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Infrared heating in greenhouses

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INFRARED HEATING IN GREENHOUSES

P. Knies*, N.J. van de Braak* and J.J.G. Breuer*

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* Climate Control Division

1 Introduction

In the majority of Dutch greenhouses a heating system consisting of a hot water boiler and steel pipes is applied. Heat transfer in this system takes place by convection and radiation - the heat transfer to the plant is governed by the convective transport via the greenhouse air.
From a physical viewpoint this is a relative inefficient process as the air is also transfered to the cool cover and some air is lost due to (natural) ventilation. Technically more attractive is to heat the plants directly using radiant heat.
Bussinger (1955) compared a radiant and a convective system. As can be expected he found that leaf temperatures under radiant heating were higher than the air temperature. This implies that for maintaining the same crop temperature in a convective and in a radiant heated house, the air temperature in the second can be lower. Theoretically this will result in a lower energy consumption.
Between 1955 and 1978 a few experiments with infrared heating were reported (NNGC and Strinson).
An increasing interest in infrared heating arose in 1978 in the Netherlands. Articles in Dutch specialist journals about successful greenhouse applications in the USA, made from the subject a topic of the hour.
The Institute of Agricultural Engineering (IMAG) investigated in cooperation with the Dutch Gasassociation (VEG Gasinstituut) the performance of infrared heating systems in comparison to pipe heating systems. The tests and results are described in the following.

2 Infrared radiator

The infrared systems used in the test are so-called low intensity radiators. This means that they operate in the region of 300 °C surface temperature.
The system basically consist of a horizontal steel pipe mounted overhead.
The pipe has a double function. In the first place it is a combustion chamber. In the second place it forms the duct for combustion gasses (Fig. 1). After combustion in the pipe the hot gasses transfer their energy to the wall of the pipe. The pipe is heated and on its turn transfers its energy to the crop mainly directly by radiation and to a lesser extent by convection. Running along the duct the gasses cool down. After a certain distance (in the case of NOR-RAY-VAC 9 m) the gasses are raised in temperature in the next burner.

After passing a certain number of burners (depending on design) the gasses leave the greenhouse.
In order to avoid high outlet temperatures either a long tailpipe or a heat exchanger might be applied.

3 Test set-up

The experimental period covered the two heating seasons, 1980/81 and 1981/82. The complete testprogram is presented in Table 1. In the first season tulips and lilies were grown one after another and in the second season chrysanthemums were cultivated.
Two adjacent compartments of 19.2 x 35.0 m each in a large single glazed greenhouse complex of the auction "Flora" in Rijnsburg were used for the tests. One compartment was used as a reference. In the other infrared heating was applied. As can be seen in Fig. 2 the reference compartment is located at an end of the greenhouse complex.
To be able to make a reliable comparison of the energy consumption of both compartments the long side walls were provided with 5 cm polystyrene insulation panels.
In the introduction it was mentioned that in a traditional heating system the heating elements consist of hot water pipes. The pipes may be located overhead or near the ground. Overhaed pipes are used by growers who prefer to keep working space in the greenhouse clear for soil management reasons. A disadvantage connected with this type of heating is a vertical air temperature gradient with the highest temperatures in the top of the greenhouse. Facing rapidly increasing costs of energy, the greenhouse industry developed other - more energy conscious - methods of heating. An important tendency was to bring down the heating pipes.
Both hot water systems mentioned e.g.
1) overhead pipes (Fig. 3)
2) crop heating with low pipes (Fig. 4)
were used as a reference. The first in the heating season 1980/81, the second in the successive season (Table 1).
In the first season a Roberts Gordon NOR-RAY-VAC infrared system was applied with a lay-out as depicted in Fig. 5.
The second season this system was replaced by a Dutch infrared installation called Vitotherm manufactured by Vito Technieken (Fig. 6).
In the latter system insulating material with decreasing thickness and retarders are inserted in the pipe. The effect is that the temperature distribution of the

pipe is even along a section of 20 m maximum. Further an attempt was made to level out the radiation distribution in the direction perpendicular to the centreline of the pipe.

