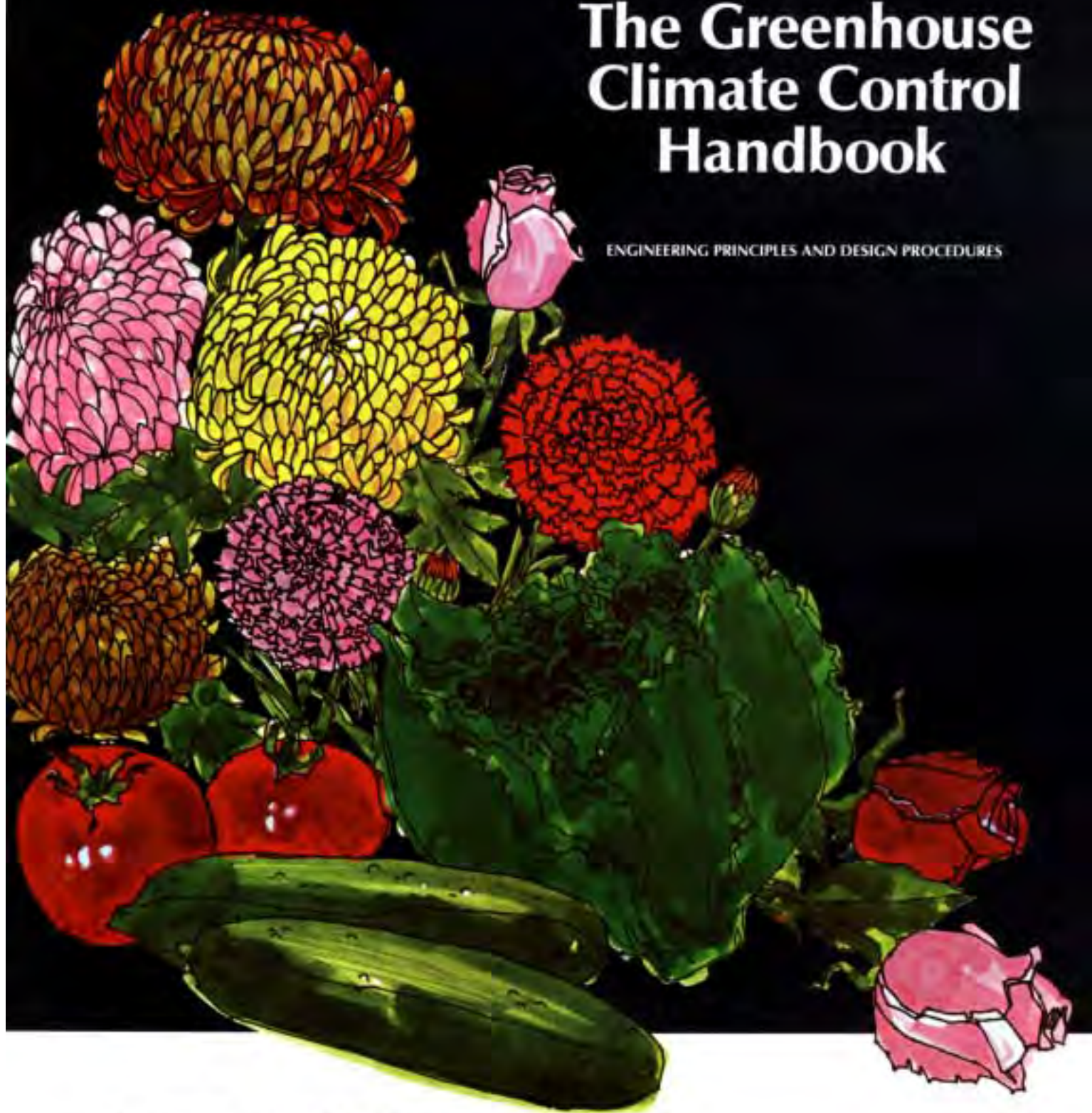


\$5.00

The Greenhouse Climate Control Handbook

ENGINEERING PRINCIPLES AND DESIGN PROCEDURES



HORTICULTURAL DIVISION

ACME ENGINEERING & MANUFACTURING CORPORATION

WORLD WIDE LEADERS IN GREENHOUSE COOLING AND VENTILATING EQUIPMENT

TABLE OF CONTENTS

	Page No.		Page No.
INTRODUCTION		WATER TREATMENT	13
FUNDAMENTAL PRINCIPLES		WETTING AGENTS	
THERMODYNAMICS OF A GREENHOUSE	4	ALGAECIDES	
TEMPERATURE CONTROL REQUIRES A HEAT BALANCE		INSECTICIDES	
SOLAR HEAT INPUT		AUTOMATIC CONTROL & OPERATION	13
HEATING SYSTEM INPUT		CONTROLLERS	
SUPPLY HEAT AT SOURCE OF HEAT LOSS		FANS	
PSYCHROMETRIC SCIENCE	4	PUMPS	
HUMIDITY CONTROL REQUIRES A MOISTURE BALANCE		SHIELDED CONTROLS	
AIR IS A MIXTURE		GENERAL	
PSYCHROMETRIC CHART		FAN-JET VENTILATION SYSTEMS	
DRY BULB TEMPERATURE		REASONS FOR A FAN-JET	
MOISTURE CONTENT IN AIR		MINIMUM VENTILATION SYSTEM	15
RELATIVE HUMIDITY		SUFFICIENT AIR FLOW CAPACITY	
EFFECT OF TEMPERATURE ON RELATIVE HUMIDITY (RH)		THOROUGH MIXING AND DISTRIBUTION	
REDUCING THE RELATIVE HUMIDITY IN A GREENHOUSE		CONTINUOUS AIR CIRCULATION	
SENSIBLE HEAT		MINIMUM AND MAXIMUM SYSTEMS ARE DIFFERENT	
LATENT HEAT		DESCRIPTION OF THE FAN-JET	
TOTAL HEAT		CLIMATE CONTROL SYSTEM	15
WET BULB TEMPERATURE		A MULTI-PURPOSE SYSTEM	
EVAPORATIVE COOLING		DESCRIPTION OF EQUIPMENT	
IMPORTANCE OF WET BULB TEMPERATURE		OPERATION OF THE FAN-JET SYSTEM	15
MOVEMENT OF AIR — AERODYNAMICS	8	SUPPLYING FRESH AIR	
JET FLOW		CONTINUOUS RECIRCULATION	
SINK FLOW—AIR FLOW TO AN EXHAUST FAN		DEHUMIDIFICATION	
POTENTIAL FLOW		SUPPLYING HEAT	
LOCATION OF EXHAUST FANS		QUICK RESPONSE	
THE GREENHOUSE COOLING SYSTEM		SELECTION OF EQUIPMENT	16
NEED FOR GREENHOUSE COOLING	8	FAN-JET DESIGN ADJUSTMENT FACTORS	
DESCRIPTION OF THE FAN & PAD COOLING SYSTEM 9		SELECTION OF FAN-JET UNITS	
EXHAUST FANS		SELECTION OF TUBES	
PAD SYSTEMS		SELECTION OF EXHAUST FANS	
TIGHT HOUSE ESSENTIAL		EXAMPLE DESIGN PROCEDURE	
DESIGN FACTORS	9	Design calculations	
ELEVATION		Fan-Jet selection	
LIGHT INTENSITY		Tube selection	
TEMPERATURE INCREASE WITHIN THE HOUSE		Exhaust fan selection	
SHORT PAD TO FAN DISTANCE		OVERHEAD HEATING SYSTEMS	
TOTAL AIR FLOW REQUIRED		NEED FOR WELL DISTRIBUTED HEAT	19
COOLING SYSTEM LAYOUT	10	DESCRIPTION OF FAN-JET HEATING SYSTEM	19
AIR FLOW ARRANGEMENT		USE OF A HEAT KIT	
PREVAILING SUMMER WIND EFFECT		UNRESTRICTED AIR FLOW	
ADJACENT BUILDINGS		DESIGN OF OVERHEAD HEATING SYSTEM	20
PREFERRED PAD TO FAN DISTANCES		DETERMINE GABLE HOUSE HEATING LOAD	
DESIGN PROCEDURE	11	DETERMINE QUONSET HEATING LOAD	
AMOUNT OF AIR REQUIRED		WINTER DESIGN TEMPERATURE MAP	
FAN SELECTION		EXAMPLE DESIGN PROCEDURE	
PAD SYSTEM DESIGN		Design Calculations	
Description		Selection of Fan-Jet Units	
Size		Selection of Tubes	
Pad within the greenhouse preferred		NEED FOR PERIMETER HEATING SYSTEM	
Pad Enclosure		IN COLD CLIMATES	22
Other considerations		DETERMINE PERIMETER HEATING LOAD	
OVERHEAD BAFFLES		PERIMETER FAN-JET HEATING SYSTEM	
BAFFLES UNDER BENCHES		EXAMPLE DESIGN PROCEDURE	
WATER SYSTEM		SELECTION OF PERIMETER FAN-JET SYSTEMS	
Flow rate		INSECT SCREENS	22
Piping and pumps		SERVICE AND MAINTENANCE	
Sump		FANS	23
Makeup water		PAD SYSTEM	23
EXAMPLE DESIGN PROCEDURE		EQUIPMENT-REFER TO CATALOG C29	
Design calculations			
Fan selection			
Fan selection (When a Fan-Jet system is also used)			
Determine pad size			

INTRODUCTION

The purpose of a greenhouse is to provide a good growing climate for the successful growing of high quality plants in all seasons of the year. Good heating systems were developed years ago for use during the cold winter months, and gravity ventilation through ridge and side vents was used for year around ventilation and temperature control.

But, the need for better climatic conditions became increasingly evident a number of years ago when crops could not be successfully grown in many localities during the summer months. Greenhouse temperatures were too high or light intensities from heavy shading were too low for proper plant growth and profitable greenhouse operations.

Early in 1954 the Acme Engineering and Manufacturing Corporation of Muskogee, Oklahoma in cooperation with progressive growers and horticulturalists, pioneered fan and pad cooling, the first commercially practical and effective cooling and ventilating system for greenhouses. Since that time this system has produced successful results in every state in the nation and in many foreign countries.

The rapid and wide spread use of this system has resulted in many improvements in products and design procedures to fulfill specific requirements. The recognition of the greenhouse environment problems led Acme engineers to develop new concepts, new systems and new products to provide better greenhouse climatic conditions for all seasons of the year.

The need for better greenhouse climatic conditions in the fall, winter and spring were rapidly recognized. Special circulating fans were developed to produce better leaf surface ventilation and a more uniform temperature and humidity. Fresh-Air Convection Tube systems made it possible to automatically supply fresh air, when needed, that was uniformly distributed and free of any cold drafts. Later, Fan-Jets combined these concepts to provide a powered tube system to produce leaf surface ventilation, automatically supply draft proof fresh air as needed, distribute heat as well as CO₂, maintain more uniform temperatures and help control the relative humidity.

Some basic principles and design procedures for greenhouse cooling systems were first published by Acme in 1955. Subsequent revisions and supplemental bulletins were issued as more information became available and as new concepts, systems and products were developed.

The purpose of this handbook is to incorporate additional fundamental data, design refinements and related improvements into a new handbook to provide a rational basis for the design, selection of equipment and operation of practical and efficient greenhouse climate control systems for all seasons of the year.

The design criteria described herein are for general applications and should be used only as a guideline. The actual design of a ventilation or cooling system for a specific installation is the sole responsibility of the buyer. The effects of the ventilating or cooling system on the crop are entirely the responsibility of the equipment operator, and Acme assumes no responsibility for the performance of the system.



**AIR MOVEMENT AND CONTROL
ASSOCIATION INTERNATIONAL, INC.**

MEMBER AIR MOVEMENT AND CONTROL ASSOCIATION

FUNDAMENTAL PRINCIPLES

THERMODYNAMICS OF A GREENHOUSE

The greenhouse presents a real 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, yet must maintain a good growing climate for plants. Therefore, some knowledge of the principles of thermodynamics is necessary before one can design a satisfactory system for climate control and establish proper operating procedures.

TEMPERATURE CONTROL REQUIRES A HEAT BALANCE

There is almost always a transfer of heat into or out of a greenhouse, and the prevailing house temperature is the result of a balance between the two. To maintain a desired house temperature we must regulate the heat supplied or removed to maintain a heat balance.

The supply of heat to the greenhouse comes from the sun's solar heat, conduction, convection, or must be supplied by a heating system. The heat removed leaves by conduction and radiation losses through and from the glass, and by convection with the air removed by ventilation. During bright sunny winter days, solar radiation supplies more heat than is removed by conduction and radiation losses, and some ventilation must be used to remove sufficient heat to maintain a proper heat balance. Conversely on a cold windy night, when large heat losses occur, the heating system must supply considerable heat to maintain a proper heat balance. In warmer seasons the solar intensity is greater and heat removal by conduction and radiation losses are nil, therefore, more ventilation or some means of cooling is needed to remove the excess heat to maintain a heat balance.

SOLAR HEAT INPUT

In outer space the sun's solar radiation intensity on a surface perpendicular to the sun's rays is about 445 BTU's (British Thermal Units) per square foot per hour, but by the time the rays penetrate the earth's atmosphere and reach ground level in a clear air region, they are reduced to about 277 BTU's in the summer time. In coastal or industrial areas where smoke and more water vapor exist in the air, the solar intensity is reduced to about 200 BTU's. This reduction in solar intensity affects the sun's light as well as its heat and explains why growers in industrial or coastal areas often need little or no shading.

Up to 85% of the solar heat in the form of electromagnetic and light rays may enter the greenhouse, but due to absorption and radiation at a different wave length, most of this heat becomes trapped inside and greatly increases the greenhouse temperature, particularly in the summer, unless removed. Since temperature control is a problem in a greenhouse, the climate control system requires a design that can remove this heat to maintain a heat balance during hot weather.

HEATING SYSTEM INPUT

The greenhouse heating system must have a larger capacity than needed for any other comparable sized structure and must be engineered for uniform distribution, close temperature control and quick response to changes in heating requirements. Since the plants in the greenhouse are largely heated by the air, the heating system whether of the steam, hot water or gas fired types is mainly used to provide a uniform temperature of the air within the house.

SUPPLY HEAT AT SOURCE OF HEAT LOSSES

It is important to supply the heat within the house in a manner to best offset the heat losses from the house to avoid having areas of reduced temperatures. In most localities, this requires a perimeter heat system for the wall losses and another heating system for roof losses. The fact that warm air rises and cold air falls makes a perimeter system particularly important in cold weather climates to prevent cold floors

since the cold air immediately adjacent to the walls flows downward to the floor.

PSYCHROMETRIC SCIENCE

HUMIDITY CONTROL REQUIRES A MOISTURE BALANCE

A greenhouse must maintain a proper relative humidity for optimum plant growth and health conditions, and this is achieved by means of a moisture balance within the house. All the water piped into the house must eventually leave. Since much of it becomes water vapor by the transpiration of moisture into the air by the plants and evaporation from the soil, most of it must be removed by ventilation. This is readily accomplished during cold weather since outside air at that time contains less moisture than the air within the house. By bringing in this drier outside air, mixing it with the humid house air, and then expelling the mixture, the water vapor is removed from the house and the relative humidity is reduced.

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

On houses constructed of plastic, the moisture removal problem is further increased because the houses are not only tighter but most plastic does not readily wet so the condensed moisture drips back into the house instead of being drained away.

AIR IS A MIXTURE

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% of the total, 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 of the mixture.

PSYCHROMETRIC CHART

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

DRY BULB TEMPERATURE

Refer to the psychrometric chart and observe the vertical lines on the chart having numbers along the bottom. These are "dry bulb" temperatures and are those air temperatures measured with an ordinary thermometer. All points falling on a given vertical line will be at the same dry bulb temperature.

