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Controlling the Greenhouse Environment for Aquaponics

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Controlling the greenhouse environment is challenging because greenhouses gain heat during the day and lose it rapidly to low nighttime temperatures. The principles behind managing a greenhouse environment are the same, regardless of its purpose. While this fact sheet explains these principles, the reader should seek professional expertise when designing a greenhouse and sizing environmental controls because the capital cost is too great to risk any design mistakes.

Ventilation and cooling

In the southeastern United States, greenhouse ventilation is required year round. In the middle of a sunny day a standard 30 foot by 90 foot (9 m × 17 m) greenhouse can collect more than 1 billion British thermal units (BTUs) of heat energy per hour. That's almost the equivalent of having 50 kitchen ovens on. There are optimum temperature ranges for every crop and there are even some crop specific problems associated with excessive heat. The grower must know the optimum temperature for the crop to prevent physiological disorders and disease.

Methods of reducing greenhouse temperatures include natural or mechanical ventilation, evaporative cooling and shading. Heating a greenhouse is not difficult, but cooling a greenhouse efficiently is almost an art. Understanding how a greenhouse is cooled and the limitations of the different cooling methods is essential to becoming an effective greenhouse manager. In fact, understanding how to manipulate the greenhouse environment can be the difference between success and failure in any greenhouse business.

Natural ventilation

Natural ventilation capitalizes on air movement to push and pull hot air out of the greenhouse through open wall sections or the roof. Wind is the driving force behind most natural ventilation. Even a small amount of wind can be effective in pushing air through the greenhouse, over a crop canopy, and out through vents installed on end walls, side walls or through the roof. Warm, humid air rises, and with roof ventilation a vacuum effect occurs as warm air exits through the roof and pulls fresh, cooler air in through the side vents. Greenhouses with high ceilings and open sides have the best natural ventilation and are being used in the southeastern U.S. The benefits of natural ventilation over fan ventilation include low noise pollution, reduced energy input, and the ability to leave doors open so employees can freely move in and out of the greenhouse. Despite these advantages, most greenhouse vegetable growers prefer the biosecurity and uniformity offered by mechanical ventilation.

Mechanical ventilation

Greenhouse exhaust fans (Fig. 1) can be used to remove warm air efficiently while also making air distribution uniform across the entire greenhouse. This uniformity is one of the major advantages of fan ventilation. To prevent pockets of stagnant air, the space between fans should not exceed 25 feet (7.6 m) and the distance a fan pulls should not exceed 150 feet (45.7 m). Fans should also exhaust air in the same direction as the prevailing winds.

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Figure 1. Slant wall exhaust fan.

If this is not an option, the manufacturer or engineer may suggest increasing your ventilation capacity. Any restriction, be it on the intake or exhaust side of the greenhouse, can reduce fan efficiency. Vents that are responsible for bringing fresh air in should be sized 1.25 to 1.5 times the combined area of all the exhaust fans.

A rule of thumb for sizing fans is to have the capacity to exchange 1.0 to 1.5 times the air volume of the greenhouse each minute. If an air exchange rate of 1.5 greenhouse volumes per minute is desired, simply multiply the total greenhouse volume by 1.5. The rate of exchange necessary for effective cooling depends on your area. Greenhouse manufacturers may use a higher exchange rate depending on the location and design of the structure. When sizing a ventilation system, it is common to limit the height in the greenhouse volume calculation to 8 to 10 feet (2.4 to 3.0 m). The volume of air above these heights is often considered stagnant and is not always included in the calculation.

Calculating the greenhouse volume

Greenhouse Volume (cubic feet; m^3) = (Greenhouse Eave Height (feet; m) × Greenhouse Width (feet; m) × Greenhouse Length (feet; m) + Area of Gable (square feet; m^2) × Greenhouse Length (feet; m)

Fans can be selected after the total cubic feet of air per minute (cfm; m^3/min) is known. Most fan manufacturers will have performance charts for each fan model. These charts will list the cfm based on the fan blade size, the motor horsepower, and the static pressure (Table 1). Often two or more exhaust fans are used to move the volume of air throughout the greenhouse and so that there is some redundancy in case one unit malfunctions. If a total of 40,000 cfm (1,132 m^3/min) is required, you may choose two fans with 20,000 cfm (566 m^3/min) or you may choose three or four fans whose total output is near 40,000 cfm (1,132 m^3/min).

Table 1. Examples of fan performance data.

