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## FOREWORD

Greenhouse Heating Efficiency Design Considerations provides an introduction to the many options available in greenhouse heating equipment. It is the intention of this document to assist in the development of action plans and setting priorities to purchase equipment for new greenhouse construction or in renovating, retrofitting or expanding an existing greenhouse.

Heating is one of the most dynamic and complex environmental control issues faced by greenhouse operators. Understanding heating dynamics is very important when developing plans for any facility.

This document is offered to help make decisions on heating systems to enhance efficiency, productivity, equipment longevity as well as promote safety. This document is not intended to create specifications, replace codes or set standards.

## THE BASICS OF HEAT LOSS

### HOW HEAT LOSS OCCURS

Heat loss occurs from a greenhouse structure whenever the interior temperature exceeds the exterior temperature. The rate at which it occurs is affected primarily by the efficiency of the covering materials (glazings) installed on each surface (roof, side walls and end walls). The most commonly used covering materials all have published heat transfer factors called “U” factors that provide a means of calculating their impact on heat loss in different scenarios.

“U” factors are the inverse of the commonly used “R” factors, where  $U = 1 / R$

The lower the “U” factor, the less ability your glazing material has to transfer heat, therefore, the lower the heat loss.

Here are a few of the most common covering materials and their associated “U” factors:

MATERIAL	“U”
Glass, single	1.13
Glass, double glazing	.70
Single film plastic	1.20
Double film plastic, inflated	.70
Corrugated FRP panels	1.20
Corrugated polycarbonate	1.20
Plastic structured sheet (winter):	
16 mm thick	.58
8 mm thick	.65
6 mm thick	.72
Concrete block, 8 in.	.51

A simple example of a heat loss calculation can be done using these variables:

Square foot area of covering = A  
“U” factor for material = U  
Temperature difference =  $\Delta T$   
BTUH heat loss per hour equals:

$$A \times U \times \Delta T$$

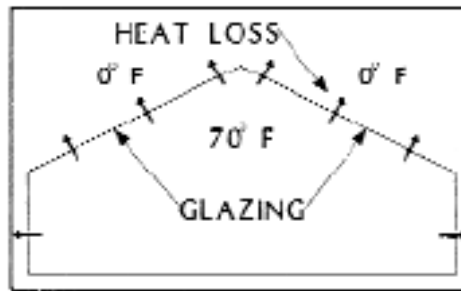
For example: 10 sq. ft. of single glass with an inside temperature of 70°F and an outside temperature of 0° would have 791

BTUH heat loss:

$$A (10) \times U (1.13) \times \Delta T (70) = 791 \text{ BTUH}$$

*Note:* The above calculation is for illustration only and does not account for construction, wind and air infiltration factors. To determine the total heat loss of a structure, please refer to the *Greenhouse Heat Loss* section of the *NGMA STANDARDS* document.

How heat loss happens:



In North America, heat loss is typically expressed in terms of total British Thermal Units per Hour (BTUH) loss.

### WHAT IS A BRITISH THERMAL UNIT?

British Thermal Unit (BTU) = The amount of energy it takes to warm one pound of water 1° (degree) Fahrenheit (F).

The National Greenhouse Manufacturers Association provides excellent documentation and calculations for determining heat loss of greenhouses. The document containing this information is the STANDARDS document available from the association. It is revised periodically to provide the most up to date information available.

The standard method of calculating heat loss in greenhouses will provide a total BTUH requirement for conductive heat loss. That is, the total heat loss of the structure were it to have all the contained volume of air heated.



Winter design temperature map

This map shows the lowest temperatures for calculating heat loss in different areas of the 48 contiguous states.

**SPECIAL CONSIDERATIONS FOR CALCULATING HEAT LOSS****UNIQUE CROP CONSIDERATIONS**

Many growers do not use the total volume of their structures to grow crops. Consequently, they may not need to have the total conductive heat load available in their heating system. While the standard means of calculating heat loss are well accepted and documented, considerations should be made as to whether your crop requirements justify installing the total number of BTUH indicated by this calculation.

For instance, if a grower does not have snow removal requirements and grows only on the floor, he or she may not require the investment of a system that inputs the total conductive heat loss of the structure since the air temperature above the crop may not be an important consideration.

Such a grower may well benefit from a “zone” type of heating system. One that places the BTU's in a specific portion of the structure.

However, a grower in snow country that produces crops on many levels in the interior of a greenhouse structure (on benches and hanging plants) is well advised to pay strict adherence to sizing his heating system to match the total conductive heat loss of the structure to avoid snow build up problems and cold damage to his crops.

Considering the true needs of your crop rather than simply heating the entire volume of a structure can yield huge efficiencies, but prudent judgment is always good advice when it comes to heating. Always determine your heating requirements for the worst case situation of both production and environment.

**VENTILATION AND INFILTRATION OF OUTSIDE AIR**

Ventilation essentially provides the same benefit regardless of the season. Ventilation, in addition to removing excess heat in the summer, replenishes carbon dioxide and assists in the control of humidity levels.

Recommended summer ventilation rates vary but a common accepted rate is 8 cu. ft. per minute (CFM) per square footage of floor space. Winter recommended ventilation rates are 1.5 CFM.

