ROBERTS GORDON®

# Gas-Fired Infrared Heating for Greenhouses

*Quality in Any Language™*



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This document is intended to assist licensed professionals in the exercise of their professional judgement.

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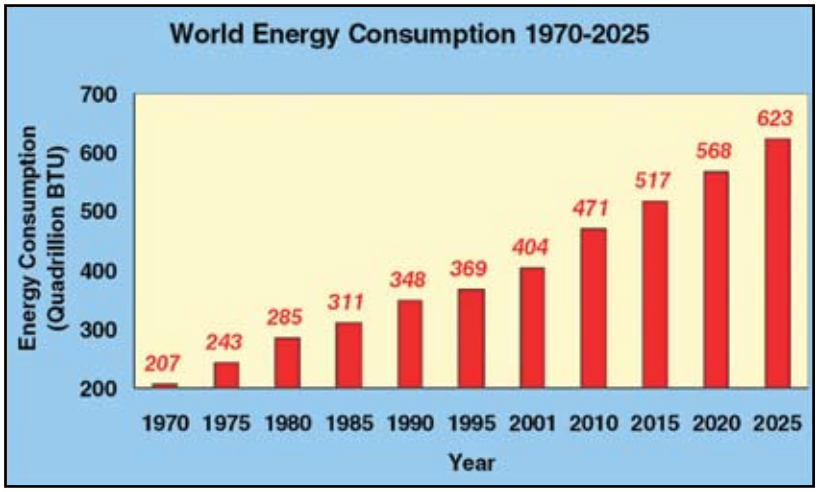
## PREFACE

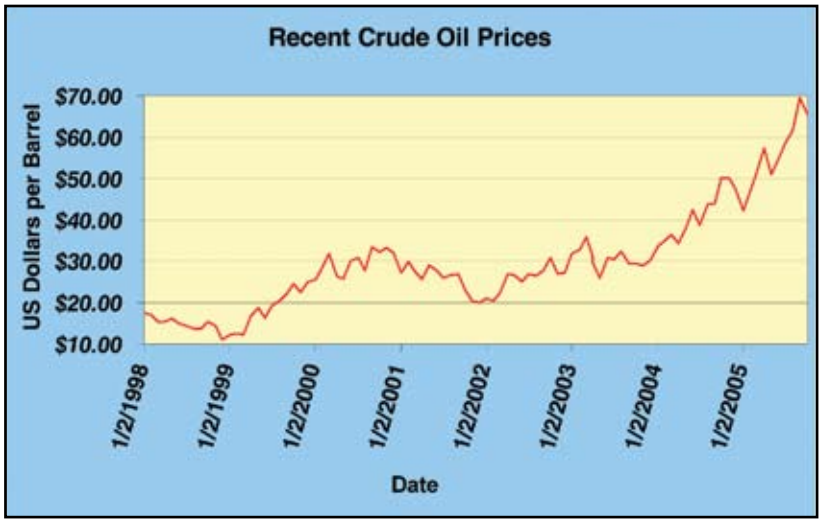
### Energy Costs

The world's energy demand has steadily risen as industry and world markets have grown. This is predicted to continue to rise as shown in graph #1. With demand continuing to increase and supply soon to be decreasing, energy costs could skyrocket at an unprecedented pace.

Oil prices have risen to 300% of what they were at the beginning of 2002. Typically, natural and propane gas prices rise as the cost of oil increases. Propane is a by-product of other fuel processing methods (natural gas processing and oil refining); its price follows demand and availability of those commodities. As these trends continue, there is a need for fuel-efficient Heating Ventilation and Air Conditioning (HVAC) equipment in all buildings, including greenhouses.




*Graph #1* [1]




*Graph #2* [1]

### Energy and Greenhouse Operation

Owners and operators are continually increasing their greenhouse production as they implement automated technologies and better utilize their greenhouse space. With new techniques and increased education, growers are consistently producing better quality crops. With increased production and better looking, higher quality plants, why are greenhouse owners seeing lower margins and/or decreasing profits? Owners and growers have an intense focus on the end product. With plant health and quality always at the forefront, some greenhouse owners have not yet set aside the time to investigate how rising energy costs are directly affecting their bottom line. Energy costs are dramatically impacting the profitability of the greenhouse industry.



1. Energy Information Administration, June 2005 Monthly Energy Review www.eia.doe.gov

With heating and energy costs in the top two or three largest expenses for greenhouse owners (labor usually being the largest expense), greenhouse businesses will have no option but to find new ways of heating their greenhouses efficiently.

Infrared heating is commonly used in commercial and industrial applications (e.g., warehousing, manufacturing, vehicle maintenance facilities). In recent years, gas-fired, low-intensity infrared heating has grown quickly in popularity for use in agricultural applications because **energy savings of up to 50% can be achieved** over traditional heating systems. Momentum for this technology increases as energy costs rise and farmers and growers spread the word.

The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) has acknowledged the fuel saving characteristics of infrared heating over conventional heating systems in the HVAC Applications ASHRAE Handbook (Chapter 15).

In the greenhouse industry, infrared heating is largely unknown or misunderstood. The purpose of this manual is to facilitate better understanding of infrared heating and to help facilitate proper design and layout in a greenhouse application. Once applied and installed properly, growers can enjoy an improved growing environment and obtain significant fuel savings over traditional heating systems.

## PART 1: INFRARED HEATING

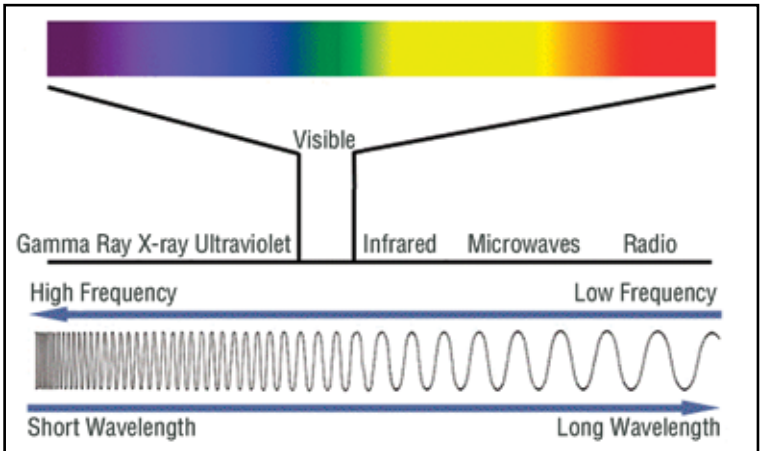
### 1.1 Infrared Heating: A New Concept?

Primitive people had only the sun to keep them warm. Then they discovered fire. Sun and fire both give off infrared heat energy. The sun's infrared energy is beamed "downward" toward Earth. Fire sends heated air, combustion gases and smoke upward, but the heat felt from fire radiates in all directions, not just upward. Thus, the popular idea that "heat rises" is not entirely true; in reality, infrared heat travels in all directions from the sun or from a fire. Rather than saying that "heat rises," it more accurate to say that warm air in the presence of cooler air rises. This describes warm air heating, a process that is entirely different than the process of infrared heating.

The sun is 93 million miles away from Earth's surface yet can heat the entire earth. This is the most significant example of the effectiveness of infrared heating. While the principle is as old as the sun, the application for its use today may seem very different than the currently accepted means of heating. For those who have only been exposed to conventional methods of heating, the concept of infrared heating opens up a whole new process of heat transfer. Understanding the principle of infrared heating has enabled Roberts-Gordon to develop highly effective and efficient heating systems. Products manufactured by Roberts-Gordon utilize the same principles as the sun when heating the Earth.

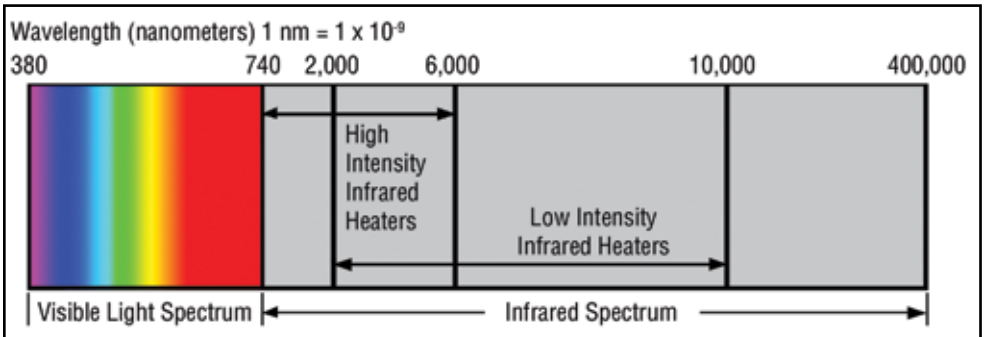
### 1.2 The Electromagnetic Spectrum

The sun gives off a wide variety of electromagnetic energy. The electromagnetic spectrum differentiates all known types of electromagnetic energy by measuring the wavelength of the energy. The wavelength is measured in microns (one million microns are equal to one meter). The shortest wavelengths in the visible light spectrum are violet and blue light. Then, as the wavelengths get longer, we see green, yellow, orange, and finally red. Those rays with wavelengths longer than red are called infrared.




*Electromagnetic Spectrum*

In 1800, an English astronomer named Sir William Herschel believed that the heat we feel from the sun is present in the visible spectrum. As he experimented with a prism to diffuse light into its visible color components, he discovered that violet and blue light carried the least heat. As he moved the thermometer through the spectrum of colors toward the red color, the temperature on the thermometer rose. It was actually beyond the red spectrum that the highest temperature was reached. This spectrum of longer wavelengths was named the "infrared spectrum."



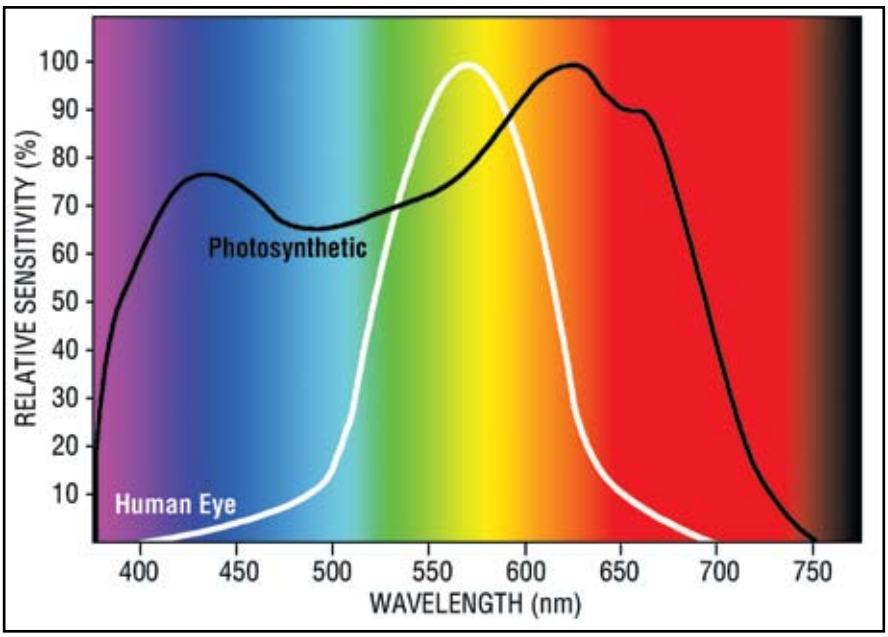

*Infrared Spectrum*

Roberts-Gordon has developed gas-fired, low-intensity infrared heating equipment that can be used for low-intensity heating. Low-intensity infrared energy is ideal for heating plants grown in greenhouses. High intensity infrared is often associated with electric infrared heaters and gas-fired infrared heaters with ceramic grids, which glow red. High-intensity infrared heaters can be used to provide work space spot heating, but are not desirable for heating plants. Some plants respond to the red glow of high intensity heaters in a way undesirable to the growers of the plants. Many plants initiate and develop flowers based on the ratio of uninterrupted darkness to the length of the day in a 24-hour cycle. Interrupting the dark cycle with red light from a high intensity heater may have an undesirable effect in flower formation and development. Since the heat exchanger tube on gas fired, low-intensity infrared heaters does not give off light in this way, it has not shown to have this effect on plants.

### 1.3 Plant Photosynthetic Response and Photosynthetic Active Radiation

As shown in the graphs above, low-intensity infrared heaters emit energy with wavelengths ranging from about 2,000 nm to 10,000 nm. The part of the light spectrum that plants respond to for photosynthesis is referred to as photosynthetic active radiation (PAR). PAR has a wavelength range of about 380 – 740 nm — shorter than the 2,000 nm – 10,000 nm range for low-intensity infrared). Electromagnetic energy in the 380 nm to 740 nm range makes up the visible light spectrum.

Plants and humans do not share the same sensitivity to the various wavelengths of visible light. Plants are most responsive to light in the red region, around 620–640 nm. Plants also have an elevated response to blue light.



## 1.4 Types of Gas-Fired Infrared Heaters

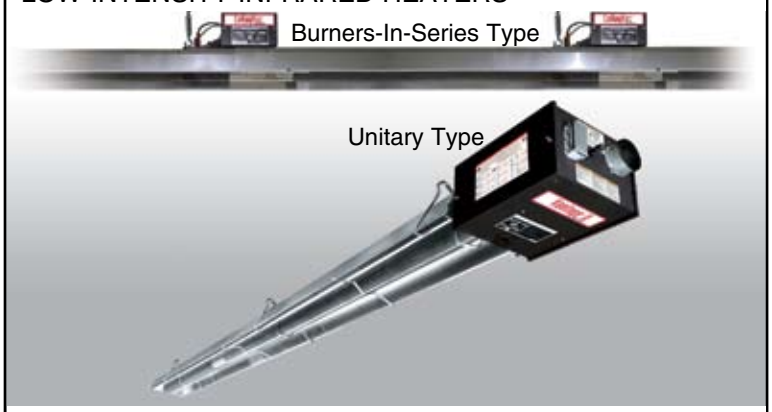
Infrared heaters are usually classified into two simple groups, high-intensity infrared heaters and low-intensity infrared heaters. **High-intensity infrared heaters** mix gas and air behind a porous ceramic grid. The mixture of fuel and air is pushed through the small holes in the ceramic grid to the grid face. The mixture is burned on the surface of the ceramic, producing an open flame. The open flame on the surface of the ceramic produces the orange glow. The surface temperatures of high intensity infrared heaters are above 1500° F (815° C), generally between 1600° F (870° C) and 1800° F (980° C). The products of combustion enter directly into the heated environment. The infrared energy emitted from high-intensity infrared heaters has a higher frequency and shorter wavelength than that from low-intensity heaters. Since the physical size of the heater is small, the heat felt from the unit is localized in a small area and has higher intensity. Due to many factors, including open flame, localized intense heat and the red/orange glow, high-intensity infrared heaters are not well-suited for greenhouse heating.

