Augsburger 81.

STABY - OSU

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Fundamental principles of a greenhouse— thermodynamics, psychrometric science and aerodynamics

THERMODYNAMICS OF A GREENHOUSE—The greenhouse presents a challenge to the thermodynamic application of climate control systems. It is one of the most difficult buildings to heat in the winter and cool in the summer and is subjected to wide extremes in temperature. Therefore, some knowledge of the principles of thermodynamics is necessary before one can design a satisfactory heating system.

A good way to approach the problem is to think of temperature control as a heat balance. There is almost always a transfer of heat to and from a greenhouse, and the prevailing temperature is the balance between the two. To maintain a desired house temperature, we must regulate this balance.

There are basically two ways that heat is lost—through the glass (conduction) and through the ventillating system (convection).

The source of heat for the greenhouse is either the sun or a man-made heating system.

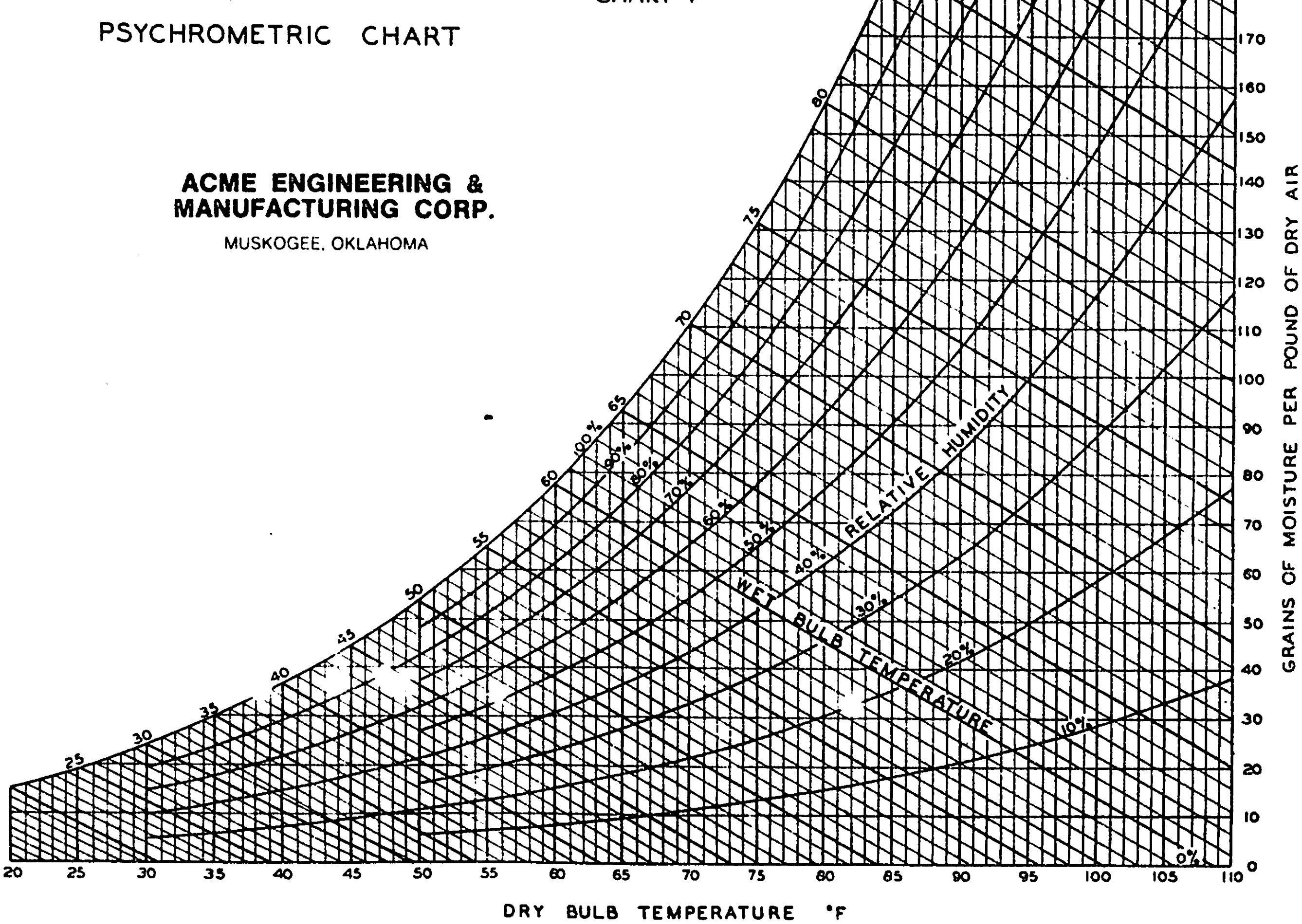
In outer space, the radiation intensity on a surface directly in line with the sun's rays is about 445 British thermal units (BTUs) per square foot per hour. This intensity is reduced to about 277 BTUs when filtered through the earth's atmosphere. In coastal or industrial areas where smoke and water vapor act as further screening agents, the reduction is even greater. This explains why growers in these areas often need little or no shading.