Winter ventilation needs to be introduced without producing cold drafts on the plants. Winter ventilation requires a thorough mixing of the ventilation air and the warm inside air. Mixing is readily achieved by admitting the air in small high velocity openings.

Ventilation air requirements do add to the heat load demand, but is very important to proper plant production.

Current practice is to not consider the additional heat load requirement for ventilation air, because heat load is calculated at the most stringent conditions which occurs during the night and early morning hours, during which time ventilation is not typically used.

Some older greenhouses have substantial air infiltration. This occurs when the greenhouse covering is “leaky” and admits fresh air, which replaces heated inside air. For example greenhouses covered with lapped glass typically require more consideration of air infiltration when heat loss calculations are made.

**EXCESSIVE WIND**

Typically, the coldest nights are very still by comparison. However, high winds can occur on cold nights and when they do, heat loss can be higher because of air “scrubbing” the outside of the greenhouse covering.

**AIR CIRCULATION**

There has been an increasing interest among horticulturist and growers to provide a better growing environment year round. The desire is for more uniform temperatures, less extremes in the relative humidity and more active air circulation and movement, particularly over the leaf surfaces.

During cold weather when greenhouses are virtually closed in there is often insufficient air circulation to maintain desired conditions. The appropriate type of air circulation equipment will help obtain a more uniform relative humidity and provide the proper air movement. Continuous circulation produces gentle air movement and has been reported to maintain better leaf surface microclimates and prevent pockets of disease producing high humidity. This gentle air circulation may result in slightly higher heating demand, yet many regard it as advantageous from a plant production and quality standpoint.

#### **PERIMETER INSULATION**

A substantial amount of heat energy can be lost out of the perimeter of a greenhouse through the ground below the perimeter walls and ends. This is conductive heat loss that can be minimized by installation of perimeter installation of insulating boards below the frost line.

#### **THERMAL BLANKET CONSIDERATIONS**

Installation of a thermal blanket system can impact the total heating requirement of your greenhouse by reducing the heat loss. These systems are typically designed to automatically retract in the daytime and close in the nighttime to trap energy.

While these systems typically reduce potential heat loss substantial (depending upon the type of fabric used) all factors should be considered before reducing the capacity of a heating system accordingly.

For example, if a grower determines that he or she needs less BTUH for his greenhouse because of the presence of a thermal blanket, they should remember that there may be times when the blanket must be opened in the nighttime to melt snow from the roof. In this situation, sizing of the heating capacity of the system must not be reduced with the consideration of the blanket.

Because retractable thermal blankets are mechanical devices, they can potentially fail to close. So even in non-snow areas, caution should be exercised before considering a blanket in heat loss circulation.

### **EFFICIENCY TERMINOLOGY**

When shopping for heating equipment it is important that you have an understanding of the common terminology used to describe different types of equipment.

There are several types of efficiency terms used when describing heating equipment. The most common terms used to describe heating equipment:

#### **COMBUSTION EFFICIENCY**

This term is the most basic description of efficiency. It denotes the percentage of fuel burned and turned into heating energy.

#### **THERMAL EFFICIENCY**

This term is a measurement of the actual amount of available energy that transfers into the heating medium. It is derived by operating a piece of equipment at a steady state and measuring how much fuel is used versus how much useable heat comes out. It is most typically used in reference to boilers.

#### **DISTRIBUTION EFFICIENCY**

This is the measure of efficiency of how well the heating equipment actually delivers the BTU's to your plants and structure. This expression addresses how energy is distributed and transferred to the objects requiring heat. All forms of heating fall into one or more of three basic principles: convection, conduction or radiation. Since all three methods of heat transfer are common and effective in greenhouse heating it is important to understand the fundamentals of each.

**Convection** - Convection utilizes the forces of natural air circulation currents to transfer heat. Convection involves two basic principles:

1. Cold air displaces warm air
2. Warm air rises in the presence of cold air.

With convection heat is transferred by air currents, which transport energy throughout the structure. When these air currents pass by plant material, energy is transferred to the plant. Because of this, it is very important that some means of air circulation is used ( Horizontal Air Flow (HAF) fans, perforated polyethylene duct tubes or ceiling fans) to assure the maximum amount of warm air is transferred to the plant environment and to evenly distribute heat throughout the structure.

Warmed air in the structure naturally rises and forms layers (called stratification), with the warmest layers generally at the highest point of the greenhouse. To maximize efficient use of the heat energy available it is important to force the mixing and circulation of these warm air layers. Convection heat air is also very valuable as a means of snow removal.

**Conduction** - Conduction utilizes direct application to transfer heat energy to the plant. Physically touching any warm object demonstrates the principle of conductive heating.

In greenhouses, this type of heating is most commonly distributed with hot water tubes and occasionally electric resistance strips, which are placed directly on the growing surface or in the growing media. The soil, containers and growing surface in direct contact with the warm tubes or strips is heated and subsequently transfers that heat energy to adjacent material.

**Radiation** - Radiation utilizes electromagnetic infrared waves to transfer heat energy. Since this is a little understood form of heating, it bears detailed explanation.