HIGH-INTENSITY INFRARED HEATER

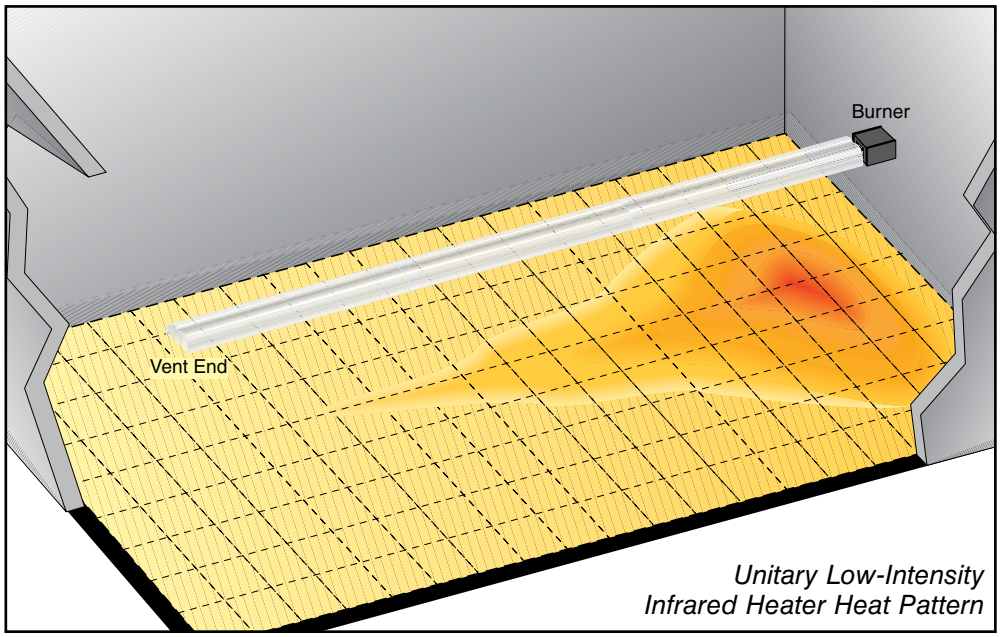
1600° F (870° C) to 1800° F (980° C) SURFACE TEMPERATURE
OPEN FLAME DIRECT FIRED (UNVENTED)

**Low-intensity infrared heaters** mix gas and air and then burn it inside a heat exchanger tube. The heat exchanger tube is usually made of aluminized steel, porcelain coated steel, a steel/titanium alloy or hot rolled steel. (Hot rolled steel heat exchanger tubing should not be used in greenhouses.) The heat exchanger tube surface temperatures of low-intensity infrared heaters reach maximum temperatures generally between 900° F (480° C) and 1100° F (595° C). Combustion takes place inside a heat exchanger tube and not directly in the heated space. The infrared energy emitted from a low-intensity infrared heater has a lower frequency and longer wavelength than high-intensity infrared heaters. Low-intensity infrared heaters have a long heat exchanger tube. This allows the heat to be spread over a much larger area compared to the more localized heat from high-intensity heaters. Since the surface temperatures are not as high, low-intensity heaters are less intense, resulting in a more comfortable environment for plants and people.

LOW-INTENSITY INFRARED HEATERS



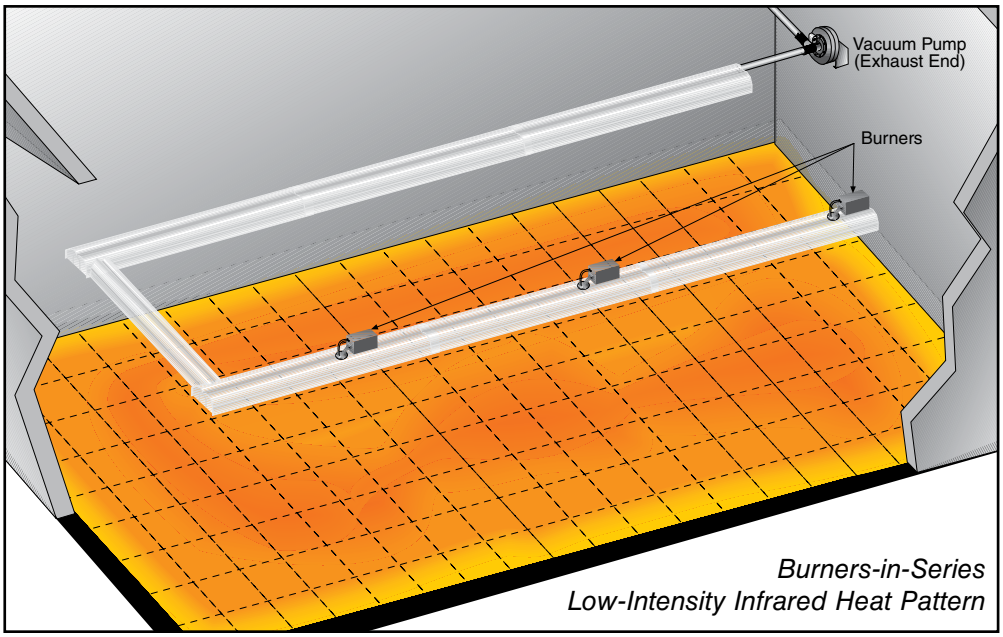

900° F (480° C) to 1100° F (595° C) SURFACE TEMPERATURE
FLAME ENCLOSED INSIDE HEAT EXCHANGER
INDIRECT FIRED (USUALLY VENTED)




*Unitary Low-Intensity Infrared Heater Heat Pattern*

Two major types of low-intensity infrared heaters are typically used in greenhouse applications: Unitary and Burners-in-Series. Unitary heaters have a single burner located at one end of the heat exchanger tube. The combustion takes place at the burner end, and the products of combustion are exhausted or vented at the opposite end. As a result, one end of the heat exchanger tube is warmer and gives off more heat than the other end. If the heater is mounted high enough, the end-to-end heat difference is minimized. Since most greenhouse buildings are relatively low (less than 20' [6 m] high), the difference in heat can be noticed from end to end. To minimize the uneven heat distribution, the heater can be installed in a U-shape. As a result of making a U-shape, the overall length of the heater is halved, reducing the area of heat coverage at the floor.

The Burners-in-Series type of gas-fired, low-intensity infrared heaters is most suitable for greenhouse installations requiring even heating. Burners-in-Series heating systems have multiple burners along the length of a heat exchanger tube. The burners are incrementally spaced along the heat exchanger tube to allow the heat exchanger tube to be reheated before surface temperatures cool. This type of infrared heating system offers heat distribution far beyond the capabilities of unitary heaters or high-intensity heaters. Overall heater lengths can be much longer and system shape is custom engineered to fit the greenhouse type. Multiple burners are vented through a single pump allowing fewer venting penetrations. Heaters with the trade name CORAYVAC® have a Burners-in-Series design.




*Burners-in-Series Low-Intensity Infrared Heat Pattern*

If properly designed, installed and used, virtually every commercially produced species of plant will respond well to the gentle and uniform heat of a CORAYVAC® system. CORAYVAC® is a linear system ideally suited to long, narrow greenhouse structures. Each burner recharges the heat exchanger tube with hot flue gases produced by burning either propane or natural gas. A pump at the exhaust end of the system pulls the hot gases through the system. By the time the gases reach the pump, nearly all of the heat energy has been released. The pump expels the flue gas outside the building at a temperature in the condensing range. Condensing of the gases releases considerable usable heat. Non-condensing boilers and gas-fired warm air unit heaters vent their flue gases at much higher temperatures, thus not taking advantage of this usable energy. With the CORAYVAC® heating system, the combustion and flue gases are always in a vacuum, eliminating the escape of flue gases into the greenhouse that could harm plants.

The heat exchanger tube is covered by an aluminum reflector that serves two purposes. First, the design of the reflector concentrates the infrared heat emitted from the tube to a 90° downward radiation pattern. This allows the system to evenly distribute the infrared energy over a floor area two times as wide as the system is high. For example, a system hanging 10' – 11' (3 m – 3.3 m) above greenhouse benches can evenly heat across a 21' (6.4 m) wide greenhouse. Second, the shape of the reflector prevents heated air, which surrounds the heat exchanger tube, from escaping. Retaining the heated air helps keep the heat exchanger tube warmer, thus allowing it to more effectively emit infrared energy to the objects below. Since different steel alloys and/or coatings on the heat exchanger tube have different emissivity (resulting in different outputs), placing different types of tubing along the length of the system can further enhance the evenness of heat distribution. The uniformity of heating achieved with CORAYVAC® is difficult to duplicate with any other type of heating system.

**Emissivity**

Materials and emissivities generally available in the industry.

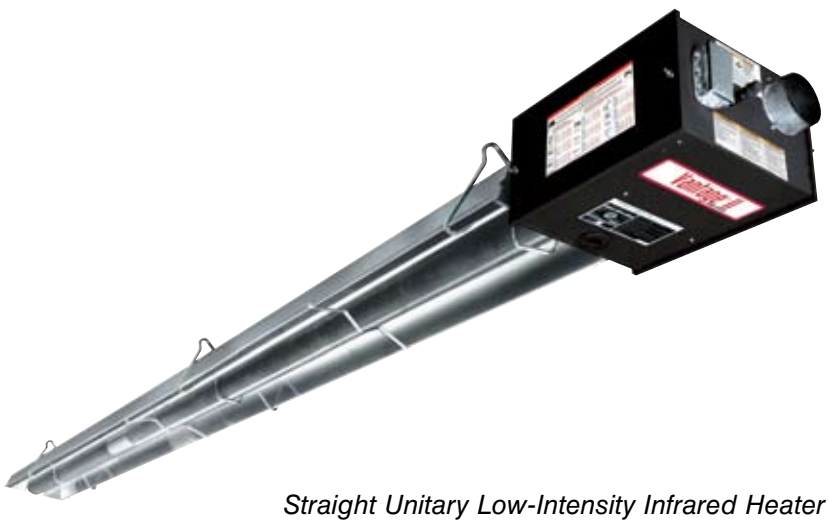
| Material | Emissivity | @Temperature °F (wavelength µ) |
|---|---|---|
| Plain Steel | 0.79 to 0.81 | 1000°F (3.6) |
| Aluminized Steel (Type 1) | 0.20 to 0.50 | 1000°F (3.6) |
| Aluminized Steel (Heat Treated) | 0.80 | 1000°F (3.6) |
| Porcelainized Steel | 0.92 to 0.96 | 100°F (9.3) |
| Cast Iron | 0.95 | 1000°F (3.6) |
| Stainless Steel (Type 304) | 0.44 to 0.62 | 1000°F (3.6) |
| Stainless Steel (Type 430 Polished) | 0.10 to 0.20 | 100°F (9.2) |
| Pyromark® Paint | 0.80 | 1000°F (3.6) |

**Reflectivity**

Materials and reflectivities generally available within the industry

| Material | Reflectivity |
|---|---|
| Tin | 0.94 |
| Chrome | 0.92 |
| Aluminum (Mill finish) | 0.91 to 0.95 |
| Aluminum (Polished) | 0.91 to 0.95 |
| Nickel | 0.90 |
| Aluminized Steel (Type 1) | 0.50 to 0.80 |
| Galvanized Steel | 0.72 |
| Stainless Steel (Type 304) | 0.48 to 0.66 |
| Stainless Steel (Type 430 Polished) | 0.80 to 0.90 |

Roberts-Gordon, LLC manufactures other types of gas-fired, low-intensity infrared unitary heaters under the trade names VANTAGE®, GORDONRAY® and BLACKHEAT®. These are unitary type products where a blower pushes or pulls air and gas through the heat exchanger tube, expelling it outside the building at the end of the unit. These units have a single burner on one end of the heat exchanger tube. Although they are not as uniform in providing heat distribution as CORAYVAC® systems, they have a great application in garden center sales and display greenhouses. These greenhouses are usually smaller in size and designed to be very open to allow customers easy access. The primary goal is to provide a human comfort level for the customers and frost protection for the plants on display. Growers also find these systems to be very effective for heating above transplant conveyor lines or auxiliary buildings such as soil handling centers, warehouses and shipping areas. Unitary heaters may be installed so that the heat exchanger tube is laid out in one of a variety of shapes. The most common heater installations are straight, U-shaped or with a 90° elbow.



*Straight Unitary Low-Intensity Infrared Heater*

*U-Tube Unitary Low-Intensity Infrared Heater*

## PART 2: CONVENTIONAL GREENHOUSE HEATING

### 2.1 History of Greenhouse Heating

Early greenhouse structures depended on their orientation to the sun to capture the sun's radiant heat. Often these glass structures were no more than a lean-to built on the south side of a thick stone or brick wall. The sun's infrared energy would pass through the glass, heating the wall and the soil. The heat sink built up in the wall would re-radiate into the space well after sundown. In the evening, the grower would place an insulated cover over the outside of the greenhouse to retain the captured heat until morning, when the cover would be removed. The earliest greenhouses were used to protect tender tropical plants from winter cold.

As glass became more affordable, growers began building glass structures to grow plants to sell. The technology of greenhouse heating is constantly evolving. In today's market, the most widely used heating systems are gas-fired, central wet systems (boilers), unit heaters (warm-air) and direct-fired heaters.

### 2.2 Central Wet Systems (Boilers)

Wet systems are among the most expensive greenhouse heating systems. Despite the cost, boiler systems have gained widespread acceptance and popularity due to their multi-functionality and good heat distribution. One of the uses is to melt snow; much of the pipe is placed overhead and under gutters. The pipes radiate heat in all directions. Convective heat also rises from the pipes. Consequently, rising convective heat and the heat radiating from the tops of the pipes keep snow and ice from accumulating above. However, much of the heat needed by the plants is directed upward and is transmitted through the roof of the greenhouse. Some growers using boiler systems find that the high installation, equipment and operating costs are outweighed by the benefits of good heat distribution and the increased yield associated with even, well-controlled temperatures.

Boiler efficiencies have improved, but this heating system still possesses inherent inefficiencies and high operating and maintenance costs that growers have come to accept. A single large boiler correctly sized for the heat loss of a greenhouse at outdoor design temperature conditions can be grossly oversized when temperatures are mild or few zones are calling for heat. This oversized condition leads to short cycling, which is inherently inefficient, although the use of staged boiler systems can reduce short cycling. As a result, many growers decide upon a system with lower upfront and maintenance costs.

### 2.3 Air Heating with Unit Heaters

Growers consider the gas- or oil-fired unit heater to be a compact, stand alone, inexpensive and acceptable method of heating. Unit heaters certainly provide less uniform heat than could be achieved with boiler systems. They are often placed at the gable end of the greenhouse with the heated air directed toward the middle of the house. Consequently, there tends to be an area in the middle of the house that is warmer than the sides and ends. Since the fan pushing air across the heat exchanger to the center of the house is drawing cold air from behind and below, the floor at the end of the house is cooler. Louvers on the unit heater can be positioned to direct some of the heated air downward to try to reduce immediate heat stratification. Perforated polyethylene tubes for air distribution can enhance the uniformity of air heating. The unit heater is positioned to direct the heated air into a powerful fan that pushes the heated air through the inflated polyethylene tube. The placement of the holes in the tube direct the heated air downward and across the house, improving heat distribution. Typically, however, the ends of the house and the floor remain cooler, while the cost of the additional fan adds to


*Gas-Fired Warm Air Unit Heater*

the cost of heating. In addition, dust particles can become magnetized to the poly surface (due to static electricity in the polyethylene tube). As dust and dirt accumulate, the tube darkens and creates a wide shadow on the crops below. Some growers believe the theory that moving air is good for plants, and leave the fan running day and night. Even with the moving air, the air temperature above the plants remains warmer than the plants themselves and the soil in which they grow.

*Unit Heater at Gable End of Greenhouse*

Considering the method in which air heating takes place, it becomes obvious that floor, soil and plant temperatures would always be lower than air temperature without additional heat sources. The heater first heats the air, and then the air must transfer its energy to the plants, the soil and other surroundings. Therefore, if air heating is used as the sole source of heat, the surface temperature of the soil or the plants can never rise above the temperature of the air. Only with the assistance of other heat sources such as infrared energy from the sun can surface temperatures rise above the air temperature.

Growers and researchers look for ways to deliver more uniform heat from unit type heaters. Heaters can be placed on the floor and an inflated tube can be directed under the benches or tables on which plants are grown. This works better for heat distribution, but impedes traffic flow and materials handling in the greenhouse. The belief of many growers that heat is introduced below the crop will warm the soil, and the plants will grow better. A new problem can arise as a result of passing warm air through the pots in which plants are grown. Warm air can hold more water vapor as humidity. The saturated air passing through the foliage can lead to water condensing on cooler surfaces such as leaves and flowers. If a condition allowing condensation persists for three or four hours, airborne spores of plant diseases can germinate in this microscopic layer of water on the foliage and penetrate the plant tissues, possibly leading to disease problems.