Blade size (inches)	Motor HP	Fan output (CFM)	
		0.05-inch SP[1]	0.10-inch SP
36	1/2	10,308	9,553
	3/4	11,911	11,253
48	3/4	18,180	16,989
	1	20,628	19,563

[1]SP = static pressure (measured in inches of water)

Design parameters can be subjective, and for that reason it is important that whoever is sizing your fans understands your geographical location and the environment associated with it. If you use a greenhouse manufacturer or an engineer not located in your region, it would be wise to get input from other growers in your area.

Evaporative cooling

Evaporative cooling has been an important technology for controlling temperature in greenhouses. When water evaporates, the energy needed to change it from a liquid to a vapor is exchanged from the air, thereby cooling the air. The potential to evaporate water depends largely on relative humidity. Air can hold only so much water vapor and the higher the humidity the lower the potential for evaporation. For this reason, evaporative cooling is significantly more efficient in arid regions. It is common to have considerably larger pads in very humid areas than in less humid ones. Despite high humidity in most of the Southeast, greenhouse operators still rely on evaporative cooling.

Evaporative cooling can use evaporative cooling pads (Fig. 2), high-pressure fog systems, or a combination of both. Systems with evaporative cooling pads work by pulling air through a column of saturated material that has a high surface area. The pad material may be matted aspen wood fibers or corrugated cellulose panels (Fig. 3), the latter being the most common. Corrugated cellulose pads may be 4 inches or 6 inches (10 cm or 15 cm) thick. To maintain constant moisture on the pads, water is pumped over them and a thin film of water drips down the pads. Exhaust fans on the opposite side of the greenhouse pull outside air across the surface of the pads. The air movement, combined with the high degree of surface area, promotes rapid evaporation. Even with evaporative cooling in place the air temperature can still rise more

Figure 2. Evaporative cooling pad system.

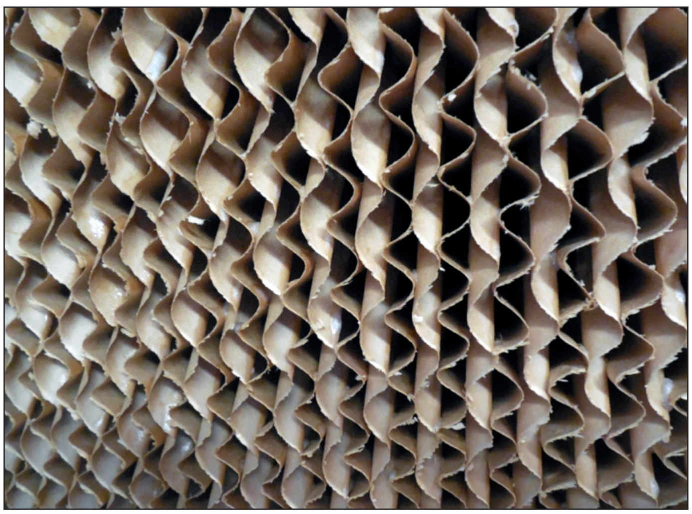

Figure 3. Close up of corrugated cellulos pad material.

than 7 °F (3 °C) as air travels from the cooling pads to the exhaust fans, but the starting temperature can be considerably lower than if no pads were used. This type of system is commonly referred to as a "fan and pad system." Water that is not lost to evaporation drips into a collection sump where it is recirculated back to the pad system with a small pump. Water lost to evaporation is constantly replaced in the sump with new water, controlled by a common float valve from a clean water source.

One of the advantages of mechanically ventilated systems is the uniformity of air flow across the greenhouse. To ensure air is distributed evenly, install cooling pads across the entire span of the air inlet side of the greenhouse. The National Greenhouse Manufacturers Association recommends that the velocity of air be 250 feet (76 m) per minute when moving through a 4-inch (10-cm) thick cellulose pad and 400 feet (122 m) per minute when moving through a 6-inch (15-cm) pad.

Cooling pads must be maintained regularly to remove both algae and mineral deposits that have accumulated on cellulose material. Dirty cooling pads can greatly diminish the efficiency of air movement through the greenhouse. The cellulose materials and adhesive used to manufacture pads are very sensitive to oxidative chemicals. It is important to consult with the manufacturer of the material to determine the most appropriate way to clean your cooling pads.

Fog systems

Mist and fog systems are less commonly used but they can provide more cooling when used with the fan and pad system. The premise behind fog systems is to apply a fine mist uniformly throughout the greenhouse. This is accomplished with high-pressure water and fine-mist nozzles distributed down the length of a greenhouse. Because the water droplets are so small, most of the water evaporates almost instantly, helping to alleviate the rise in temperature that occurs as air is moving through the greenhouse.

