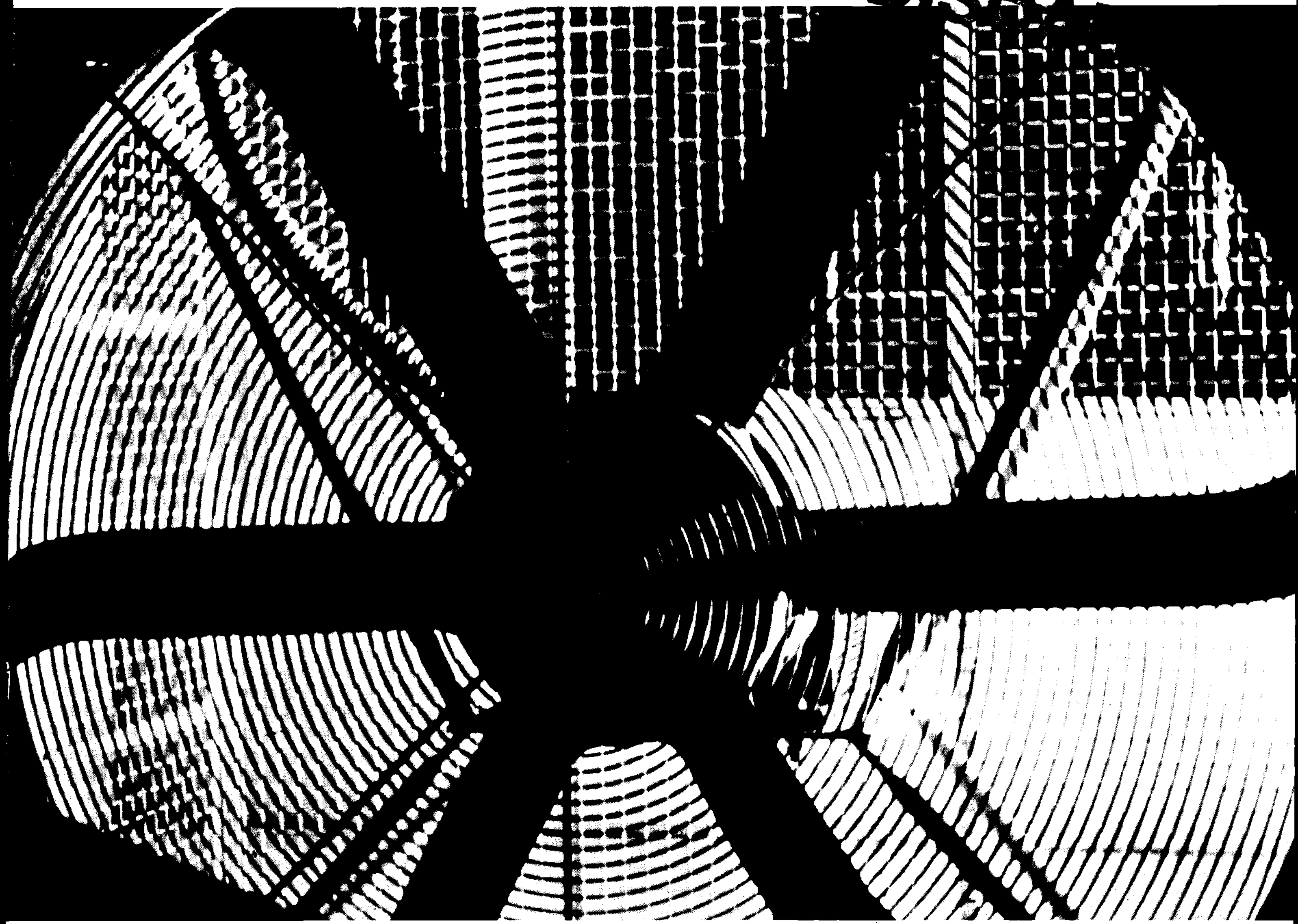
ONION STORAGE

Guidelines for Commercial Growers



Extension Circular 948
Oregon State University Extension Service
July 1978

OREGON STATE UNIVERSITY
EXTENSION
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ONION STORAGE
Guidelines for Commercial Growers

This publication is a guide to storing yellow sweet Spanish onions in the Columbia basin, Snake River Valley, and in eastern Oregon, and the Yellow Globe Danvers onion variety in western Oregon. Where storage conditions differ for the various areas, appropriate instructions are given.

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

Preharvest factors include: (1) the choice of variety, (2) the timing and rates of fertilization and irrigation, (3) application of growth regulators to inhibit storage sprouting, (4) curing of tops, and (5) topping.

The harvest date is extremely important in many ways. Early season maturity, through use of early varieties or early planting, increases the probability of good field curing and maturing conditions. Immature onions do not store well in unrefrigerated storages and, in most cases, must be sold quickly to avoid heavy storage losses. Immature onions are more subject to increased incidence of neck rot and other storage disease problems.

Harvest injury occurs for a number of reasons. A major factor is carelessness during the harvesting operations. If you use machine topping, the machine speed, conveyor speed, machine setting, and sharpness of onion topcutting device are all important factors to consider. Transport to the storage with care to avoid bruising. Onions bruise if you handle them roughly when loading onto the truck or into the bins and when unloading into storage.

The phases of storage management of onions are **drying, curing, cooling, holding,** and **conditioning** prior to marketing.

Drying Period

Climatic or cultural conditions may prevent the complete maturation and/or the desired field drying. This necessitates drying of onions in storage.

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You should remove the external free moisture as quickly as possible; the atmosphere surrounding the onion will be saturated until this moisture is removed. In a saturated atmosphere, rot-causing fungi and bacteria carried by the onion bulb can infect the onion. To preserve onion quality, air supplied to the storage should not have a relative humidity higher than 75 percent during the drying period. Keep the air temperature below 95°F (35°C). During this drying period, large amounts of air (2 cubic feet per minute per cubic foot of onions *or* 120 cubic meters per hour per cubic meter of onions) are desirable. Rapid circulation of air without artificial heat has proved satisfactory when the drying period was extended to three days. The drying period can be generally monitored with a hygrothermograph placed at the top of the onion stack.

The drying period is normally completed when relative humidity drops suddenly after the initial period of continuously high relative humidity readings, providing that no additional heat was added. Check onion outer scales and neck for proper moisture content. The wet onions offer a fairly high resistance to air flow. It would be advisable to have an onion pile depth of not more than 8 feet (2.4 meters).

An approximate static pressure of 1¼ inches (32 mm) of water would be needed to push the air through these wet onions and the air distribution systems. This is especially true when the tops are left on the onions. The pressure drop through dry onions without dirt and trash is almost negligible under normal ventilation rates; in this case, the static pressure loss is attributed to design of the air distribution system.

Curing Period

The objectives of the curing period are to allow the development of the natural dormancy, to seal the onion against infestation by disease organisms that may be present in the tops, to provide for maximum retention of the outer onion scales, and to reduce the respiration rate of the bulbs. Protection from disease organisms occurs through drying and shrinking of the onion necks and healing of any damaged areas on the onion skin. This curing needs to be completed quickly to isolate the disease and rot organisms from the interior of the onion. Normally, field curing accomplishes these goals in 6 to 14 days. 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. The weight loss of properly stored onions should not normally exceed 5 percent during the curing period. The outer scales of the onion provide protection against decay organisms through the antifungal compounds they contain. These inhibitors are necessary for extended storage.

Immature onions have fewer outer scales and high moisture content; therefore, they require more extensive curing conditions than do mature onions. To properly cure onions that are immature or onions that have had inadequate field curing, you need:

1. large amounts of air,
   up to 2 cubic feet of air per minute for each cubic foot of onions (2 cfm/ft^3)
   or
   up to 120 cubic meters of air per hour for each cubic meter of onions (120 m^3/hr/m^3);
2. high temperatures,
   up to 95°F (35°C);
3. low moisture content air,
   less than 50% relative humidity.