In a representative part of each compartment temperature measurements were made. Special attention was paid to the determination of the effect of the uneven distribution of the radiating pipes (in the first season 1 in each span of 6.40 m and in the second season 2 in 3 spans) and of the decreasing pipe temperature in one section between two burners. Further temperature measurements were made at several heights to be able to determine vertical temperature gradients.

In order to be able to compare the gross energy consumption gasmeters were installed in both systems.

Comparing gasmeter readings would confuse the effect of combustion efficiency and the efficiency of the heat transport towards the crop. For this reason the nett energy consumption (gross energy consumption multiplied by the combustion efficiency and upper burning value) per unit area is used as a basis for comparison. For determining the efficiency several manual measurements were made. In addition a heatmeter was installed in the hot water system.

Data which were available before running the tests as described inhere, showed that the radiating pipe temperature of the NOR-RAY-VAC system varied along the length. No other conclusion could be drawn than that this had to effect the radiation intensity level. Apart from this length effect a width effect was expected despite the presence of a reflector. A proper measurement implied the determination of the contribution of the radiant heater to the radiation intensity at a certain spot. Using a thermopile mounted on a black plate, the total radiation was measured in the nodal points of the measuring grid after sunset. The roof temperature was measured at several locations with the aid of an infrared thermometer and the average roof temperature was used to calculate the value of the background radiation. Subtraction of this value from the measured total radiation provided the contribution of the infrared system in each point of the measuring grid.

4 Results

4.1 Temperature distribution

Fig. 7, 8 and 9 depict the typical temperature distribution in a direction perpendicular to the centreline of the radiating tube in season 1 and 2 respectively.
Fig. 7 shows that the temperature distribution under radiant heat is quite even in season 1. The same tendency was found with Vitotherm in season 2.
A large vertical temperature gradient was found in the compartment with overhead pipes (Fig. 8). This gradient disappeared in the second season when the heating pipes were near the ground (Fig. 9).
The horizontal distribution of the air temperature in the direction of the ridge of the greenhouse is quite even in both the infrared and the traditionally heated compartments. This was the case in both seasons.

4.2 Distribution of radiation intensity

Figures 10 and 11 show that the uniformity of the distribution of the radiation intensity is poor for both IR systems. In both cases the intensity in the direction perpendicular to the radiating pipes drops dramatically from a point straight under the pipe to the boundary of the working area.
In the case of Vitotherm the distribution in plane A and B is about the same.
For NOR-RAY-VAC however the pattern of the distribution was not uniform through the planes A, B and C.
Neglected in the comment on Fig. 10 and 11 sofar is the fact that the lay-out of the NOR-RAY-VAC system differs from the one of Vitotherm. Especially the working area covered by one burner of the second system is more than twice as large as that of the first system. It was felt however that the uniformity within the actual working area is relevant.

4.3 Matureness

As a result of the poor distribution of the radiation intensity, temperature differences of about 2 °C occurred in the crop and soil top layer.
It took the tulips on the cold spot 10 days longer to flower than on the hot spots. No appreciable differences were found with the other crops. This may have been caused by the fact that tulips are particularly sensitive for

differences in radiation intensity, or by the circumstance that outside wheather conditions indirectly (duty cycle of radiant heaters) effected the average temperature difference in the crops.
"Cold spots" refers to locations with a low radiation level, excluded are compartment edge effects. Serious edge effects appeared during the first phase. The lay-out hardly dealt with heatloss through the walls as can be seen in Fig. 5. In the second phase a fluegascondensor was used to heat the water for the convective wall heating system which consisted of steel pipes. Edge effects were less serious in season 2.

4.4 Burning efficiencies

Based on the upper burning value of 35.17 MJ/m^3 for natural gas, the burning efficiency of the hot water boiler appeared to be 76%. For the NOR-RAY-VAC IR system a value of 86% was found. The efficiency of the Vitotherm system has been measured with and without the fluegascondensor. Values of 76% and 88% have been established respectively.