## 2.4 Gas or Oil-Direct Fired Heaters

Direct-fired heaters are another form of warm air heater. Direct-fired heaters burn gas and blow all the products of combustion directly into the area to be heated. The main attraction of direct-fired heaters is that one of the combustion by-products blown into the space is carbon dioxide. In addition to heating the air and providing a source of $CO_2$, the units have very high thermal efficiencies. Since hot products of combustion are not exhausted outdoors, there is no reduction in the thermal efficiency of the heater due to flue losses. Direct-fired heaters are self-contained units and, for greenhouse applications, generally smaller in physical size than most unit heaters, so finding space for installation is easy and installation costs are low.

The biggest drawback to direct-fired units installed within the greenhouse is that all the products of combustion are introduced into the greenhouse. Exhaust gases contain more than just $CO_2$. Among the other components of the combustion gases are water, oxygen and trace amounts of NOx and CO. Properly designed, approved, installed and used, operating units should not produce levels of NOx and CO that are dangerous. Care and maintenance of the units must be performed to guard against improper combustion that can lead to elevated levels of these by-products. Prolonged exposure to elevated levels of these gases can lead to crop damage.

In colder climates, where heaters may need to run longer to keep the greenhouse warm, $CO_2$ sensors should be installed to prevent $CO_2$ overdosing. If $CO_2$ levels rise over 4500 ppm, some crops will respond negatively. When direct-fired heaters shut off to prevent $CO_2$ overdosing and do not operate long enough to satisfy heat demand, it is apparent that another heating source is needed for supplemental heating. Growers in cooler climates need to provide an additional heat source, so unit heaters are commonly installed for this purpose.

## 2.5 Bench-Top Heating

Many varieties of bench-top heating have been introduced. One method gaining widespread use consists of very small hot water tubes spaced several inches apart on an insulated surface and covered with a mat or plastic woven material. Pumps and valves control the flow of heated water to each growing surface. This system is widely used for propagating seedlings or rooting cuttings. The soil is made warmer than the air above, causing seeds to germinate quicker. Roots form quicker on cuttings placed in warm soil when the leaf surface above the soil can be kept cool and moist by means of a timed misting system. These bench-top mat systems can be modified slightly so that they may be used for beds as well.

## 2.6 Attempts to Solve Inherent Heating Problems and Lower Heating Costs

To reduce heating costs, growers have been advised to grow at lower temperatures or switch to crops that grow at cooler temperatures. It is estimated that for each one degree Fahrenheit (.5 degree Celsius) reduction in temperatures, the cost of heating can be reduced 3%. Of course, all other operating costs remained nearly the same, so in some cases, the fuel savings does not compensate for the reduced yield and financial return from the crops. If yield and financial return declines, temperatures can be dropped for a portion of the night, preferably just before dawn. The thought is that if the plants are cool only a part of the night, they won't respond by growing slower. However, lowering air temperature raises humidity, increasing the potential for disease problems.

Because light intensity is important during the day but not at night, thermal curtains are quite popular. These curtains are drawn across the house during the night to conserve heat. Thermal curtains are relatively expensive to install, but are believed to reduce heat loss between 25% and 30%. However, the cost of a curtain system to save 25% to 30% of fuel costs may exceed the cost of a well-designed CORAYVAC® system, which may reduce heating and energy costs up to 50%.

Growers often use horizontal airflow fans to circulate air and attempt to gain a more even temperature. Moving air across objects such as plants and soil increases the rate of evaporation, thus cooling the plants rather than warming them. Moving heated air across roofs and outside walls also increases the rate of heat loss from the greenhouse. Growers justify moving air, with the belief that keeping the foliage dryer will reduce disease. However, plant disease is often caused by airborne spores, which are transferred by air movement, so the solution to one problem could cause another problem. Some efforts to conserve heat are merely an effort to try to cure problems of an inherently ineffective heating system.

All installation and service of the equipment mentioned above must be performed by a contractor qualified in the installation and service of that equipment and conform to all requirements set forth in the applicable manufacturers' manuals and all applicable governmental authorities pertaining to the installation, service and operation of the equipment.

## PART 3: Why Infrared Heating?

*CORAYVAC® Low-Intensity Infrared Heating System over Poinsettias*

Growers have traditionally relied on knowing the air temperatures in their greenhouses, as nearly all crop recommendations are based on the air temperature required for best growth. Growers install aspirated thermostats with small fans blowing air across shielded sensors to more precisely measure and control air temperature. While this may satisfy the grower that the most advanced methods available to control the air temperature are being used, the most important questions remain unanswered:

- What is the temperature of the plant?
- What is the temperature of the soil?
- How do conditions influenced by sunlight, humidity and air movement affect the relationship between the plant temperature and the air temperature?

The concept of heating plants with infrared energy changes the way a grower must consider environmental control of the greenhouse.

Gas-fired, low-intensity infrared heating systems manufactured by Roberts-Gordon have proven their effectiveness in duplicating the principle of the sun's heat. CORAYVAC® systems have been used in commercial greenhouses effectively and efficiently since the early 1970's, although low-intensity infrared systems have not yet gained widespread popularity and acceptance as heating systems. Some growers have found that CORAYVAC® heating systems exceeded their expectations and proved beneficial in many ways for a variety of greenhouse crops. When properly designed, installed and used, they offer many advantages over conventional heating systems.

### 3.1 Benefits of Infrared Heating

### Designed for Energy Savings - Fuel and Electricity:

Once a grower understands how and why infrared heating works effectively in the greenhouse, the first question asked may be: "What are my energy savings?" Converting fuel, whether natural gas or propane, into infrared energy is a very efficient transfer of energy to usable heat.

By using the benefits of infrared heat transfer and by harnessing the usable energy along the entire system, CORAYVAC® can evenly and effectively heat greenhouses with a fraction of the fuel required by conventional heating systems.

Additional economy from reduced electrical use is attained because infrared heating is accomplished without moving air to transfer heat. Adding the savings of eliminating fans for air movement and de-stratification to the savings in fuel consumption, CORAYVAC® becomes a highly efficient method of heating a greenhouse. A CORAYVAC® low-intensity infrared heating system is hung from the structure, suspended in air above the plants. In a CORAYVAC® system, the burners fully pre-mix air and gas before the mixture is burned in the combustion chamber. The infrared energy is beamed from the tube's surface or redirected by the reflector down toward

the plants, floors and objects below the heating system. The warmer (as long as it does not exceed approved temperature) the heat exchanger tube temperature and the greater the reflectivity of the reflector, the greater the rate of heat transfer by the infrared rays. Infrared rays do not need a medium such as air for heat transfer to occur; the infrared rays pass through air until they strike an object.

Once an object is struck by the infrared waves, heat transfer to the object begins. The objects can be plants, the floor, soil, benches, trays, people or surrounding equipment. Assuming the object is not reflective, the object absorbs the infrared energy and the energy heats the object. It then begins to transfer its heat to surrounding objects. This secondary heat transfer is in the form of re-radiation, conduction and convection. Heat can conduct from leaves to other parts of the plant and from the soil to adjoining soil and plant roots. This is one of the keys to the even heat created by a CORAYVAC® low-intensity infrared heating system. By directly charging objects with infrared energy, an infrared heating system is not limited to heat transfer by only heating air (called convection) as done by traditional heating systems. An infrared heating system transfers heat to objects first by the infrared rays; the heat "charge" in the object allows the secondary heat transfer processes from those objects to take place by radiation, conduction or convection in all directions. Spreading the heat to multiple surfaces elevates the mean infrared temperature of the entire indoor environment. The heated objects will also transfer heat to the air by convection and raise the air temperature.

*CORAYVAC® Low-Intensity Infrared Heating System over ferns in hanging baskets and on benches.*

**Reduced Heat Loss:**

The plants and soil become the heat exchangers in the greenhouse and transfer their heat to the surrounding objects and air. As a result, the plants and soil may be 3° F (1.7° C) or more higher than the surrounding air temperature during a heating cycle. This difference between plant temperature and air temperature is not enough to fully stratify warm air in the greenhouse. The air temperature remains nearly the same anywhere in the greenhouse from the floor to the peak. In an air-heated greenhouse, the air temperature may be as much as 1° F (.5° C) warmer for each foot higher of elevation. When this occurs, the temperature of the warm air floating to the top of the greenhouse may be 10° – 15° F (5.5° – 8.3° C) warmer than the desired plant temperature. It is the increased temperature difference between the inside and outside wall surfaces that causes higher heat loss with air-heated buildings.

## Reduced Heat Loss Calculation:

Due to the heating capability of low-intensity infrared heating, and because infrared heating reduces heat loss from infiltration, stratification and transmission, the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Handbook for HVAC Systems and Equipment calculates a reduction in heat loss of 15%–20% in buildings with this type of technology. The cost to heat a building with low-intensity infrared heating is therefore directly reduced.

In contrast, with a conventional heating system, the builder must calculate the heat loss value of the building, and then add in the cost of losses due to equipment inefficiencies. Such losses can be in the form of stack losses or transfer losses, as in the case of boiler systems.

## Equipment Requirements:

A comparison can be made between the input requirements of a boiler system and an infrared system.

**Boiler Capacity = Building heat loss + 15% (for water boilers)**

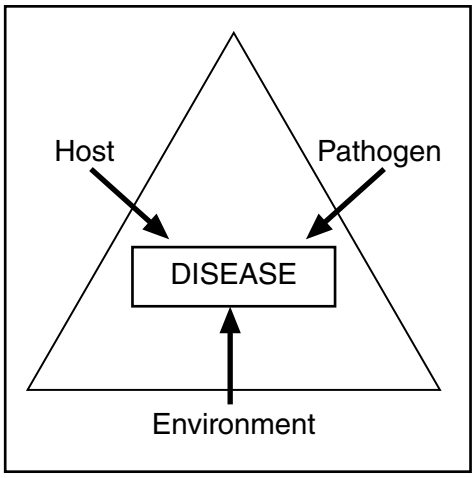
**Low-Intensity Infrared Heating System Capacity = Building heat loss - 15% to 20% (depending on heater type)**

**Low-intensity infrared heaters require 30% to 35% less heating capacity to heat the same building.** The potential fuel savings are up to 50% even before electricity is taken into consideration. Boiler systems require pumps to circulate the water throughout the building. A typical CORAYVAC® system uses a fractional horsepower pump for exhausting flue gases from multiple burners, resulting in lower electricity consumption than some of the other heating systems.

## Reduce Disease Incidence:

To help reduce the chances of plant disease, growers try to eliminate one of the components of the **plant disease triangle.**

The three sides of the plant disease triangle represent the three components necessary for plant disease to occur. The three components are the host, the pathogen and the environment. The **host** is the plant or part of




the plant. The **pathogen** is the biological infectious agent (i.e., virus, fungi, bacteria, plant parasitic nematodes, phytoplasmas). The **environment** creates a condition conducive to the spread and/or manifestation of the disease.

Heating with a well-designed, installed low-intensity infrared system can, in many cases, help to interrupt disease-conducive environmental conditions, thus breaking the plant disease triangle. Two of the most common conditions that encourage many plant diseases are plant wetness/free moisture on plants and high humidity. These common greenhouse conditions are controlled very effectively with infrared heating.

Since infrared heating keeps surface temperatures above air temperatures, surface moisture is evaporated more rapidly than is possible with conventional heating systems. Low-intensity infrared heating therefore can help the grower to effectively control humidity– one of the key environmental factors leading to many diseases. This natural and beneficial "side effect" of elevated surface temperature happens with even-heating infrared systems and occurs without the grower applying any special techniques.

The ease of controlling free moisture on plants is a tremendous benefit of infrared heating. According to plant pathologists, free moisture/plant wetness promotes the following diseases:

- Fungal Leaf Spots — Cercospora, Alternaria, Collectotrichum
- Gray Mold (Botrytis Blight)
- Downy Mildew
- Leaf Rusts
- Bacterial Leaf Spots — Xanthomonas, Pseudomonas
- Root Rots — Pythium (Black Rot or Water Mold), Phytophthora (Crown Rots), Rhizoctonia, Sclerotinia Sclerotiorum (Cottony Rot). *Periods of plant wetness, as well as wet potting medium allow a suitable environment for root rots. Infrared heating keeps the soil warm to help control periods of overly wet soil medium.*

Disease can also be spread by insects in wet environments. Certain insects thrive on algae growth on pots, soil, floors or benches in wet environments. These insects can deliver bacteria or fungus-causing diseases like Thielaviopsis root rot (black root rot). Since infrared heating quickly evaporates moisture on all of these surfaces, it can interrupt the wet environment and help to prevent the environmental conditions that attract insects. Insects that thrive on wet environments include fungus gnats and shore flies.

## Heat Where Needed:

The greenhouse grower has three locations to grow plants: on the floor, on raised benches or as hanging plants suspended from above. With warm air systems, it is most difficult to evenly heat plants grown on the floor. This is particularly true when a bedding plant grower first begins growing in a house that has been unheated during the winter. The floor may even be frozen when the first flats of annuals are set out, which delays root development and slows growth. With raised benches, the plants are grown a few feet above the floor. Since growers know that stratification from traditional air heating can cause increasing air temperature toward the higher parts of the greenhouse, thermostats are usually placed slightly above plant level so the air temperature at the plant is more accurately monitored. Plants grown in hanging baskets overhead are located closer to where warm air accumulates in the peak of the greenhouse, so the grower has less temperature control over plants grown overhead.

CORAYVAC® low-intensity infrared heating helps solve these problems. Infrared rays heat the hanging plants, plants on benches and plants in containers on the ground, as well as the soil below the containers. As the infrared energy penetrates the soil, it is converted to heat, warming the soil and resulting in quick rooting action and accelerated plant growth. In a greenhouse consistently maintained at a uniform temperature, the grower will find very little difference in the temperature of the soil and plants from the floor to the ceiling.

CORAYVAC® systems are linear, so they deliver infrared heat in a manner that can be compared to flourescent tubes delivering light. Flourescent tubes producing a linear source of light do not create harsh or well-defined shadows. By contrast, a light bulb is a compact source, so an object blocking the light from a bulb will cast a well-defined shadow. In a CORAYVAC® the heat is emitted from a linear source, so infrared shadow effect is minimized. If an object can “see” the heat exchanger tube or reflector, it will receive infrared energy from the CORAYVAC® system. Any remaining objects that cannot see the tube or reflector can still benefit from the re-radiation and conduction of heat from surrounding objects, as well as from the convective heat transfer from the air.

## Practical Design and Zone Heating:

Greenhouses are usually built as long, narrow structures. This shape requires a heating method that is adapted to the configuration of the greenhouse. The custom designed layout of CORAYVAC® heating systems are easily adapted to deliver uniform heat to an area 150' (46 m) long or even more. Houses 300' (92 m) long can be equipped with two CORAYVAC® systems where the first burners in the series (end burners) are located in the middle of the house, with the pump exhausting flue gases located at each gable end. Gutter connected houses are easily equipped so that each house can be treated as a separate heating zone. The heated area of each zone can be so precise that temperature differences can be maintained without a dividing wall or curtain separating the zones.

*Zoned low-intensity infrared heating for different plant needs.*
*One zone in foreground (right), another in background (left).*

*CORAYVAC® Low-Intensity Infrared Heating Systems heat the cold gable end of a greenhouse.*

**More Productive Use of Space:**

Since CORAYVAC® systems can be designed to uniformly heat the entire greenhouse, growers are finding that they can increase productive space. Gable ends of houses that were cold when heated with air heating systems can be converted from aisles to production areas with CORAYVAC®. Growers are finding that they can grow layers of plants from the floor to the peak and still have uniform temperatures.