Under favorable conditions, when onions are fully mature and partially field cured, an air volume of 1 cubic foot per minute per cubic foot of onions (60 cubic meters per hour per cubic meter of onions) may be adequate. You can use heated air to increase the rate of curing.

The presence of condensed free water on the onions results in an environment that promotes early

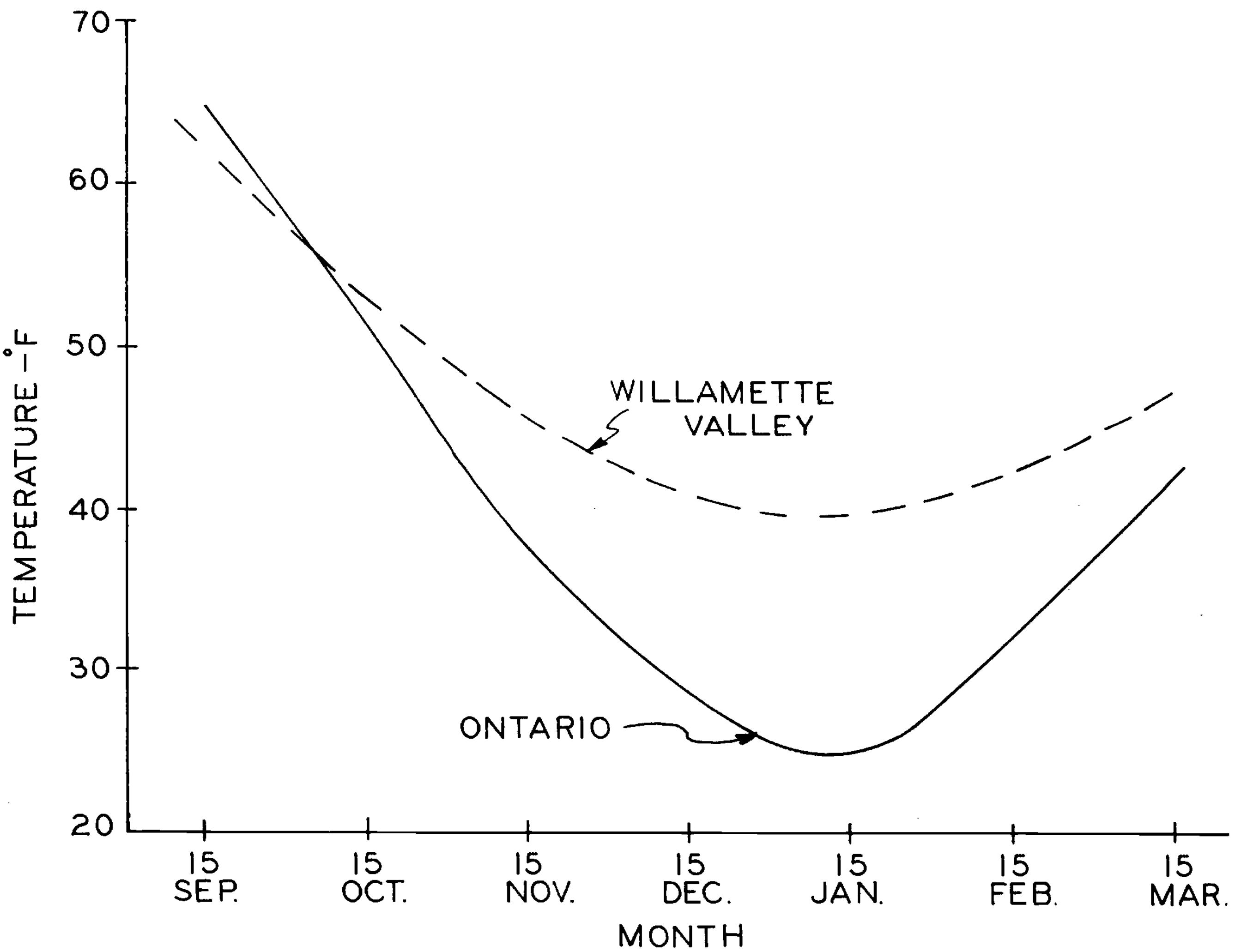


Figure 1. Monthly average temperatures.

sprouting and allows disease and rot organisms to develop. You can prevent condensation of water vapor during the curing period by using warm, dry air and by not using outside air when its dew point temperature is at or above the temperature of the onions. You can use the psychrometric chart to determine the dew point temperature (see page 11 for examples). Keep a record of daily onion pulp temperatures, taken from various locations within the storage; see page 13 for an example temperature record.

Cooling

After curing, lower the temperature of stored onions steadily and evenly toward the desired storage temperature. The cooling rate should coincide with the normal temperature drop of the area. Bring onion temperature down to holding temperature in gradual steps, following normal seasonal temperature monthly drop unless refrigeration is used.

Long-term average monthly temperatures serve as a guide (see figure 1 for monthly average temperatures for the Willamette Valley and Ontario, Oregon). You can also follow shorter range seasonal temperatures. For best management, keep all onions in a storage within 5°F (3°C) of the same temperature. For this reason, cool air (that is, within 5°F [3°C] of the onion pulp temperature) is desirable. During freezing weather, it may be necessary to mix inside air and cold outside air to obtain the desired air temperature. Large temperature variations of the onions within the pile can lead to dehydration of those onions nearest the ventilating tubes and to condensation problems on the surface of the cooler onions.

Holding

The ideal holding temperature for onions is at or near 32°F (0°C) with a relative humidity between 60 and 70 percent. Do not allow the air relative humidity to rise above 80 percent, as this will promote root growth and decay in onions. The desired temperature and humidity is difficult to maintain without refrigeration. In order to keep a uniform holding temperature, hold your stored onions at 35°F (2°C) if you live east of the Cascade Range. A minimum temperature of 40°F (4.4°C) would be more appropriate for western Oregon. These temperatures are desired to reduce fluctuations in onion holding temperature in order to minimize sweating and sprouting of stored onions.

After you have lowered temperatures to the desired holding point, take care, in the operation of the ventilating system, to prevent condensation from occurring on the onions. During the holding period, reduce the ventilation rate to 1 cfm per cubic foot (60 $m^3/hr/m^3$) of onions. Ventilate only when necessary to maintain storage temperature or exhaust stale humid air. Normally, you can accomplish this by cycling fan operations a portion of each day when outside air is cooler than onion tissue temperature. Circulating the air within the storage during other periods helps maintain even temperatures throughout the storage. 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 has spoiled dry, well-cured onions.

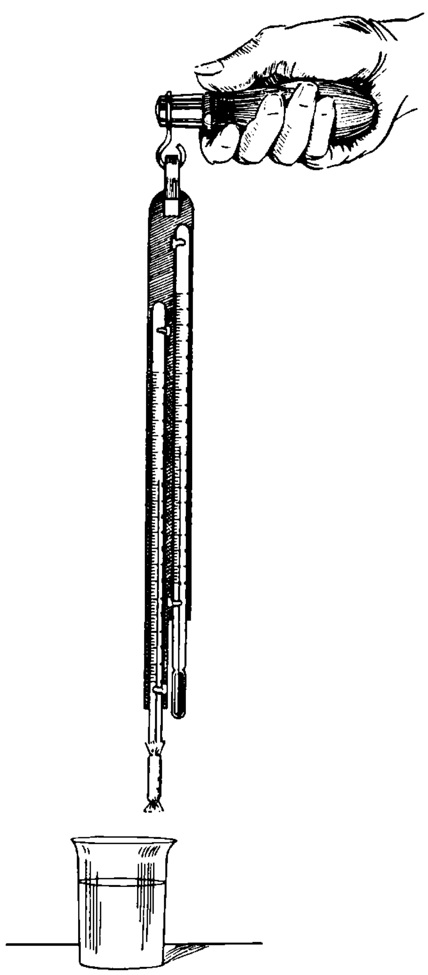
Every operator of an onion storage should have and understand the use of a sling psychrometer or various types of aspirating psychrometers. The sling psychrometer is a device made of two identical mercury thermometers mounted together with one of the thermometer bulbs fitted with a cotton wick. The two thermometers should be mounted in such a way as to allow them to be spun in the air. Prior to spinning the thermometers, the cloth wick is saturated with water. The thermometers are then spun around for approximately one minute. The thermometer with the wick (wet bulb) will have a lower reading, because of the evaporating moisture, than the dry bulb thermometer (without the wick). Figure 2 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 dew point values. The use of the psychrometric chart and the definition of dew point are explained in detail below.

