tates the storage of more radiant energy and reduces the need for cooling and shading.

As we learn to apply these improvements in greenhouse technology, energy conservation will be automatic. It seems that we can also expect fewer disease problems and a healthier plant as an end product.

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RADIANT HEATING FOR PROPAGATION AND ENERGY CONSERVATION

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I want to introduce a concept of heating that is new to the greenhouse industry, but is as old as the sun. The system is a gas fired, low intensity, infrared radiant system Infrared is proving to be an ideal method of heating greenhouse crops from propagation to finish while saving substantially on fuel consumption. The name of the system is CO-RAY-VAC and it is manufactured by Roberts-Gordon Appliance Corporation.

Infrared energy is as old as the sun and its principles have been applied for many years in heating. The cave man used it when he heated the rocks around his campfire. The sun itself is the source of infrared energy which heats the earth's surface. Infrared radiation is energy in the form of electromagnetic waves and has some similar properties to visible light waves. Light, radio waves, x-rays are all electromagnetic waves with different wave lengths and physical properties. Infrared energy travels in a straight line until it strikes and is absorbed by the object to be heated. The energy is then converted into heat that warms that object. In other words, heat is transmitted from one object to another without heating the air between the objects. The radiant heat does not directly warm the air, but the object receiving the radiation is warmed and acts as a heat exchanger to warm the air. The objects warmed by radiation then warm the air due to the principles of conduction and convection. During the heating cycle the air within the greenhouse will be warmed to almost the level of the soil and plant temperature. The air temperature will not exceed the temperature of the objects in the greenhouse heated by infrared radiation.

Conventional heating systems encounter a very difficult problem in that they are basically air heaters. That is, they heat the air and deliver heated air to a desired area. There are three physical principles working against each other in such a system:

1. Warm air rises.
2. In the presence of rapidly moving air, plants and people are cooled.
3. Air movement inside the greenhouse contributes to heat loss to the outside covering.

These factors are in conflict with each other when economics are considered. In order to move the lighter weight heated air down to the level occupied by the plants, we must force the hot air down with fans or turbulators consuming considerable electrical energy. The result is that by moving air we are cooling the plants in order to warm them. The same thing occurs with people. Human comfort at 19.5°C (67°F) is matched with about 15.5°C (60°F) using low intensity radiant heat. When using infrared as a means of heat transfer, we are able to eliminate this basic problem. Infrared energy travels independently of air. Since moving air is not required in delivering infrared heat, we are able to heat the plants by directing the infrared rays to the area we want. By using draftless heating we have developed a new and economical means of heating greenhouses. Savings have exceeded 60% heating with CO-RAY-VAC when compared with systems heating the air.

Hot water or steam pipes placed under benches are hotter than the air, and convection currents around the hot pipes move heated air up to the top of the greenhouse through the benches to be lost through the roof. Placing the pipes in the soil on the bench and insulating below may improve efficiency but still would not match the advantages in savings generated by the radiant CO-RAY-VAC system. Savings have exceed 50% heating with CO-RAY-VAC when compared with steam systems.

Four years ago, I was maintenance supervisor for Skagit Gardens, a wholesome greenhouse located in Washington State. Primarily they produce bedding plants, poinsettias, and flowering perennials. I worked three years there and during that time fuel costs dictated that we consider some means of fuel conservation. Double poly was not acceptable due to the low light already available during winter months. Washington is not known for lots of sunny days — some winter months we don't even see the sun.

Also, experience with unit heaters in dealing with cold and hot spots, frequency of repair, and cleaning and annual replacement of poly tubes, led to considering alternate ways of heating. The local gas company recommended we look into radiant heat. After studying the infrared system of heating it seemed to be a sound concept and the application in the greenhouse appeared to be practical. After nearly five years of use and comparisons with other heating systems, it is well received and endorsed as a new concept in greenhouse heating and fuel economy. Our test data was printed in the September, 1978 issue of the "Ohio Florists' Bulletin". CO-RAY-VAC saved us over 60%.

The infrared system is hung as high as possible in the greenhouse out of the way of plants and equipment. The gas is fired inside a four inch pipe and the heat warms the pipe to between 500°F and 900°F. The radiant pipe is covered with a lightweight polished aluminum reflector which directs the infrared rays towards the plants and floor of the greenhouse. The heaters are fired in series with one about every 20 to 40 feet depending on burner size and requirements. A vacuum pump pulls the gases down the tube and exhausts them outside the greenhouse. The pipe section twenty to thirty feet past the last burner is referred to as the tailpipe. It is at the cooling end of the heating system where the last of the heat from combustion is released. To meet the heating requirement for Northwest Washington in houses 21'×158', four 60,000 BTU units were used, providing a total of 240,000 BTU's per house. These proved to be more effective than the houses equipped with two 200,000 BTU unit heaters directed into fan jets with convection tubes at each end of the house for a total of 400,000 BTU's.