Layering plants in this fashion multiplies the grower's revenue per square foot of greenhouse space. Foliage plant growers grow their most shade tolerant plants on the floor and those requiring more light on benches or as multiple layers of hanging baskets — without having to worry about even heat. The limiting factors are more related to visible light as it filters through the layers, rather than to uniformity of heating.

## Overhead System:

The entire CORAYVAC® system is located overhead, as high as possible in the greenhouse. The distribution width of uniform heat transfer is approximately two times the hanging height of the heat exchanger tube: i.e., if the system is hung at 15' (4.5 m) above the floor, it will distribute an infrared pattern at the floor that is 30' (9.1 m) wide. *See Page 39, Section 8.3.2* for a typical pattern. In wider houses, particularly in colder climates, two runs of CORAYVAC® may be required. In that case, each system is suspended between the gutters and the

*CORAYVAC® Low-Intensity Infrared Heating System installed near roof ridge.*

ridge so that each run of burners will heat half the house lengthwise.

## Quick Recovery:

The moment the flame ignites in the combustion chamber, the heat exchanger tube quickly heats. Infrared heat begins to be emitted as quickly as the heat exchanger tube warms. Within a few minutes, one can begin to feel the heat transmitted from the tube. The quick response time is much different than central wet systems or warm air systems. The system does not need to heat and then pump large volumes of water or air and blow it through the house before an effect can be felt. A CORAYVAC® system is able to efficiently deliver the heat needed directly to the plants — moments after the call for heat is initiated.

## Dependability:

CORAYVAC® systems have proven to be extremely reliable. If one burner in a series of burners fails to ignite, the other burners will continue to operate. Multiple burners that do not depend on the other burners for operation create a degree of redundancy that results in reliable and dependable performance. CORAYVAC® systems are mechanical equipment and, as such, must be maintained. Growers should keep some essential parts in stock so that a quick and easy repair can be accomplished. Every grower should install temperature alarms in the greenhouse to provide an alert if there is power failure or mechanical problem causing temperatures to drop. Snow sensors in northern climates can be installed that will automatically start heating systems in unheated

houses.

### Uniformity of Heating:

When a greenhouse is devoted to production of a single seasonal crop, such as Easter lilies or poinsettias, it is important to bring the entire crop to maturity in a timely manner. The grower must have precise control of the temperature in the entire growing area. Cold corners, sides and ends delay crops, causing missed finish dates and longer crop rotation. A well-designed CORAYVAC® system may provide a +/-1° F (+/- .5° C) temperature differential over 95% of the greenhouse growing area. This control is a tremendous advantage for the precision grower who wishes to maximize quality and productivity.

*Uniform chrysanthemum growth with CORAYVAC® overhead.*

### Even Plant Temperature Throughout the Day and Night:

During the day, greenhouses require a heating system to run less often than at night, as the sun's infrared rays enter the greenhouse and is absorbed by the plants, soil, walkways, equipment and fixtures. Just as when these objects are heated with infrared heaters, the objects absorb the infrared energy and are heated. As the heated objects become warmer than the surroundings, they re-radiate and transfer some of their heat away, which helps to heat the air and other cooler objects. When the infrared heat from the sun is gone, plant and soil temperatures drop below the air temperature, as they re-radiate their heat away to the surroundings. Conventional heating systems do not raise the soil and plant temperatures like the sun does, so when the plants cool, they rely solely on the surrounding air temperature for warmth. The fluctuation in plant temperature creates an additional stress on the plant, so growers try to keep temperatures as consistent as possible. Although growers can maintain an even air temperature with conventional heating, the actual plant temperatures fall at night. Infrared heaters heat the plants and objects first. Due to the nature of the heat transfer from the infrared heating system, the plant temperature remains above the air temperature, just as the sun keeps plant temperature above air temperature during the day.

### Creates a Heat Sink:

Engineers refer to the capacity of the soil in pots, beds, and floor areas under benches to accumulate heat as a heat sink. Since infrared energy is directed downward in a greenhouse and the conversion of energy to heat occurs in both the soil and the plant material, should a power failure occur on a cold night, the grower can rest comfortably knowing that a huge mass of warm soil underlies his greenhouse crop.

### Penetration at All Levels:

Soil in shallow containers, such as seedling trays or bedding plant flats, warm up within hours of being placed under infrared heating. Soil in pots and large containers may take several days to reach the temperature of the thermostat set point. The results are consistent throughout the growing area of the greenhouse at all levels. Because of the warming of the soil, the grower can count on quick establishment of roots on newly transplanted plants.

*Quick germination and fast establishment of transplants.*

## Maintaining Soil Temperatures:

An often asked question is: "If the canopy of foliage grows large, tall or dense, will the soil remain warm?" When small plants are first transplanted, a considerable amount of soil receives direct infrared rays, with little shade effect from the leaves above. Once the soil is warm, the temperature of the soil remains nearly constant. Once the foliage has grown, air heating systems must force warm air downward through the foliage. The foliage acts as a partial barrier, reducing air movement beneath it. Because colder air lies below the plants and warm air rises in the presence of cold air, it is even more difficult to maintain the desired soil temperature. During the day, the sun can assist a warm air system in heating the soil, but at night warm air alone can never raise the soil temperature above the air temperature. On the contrary, infrared rays pass through spaces between leaves, but also re-radiates from warm upper leaves to leaves below and then to the soil.

## Plant-Tissue Responds to Infrared:

Growers have often debated the relationship between soil temperature, leaf temperature, humidity and air temperature and their influences on plant growth. Plant tissue temperature is a key factor in greenhouse heating. To best measure plant tissue temperature, sensing devices such as thermistors that receive infrared energy at the same rate as plants can be used. Aspirated thermostats and thermistors used to measure air temperature will not give accurate information about plant temperature.

## Dry Floors:

In greenhouses with concrete aisles, wet floors are quickly dried by infrared heating systems. The aisles absorb the infrared energy in the same manner as the other objects under the heating system. Due to its elevated temperature, the warm concrete dries.

## Comfort:

Providing a comfortable working environment is a major concern for employers who wish to attract and retain good employees. Employees feel comfortable working in a greenhouse when the floor is as warm as the soil and plants with which they are working.

### Ease of Maintenance:

As with all heating systems, maintenance is required for efficient system operation. CORAYVAC® systems have a list of simple maintenance items. Since the entire length of the system is visible, some maintenance items can be completed during normal daily activities as a conscientious grower works below the system. Proper clearances of plants and combustible material from the system must be maintained. Nothing should be suspended or hung from the heating system. Heat exchanger tubes and reflectors should be secure and properly supported, without signs of wear or separation from the rest of the system. Reflectors should be kept free of debris, dirt and plant material. Vacuum pumps should be operating quietly without excessive vibration. Combustion chamber windows can be viewed during system operation to ensure the burners are operating. Annual maintenance includes: close visual inspection of pump, venting and thermostat or sensor wiring; inspection and/or replacement of filters; checking for proper vacuum reading; and confirmation that all burners are operating during system use. For complete details, see the CORAYVAC® Installation, Operation and Service Manual.

## 3.2 Shading Concerns

Growers realize the effect of shading and try to minimize shading whenever possible. Some growers question the total effect of shading from the reflector on the plants below. A CORAYVAC® system has a reflector that is 14" (35.5 cm) wide. Typical system layouts will have one run of CORAYVAC® along the roof peak. The many added benefits of CORAYVAC® far outweigh a 14" (35.5 cm) shadow, as the shadow's effect is so small. In cases where CORAYVAC® is used instead of overhead piping from a wet system, the shadowing may actually be less.

## 3.3 Infrared vs. Air Heating (Gas and Oil Direct Fired Unit Heaters)

Air heating systems usually cost less to install than a CORAYVAC® system. However, these systems usually cost the grower considerably more to operate. Air heating systems are deficient in two basic laws of heat transfer. First, due to natural convection, warm air in the presence of cold air rises. Infrared energy does not rise. Infrared heats objects, not air, so stratification of air does not occur to nearly the same extent. The reflector over the system ensures that the energy is directed downward where it is most useful. Second, moving warm air over objects (plants and soil) cools objects that contain moisture. Evaporation of water has a cooling effect. Properly designed, installed and used, CORAYVAC® systems will provide a much more uniform heat distribution compared to air heating systems. Zoning CORAYVAC® systems is easy; each branch of a CORAYVAC® system can be used to maintain separate temperature zones.

## 3.4 Infrared vs. Wet Systems

Steam and hot water boilers have been used for generations and have been traditionally accepted as the ultimate choice for heating greenhouses. That view is changing, as growers realize boilers and piping systems are expensive to install. Separate equipment areas or buildings are required to house boilers, adding to construction costs and using valuable floor space. On the other hand, CORAYVAC® does not take up floor space, and additional systems can be added as additional greenhouses are built.

While efficiency is being improved, wet systems are still a long way from being as fuel efficient and effective as CORAYVAC® systems. The recommended maintenance schedule for boilers can be expensive. If a boiler is shut down for repair, there is no heat source for the greenhouse unless a second expensive standby boiler can be put into operation. There is solid economic justification for replacing older boilers with new CORAYVAC® systems, as the payback can occur in just a few years.

## 3.5 Infrared as the Energy-Saving Option of Choice

Many solutions to enhance energy savings have been offered to growers. As discussed earlier, these proposed energy-saving solutions commonly create other problems, which need more solutions, and so on. With CORAYVAC® low-intensity infrared heating, the energy-saving problem is solved with energy savings up to 50% over conventional heating systems. On top of energy savings, an objective grower must consider the additional intrinsic benefits that may help enhance the grower's profits. Low maintenance costs, promotion of quick rooting and plant health, as well increased productive area, all add up to the overall profitability of the greenhouse.

## PART 4: COMMON QUESTIONS

When growers are first introduced to the CORAYVAC® system of heating greenhouses with a heat source mounted in the peak of the greenhouse, they often ask: "If heat rises, how can it work to put the heat source in the ceiling?" Growers also ask about the effect of CORAYVAC® on crops in a greenhouse. This section will attempt to answer the questions most frequently asked by growers.

### Will the Heat from a CORAYVAC® System Burn Plants?

A properly designed, installed and used a CORAYVAC® system is located high enough above plants so that its gentle, low-intensity, infrared wavelengths will not be intense enough to damage plants. Growers are often tempted to hang basket plants overhead, placing them nearer to the heat source. Because various types of plants respond differently to heat, some can be closer to the heater than others. The distance between the low-intensity infrared tube and the foliage should be at least 4–5' (1.2–1.5 m). (The distance can be determined by the heater's listed clearances to combustibles.) Keep in mind that it is not the infrared rays that damage plants but an excessive build-up of heat in the plant tissue that may cause damage. The intensity of the sun is much greater than the radiation given off by a CORAYVAC® system. On a hot day, the sun can easily raise the temperature of some objects up to 15° F (8.3° C) higher than the surrounding air temperature. In a properly controlled and managed greenhouse, plants are safe and will thrive when grown with low-intensity, infrared heating.

*Hanging baskets with growth toward the CORAYVAC® Heating System.*

## Will Dense Crop Foliage Block the Effectiveness of a CORAYVAC® Heating System?

When low-intensity infrared energy warms an object, that object will re-radiate energy to other nearby objects. Consequently, the temperature at all levels of the greenhouse remains nearly the same. Tall growing plants such as roses, cucumbers, peppers and tomatoes do very well grown under a CORAYVAC® system. The critical issue is installing the heaters at a sufficient height above the tops of tall plants. Generally, at least 4'–5' (1.2–1.5 m) above plant tops is recommended.

*Dense foliage under low-intensity CORAYVAC®.*

## How Will a CORAYVAC® System Affect Humidity in the Greenhouse?

In general, expect about a 10% drop in humidity while the CORAYVAC® system is operating. Humidity is a subject of much discussion and opinion among growers. What is known is: (1) plants wilt when the soil is too dry; (2) plants evaporate (or transpire) less moisture when humidity is high; and (3) incidence of airborne diseases increases as humidity increases.

## Can Productivity Be Increased With Infrared Heating?

There is evidence that productivity can be increased with a properly designed, installed and used CORAYVAC® system. Soil quickly warmed by infrared heating provides an environment for quicker germination of seeds and faster establishment of transplants. Growers may find that they can grow plants at a tighter spacing or grow plants at multiple layers in the greenhouse, thus increasing productivity.

## Will Infrared Heating Prevent Plant Disease?

Low-intensity infrared heating can help control environmental conditions that can cause some very common plant diseases. See Page 12, Part 3.1 for more information on how low-intensity infrared heating can reduce disease incidence.

## Are There Any Crops That Will Not Tolerate Low-Intensity Infrared Heating?

It would be difficult to find a greenhouse crop of any kind that has not been grown under a CORAYVAC® system. CORAYVAC® is installed in numerous commercial greenhouses with many varieties of plants.

## If CORAYVAC® Is So Good, Why Isn't Everyone Using It?

New products and new concepts take time to be accepted and adapted in a society. Greenhouse growers are no different. It takes time for the information to reach them. Many do not want to be the first to try a new concept. They are more comfortable allowing their competition to take the risks that may accompany a new product or technique. The question of cost and return on investment may make growers reluctant to try new products. As the cost of fuel and the need for fuel-efficient products increases, growers are looking for new systems and techniques for growing.

## How Long Will It Take for the Savings Offered by a CORAYVAC® System To Pay Back Its Cost?

Many variables affect this answer. In colder climates, the payback will be quicker. Greenhouses used all year will use the heaters more frequently and will provide a quicker payback. If comparing the cost of operating a CORAYVAC® system to the cheapest entry-level cost of a heating system, the payback for the entire system may occur in as little as 2 years. In most cases, the savings in fuel and electricity will provide an excellent return on the investment. The intangible savings, such as greater productivity and profitability, cannot easily be calculated but will add substantially to the return on investment.

## PART 5: CONTROLLING GREENHOUSE HEAT LOSS

### 5.1 Greenhouse Glazings:

Greenhouse glazings are selected for their properties of thermal insulation, light transmission, UV protection, structural strength and longevity, and price. Some companies that sell greenhouse glazings understand the efficiency and benefit of low-intensity infrared heating. Thermal poly films are being sold that (with fillers and coatings) selectively block certain longer wavelength infrared energy from escaping, trapping useful infrared energy in the building.

### 5.2 Greenhouse Curtains for Reducing Heat Loss:

Greenhouse curtains (also called screens, blankets or shades) are films or fabrics that are pulled across the greenhouse for various combinations of thermal and light control. Energy curtains retain energy in the greenhouse at night and lower the portion of the heat loss of a building through its roof. During hot days in the summer, the curtains (depending on material type) can be drawn to reflect the sun's heat back out, reduce the heat gain in the building, and provide shading. Some curtains are used exclusively for shading and do not have any heat-retaining ability.

Different curtain materials are used depending on the user's needs for shading, heat retention and porosity. Curtains can be made of porous woven materials, non-porous materials like polyethylene and aluminized woven fabrics, or aluminized strips woven through a mesh with alternating open mesh or clear materials.

Manufacturers of curtains with aluminum or aluminized type fabric content promote the ability of the curtains to reflect longer infrared rays that are emitted from warm greenhouse surfaces below the curtain back down into the greenhouse. These aluminized type curtains work well with low-intensity infrared heaters to keep secondary re-radiated heat in the greenhouse. Since infrared heating leads to less warm air stratification, some growers may find that they can select an aluminized curtain with a more open, porous fabric and need them less for blocking warm air and more for retaining and reflecting infrared heat back down to the plants and floor.