As a general rule, it is safe to blow air through the onions when the dew point temperature of the air to be circulated is at least 1 degree F (.5°C) lower than the tissue temperature of the coldest onions in the storage. Another rule is that it is safe to ventilate any time the ventilating air (dry bulb) temperature is at least 1°F (.5°C) lower than the onion tissue temperature—but not below 29°F (–1.7°C), the freezing temperature of onions. Study the examples on the use of psychrometric chart. Understanding the chart and its use will help eliminate the danger of condensing moisture from the ventilating air.

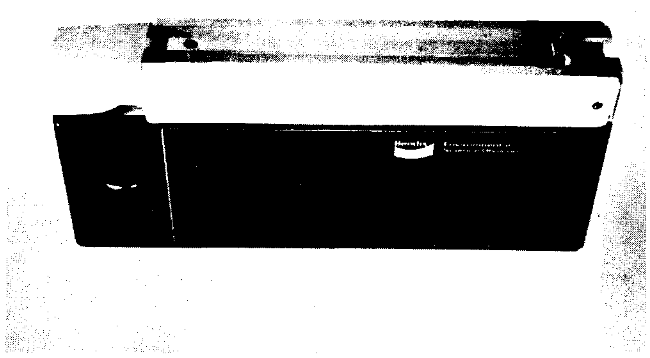
A common mistake in onion storage management is to ventilate on a sunny and warm winter day, when the onions in storage are cooler than the air being blown into the storage, and the dew point of the air being used is higher than the temperature of the onions, resulting in moisture condensing on the cooler onions.

Conditioning

You must often condition onions before removing them from storage. You either haul them to a warm



Sling psychrometer



Electric operated psychrometer

Figure 2. Two types of psychrometers. The sling psychrometer is reproduced, with permission, from *Trane Air Conditioning Manual* (La Crosse, Wisc.: The Trane Co., 1961). Trade-name products are shown for purposes of illustration only, and their use does not constitute an endorsement by the Oregon State University Extension Service.

packing plant or condition them in the storage before moving them into a packing line. During this time, there is danger of water condensing on onions if the air has a high moisture content. A packing plant air temperature of 68°F (20°C), with a relative humidity of 50 percent, has a dew point temperature of near 50°F (10°C). If the onions are at 40°F (4.4°C), moisture will condense on the onion surface. For further information, see the section on the use of psychrometric charts (page 9). The surface moisture will prevent the removal of the loose outer bulb scales (called "shucking") and pose problems in cleaning. When this occurs, it is necessary to dry the onion to a point at which shucking can occur. During the time required for this additional drying, the packing line cannot operate, and the processor can suffer an economic loss. In the process of artificially heating the onion, too much moisture may be rapidly removed; this could produce "bald" onions, which have lost too many scales.

You can greatly reduce the shucking and balding problems by having separate facilities to control the environmental conditions of those onions to be packed each day. This conditioning facility should handle at least a two- or three-day processing line supply. The facility is used to bring the onion temperature up to the packing room temperature slowly, in a stepwise fashion.

A Bulk Storage System

Before you can consider the design of a building for environmentally controlled onion storage, it is essential that you understand the interaction of the building, its fixed equipment design, and the stored product.

The building's design must accommodate the bulk and weight of the stored product. The product must not freeze while in storage. The walls and ceiling must have adequate insulation to eliminate condensation and to reduce heat losses or heat gains to an economically controllable level. The air ducts must be of adequate size to economically distribute the air in a uniform fashion. The controls must proportion the air temperature, humidity, and volume to the desired conditions.

Insulation

The "R" value describes the ability of a material to resist heat flow. The greater the R value, the better the insulator 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.

In western Oregon, 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 that has an R factor of 5 to 6 per inch (2 to 2.4 per cm). In eastern Oregon, use R-19 insulation for the walls. This amounts to approximately 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 on the inner surface.

In locations both east and west of the Cascades, the ceiling of the storage should have an R insulation value of 25, which amounts to 7 to 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. The vapor barrier should face the interior of the building. Insulation is important to maintain a uniform holding temperature.

Ventilation Systems

For bulk storages, design your ventilation system to cover these points:

1. It should provide 2 cfm of air per cubic foot of onions (120 $m^3/hr/m^3$) at 1¼ inches (32 mm) of static pressure, distributed uniformly through the onions.

2. Air flow velocity in the lateral ducts should not be higher than 1200 feet per minute (6 m per second—or 6 m/s) at an air flow rate of 2 cfm per cubic foot of onions (120 $m^3/hr/m^3$), and not 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 (60 to 120 $m^3/hr/m^3$). Air flow rates within this range will maintain a sufficient pressure drop through the lateral holes to give good air distribution. The general recommendation for duct design is to keep air duct velocities under 1000 feet per minute (5 m/s) in order to minimize high pressure losses and to provide uniform air distribution.

   However, because of the need for high volumes of air during drying and curing and the relatively low air flow rates during the holding period, use a range of air velocities that will provide adequate uniformity of 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. The sum of the cross-sectional areas of the discharge orifices of the laterals 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.

   In order to obtain a wide range of air volume options, use two or more fans. This will provide a high volume when using all the fans and a lower volume when using one or more fans for the holding-period ventilation needs. Be sure that all fans have louvers that can be fully closed when the fan is not in operation.

3. In selecting fans, consider those that will provide the necessary rated air flow at 1¼ inches (32 mm) of static pressure. This is desirable in case onions get wet from condensation or damp from rain in the field prior to storage; they will then have a higher resistance to air flow than dry onions.

   The air laterals should not be spaced more than 5 feet (1.5 m) apart on centers. It has been found that air in a bulk onion pile does not travel out horizontally into the onion pile very far from the duct, even at fairly high discharge pressures through duct outlet holes. The suggested maximum length of duct is 40 feet (12 m). See figure 3 for additional ideas for bulk storage. Lateral duct outlet holes must have protection from possible plugging of holes by onions. In round ducts the holes are located along a horizontal line on the lower ⅓ of the duct circumference.

4. Fans should have automatic controls that will (a) turn them on and off in order to maintain a desired onion pulp temperature; (b) protect the onions from freezing; and (c) reduce sweating by use of differential temperature controls, which 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 will not give 100 percent utilization of the available night cooling hours.

Pallet Box Storage

Pallet box handling and storage of onions is still popular. The major problem associated with it is that it is difficult to cool the onions in boxes. This is because: (1) designs of many boxes do not provide for adequate bottom slots to assist in ventilation through onions; (2) pallet boxes are difficult to arrange in a storage to obtain maximum cooling efficiency of ventilating air; and (3) the optimum pallet box design has not as yet been established that could do a more efficient job in storing onions.