MOISTURE CONTENT IN AIR

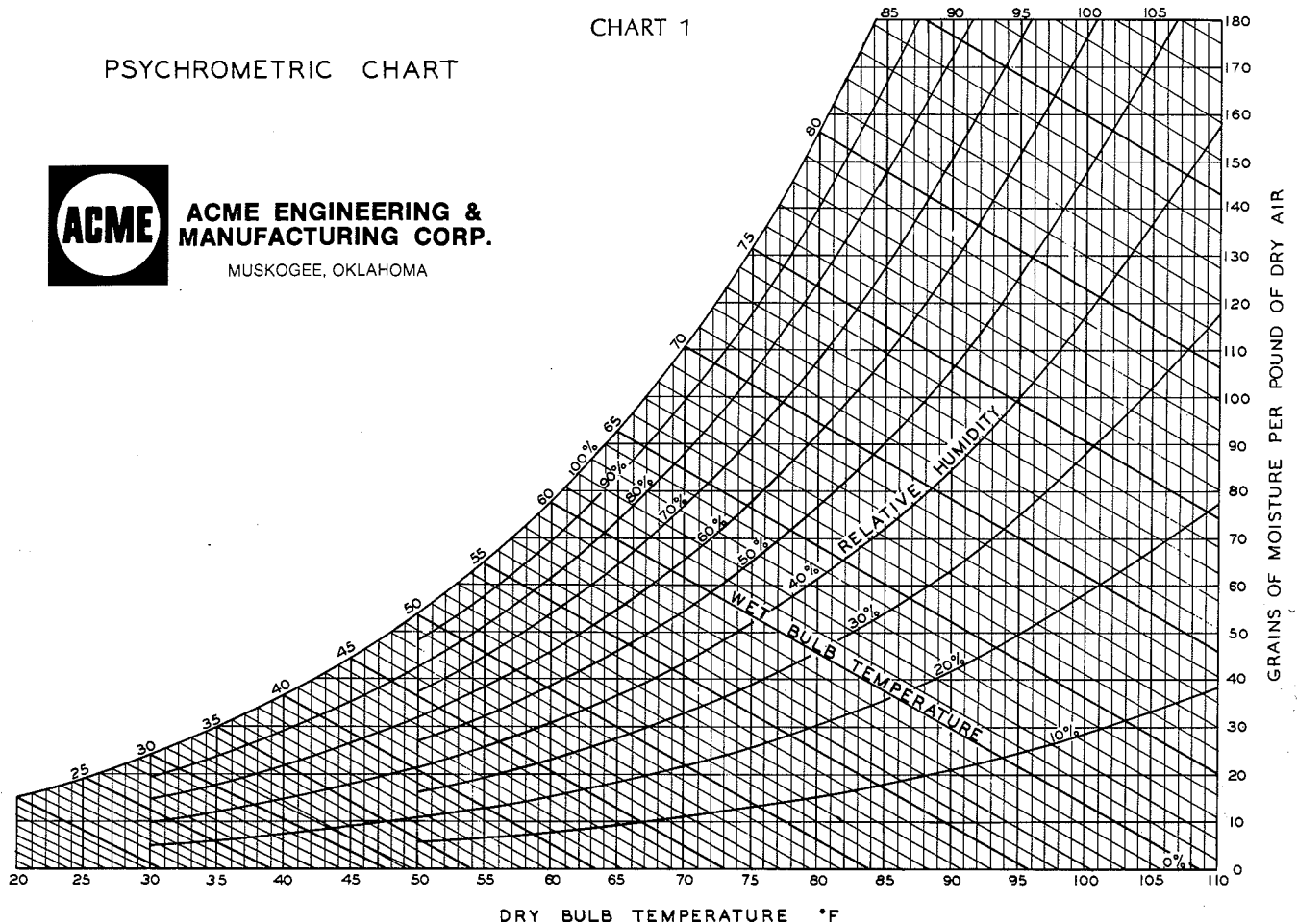
The horizontal lines are "water content" lines and the numbers on the right side designate the water vapor content of air in terms of grains of moisture per pound of dry air. All points on a given horizontal line contain the same amount of water vapor. This term is better understood if one knows that 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 instead of pounds 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.

PSYCHROMETRIC CHART

CHART 1



ACME ENGINEERING & MANUFACTURING CORP.
MUSKOGEE, OKLAHOMA



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% RH line and coincides with the 0 grains of water content line. The uppermost curved line is the 100% 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% RH line locate the terminus of the 60°F dry bulb line and note that at this condition a pound of air contains 77 grains of water vapor. Follow the 60°F dry bulb line down to the 50% relative humidity 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% full and thus has an RH of 50%. Relative humidity therefore, is a fraction in terms of percent that states the amount of water vapor in air compared to the amount it could actually hold at that temperature.

EFFECT OF TEMPERATURE ON RELATIVE HUMIDITY (RH)

The temperature of air greatly affects its capacity to hold water vapor. In the previous example, a pound of air at 60°F dry bulb and 100% RH contained 77 grains of water vapor. If this air is warmed up 20° to a temperature of 80° (locate the point designated above and move horizontally to the right to 80°) the RH is now about 50%. Air at 80° could hold 156 grains of water vapor when saturated (follow the 80° line up to the saturation line), but it actually contains only 77 grains, therefore is only 1/2 full. If this air is warmed another 20° up to 100°, its RH will drop to about 25%.

These examples show that for every 20° 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° with a 90% RH. As the sun warms up the air to 85° the following day, its RH will drop to 45%, and as night again approaches the cycle is reversed to produce a high RH even though the actual water content in the air may have remained unchanged at 84 grains per pound of air.

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° dry bulb temperature and 75% relative humidity. If due to poor heat distribution, random air currents or wind affects, a cold spot developed in a certain area that dropped the temperature only 9° down to 56° dry bulb (move horizontally to the left), the relative humidity would reach 100% at this spot. This would immediately become a potential disease propagation area. This, therefore, shows the need to avoid wide variations in the temperature within a house because of its direct affect on the relative humidity.

It was shown in earlier examples that a pound of air at 100% relative humidity and 60° contained 77 grains of water vapor. If it is cooled down to 40° (follow the curved 100% relative humidity line downward to 40° dry bulb) it can now contain only 38 grains. The other 39 grains of water vapor it previously contained had to condense out 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 warmed up, 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°, obviously at about 100% relative humidity, and a greenhouse having an inside temperature of 65° at 90% relative humidity. If the inside condition is considered too humid for plant health, it is readily possible, even in this situation, to lower the relative humidity in the house to a satisfactory level.

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 while only 37 grains enter the house with the make-up air. This results in a net removal of 46 grains of water vapor per pound of air exchanged.

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%. 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 up 25°F by the heating system to maintain the desired house temperature of 65°. Using normal fuel costs, 20,000 cubic feet of the 40° outside air could be heated to 65° for approximately \$0.02.

By understanding and properly applying these principles of climate control, an excessively humid greenhouse condition can be lowered to a more desirable level, for only a few cents cost, even under adverse weather conditions.

SENSIBLE 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.

LATENT HEAT

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, in the form of heat, that is required to convert water from liquid to vapor without any change in temperature. It requires approximately 1,060 BTU's 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, therefore it is called "latent heat".

TOTAL HEAT

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 a stream of air blowing over it. At 100% relative humidity the dry bulb and wet bulb temperatures of air are the same, but at any other condition less than saturation, the wet bulb temperature is always less than the dry bulb temperature.

WET BULB TEMPERATURE

Perfectly dry (0% relative humidity) air at 98° dry bulb has a wet bulb temperature of 56° and contains only sensible heat, having no latent heat due to the complete absence of moisture. However, if moisture is evaporated into this dry air until it becomes 100% humid, its dry bulb temperature will drop to 56° (Locate 98° dry bulb at 0% RH and follow the diagonal 56° wet bulb line upward to the 100% RH line).

This decrease in dry bulb temperature is caused by using up some of the sensible heat of the air to evaporate the water into the air. This loss in sensible heat energy (reduction of the dry bulb temperature to 56°) 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 follows along any of the wet bulb lines on the psychrometric chart and is called the adiabatic cooling of air by the evaporation of water. Therefore, 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. This circumstance exists because as long as the skin is wet while in a strong breeze, its temperature will drop to the prevailing wet bulb temperature.

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 it passes through the greenhouse. On the psychrometric chart, the wet bulb line running through the intersection of 95° dry bulb and 40% relative humidity is the 75° wet bulb line. If the air at 40% relative humidity and 95° 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°.

Thus, the wet bulb temperature tells 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 4° of the wet bulb temperature and in the above example, the 95° air could be cooled down to about 81% of the difference between the wet bulb and dry bulb temperatures to a 79° dry bulb temperature.

IMPORTANCE OF WET BULB TEMPERATURES

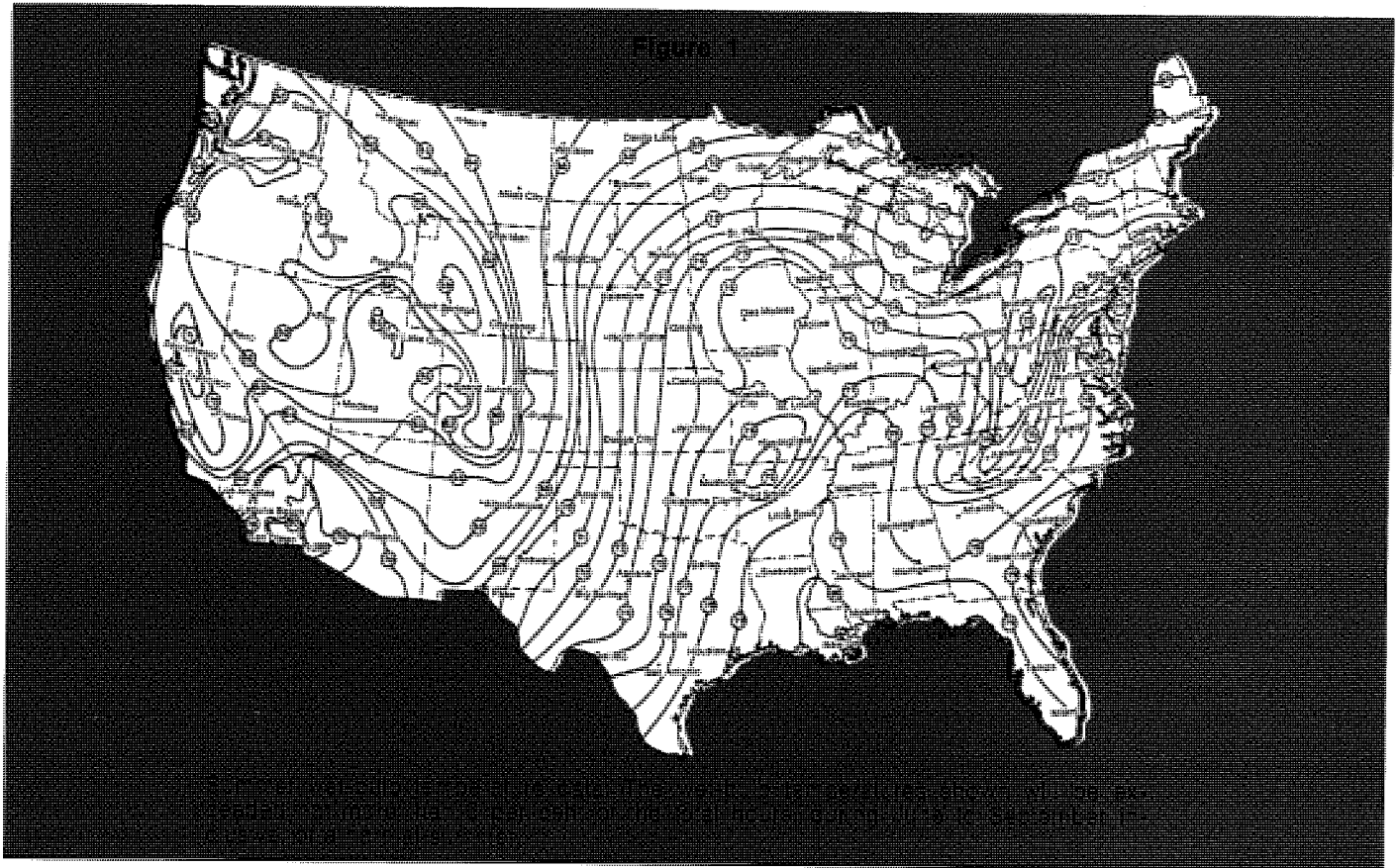
Since the wet bulb temperature, and not the relative humidity, determines to what temperature air can be cooled by evaporation of water, it has paramount importance. Wet bulb temperatures compiled for many years from meteorological data are available from government sources for most all localities. For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

It was previously explained that air can be cooled down, in commercial evaporative cooling applications, to within about 4° of the wet bulb temperature. One can therefore look at this map and tell almost exactly what temperature such a cooling system can reach. It would range from 73° to 83° during the normal hottest summer afternoon.

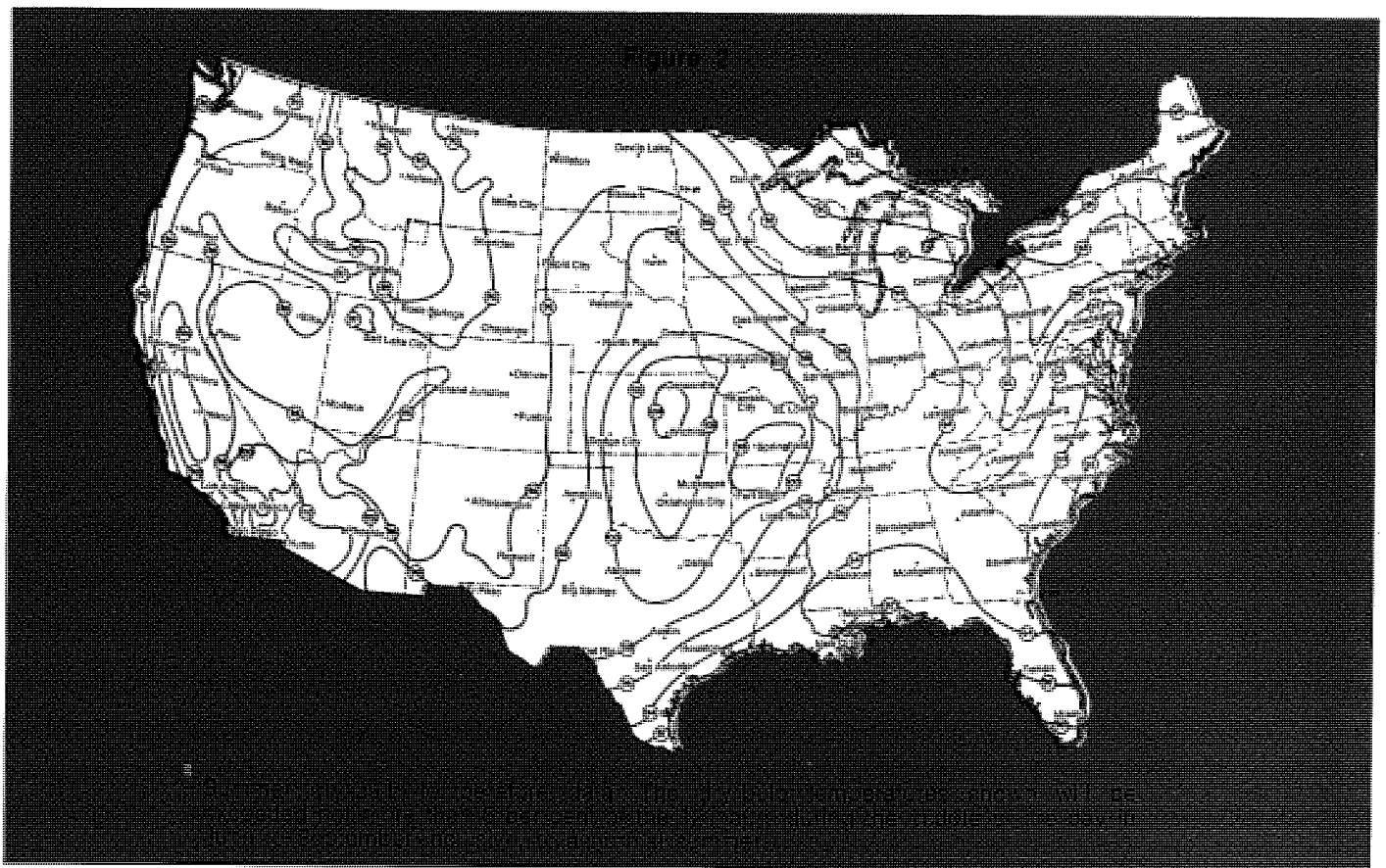
Contrary to some opinions evaporative cooling will work in most all parts of the country. Whereas the dry bulb temperature change is quite large in a 24 hour day, the wet bulb temperature is more consistent and changes only 1/3 as much.

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.

SUMMER WET BULB TEMPERATURE



SUMMER DRY BULB TEMPERATURE

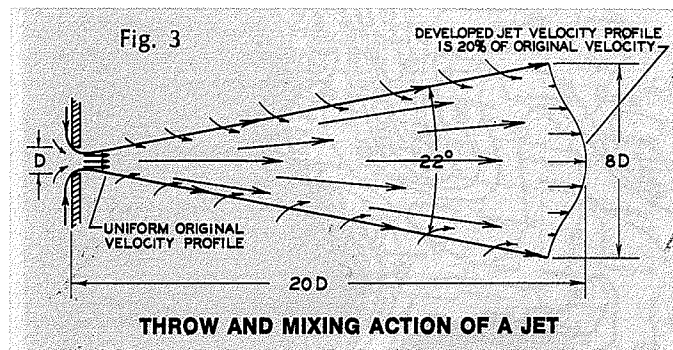


MOVEMENT OF AIR — AERODYNAMICS

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 paragraphs.

JET FLOW

Jet flow is the rapid flow of air in a perpendicular direction from a hole into an open space due to the difference in air pressure. The jet being a relatively high velocity stream of air is turbulent with the air particles swirling about as they travel in the jet stream. However, due to its extremely turbulent flow, the jet 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 centerline velocity of about 20% of its original outlet velocity, but is 90% mixed with the inside air. It expands at an included angle of about 22° due to its mixing action and at 20 diameters from the opening becomes about 8 diameters wide.

For example, a 1/4" diameter hole would throw a jet a distance of about 6 inches. A jet from a 16" 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 objectional draft if cold. 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 the drain hole in a wash basin. 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% of its exit velocity.