Some of the important advantages of infrared as applied to greenhouse heating are as follows:

1. The compact linear design of the system readily adapts itself to greenhouse application. It is lightweight, about 3½ pounds per linear foot, and casts only a narrow shadow the length of the house.
2. Clean, safe, and comfortable growing and working conditions are provided. Several built-in fail-safe features reduce the danger of leaking gas or fumes into the greenhouse and the chances of fire or explosion. Personnel feel very comfortable working under infrared heating.
3. High efficiency in converting fuel to radiant energy provide substantial savings in fuel costs. The infrared waves are directed downward so the heat radiates to the lowest point in the greenhouse which is either the plant, the walks, or the benches.
4. Infrared radiant energy is converted to heat when it strikes

an object and is absorbed by the object to be heated. The exhaust gases leave the system at 100° to 125°F, indicating that nearly all the heat has been taken out. Because objects are heated (not air), it is unnecessary to move air to deliver the heat. By eliminating the problem of heated air rising to the peak of the greenhouse, the heat difference between the inside and the outside is much less, which greatly reduces heat loss to the outside.

5. Incremental units allow for zone control of heating. Systems can be designed so that various areas can be heated independently of other areas.
6. Uniform heat distribution allows for more uniformity and quality control of the products. The reflectors direct the heat in a rectangular pattern corresponding to the shape of the greenhouse. Cold ends and sides are no longer a problem as a well designed system gives uniform heat distribution.
7. The CO-RAY-VAC infrared system is not affected by negative pressure in the greenhouse. Exhaust fans, drafts or high winds will not reduce the heating effectiveness because the system operates at a negative pressure greater than experienced from outside forces.
8. The infrared rays can be directed at the objects to be heated. Only the plants, benches and walks receive the energy from the infrared rays. The soil and walks serve as a heat sink that slowly release heat between heating cycles. The plant tissue is warmed even though the air is not heated directly. The warm soil, walks and plant tissue act as heat exchangers and warm the adjacent air, but productive growing conditions are achieved at air temperatures about 7°F lower than that required by a hot air system.

To understand the principle of infrared heating one must realize that this is a totally different concept than conventional hot air systems. The basic difference is that objects are heated directly with the radiant energy. The heated objects then warm the air touching them. (With heated air systems, the warmed air heats the objects.) With infrared the objects are warmer, the air cooler, thus reducing condensation or high humidity on or near the plant. This condition is desirable to aid in control of plant diseases. To move air with circulating fans in an infrared system would defeat the major advantage of the system. Because of the 900°F heat generated by the burner it is necessary to use care in placing plants near the reflector or hanging the system directly above flammable objects. Some injury to temperature-sensitive plants has been experienced where hanging plants were less than five feet from the heat source. Many heat tolerant plants have shown no injury when growing within three or four feet from the radiant pipes.

In order to establish an accurate record of the amount of fuel burned, a separate meter was installed to measure the amount of gas burned by the infrared system. After one full year the data provided by the local gas company showed an average of 62% reduction in fuel consumption for the CO-RAY-VAC infrared system compared to unit heaters and convection tubes. At this writing, the savings has consistently been in the area of 60% after over four years of use. Additional systems have been installed to now heat 70,000 square feet of glass greenhouse space. A new area of 60,000 square feet of glass to be heated with CO-RAY-VAC is currently under construction

In addition to reduced gas consumption, it was discovered that the electrical energy required to operate the heating system was only 10% of that required to operate unit heaters and convection tube fans.

In our installation the energy savings were enough to pay the entire cost of the equipment and installation in two years. The cost of energy now has increased to the point where in 1980 the savings will be equal to the original cost and each succeeding year the amount of dollars saved will be greater. We estimate that over a ten year period, with expected energy cost increases, we will save an amount in excess of ten times the original cost.

Infrared radiant heating has now been used successfully on a wide variety of greenhouse crops. Plants grown on the floor, raised benches, hanging baskets, or even densely populated combinations of the above have all responded favorably to this even, gentle means of heating. At this time, no crops have shown adverse effects in a properly installed infrared system. One should be careful to follow factory recommendations to insure the best results. Comparing the trade-offs one must accept with other means of energy conservation now on the market, infrared offers so many advantages that it promises to be the heating system of the future.

X-RAY DETERMINATION OF HORTICULTURAL SEED QUALITY

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Abstract: X-radiography is a quick and inexpensive means of assessing soundness of the internal structure of seeds. an indirect indication of seed viabil-