When you can cure onions in the field in boxes, this process reduces storage air requirements and provides for fairly efficient handling of onions into storage. Extensive research work conducted on the storage of fruit (such as apples) in pallet boxes has suggested the following applications, as illustrated in figures 4 and 5, that may be useful hints to stacking pallets in a storage:

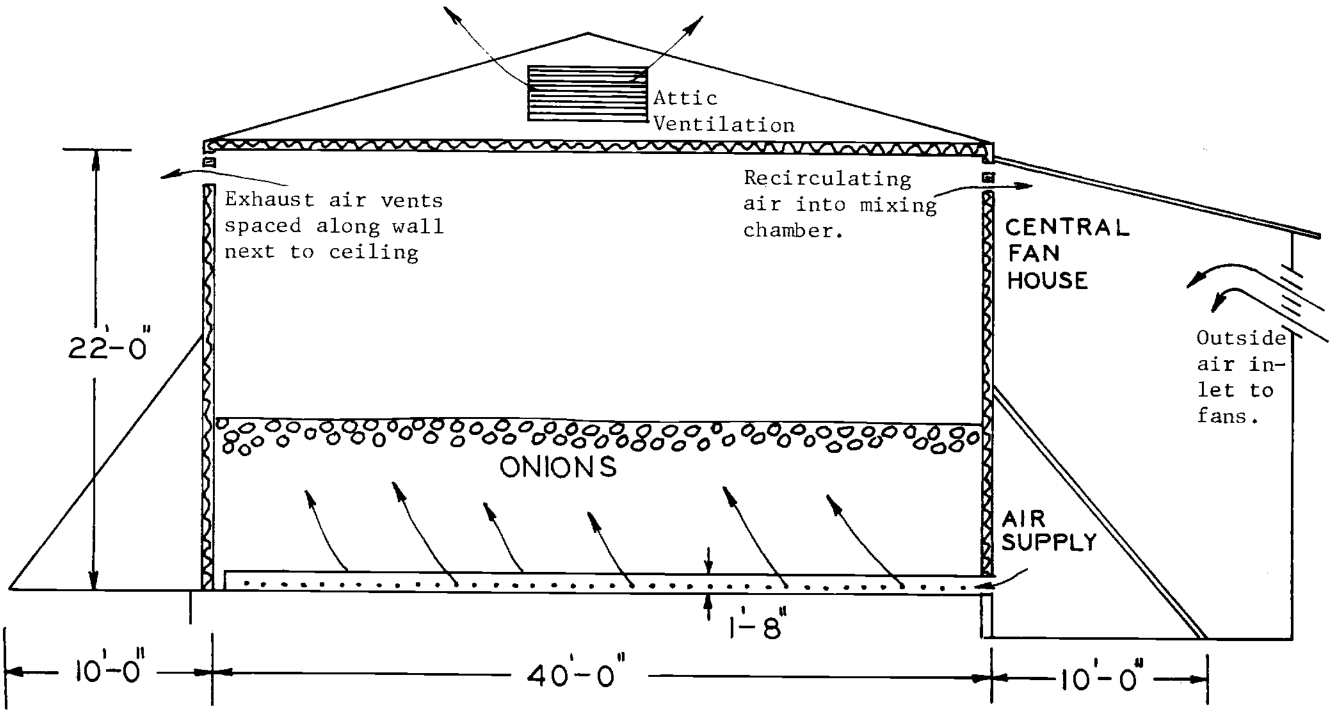


Figure 3. Elevation view of bulk onion storage. In this and similar figures, keep in mind that 1 foot = approximately 0.3 meter.

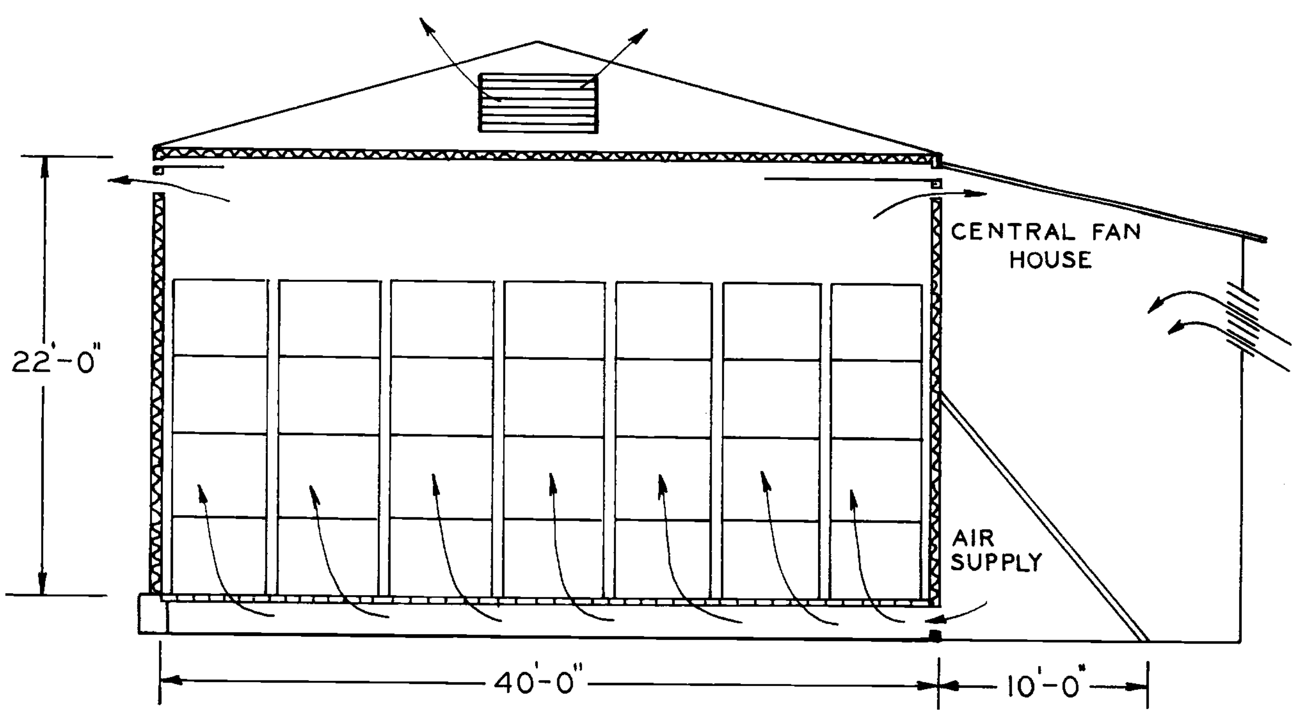


Figure 4. Elevation view of a palletized onion storage.