Man-made heating systems for greenhouses must have a larger capacity than would be required for any comparably sized structure. During cold winter nights, they must be able to generate a considerable amount of additional heat. Conversely, in warmer climates, they are generally used for a cooling function. They must also be engineered for uniform heat distribution, close temperature control and rapid response to changes in heating requirements. The majority of man-made systems concentrate on heating the atmosphere rather than the more esoteric soil-warming.

It is important to supply heat in a manner that provides uniform distribution. In most localities, this requires a perimeter heating system for the walls and another for the roof. The fact that warm air rises and cold air sinks makes a perimeter system particularly important in freezing climates to prevent cold floors.

A greenhouse must also maintain a proper relative humidity for optimum

CHART 1



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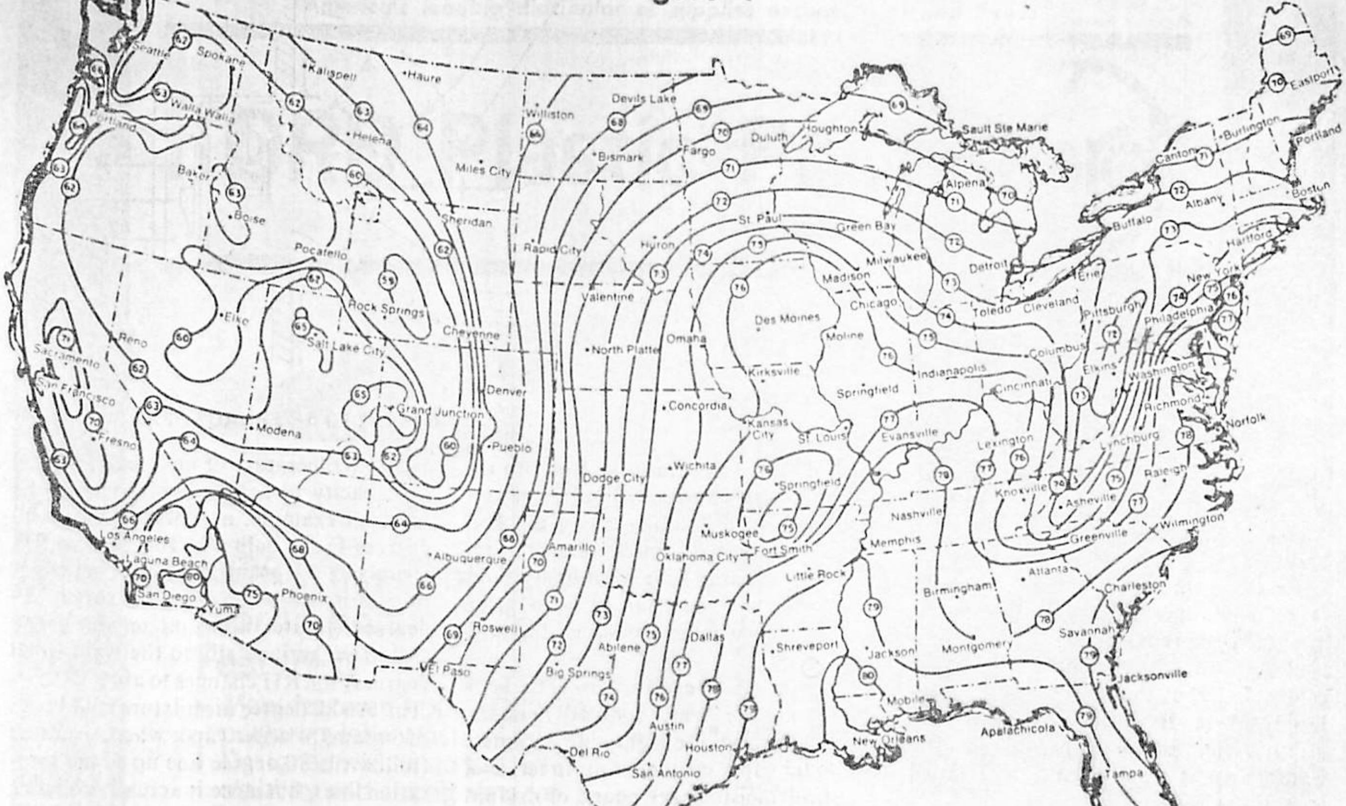
SUMMER WET BULB TEMPERATURE