Curtains can be attached to the greenhouse structure from **gutter-to-gutter** or from truss-to-truss. Gutter-to-gutter curtains are pulled across the greenhouse at gutter height. Gutter-to-gutter curtains will hinder the proper operation and effectiveness of equipment located above gutter level, i.g., fans, unit heaters, boiler pipes, low-intensity infrared heaters, etc. **Low-intensity infrared heaters cannot be hung higher than gutter height if gutter-to-gutter curtains are installed.** Because low-intensity infrared heaters need to be mounted as high as possible to most effectively heat the largest possible area, they are not always compatible with gutter-to-gutter curtains. Proper planning up front will allow the greenhouse owner to make provisions for use of curtains with infrared heaters. If a greenhouse has sufficient gutter height to allow for proper clearances to plant material, mounting infrared heaters under the gutters is a possible option. Gutter-to-gutter, non-porous curtain systems help to restrict heated air from rising but they also hold the largest amount of colder air above them, which makes heat recovery more of an issue when the screen is retracted in the morning. In addition, there is a potential problem with trapping colder air at the roof. Although heat loss through the roof can be reduced when less warm air rises to the roof, snow cannot be melted off the roof as fast, creating issues with respect to weight of snow and strength of the structure. If porous curtains are used, stratification of warm air to the ceiling is slowed to some extent, but the warm air will still be able to flow through the curtain and rise to the roof.

**Truss-to-truss** curtains can be installed flat at gutter height, **slope-flat-slope** or **slope-slope**. Sloped installations require more labor for installation, but allow equipment to be installed and utilized above gutter level. Sloped installations minimize the volume of colder air that is trapped by the roof at night. Low-intensity infrared heaters and sloped curtain systems complement each other very well. The curtains are installed above the heaters so that they are not blocking the infrared heat from the plants.

Greenhouses are built with roofs and sidewalls that can open, and with mechanical vents and fans to allow ventilation on warm days. These features allow infiltration to occur around their edges and seams even while they are closed. Infiltration heat loss cannot be eliminated and is not reduced by energy curtains. It is important to maintain the greenhouse structure properly to minimize unwanted infiltration losses.

- Repair cuts, cracks or broken panels in greenhouse coverings.
- Seal gaps around mechanical vent inlets and cover inlets if they are not used in winter.
- If covers are not used on inlets, maintain louvers to ensure proper sealing when louvers are closed.

*Curtains installed above a CORAYVAC®*
*Low-Intensity Infrared Heating System.*

## PART 6: PLANNING AND DESIGN CONSIDERATIONS

A heating system must not only be reliable but also have the capacity to heat the greenhouse in all weather and cropping situations. In selecting a style, design and layout, consideration must be given to how well the heating system will fit and perform. Considerable cost savings and improved efficiencies could result if the greenhouse and the heating system are designed simultaneously. All parts should work well together and be compatible. If a CORAYVAC® system can be hung in a greenhouse to give a 2:1 ratio of width to height, it is likely that a workable design can be achieved. Longer houses of 100'–300' (30.5–91.5 m) or more offer additional design advantages. Installation in structures that have low rooflines is not recommended.

A grower should not design for the minimum heating load only. A grower who currently grows cool temperature crops may decide to switch to warmer crops. If the house is minimally designed, problems may result when warmer indoor temperatures are required during cold periods. Sometimes, an unusually long cold period will require more heating capacity than what is available. Greenhouses should therefore be designed to withstand the worst-case scenario.

### 6.1 Types of Greenhouses

#### Free Standing/Gutter-Connected Houses

Free standing houses have considerably more surface area, resulting in a greater heat loss. Building gutter-connected houses eliminates some side walls. The majority of heat lost from a greenhouse is lost through surface sides, ends and roofs. Minimizing the ratio of surface area to ground covered will reduce heat loss and increase efficiency.

*CORAYVAC® Low-Intensity Infrared Heating System in a gutter-connected glass house.*

#### Curved Roof Houses

Greenhouses with curved roofs come in many shapes and sizes. Curved roof houses are usually designed to be covered with two layers of polyethylene film. Air is blown to inflate the space between the layers and provide an insulating effect.

Curved roof houses are less expensive to build than glass houses and are a popular choice for growers who want production space at the lowest initial cost. Add a CORAYVAC® system to the equation, and energy savings will result. Most curved roof structures have adequate height to hang CORAYVAC® systems.

#### Arched/Bowed/Quonset/Gothic Arch Houses

Most arched, bowed or curved roof houses can be built on walls or posts of 14' (4.3 m) or more in height. Quonset houses are usually freestanding with the curved roof members originating at ground level. If the grower chooses to add height with a short sidewall, Quonset houses can easily accommodate a CORAYVAC® system.

Gothic arch greenhouses have a curved roofline, but still have a peak in the middle. Often the gothic style houses have roof venting that allows one whole side, or half of the total roof, to be hinged at the ridge for ventilation. Most gothic houses are built with posts that raise the house high enough to accommodate a CORAYVAC® system. The CORAYVAC® must be hung so that there is no interference with ridge-venting mechanisms.

*CORAYVAC® Low-Intensity Infrared Heating System in an arched poly house.*

## Saw-Toothed or Arched

### Saw-Toothed Houses

Saw-tooth greenhouses are built on posts, without a peak in the center. The roof spans from minimum height at one gutter to its maximum height at the next gutter. A vertical wall drops from peak to gutter and doubles as a vent. Most often, they are located in warm climates where very little, if any, heating is required. It is more difficult to design an effective CORAYVAC® system in a sawtooth house since the highest point of the roof is over a gutter rather than in the center of the house.

### Venlo Houses

Venlo houses began as narrow houses glazed with single sheets of glass from gutter to peak. They were about 10.5' (3.2 m) wide with posts about 10' (3 m) apart. As the style became more popular, builders adapted web trusses so that two or three spans of roof could be supported between the rows of posts. This allowed more freedom to work equipment and lay out growing beds. At first, the posts supporting the web trusses were short, making it difficult to install a CORAYVAC® system. Later house designs lengthened the posts significantly making it easier to design a CORAYVAC® system for this type of greenhouse. The CORAYVAC® must be hung so that there is no interference with ridge venting mechanisms.

## Retractable Roof Houses

Retractable roof houses have a traditional peaked design, but instead of a permanently attached roof, a reinforced flexible covering is used. The cover allows the roof to adjust from completely open to closed. While they are not energy efficient, they are very well suited for CORAYVAC® heating systems, because they have a peaked roof to allow adequate height for attaching the systems. Retractable roof houses are not as air tight as other house types. The higher number of air exchanges in a closed retractable roof greenhouse must be taken into account when designing a heating system.

*CORAYVAC® Low-Intensity Infrared Heating System in a retractable roof house.*

## Cold Frames and Hoop Houses

Cold frames and hoop, or tunnel houses, are constructed to provide minimal protection for plants. Because of their low and narrow profile, they are usually not heated and they are not well suited for CORAYVAC® infrared heating systems.

## 6.2 Heat Coverage

The reflector on a CORAYVAC® system is designed to give a uniform infrared pattern across the greenhouse. The proximity of burners in the system and the types of heat exchanger tubes control the uniformity of infrared heat lengthwise in the greenhouse. Factors such as width and height of the house also influence uniformity. Where height and width are limiting factors, uniformity may vary.

## 6.3 Clearances to Plants and Combustibles

Two clearances must be accounted for. The first is the distance below and to the side of any possible combustible materials. The location of gas lines and shade curtains may be considerations in meeting the clearances-to-combustibles requirement. The second is the distance from the heat exchanger tube to any plant material. It is possible to damage plants if their foliage grows too close to the heat exchanger tube. While many plants can tolerate the infrared energy they receive when grown close to the heat exchanger tube, a safe and comfortable recommendation would be to keep plant material at least a distance equal to the clearances to combustibles from the heat exchanger tube. The CORAYVAC® Installation, Operation and Service Manual or specification sheet will give specific distances above, beside and below combustibles. Be sure to follow these important specifications.

## 6.4 Location of Other Mechanical Systems

When designing and installing CORAYVAC® systems, it is important to avoid conflict with structural and mechanical features such as thermal or shade screens, ventilating apparatus, watering boom tracks and supports and misting systems.

## 6.5 Heating Criteria

CORAYVAC® systems offer flexibility in design. Long narrow greenhouses are a convenient shape for CORAYVAC® but offer solvable challenges to provide the uniformity the grower desires. Growers generally prefer to control temperatures to plus or minus 1° F (.5° C) in 95% of the greenhouse production area. Commercial buildings are heated for creature comfort. Greenhouse heating is process heating, where the temperature of the plants is an integral part of their growth.

## PART 7: SYSTEM DESCRIPTION

The design of CORAYVAC® systems should be done by a trained and experienced designer approved by Roberts-Gordon. For those that are unfamiliar with CORAYVAC®, the following sections describe the system in general terms. For complete details, see the CORAYVAC® Installation, Operation and Service Manual.

### 7.1 Burner Considerations

CORAYVAC® burners are available in Btu output ratings from 20,000 to 120,000 Btu/h. Because of the high amount of heat required for greenhouses, burners with higher Btu output are most frequently used. Burners with higher Btu ratings can be spaced farther apart so fewer burners may be needed in the length of the greenhouse. Width, height and length of the greenhouse, as well as heat required, influence the choice of burner capacity.

### 7.2 Heat Exchanger Tube

The standard heat exchanger tube comes in 10' (3 m) sections. Heat exchanger tubes are available in a number of alloys or coatings. In the greenhouse, a non-heat treated aluminized tube should be selected for the first and/or second tube after a burner. This portion of the low-intensity infrared system is immediately downstream of a burner and operates at the highest temperature. Non-heat-treated aluminized tube has a lower emissivity than other types of tube. The intensity of the heat for the first 5'–6' (1.5 m–1.8 m) after the burner will heat-treat, but the non-heat-treated portion will still be a lower level emitter of infrared energy. The choice for the next heat exchanger tube could be either heat-treated aluminized or ceramic-coated. These tubes have a higher emissivity and help provide a more even output of infrared energy from one burner to the next. Hot rolled steel heat exchanger tubing should not be used in greenhouses.

### 7.3 Tailpipe

One of the features that adds to the efficiency of a CORAYVAC® system is its ability to extract nearly all of the heat from combustion in the form of infrared energy. This is accomplished in part by the added lengths of tube after the last burner. A tailpipe portion of 40' (12 m) or more of tube emits the last of the heat of combustion until the gases reach the pump.

Proper positioning of the tailpipe allows for maximum uniformity and effective heat output in the greenhouse. The majority of the infrared energy is released from the burners running parallel with the greenhouse. The total length of heat exchanger tube including the tailpipe is often longer than the greenhouse. This additional length has to be designed to give off the maximum heat available and distribute it evenly. One solution for the downstream end of the tailpipe is to use an elbow to make a right angle turn directing the pipe downward towards the eaves. With two more 90° elbows, the tube is then directed across the gable end of the greenhouse at eave height to the other side, where it then connects to the pump. An adjacent gutter connected house can be laid out the same way, but as a mirror image. That way both tailpipes from two adjacent systems can share one pump. The tailpipes merge into a tee, which goes directly into the pump. With planning, the system may be designed so that as many as four separate runs can share one large pump. Each series of burners may be on separate thermostats, so that effective temperature zoning is accomplished.

*Tailpipe hung lower than gutter height supplies additional heat to gable end of greenhouse.*

## 7.4 Pump

Pumps come in different sizes. The correct size depends on the number of burners and the amount of Btu's burned in each system. Each size pump handles a different flow load. It is possible to have more than one temperature zone for each pump. The larger pumps are heavy-duty cast metal with balanced cast impellers. They are durable, reliable and effective in creating the vacuum that is required for all the burners in the system.

*Pump vented through sidewall.*

## PART 8: SYSTEM DESIGN AND LAYOUT

This section is for the infrared specialist that already knows the proper design and layout procedures for low-intensity infrared heating in traditional space heating applications. It covers design guidelines specific to greenhouse heating applications and should be used in conjunction with the CORAYVAC® Design Manual and the Installation, Operation and Service Manual.

### 8.1 Layout for Commercial vs. Retail Greenhouses

Retail greenhouse heating is usually very similar to other traditional low-intensity infrared space heating applications. Customer and employee comfort is the main concern. Since there are a wide variety of grown plants ready for sale, a retail greenhouse application does not generally require a highly engineered design to obtain great results. Retail greenhouses can utilize either custom burners-in-series CORAYVAC® systems or standard unitary low-intensity infrared heaters.

Commercial production greenhouses have a more focused purpose. The crop tends to be grouped into more well-defined categories. The greenhouse operators and owners have specific needs and desires for creating proper environmental conditions for their particular crops. Crop production is monitored to ensure the optimum growing environment. Some crops (such as mums, Easter lilies and poinsettias) have definite ship deadlines after which the crop's profitability drops drastically. The growth and shipment timing of certain seasonal crops is of critical importance for the grower's business.

To the low-intensity infrared heating specialist, **commercial production greenhouse heating should be considered as a specific type of process heating**, not as a general space heating application. A consistent environment throughout the crop is essential for effective greenhouse management. If some plants require watering more often, or mature faster than others, due to elevated temperatures in some areas of the greenhouse, the extra time required to treat these plants differently than the others creates unwanted inefficiencies in day-to-day greenhouse operations. Therefore, commercial production greenhouse heating layouts must incorporate specialized design to maximize evenness of heat distribution.

### 8.2 Heat Loss Considerations

Because greenhouses are made of materials that do not possess the insulating properties of traditional commercial or industrial buildings, the heat loss of a greenhouse can be many times what it would be for a traditional building of similar size.

The basic formulas to calculate heat loss for a greenhouse are as follows:

$$\mathbf{Q_T = (Q_C + Q_A)\, f_W}$$

Where $Q_T$ = total heat loss
$Q_C$ = heat loss by conduction
$Q_A$ = heat loss by air exchange
$f_W$ = wind factor

$$\mathbf{Q_C = U \times A \times \Delta T}$$

Where $Q_C$ = heat loss by conduction through surface material
U = U value,
(Btu/(h ft² °F)), *metric (W/(m² K) = (U value in English units multiplied by 5.7)*
A = building's surface area (ft²), *metric (m²)*
$\Delta T$ = temperature difference between inside and outside (°F),
*metric (K), K = °C + 273.15*

**$Q_A$ = .018 x ΔT x ((Volume x # of air changes) + Mechanical Ventilation)**

***Metric, $Q_A$ = .373 x ΔT x ((Volume x # of air changes) + Mechanical Ventilation)***

Where $Q_A$ = heat loss by air changes
.018 *(or .373)* = constant representing heat content in air, English units, *(metric units)*
ΔT = temperature difference between inside and outside temperature (°F), *metric (K), K = °C + 273.15*
Volume = building's volume ($ft^3$), *metric ($m^3$)*
# of air changes = number of air changes per hour
Mechanical Ventilation = forced ventilation ($ft^3$/h), *metric ($m^3$/h)*

### 8.2.1 U-Values:

It is important to verify the material of the greenhouse prior to designing the low-intensity infrared system layout. Most manufacturers publish specification sheets for all of their products, which will usually list the U-value of the material. If the U-value is not listed, contact the dealer or manufacturer for the specific U-value. Remember that some greenhouse covering materials can be installed in multiple layers for better insulation (lower U-value). Make note of how many layers are being installed and use the U-value for the number of layers that are installed, since it can have a significant effect on the heat loss of the greenhouse.

The chart below lists some U-values for common glazings.