Anyone who has warmed themselves by a hot wood stove or warmed their hands at a camp fire has experienced radiant heat. It is also demonstrated by standing in the sun on a winter's day or walking near a brick wall that has been exposed to the sun during the day. In both examples although the air may not be warm, you are able to feel the heat energy radiating from these surfaces.

Distribution efficiency is greatly affected by the system(s) you select, and how you utilize your equipment. Some examples:

- Forced hot air systems' distribution efficiency is largely dependent upon the means of air circulation used in the greenhouse.
- Infrared systems, properly installed, can transfer heating energy very well to crops without the necessity of air circulation.
- With hot water, distribution efficiency is affected tremendously if the supply and return lines are poorly installed or are not insulated.
- Some hot water systems deliver heat much more efficiently than others. Finned pipes heat faster than bare pipes.
- With hot water, a high efficiency distribution system coupled to a poor efficiency boiler may be better than a high efficiency boiler with poor efficiency distribution.

Look at all aspects of efficiency, whatever system you choose consider all facets of heating system efficiency when making heating equipment purchases. Making your decision based solely on one facet of efficiency may not necessarily be your best option.

## AVAILABLE SYSTEMS

The heating process is often oversimplified with too little consideration given to the dynamics involved. After all, we don't need to know how an engine works to drive our car or how power is generated to turn on a light switch. Although it may not be necessary for its operation, it makes good sense for a greenhouse operator to understand a little about what's involved in "turning on the heat."

There are four functions that must occur to heat a greenhouse:

1. Conversion of fuel to heat energy
2. Distribution of the heat energy
3. Transfer of the heat energy
4. Conversion of the heat energy into useable heat by the plant

The conversion of fuel to heat energy is typically accomplished through combustion with a burner installed in a boiler or heater combustion chamber. That heat energy is then distributed in the greenhouse through pipes, ducts, tubes or air. Once the energy is distributed through the house, it must then be transferred to the plants and soil by convection, conduction or radiation. Finally, once transferred to the plants and soil, they must in turn absorb its energy and convert it to usable heat. How each of these functions is accomplished has a significant effect on both the efficiency and effectiveness of the heating system.

There are almost as many types of heating systems to install in greenhouses as there are crops to grow. However, this section will provide a quick overview of the most popular and common systems.

### UNIT HEATERS

The definition of a unit heater is a fan equipped device with a means to heat the air being provided by the fan. They are the most commonly used greenhouse heating equipment. Unit heaters are valuable in that they provide warm air temperatures which are imperative for leaf transpiration and snow load concerns.

Unit heaters gently circulate warm air to prevent temperature stratification, reduce mold and fungal disease.

Typical Unit Heater



Unit heaters are typically suspended from the greenhouse framing. Floor mounted units are also available.

Unit heaters are the most commonly used form of heating due to the following reasons:

- they provide the air circulation needed

- they can be used in conjunction with ventilation systems
- they can provide uniform bench top temperatures
- they can provide uniform under the bench temperature
- they are comparably the least expensive
- they provide quick response to temperature changes
- they provide snow load protection which facilitates solar gain and plant growth
- they are easy to install
- they offer inexpensive expansion for additions
- they can be used in conjunction with waste heat applications

There are five basic types of unit heaters:

1. **Vented gas fired unit heaters** - The most common style used is the gas fired unit heater. Available for use with natural or propane gas. Gas fired unit heaters provide a reliable and energy efficient low cost heating system.

Gas fired unit heaters have evolved in three “generations”. All three types are currently available.

The initial design utilized a **natural gravity vented** system. This initial design utilizes the air in the greenhouse for the combustion process and has a flue pipe that must be terminated above the ridge of the greenhouse.

The second generation of gas fired greenhouse equipment answered the need for efficiency and are **power vented**. Modifications to the venting system increased the efficiency 20% by adding a fan unit that actively expels the products of combustion. This enhancement eliminates “thermal siphoning” of heated air out the flue pipe between heating cycles.

The most recent generation is called the **separated combustion** style. They capitalize on the efficiency gained and increased longevity offered by utilizing air from outside the greenhouse for the combustion process. These products eliminate most of the concerns of combustion air quality and corrosion.

These enhancements by various manufacturers insure that greenhouse heating will be done with gas fired unit heaters for years to come.

Gas fired units heaters are available with propeller fan or blower wheel air delivery systems. Propeller fan gas unit heaters are most common. The propeller model is used to deliver the heated air directly to the greenhouse or in conjunction with a fan jet system. Blower units have the capability to be used in high static systems like polyethylene tube ducts for overhead or below the bench heating.

2. **Direct unvented gas fired heaters** do not vent hot flue products out of the greenhouse; instead, a direct-fired heater expels all heated combustion products into the greenhouse. Products of combustion are carbon dioxide (CO<sub>2</sub>), water (H<sub>2</sub>O), and carbon monoxide (CO). Direct-fired heaters require intermittent ventilation to dilute their products of combustion. It is recommended the direct-fired heaters use outside air to optimize combustion.
3. **Hot water unit heaters** - This style of unit heater is used in conjunction with a boiler system or other hot water or steam source. They extract heat from the water or steam and deliver the heated air to the greenhouse. Hot water unit heaters are very reliable and are inexpensive.