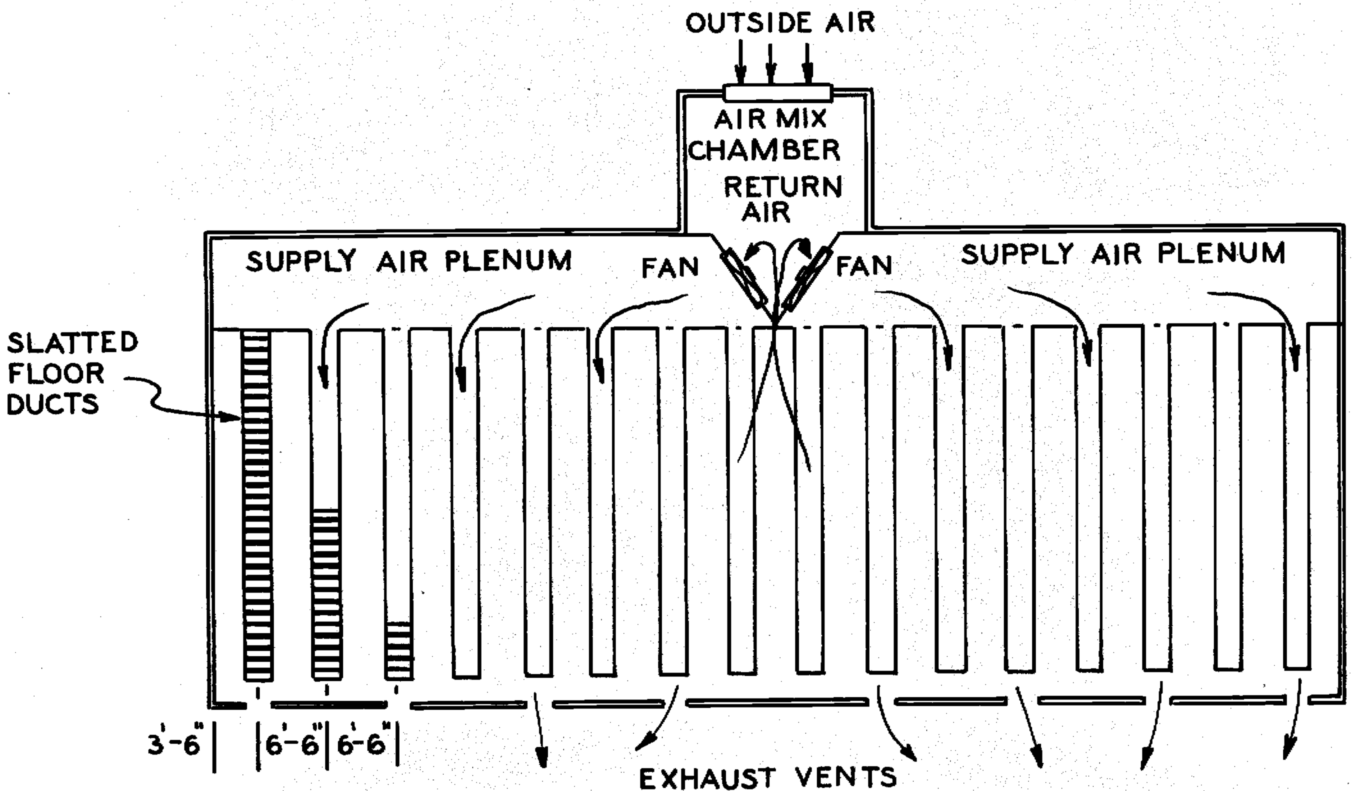


Figure 5. Floor plan of a palletized onion storage.

1. Do not place pallets directly against walls. Heat and cold from walls are readily transmitted to nearby onions and cause severe problems to the flow of adequate 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 the rows parallel to the direction of air flow.
4. Make stack rows of similar pallets, so that all dimensions are very nearly the same. Height, width, and length should not differ betwen various pallets. Position each column of boxes over an air lateral when underfloor laterals are used.
5. If you place immature or inadequately field-cured onions in pallet boxes for completion of drying and curing, they may pose a severe problem because of a lower rate of air circulation within the boxes.
6. Exhaust the air at a high point on opposite wall from low or underfloor air inlet entrance. Space the exhaust outlets along length of 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 create adequate exhaust of moist air from the central portion of the bin. When bringing in outside air for drying, cooling, holding, or conditioning onions in pallet boxes, the same principles regarding dew point apply.
8. The total open area between slats of floor ducts should be about 30 percent 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 floor duct for slats. Provide approximately 0.6 inch (1 cm) of opening width between slats having openings. Not all adjoining slats need to have open spaces as this depends on required open area compared to duct cross-sectional area.

Properties of Moist Air and the Use of the Psychrometric Chart

You can use the psychrometric chart to help determine moist air properties. This chart is one of the most useful tools available to those people involved with the drying, curing, and storage of onions. Understanding how to use the chart is necessary to proper operation of an onion storage. The simplified version of a psychrometric chart shown in figure 6 presents the relationship between moist air properties.

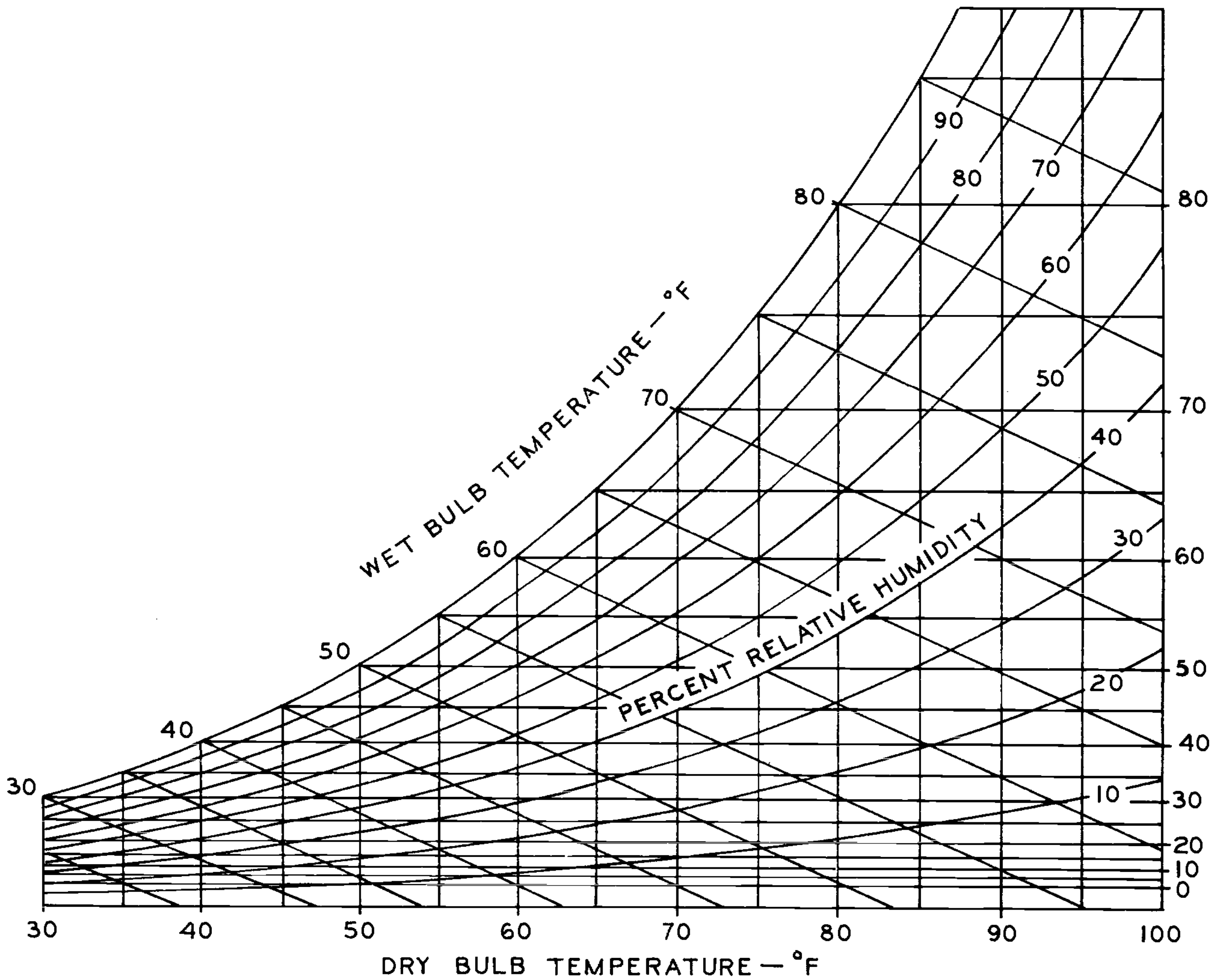


Figure 6. Simplified version of a psychrometric chart.