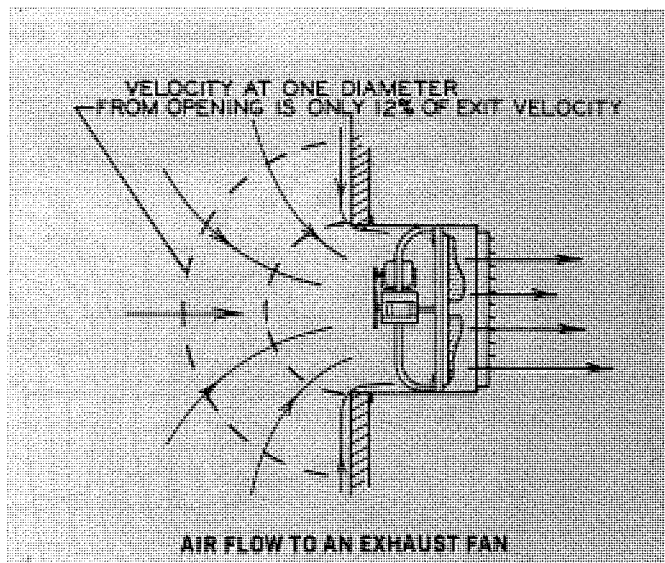


FIG. 4

POTENTIAL FLOW

Potential flow consists 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 low velocity through the growing region of the house with a minimum of mixing with other air in 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.

LOCATION OF EXHAUST FANS

Acme exhaust systems are based on the principle that all flow is due to pressure differences and that the pressure is constant within an enclosed space. Exhaust fans create a slight vacuum that is essentially uniform throughout the entire greenhouse, therefore, air will enter at the same velocity through any and all openings, regardless of their location.

According to the aerodynamic principles just explained for ventilation, air distribution, flow patterns, mixing and circulation within a greenhouse are mainly determined by how and where the air enters the house and where it goes out has very little importance. While the location of both the exhaust fan and the air inlet openings 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.

THE GREENHOUSE COOLING SYSTEM

NEED FOR GREENHOUSE COOLING

Nearly every locality experiences periods of intense summer heat causing greenhouse temperatures to become 10° to 20°F higher than outdoors, and such conditions are much too hot for satisfactory plant growth. Using the principles of thermodynamics and aerodynamics, an effective and economical method of evaporative cooling can be designed to maintain a greenhouse temperature in the summertime from 10° to 20° below the outdoor dry bulb temperature. This in effect would often result in greenhouse temperatures from 20° to 30° lower than in a conventional uncooled house.

The fan and pad evaporative cooling system originated and developed by Acme offers the grower an economical opportunity to prevent excessively high greenhouse temperatures,

maintain more uniform and positive ventilation throughout the house and obtain better temperature and humidity control to produce a much improved growing climate. This improved environment offers the following benefits:

1. Cools greenhouses 20° to 30° during hot summer months.
2. Profitable production of high quality crops the year around.
3. Permits growing crops not previously successfully grown.
4. Keeps plants on schedule.
5. Permits higher light intensities for more lush vigorous growth.

6. Reduces watering requirements.
7. Clean, filtered moist air ideal for plant growth.
8. Better insect control.
9. More comfortable working conditions and improved employee efficiency.
10. Eliminates stagnant air and produces a better leaf surface micro-climate for improved plant growth.
11. Simplifies greenhouse design and reduces basic construction costs.

DESCRIPTION OF THE FAN & PAD COOLING SYSTEM

The system must be properly designed to obtain maximum evaporative efficiency during periods of intense hot weather. This requires a non-turbulent potential flow through the greenhouse to avoid mixing the cooled air with the warmer air in the top of the greenhouse.

EXHAUST FANS

The fan and pad cooling system consists of large volume exhaust fans and a correctly sized continuous wet pad system, both properly located with respect to the greenhouse layout. The fans exhaust the air and develop a slight vacuum or negative pressure throughout the entire house because it is substantially air tight.

This slight vacuum draws air in through the cooling pad system and causes cooled air to move smoothly through the growing region of the crops absorbing heat. The warmed air is then expelled by the exhaust fans in the opposite wall. This system produces a potential type air flow that moves a cool layer of non-turbulent air through the plants for best cooling efficiency.

PAD SYSTEM

The pad system requires a sufficient flow area to accommodate the large air volume needed to remove the intense solar heat. It is composed of wettable, fibrous material, in the form of self supporting special fluted cellulose cooling cells. It is kept wet by water recirculating through it, thereby cooling the incoming air to within 3° or 4° F of the outdoor wet bulb temperature. The pad system also distributes the air uniformly and by virtue of its resistance, restricts the turbulence from the outdoor air, delivering a smooth, laminar flow of cool air into the house.

TIGHT HOUSE ESSENTIAL

Since the operation of a fan and pad cooling system puts the house under a slight vacuum the house should be kept in a good state of repair.

All access openings and doors should remain closed to avoid the infiltration of warm air that would dilute the cooled air and reduce the cooling effectiveness.

As the cooled air proceeds through the house, it picks up the solar heat, increasing in temperature about 7°F by the time it reaches the exhaust fans. This temperature rise of air moving through the house is a result of the heat removal

process but can be reduced by increasing the air flow or reducing the light intensity. Increased fan capacity can produce increased air flow, shading can reduce light intensity, and good maintenance can minimize infiltration or air leakage.

DESIGN FACTORS

Since the solar heat comes into the greenhouse on a ground surface area basis, the air flow rates for cooling are always determined on a cubic feet per minute (CFM) for each square foot of ground area basis. The basic air flow rate of 8 cfm per square foot has been determined to be sufficient for moderately shaded greenhouses having a maximum interior light intensity of about 5000 foot candles. This basic air flow rate is then adjusted for elevations over 1,000 feet above sea level, the expected interior light intensity, the allowable greenhouse temperature increase and the distance from the pad to the fan.

ELEVATION

The heat removal capacity of air depends on its weight and not on its volume. Since air is less dense at higher altitudes the elevation of the greenhouse must be considered in design calculations. At higher elevations a greater volume of air is needed to provide the equivalent weight of air required at normal elevations. Mathematically, this can be stated in terms of the local barometric pressure BP and can be compensated for by an **elevation** factor F_{Elev} :

$$F_{Elev} = \frac{29.92}{BP}$$

LIGHT INTENSITY

The interior light intensity, which depends on the location of the greenhouse and the amount of shading determines the amount of heat input into the greenhouse. If the interior light measured in foot candles is FC, then the **light intensity** factor F_{Light} is:

$$F_{Light} = \frac{FC}{5000}$$

TEMPERATURE INCREASE WITHIN THE HOUSE

The greenhouse temperature increase from pad to fan ΔT° is a design factor. It is inversely proportional to the air flow rate and can be adjusted to any value desired. If this value is to be different than 7°F the **temperature increase** factor F_{Temp} is:

$$F_{Temp} = \frac{7.0^\circ}{\Delta T^\circ}$$

This completes the adjustment and design factors necessary for a heat balance. Combining all these factors determines the **house** adjustment factor F_{House} which is used to

FIG. 6

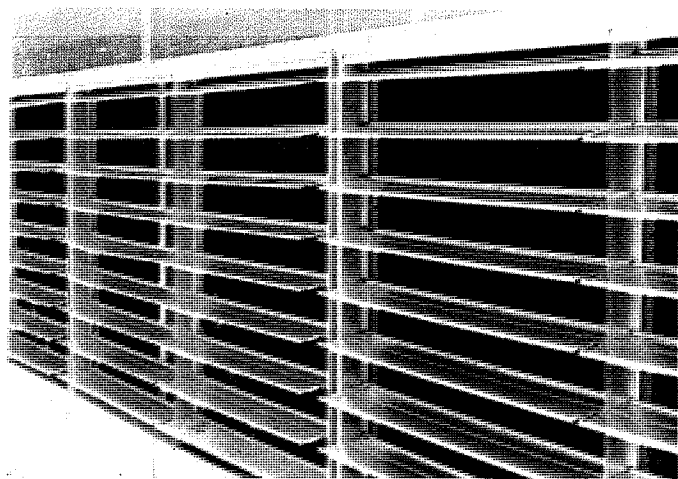


FIG. 5



complete the design capacity of the cooling system.

$$F_{\text{House}} = F_{\text{Elev.}} \times F_{\text{Light}} \times F_{\text{Temp.}}$$

For design convenience all these factors have been calculated and are listed in Tables 1 through 3. But, there is a very important aerodynamic situation related to the inlet to fan distance that must also be considered.

SHORT INLET TO FAN DISTANCE

For short inlet to fan distances the cross sectional air flow velocity within the house becomes too low, and the house often feels clammy or stuffy even though the air flow rate is sufficient for heat balance purposes. To help avoid this and to produce a more desirable air velocity level within the house a **velocity** adjustment factor F_{Vel} is used when the inlet to fan distance D is less than 100 feet and is:

$$F_{\text{Vel.}} = \frac{10}{\sqrt{D}}$$

This factor is ignored for inlet to fan distances of 100 ft. or more. For houses having less than 100 ft. inlet to fan distance, it is necessary to determine **both** the house adjustment factor F_{House} and the velocity factor F_{Vel} found in Table 4, and use the **larger** of the two in completing the cooling system design calculations. (For inlet to fan distance of 100 ft. or more ignore F_{Vel} and use only F_{House} .)

TOTAL AIR FLOW REQUIRED

After selecting the proper adjustment factor, F_{House} or F_{Vel} , described above, the total volume of air required for a greenhouse cooling system is found by multiplying the greenhouse floor area by the basic air flow rate and by the proper adjustment factor. For a house or group of connected houses of **length** L and **width** W the total cfm is:

$$\text{TOTAL CFM} = L \times W \times 8.0 \times F_{\text{House}} \quad (\text{unless } F_{\text{Vel}} \text{ is larger, then use } F_{\text{Vel}})$$

The proper size and number of fans are then selected to produce the required volume of air at 0.1 SP (inches of water static pressure). When using the slant wall housing, select fans at .05" SP. The pad area is then determined and the complete pad system is designed. This includes specifying the length and height of the pad system, the number and size pumps, filters, sumps and related components.

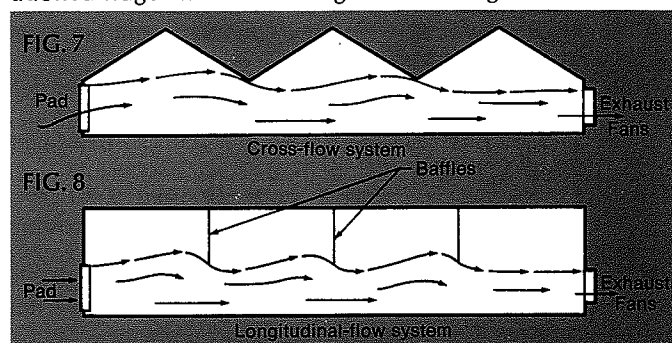
COOLING SYSTEM LAYOUT AIR FLOW ARRANGEMENT

Careful consideration should first be given to the direction of the air flow within the houses to be cooled and the velocity of the air flow to assure the best air flow patterns and uniform distribution.

The arrangement of the houses, location of attached or adjacent buildings, partitions and walls, access doors, type construction, direction of prevailing summer winds, and wall space limitations all affect the location as well as the size of the fans and the pad system.

In open ridge and furrow ranges the direction of air flow is usually across the houses and is referred to as a cross-flow

system. The longitudinal-flow system is usually used in partitioned ridge and furrow ranges and in single houses.



PREVAILING SUMMER WIND EFFECT

When possible locate the pads on the prevailing summer wind side and the fans on the down wind side of the greenhouse. If it is sheltered from prevailing winds by another building or greenhouse within 25 ft., the wind effect is negligible and can be ignored.

If the fans must face into the prevailing wind, increase the fan cfm capacity by 10% and use fans having 3/4 HP or larger motors.

ADJACENT BUILDINGS

The exhaust fans should not discharge toward the pad system of an adjacent greenhouse unless the houses are separated by at least 50 feet.

When fans from two adjacent greenhouses within 15 ft. of each other exhaust into a common space between the houses, they should be offset from each other to avoid the air from one blowing directly against that of the other.

The fans should have at least 1 1/2 fan diameters of clearance between their discharge opening and the nearest obstruction such as a building wall. When less than this space is available roof mounted fans should be used.

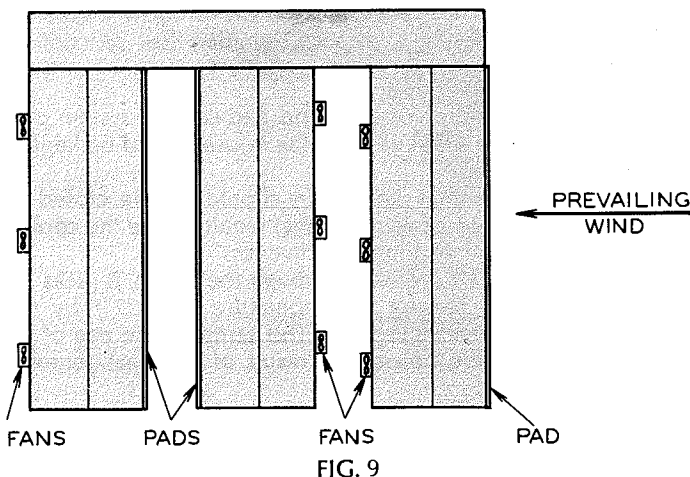


TABLE 1

Elevation, feet above sea level

feet	Under 1000	1000	2000	3000	4000	5000	6000	7000	8000
$F_{\text{Elev.}}$	1.00	1.04	1.08	1.12	1.16	1.20	1.25	1.30	1.36

TABLE 2

Maximum Interior Light Intensity, foot candles

FC	4000	4500	5000	5500	6000	6500	7000	7500	8000
F_{Light}	.80	.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60

TABLE 3

Inlet to Fan Temperature Variation, $\Delta T^{\circ}\text{F}$

$^{\circ}\text{F}$	10	9	8	7	6	5	4
F_{Temp}	.70	.78	.88	1.00	1.17	1.40	1.75

TABLE 4

Inlet to Fan Distance, feet

feet	20	25	30	35	40	45	50	55
F_{Vel}	2.24	2.00	1.83	1.69	1.58	1.49	1.41	1.35

feet	60	65	70	75	80	85	90	95	100
F_{Vel}	1.29	1.24	1.20	1.15	1.12	1.08	1.05	1.02	1.00

PREFERRED PAD TO FAN DISTANCES

The preferred pad to fan distance ranges from 100 to 225 feet limited only by acceptable airflow velocities within the house and available pad area.

For very long houses consider installing a pad at each end with the exhaust fans located at the mid point using side wall or roof mounted fans. The cool air then flows in from each end and is exhausted at the mid point of the house.

DESIGN PROCEDURE

AMOUNT OF AIR REQUIRED

First decide what airflow arrangement is to be used, including the location of the fans and the inlet system. Then proceed with the design calculations using the tables on page 10 that have the adjustment factors precalculated.

FAN SELECTION

For most reliable fan performance use only fans that have been tested and rated in accordance with the AMCA (Air Moving and Conditioning Association) standard test code and which bear the AMCA Certified Rating Seal. This assures the user that he is getting the capacity stated in the manufacturer's catalog.

WARNING! DO NOT use in HAZARDOUS ENVIRONMENTS where fans electrical system could provide ignition to combustible or flammable materials, unless unit is specifically built for hazardous environments.

Always select fans on the basis of their certified air delivery at 0.1" SP (.05" SP when using slant wall housings), since they must draw air in through the pads and will operate against a constant resistance.

The amount of air required, available wall space and airflow distribution will influence the size and number of fans to use. Generally fewer larger fans offer the most economical selection based on initial cost and on installation and operating expense.

The fans should be spaced not over 25 ft. apart to assure good air distribution. When wall space is not available use roof mounted fans.

Cooling systems with two fans or less should have at least one fan with a two-speed motor to provide more flexibility in the cooling and ventilating operation. The low speed capacity of a two-speed fan is about $\frac{1}{2}$ of its high speed capacity.

For greenhouse equipped with Fan-Jet ventilation systems, select an exhaust fan combination that will provide an airflow closely matching but **not exceeding** the Fan-Jet system capacity for cold weather operation.

Any combination of Windmaster fan models that provide the total air needed is satisfactory. When possible select all fans of one model to simplify servicing.

In the event additional air is desired for an existing cooling system, do not increase the fan speed by changing the sheaves as this will overload the motor. Consult the factory for recommendations.

All exhaust fans should be equipped with automatic shutters for weather protection and to prevent backdrafts when part of the fans are not in use.

The wall fans should be mounted in metal wall housings for weather protection and to provide convenient means for installing fans on side wall. Special roof fans are used for mounting fans on the roof.

CAUTION! Guards must be installed when fan is within reach of personnel or within seven (7) feet of working level or when deemed advisable for safety.

PAD SYSTEM DESIGN

A correctly designed pad system is essential to achieve maximum cooling performance. It must be a continuous section along the entire side or end of the greenhouse, be the correct size, properly located and have the right thickness and density. A blank space in the pad, such as a doorway, will cause a hot spot through the house for a distance of 6 to 8 times the width of the blank.

Description

The system is composed of self supporting fluted cellulose cooling cells positioned adjacent to each other for the full length of the pad system.

A recirculating water system keeps the pads sufficiently saturated to achieve good evaporating cooling efficiency.