**U-Values for Common Greenhouse Materials**

| Material | U-Value (Btu/h ft² °F) |
|---|---|
| *Glass, single layer, 3 mm* | *1.13* |
| *Glass, double layer, 3 mm* | *.49–.70* |
| *Polyethylene film, single layer, 6 mil or 4 mil* | *1.15 or 1.20* |
| *Polyethylene film, 6 mil double layer inflated* | *.70* |
| *Fiberglass* | *1.20* |
| *Corrugated Polycarbonate, .79 mm thick (LEXAN®, VEROLITE®, DYNAGLAS®)* | *1.20* |
| *Bi-wall polycarbonate (LEXAN®, VEROLITE®, depends on thickness)* | *.55–.68* |
| *Bi-wall Acrylic (DEGLAS®, depends on thickness)* | *.49–.56* |

*U-values shown for proprietary products are from manufacturers' technical specifications at the date of this publication.*

### 8.2.2 Air Changes and Mechanical Ventilation

Infrared design specialists know the importance of air changes on a building's total heat loss. Of course, air change is important for greenhouses as well. Since greenhouses are built with summer ventilation in mind, there are many sources for air infiltration. Some typical types of venting are:

- Ridge venting
- Open roof
- Retractable roof
- Lifting up the roof near the gutter
- Roll up walls
- Mechanical vents and fans

It is difficult to maintain a tightly sealed building when there are so many areas of possible air infiltration. As a result, air changes for greenhouses can be somewhat higher than in other applications. Since tightness can vary based on existing equipment and structure maintenance, a heat loss calculation should list any assumptions that lead to the final heat loss. Ask the greenhouse owner how the greenhouse will be prepared for winter. Make note of the owner's practices and adjust the air changes accordingly.

- Will vents still be used in the winter?
- Are ventilation fans going to be used in the winter? If so, what is the volume of air (CFM) that is moved with the fans?
- Are unused vents and fans covered to avoid drafts in the winter?
- Are broken glass panels or torn plastics replaced and repaired prior to heating season?

Below is a chart listing air changes for greenhouses of various types. These values can vary based on greenhouse age, maintenance of the structure (as mentioned previously), wind speeds, etc.

| Greenhouse Construction | Air Changes per Hour |
|---|---|
| Double Layer Films such as poly (new) | .5 – 1.0 |
| Double Layer Films such as poly (well maintained) | .5 – 1.25 |
| Glass or Rigid Plastics (new) | .75 – 1.75 |
| Glass or Rigid Plastics (well maintained) | 1.0 – 2.0 |
| Glass or Rigid Plastics (in need of repair) | 2.0 – 4.5 |

Rigid paneled houses have a higher number of air changes, since there are many seams and edges. Conversely, houses covered with films and plastics are more seamless and continuous. Air changes should be tailored to the climate and wind protection of the greenhouse location. Designers use higher air changes for coastal or unprotected locations than they would for inland, wind-protected areas. The heating system will be in place for many years, the building will age, and changes in the building condition tend to result in more air changes. Use conservative estimates so that the size of the heating system will be sufficient for extreme weather and aging buildings.

### 8.2.3 Wind Factor

The wind, or exposure, factor is used based on judgement. The factor allows the heat loss to be adjusted for the building's exposure to wind conditions. For wind speeds below 15 mph (25 km/h), the wind factor can be ignored.

**Wind Factor, $f_w$**

| Wind Speed, mph (km/h) | $f_w$ |
|---|---|
| Less than 15 (25) | 1.0 |
| 19 (30) | 1.03 |
| 25 (40) | 1.08 |
| 31 (50) | 1.13 |
| 37 (60) | 1.18 |
| 44 (70) | 1.22 |

### 8.2.4 Energy Curtains

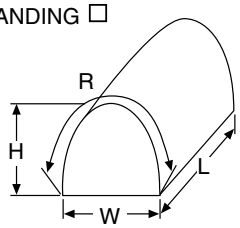
Energy curtains are discussed on *Page 25, Section 5.2*. Greenhouse manufacturers can be unclear when accounting for their energy curtain in a heat loss calculation. If documentation cannot be provided by the curtain manufacturer, greenhouse heat loss should be calculated without taking into account any benefit that may be provided by the curtain. Designers cannot assume that curtains will always be used properly, or that curtain mechanisms will always be in proper working order. The heating system is still expected to maintain temperatures in a greenhouse if the curtain system was removed or is in disrepair.

### 8.2.5 Basic Building Data

Use the form on the following page to record the basic dimensional and growing environment data required by the grower.

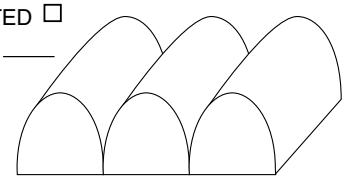
Company Name: _____ Phone: _____
Your Name: _____ Phone: _____
Other Contact: _____ Title: _____ Fax: _____
Mailing Address: _____ City/State: _____ Zip Code: _____

**QUONSET TYPE**
FREE STANDING ☐




W = _____
H = _____
L = _____
R = _____

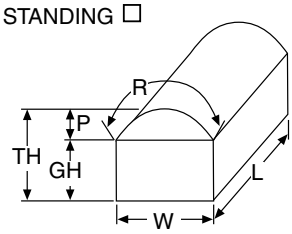
GROUND CONNECTED ☐
NUMBER ____



**END AREA:**
$\frac{2 \times H \times W}{3}$ = _____

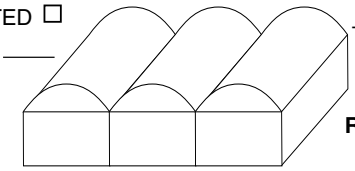
**ROOF AREA:** _____
R x L = _____
BOW/TRUSS SPACING = _____

**RIGID FRAME - DOME**
FREE STANDING ☐




W = _____
GH = _____
P = _____
TH = _____
L = _____
R = _____

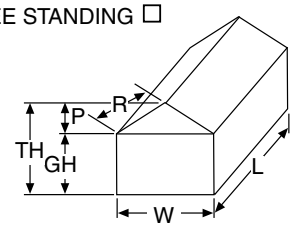
GUTTER CONNECTED ☐
NUMBER ____



**END AREA:**
GH x W = _____
$+ \frac{2 \times P \times W}{3}$ = _____

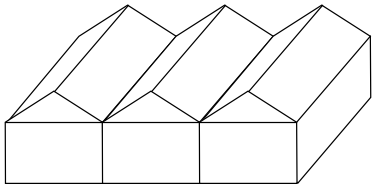
**ROOF AREA:**
R x L = _____
BOW/TRUSS SPACING = _____

**RIGID FRAME - GABLE**
FREE STANDING ☐




W = _____
GH = _____
P = _____
TH = _____
L = _____
R = _____

GUTTER CONNECTED ☐
NUMBER ____



**END AREA:**
GH x W = _____
$+ \frac{2 (P \times \frac{W}{2})}{3}$ = _____

**ROOF AREA:**
R x L = _____
TRUSS SPACING = _____

**FUEL DATA:**
LPG ☐
Natural ☐
Fuel Cost Last Season From mo/yr
_____ to _____ $ _____

**PRESENT HEATING SYSTEM:**
UNIT HEATERS ☐ BOILER ☐
DIRECT-FIRED ☐
OTHER _____

**CLIMATE DATA:**
Inside Temperature: _____°F or °C
Design Outside Low: _____°F or °C
Temperature Rise: _____°F or °C
Prevailing Wind Direction/Speed: _____
Elevation Above Sea Level: _____

**INFILTRATION:**
Mechanical Ventilation (CFM) or ($m^3$/h) in Winter Use: _____
# of Air Changes: _____

**COVERING MATERIALS:**
Roof: _____
Sidewalls: _____
Endwalls: _____
Insulation: _____
Retractable Roof ☐
Outdoor Area (Frost Protection Only) ☐

**GROWING DATA:**
Crop Type/Mature Height: _____
(Floor to Top of Plant)
Bench Height: _____
Retail Center: _____
Other: _____

**OTHER COMMENTS:** _____

**COMMENTS:**

Curtains? ☐ Type; Mounting Position: _____

Overhead Irrigation ☐ _____

Additional Comments: _____

_____

_____

_____

_____

**SKETCH:**

## Installation Code and Annual Inspections:

All installations and service of ROBERTS GORDON® products must be performed by a contractor qualified in the installation and service products sold and supplied by Roberts-Gordon and conform to all requirements set forth in the ROBERTS GORDON® manuals and all applicable governmental authorities pertaining to the installation, service and operation of the equipment.

To help facilitate optimum performance and safety, Roberts-Gordon recommends that a qualified contractor annually inspect your ROBERTS GORDON® products and perform service where necessary, using only ROBERTS GORDON® replacement parts.

This product is not for residential use.

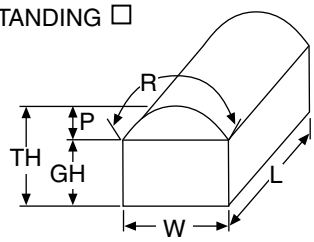
This document is intended to assist licensed professionals in the exercise of their professional judgement.

### 8.2.6 Heat Loss Example

A new, single layer poly, gutter connected greenhouse (15 bays total) in Salinas, California (about 100 miles [161 km] south of San Francisco). The building dimensions are: width 21'(6.4 m); length 96' (29.26 m); gutter height 12' (3.66 m); total peak height 17' (5.18); truss spacing 12' (3.66 m).

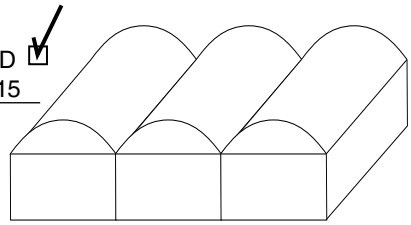
The grower indicates an indoor design temperature of 68° F (20° C). From the ASHRAE Handbook, the Heating Outdoor Design Temperature is 36° F (2.2° C). See Section 8.2 for basic formulas. See Appendix B for metric solution.

**RIGID FRAME - DOME**
FREE STANDING ☐




W = 21'
GH = 12'
P = 5'
TH = 17'
L = 96'
R = 24'

GUTTER CONNECTED ☑
NUMBER 15



**END AREA:**

GH x W = 252 ft²
+ 2 x P x W / 3 = 70 ft²

**ROOF AREA:**

R x L = 2304 ft²
BOW/TRUSS SPACING = 12'

$$\mathbf{Q_C = U \times A \times \Delta T}$$

Where U = single poly (6 mil thick) U-value is 1.15
A = [(((End area x 2) + roof area) x number of houses) + (sidewall area x 2)]
= [((644 + 2,304) x 15) + (2,304)]
= 46,524 ft²
$\Delta T$ = 68° F – 36° F = 32° F
$Q_C$ = 1.15 x 46,524 x 32
$Q_C$ = 1,712,083 Btu/h

$$\mathbf{Q_A = .018 \times \Delta T \times ((Volume \times \#\ of\ air\ changes) + Mechanical\ Ventilation)}$$

Where $\Delta T$ = 68° F – 36° F = 32° F
Volume = [(2/3 P x W x L) + (GH x W x L) x number of houses]
= [(6,720 + 24,192) x 15]
= 463,680 ft³
# of air changes = 1.0, taking into account aging of the poly over its lifespan
Mechanical Ventilation = 0, assuming no mechanical ventilation is used at outdoor design temperature

$Q_A$ = .018 x 32 x ((463,680 x 1) + 0)
$Q_A$ = 267,080 Btu/h

$$\mathbf{Q_T = (Q_C + Q_A)\ f_W}$$

Where $Q_C$ = 1,712,073 Btu/h
$Q_A$ = 267,080 Btu/h
$f_W$ = 1.0

$Q_T$ = 1,979,153 Btu/h

## 8.3 Layout for Even Heat Distribution

The most critical consideration for commercial greenhouse low-intensity infrared heating is even heating. Designers must present a low-intensity infrared system layout with the most even heat possible with the desired building temperature. Many professionals who design infrared systems know that the unique burners-in-series design of CORAYVAC® offers more even heating than other infrared systems. However, commercial greenhouse heating demands are very stringent and require even more attention to detail when designing for even heat distribution. Making sure that the heat delivered to the plant surface is even throughout the house, from gable to gable and from side to side, will directly affect the growth pattern of the plants.

### 8.3.1 Even Heat Along the Length of the Greenhouse

The most practical orientation of a CORAYVAC® system is parallel to the peak of the greenhouse. The long length of a greenhouse along the peak compliments the long shape of a straight branch of CORAYVAC® burners. Since we know that the system will emit more infrared just after each burner, it is a good practice to install heat exchanger tubes of varying emissivity that will even out the infrared output between burners. Systems should be designed using the least emissive tubes (non-heat-treated aluminized tube) for the first 10' (3 m) to 20' (6 m) after the combustion chamber, then follow with heat-treated aluminized tubing and/or porcelain coated steel tubing. Hot rolled steel heat exchanger tubing should not be used in greenhouses. Tailpipe tubing should be heat-treated aluminized and/or porcelain coated. Even heating along the length of a branch of CORAYVAC® can be enhanced by using many moderate input burners rather than a few high input burners. This will allow distances between heaters to be shorter so that the heat exchanger tube is “recharged” more often before any significant reduction in infrared output occurs.

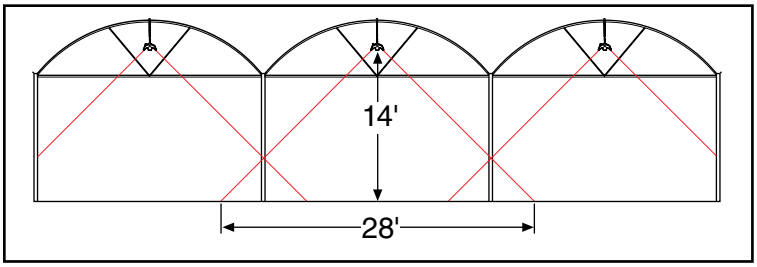
### 8.3.2 Even Heat Across Greenhouse Width

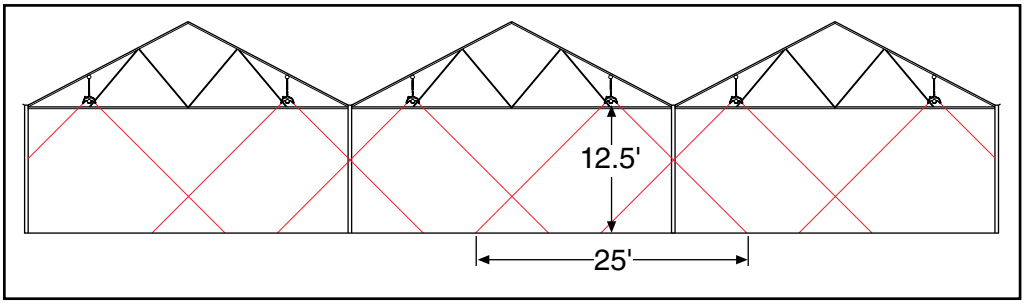
Past installations have shown that plants in the center of the greenhouse directly under the low-intensity infrared section of a system tend to be warmer and require more frequent watering than plants positioned closer to the sides. The low-intensity infrared energy from the heater starts to reduce the further the heated object is from the centerline of the tube and reflector. To reduce the infrared intensity directly under the heater and increase it toward the sides, lower clearance shields can be installed. By redirecting some of the infrared toward the sides of the house, the plant growth, plant temperatures and watering requirements are more consistent from side to side. Lower clearance shields may not be necessary under tailpipe sections.

In gutter-connected houses, a certain amount of infrared pattern overlap between houses can be achieved by varying the mounting height of the system. Radiant pattern overlap can supplement infrared intensity at the sides of the houses (the sections under the gutters.) The width of the infrared distribution at the floor is equal to twice the mounting height of the heater.

In colder climates, one row of tube and reflector along the peak may not be enough to satisfy the greenhouse heatloss. Two rows of infrared may be required. Typically these strips still run parallel with the peak, but the positioning of the infrared branches will be on each side of the peak (part way between the peak and gutter.) In this case, an overlapping of infrared pattern will occur, creating a more even, multi-directional heat distribution from side to side.