1. The Psychrometric Chart
   a. *Dry bulb temperature* (vertical lines)
      This is the air temperature as taken with a standard thermometer.
   b. *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 upon 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 percent relative humidity), wet bulb and dry bulb temperatures are the same.
   c. *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 if the air were saturated. Saturated air has a relative humidity of 100 percent. Air that is carrying only half of its capability for water vapor at a given temperature has a relative humidity of 50 percent.
   d. *Dew point temperature* (horizontal lines)
      Dew point temperature is the temperature at which a cooling air mass reaches its saturation point without addition of water vapor. Warm air can hold more water vapor than can cool air. As an example (see figure 7, example 1), air with a dry bulb temperature of 70°F (21.1°C) and a relative humidity of 40 percent is completely saturated when its dry bulb temperature is lowered to 45°F (7.2°C). This is, therefore, the dew point temperature for air with a dry bulb temperature of 70°F (21.1°C) and a relative humidity of 40 percent.

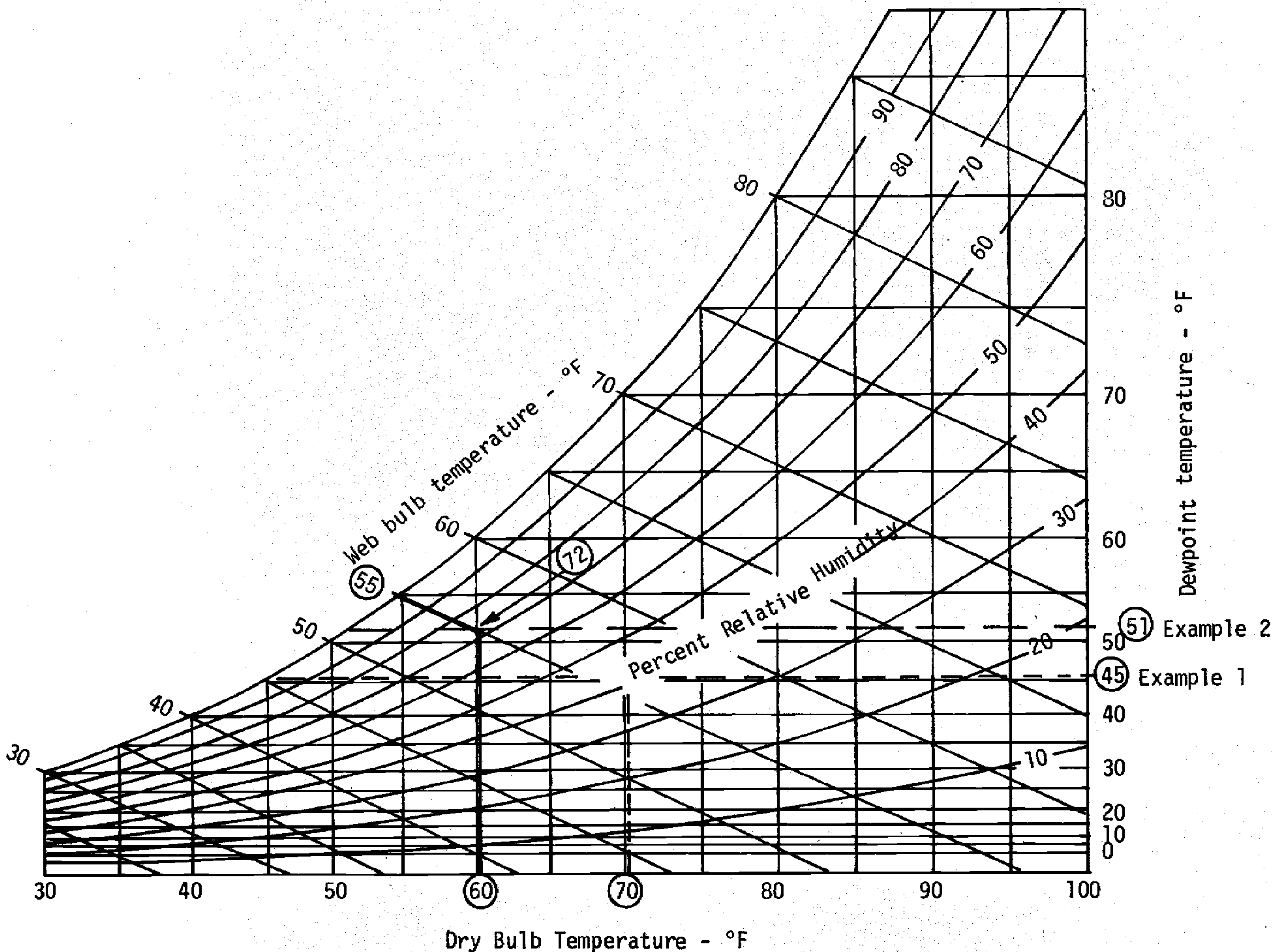


Figure 7. Psychrometric chart solution to examples 1 and 2.

Example 2 identifies an air mass with a dry bulb temperature of 60°F (15.6°C) (vertical line) and a wet bulb temperature of 55°F (12.8°C) (diagonal line). The relative humidity (curved line) is about 72 percent. The dew point (100 percent relative humidity) temperature (horizontal line) is 51°F (10.6°C).

2. Operational Rules of Thumb
   a. *Do not use outside air to ventilate stored onions unless its dew point temperature is at least 1°F (.5°C) below the temperature of the coldest onions.*

   Figure 8 shows two examples. Example 3 is a situation that 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 dew point 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 percent relative humidity) on the onion surfaces.

   Example 4 shows a situation that could exist during the latter 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 as a result 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 dew point temperature of 44°F (6.7°C). Circulating this air through the onion storage would *not* remove the moisture on the ceiling but 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 percent relative humidity, the dew point temperature would be 35°F (1.7°C). This air could be used safely and effectively to dry off the storage ceiling.