Size

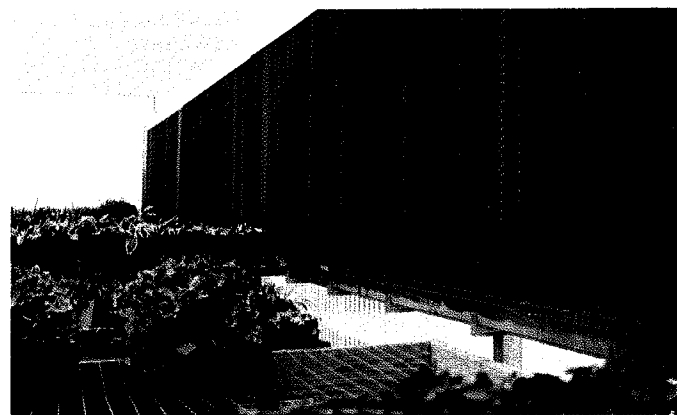
The size of the pad system is determined by adding the CFM for each exhaust fan, which is shown in the Windmaster Certified Performance Table in catalog C29 and dividing by 250 for 4" pads and 400 for 6" pads. This area divided by the length of the system determines the actual pad height. The overall height of the pad system including the overhead water distributor and the bottom return gutter is about 10" more than the actual pad height.

When the 4" Kool-Cel pad system is over 48" high, multiple pad stacking is utilized and a tall pad support is required. EXAMPLE: 84" high pad is composed of a 48" and a 36" section. 96" high pad is composed of two 48" sections.

Pad Within The Greenhouse Preferred

The pad system should be installed within the greenhouse or built into the wall and have motorized shutters or hinged sash vents on the outside. This produces less turbulent air flow inside and facilitates opening and closing the vents for rapid changes from heating to cooling and the in-between seasons.

The air inlet opening need not be continuous but should be sized not to exceed 400 FPM inlet velocity and be reasonably well distributed. For sash vents, the inlet opening area will vary with the opening angle and is equal to the sash length times the shortest distance from the sill to open sash.



Pad Enclosure

The pad system air inlet should be equipped with a weather protected closure for cold weather protection and to shut off the flow of air through the pad system when it is not in use. Motorized shutters and sash vents are highly recommended for this purpose to provide for automatic opening and closing when called for by the Greenhouse Climate Controller or thermostat.

Other Considerations

When circumstances permit, the top of the pad system should be near the top of the crop being cooled or have its midpoint centered on the crop to be cooled. Minimum height of the pad should be 24".

The sun shining directly on the pad system has an insignificant effect on its cooling ability and can be ignored in determining the pad system location.

To reduce the build-up of deposits and scale on the evaporative surface, a bleed off from 1 to 2% of the recirculating water is usually required. This is particularly true in areas that have a high mineral content in their water.

The Acme cooling cell type pad contains anti-rot ingredients. Experience has shown that with proper care and cleaning it will perform satisfactorily for many years.

OVERHEAD BAFFLES

The cooled air passing through the house will tend to diverge at a 7° angle or about 1 foot in every 8 feet. Consequently, the upper layer of cooled air tends to rise toward the peak of the house above the crop zone and do little cooling of the plants. In cross flow arrangements of gutter connected houses, the gutters serve as baffles and tend to keep the cool air at crop level.

In longitudinal flow arrangements where the air flow is lengthwise with the house, vertical baffles extending from the roof down to the top of the crop level help reduce mixing with the overhead air and keep the cool air down at the crop level. (See Fig. 8). The baffles should be transparent, spaced about 30 feet apart, held in a fixed vertical plane and have their lower edge just above the top of the crop level.

In longitudinal air flow arrangements using roof mounted fans, a vertical baffle should be installed 3 to 5 feet upstream from the fans to help keep the cooling air at crop level.

The baffles should be rolled up or removed during cold weather, unless the house is equipped with a Fan-Jet system. The Fan-Jet tubes may go through holes cut in the baffles.

BAFFLES UNDER BENCHES

In greenhouses containing raised benches a substantial volume of air may travel under the benches to the fan without removing much heat. A baffle covering $\frac{2}{3}$ of the distance from the bench to the ground will force most of the cooling air to crop level for more effective plant cooling.

WATER SYSTEM

Flow Rate

For adequate wetting and best evaporative efficiency much more water than is actually evaporated should be supplied to the pad system. To conserve the unevaporated water, a water recirculating system is necessary to recycle the water.

The water flow rate should provide a minimum of $\frac{1}{2}$ gpm for 4", $\frac{3}{4}$ gpm for 6" and $\frac{1}{4}$ gpm for 2" per linear foot to insure adequate water and optimum evaporative performance.

The water supply system should provide somewhat more water than necessary since the flow rate can be adjusted with a valve to the proper rate required. However, too much water must be avoided as it may form a solid curtain of water on the pad and this will block the flow of air through the pad at such areas and impair the overall performance.

Piping and Pumps

Water is supplied to the pad by an over-head pipe distributor having metered outlet holes for uniform water distribution. It is furnished with a flush-out end plug for convenient clean out when necessary.

Use the recommended size pipe in the piping system from the sump to the pump and to the water distributor to avoid needless losses.

The piping system from the pump to the water distributors should be equipped with the recommended size and type filter. The filter should have a flush-out valve as shown in the piping instructions for convenient cleaning.

Sump

The water systems should be provided with a sump sized for $\frac{3}{4}$ gallon for 4", 1 gallon for 6" and $\frac{1}{2}$ gallon for 2" capacity for each square foot of cooling cell system. These capacities would provide for an operating level at the approximate midpoint of the sump. The sump should be located near the midpoint of the pad system.

All elements of the water system should be enclosed or well covered to protect it from insects and other wind borne debris. The recirculated water returning to the sump should be screened as it enters the sump.

The sump should have a drain or flush-out means as shown in the piping instructions to permit periodic clean out of accumu-

lated sediment.

It is recommended that the sump and pump be installed inside when practical. When located outside, they should be drained before cold weather to prevent damage from freezing.

Since water is used up in the evaporative cooling process a supply of make-up water is needed. An automatic float valve should be used for this purpose to maintain a proper water level in the sump.

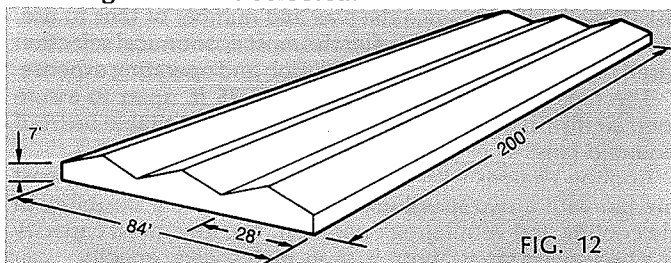
The water consumption rate will vary from little or none at night or on a rainy day and up to one gallon per minute per 100 sq. ft. of pad area on hot days.

The evaporative cooling process will bring the temperature of the recirculating water and the make-up water to the prevailing outdoor wet bulb temperature very quickly. Therefore the use of cold well water instead of recirculated water to wet the pads to obtain more cooling has an insignificant effect.

EXAMPLE — DESIGN PROCEDURE

Design Calculations

Consider three gutter connected glass greenhouses each 28 ft. wide and 200 ft. long with 7 ft. walls and having the conditions listed below. For this 84 ft. by 200 ft. block of houses a cross-flow arrangement was selected.



Each house 28' x 200'
Overall range size 84' x 200'
Elevation 3000 ft.
Expected interior light intensity 6000 ft. candles
From Table 1 for 3000 ft. elevation, F_{Elev} is 1.12.
From Table 2 for 6000 ft. candles, F_{Light} is 1.20.
From Table 3 for 7° temp. increase, F_{Temp} is 1.00.
The house adjustment factor F_{House} is:

$$\begin{aligned} F_{\text{House}} &= F_{\text{Elev}} \times F_{\text{Light}} \times F_{\text{Temp}} \\ &= 1.12 \times 1.20 \times 1.00 \\ &= 1.34 \end{aligned}$$

From Table 4 for an 84 ft. pad to fan distance, by interpolation, F_{Vel} is 1.09.

Now compare $F_{\text{House}} = 1.34$ with $F_{\text{Vel}} = 1.09$. The F_{House} factor of 1.34 being larger will be used in the design calculations.

The total air flow requirements for this 200 x 84 block of houses is:

$$\begin{aligned} \text{Total CFM} &= L \times W \times 8.0 \times 1.34 \\ &= 200 \times 84 \times 8.0 \times 1.34 \\ &= 180,096 \text{ cfm} \end{aligned}$$

Fan Selection

For a cross-flow arrangement the fans will be installed in the 200 ft. long wall and require at

least 8 fans for proper spacing.

From the Windmaster Certified Performance Table in Catalog C29, 10 Model DC48H fans @ 17,800 cfm will provide 178,000 cfm at 0.1" SP. This is a satisfactory selection and will space the fans 20 ft. apart.

Select 10 — Model DC48H @ 17,800 = 178,000 CFM.

Fan Selection (When a Fan-Jet System is Also Used)

Assume this block of houses is to be equipped with a Fan-Jet system. Refer to example on pg. 19 and find that 32,520 cfm exhaust capacity is required for the Fan-Jet system.

Two DC48H fans @ 17,800 would provide 35,600 cfm which would be too much for cold weather ventilation.

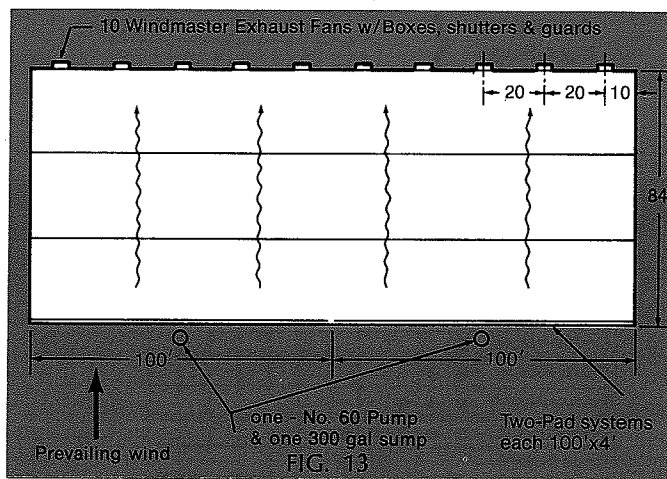
But a selection of six DC48H, three DC48J and one DC48G Windmaster fans will provide 106,800 + 58,800 + 14,600 CFM = 180,200 CFM for the fan and pad cooling system. Of this group the operation of one DC48H and the DC48G will provide 17,800 + 14,600 = 32,400 CFM and closely matches the Fan-Jet system requirements.

Select

6 — Model DC48H @ 17,800	= 106,800 cfm
3 — Model DC48J @ 19,600	= 58,800
1 — Model DC48G	= 14,600
Total CFM	= 180,200 cfm for fan & pad cooling

Operate

1 — Model DC48H	= 17,800 cfm
1 — Model DC48G	= 14,600
Total CFM	= 32,400 cfm for Fan-Jet system.



Determine Pad Size

To determine the size of the 4" Kool-Cel pad system refer to the Windmaster Certified Performance Table in Catalog C29 and total the CFM specified for each fan selected.

6 — Model DC48H @ 17,800	= 106,800
3 — Model DC48J @ 19,600	= 58,800
1 — Model DC48G @ 14,700	= 14,700
Total CFM used	180,300

Divide total CFM by 250 (180,300 ÷ 250 = 721 sq. ft.)

The pad system is to be installed in the 200 ft. long side, therefore its height will be 721 ÷ 200 = 3.61 ft.

Use a 4 ft. height

The Pad Size = 4 ft. high by 200 ft. long. For the 200' long Kool-Cel system use two No. 60 pumps and two sumps each having a capacity of 300 gallons. The pad system should be divided into two 100' lengths with a sump and pump located near the midpoint of each.

WATER TREATMENT

WETTING AGENTS

Sometimes, particularly with newly packed pads, it is desirable to add a wetting agent to the water system to produce more thorough wetting of the pads. Standard liquid type household detergents are suitable at a concentration of 100 parts per million (ppm) or about 5 teaspoonsful per 100 gallons of water.

ALGAEICIDES

The growth of algae in the pads sometimes becomes a serious problem in some localities or in certain periods. Algae clogs the pads and promotes accelerated deterioration and should be avoided. The periodic addition of an algicide in the cooling water system will help control it. Algaecides are available from most horticultural, farm or swimming pool supply firms.

INSECTICIDES

The natural operation of the Acme fan and pad cooling system normally eliminates large insects from the greenhouse. For more positive insect protection the use of insect screens is recommended. Reasonably effective control of small air borne insects from outdoors, such as thrip, can be obtained by the addition of non volatile insecticides in the pad water system. Precautions should be taken to keep children and pets from water that has been treated with certain chemicals.

AUTOMATIC CONTROL & OPERATION

CONTROLLERS

Thermostats have been in use for many years to regulate greenhouse heating systems to maintain more uniform temperatures and reduce operating cost. In a similar manner thermostats and humidists have been very useful in automatically regulating the greenhouse cooling and ventilating systems.

Through the years, excellent heating, ventilating, cooling and air circulating systems have been developed, but the control of these systems has been difficult to automate with individual thermostats and humidists because of the interaction of these systems. To overcome this difficulty, the control of all systems must be tied together so that all equipment turns on and off at the proper time and in the proper sequence.

The Acme ACC-I and Grotron II Controllers automatically operate the proper equipment to maintain a good climate for successful growing of high quality plants in all seasons of the year.

The Acme ACC-I Controller offers eight sequential stages with the flexibility of choosing zero, one, two or three stages of heat, one circulation stage and four, five, six or seven stages of cooling. Remote temperature sensing with optional day/night control and selectable programmed staging differentials make this a very desirable unit. For further information refer to Acme catalog C29 or contact your Acme representative.

The Acme Grotron II controller automatically operates two stages of heating, recirculation, and five stages of ventilation or cooling. This controller separates the heating and cooling operations on separate dials. The heating operation is further divided into separate day and night control dials. Automatic switching from day to night and night to day is controlled by a photocell. It has a remote temperature sensor that allows the control panel to be placed in a

convenient location for easy operation of the greenhouse climate control equipment. It also incorporates a humidistat for proper humidity control. For additional information refer to Acme catalog C61.

FANS

The greenhouse fans should be automatically controlled with an Acme Grotron II Controller, ACC-I, or with thermostats which would turn the fans on with temperature rise to obtain the best temperature regulation and conserve power. In such cases the fans should be equipped with automatic closures such as shutters to prevent back draft through non-operating fans.

The fans should be divided into banks, each bank being separately controlled. The Acme Controllers have built-in staging to provide gradual changes in air flow for a more uniform temperature control. If thermostats are used they should have slightly different temperature settings to provide this same control. And every third fan should be a member of one bank to provide a more uniform air flow pattern in the greenhouse.

The Acme Controllers also provide proper staging for the operation of two speed fans. If a two speed fan is controlled with a thermostat it must be a two stage thermostat. This arrangement will permit the first stage to turn the fan on and off as required; the second stage will run the fan on low or high speed as required.

During the fall, winter and spring when the heating system as well as the ventilating system is in use the proper staging is even more critical and the ACC-I Controller and Grotron II automatically provide an even uniform greenhouse temperature and circulation. If only thermostats are used it is necessary that the cooling thermostat that controls the first stage fans be set several degrees (usually 5° or more) above the setting of the heating thermostat to avoid having the heating and cooling system on at the same time. This is due to an overriding tendency that frequently occurs in a heating system.

All electrical wiring and controls should comply with national and local electrical codes and ordinances.

PUMPS

The cooling system pumps can be controlled with the ACC-I or Grotron II Controller to provide the designed evaporative cooling, avoid excess humidity and conserve power and water. If an Acme Controller is not used the pump should be controlled by a humidistat and thermostat wired in series.

In some localities where the outdoor relative humidity tends to be high early in the evening, the Acme Controllers or a humidistat can help avoid an excess humidity in the house. But in all cases a thermostat should be used for the main pump control as is the case with the Acme Controllers. These Controllers are sequenced so as to turn off the pump before all the fans are shut off so that the pad can dry out and this same operation should be provided with a thermostat when the Acme Controllers are not used.

SHIELDED CONTROLS

The remote sensor of the ACC-I and the Grotron II Controllers, thermostats, humidistats and thermometers should be shielded from the direct ray of the sun to avoid being influenced by solar radiation and to provide correct readings and control settings. Shielding with at least ½" thick wood is usually satisfactory. They should be mounted in a manner that will permit circulation of air about the sensing elements and be located where they represent the average greenhouse conditions at plant level, being careful to avoid locating them near heating lines or a sizable air inlet opening.

GENERAL

Each fan, heater and pump should have a manual control switch wired in parallel with the automatic controls to permit manual operation when desired.