4.5 Energy consumption

The nett heat consumption for the three growing periods included in the test is summarized in Table 2. Savings of 12.2 and 12.8% were obtained when IR is compared with overhead hot water heating. In the second season when radiant heat was compared to a type of hot water bed heating, energy consumption of IR was 6% lower. The remark has to be made that in the second season the overhead pipes (lower number than in the first season) were used quite often. A cold winter and disease control made it necessary to use the overhead heating pipes more often than foreseen. As no measures were taken to determine energy consumption of both groups separately, no true comparison between infrared and crop heating could be made. The hot water system during season 2 actually may be characterized as a hybrid system consisting out of a combination of overhead and crop heating pipes.

5 Conclusions

The air temperature distribution in the greenhouses was even under both IR-systems used in the test.

The heat radiated by the systems was not evenly distributed over the working area. The distribution in the width of the greenhouse was bad for both systems, distribution in the length direction was bad for the NOR-RAY-VAC and good for Vitotherm.

The differences in radiation intensity resulted in differences in matureness of about 10 days when growing tulips.

The nett energy consumption of NOR-RAY-VAC when compared to a hot water system with overhead heating pipes was 12-13% lower.

The nett energy consumption of Vitotherm compared to a hot water system with bed heating and overhead pipes (hybrid) was 6% lower.

6 Summary

The performance and energy consumption of two infrared heating systems has been compared to traditional hot water pipe heating systems.
Air temperature gradients appeared to be within an acceptable range under infrared. The nett heat consumption with infrared was about 12% lower compared to overhead heating pipes and was 6% lower when compared to a crop heating system combined with overhead pipes. The distribution of the radiation intensity showed to be very uneven. With the cultivation of tulips this resulted in differences in matureness.

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8 Tables and figures

Table 1 Testprogram.

Season	Period	Crop	IR system	Traditional system
1	02-12-'80/06-02-'81	tulips	NOR-RAY-VAC	overhead hot water pipes
	17-02-'81/27-05-'81	lilies		
2	09-10-'81/19-02-'82	chrysan-themums	Vitotherm	crop heating with low hot water pipes

Table 2 Nett heat consumption.

Season	Period	Crop	Nett heat MJ/m² IR	Nett heat MJ/m² Trad.	Difference compared with trad.	
1	02-12-'80/06-02-'81	tulips	444.8	506.8	-12,2%	overhead pipes
	17-02-'81/27-05-'81	lilies	272	312	-12,8%	
2*	01-01-'82/19-02-'82	chrysan-themums	586	623	- 6 %	crop heating