Shading

Shading is often used in combination with ventilation to reduce air temperature and/or light intensity and the amount of radiation entering the greenhouse. Shade can be applied as a shade compound (whitewash) that is sprayed on the greenhouse, or as a cloth material covering the greenhouse. In the Southeast, shade cloth is more often used as it offers more flexibility. Shade cloth is sold in several gradations of shade that are expressed as percentages (e.g., 30, 50, or 60 percent). Although the percent shade often correlates with the amount of light diffused, the shade percentage does not necessarily represent the amount of heat energy reduced. For example, 30 percent shade cloth may not provide a 30 percent temperature reduction.

Shade cloth can be applied either internally or externally. Often internal shade is retractable. Internal shade curtains may double as an "energy blanket" to trap heat at night during cold weather. Retractable exterior shade curtains are also available and may offer a greater degree of flexibility when transitioning between seasons.

Shade cloth can be purchased in several colors, but black is most often used as it is the least expensive and most durable. The color of shade cloth can have a big impact on reducing temperatures. Black shade cloth can get very hot in the sun as it absorbs heat. Heat absorbed by the cloth is radiated into the greenhouse. White shade cloth and reflective shade cloths are becoming more common because they are more efficient at lowering temperatures.

Heating

Maintaining an optimum temperature range in the greenhouse often requires heating during cool weather. Heating replaces conductive, convective, and radiation heat loss. Understanding the ways in which a greenhouse loses heat is key to knowing how to improve heat retention and properly size your heating equipment.

Heat loss

There are many factors that can be used to calculate the amount of heat lost from a greenhouse, but for practical purposes transmission heat loss, air infiltration, and perimeter heat loss are the primary factors considered. The British thermal unit is the most common measure to report heat loss. The greenhouse structure naturally creates a temperature gradient. Until an equilibrium occurs the movement of energy always flows from higher concentrations (warmer inside air) to lower concentrations (cooler outside air). The larger the gradient the more rapid the movement of energy; in other words, the colder the outside temperature the faster the greenhouse will lose heat. The difference between inside (T_I) and outside (T_O) temperatures is usually expressed as "ΔT." A greenhouse should be designed for extreme weather events. A general rule of thumb in the Southeast is to take the average January minimum temperature for the area where the greenhouse will be located and subtract an additional 15 °F (7 °C).

Most heat loss occurs through the surface area (i.e., walls and roof) of the structure. The rate of heat is loss is heavily influenced by the insulation properties of the material covering the greenhouse. The material used to cover a greenhouse is called "glazing." Glazing can be glass, fiberglass, polycarbonate or polyethylene plastic sheeting. The factors influencing glazing choice include light infiltration, insulation properties, expense, and durability. In the Southeast, most growers prefer polyethylene sheeting over rigid materials, primarily because it is significantly less expensive and easier to replace. Growers using polyethylene may install two sheets of plastic over the greenhouse and inflate the space between the two layers to improve insulation. Double-layered poly greenhouses can improve heat retention by more than 30 percent compared to single-layer greenhouses.

The measure of a glazing's ability to retain heat is reported as the U-value (BTU per square foot per degree Fahrenheit; BTU per m^2 per °C). The lower the U-value the greater a material's ability to retain heat. Table 2 lists some of the common greenhouse glazing materials and their U-values. The material used to build the structure, that is in contact with the glazing, may also contribute to heat loss. While the effect on the total heat loss is minimal, it is still an important factor to consider. This factor is commonly referred to as the "construction factor." Values for various materials are found in Table 3. To calculate heat lost due to temperature differences, the U-value, construction factor, and surface area must be known. Wind can also influence transmission losses and must be taken into account if wind speed averages 15 miles per hour (24 km/h) or high winds are frequently an issue in your area. For an average wind speed of 15 to 20 miles per hour (24 to 32 km/h), increase transmission losses by a factor of 1.04. For higher wind speeds consult your greenhouse manufacturer.

Table 2. Heat transmission coefficients for common greenhouse glazing materials.

Glazing material	U-value (BTU/°F/ft²)
Glass, single layer	
Single-layer polyethylene film	1.2
Double-layer polyethylene film (inflated)	0.7
Twin-wall polycarbonate sheeting (8 mm)	0.65

For a complete list of heat transmission coefficients for greenhouse glazing and wall materials consult the National Greenhouse Manufacturers Association Heat Loss Standards.