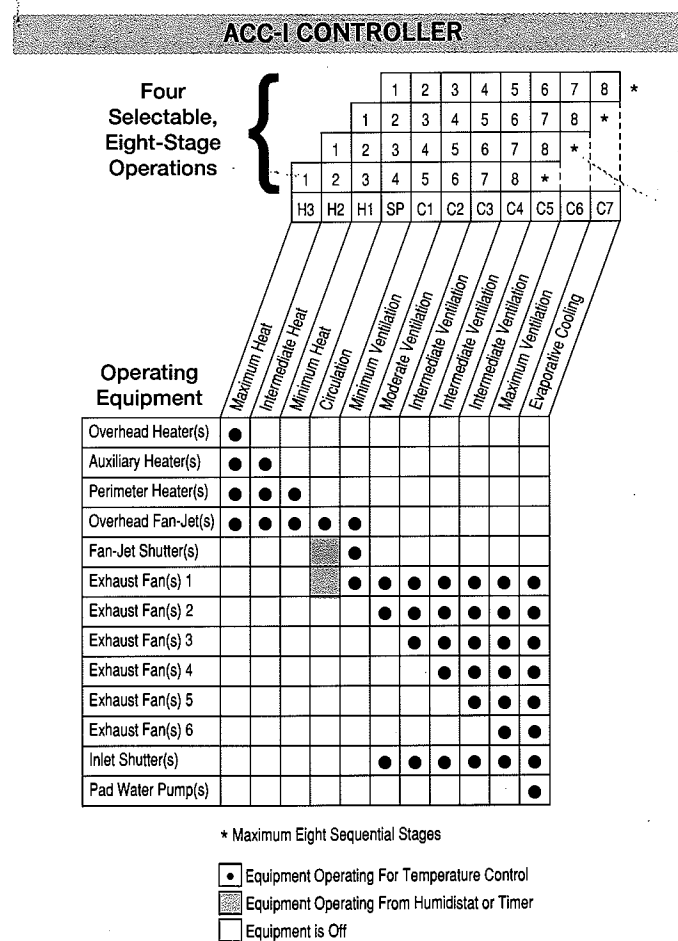
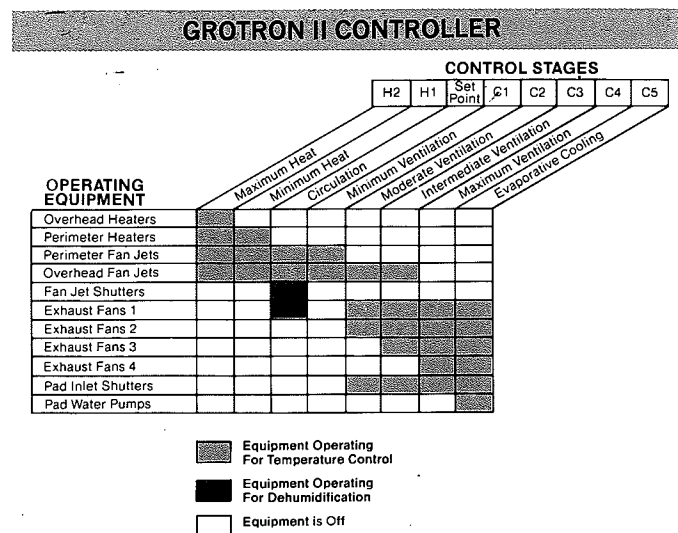
A safety disconnect switch should be located near each fan and pump.

It is recommended that motorized shutters or motorized hinged wall sash vents be installed at the pad system and automatically controlled to provide a more complete automatic operation of the greenhouse climate.

Small installations which require only one or two thermostats usually use line voltage controls. Larger ranges are usually divided into three or four banks and are each controlled as a unit. For such cases, low voltage controls like the ACC-I or Grotron II should be considered because of their reduced cost in labor and power wiring. Additional savings can be realized by utilizing the EMS system of prewired controls and relays. (See Brochure B127.)

Figure 14

ACC-I AND GROTRON II EQUIPMENT STAGING



FAN-JET VENTILATION SYSTEMS

REASONS FOR A FAN-JET MINIMUM VENTILATION SYSTEM

During cool nights of spring, summer and fall and on most sunshiny winter days, minimum ventilation is needed to control the house temperature. This type of ventilation, using cool or cold outside air, is quite different from summer ventilation and evaporative cooling. The flow must be turbulent with small to moderate quantities of air required, while in the summer the flow should be smooth and use large quantities of air.

SUFFICIENT AIR FLOW CAPACITY

The minimum ventilation system is an important part of the climate control system and requires several distinct characteristics. First, it must have ample air flow capacity to maintain a proper heat balance by removing the excess solar heat on mild sunlit days.

THOROUGH MIXING AND DISTRIBUTION

Secondly, the minimum ventilating system must be able to introduce the very cold winter air into the greenhouse without producing cold drafts on the plants. This requires a very thorough mixing of the cold outside air with the warm inside air before the plant level is reached. Since powered ventilating has the energy available to produce the turbulence necessary for thorough mixing, it supplies properly tempered fresh air.

CONTINUOUS AIR CIRCULATION

Thirdly, it is important that all parts of the greenhouse be at the same temperature. To achieve this, the ventilating system must distribute the air very uniformly throughout the house and maintain positive air movement and continuous circulation. A powered ventilating system has a real advantage over gravity systems that rely on thermal air currents, since it has the energy required to provide uniform air distribution and mixing. Continuous circulation also produces a gentle air movement that maintains a better leaf surface micro climate and prevents pockets of disease producing high humidity.

MINIMUM AND MAXIMUM SYSTEMS ARE DIFFERENT

Essentially minimum and maximum ventilation systems are two separate systems having different characteristics and requirements, yet they must tie in with each other to switch from one system to the other during the in-between seasons. The tie-in or transition point is very important as it determines the minimum inside to outside temperature difference available on a mild sunny day while it establishes the airflow design capacity of the minimum ventilation system.

The flow rate for the transition point is determined by the heat removal capabilities of the air and is largely affected by the increase in latent heat of the air going through the house. The increase depends on the outside wet bulb temperature and the transpiration rate of the greenhouse crops. Increased transpiration results in an increase in the cooling effect for a given flow rate. For average conditions an air flow of $1\frac{1}{2}$ to 2 cfm per square foot of floor space will hold the house temperature within 15°F of outside temperature. For hobby greenhouses 3 cfm/sq. ft. will be required. Obviously, a larger ventilation rate will reduce the inside to outside temperature differential and a smaller one will increase it. The selection charts that follow are designed for selection of Fan-Jet equipment to hold a 15°F inside to outside temperature differential at elevations below 1,000 ft. with a maximum interior light intensity of 5,000 foot candles. For other conditions refer to Tables 5, 6 and 7 and the explanation of the Fan-Jet adjustment factors.

DESCRIPTION OF THE FAN-JET CLIMATE CONTROL SYSTEM

A MULTI-PURPOSE SYSTEM

The use of exhaust fans for mechanical ventilation of greenhouses combined with perforated transparent plastic tubes made an ideal method of introducing cold air into a greenhouse in the winter without cold drafts. The development of these principles has produced the Acme Fan-Jet Climate Control System. This is a multi-purpose system that can alternatively heat, dehumidify, ventilate or recirculate the air in a greenhouse for proper climate control in the

fall, winter and spring seasons. This system is not designed to provide temperature control in warm seasons. Moreover, the exhaust fans of this system can also serve as the fans for the summer fan and pad cooling system.

DESCRIPTION OF EQUIPMENT

The Fan-Jet system consists of a specially constructed pressurizing fan attached to a custom designed perforated plastic tube located in the upper section of the house that extends along the length of the greenhouse with its far end closed.

The pressurizing fan runs continuously inflating the tube and blowing air through the holes in the form of jets into the greenhouse space. This uniformly distributes the air for the full length of the tube creating turbulence, thorough mixing and active air motion throughout the entire greenhouse. It maintains a more uniform temperature and humidity, and prevents cold spots.

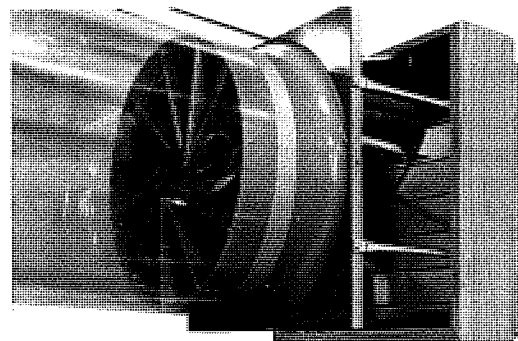
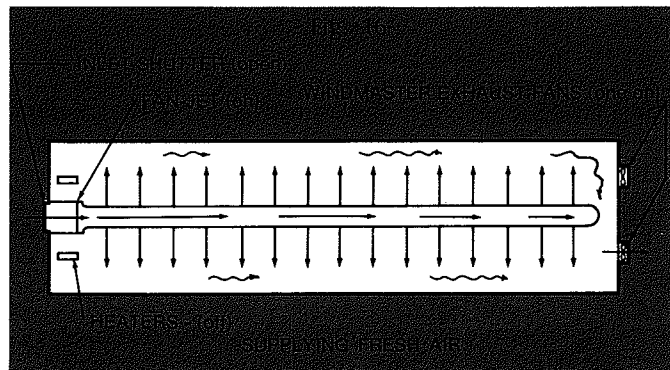


Fig. 15

The fan is mounted inside the greenhouse a specified distance from the gable end wall in front of a special sized motorized shutter that functions as the fresh air inlet. Several sizes of Fan-Jets with matching air inlet shutters and perforated tubes are offered for different requirements and often two or more units are needed for a greenhouse depending on its size.

OPERATION OF THE FAN-JET SYSTEM SUPPLYING FRESH AIR

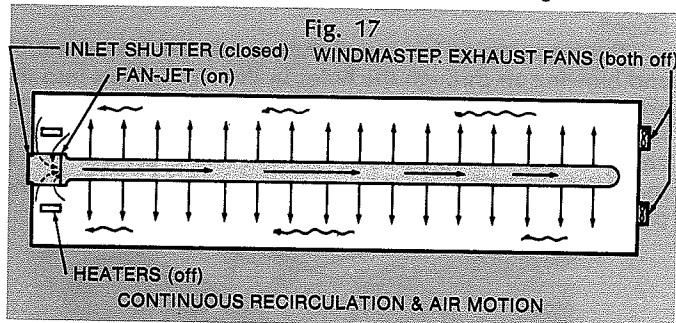
When the house temperature becomes too high and cooling is needed, the equipment controller or cooling thermostat simultaneously opens the motorized shutter and energizes an exhaust fan. The vacuum produced by the exhaust fan draws fresh, cold outside air in through the shutter which enters the inlet of the pressurizing fan. The air is propelled down the tube and discharges through the custom sized perforations in the form of jets. It is rapidly mixed with the warm greenhouse air and distributed uniformly within the greenhouse space to lower the temperature. When the desired temperature has been reached, the equipment controller or thermostat turns off the inlet shutter and the exhaust fan, thereby shutting off the supply of outside air. The Fan-Jet unit which is manually controlled continues to recirculate the air within the house. This cycle is repeated as necessary to maintain desired house temperatures.



CONTINUOUS RECIRCULATION

When temperature and humidity conditions in the greenhouse are at the desired control level, neither heating nor cooling is required and the continuous running Fan-Jet recirculates the air within the house providing a gentle air movement.

The result is a uniform climate without cold and humid pockets and the maintenance of a better leaf surface micro climate. It is also ideal for distribution of air borne materials such as insecticides or CO₂ gas for plant feeding.



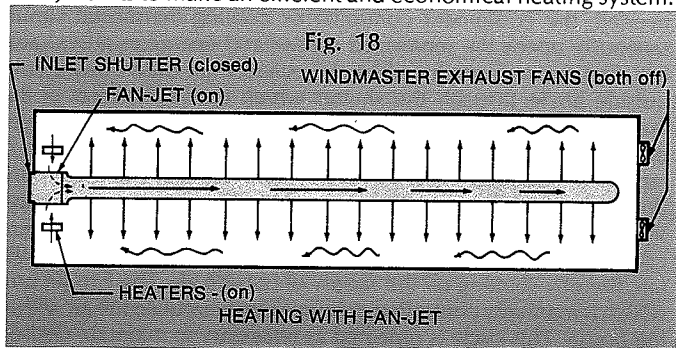
DEHUMIDIFICATION

When the relative humidity in the house exceeds the desired level it can be reduced by bringing in cooler outside air that has a lower water vapor content. The humid house air is expelled by the exhaust fan while the drier incoming air is heated and mixed with the house air.

This method of humidity control has been programmed into the ACC-I and Grotron II equipment controllers and can be automatically controlled by using a humidistat, thermostats, relays and other related switches in proper combination with each other.

SUPPLYING HEAT

Since the Fan-Jet ventilating system provides excellent distribution and circulation of air it can also serve as a highly efficient heat distribution system. When equipped with an accessory "heat kit" package it becomes part of a heating system without affecting its other functions of minimum ventilation and recirculation. The heat kit comprises a baffle arrangement that permits the use of conventional horizontal discharge type unit heaters in combination with Fan-Jet units to make an efficient and economical heating system.



QUICK RESPONSE

Since the Fan-Jet Climate Control System works directly with the air it reacts quickly to changes in requirements. By using high velocities and the rapid mixing turbulence of the jets, it achieves the maximum capability of the equipment in a matter of seconds and provides the quick response necessary for maintaining a uniform climate.

SELECTION OF EQUIPMENT

The equipment for Fan-Jet ventilation systems includes Fan-Jet units, motorized air inlet shutters, plastic tubes and exhaust fans. To provide the best ventilation for a wide range of design requirements, the Fan-Jet units are offered in four sizes with matching motorized air inlet shutters and custom punched tubes.

Certain other criteria must also be considered to

select the proper equipment from the tables and charts that follow. For good air distribution, the maximum width a Fan-Jet and tube should cover is 30 ft. of actual house width. Houses from 30 to 60 ft. wide should use two Fan-Jets and tubes. For very wide houses, three or more systems may be necessary.

FAN-JET DESIGN ADJUSTMENT FACTORS

The elevation of the greenhouse and the interior light intensity have a direct bearing on the amount of air needed to control the house temperature with Fan-Jet ventilation in the fall, winter and spring just as they do in summer cooling. These factors have been explained in detail under Design Factors in the section on THE GREENHOUSE COOLING SYSTEM, and are also used in designing Fan-Jet ventilation systems. For convenience $F_{Elev.}$ and F_{Light} are shown in Tables 5 and 6.

One other element of winter climate control that needs further consideration in controlling the house temperature is how small a difference in the inside to outside temperature is desired on a mild sunny day.

Standard Fan-Jet selection charts are based on maintaining about a 15°F maximum differential between inside and outside temperature during a mild sunny day. For example, with a 15° differential system, a 65° house temperature could be maintained provided the outside temperature does not exceed 50°. But, to hold 65° inside with a 55° outside temperature would allow only a 10° differential. Obviously more air would be required to achieve this, and this can be accomplished by applying the design factor F_{Winter} shown in Table 7.

The final Fan-Jet adjustment factor F_{Jet} is obtained by

$$F_{Jet} = F_{Elev.} \times F_{Light} \times F_{Winter}$$

SELECTION OF FAN-JET UNITS

To select the correct Fan-Jet units consider the elevation, interior light intensity and the temperature differential adjustment factors to obtain the Fan-Jet factor F_{Jet} .

$$F_{Jet} = F_{Elev.} \times F_{Light} \times F_{Winter}$$

Multiply F_{Jet} times the actual house width W under consideration to obtain the equivalent house width.

$$W_{Equiv.} = F_{Jet} \times W$$

Refer to the Fan-Jet ventilation selection Chart 2 to select the proper Fan-Jet unit for each house based on the equivalent house width $W_{Equiv.}$ and the actual length. Select the model number designated. **If the Fan-Jet ventilation system is also to be used for a Winter Overhead Heating System, then be sure to check the heat distribution requirements before selecting the equipment. Oftentimes, larger Fan-Jet sizes are required for heating than for ventilating and in such cases the larger sizes should be used.**

TABLE 5

Elevation, feet above sea level

feet	Under 1000	1000	2000	3000	4000	5000	6000	7000	8000
$F_{Elev.}$	1.00	1.04	1.08	1.12	1.16	1.20	1.25	1.30	1.36

TABLE 6

Maximum Interior Light Intensity, foot candles

FC	4000	4500	5000	5500	6000	6500	7000	7500	8000
F_{Light}	.80	.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60

TABLE 7

House Temperature above Outdoor Temperature °F

°F	18	17	16	15	14	13	12	11	10	9
F_{Winter}	.83	.88	.94	1.00	1.07	1.15	1.25	1.37	1.50	1.67

TABLE 8

FAN-JET PERFORMANCE DATA										
Fan-Jet Model	HP	RPM	Tube Size	System CFM	▼Motorized Shutter Model	Heat Accessory	‡Heating Capacity With Heat Kit BTU/hr. Output			
							Heater Temperature Rise of			
							40°	50°	60°	70°
†RC12D4	1/6	1725	12"	1180/780	WAAC1818	Not Available	NOT APPLICABLE			
RC18E6	1/4	1160	18"	3120	WAAC2626	HT18	112,000	138,000	163,000	186,000
RCA/RC24F	1/3	735	24"	5420	WAAC3333	HT24	172,000	212,000	250,000	287,000
RCA/RC30G	1/2	607	30"	8550	WAAC4040	HT30	278,000	342,000	403,000	463,000
RCP12B4	1/10	1625	12"	1100	WAAC1818	Not Available	NOT APPLICABLE			
RCP18B4	1/10	1625	18"	2140	WAAC2626	PHT18	77,000	95,000	112,000	128,000
RCP18F4	1/3	1625	18"	3050	WAAC2626	PHT18	109,000	135,000	159,000	182,000
RCP24G6	1/2	1075	24"	5115	WAAC3333	PHT24	162,000	200,000	236,000	271,000

†RC12D4 has a 2-speed motor therefore two different system CFM's.