Hydronic unit heaters are mainly used in hybrid systems with an under the bench root zone heating system. The unit heater is used to assist in air circulation needs and handle snow load requirements.

4. **Electric unit heaters** - This style of heater is preferable when the location of the greenhouse is remote. Electricity is typically a more expensive source of heat but it is flexible in its ease of installation.
5. **Oil fired unit heaters** - This style is utilized regionally. The northeast region of the U.S. utilizes oil fired equipment more than other areas. Oil fired equipment is available for suspended or floor mounted installation. Oil fired equipment normally requires more annual maintenance by a service company.

#### **COST CONSIDERATIONS**

Comparing initial unit costs using comparable BTU capacities, oil fired units are the most expensive followed by gas, then electric then hot water unit heaters. When installation expenses are considered, oil fired again are the most expensive followed by hot water units. Gas fired unit heaters with one way gas piping and venting can be installed for one-half the cost of hydronic units.

Hot water or “hydronic” unit heaters are discussed further in the hot water section of this document.

*Cautionary note:* Unit heaters that vent products of combustion directly into the greenhouse structure should be used only in areas where adequate ventilation is available to avoid exposure to personnel, or crop damage from combustion by-products such as carbon monoxide and ethylene\*

#### **CO<sub>2</sub> GENERATORS**

There are several CO<sub>2</sub> generator products on the market and these are essentially direct-fired unit heaters. Typically, they are designed to efficiently eliminate most of the ethylene\* and carbon monoxide from their products of combustion, however they still should be used only as a means of replenishing CO<sub>2</sub>, not the primary source of heat.

#### **STEAM SYSTEMS**

In the past century, there was a time when steam was very common as a means of heating greenhouses. It is a manageable, transportable method of heating that is easy to provide bottom, top and perimeter heating with.

Steam can be plumbed through pipe coils in the greenhouse with either bare or finned pipes, or using hydronic forced air unit heaters.

The initial cost of equipment, excessive maintenance, the lack of qualified technicians and installers, and the many advances in other systems have all conspired to make steam systems most probably a heating method of the past.

There is however, renewed interest in the ability to generate steam as a means of sterilizing soil media as chemicals such as methyl bromide are pulled from the market over environmental concerns.

#### **HOT WATER SYSTEMS**

Hot water or “hydronic” systems are available for providing heating to a greenhouse space. Because of their initial cost, many growers have felt that they cannot justify the investment required to install hot water. However, many advancements in technology over the past decade have made these systems more affordable.

Hot water systems do require specific engineering for each and every application and installation is complex. However, the energy efficiency advantages they offer and the potential to enhance evenness and growth in a greenhouse facility make them attractive enough to warrant researching if hot water is a logical alternative for you.

Hot water facts:

- Hot water can be transported from a heat source to a greenhouse over great distances using insulated pipelines.

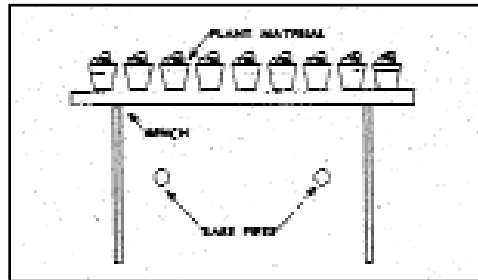
\* May be present in some gas supplies

- Hot water can be proportionately controlled to operate at various flow rates and temperatures, all from the same heat source.
- Hot water can be transferred into useable heat in a greenhouse in many ways - finned pipes to unit heaters.
- Any energy source can be utilized with a hot water distribution system.

### HOW MANY WAYS CAN HOT WATER BE USED TO HEAT?

**BARE PIPES** - Perhaps the simplest of means of transferring heat from hot water is through bare pipes of steel, black iron, copper or aluminum. Pipes can be located around the perimeter of a structure and installed under benches, in the rows of cut flowers or vegetable crops and at gutter height as well. Pipes can be threaded, welded or with special fittings crimped together. While the amount of water being heated in relationship to the heating potential realized may not be the most effective, hot water heating with bare pipes will deliver quiet gentle heat to your greenhouse area.

Typical Bare Pipe Hot Water Installation

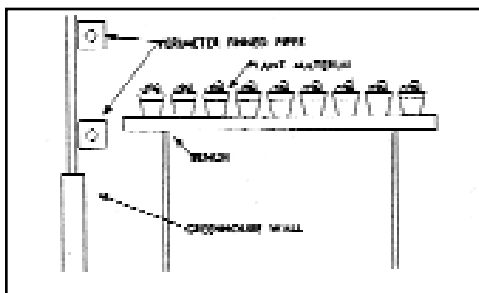


**FINNED PIPES** - The addition of finned elements to the surface of a pipe enhances its ability to transfer heat by expanding the pipe's surface area. This reduces water volume to heat and less actual footage of piping is required to do the same work.