Figure 1



SUMMER DRY BULB TEMPERATURE

Figure 2

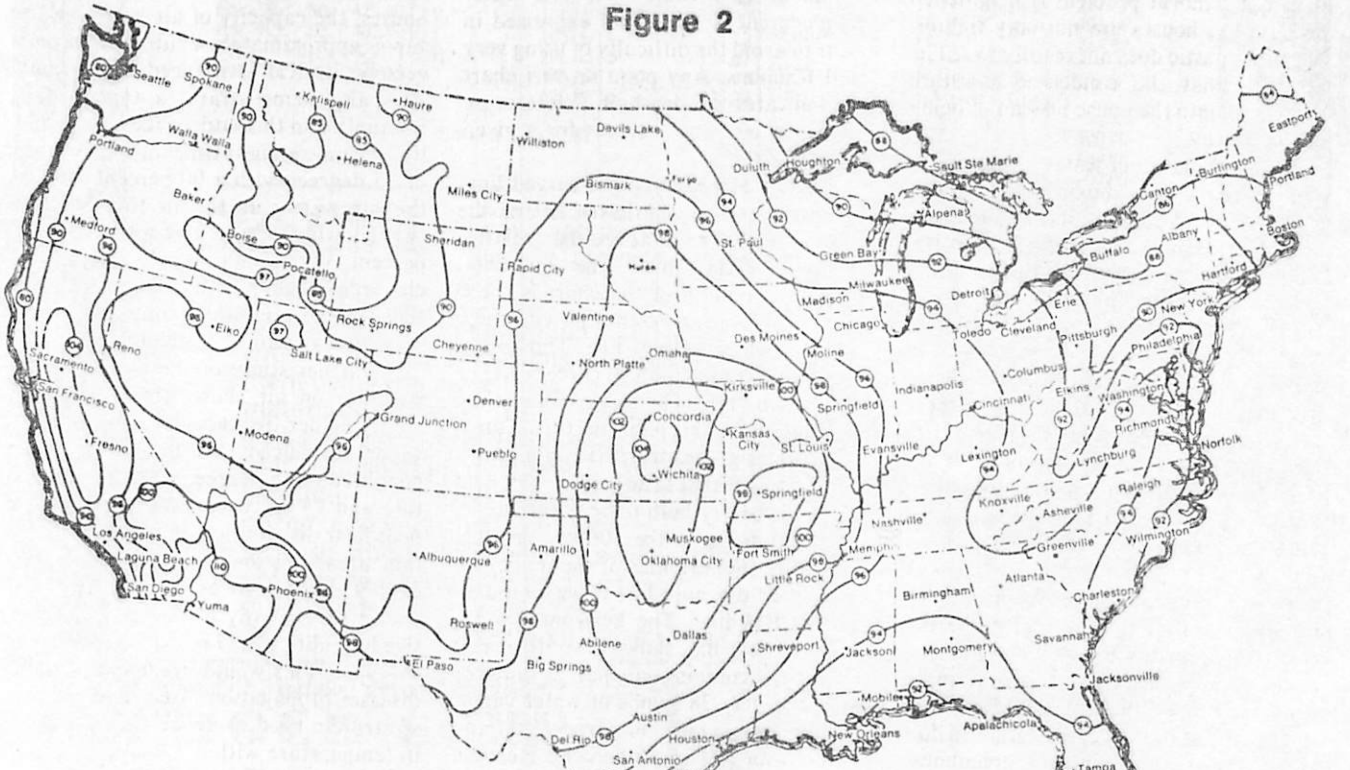
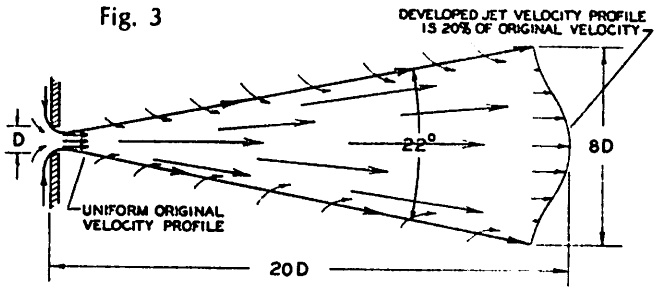
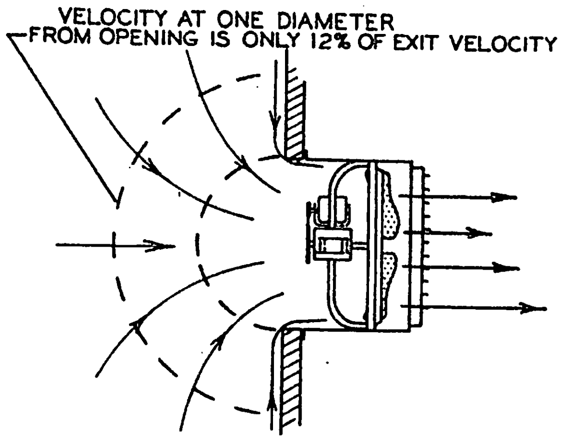


Fig. 3



THROW AND MIXING ACTION OF A JET



AIR FLOW TO AN EXHAUST FAN

plant growth. This is achieved by means of a moisture balance within the house. All water piped into the house must eventually leave. Since much of it becomes water vapor through the transpiration of plants and evaporation, ventillation is the most common removal method.

This is readily accomplished during cold weather, as the outside air contains less moisture. By bringing in this drier air, and then expelling the mixture, the water vapor is removed and the relative humidity is reduced.

Many older greenhouses with more leakage accomplished this automatically by infiltration losses, but newer, tighter houses require sufficient ventillation to properly control the moisture balance.

In houses constructed of plastic, the moisture removal problem is heightened because the houses are not only tighter, but most plastic does not readily wet. The result is that the condensed moisture drips back into the house instead of being drained away.

Air is a mixture of water vapor, nitrogen, oxygen, carbon dioxide and traces of other gases. Although its water vapor content is often less than 1 percent, it is a major factor in determining the condition of the air mixture. This is due not only to the necessity of water in the life cycle but also to its great energy content when in vapor form. The latent heat in water vapor (the energy in the form of heat required to change water from liquid to vapor) is the largest of any common liquid. As a result, the small amount of water vapor in the air mixture often contains the major part of the total heat energy.

A psychrometric chart is a graphic representation of the thermal properties of moist air and is used by engineers to analyze and solve thermodynamic problems. It is important that growers understand some of its concepts in order to do a better job of controlling the greenhouse climate. The following paragraphs (and accompanying chart) briefly explain a psychrometric chart and show how this information can be useful to growers.