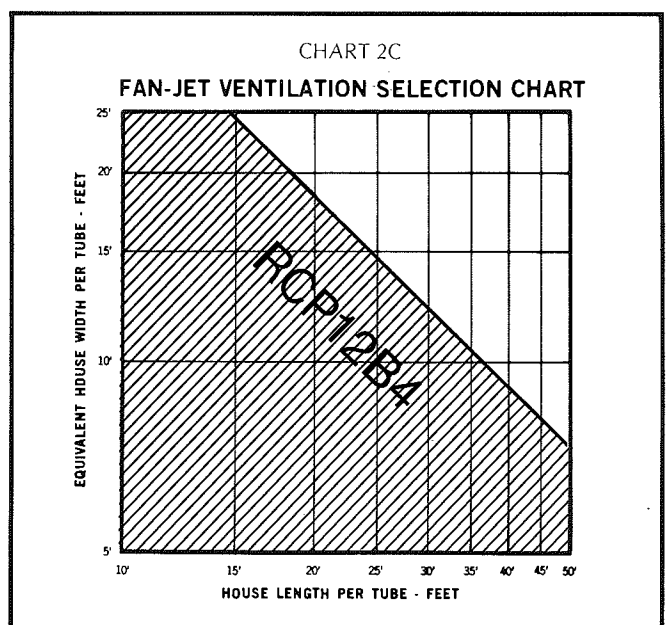
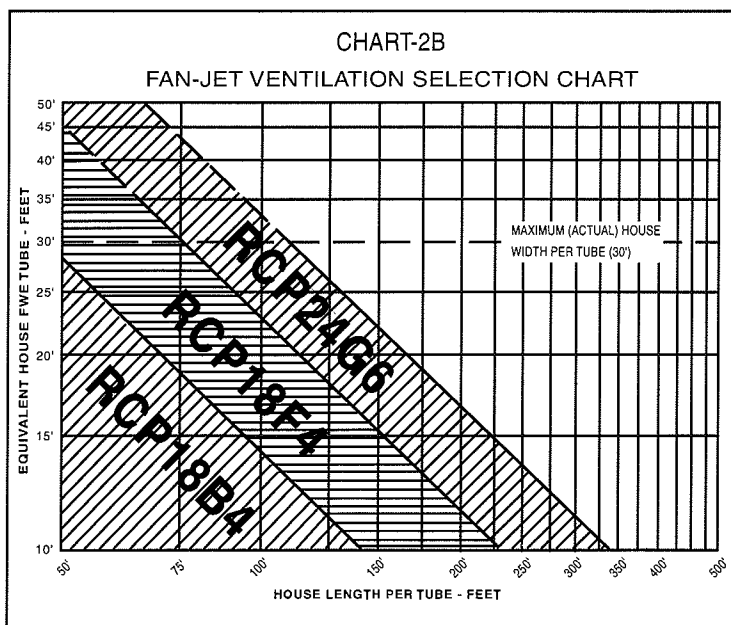
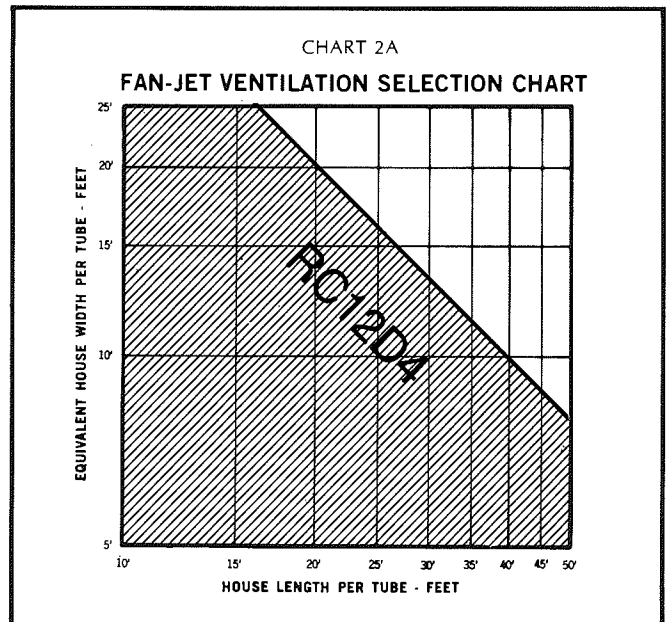
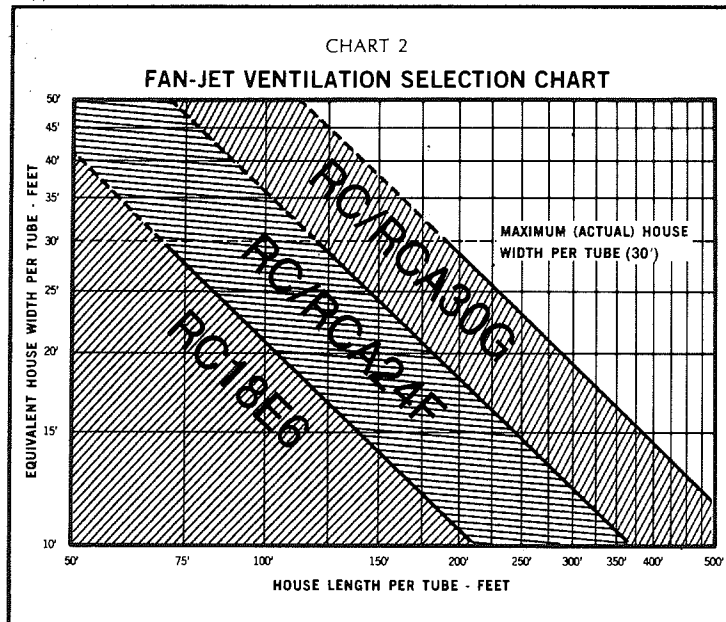
‡The Output rating for gas fired heaters is 80% of their input BTU ratings.

▼Order CAM motorizing kits separately.

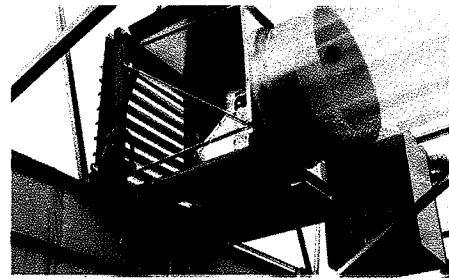
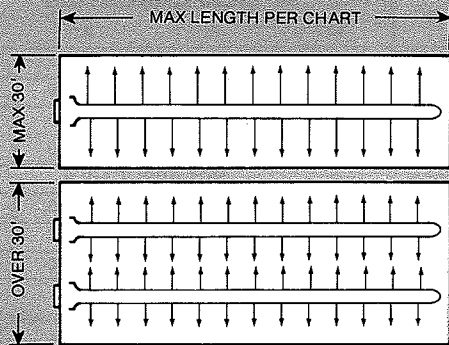
* The unit heater louvers should be at the same elevation as the Fan-Jet inlet opening and spaced a proper distance from it, with the axis of the unit heater discharge opening directed toward the Fan-Jet inlet opening. If the heater must be positioned below the level of the Fan-Jet inlet opening to maintain the proper spacing, the louvers should be adjusted to direct the heated air upward toward the top of the Fan-Jet inlet opening.
If the Fan-Jet end of the greenhouse is colder than the remainder of the house, this condition usually can be corrected by adjusting one or two of the lower louvers of the heater to a downward position to divert part of the heated air to the end wall area.

CAUTION

Caution: to avoid combustion malfunctions when two heaters are used with one Fan-Jet; the minimum heater distance from Fan-Jet opening must be maintained, both heaters must operate simultaneously, unless center baffle is used, and the discharge louvers must be directed toward the top of the Fan-Jet Opening.



TYPICAL TUBE ARRANGEMENT PLAN



View of Fan-Jets,
motorized inlet
shutters and
tubing with
Heat Kit.

TABLE 9
FAN-JET TUBE SELECTION TABLE

12" FAN-JET		18" FAN-JET or 18" INLET		24" FAN-JET or 24" INLET		30" FAN-JET or 30" INLET	
TUBE MODEL	TUBE LENGTH	TUBE MODEL	TUBE LENGTH	TUBE MODEL	TUBE LENGTH	TUBE MODEL	TUBE LENGTH
HFT	10' - 20'	HFY	18' - 20'	HKX	24' - 27'	HKT	39' - 42'
HLT	20' - 25'	HDY	20' - 22'	HJX	27' - 30'	HJT	42' - 47'
HRT	25' - 30'	HCY	22' - 25'	HHX	30' - 33'	HHT	47' - 52'
HLW	30' - 35'	HBV	25' - 27'	HFX	33' - 37'	HFT	52' - 58'
HMW	35' - 40'	HKN	27' - 30'	HDX	37' - 41'	HDT	58' - 66'
HLV	40' - 50'	HJN	30' - 33'	HGX	41' - 45'	HCT	66' - 77'
HRY	50' - 60'	HHN	33' - 36'	HGX	45' - 48'	HKS	77' - 84'
HMZ	60' - 75'	HFN	36' - 40'	HKP	48' - 53'	HJS	84' - 94'
HRZ	75' - 100'	HDN	40' - 45'	HJP	53' - 59'	HHS	94' - 104'
		HCN	45' - 50'	HHP	59' - 66'	HFS	104' - 116'
		HBN	50' - 55'	HFP	66' - 73'	HDS	116' - 129'
		HKA	55' - 61'	HDP	73' - 81'	HCS	129' - 145'
		HJA	61' - 68'	HCP	81' - 90'	HBS	145' - 163'
		HHA	68' - 76'	HBP	90' - 101'	HKU	163' - 183'
		HFA	76' - 85'	HKI	101' - 112'	HJU	183' - 206'
		HDA	85' - 96'	HJI	112' - 126'	**HHU	206' - 232'
		HCA	96' - 108'	HHI	126' - 142'	HFU	232' - 263'
		*HBA	108' - 121'	HFI	142' - 160'	*H DU	263' - 305'
		**HKE	121' - 138'	**HDI	161' - 182'	HCU	305' - 348'
		HJE	138' - 154'	*HCI	182' - 206'	HBU	348' - 405'
		HHE	154' - 177'	HBI	206' - 233'		
		HFE	177' - 205'	HKO	233' - 269'		
				HJO	269' - 311'		
				HHO	311' - 360'		

* Maximum tube length for Fresh Air Convection Tube System.

** Maximum tube length for Fan-Jet with Heat Kit.

+ When 12" tubing is used for Perimeter Heating the Tube Model is prefixed by the letter P.

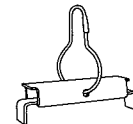
POLYETHYLENE TUBING

All tubes are engineered for uniform distribution and proper mixing of air to produce the best aerodynamic effect in greenhouse structures.

- Furnished in clear 4 mil thick UV stabilized polyethylene material.
- Each tube is custom punched to match the selected Fan-Jet Unit with each specific house. Since tubes are custom punched, orders already processed or shipped cannot be cancelled or returned for credit.

THE HANGER SET

Unique hanger clamps onto tubing for easy attachment to overhead support wire with snap ring.



RECOMMENDED SPACING

12" Tubing every 10 ft.
18" Tubing every 10 ft.
24" Tubing every 8 ft.
30" Tubing every 6 ft.

Wire support kits, available in 50', 100', 150', 200', and 300' lengths, include six strand 10 gauge wire, turnbuckle and 2 securing clips.

***CAUTION!** This tubing, for use in greenhouses, does not contain fire retardants. Due care should be taken during installation and operation to keep away from open flame.

For houses longer than those shown on the chart, consider using Fan-Jets on each end. Divide the house at the midpoint and make a selection for each half of house. For long houses having only one exposed gable end, divide the house lengthwise into narrower sections and select the equipment for each section.

When ordering Fan-Jet units, also order the matching motorized air inlet shutter for each. Order by Model Number and specify phase and voltage for all equipment.

SELECTION OF TUBES

All tubes are custom punched using different sizes and spacings of holes to provide the best distribution and greatest airflow capacity for each application. Refer to tube selection Table 9 to select the correct tube for each Fan-Jet unit. Note that each tube model number covers a specific minimum and maximum tube length.

When ordering, specify the tube Model Number for each Fan-Jet unit and state the length of tubing required. (Since all tubes are custom made, orders already processed or shipped cannot be cancelled nor returned for credit.)

SELECTION OF EXHAUST FANS

As previously explained, exhaust fans are required to supply the fresh air needed. It is important that the total capacity of the exhaust fans match the total CFM capacity of the Fan-Jets used to achieve the full benefit of the system. **But in no event, during cold weather should the exhaust fan capacity exceed that of the Fan-Jets. This would draw in more air through the inlet shutter than the Fan-Jet system could handle and might cause cold air to spill out and create a cold spot in that area.**

Greenhouses already equipped with fan and pad cooling systems would have sufficient exhaust fans for a Fan-Jet system. But, it may be necessary to install a smaller capacity fan or equip one of the existing fans with a two speed motor to reduce its capacity to match the Fan-Jet system. The low speed capacity of a two speed fan is about 1/2 of its high speed capacity.

Refer to the Windmaster Certified Performance Table in Catalog C29 and select the appropriate models based on their performance capacity at 0.1" SP. (Use .05" SP for slant housing).

EXAMPLE — DESIGN PROCEDURE

Design Calculations

Consider the three gutter connected houses each 28 ft. wide by 200 ft. long located at 3,000 ft. elevation and having a winter interior light intensity of 5,000 foot candles. Assume a 15° allowable inside to outside temperature difference. Refer to Tables 5, 6 and 7 for adjustment factors to select proper Fan-Jet Units.

$$\begin{aligned}F_{\text{Jet}} &= F_{\text{Elev}} \times F_{\text{Light}} \times F_{\text{Winter}} \\&= 1.12 \times 1.00 \times 1.00 \\&= 1.12\end{aligned}$$

$$\begin{aligned}W_{\text{Equiv}} &= F_{\text{Jet}} \times W \\&= 1.12 \times 28 \text{ ft.} \\&= 31.4 \text{ ft.}\end{aligned}$$

Fan Jet Selection

Refer to selection Chart 2 for a 31.4 equivalent width and 200' length which shows that a single Fan-Jet unit is inadequate. Divide the house at its mid-point and for minimum ventilation select a Model RC24F for each half. Each house therefore requires two RC24F Fan-Jets, one centered at each end. If the Fan-Jet ventilation system is also to be used for an overhead heating system, then be sure to check the heat distribution requirements before selecting the equipment. Often times for heating, a larger size Fan-Jet is required.

Tube Selection

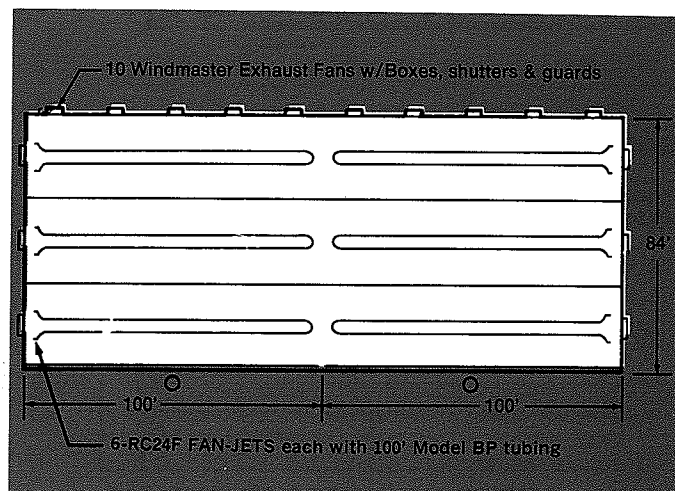
Refer to Fan-Jet Tube Selection Table 9 to select 100 ft. of Model BP tubing for each unit.

Exhaust Fan Selection

The three gutter connected houses require 6 — RC24F Fan-Jets having a total capacity of 32,520 cfm. For fall, winter and spring ventilation only, 3 Model DC36G Windmaster fans would provide 31,500 cfm, a satisfactory selection.

In an earlier example this block of houses was equipped with fan and pad cooling and required much more air. However, in that group of fans a combination of models was selected to provide the proper volume of air for the Fan-Jets.

1 — Model DC48H	=	17,800 CFM
1 — Model DC48G	=	14,600
Total for Fan-Jets	=	32,400 CFM



OVERHEAD HEATING SYSTEM

NEED FOR WELL DISTRIBUTED HEAT

A greenhouse is a difficult structure to heat and it contains plants that are extremely sensitive to temperature variation. The greenhouse heating process is in itself unstable since the warmed air being lighter rises to the roof, while the cold air produced near the glass or plastic covering is heavier and tends to settle to the floor. Should this settling occur at any point, which it tends to do with still air in the house, a cold spot with extreme humidities may develop.

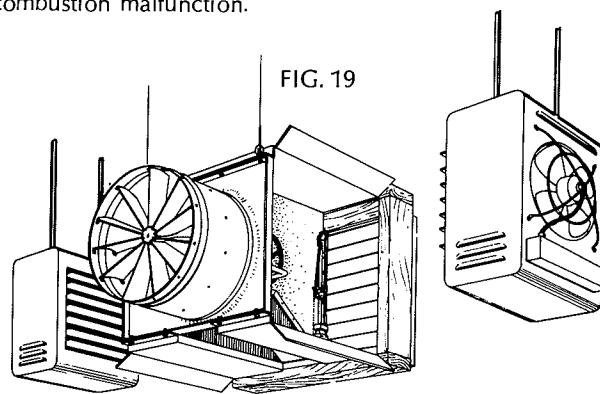
Overhead air motion and mixing will help prevent this settling action from the roof, but will only partially reduce the normal cold film of air flowing down the walls. This film of cold air is best handled by the release of heat from a perimeter heating system to intercept the cold air pouring down the walls before it gets to the floor. Also, in those areas where snow melting is required in gutter connected houses, provision should be made to supply gutter heat.