* not covering complete testperiod

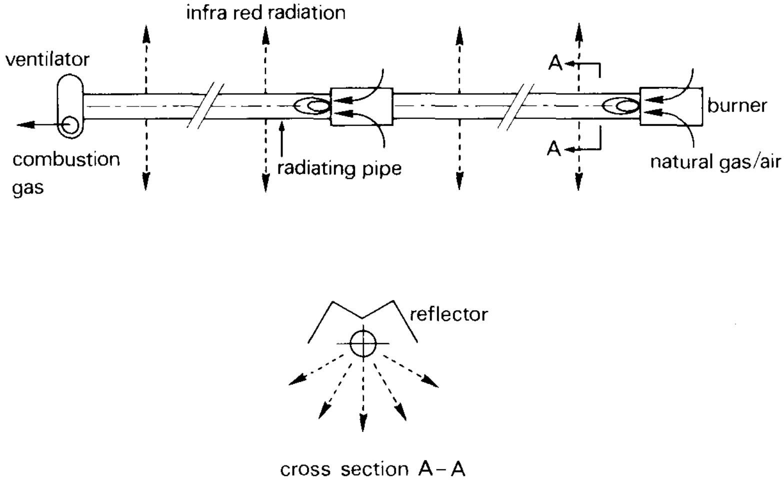


Fig. 1. Schematic presentation of a infra red radiator

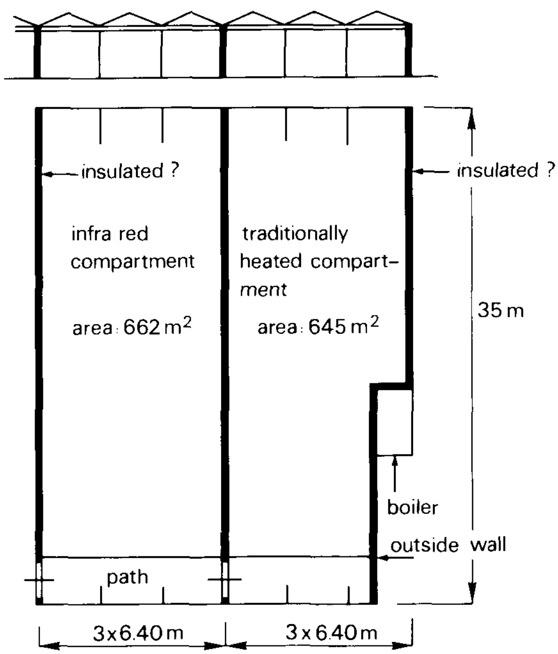


Fig. 2. Plan of the two test compartments.

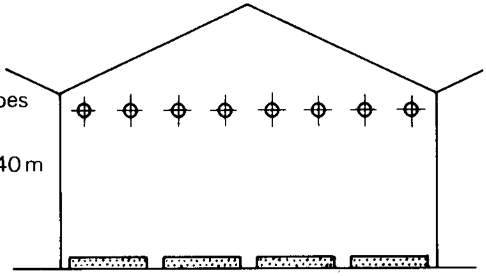


Fig. 3. Traditional hotwater system with overhead pipes.

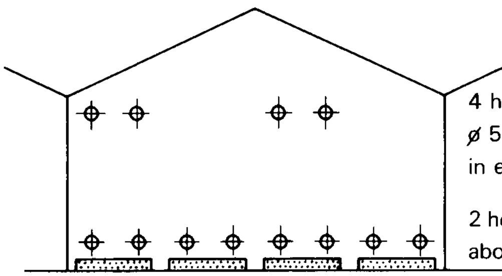
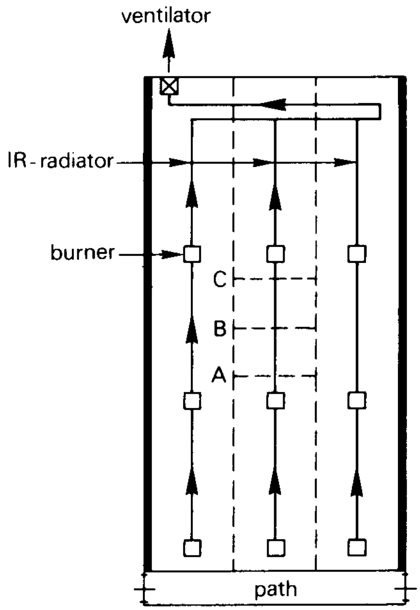


Fig. 4. Traditional hotwater system with cropheating.



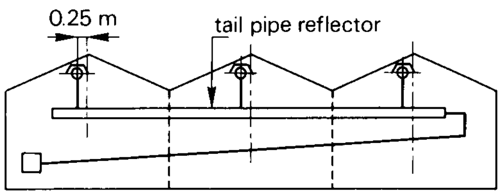


Fig. 5. Layout of NOR A VAC system in first growing season.

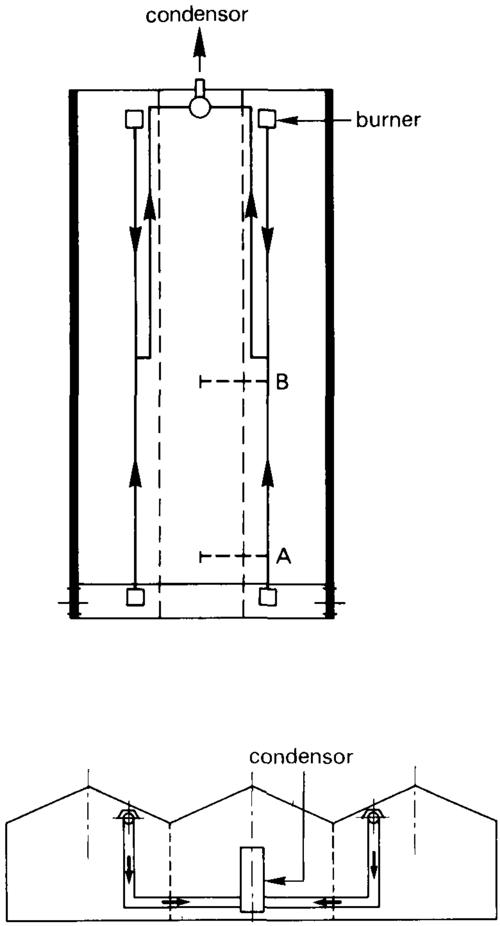


Fig. 6. Layout of the Vitotherm system in the second season.