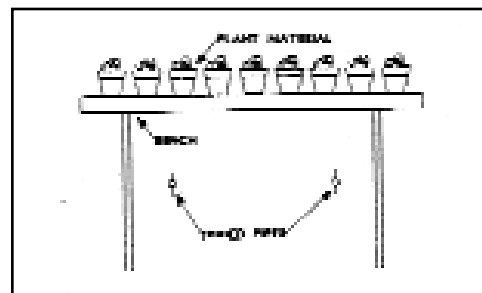
There are many variations in the design of finned pipes. There are black pipes with steel fins attached, copper tubes with aluminum fins and completely aluminum products. All of them seek to do the same job, enhance heating potential while minimizing footage and the water volume required.

Some finned pipes are well suited to installation under growing benches, while some are best installed around the perimeter of the structure.

Typical Finned Pipe Installation - Perimeter



Typical Finned Pipe Installation - Under Bench



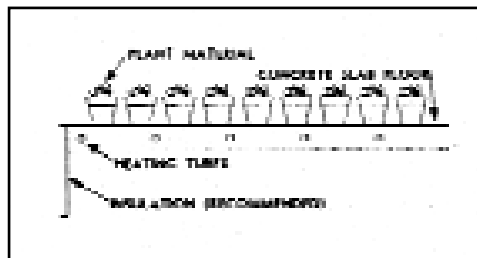
HEATED

**CONCRETE SLAB FLOORS** - Concrete floors are becoming quite common in greenhouses. In part because of environmental legislation that requires growers to capture drainage and run-off and also to accommodate mechanization equipment and general cleanliness.

A hydronic heated slab floor provides floor grown plants with very even temperatures. Most typically, a thermoplastic or synthetic rubber tube is used on 6"-12" centers, cast in the center or placed under the slab. Warm water is pumped through these tubes from manifolds placed at an accessible location, usually at one end of the greenhouse.

Unlike systems that heat air, a heated concrete slab floor should be controlled by monitoring either the slab temperature directly or the soil media temperature.

Typical Heated Concrete Slab Floor



A heated concrete slab floor can usually provide 30-50% of the total conductive heat loss of a greenhouse. Most often, other type of hot water system (bare pipes, finned pipes, unit heaters or other system) is installed to supplement the floor system on cold nights. Also, many growers will install gas-fired unit heaters to carry the balance of the heat load.

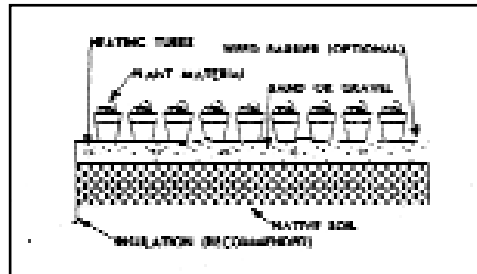
When selecting a heated concrete slab floor, it is important to consider many factors:

- The tubing you use must last as long as the concrete itself, so make sure it has been developed for your specific purpose. Use of irrigation tubing or other non-specific products can ruin the entire project.
- The type of concrete and the way it is mixed will have a long term effect on the durability and usefulness of your floor.
- Floor reinforcement: There are three basic methods used "re-bar", "re-mesh" and "fiber-mesh". The latter is an additive to the wet concrete and reportedly can offer the most integrity and longevity. Spend some time researching the best means of reinforcement for your project. Remember that you will need to secure your heating tubing to something and a reinforcement mesh might be the best choice.
- Select a highly qualified contractor. It is imperative that there are no low or high spots that could affect plant quality when you irrigate. A good concrete contractor is worth an extra investment.
- Insulate! It cannot be stressed enough that a heated concrete slab floor should be insulated around the perimeter and as deep as the frost line in your area. Some reports indicate that up to 50% of your heat can be lost out the perimeter of a heated slab if no below grade insulation is installed. Some growers have even installed insulation below the slab. The best type of insulation to use is one of the extruded styrene boards, usually 1.5" - 2" in. thick.
- Engineering: A good design and plumbing plan are the keys to a well designed heated concrete slab floor. A well designed system will include an appropriate boiler and pump sized to handle the load. Also important is a means of balancing the flow of hot water to achieve even floor temperatures.

**FLOOR HEATING WITHOUT A SLAB** - Some systems can be installed on top of weed barrier or down in the sand or gravel of the floor of your greenhouse. These systems are quick and simple to install, but they do not provide the run-off protection of a slab.

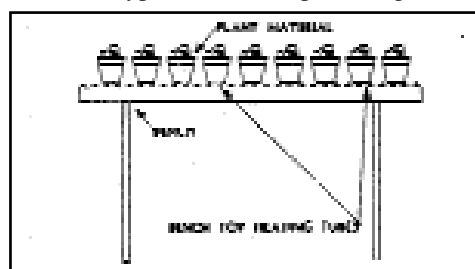
The most important facet of these systems is the requirement that the tubing used be able to withstand foot and cart traffic and abrasion from either plant material being set directly on top of it or from the shifting of the sand or gravel it is buried in. Buying quality materials will pay dividends over time.

Typical Floor Heating without Slab



**BENCH TOP HEATING** - Bench top heating systems use conductive heat transfer to deliver heat to plants placed directly on top of a multiplicity of parallel tubes. Small synthetic rubber tubes with high UV, heat and chemical resistance are placed on the growing surface of benches and contain warm water, which is circulated to and from a hot water supply typically a boiler.