### 8.3.3 Heater Inputs and Clearances to Plants



Heater inputs need to be considered and selected based not only on building heat loss, but also on clearances to combustibles and clearances to the tops of mature plants. Discuss with the greenhouse owner the height of the mature plants as well as the final mounting height of the bottom of the tube and reflector. The distance from any plant top to the bottom of the tube and reflector should never be less than the clearances to combustibles for the heater. Since tailpipe heat exchanger tubing is not as hot as infrared heat exchanger tubeing, the tailpipe can be much closer to the tops of plants and to hanging pots. Growers can monitor hanging pots to see if their position is over-heating the plants or the plants are requiring water too frequently. Once a grower familiarizes himself with the system and the position of the burners, placement of hanging potted plants will be easy.

### 8.3.4 Tailpipe Heat Exchanger Tube Placement

The most popular use of a tailpipe is to hang it lower than gutter height rather than in the peak so that the heat given off provides usable infrared heat to maintain temperatures in harder to heat or higher heat loss areas. In gutter-connected greenhouses, it is common for tailpipe to run beneath gutters. Any convective heat from the top of the reflector will keep gutters warmer to guard against freezing. By mounting below gutters, concern of shading from the reflector can be reduced. In addition, the gentle infrared heat of the tailpipe at lower mounting heights can supplement areas between houses that receive less infrared heat. Outer walls of the house are always areas of larger heat loss. It is desirable to have the tailpipe run at a lower mounting height along the sidewall so that temperatures near the sidewall do not fall below temperatures in the center of the house. Lower temperatures near the sidewall can be evident in slower plant growth.

*Tailpipe at gable end of glass house.*

### 8.3.5 Pump Placement and Venting Direction

Pumps may be vented through the roof or through the sidewall. Owners tend to prefer sidewall venting for ease of installation, easy access, maintenance and decreased overhead shading. For installations where the tailpipe is routed down a sidewall, it may be most convenient to mount the pump on the floor and vent through the lower part of the wall. When venting through the lower wall, ensure that the vent terminal is located at a height sufficient to prevent blockage from snow. The vent must not terminate near any air inlet to the greenhouse. See the current CORAYVAC® Installation, Operation and Service Manual. Abide by all local codes for venting.

*Pump vented through the sidewall.*

### Installation Code and Annual Inspections

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## 8.3.6 CORAYVAC® Layout Examples

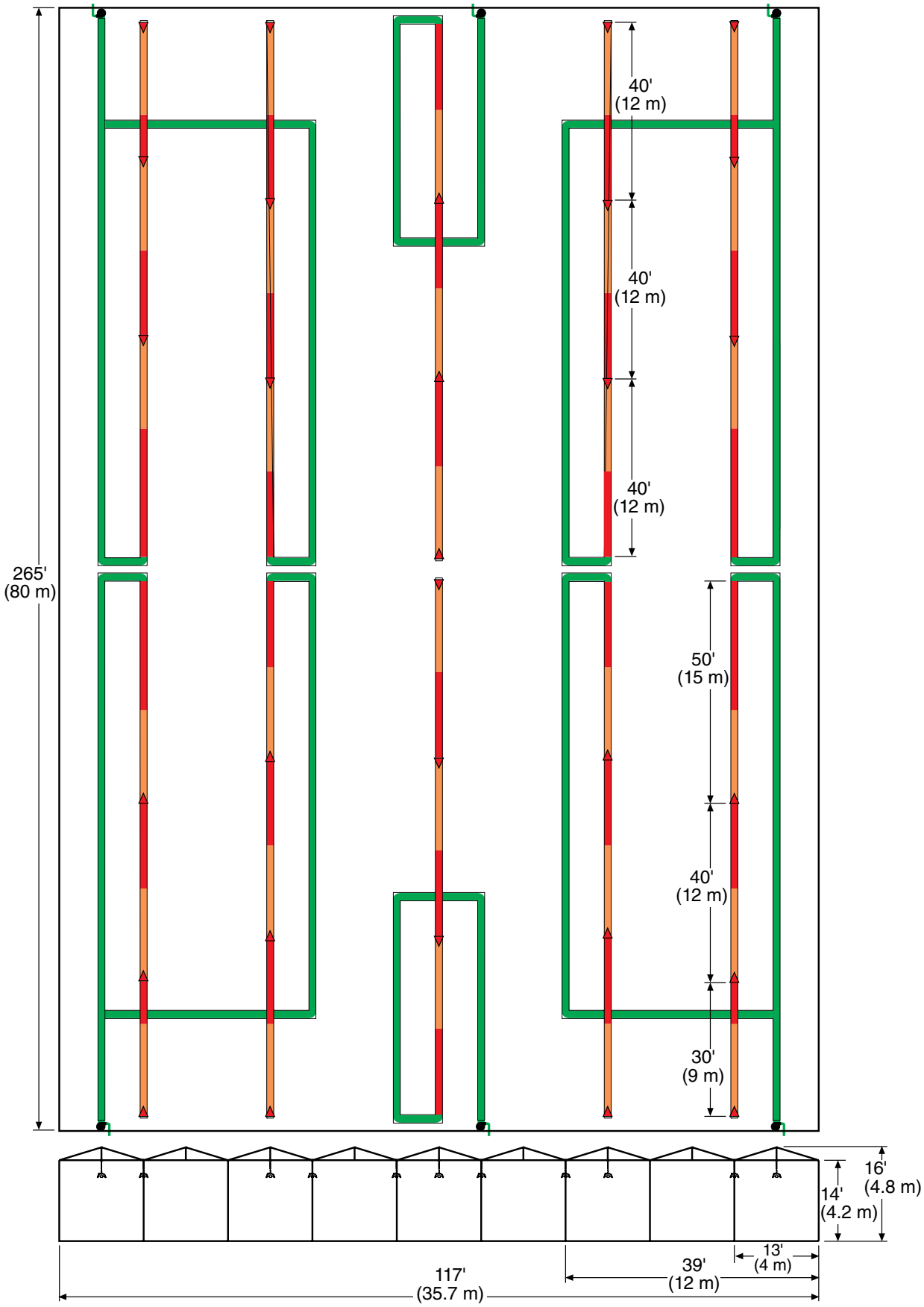
### Cold Climate Example

| | |
|---|---|
| **Heating Design Temperature (99%):** | 7° F (-14° C) |
| **Indoor Temperature:** | 65° F (15° C) |
| **Venlo Style Houses** | (3 peaks per width) |
| **Width:** | 39' (12 m) |
| **Length:** | 265' (80 m) |
| **Gutter Height:** | 14' (4.2 m) |
| **Peak Height:** | 16' (4.8 m) |
| **Construction:** | Single Layer Glass |
| **Plants:** | Misc. Flowers |
| **Bench Height:** | None, grown on ground |
| **Curtains:** | Gutter-to-Gutter |

**Comments:** Heaters installed at just below gutter height (under curtains). Mounting height allows about 24'–26' (7.3 m–7.9 m) wide heat spread at floor. Reflectors run beneath gutters when possible for reduced shading and gutter ice protection.

Staggered burner positions and opposing burner direction between branches help even heat distribution throughout the house, in addition to varying tube types and lower clearance shields.

Layout offers additional heat in outer houses where heat loss is greater. Radiant branches spaced to give overlapping infrared patterns at floor. Lower clearance shields will help widen pattern. About 100 Btu/ft$^2$ (272 W/m$^2$).




ORANGE Indicates Aluminized Tubing (radiant section)
RED Indicates Heat Treated Aluminized (radiant section)
GREEN Indicates Porcelain Coated Tubing (tailpipe section)

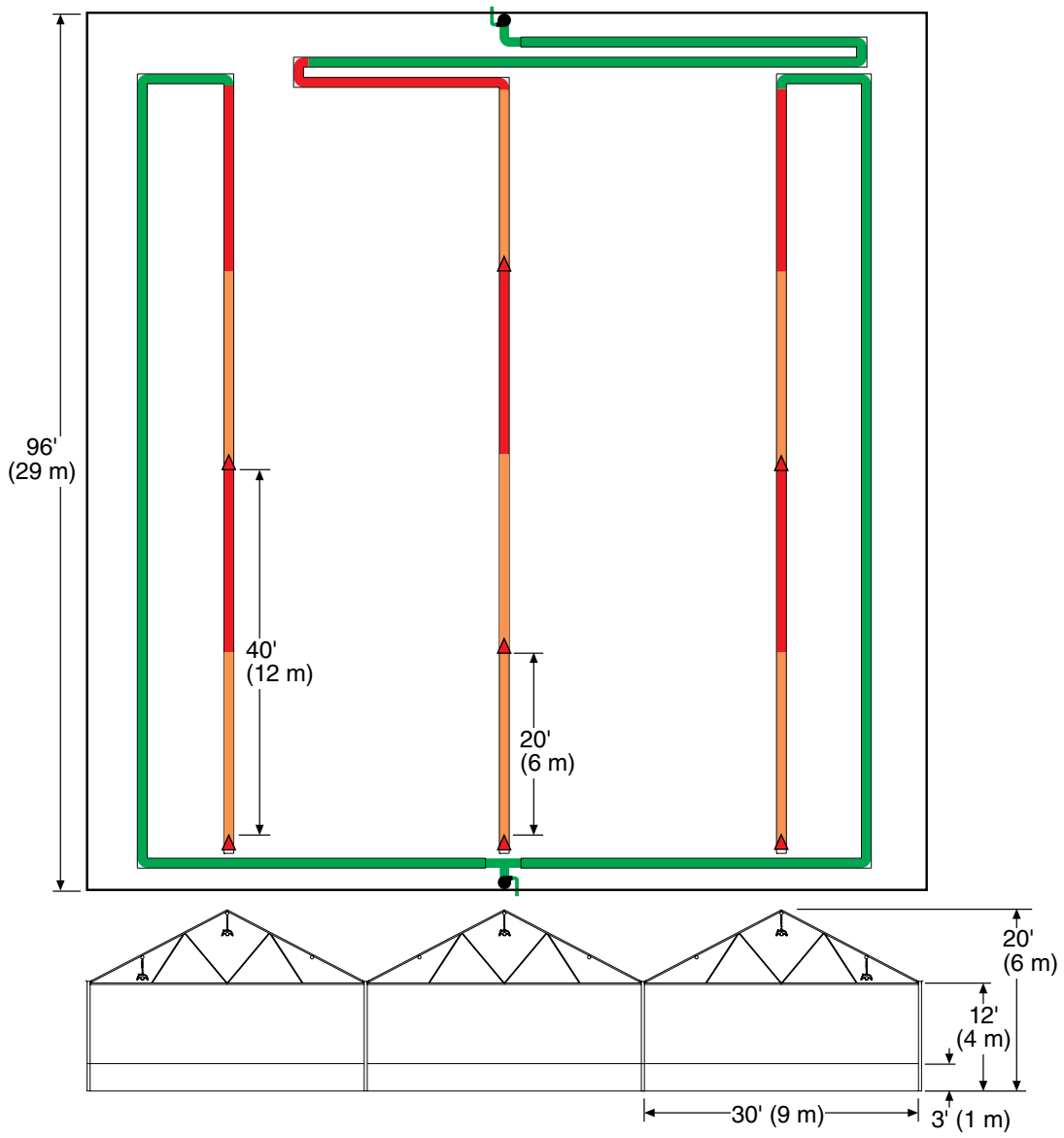
= CORAYVAC® Burner
= Vacuum Pump

## Mild Climate Example

**Heating Design Temperature (99%):** 33° F (1° C)
**Indoor Temperature:** 70° F (21° C)

**Gable Style Houses**
**Width:** 30' (9 m)
**Length:** 96' (29 m)
**Gutter Height:** 12' (4 m)
**Peak Height:** 20' (6 m)
**Construction:** Single Layer Poly
**Plants:** Misc. Flowers
**Bench Height:** 3' (1 m)
**Curtains:** Slope-to-Slope

**Comments:** Staggered burner positions between branches help even heat distribution throughout the house, in addition to varying tube types and lower clearance shields.
Layout offers additional heat in outer houses where heat loss is greater. Radiant branches spaced to give overlapping infrared patterns at bench. Lower clearance shields will help widen pattern.
About 80 Btu/ft² (218 W/m²).




ORANGE Indicates Aluminized Tubing (radiant section)
RED Indicates Heat Treatment Aluminized (radiant section)
GREEN Indicates Porcelain Coated Tubing (tailpipe section)

▶ = CORAYVAC® Burner
● = Vacuum Pump

## 8.4 Common Obstacles

### 8.4.1 Structure

Location and spacing will dictate hanger and burner positions. Heaters should be hung as high as possible while maintaining proper mounting chain length as well as clearances to combustibles above the heater. Sometimes trusses will be large enough for heaters to pass through, creating a perfect place for infrared. Trusses also may allow passage of the tube and reflector but may not allow enough space for suitable mounting chain lengths. In such cases, heaters may pass through trusses without being suspended from them.

### 8.4.2 Curtains (Screens, Blankets or Shades)

Owners' plans for curtains, curtain type and mounting location need to be taken into consideration. Even if the owner is not installing curtains until some later date, infrared designers should explain to the owner the relationship between curtain position and heater position. All screens, curtains and blankets must always be installed in accordance with the heater's clearances to combustibles and with the manufacturer's installation, operation and service manual.

### 8.4.3 Roof Vents

Low-intensity infrared heaters are usually mounted above gutter height. Typically, only vent locations that are gutter height or higher will concern the infrared designer. The main obstacle to look out for is a rack and pinion assembly that is driven to open and close vents in the roof. The infrared designer must be aware of the location of these assemblies so that the heater location does not conflict with them.

*CORAYVAC® low-intensity infrared heating system location taking structural members and roof vents into account.*

### 8.4.4 Watering Booms

There are many other watering techniques used in greenhouses, so watering booms may not always be a consideration. Howerver, when watering booms are located between the infrared heaters and the plants, proper clearances to combustibles must be observed at all times.

### 8.4.5 Lights

Preferably, the lights and heaters should not be located directly above or below one another. Proper clearances to combustibles must be maintained at all times.