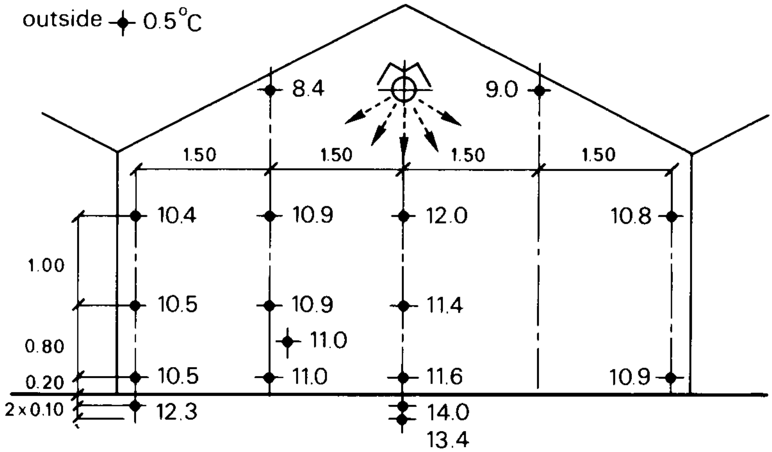


Fig.7. Temperature profile under IR in first season.

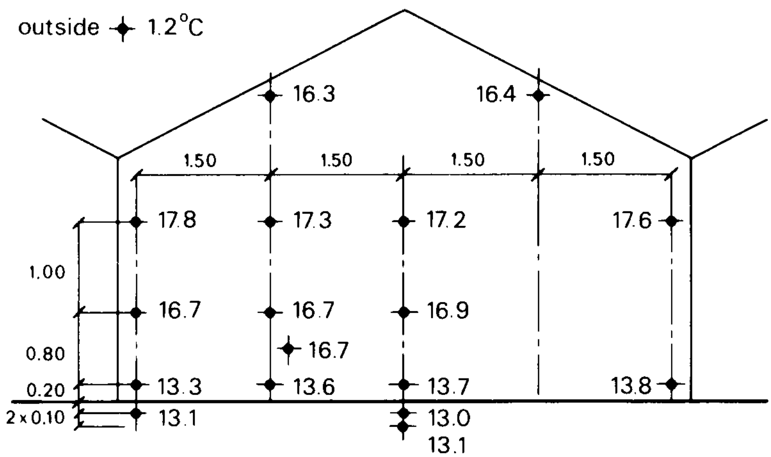


Fig.8. Temperature profile under overhead heating pipes.