Typical Bench Top Heating



These systems offer growers the ability to control the soil temperature of their plants and they also contribute a portion of the heating energy required to meet the total conduction heat loss of a greenhouse structure. Usually gas fired unit heaters are used to augment these systems.

A well engineered bench top heating system will be flow balanced in order to deliver the same amount of BTU's to each square foot of bench top. Usually a sensor is placed in a sample flat or pot to control the system based on media temperature.

Because bench top systems rely on conduction for heat transfer, many individual "zones" or separate temperatures can be maintained independently in one greenhouse structure without using partitioning walls or curtains.

Again, it is vital to have an engineered design to ensure proper performance of a bench top system.

**HOT WATER (HYDRONIC) UNIT HEATERS** - Hydronic unit heaters are enclosures equipped with a finned-tube heat exchanger and a fan. They utilize hot water from a hot water source like a boiler and extract heat from the hot water by moving air from the fan over the heat exchanger.

Hydronic unit heaters are often used as a way to supplement another hydronic heating system, like a heated slab floor system or bench top heating system. They are quick and very responsive to control inputs.

See the unit heater section of this document for more information on hydronic unit heaters.

**BOILERS** - All of the systems discussed in this section use hot water to do their jobs. They all rely on the availability of hot water and typically the hot water comes from a boiler system. Boilers come in many shapes and sizes. They also come in many styles, construction methods and materials.

Because the boiler is where the action of converting your fuel into heat energy takes place, it's important that you consider purchasing the most efficient boiler for your particular needs.

Remember, purchasing a boiler represents an investment not only in the initial equipment, but in how you will utilize fuel dollars for many years to come. Don't get caught up in the initial cost, try to project the operating cost over the life of the equipment to determine your best investment.

These are the most common boiler designs available for greenhouse heating:

- **Cast iron sectional boiler** - These boilers are the oldest designs and are still quite popular. They are manufactured by casting "sections" of cast iron. Each section has internal water passages and an external "fire-side" where the flames and flue gasses pass to transfer heat to the internal water. These sections are modular and can be bolted together in various quantities to make up a boiler package to fit individual needs.
- **Fire tube boiler** - Typically, the appearance of this type of boiler resembles a horizontal water tank and essentially that's what it is. On one end the burner is placed and on the other the flue collector and chimney attachment. In between are "fire-tubes" through which the products of combustion flow and as they go transferring heat to the water surrounding the tubes.
- **Steel water tube boiler** - With this boiler design water circulates through steel tubes. The flames and products of combustion pass over these tubes, transferring heating energy and then exit through the vent stack.
- **Copper water tube boilers** - These boilers are similar to the steel fire tube design except that they use copper tubes instead. Copper has a higher capacity for transferring energy and can withstand quick temperature changes that might adversely affect cast iron or steel boilers. Copper water tube boilers can be purchased in many designs and have finned heat exchanger tubes in most designs. They can only be fired using gaseous fuel sources, natural gas (NG) or liquid propane (LP).

Other considerations when considering a boiler purchase:

- Do you plan to expand your system later? If so, planning should be done now to eliminate expense in the future.
- Should you have multiple boilers to provide backup heating?
- Do you need the capability of burning multiple fuels?
- Do you require automatic switch-over between fuel sources or manual?
- Do you plan to recover CO<sub>2</sub> from the flue gas?
- Does your region require low exhaust emission equipment? Many areas of the U.S. are beginning to regulate the NOX (Oxides of Nitrogen, the basic component of smog) output of boilers. Do you need a low NOX system to comply with regulations in your area?

#### **INFRARED RADIANT HEATING SYSTEMS**

Any object that is warmer than absolute zero radiates energy. Approximately 50% of the sun's energy is infrared radiation or energy in the "far-end" spectrum. This spectrum of energy is not visible so it does not interfere with photosynthesis or

photo period sensitive plant material. Infrared energy travels at the speed of light, reaching the 93 million mile distance from sun to Earth in about 8 1/3 minutes. This energy is then absorbed by the Earth, objects on the Earth and then converted to heat. That's why it is warmer close to the ground than it is at 35,000 ft. in the air, even though that is closer to the sun.

The same concept is valid for greenhouse infrared heating systems.

Most Infrared radiant heating systems utilized in greenhouses are gas fired, low intensity tube systems. These tubes are installed in or near the peak of the greenhouse, and run the length of the house. The tubes are heated and the infrared energy from the heated tube is reflected to the crop, benches and below by an aluminum reflector mounted over the tube.

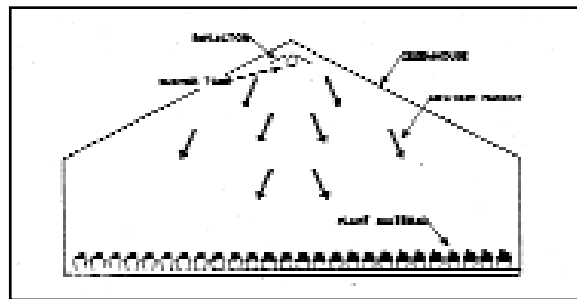
Conversion from fuel to heat energy occurs in the same way as in a boiler or unit heater. A small burner heats the air in a combustion chamber. The hot air is then distributed in a round steel tube which generally runs down the length of the greenhouse, near the peak. The heat energy is then transferred directly to the plants and the growing surface through electromagnetic waves traveling at the speed of light. The plants and growing surfaces then absorb this energy and convert it into heat, thus warming the plants and soil.