Table 3. Construction factor (C) for transmission heat loss calculations.

Metal frame and glass 16- to 24-inch spacing	1.08
Metal frame with polyethylene sheets	1.02
Polyethylene sheet on wood	1

For a more complete list of construction factors consult the National Greenhouse Manufacturers Association Heat Loss Standards.

Calculating total surface area

Greenhouses differ in design and are made in many shapes and sizes. Basic geometry is used to calculate the surface area, where both dimensions in a two-dimensional object are multiplied (length × width; height × length). Examples of how to calculate each greenhouse component are shown in Figures 4 to 8. Remember that there are two end walls, side walls, and gable ends. The total surface area equals the sum of both end walls, both sidewalls, both gable areas, and the surface area of the roof. Use the following calculation to determine the total surface area of a greenhouse structure:

Total Surface Area = (End Wall Area × 2) + (Side Wall Area × 2) + (Gable Area × 2) + Roof Area

Once the surface area is calculated, the following formula is widely used to calculate a large portion of heat loss resulting from transmission:

$$Q_T = UA(\Delta T)C$$

Where:

Q_T = heat loss due to transmission (BTU/hour)
U = heat transmission coefficient (BTU per hour per square foot per degree F; BTU/hr/m²/°C) (Table 2)
A = greenhouse surface area (square feet; m²)
ΔT = the difference between inside and outside temperatures
C = construction factor (Table 3)

After transmission, the second greatest cause of heat loss is air infiltration. This can represent as much as 20 percent of the total heat loss in older structures. Greenhouse manufacturers refer to the air infiltration of a house as the "tightness." Newly constructed structures tend to be very tight with a small degree of air infiltration. In older structures, gaps in aging lumber, worn out louvers, and tears in plastic can cause air infiltration. Often, erosion created by greenhouse driplines will cause gaps to form between the greenhouse frame and the original ground level. Regular maintenance to louvers, installing weather stripping on doors, and patching gaps between lumber can significantly reduce heat loss. The number of air exchanges per minute is included in the calculation to determine heat lost to air infiltration. Table 4 lists some estimated air exchanges per minute for different greenhouse conditions. The following formula can be used to calculate the amount of heat that can be lost to infiltration:

$$Q = 0.018NV(\Delta T)$$

Where:

Q = heat lost to infiltration
N = infiltration rate (see Table 4)
V = total greenhouse volume in cubic feet (m³)
ΔT = difference between inside and outside temperatures
0.018 = heat capacity of air at sea level (BTU per square foot per degree F; 1.0035 kj/kg/°C)

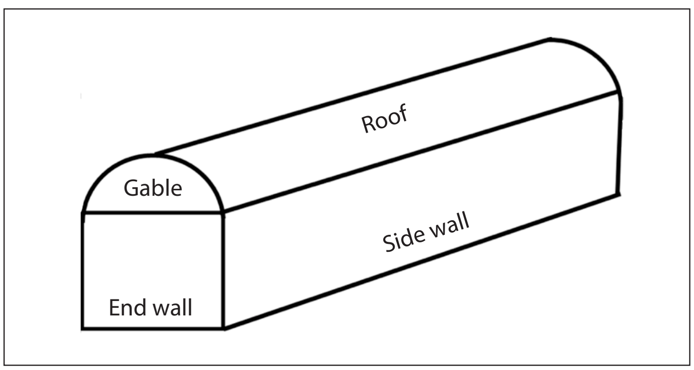

Figure 4. Greenhouse components for surface area calculations.

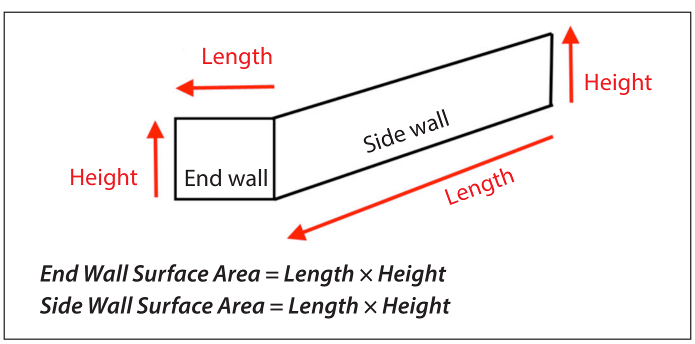

Figure 5. Calculating end wall and side wall area.