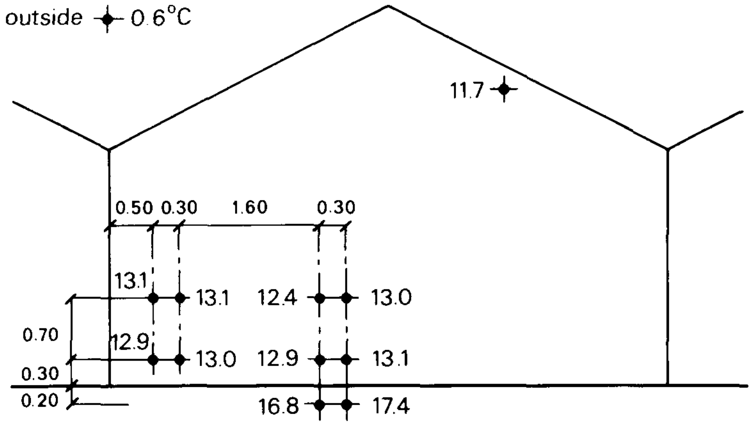


Fig. 9. Temperature profile with the crop heating system

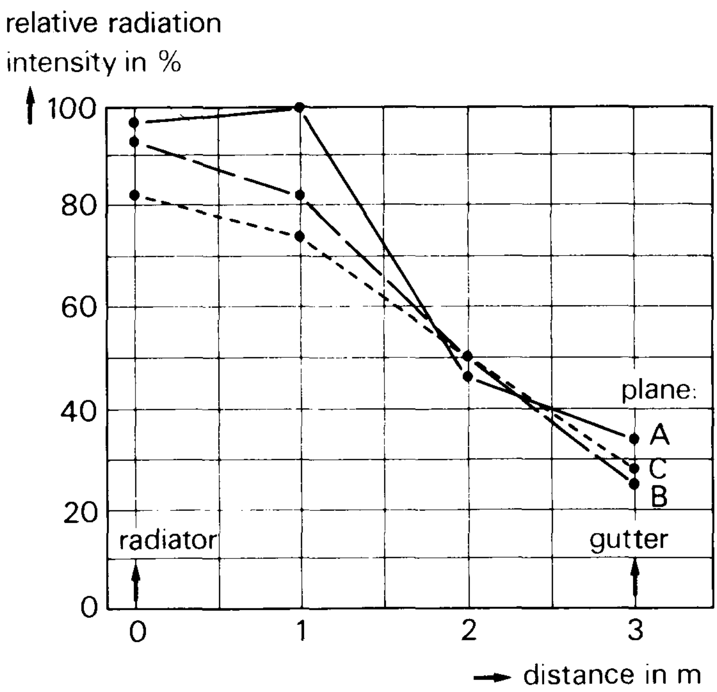


Fig. 10. Relative radiation distribution at 1 m above ground level in the first season.

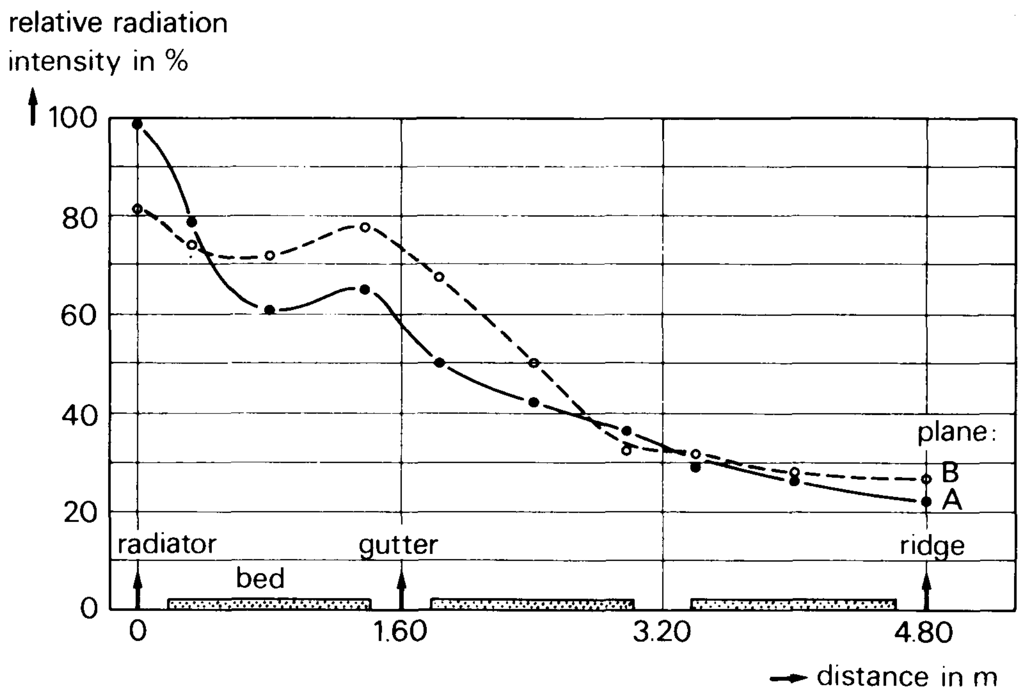


Fig. 11. Relative radiation distribution at 1 m above ground level in the second season.

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