Infrared systems are easy to install in many applications and can provide an environment with warm dry leaves and may not require air circulation to transport BTUH's throughout the greenhouse.

Special provisions of some systems:

Some infrared systems have documented adjustment factors that provide a factor for sizing the input BTUH at a lower quantity than indicated by standard calculations. Using this factor the system will yield the same heating result as a system sized for the total conductive load. Most manufacturers can provide information about sizing adjustments for their equipment.

Typical Infrared Radiant System



### SMALL ELECTRICAL RESISTANCE SYSTEMS

Because electricity is typically substantially more expensive to heat with than other energy sources, these types of systems are not common in commercial environments. In most locations in the United States electricity costs 3-6 times what natural gas costs per BTU delivered. Propagation mats and cables: For small applications of bench top heating there are several choices of electrical resistance heating systems. These systems are typically installed for "spot heat", usually in spaces of under one hundred square feet.

Common systems are either rubberized or plastic encased mats that are pre-wired to a thermostat and wall plug or heating cables that can be buried in rooting media.

### "HYBRID" SYSTEMS

Many growers are installing multiple heating systems in an attempt to "get the best of all worlds." For example, on warm temperature nights they can rely on a bench top system only, and on the cold nights unit heaters are utilized to carry the worst case load and melt snow. Others are installing Infrared systems in conjunction with bench top heating systems.

By determining what your operation will benefit from most, you may be able to install your own hybrid approach.

*Note:* Many growers are installing **Supplemental Lighting Systems** in their greenhouses and, while these lights do produce heating energy, their energy output should never be included in the heating equipment capacity sizing. This is because of the fact that there are times when full heating is required and the lights may not be operated.

### APPLICATION CONSIDERATIONS FOR VARIOUS SYSTEMS

Every type of heating equipment has its strength. Depending on the type of production you are planning, you'll need to choose the style of system that integrates best with your production scheme.

For example, growers that install mobile tray systems for benching cannot install a bench top heating system because the bench tops need to be free to move around.

If you are planning to have a flooded floor irrigation system you might be well advised to install a heating system in the concrete floor.

If you are growing cut flowers or vegetables you may be best advised to have a hybrid system of a media warming hot water system in the row and utilize unit heaters for the balance of the heating requirement.

Or, you may desire to have a hot water piping system that is suspended in the actual crop. Some systems can even be raised along with the growth of the plants.

If you are growing hanging plants in your greenhouse you will certainly want to make certain your air temperatures are adequate and a unit heater system might be the best choice.

If you have the opportunity to utilize waste heat from an industrial facility you will need to apply a hot water based system to your facility.

There are almost endless variations and combinations that can be utilized to create the best environment for your particular production. It's simply a matter of determining your needs and researching the best options with expert industry professionals to develop the best strategy for you.

### CONTROL CONSIDERATIONS

Please see the NGMA document [Environmental Control Considerations for Commercial Greenhouses](#)

### INSTALLATION AND MAINTENANCE CONSIDERATIONS

#### FUEL SUPPLY

Piping to equipment must be in accordance with local codes, and ANSI Z223.1 National Fuel Gas Code for gas equipment or NFPA No. 31 for oil fired equipment. The piping should conform to the requirements for type and volume of fuel handled and pressure drop allowed in the line. Local Code adherence is very important for proper and approved installations. Installation by professional local companies assures proper operation of the equipment which in turn will provide long life of the equipment.

#### SPECIAL CONCERNS

- **Gas fired equipment** - Determine the usage rate of all the equipment to be served by the line. The usage rate is measured in cubic feet per hour. Using this CFH value and the total length of pipe necessary the pipe diameter can be determined.

Tank size is very important for propane systems. Liquefied Propane gas has to vaporize to provide the proper gas pressure in the supply lines. The size of the tank is one major factor that affects the vaporization rate. The temperature difference between the liquid gas in the tank and the outside air also affects the rate of vaporization. During cold evenings the difference in temperatures are decreased thus the rate of vaporization is lowered. This is a major concern because it is during these times that the demand for heat to maintain temperatures in the greenhouse are the greatest. Many propane systems include a gas-fired vaporizing device to ensure good vaporization on cold nights.

If the tank is not sized properly and the pipes are not large enough to allow the gas pressure to be replenished design temperatures in the greenhouses are at risk.

- **Oil fired equipment** - The piping for oil fired equipment requires even more professional capabilities. Oil fired systems can be installed with either a one pipe or two pipe system. Both systems have specific requirements for the proper adherence to local codes and thus proper operation of equipment.

Oil tanks and supply lines have limitations of the length of run available and/or vertical lift. If a long length of run is required in combination with vertical lift the system will require booster pumps.

Filters are highly recommended for proper operation of the oil burner.

### **ELECTRICAL**

A safe and efficient electrical system is of the utmost importance for proper operation of greenhouse heating equipment.

A qualified professional electrical contractor will work to provide an electrical system that meets the requirements for safety, efficiency and capacity. It is important to have a qualified installer do the work for all these reasons.