❶ Dry Bulb Temperature—Refer to the psychrometric chart and observe the verticle lines with numbers along the bottom. These are "dry bulb" temperatures and are measured with an ordinary thermometer. All points falling on a given vertical line will be the same dry bulb temperature.

❷ Moisture Content in Air—The horizontal lines are "water content" lines and the numbers on the right side designate the water vapor content of air in terms of grains of moisture per pound of dry air. All points on a given horizontal line contain the same amount of water vapor. This term is better understood if one knows that 7,000 grains equal one pound of water and that one pound of air at normal greenhouse temperatures occupies about 13.5 cubic feet. The water vapor content is commonly expressed in grains to avoid the difficulty of using very small fractions. Any point on this chart thus indicates the dry bulb temperature and the water vapor content for a given pound of air.

● Relative Humidity—The curved lines that radiate from the lower left of the chart to the upper right are the "relative humidity" (RH) lines. The horizontal line at the bottom of the chart is the 0 percent RH line and coincides with the 0 grains of water content line. The uppermost curved line is the 100 percent RH or "saturation" line. The water content line terminating at any point on this saturation line designates the maximum grains of water vapor that saturated air can hold at that given dry bulb temperature.

For example, on the 100 percent RH line locate the terminus of the 60 degree Fahrenheit dry bulb line down to the 50 percent RH line. The horizontal water vapor content line shows that air at this latter point contains only half as much or approximately 38 grains of water vapor. The air now is only 50 percent full and thus has an RH of 50 percent. Relative humidity, therefore, states the amount of water vapor in air compared to the amount it could actually hold at that temperature.

The temperature of air greatly affects its capacity to hold water vapor. In the previous example, a pound of air at 60 degrees F dry bulb and 100 percent RH contained 77 grains of water vapor. If this air is heated to a temperature of 80 degrees (locate this point on the graph and move horizontally to the right to 80 degrees) the RH changes to about 50 percent. An 80 degree air mixture could hold 156 grains of water vapor when saturated (follow the 80 degree line up to the saturation line), but since it actually contains only 77 grains, it is half full. If this air is warmed another 20 degrees to 100 degrees, its RH will again drop to about 25 percent.

These examples show that for every 20 degree rise in dry bulb temperature, within the ranges encountered in greenhouses, the capacity of air to hold water vapor approximately doubles, and, conversely, its RH is reduced by one half. This also demonstrates a typical daily fluctuation in the outdoor relative humidity. Assume a night time air temperature of 65 degrees with a 90 percent RH. As the sun warms up the air to 85 degrees the following day, its RH will drop to 45 percent. When night approaches, the cycle begins again with a high RH even though the actual water content in the air may have remained unchanged.

A further study of the affect of temperature on air shows that, as air becomes colder, its capacity to hold water vapor is reduced. Assume a greenhouse condition of 65 degree dry bulb temperature and 75 percent relative humidity. If poor heat distribution developed in a certain area and lowered the temperature only 9 degrees to 56 degrees dry bulb (move horizontally to the left), the relative humidity would reach 100 percent at this spot. This would become a potential disease propagation area and demonstrates the need to avoid wide variations in temperature within a house.

It was shown in earlier examples that a pound of air at 100 percent relative humidity and 60 degrees containes 77

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Fundamental principles

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grains of water vapor. If it is cooled to 40 degrees (follow the curved 100 percent relative humidity line downward to the 40 degree dry bulb) it can now contain only 38 grains. The other 39 grains of water vapor it previously contained had to condense as liquid drops of water. (This is essentially how rain is formed.)

REDUCING THE RELATIVE HUMIDITY IN A GREENHOUSE—If cold air, having a low water vapor content, is brought into a greenhouse and heated, its capacity to hold water vapor increases and therefore has a great drying ability. This is demonstrated in the following example. Assume a rainy weather condition of 40 degrees and 100 percent relative humidity, and a greenhouse having an inside temperature of 65 degrees and 90 percent relative humidity. If this condition is too humid for plant health, it is readily possible, even in this situation, to lower the relative humidity in the house.