Since the temperature of the plants in a greenhouse is primarily determined by the inside air temperature, the main function of the heating system is to maintain a uniform air temperature in the house. The Fan-Jet systems both overhead and perimeter working directly with all the air in the greenhouse make an ideal method of heating the air and achieving this uniformity.

DESCRIPTION OF A FAN-JET HEATING SYSTEM

USE OF A HEAT KIT

The Fan-Jet unit with a heating accessory "heat kit" is designed to receive the heated air from conventional type unit heaters, and in turn distribute this heated air uniformly throughout the house. The heating accessory consists of a baffle arrangement that closes the top and bottom space between the pressurizing fan and the inlet shutter. The sides remain open to admit the heated air blown from conventional horizontal discharge type unit heaters spaced a fixed distance away from the side inlets. A center baffle accessory for the heat kit is included for use when opposing heaters are not operating simultaneously. The baffle prevents blow-through of heated air and possible heater motor, or heater combustion malfunction.



When the equipment control calls for heat and turns on the unit heaters, they blow heated air into the open sides of the Fan-Jet which is propelled down the tube and distributed uniformly within the house. After the desired temperature is reached the unit heaters are automatically turned off while the Fan-Jet continues running and recirculating the air within the house.

UNRESTRICTED AIR FLOW

Since the heaters are not built into the main air flow path of the Fan-Jet system, they never restrict the flow of air whether the system is supplying fresh air, heating, or recirculating air within the greenhouse. This results in much higher efficiency than other systems thus providing much more air flow for all its uses and at lower horsepower and operating costs. Moreover, steam or hot water type unit heaters may be used without any risk of freeze up.

DESIGN OF OVERHEAD HEATING SYSTEM

To design an overhead air heating system, it is necessary that the heat loss of each house in the range be known. The exact calculations for this determination are given by the *Standards for Greenhouse Heat Loss Calculation* prepared by the National Greenhouse Manufacturers Association. The following tables and charts derived from that standard simplify the method of determining greenhouse heat losses and are based on a 6/12 roof pitch.

DETERMINE GABLE HOUSE HEATING LOAD

Table 10 gives the overhead and gable heat losses in 1000's of

BTUH (BTU per Hour) per house for various lengths and widths and having conventional roof pitches. This data is also satisfactory for arched roof houses. Table 10 also list separately the losses for both gable ends. Table 11 gives the heat losses for the walls. These tables and charts are based on a 70°F temperature differential and a 15 mph wind. For other temperature differentials and wind velocities refer to Table 12 for correction factor K. Table 13 shows the Construction Factor C that is determined by the type of house construction. Although the wall heat loss factor for curtain walls around the greenhouse is less than that of the glazing system, the effect on the total heat loss is insignificant and, therefore, not included in the calculation.

Roof Length feet	TABLE 10 OVERHEAD HEAT LOSS (SLOPED ROOF)														
	HOUSE WIDTH — feet														
	16'	18'	20'	22'	24'	26'	28'	30'	32'	34'	36'	38'	40'	50'	60'
	Gable Loss (both) MBTUH														
	5	6	8	10	11	13	15	18	20	23	26	29	32	50	72
Roof Loss MBTUH															
5	7	8	9	10	11	12	12	13	14	15	16	17	18	22	26
10	14	16	18	19	21	23	25	27	28	30	32	34	35	45	54
20	28	32	35	39	42	46	50	53	57	60	64	67	71	88	106
30	42	48	53	58	64	69	74	80	85	90	96	101	106	133	160
40	57	64	71	78	85	92	99	106	113	120	127	135	142	177	212
50	71	80	89	97	106	115	124	133	142	151	159	168	177	222	266
60	85	96	106	117	127	138	149	159	170	181	191	202	212	265	318
70	99	112	124	136	149	161	173	186	198	211	223	235	248	310	372
80	113	127	142	156	170	184	198	212	227	241	255	269	283	354	424
90	127	143	159	175	191	207	223	239	255	271	287	303	319	398	478
100	142	159	177	195	212	230	248	266	283	301	319	336	354	443	532
200	283	319	354	390	425	460	496	531	567	602	637	673	708	885	1062
300	425	478	531	584	637	690	743	797	850	903	956	1009	1062	1328	1594
400	566	637	708	779	850	920	991	1062	1133	1204	1274	1345	1416	1770	2124
500	708	797	885	974	1062	1150	1239	1328	1417	1505	1593	1682	1770	2213	2666

Wall Length feet	TABLE 11 (WALL HEAT LOSS)				
	Wall Height - feet				
	2'	4'	6'	8'	10'
Wall Loss MBTUH					
5	1	2	2	3	4
10	2	3	5	6	8
20	3	6	9	13	16
30	5	9	14	19	24
40	6	13	19	26	32
50	8	16	24	32	40
60	9	19	28	38	47
70	11	22	33	44	55
80	13	25	38	51	63
90	14	28	43	58	71
100	16	32	47	64	79
200	32	63	95	128	158
300	47	95	142	192	237
400	63	127	190	256	316
500	79	158	237	320	395

Inside Outside ΔT°	TABLE 12 CLIMATE FACTOR K				
	Wind Velocity - mph				
	15	20	25	30	35
30	.41	.43	.46	.48	.50
35	.48	.50	.53	.55	.57
40	.55	.57	.60	.62	.64
45	.62	.65	.67	.70	.72
50	.69	.72	.74	.77	.80
55	.77	.80	.83	.86	.89
60	.84	.88	.91	.94	.98
65	.92	.96	.99	1.03	1.07
70	1.00	1.04	1.08	1.12	1.16
75	1.08	1.12	1.17	1.21	1.25
80	1.16	1.21	1.26	1.30	1.35
85	1.25	1.30	1.35	1.40	1.45
90	1.33	1.38	1.44	1.49	1.54

**TABLE 13
CONSTRUCTION FACTOR C**

All metal (good tight glass house — 20 or 24 in. glass spacing)	1.08
Wood & steel (good tight glass house — 16 or 20 in. glass spacing) Metal gutters, vents, headers, etc.)	1.05
Wood houses (glass houses with wood bars, gutters, vents, etc. — up to and including 20 in. glass spacing)	
Good tight houses	1.00
Fairly tight houses	1.13
Loose houses	1.25
Corrugated Fiberglass covered wood houses	1.06
Corrugated Fiberglass covered metal houses	1.09
Double glazing with 1" air space	.70
Plastic covered metal houses (single thickness)	1.08
Plastic covered metal houses (double thickness)	.70
Plastic structured sheet metal frame (16mm thick)	.54
Plastic structured sheet metal frame (8mm thick)	.60
Plastic structured sheet metal frame (6mm thick)	.67

TOTAL HEAT LOSS = [OVERHEAD LOSS (TABLE 10 OR 15) + SIDE LOSS (TABLE 11)] x K FACTOR (TABLE 12) x C FACTOR (TABLE 13)

DETERMINE QUONSET HEATING LOAD

Since quonset houses have no clear delineation between the roof and sidewall, the total heat loss must be obtained in one calculation. Table 15 is provided for this purpose. The wall loss

can be taken as 35% of this total to be supplied by a perimeter heating system and the roof loss becomes 65% of the total to be supplied by the overhead heating system.

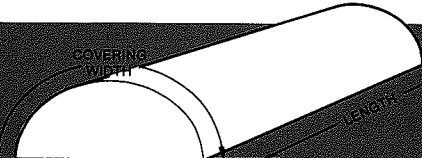
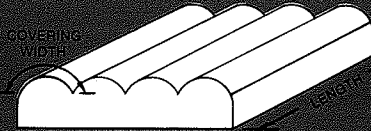


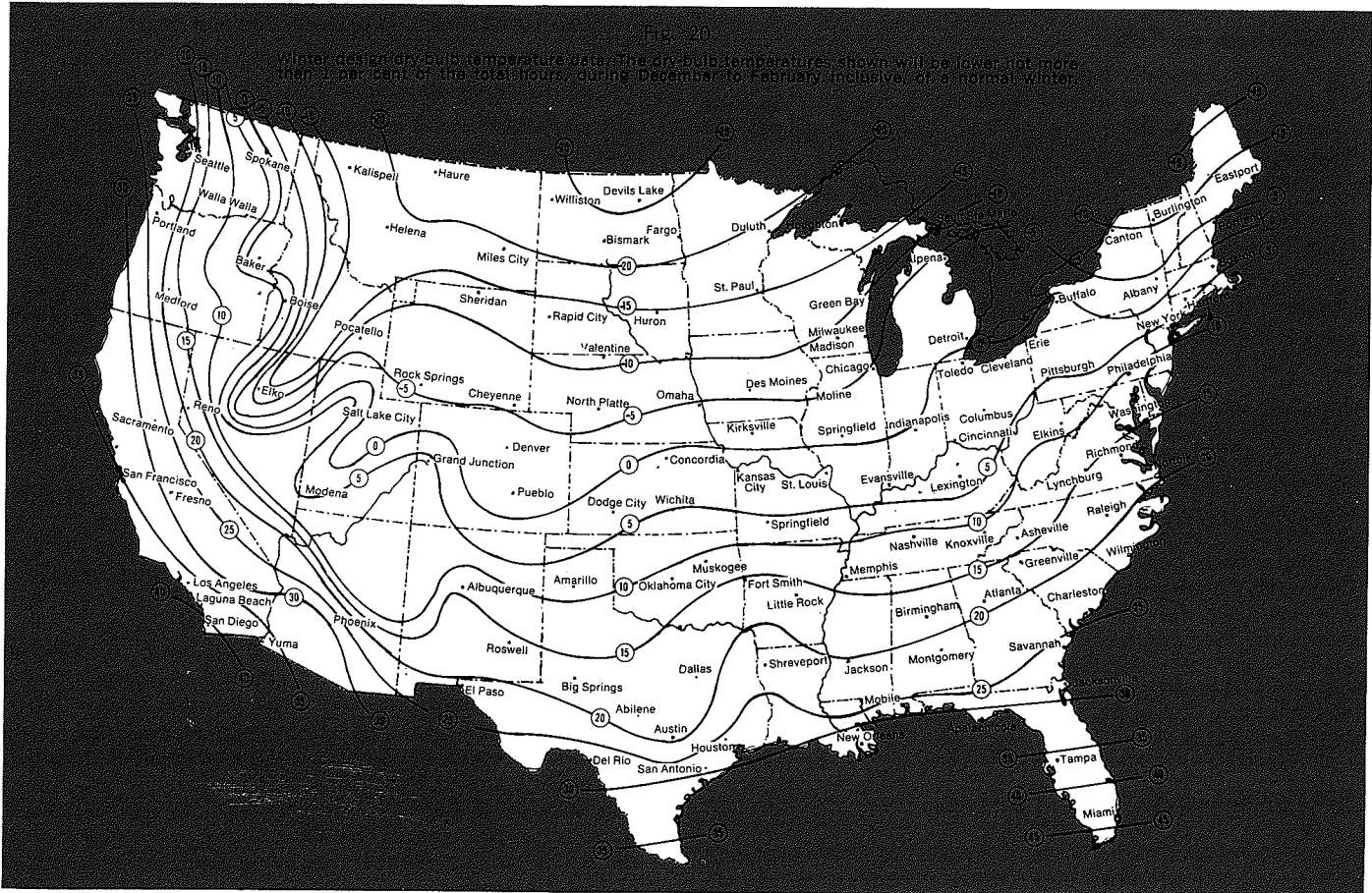
TABLE 15

QUONSET TYPE GREENHOUSE OR ARCHED ROOF HEAT LOSS													
Roof Length feet	COVERING WIDTH — feet												
	18'	20'	22'	24'	26'	28'	30'	32'	34'	36'	38'	40'	48'
	End Loss (both) MBTUH												
	8	10	12	15	17	20	23	26	29	33	36	40	60
Covering Loss MBTUH													
5	7	8	9	9	10	11	12	13	13	14	15	16	18
10	14	16	17	19	21	22	24	25	27	28	30	32	38
20	28	32	35	38	41	44	47	51	54	57	60	63	76
30	43	47	52	57	62	66	71	76	81	85	90	95	114
40	57	63	70	76	82	89	95	101	108	114	120	127	152
50	71	79	87	95	103	111	119	127	134	142	150	158	190
60	85	95	104	114	123	133	142	152	161	171	180	190	228
70	100	111	122	133	144	155	166	177	188	199	211	222	266
80	114	127	139	152	164	177	190	202	215	228	240	253	304
90	128	142	157	171	185	199	214	228	242	256	271	285	342
100	142	158	174	190	206	221	237	253	269	285	301	316	380
200	285	316	348	380	411	443	475	506	538	570	601	633	760
300	427	475	522	569	617	664	712	759	807	854	902	949	1138
400	570	633	696	759	822	886	949	1012	1075	1139	1202	1265	1518
500	712	791	870	949	1028	1107	1187	1265	1345	1424	1503	1582	1898

WINTER DESIGN TEMPERATURE MAP

Recommended outdoor winter design temperatures for localities throughout the United States are shown in Fig. 20. These are used to select the proper inside to outside temperature

difference (ΔT°) in Table 12 to determine the correct climate factor K. For example, for an outdoor winter design temperature of -10°F and a required greenhouse temperature of 60°F , the outside to inside temperature difference ΔT° would be 70° .



EXAMPLE — DESIGN PROCEDURE

Design Calculations

Assume an all metal framed glass covered greenhouse 36 ft. wide by 210 ft. long with 6/12 roof pitch and 6 ft. glass side walls on a 2 ft. high transite wall. The winter wind velocity is 20 miles per hour and the indoor-outdoor design temperature difference is 70°F. Find the design heat loss and select equipment for an overhead heating system.

From Table 10 the gable loss = 26 26,000 BTUH

From Table 10 the roof loss is

for 200' length = 637 637,000 BTUH

for 10' length = 32 32,000 BTUH

Total Overhead heat loss 695,000 BTUH

Applying correction factors found in Tables 12 and 13 for temperature differential, wind velocity and type construction:

$K = 1.04$, $C = 1.08$, therefore $KC = 1.04 \times 1.08 = 1.12$
Corrected overhead heat loss = $1.12 \times 695,000 = 778,400$ BTUH

It requires 778,400 BTU per hour to provide the necessary overhead heat for the prescribed design conditions.

Selection of Fan-Jet Units

Refer to heat distribution capacity Table 8 to determine the size and number of Fan-Jets needed. Two Model RC30G Fan-Jets are needed, each having a heat distribution capacity of 403,000 BTU per hour with unit heaters rated to deliver this heat at a 60°F rise.

Selection of Tubes

Each Fan-Jet would use 206 ft. of Model JU tubing. For this application each Fan-Jet would need unit heaters having an output capacity of about 390,000 BTUH.

In case overhead structurals would not permit using 30" tubes then consider four Model RC24F units, two at each end with the tubes extending to the center of the house. Each Fan-Jet would need about 200,000 BTUH supplied by unit heaters and each would need 102 ft. of Model KI tubing.

NEED FOR PERIMETER HEATING SYSTEM IN COLD CLIMATES

In a typical greenhouse heating system, the lighter, warmer air rises to the top portion of the greenhouse, while the heavier, colder air produced along the roof and sidewalls flows down the roofline and sidewalls to settle on the floor. Unless this natural tendency is overcome the house will be too hot overhead, yet have cold floors. This results in poor plant growing conditions and a needless waste of heat and fuel. The Fan-Jet Overhead System does a good job of distributing overhead heat in a greenhouse but supplies a rather limited amount of heat to the perimeter walls of the house. Therefore, a greenhouse heating system, particularly in colder climates, should include a perimeter heating system in addition to the overhead heating system.

DETERMINE PERIMETER HEATING LOAD

The perimeter heating system should be designed to provide the total heat loss of the entire wall area. Within reasonable limits, the overhead and perimeter heating system are

complimentary and one can be increased in capacity and the other reduced as long as the total input to the house is the correct amount for all losses.

INSECT SCREENS

Before sizing screens it is imperative that the characteristics of the exhaust fans be known as different sizes and horsepower combinations have different maximum performance limitations. Refer to Catalog C29 for fan limitations. It is suggested that a safety operating range of .05" static pressure be provided to account for catching insects and debris. As an example, if the maximum performance of the fan was .30" static pressure, the design calculations would not exceed .25" static pressure.

In order to maintain the proper cooling (heat removal), it is necessary that the calculated CFM requirements be maintained. If fans were preselected prior to the additions of screens, the performance or CFM of air could drop below the calculated requirements. This will result in an increase in house temperature, increased electrical consumption and reduced motor life.

EXAMPLE

A greenhouse calculated requirements of 29,000 Total CFM has fans selected or installed that deliver 30,000 CFM at .10" SP.

Now, with the addition of screens, the pressure increases to .20" SP and the fan performance drops to 25,500 CFM. This is approximately a 15% reduction of CFM, which will result in an increase of the temperature rise from pad or inlet to exhaust fans of 15% and approximately 40% increase in operating cost.

EXAMPLE

A greenhouse that we want to screen both inlet and outlet (fan discharge) are utilizing two fans that have a maximum static pressure of .25".

