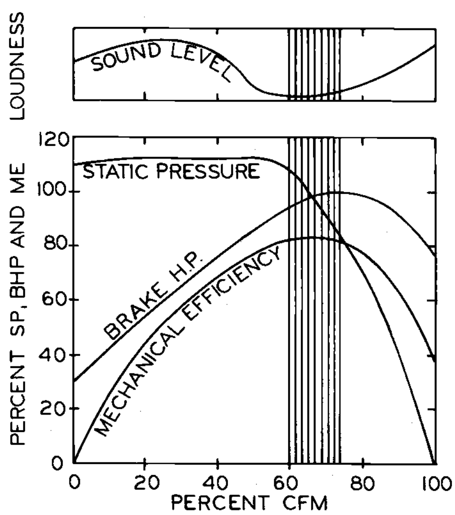


Figure 14.—Characteristic curves for a backward-curve centrifugal fan

For most storage sizes, a double-width, double-inlet fan is the most efficient and least expensive. Normally, a fan that has an outlet area of 8 square feet (.8 m^2) or more should be less expensive in a double-width size. For the same capacity, a double-width fan requires less ceiling height in your fan room because it draws half the air through each inlet.

Propeller fans

Air flow from this type of fan is parallel to the shaft or axis. Propeller fans are classified as *axial flow* or *vane axial flow*. Technically, axial flow and propeller fans are the same; the term *propeller* fan is a general one.

Propeller fans have two or more blades, which may be narrow or wide and may have uniform or varied pitch. Normally, the narrow-blade fan (see figure 11) is used to handle large volumes of air against free-delivery or low-static pressure heads.

The common range of static pressure used for these is from 0 to 1 inch (0 to 25 mm) of water pressure equivalent. It's also very important that, when you operate a propeller-type fan against a static head, you use a fan with a fairly large center hub (figure 15) to prevent recirculation of air back through the low-velocity portion of the center axis.

For onion storage ventilation systems, you'll need a fan that will operate against a minimum system static pressure head of 1¼ inches (32 mm). If you use a refrigeration system, you'll have to use a higher system static pressure, according to the recommendations of the manufacturer of the refrigeration equipment.

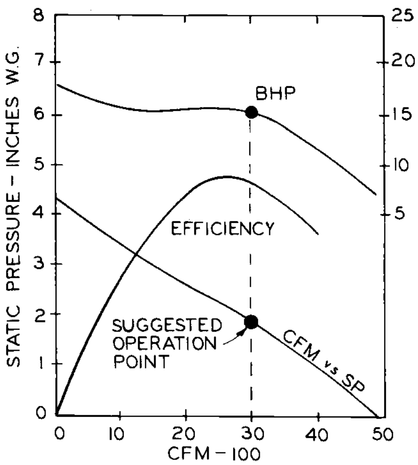


Figure 16.—Characteristic curves for a high-pressure multiblade propeller fan

The multiblade propeller fan shown in figure 15 carries its efficiency farther along the pressure range than the narrow-width, two- or four-blade models. Notice the larger center hub. Typical characteristic curves are shown for such a fan in figure 16.

Note the desired steep slopes on the "cfm vs. static pressure" curve. You could use this fan with refrigeration coils because of its capability to operate at high static pressures. If you don't use a refrigeration system, select a fan that operates at a static pressure near 1¼ inches (32 mm) of water column.

The vane axial propeller fan shown in figure 17 is designed to move large volumes of air at high pressures. The fan housing has guide vanes to convert rotational energy to useful static pressure. The large hub prevents backflow of air. This fan is more expensive than the multiblade propeller type.

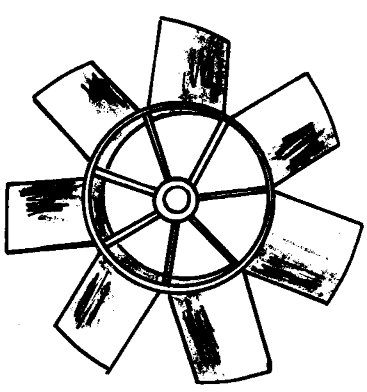


Figure 17.—Vane axial propeller fan

Using fan laws to calculate performance

It's important to know some of the basic fan performance laws when you match a fan to your ventilation system. These laws apply to both propeller type and centrifugal type fans. When the speed of a fan is varied, these laws apply:

1. The air delivered in CFM (cubic feet per minute) by the fan will vary directly as the fan RPM (revolutions per minute) ratio.

$$CFM_2 = \frac{RPM_2}{RPM_1} \times CFM_1$$

or

$$m^3/min_2 = \frac{RPM_2}{RPM_1} \times m^3/min_1$$

(CFM_1 and RPM_1 denote air flow and fan revolutions before changing the speed of the fan. CFM_2 and RPM_2 are the final air flow rate and fan speed, respectively.)

2. The static pressure (SP) developed by the fan varies as the RPM ratio squared.

$$SP_2 = \left(\frac{RPM_2}{RPM_1}\right)^2 \times SP_1$$

3. The horsepower (HP) required by the fan varies as the RPM ratio cubed.

$$HP_2 = \left(\frac{RPM_2}{RPM_1}\right)^3 \times HP_1$$

The following example might help you to understand better how to apply these laws to fan performance calculations.

Example 5. A centrifugal fan with a 44-inch (112-cm) wheel diameter has an air volume capacity of 13,668 cfm (387 m^3/min) at a wheel rpm of 381; the outlet static pressure is 7/8 inch (22 mm) of water column; and the required horsepower is 2.54 (bhp).

The *bhp* stands for "brake horsepower," and in simple terms it indicates the actual horsepower required by the fan. The motor horsepower must be somewhat higher, depending on losses between motor and fan drives.

Suppose that you want to increase the fan capacity to 18,000 cfm (510 m^3/min). What is the required fan rpm, and what will be the required horsepower applied to the fan drive? What is the change in static pressure?

CFM_2 desired is 18,000
CFM_1 presently available 13,668
RPM_1 presently in use 381

$$RPM_2 = \frac{CFM_2}{CFM_1} \times RPM_1 = \frac{18,000}{13,688} \times 381 = \underline{\underline{501}}$$

$$SP_2 = \left(\frac{501}{381}\right)^2 \times .875 = \underline{\underline{1.51}} \text{ inches of water}$$

$$HP_2 = \left(\frac{501}{381}\right)^3 \times 2.54 = \underline{\underline{5.8}} \text{ hp}$$

Note the drastic change in horsepower (from 2.54 to 5.8) required to produce the needed change in air volume. Note also that the horsepower varies as the cube of the rpm ratio. The static pressure increased from ⅞ or .875 inch (22 mm) of water to 1.512 inches (38.4 mm) of water.

Fan motors

All motors used for ventilation fans should have ball bearings. All motors subjected to dusty ventilation air should be totally enclosed and resistant to moisture conditions. Motors should be protected from overloads by electrical overload devices rated at not more than 125% of full load.

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This publicaton was prepared at Oregon State University by Walter E. Matson, Extension agricultural engineer emeritus, N. S. Mansour, Extension vegetable crops specialist, and Daryl G. Richardson, associate professor of horticulture. It was reviewed by Extension agricultural engineering and horticulture specialists at Washington State University and the University of Idaho.

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