### 8.4.6 Fans

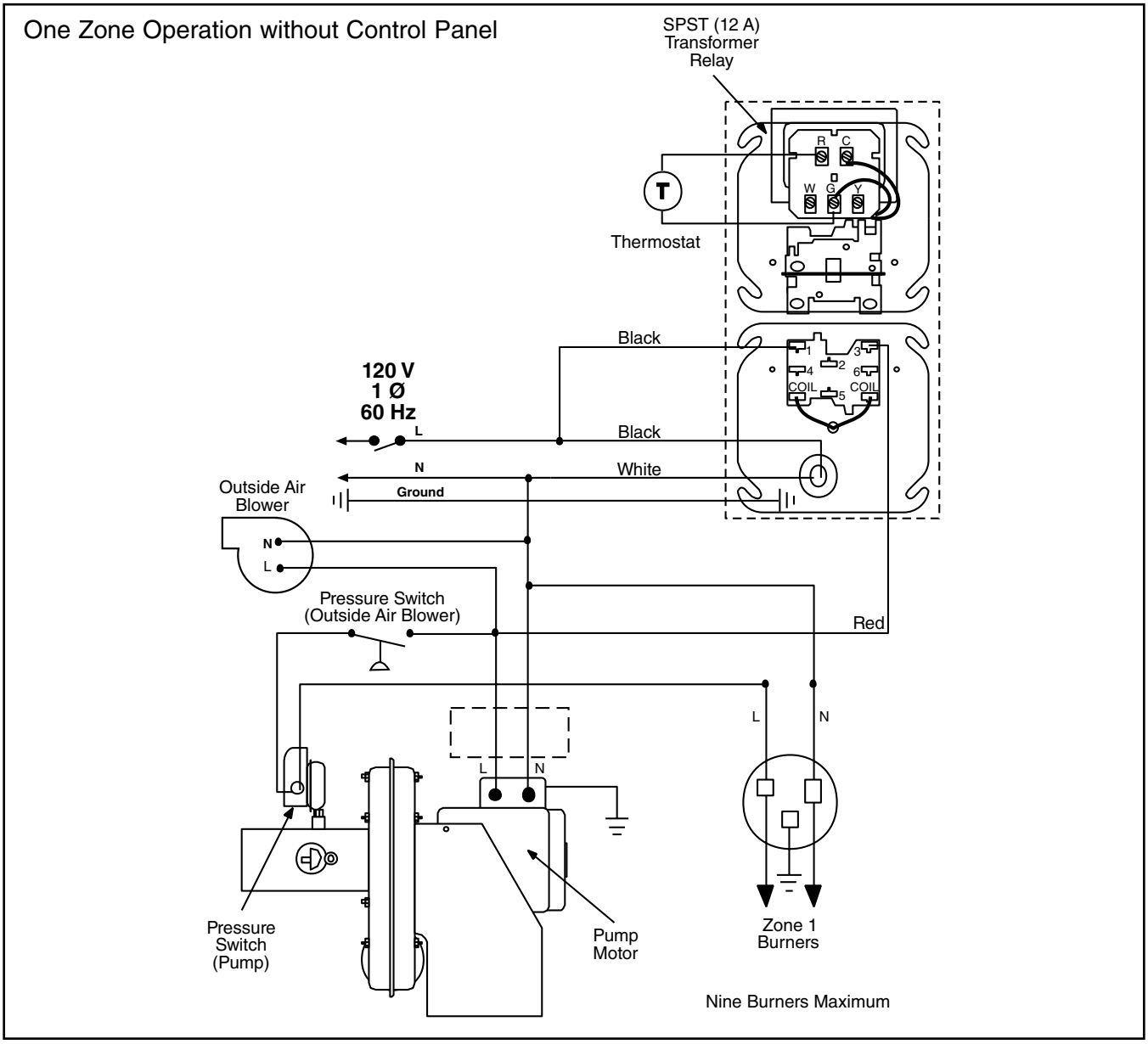
Since low-intensity infrared heaters will normally be running parallel with the gutters and ridge, there is little concern of the heater blocking air flow or fans blowing against the reflector. Discuss heater and fan location with the owner to avoid any conflicts.


*CORAYVAC® low-intensity infrared heating system installed in a garden shop.*

## PART 9: CONTROLS

Today, greenhouse controls operate and monitor the entire greenhouse environment. Heating, venting, lighting, irrigation, shade and energy curtains, fans, supplemental $CO_2$, etc. can all be controlled using the greenhouse control systems available on the market. Reputable companies focus on providing entire environmental control solutions for the greenhouse operator. Most offer a few complementary products, but tend not to specialize in other equipment. As a result, they can offer the most up-to-date methods of computerized control for the highly complex environmental equations that are involved when all of the greenhouse systems are working simultaneously. Controls companies employ software engineers to continually create better programming algorithms that improve the seamless operation of all pieces of greenhouse equipment. Greenhouse controls manufacturers also provide enclosures with the additional protection needed to isolate sensitive computer circuit boards from the greenhouse environment.

Since greenhouse controls manufacturers offer a product that integrates all greenhouse equipment, most greenhouse owners will have selected a control system that meets their needs. Even the most basic control switch will have the capability of controlling low-intensity infrared heating equipment. Electrical connection of a CORAYVAC® system to the heating contact on a controller via relay is shown below.



## PART 10: INSTALLATION TIME-FRAME FOR GREENHOUSES

ROBERTS GORDON® independent distributors, sales and engineering staff can provide a plan or layout showing where a CORAYVAC® system should be placed in a greenhouse. The greenhouse owner should have a clear understanding of the structural details of the greenhouse and all of its mechanical equipment. The owner has critical knowledge of how the greenhouse is operated: the traffic and work flow. The CORAYVAC® specialist understands the mechanics and operation of the heating system. Together, the CORAYVAC® specialist and the greenhouse owner can realistically plan an effective installation together.

The ideal time to schedule installation of a CORAYVAC® system in a new greenhouse is when the roof has been completed and before any plant beds or benches have been placed on the floor. Gas piping and electrical wiring for controls are installed concurrent with the CORAYVAC® installation. It is difficult to predict the number of man-hours required to install CORAYVAC® because every installation is different. If all the components of the system are easily accessible, an experienced installer should spend approximately 8 hours per burner, including gas piping and electrical wiring for controls. The larger the installation, the more efficiencies present themselves. Smaller and more complex layouts are likely to take longer per burner to install.

## PART 11: MAINTENANCE

Each fall before the heating season gets underway, it is advisable to do a thorough inspection of the system. Turn on the system and check to see that each burner lights. Have a contractor qualified in the installation of gas-fired heating products check the flame to insure that is has proper color, and check the vacuum with a manometer at the end vent plate of each branch. If necessary, make adjustments to the pump to obtain the proper vacuum. Check the pump to make sure it is securely mounted and does not vibrate. Check the outlet vent to make sure that the bird screen is in good condition.

Visual inspection of the air filters is required for a CORAYVAC® system. A filter is externally mounted on each burner, so inspection is quick and easy. In most greenhouse conditions, filters may last for several years, but should be checked each year. During filter inspection, the tops of the reflectors should be checked for dirt, dust or plant material accumulation. A simple dusting to keep reflectors clean allow them to continue efficiently directing the infrared rays toward the floor.

Any mechanical system will require care and maintenance to remain in peak operating condition. Because the CORAYVAC® system is in plain sight overhead an owner can easily keep an eye on the general condition and operation of the system during the normal daily routine.

### 11.1 Maintenance Checklist

### Installation Code and Annual Inspections

All installations and service of ROBERTS GORDON® products must be performed by a contractor qualified in the installation and service products sold and supplied by Roberts-Gordon and conform to all requirements set forth in the ROBERTS GORDON® manuals and all applicable governmental authorities pertaining to the installation, service and operation of the equipment.
To help facilitate optimum performance and safety, Roberts-Gordon recommends that a qualified contractor annually inspect your ROBERTS GORDON® products and perform service where necessary, using only ROBERTS GORDON® replacement parts.

| | |
|---|---|
| **The Vicinity of the Heater** | Do not store or use flammable objects, liquids or vapors near the heating system. Immediately remove these items if they are present. See the CORAYVAC® Installation, Operation and Service Manual. |
| **Vehicles and Other Objects** | Maintain the clearances to combustibles.<br>Do not hang anything from, or place anything on, the heater.<br>Make sure nothing is lodged underneath the reflector, in between the tubes or in the decorative or protective grilles (included with select models).<br>Immediately remove objects in violation of the clearances to combustibles.<br>See the CORAYVAC® Installation, Operation and Service Manual. |
| **Reflector** | Make sure there is no dirt, sagging, cracking or distortion.<br>Do not operate if there is sagging, cracking or distortion.<br>Make sure reflectors are correctly overlapped.<br>Clean outside surface with a damp cloth. |

| | |
|---|---|
| **Vent Pipe** | Venting must be intact. Using a flashlight, look for obstructions, cracks on the pipe, gaps in the sealed areas or corrosion.<br>The area must be free of dirt and dust.<br>Remove any carbon deposits or scale using a wire brush. |
| **Outside Air Inlet** | Inlet must be intact. Look for obstructions, cracks on the pipe, gaps in the sealed areas or corrosion.<br>The area must be free of dirt and dust. Clean and reinstall as required. |
| **Heat Exchanger Tubes** | Make sure there are no cracks.<br>Make sure tubes are connected and suspended securely.<br>See the CORAYVAC® Installation, Operation and Service Manual.<br>Make sure there is no dirt, sagging, bending or distortion.<br>Clean or replace as required. |
| **Gas Line** | Check for gas leaks.<br>See the CORAYVAC® Installation, Operation and Service Manual. |
| **Combustion Chamber Window** | Make sure it is clean and free of cracks or holes.<br>Clean or replace as required. |
| **Blower Scroll, Wheel and Motor** | Compressed air or a vacuum cleaner may be used to clean dust and dirt. |
| **Burner Head and Orifice** | Clear of obstructions (even spider webs will cause problems).<br>Carefully remove any dust and debris from the burner. |
| **Electrode** | Replace if there are cracked ceramics, excessive carbon residue, or erosion of the electrode.<br>The electrode gap should be 1/8” (3 mm). |
| **Thermostat or Sensor** | There should be no exposed wire or damage to the thermostat or sensor. |
| **Suspension Points** | Make sure the heater is hanging securely. Look for signs of wear on the chain or ceiling.<br>See the CORAYVAC® Installation, Operation and Service Manual. |
| **Decorative & Protective Grille (optional)** | The grille must be securely attached.<br>Check that side reflector extensions are installed correctly and secured in place if necessary. (Decorative grille only.)<br>See the CORAYVAC® Installation, Operation and Service Manual.<br>Make sure shield is installed correctly and secured in place if necessary. (Decorative grille only.) See the CORAYVAC® Installation, Operation and Service Manual. |
| **Pump** | With pump operating, check for excessive vibration or noise. Vibration is usually a sign that the impeller is out of balance. Turn off the system, insure power is shut off and remove the inlet plate. Check the shaft seal and replace it if worn or missing.<br>**With the Power off:**<br>Check the inlet and outlet of the pump for blockage or excessive soot and clean as necessary.<br>Check boots for cracking or deterioration and replace if necessary.<br>If a condensate trap is installed, check the condition of the trap and the drain line attached. Note: the condensate trap should be filled with water at the beginning of each heating season.<br>Check the condition of the motor mounts. Lift the motor from the rear; look for breaks in the rubber and replace if necessary.<br>Check the condition and operation of the pressure switch. |

The CORAYVAC® Installation, Operation and Service Manual can be found online at www.rg-inc.com

## Appendix A: Basic CORAYVAC® Design Parameters

The following table is an excerpt from the CORAYVAC® Design Manual (P/N 127500NA) and should be used in conjunction with the CORAYVAC® Design Manual for complete design rules.

**CORAYVAC® Design Parameters**

| **Burner Model** | **B-2** | **B-4** | **B-6** | **B-8** | **B-9*** | **B-10** | **B-12A** | **B-12** |
|---|---|---|---|---|---|---|---|---|
| Input (Btu/h) x (1000) | 20 | 40 | 60 | 80 | 90 | 100 | 110 | 120 |
| Flow Units per Burner | 2 | 4 | 6 | 8 | 9 | 10 | 12 | 12 |
| Flow Units per End Vent (Minimum Flow Units Entering Combustion Chamber) | 6 | 10 | 15 | 20 | 15 | 20 | 20 | 20 |
| Maximum Number of Burners per Branch | 6 | 4 | 4 | 4 | 2 | 4 | 3 | 3 |
| Maximum Number of Flow Units per Branch | 18 | 26 | 39 | 52 | 33 | 60 | 56 | 56 |

**Radiant Tube Length** (Average Distance between Burners)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Minimum (ft) | 10 | 12.5 | 20 | 20 | 20 | 30 | 35 | 35 |
| Recommended (ft) | 15 | 20 | 25 | 30 | 30 | 40 | 50 | 50 |
| Maximum (ft) | 20 | 25 | 35 | 45 | 50 | 60 | 70 | 70 |
| Minimum Distance from Burner to Downstream Elbow (ft) | 5 | 5 | 10 | 10 | 10 | 15 | 15 | 15 |
| Suggested Minimum Mounting Height (ft) | 8 | 8 | 8 | 10 | 10 | 15 | 15 | 15 |

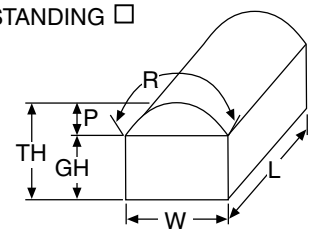
* CRV B-9 requires the first downstream tube from the burner to be aluminized heat-treated.

## Appendix B: Sample Heat Loss Calculation (Metric)

A new, single layer poly, gutter connected greenhouse (15 bays total) in Salinas, California (about 100 miles [161 km] south of San Francisco). The building dimensions are: width 21' (6.4 m); length 96' (29.26 m); gutter height 12' (3.66 m); total peak height 17' (5.18); truss spacing 12' (3.66 m).

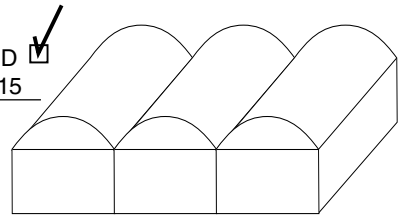
The grower indicates an indoor design temperature of 68° F (20° C). From the ASHRAE Handbook, the Heating Outdoor Design Temperature is 36° F (2.2° C). See Section 8.2 for basic formulas.

**RIGID FRAME - DOME**
FREE STANDING ☐




W = 6.4 m
GH = 3.66 m
P = 1.52 m
TH = 5.18 m
L = 29.26 m
R = 7.32 m

GUTTER CONNECTED ☑
NUMBER 15



**END AREA:**
GH x W = 23.42 $m^2$
+ 2 x P x W / 3 = 6.49 $m^2$

**ROOF AREA:**
R x L = 214.18 $m^2$
BOW/TRUSS SPACING = 3.66 m

$$\mathbf{Q_C = U \times A \times \Delta T}$$

Where U = single poly (6 mil thick) U value is 1.15 x 5.7 = 6.555
A = [(((End area x 2) + roof area) x number of houses) + (sidewall area x 2)]
= [((59.82 + 214.18) x 15) + (214.18)]
= 4324.18 $m^2$
$\Delta T$ = 293.15 °K - 275.35 °K = 17.8 °K
$Q_C$ = 6.555 x 17.8
$Q_C$ = 504,540 W

$$\mathbf{Q_A = .018 \times \Delta T \times ((Volume \times \# \text{ of air changes}) + Mechanical\ Ventilation)}$$

Where $\Delta T$ = 293.15 °K - 275.35 °K = 17.8 °K
Volume = [(2/3 P x W x L) + (GH x W x L) x number of houses]
= [(189.76 + 685.39) x 15]
= 13,127.25 $m^3$
# of air changes = 1.0, taking into account aging of the poly over its lifespan
Mechanical Ventilation = 0, assuming no mechanical ventilation is used at outdoor design temperature

$Q_A$ = .373 x 17.8 x ((13,127.25 x 1) + 0)
$Q_A$ = 87,157 W

$$\mathbf{Q_T = (Q_C + Q_A)\ f_W}$$

Where $Q_C$ = 504,540 W
$Q_A$ = 87,157 W
$f_W$ = 1.0

$Q_T$ = 591,697 W = 591.7 kW

## Appendix C: Additional Photos

*Tropical foliage grown under a CORAYVAC® low-intensity infrared heating system.*

*Growing cucumbers under a CORAYVAC® low-intensity infrared heating system.*

*CORAYVAC® low-intensity infrared heating system installed over poinsettias. Zoning of heaters allows different temperature setpoints for various stages of plant growth. Far background and right show plants ready to ship; foreground shows plants in an earlier stage of development.*

*CORAYVAC® low-intensity infrared heating system over hanging baskets & geraniums.*

*Carnations with CORAYVAC® low-intensity infrared heating system overhead.*

*Roses under CORAYVAC® low-intensity infrared heating system.*

*CORAYVAC® low-intensity infrared heating system installed in gutter-connected glass houses.*

*CORAYVAC® low-intensity infrared heating system over various flowers and hanging baskets.*

*Orchids heated under CORAYVAC® low-intensity infrared heating system.*

*Poinsettias grown under a CORAYVAC® low-intensity infrared heating system in a lower arched poly house.*


*CORAYVAC® low-intensity infrared heating system in a garden center.*

*Unitary low-intensity infrared heater in a garden center.*