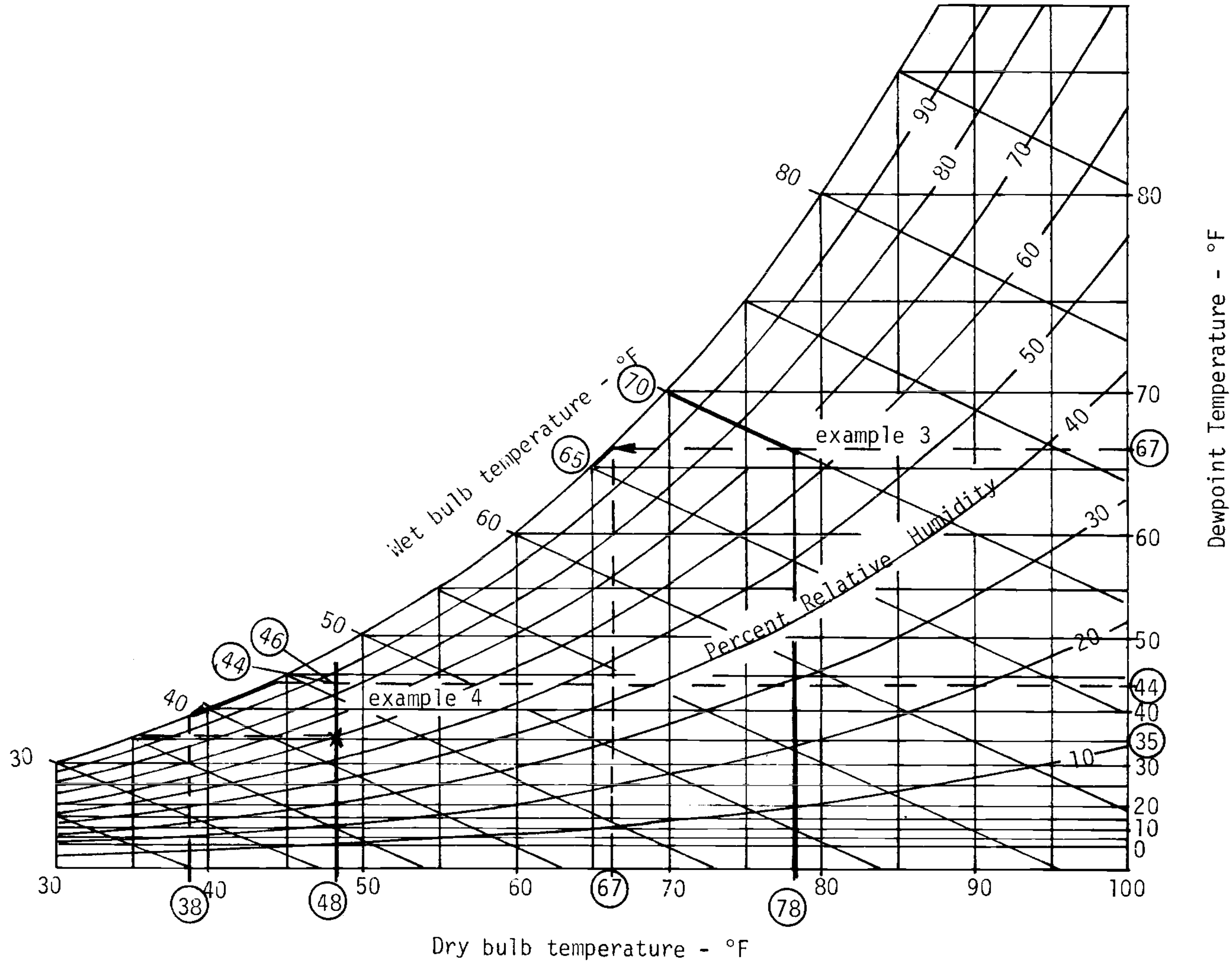


Figure 8. Psychrometric chart solution to examples 3 and 4.

Heating can increase the wet bulb temperature and lower the relative humidity of air. Heating *does not* change the dew point temperature. However, this practice can allow a storage to be "dried out," but it will contribute to increased onion temperatures. When this situation persists, market the onions before sprouting and/or deterioration occur.

Measuring Wet and Dry Bulb Air Temperatures

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

As noted in figure 2, sling psychrometers have a thermometer with a wet sock around the bulb. You spin one by hand to provide the necessary air movement. You can obtain accurate readings from them, but they require considerable unrestricted space to operate and are subject to breakage. They cost from $25 to $40.

Electric psychrometers cost $72 to $100 but can be operated in restricted areas and are less subject to breakage.

There is also an aspirator type of psychrometer where air is passed by the dry bulb and wet bulb thermometers by squeezing a rubber bulb. You can use it, too, in restricted spaces. This instrument costs about $50.

The electric psychrometer is the most accurate of these three types.

You can purchase psychrometers from laboratory equipment supply houses or through ventilation-air conditioning distributors.

Tack a psychrometer chart on the wall by the entryway to the onion storage building, or keep it at some other convenient place for reference. Ob-

Example Record of Temperatures in an Onion Storage

Date	Time	Storage location	Temperature			
			Onion tissue	*Air dry bulb*	*Air wet bulb*	*Air dew point*
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 1	48°F (8.9°C)	....	....	....
20 Oct.	0920	2	46°F (7.8°C)	....	....	....
20 Oct.	0925	3	46°F (7.8°C)	....	....	....

tain a psychrometer that can accurately measure dry bulb and wet bulb temperatures within 0.5°F (.3°C). When taking onion tissue temperature, remember to take several readings in various locations in the storage. This procedure will provide information on variations in tissue temperatures and could prevent losses of onions because of freezing or high onion temperatures. Maintain a log of onion tissue temperatures and storage air temperatures.

In order 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. The temperature log should also indicate date, time, and recorded values for the wet bulb and dry bulb temperatures of the air entering and leaving the stored onions. Then show the calculated dew point temperatures. An example record of storage temperature is shown in the table above. Good recordkeeping is highly recommended; it is an important tool for you as a manager of a storage facility.

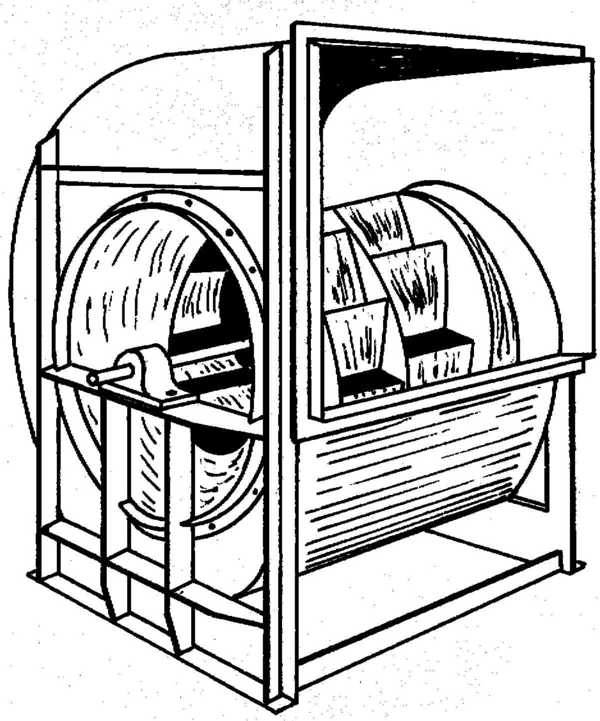


Figure 9. Double-inlet, backward-curve-blade centrifugal fan.

Fan Selection

Two general types of fans are normally used for onion storage ventilation systems. These are the centrifugal and propeller type fans shown in figures 9 and 10.

The centrifugal fans can be further classified into three groups, according to blade: forward curve, radial, and backward curve. The radial-blade fan is generally used only for pneumatic conveying of materials. Be cautious when using forward-curve-blade fans for onion storage ventilation systems, for the following reasons:

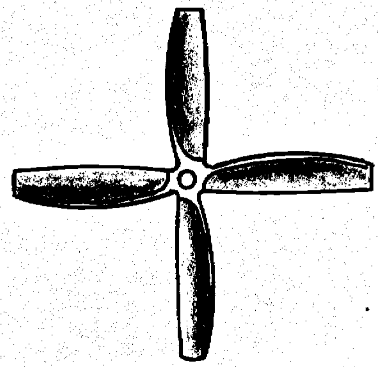


Figure 10. High-volume, low-static head propeller fan.

1. If the fan was designed for operation near 70 percent of maximum head of water static pressure and if this static head has been reduced, the horsepower requirements increase sharply. Unless you anticipated variations in static head, the fan's motor could easily overload as seen in figure 11.

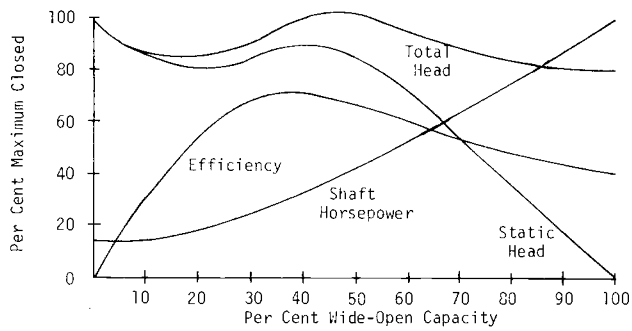


Figure 11. Forward-curve centrifugal fan performance curves.

2. A small change in static pressure head causes a large change in the air flow volume since the static pressure curve is relatively flat compared to the operating range of the static pressure curve for a backward-curve-blade fan, as shown in figure 12.