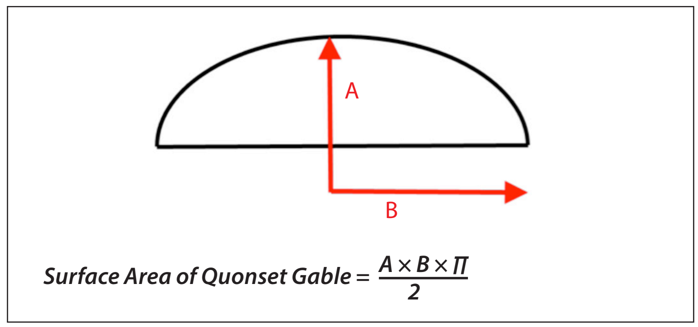

Figure 6. Calculating Quonset gable area.

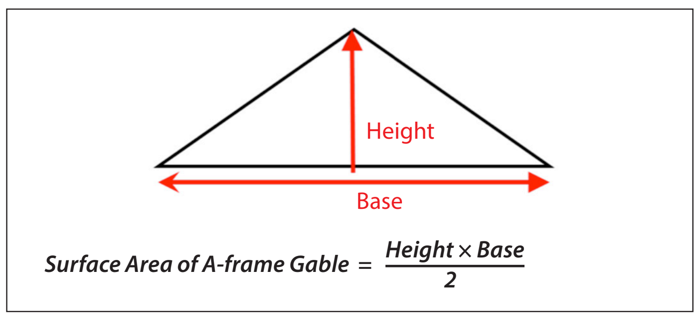

Figure 7. Calculating A-frame gable area.

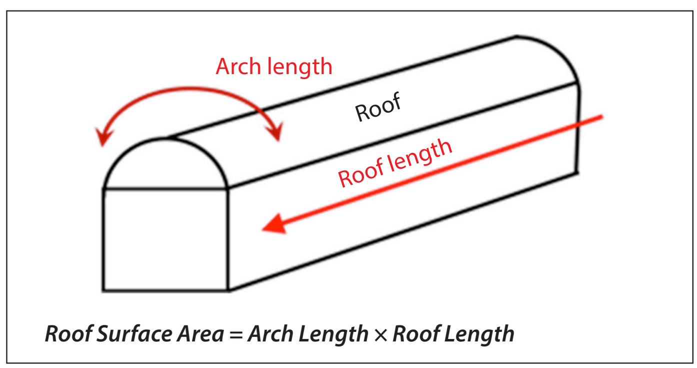

Figure 8. Calculating roof surface area for a Quonset roof.

Table 4. Infiltration rates (N) for greenhouses.

New construction	N-Factor
Plastic film	0.6 to 1.0
Single glass unsealed	1.25
Old construction	
Well maintained	1.5
Poorly maintained	2.0 to 4.0

For a more complete list of infiltration rates consult the National Greenhouse Manufacturers Association Heat Loss Standards.

Heaters

The most common greenhouse heater used in commercial production is a gas-fired unit heater (Fig. 9). Gas unit heaters can be fueled by natural gas (NG) or by liquid propane (LP). Commercial growers use vented heaters with exhaust fumes vented outside of the greenhouse to prevent the accumulation of noxious gases. Super-heated exhaust fumes are channeled through a heat exchanger before being vented. To disperse heat from the heat exchanger, a high-velocity fan forces air through the heat exchanger where it picks up heat and is then distributed to the greenhouse air. Because heat has to be transferred from the exhaust fumes to the heat exchanger and then from the heat exchanger to the greenhouse air, efficiency suffers. Some growers use non-vented heaters thinking they have a higher efficiency because all of the heat is exchanged. However, these heaters often require more ventilation to reduce humidity and noxious gases, thereby lowering the efficiency of the overall system. Vented heaters are safer for employees and crops and should be used when possible.

Most growers in the Southeast use gas-fired heaters but are always on the lookout for more affordable ways of heating their greenhouses. Great strides have been made in solar, geothermal, and biomass fuel sources. These fuel sources have a much lower cost per million BTU than LP or NG, but the equipment costs more. Before investing in alternative energy be sure to ask yourself the following questions?

Figure 9. Gas-fired unit heater.

Reliability – Can I rely on this piece of equipment when it counts? Is the fuel material and source consistent and available during the season most needed?

Maintenance and labor – What does it cost and how much time does it take to reload the heater? How often will this piece of equipment require maintenance? If there is a problem with the equipment, who will be able to repair it?

Fuel shipping cost – What will it cost to transport the fuel to my location?