The heating equipment electrical demand will be a part of the total electrical load. Once the total load is known for a new location or an addition the local utility should be contacted to make sure your service is adequate.

Please refer to the NGMA document [Electrical Design](#) for a complete discussion of this topic.

### **MAINTENANCE**

During the later part of the summer it is time to start up the heating system. This is the time to make some routine checks which are necessary to ensure that your heating equipment will be ready to function properly in the fall and winter.

- Check equipment for physical damage. Check the sheet metal, fans and air movers, wiring fuel piping and vent system.
- Check for the cleanliness of the equipment's heat exchanger and burner.
- Check the vent system. Sometimes birds will make nests in the vent system.
- Check to make sure no obstructions block the air intake or air discharge of the equipment.
- Check lubrication of the motors on fans and pumps. With the power off check to see that the motor shafts turns freely.
- Check the belt tension on equipment that utilizes a centrifugal blower system.
- Check the heat exchanger of the equipment for any signs of cracks or corrosion. A flash light can be useful to check the inside and outside of the heat exchanger.



- Check the heat exchanger of the equipment for signs of overheating. Metal that has been over heated will have a dark discoloring of the area overheated. Overheating could be the result of over-firing, improper venting, or inadequate combustion air.
- Inspect the burner for general cleanliness. It is not uncommon to find that spiders or mice have nested in the control or burner area.
- Check the control wiring to make sure the connections are tight.
- Check to make sure the manual valves are opened.
- If your greenhouse has an alarm system make sure it is operational.

It is recommended that a record be kept of the date the heating equipment service was performed. It is also recommended that these same service checks be performed on a periodic basis throughout the heating season. By keeping a service record and updating it, it is less likely that this important maintenance will be overlooked.

## COMBUSTION AIR

All gas fired and oil fired equipment require a sufficient supply of oxygen to the burners in order to achieve efficient combustion. Without proper amounts of oxygen the gas or oil cannot be properly burned and poor combustion will result. National standards have been established which detail how combustion air should be supplied to fuel burning equipment. These standards can be found in the National Fuel Gas Code NFPA54.

Three items required for combustion to take place are fuel, oxygen and heat. All must be present. Otherwise burning will not start or will not sustain itself after it starts. Take away any one of the three and burning will stop.

A couple valuable tips which will insure proper combustion air are:

- If louvers are used as a combustion air source they must have one square inch of free area for each 1000 BTU burned. Louver dimensions do not guarantee equivalent free space. Metal louvers normally provide 60% free space. Example: A 20 by 20 louver would have a free area of 240 sq. in. (20 x 20 x.60)
- If mechanical combustion air fans are used provide 15 to 20 cu. ft. of combustion air for each 1000 BTU burned.

Historically, glass houses and walk in doors had enough cracks that would provide the free space mentioned. During the last decade the use of double polyethylene coverings have tightened up greenhouses. Many houses are so tight that adequate combustion air is not available. Recent advances in fuel burning product designs incorporate the ability to regulate and provide the required amount of combustion air from outside the greenhouses. These separated combustion advances take care of the combustion air needs and can also combat the negative air pressure problems caused by using up the oxygen in these new tight greenhouses. These new designs do not compete with the plants for the oxygen and allow the burning process to continue.

## VENTING

There are several rules to follow to assure proper venting of gravity vented equipment:

- Keep vent runs as straight as possible with few turns or bends.
- Never use a vent size smaller than the size recommended by the equipment manufacturer.
- All vents must terminate with a proper wind proof vent cap.

- Limit horizontal vent runs to a maximum of 75% of the vertical run. Example, if the vertical run is 10 ft. the horizontal run must not exceed 7.5 ft.
- Horizontal runs must be pitched with a minimum upward slope of .25 in. per foot of run.
- Vents must terminate a minimum of 2.5 ft. above any obstructions within a 10 ft. radius of the vent pipe.
- Always provide a drip leg as near to the equipment as possible. This is to prevent condensation of flue gases in the vent pipe from entering the equipment.
- Keep combustible material 6 in. away from single wall vent pipe.
- When venting into a common vent the area of the common vent should be equal to or greater than the area of the largest vent plus 50% of the area of all additional vents
- When venting into a common vent, the individual vents should enter at different levels.

The rules for power vented equipment generally are the same as gravity vented equipment with the following exceptions:

- Approved power exhausted equipment may have its vent system terminate horizontally out of a wall. A proper vent cap must still be installed.
- Horizontal run lengths may exceed vertical run lengths. The combined total run length must not exceed the manufacturers recommendations. If elbows are used in the vent system you must attribute 6 ft. of equivalent length of run for each 90 degree elbow.
- If a vent terminates horizontally out a wall make sure it does not terminate near an air inlet opening. A minimum of 3 ft. is recommended.
- Make sure the horizontal vents are sufficiently high enough or guarded so as to prevent accidental contact by people or equipment.
- No common venting should be utilized.

### REFERENCES

- NGMA Standards
- NGMA Guidelines
- National Fuel Gas Code, Published by the National Fire Protection Association and American Gas Association

OTHER PUBLICATIONS AVAILABLE FROM NGMA

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