House ventilation requirements: 24,000 CFM.

Maximum fan static pressure	.25" SP
Safety operating range	— .05" SP
Available operating range	.20" SP
Standard operating pressure before applying screens	— .10" SP
Available for screen use	.10" SP

Divide available screen use static pressure by number of areas to be screened. In this example we have two, the inlet and the outlet areas. It should be noted that the available static pressure may be divided into any proportion desired (i.e., .03" SP for inlet and .07" SP for outlet area) as long as total available static pressure is not exceeded. For purposes of this example, we will treat inlet and outlet areas equal. Taking .10" SP divided by two areas equals .05" SP static pressure available per screen (inlet and outlet).

Looking at chart 3 for screen material "A" shows that for .05" static pressure, the velocity is 200 ft. per minute.

24,000 CFM divided by 200 ft. per minute = 120 sq. ft. of screening required for screen "A" for each inlet and outlet area (fans). Using two fans will require 60 sq. ft. each of screen area (120 sq. ft. divided by 2 fans = 60 sq. ft. each).

Now look at chart 3 for screen "B" material. It shows for .05" static pressure, the velocity is 400 ft. per minute.

24,000 CFM divided by 400 ft. per minute = 60 sq. ft. of screening required for screen "B" for each inlet and outlet area (fans). Using two fans will require 30 sq. ft. for each of screen area (60 sq. ft. divided by 2 fans = 30 sq. ft.).

By looking at the two materials you can see that it will require twice as much of the screen area of material "A" as material "B" to provide the same air entry into the structure at .05" static pressure.

OTHER CONSIDERATIONS

If there are other air entry levels such as roof vents which lead into a corridor area and allows air to go into individual greenhouse cubicles or units, it will be necessary to calculate the additional static pressure of the vent opening area and the vent screening area.

$$\text{Vent opening vel} = 4005 \sqrt{pv}$$

It is also recommended that the screen be kept dry as possible. This would require putting it on the inlet side of an evaporative cooling system so that the water is not pulled off of the pads into the screen.

It is also recommended that the screens be placed on the inside of the fan where they will not produce as much restriction as when placed on the discharge side of the fan where the air is coming off of the blades in a turbulent motion.

If using different materials for inlet and outlet areas, it would be necessary to look at the performance characteristics of each material when determining the velocity or screening area required. Some growers have determined they want a finer mesh screen on the air entry into the structure with a coarser mesh material on the discharge or fan area.

DAILY OPERATION

It is highly recommended to use a manometer to measure pressure in the house. This will allow the grower to know when to clean the screens following the screen manufacturer's recommended methods. If the screens are allowed to accumulate with insects or debris the result will be a static pressure buildup which will then result in reduced air flow through the structure and a resultant higher temperature in the greenhouse structure.

SERVICE AND MAINTENANCE

FANS

Guards should be installed before operating fans which are within reach of personnel.

The fan shaft bearings are prelubricated and sealed and no service is ever required.

The motor bearings are prelubricated and should not require relubrication until after 5 years of continuous duty or 10 years of intermittent duty. Consult information printed on motor for lubrication instructions. Both the fan shaft and motor bearings should be protected from the weather or from direct exposure to water, paint and chemicals.

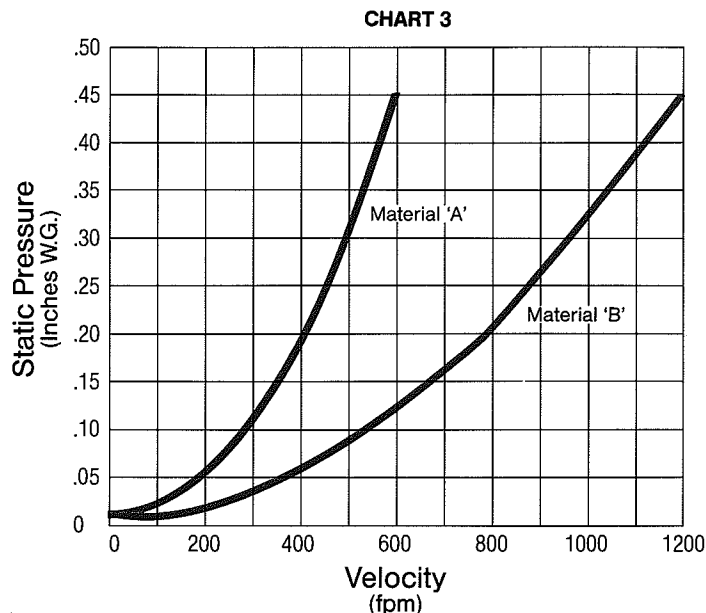
Belt tension should be checked after first month of operation and every two months thereafter. A firm thumb pressure on the belt midway between the pulleys should depress the belt about $\frac{3}{8}$ inches. Use of belt dressing is not recommended on V belts.

When replacing worn belts, closely inspect the motor pulley for a "shoulder" worn in the V groove. Replace the pulley if a shoulder exists. Do not replace with a larger diameter pulley as this will overload the motor. Special high quality belts are used on Windmaster fans. For your protection order replacements from your Acme distributor stating fan model and serial number.

Automatic belt tighteners are available for Windmaster fans to provide optimum performance and longer belt life.

PAD SYSTEM

The holes in the overhead pipe distributor for the pad system



If one point is known on the curve then others can be calculated. The formula is:

$$v = c \sqrt{pv}$$

v = face velocity

c = resistance constant

pv = velocity pressure

Calculate the constant, c , using the tested data then develop other points using tested constant and selected velocities.

must be kept open and periodic clean out should be done when necessary as described in the Water System section under Piping & Pumping, page 12.

The sump will require periodic draining or flushing-out to remove the accumulation of sediment. The filter in the pump-to-water distributor pipe system should be flushed out weekly or as needed. The pump and piping system should be drained before cold weather to avoid freeze damage.

The pumps are of the centrifugal type, positive self-priming, and when once filled will reprime themselves without aid of auxiliary devices. The pumps come equipped with a self-lubricating mechanical shaft seal which requires no oil or grease. Should the shaft seal begin to leak or the pump lose its prime, the seal should be replaced to insure proper operation of pump.

An important point in maintaining a good pad condition is the water quality. As the water is continuously evaporated and replaced by fresh water, the salts and minerals are left behind in the recirculating water. As these impurities become more concentrated they build up in the pad. It first appears as a frosty deposit on the outside of the pad but can be reduced or even eliminated with proper bleed-off of the recirculating water. Depending on the hardness of the water and the intensity of the evaporation the rate of bleed-off water should range from 1 to 2% of the recirculating water. For Kool-cel pads a bleed-off should definitely be considered as these pads, if properly cared for and maintained, can last for many years.

FOR MORE INFORMATION REFER TO CATALOG C29

TERMS AND CONDITIONS OF SALE

ACCEPTANCE All orders and sales are subject to written approval and acceptance by an executive officer of Acme Engineering & Manufacturing Corporation at Muskogee, Oklahoma, (the "Company") and are not binding on the Company until so approved.

DELIVERY All shipping and delivery dates are estimated only. No delays in delivery will subject the Company to any costs, damages or fees for late delivery. Delivery of the products herein specified shall be made F.O.B. point of shipment, unless otherwise stated. The Company shall not be liable for delay due to causes beyond its reasonable control, such as Acts of God, acts of the purchaser, acts of civil or military authorities, priorities, fires, strikes, floods, epidemics, war, riots, delays in transportation, car shortages, and inability, due to reasons beyond its reasonable control, to obtain necessary labor, material, or manufacturing facilities. In the event of such a delay, the date of delivery shall be extended for a period equal to the time lost by reason of the delay.

TERMS OF PAYMENT If, in the judgment of the Company, the financial condition of the purchaser at any time does not justify continuation of manufacture or shipment on the terms of payment specified, the Company may require full or partial payment in advance.

Pro rata payments shall become due as shipments are made. Each shipment or delivery shall constitute a separate sale, and the default of any shipment or delivery shall constitute a separate sale, and the default of any shipment or delivery shall not vitiate the contract as to other shipments or deliveries.

PRICE ADJUSTMENT Prices are subject to change until the Purchaser's order has been accepted by the Company.

SALES AND SIMILAR TAXES The Company's prices do not include sales, use, excise, or similar taxes. Consequently, in addition to the price specified herein, the amount of any present or future sales, use, excise,

or other similar tax applicable to the sale of the product herein shall be paid by the Purchaser, or in lieu thereof the Purchaser shall provide the Company with a tax exemption certificate acceptable to the taxing authorities.

CANCELLATION Any contract resulting from the Purchaser's order may be canceled by the Purchaser only by negotiations and upon payments of reasonable cancellation charges which will take into account expenses already incurred and commitments made by the Company.

DESIGN CHANGES The Company reserves the right to make changes in design, improvements and additions in and to its products any time without imposing any liability or obligations to itself to apply or install the same in any product manufactured by it.

TITLE The title and right of possession of the products sold herein shall remain with the Company and such products shall remain personal property until all payments herein (including deferred payments whether evidenced by notes or otherwise) shall have been made in full in cash and the Purchaser agrees to do all acts necessary to perfect and maintain such right and title in the Company.

PRICE ADJUSTMENTS AND PROTECTION Prices on products manufactured by the Company are firm for shipment up to four months from the date of the original order entry. Such prices are subject to adjustment if shipment is made after four months and up to ten months from the date of the original order entry, if products are shipped ten months from the date of the original order entry, prices will be adjusted to the price in effect at the time of shipment automatically. All complete component accessory material manufactured by others and furnished with the Company's products such as motors, drives, vibration equipment, controls or other completely assembled component structures, are subject to adjustment to the price at time of shipment regardless of the date of original order entry.

SAFETY ACCESSORIES The Company manufactures products designed to serve multiple applications and offers a wide range of safety equipment, including guards and other devices, as may be required to meet customer specifications. Without exception, the Company recommends that all orders include applicable safety devices. Products ordered without applicable safety devices is clearly the responsibility of the Purchaser. Further, the Purchaser warrants that it has determined and acquired any and all safety devices required for products sold by the Company. Weather covers and guards for motor and V-belt drives, couplings, shafts and bearings, along with inlet and outlet screens, are optional accessories noted in the price list.

GOVERNING LAW The rights, obligations and remedies of Purchaser and the Company, the interpretation of these terms and conditions and the sale of products by the Company shall be governed by Oklahoma law, without regard to any principles of conflict of laws.

ARBITRATION Any dispute arising under or in connection with these terms and conditions or the sale of products shall be settled by binding arbitration administered by the American Arbitration Association under its Commercial Arbitration Rules, and judgment on the award rendered by the arbitrator may be entered in any court having jurisdiction thereof. The dispute shall be resolved by one neutral arbitrator who shall have no affiliation with either Purchaser or the Company and shall be selected by the American Arbitration Association office in Dallas, Texas. The arbitration proceedings shall be held in Muskogee, Oklahoma.

APPLICABLE DOCUMENTS The agreement between the Company and the Purchaser relating to the products includes these terms and conditions of sale, any applicable installation and maintenance instructions provided by the Company and any terms appearing on the Company's quotation, sales order acknowledgment and invoice.

WARNING Acme products are designed and manufactured to provide reliable performance but they are not guaranteed to be 100% free of defects. Even reliable products will experience occasional failures and this possibility should be recognized by the Purchaser and all End Users. If these products are used in a life support ventilation system where failure could result in loss or injury, the Purchaser and all End Users should provide adequate back-up ventilation, supplementary natural ventilation or failure alarm system, or acknowledge willingness to accept the risk of such loss or injury.

WARNING DO NOT use in HAZARDOUS ENVIRONMENTS where fan's electrical system could provide ignition to combustible or flammable materials unless unit is specifically built for hazardous environments. Comply with all local and national safety codes including the National Electrical Code (NEC) and National Fire Protection Act (NFPA).

CAUTION Guards must be installed when fan is within reach of personnel or within seven (7) feet (2.134 m) of working level or when deemed advisable for safety.

DISCLAIMER The Company has made a diligent effort to illustrate and describe the products accurately in all Company literature; however such illustrations and descriptions are for the sole purpose of identification and do not express or imply any warranty.

LIMITED WARRANTY

WARRANTY AND DISCLAIMER: the Company extends this limited warranty to the original purchaser and warrants that products supplied by the Company, shall be free from original defects in workmanship and materials for two years from date of shipment (except for the warranty periods noted for products listed below), provided same have been properly handled, stored, installed, serviced, maintained and operated. This warranty shall not apply to products which have been altered or repaired without the Company's express authorization, or altered or repaired in any way so as, in the Company's judgment, to affect its performance or reliability, nor which have been improperly installed or subjected to misuse, negligence, or accident, or incorrectly used in combination with other substances. The Purchaser assumes all risks and liability for results of use of all products.

Evaporative cooling pads are warranted to be free of defects in materials and workmanship for a period of two years from date of shipment provided same have been properly handled, stored, installed, serviced, maintained and operated; and further, not subjected to excessive heat, corrosive agents or chemicals, or mechanical abuse that may cause tearing, crushing or undue deterioration, nor used on a system or in a manner other than that for which it was designed as explained in the product literature.

The following products are warranted to be free of defects in materials and workmanship for the periods shown from date of shipment: Acme's exclusive duplex split pillow block bearings and shaft five years, belts one year, Polyethylene tubing 90 days, AIR40 Heater warranty one year, AIR40 Emitter warranty three years and DDP fan lifetime warranty on its propeller, cone, and housing.

LIMITATION OF REMEDY AND DAMAGES: All claims under this warranty must be made in writing and delivered to P. O. Box 978, Muskogee, Oklahoma, 74402, within 15 days after discovery of the defect and prior to the expiration of two years from the date of shipment by the Company of the product claimed defective, and Purchaser shall be barred from any

remedy if Purchaser fails to make such claim within such period.

Within 30 days after receipt of a timely claim, the Company shall have the option either to inspect the product while in Purchaser's possession or to request Purchaser to return the product to the Company at Purchaser's expense for inspection by the Company. The Company shall replace, or at its option repair, free of charge, any product it determines to be defective, and it shall ship the repaired or replacement product to Purchaser F.O.B. point of shipment; provided, however, if circumstances are such as in the Company's judgment to prohibit repair or replacement to remedy the warranted defects, the Purchaser's sole and exclusive remedy shall be a refund to the Purchaser of any part of the invoice price, paid to the Company, for the defective product or part.

The Company is not responsible for the cost of removal of the defective product or part, damages due to removal, or any expenses incurred in shipping the product or part to or from the Company's plant, or the installation of the repaired or replaced product or part.

The warranties set forth above do not apply to any components, accessories, parts or attachments manufactured by other manufacturers; such being subject to the manufacturer's warranty, if any. To the extent not prohibited by the manufacturer's warranty, the Company shall pass through to Purchaser such manufacturer's warranty.

THE COMPANY'S WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, ARISING BY LAW OR OTHERWISE, INCLUDING WITHOUT LIMITATION THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, WHICH ARE HEREBY EXPRESSLY DISCLAIMED AND WAIVED. THIS WARRANTY CONSTITUTES THE COMPANY'S SOLE AND EXCLUSIVE WARRANTY FOR DEFECTIVE GOODS AND PURCHASER'S SOLE AND EXCLUSIVE REMEDY FOR DEFECTIVE PRODUCTS.

No employee, agent, dealer, or other person is authorized to give any warranties on behalf of the Company or to assume for the Company any other liability in connection with any of its products except in writing and signed by an officer of the Company.

REPLACEMENT PARTS If replacement parts are ordered, purchaser warrants that the original components in which these replacement parts will be placed are in satisfactory working condition, and

when said replacement parts are installed, the resultant installation will operate in a safe manner, at speeds and temperatures for which the original product was purchased.

TECHNICAL ADVICE AND RECOMMENDATIONS, DISCLAIMER: Notwithstanding any past practice or dealings or any custom of the trade, sales shall not include the furnishing of technical advice or assistance or system design. Any such assistance shall be at the Company's sole option and may be subject to additional charge.

The Company assumes no obligation or liability on account of any recommendations, opinions or advice as to the choice, installation or use of products. Any such recommendations, opinions or advice are given and shall be accepted at Purchaser's and End User's risk and shall not constitute any warranty or guarantee of such products or their performance.

LIMITATION OF LIABILITY The cumulative liability of the Company to the Purchaser and any other persons for all claims in any way relating to or arising out of the products, including, but not limited to, any cause of action sounding in contract, tort, or strict liability, shall not exceed the total amount of the purchase price paid for those products which are the subject of any such claim. This limitation of liability is intended to apply without regard to whether other provisions of this agreement have been breached or have proven ineffective even if the Company has been advised of the possibility of such claims or demands. In no event shall the Company be liable to the Purchaser or any other person for any loss of profits or any incidental, special, exemplary, or consequential damages for any claims or demands brought by the Purchaser or such other persons.

INDEMNITY The Company's maximum liability to Purchaser and to any end user is as set forth above. The Company makes no warranty to anyone for any products not manufactured by the Company and shall have no liability for any use or installation of any products (whether manufactured by the Company or other manufacturers) not specifically authorized by this sale. Purchaser acknowledges various warnings by the Company regarding the products and its installation and use. If the Company incurs any claims, lawsuits, settlements, or expenses (including attorney fees) for any loss, injury, death or property damage including, but not limited to, claims arising out of the Purchaser's or any end user's installation or use of the products, the Purchaser shall indemnify and hold the Company harmless.



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