Equipment cost – Will the long-term savings associated with an alternative energy source outweigh the initial investment in the equipment?

If using an alternative heating source, make sure a backup, gas-fired heater is in place to reduce any risk associated with system failure. In some areas, only a fraction of the total BTU design load for a particular greenhouse is required most of the time. An integrated approach may allow a smaller alternative heater to be used with a gas-fired heater for backup. Alternative heating equipment does not have to supply the entire load capacity needed. More research is needed on a systems approach to greenhouse heating when using alternative heat sources.

Controlling humidity

Controlling humidity in a greenhouse is a constant challenge. As plants transpire they release water vapor into the air. The high relative humidity often increases disease pressure, especially if water droplets begin to accumulate on the leaves. Humidity can be reduced by ventilating the greenhouse and purging humid air. Dry, cool air can be pumped with a jet fan through perforated poly tubing and evenly distributed through the greenhouse ceiling. Bringing the cool air in higher than the crop canopy allows the air to mix with the warm air as it falls toward the crop. Many growers use horizontal airflow fans (HAF) positioned above the crop canopy to circulate air when the exhaust fans are off (Fig. 10). Air movement across leaf surfaces keeps leaves dryer and reduces disease pressure. HAF fans also keep the air in the greenhouse from stratifying by mixing warm air in the ceiling with cooler air near the plant canopy. The placement of HAF fans is dependent on greenhouse size. We recommend consulting the manufacturer for proper placement in your specific structure. A rule of thumb for calculating the total air flow needed is 2 cfm per square foot (0.53 $cm^3/min/m^2$) of greenhouse floor.

Figure 10. High airflow (HAF) fan.

Figure 12. Aspirator box to house thermostats.

System management and control

The environmental equipment in a greenhouse needs to be carefully monitored to maximize its efficiency and reduce labor. Constantly having to open and close vents manually is not cost effective. Automation can significantly reduce labor cost and the stress associated with managing a greenhouse. Equipment should be properly staged for the most efficient energy use while also maintaining a constant temperature. Many devices are available for controlling the equipment, ranging from simple on/off switches to high-tech computerized systems. Small growers often choose environmental control systems based solely on the price. Therefore, the most widely used device is a common, inexpensive thermostat (Fig. 11).

Figure 11. Greenhouse thermostat.

Thermostats are not very accurate or consistent, as two thermostats mounted side by side may give different readings. Humidity and heat can further diminish the accuracy of thermostats over time. It is important to position thermostats so they represent temperatures the crop is experiencing. This means shielding thermostats from direct sunlight and strong air currents. An aspirator box can be used to protect thermostats from false readings (Fig. 12). These boxes are often made of wood and have a small fan to pull air through the box and across the thermostat. Efficiency and accuracy are especially important in greenhouses with equipment that must operate in stages. Each thermostat must be properly calibrated to ensure that multiple environmental controls do not unnecessarily operate simultaneously. For example, the fan and the heater do not need to be running at the same time.

Smart controllers or computerized controllers offer a great deal of flexibility and can be adjusted quickly. Some can even be monitored and adjusted from a mobile phone. Smart controllers may be worth the extra expense when considering the ease of use and the flexibility they afford.

Mitigating risk

An emergency call system that monitors power outages and indoor temperatures is a good way to reduce risk. Alarms and backup generators are important for the conventional greenhouse grower, but are a must for the aquaponics grower. Some growers will have extra consumables such as fan belts, motors (Fig. 13), and even extra heaters on hand in case of equipment malfunctions.

Figure 13. Spare motor and fan belt.

Growers can choose to divide their total requirement for heat or ventilation among several smaller pieces of equipment rather than a few large ones. If one piece of equipment fails the others may prevent a total crop loss. For example, if your system requires 40,000 cfm (1,132 m^3/min) of fan power you may choose two large fans or four smaller fans. The same approach can be used with heaters. Using larger motors and heaters may be more energy efficient, so carefully consider the benefits of risk reduction versus long-term energy use.

Summary

When planning an aquaponic facility, environmental controls should be considered early on during the design process. The ambient environment in the greenhouse can be as important as the aquatic environment of the aquaponic production system. The correct environmental controls can make an operation successful, while incorrect environmental controls can compound management and operational difficulties of the facility. To have the best chance of success when starting a new aquaponics operation, we highly recommend letting an experienced engineer, Extension specialist or consultant help you correctly design your greenhouse and choose the appropriate equipment for it.

Suggested readings

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USDA United States Department of Agriculture National Institute of Food and Agriculture

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