The psychrometric chart shows that each pound (13.5 cubic feet) of this greenhouse air contains 83 grains of water vapor while the outside air contains only 37. With each pound of air removed with an exhaust fan, 83 grains are carried out. They are replaced with only 37 grains from the new air. This results in a net removal of 46 grains of water vapor per pound of air.

An exhaust fan operating only a few minutes to remove one half of the humid greenhouse air would lower the inside relative humidity to about 65 percent. It would be lowered even more if this ventilating process were continued for a longer time. Obviously, the colder incoming air would have to be warmed by the heating system to maintain the desired house temperature at 65 degrees. Using normal fuel costs, 20,000 cubic feet of the 40 degree outside air could be heated to 65 degrees for approximately $0.02.

By understanding and properly applying these principles of climate control, an excessively humid greenhouse can be adjusted to a more desirable level, even under adverse weather conditions.

DIFFERENT KINDS OF HEAT—The psychrometric chart also indicates the energy content of the air-water vapor mixture. The energy or heat content of dry air is completely determined by, and is proportional to, its dry bulb temperature. It is called "sensible heat" because one can feel it.

The energy content of the water vapor is due to its "latent heat" of vaporization and is proportional to the amount of water vapor in the moist air mixture. "Latent heat" is the energy that is required to convert water from liquid to vapor without any change in temperature. It requires approximately 1,060 BTUs of heat to convert one pound of water from a liquid to a vapor. This energy cannot be felt because there is no change in temperature, only a change in its form.

The sum of these two energies is called "total heat" and is proportional to the "wet bulb" temperature of air. The wet bulb temperatures are designated by the diagonal lines that slope from the upper left to the lower right of the chart. The wet bulb temperature of air is measured with a thermometer having a wet wick on its bulb and air blowing over it. At 100 percent relative humidity, the dry bulb and wet bulb temperatures of air are the same, but at any other condition, the wet bulb temperature is always less than the dry bulb.

Perfectly dry (0 percent relative humidity) air at 98 degree dry bulb has a wet bulb temperature of 56 degrees and contains only sensible heat, having no latent heat due to the complete absence of moisture. However, if the moisture level increases until it becomes 100 percent humid, its dry bulb temperature will drop to 56 degrees (locate 98 degree dry bulb at 0 percent RH and follow the diagonal 56 degree wet bulb line upward to the 100 percent RH line). This decrease in dry bulb temperature is caused by utilizing the sensible heat to evaporate water. This loss of sensible heat energy (reduction of the dry bulb temperature to 56 degrees) is exactly balanced by an equal increase in the latent heat energy. Consequently the total energy content of the air mixture remains unchanged. This process can be followed along any of the wet bulb lines on the psychrometric chart and is called adiabatic cooling. The lowest temperature to which air can be cooled by adiabatic cooling is the wet bulb temperature.

To better illustrate the wet bulb temperature, it is the temperature one would feel when stepping out of a swimming pool when the wind is blowing.

EVAPORATIVE COOLING—Excessive summer temperatures are a serious problem to greenhouse operators. They can be controlled if the houses are equipped with a well engineered evaporative cooling system to pre-cool the outside air before use in the greenhouse. On the psychrometric chart, the wet bulb line running through the intersection of 95 degree dry bulb and 40 percent relative humidity is the 75 degree wet bulb line. If the air at 40 percent relative humidity and 95 degree dry bulb were passed through a wet cooling pad, it would evaporate water from the pad, increasing its water content (latent heat) and reducing its dry bulb temperature (sensible heat) until its dry bulb temperature was reduced to nearly 75 degrees.

Thus, the wet bulb temperature indicates to what temperature air can be cooled by evaporative cooling. In actual commercial practice, the wet bulb temperature is not quite reached, but the air can be cooled down to within about 3 degrees of the wet bulb temperature, and, in the above example, the 95 degree air could be cooled down to about 85 percent of the difference between the wet bulb and dry bulb temperatures to a 78 degree dry bulb temperature.