3. Forward-curve fans tend to be noisier than backward-curve-fans in wheel diameters above 2 feet (50 cm).

The backward-curve-blade fan is better suited for onion storage ventilation systems, for two primary reasons. One is that its 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-blade fan fundamentally more efficient for onion ventilation applications. Figure 12 shows the other advantage. The horsepower curve has a flat peak that shows a maximum value not much higher than the horsepower at the point of maximum efficiency. Under these conditions, the fan motor may be economically sized so that you can use the complete range of operation, from a high static pressure to a wide open, low-static-pressure condition, without problems of motor overload. This is extremely valuable when your pressure calculations are in doubt or where the system requirements will be variable. The shaded area of the characteristic performance curve is the suggested operation span. Within this span, the fan is operating at or near maximum efficiency, rated horsepower, steeper slope of static-pressure curve, and lowest sound level.

Since the backward-curve-blade fan pressure curve 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 that the point of maximum efficiency is to the right of the static pressure peak, thus allowing efficient fan selection with a built-in static pressure reserve. Dusty air will not cause serious problems with backward-blade fans as compared to forward-curve-blade fans, where the blades' curved pockets can quickly fill with dirt and cause the fan to lose efficiency.

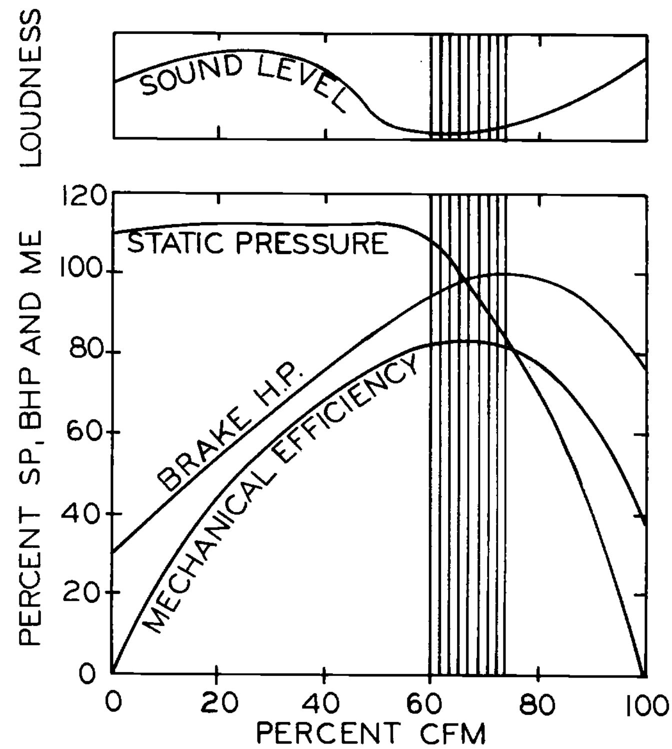


Figure 12. Characteristic curves for a backward-curve-blade fan.

For onion storage ventilation systems, select the backward-blade centrifugal fan to operate with a fan outlet velocity range of 1200 to 1600 feet per minute (6 to 8 m/s). This range provides quiet operation with maximum efficiency and is within the shaded area of figure 9. Note that the sound level is at a minimum.

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 fan room ceiling height 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 can be further 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.

The propeller fans may have two or more blades. The blades may be narrow or wide and may have uniform or varied pitch. Normally, the narrow-blade propeller fan (see figure 10) 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 is also very important that, when you operate a propeller-type fan against a static head, the fan's center hub be fairly large (as shown in figure 13) to prevent recirculation of air back through the low-velocity portion of the center axis. For onion storage ventilation systems, select a fan to operate against a minimum system static pressure head of 1¼ inches (32 mm). If you use a refrigeration system, you must use a higher system static pressure, according to the recommendations of the manufacturer of the refrigeration equipment.

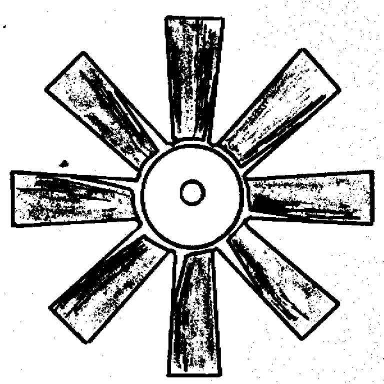


Figure 13. Multiblade propeller fan.

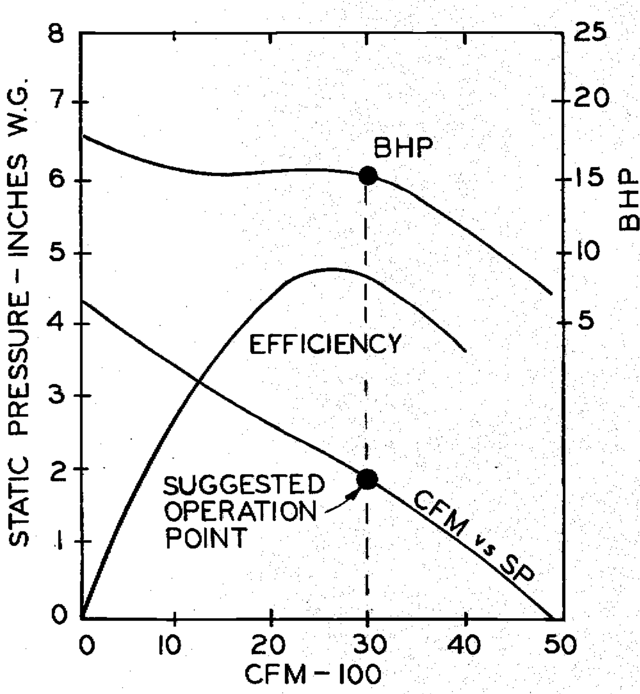


Figure 14. Characteristic curves for a high-pressure multiblade propeller fan.

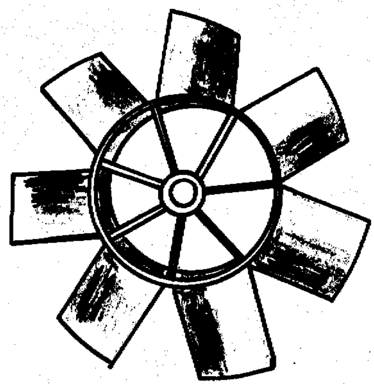


Figure 15. Vane axial impeller.

The multiblade propeller fan shown in figure 13 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 14. Note the desired steep slope 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 do not use a refrigeration system, select a fan to operate at a static pressure near 1¼ inches (32 mm) of water column.

The vane axial propeller fan shown in figure 15 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 type fan is more expensive than the multiblade propeller fan.

Fan Laws Used in Performance Calculations

It is important to know some of the basic fan performance laws when matching a fan to a ventilation system. These laws apply to both propeller type and centrifugal type fans. When the speed of a fan is varied, the following principles 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

$$m^3/hr_2 = \frac{RPM_2}{RPM_1} \times m^3/hr_1$$

(CFM_1 and RPM_1 denote the air flow in CFM and the fan revolutions in RPM prior to change of speed of 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.

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

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

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

The following example of the use of fan performance calculations might help you to understand their application.

A centrifugal fan with a 44-inch (112-cm) wheel diameter has an air volume capacity of 13,668 cfm (23,222 m^3/hr) at a wheel rpm of 381; the outlet static pressure is ⅞ 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 your fan capacity to 18,000 cfm (30,582 m^3/hr). 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?

Step 1: CFM_2 desired is 18,000
CFM_1 presently available 13,668
RPM_1 presently in use 381

$$RPM_2 = \frac{CFM_2}{CFM_1} x\ RPM_1 = \frac{18{,}000}{13{,}668} x\ 381 = \underline{\underline{501}}$$

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

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

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 1.51 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 percent of full load.