Since the wet bulb temperature, and not the relative humidity, determines to what temperature air can be cooled by evaporation, it has paramount importance. Wet bulb temperatures compiled from meterological data are available from government sources for most localities. For convenient reference this information is shown on the map of the United States (Figure 1). It shows that the average maximum wet bulb temperature for the four hottest months, June through September, ranges from 70 to 80 degrees. For regions at certain high elevations it is even lower. For design wet bulb temperatures in Canada and other foreign countries throughout the world, contact Acme Engineering & Mfg. Co., Muskogee OK.

It was previously explained that air can be cooled down in commercial evaporative cooling applications, to within about 3 degrees of the wet bulb temperature. One can therefore look at this map and tell almost exactly what temperatures such a cooling system can reach. It would range from 73 to 83 degrees during the normal hottest summer afternoon.

Contrary to some opinions, evaporative cooling will work in almost all parts of the country. Whereas the dry bulb temperature change is quite large in a 24 hour day, the wet bulb temperature is more consistent and changes only one-third as much.

During the heat of the day when both the dry bulb and wet bulb temperatures are at their peak, the difference between them is greatest. Consequently, the greatest amount of potential for cooling is obtained during the heat of the day when it is needed most.

MOVEMENT OF AIR—A brief study of some of the principles of aerodynamics will aid in the understanding of proper greenhouse climate control. There are several basic types of air flow that are important in a greenhouse climate control system and these are explained in the following:

- Jet flow—Jet flow is the rapid flow of air in a perpendicular direction caused by a difference in air pressure. The jet is a relatively high velocity stream and is turbulent with air particles. However, it immediately begins mixing with the surrounding air and gradually slows down. At a distance of 20 diameters from the opening, the jet has slowed down to a cen-

Greenhouse azaleas—p50

terline velocity of about 20 percent of its original outlet velocity, but is 90 percent mixed with the inside air. It expands at an included angle of about 22 degrees due to its mixing action and at 20 diameters from the opening becomes about eight diameters wide.

For example, a one-fourth inch diameter hole would throw a jet a distance of about six inches. A jet from a 16-inch hole, such as a missing pane of glass, would travel over 30 feet before being mixed with the surrounding air and would produce a very objectionable draft. It is apparent from this that jets of proper size and velocity that are well distributed will produce good mixing, uniform distribution and thorough circulation within the greenhouse.

- Sink flow (air flow to an exhaust fan)—In contrast to the characteristics of jet flow from an opening, the flow of air to an opening, such as to an exhaust fan, is of an entirely different nature, although still dependent on a pressure differential. This type of flow is called a sink flow. The air having no momentum, flows uniformly to the fan from all directions just as water moves from all directions toward a drain. At a distance of only one fan diameter from the inlet of the fan, the velocity of the air moving toward it is less than 12 percent of its velocity.
- Potential flow—Potential flow con-

sists of a relatively large quantity of air flowing smoothly in one direction with each particle of air moving in a straight line. This type of flow is used in greenhouse fan-and-pad cooling systems having a large mass of cool air flowing smoothly and at a low velocity through the growing region of the house. To achieve this, the location and type of inlet and outlet openings are very important. In greenhouse cooling, the air enters the house at a relative low velocity through a large pad opening at crop level and leaves through exhaust fans in the opposite wall.

LOCATIONS OF EXHAUST FANS—According to the aerodynamic principles just explained for ventilation, air distribution and flow patterns, mixing and circulation within a greenhouse are mainly determined by how and where the air enters the house—not how it leaves. While the location of both the exhaust fan and the air inlet opening are important for proper fan-and-pad cooling, the location of the exhaust fans is of little importance for winter ventilation. Therefore, exhaust fans should always be located where required for summer cooling.

EDITOR'S NOTE: Norman D. Augsburger is vice-president and director of marketing at Acme Engineering & Manufacturing Corp., Muskogee OK. Roy R.