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Negative DIF: Mean room temperature control and its effect on environment and energy consumption

Negativ DIF: Middeltemperaturregulering og dens effekt på klima og energiforbrug

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Summary

During the winter 1989-1990 two experiments were carried out. In both the effect of traditional zero DIF (18°C/18°C) room temperature set points were compared with a negative DIF (14°C/22°C) programme based on a 168 hours mean room temperature. Supplementary light was applied whenever outside irradiation was less than 40 µmol/m^{2}s.

The first experiment - October to January - comprised short-day plants, the second experiment - February to May - comprised long-day plants.

High priority of negative DIF implicates ventilation of warm air at sunrise to provoke a fast decrease in room temperature, this is an expense which should be avoided. 9 and 13 per cent higher energy consumption was measured as compared to a traditional - zero DIF - temperature programme.

The mean room temperature control which preferably causes heating at night when the greenhouse is insulated did not alter this.

Key words: Greenhouses, district heating, mean room temperature control, programme call, computer control, negative DIF.

Resumé

I vinterperioden 1989-1990 blev der udført et forsøg, der undersøger virkningen af to rumtemperaturstyringer: Traditionelt nul DIF (18°C/18°C) sammenlignes med negativ DIF (14°C/22°C) kombineret med rullende gennemsnitstemperaturstyring. Tilskudslys, når lysintensiteten var mindre end 40 µmol/m^{2}s. Tilskudslys af højtryks-natriumlamper med en installeret effekt på 30 W/m^2 eller 40 µmol/m^{2}s.

Forsøget omfattede dyrkning af kortdagsplanter i efterårssæsonen (oktober-februar) og langdagsplanter - 18 timer - i forårssæsonen (februar-maj).

Høj prioritering af negativ DIF, der medfører udluftning af varm luft ved solopgang, for at tvinge rumtemperaturen ned, medfører et højere energiforbrug end et traditionelt temperaturprogram. For efterårs- og forårsforsøget fandtes et merforbrug.

Anvendelse af middeltemperaturregulering, der fortrinsvis varmer i de perioder, hvor gardiner er trukket for, kunne ikke ændre det.

Nøgleord: Væksthusopvarmning, fjernvarme, middeltemperaturstyring, modulkald, computerstyring, negativ DIF.

Introduction

The special problems when many commercial greenhouse nurseries are connected to district heating were widely discussed in previous papers. The solution lies primarily in reducing energy consumption peaks at sunrise and sunset (1, 2).

The specific topics reviewed in these experiments may be summarized as follows:

- avoiding energy consumption peaks in morning and evening hours.
- negative DIF room temperature programme.
- supplementary light.
- move energy consumption to night periods.

In general a reduction of energy consumption peaks in greenhouses can be obtained, when high night room temperature and low day room temperature set points - negative DIF - are used (1, 2, 4).

Previous experiments with reduction of energy peaks have shown that negative DIF with a modified analog control system produces good results (1) and even better results can be obtained by computer control (2). But computer control has pronounced advantages as compared to traditional analog control systems due to a free choice of ramp functions when changing set points.

The development and design of DGT-Volmatic computers has added a new facility - programme call routine - which enables growers as well as research workers to apply individual control strategies with the standard routines of the computer. As a consequence room temperature control in this experiment was based upon computers.

Some aspects of the experiment appear to be contrary as the requirements for plant development and energy conservation tend to be incompatible.

The fast decrease in room temperature in the morning, which was believed to be essential to obtain a maximum growth retarding effect, is not in agreement with a control strategy which reduces energy consumption.

The negative DIF programme was given a very high priority. The effect of this priority on the energy consumption pattern is essential when evaluating the results.

In the experiment the design of the room temperature programme was based upon:

- a minimum of three hours at 22°C before start of light period
- a minimum of two hours at 14°C after start of light period
- room temperature should not exceed 22°C
- an average room temperature of 18.6°C based upon the last 168 hours.

This paper will report on the effect of the climatic control programme upon energy consumption and the variations in environment. The effect upon plant growth and development will be reported in a separate paper (9).

Materials and methods

Greenhouses

The experiment was carried out the Department of Horticultural Engineering at Årslev. Two identical east-west orientated greenhouses clad with single glass and 8 m × 21.5 m were used.

The greenhouses are equipped with shading screens (Ludvig Svensson No. 15), which are drawn along the greenhouse, and stated to reduce irradiation by 55 per cent. The screens are also applied during the night as thermal screens.

The greenhouse comprises four movable benches, 1.6 m × 18 m. The benches are equipped with a capillary irrigation and liquid feeding system. During the experiment plants are grown on the benches (9).

The heating system (83 kW) is designed to meet a difference of 30°C between inside and outside air temperature. It consists of the top and wall heating system and the floor heating system, which are operated simultaneously. The floor heating system consists of 12 pipes, 0.5 m above the ground level. The bench heating system was disconnected in this experiment.

High pressure sodium lamps, Philips son-T are installed with an effect of 30 W/m^2 or an average light intensity of 40 $\mu mol/m^2s$ at the top of the plant canopy. The standard operaton comprises both clock and light intensity measurements.

Data aquisition

The environmental parameters are recorded every ten minutes and hourly mean values are stored for analysing.

Dew point temperature is computed from dry and wet bulb temperatures.

Plant canopy temperature is measured by infrared thermometry. The sensor is placed 30 cm over the canopy and covering approximately 0.6 m^2.

Dry and wet bulb room temperatures are measured by pt 100 thermo sensors placed in an aspirated screen exposed to an air velocity of approximately one meter per second.

The sensors for computer control are placed in a standard aspirated screen of the manufacturer's own design.

The aspirated screens are placed 0.3 m above the average plant canopy in the middle of each greenhouse.

The energy consumption is calculated from total water flow, measured by a magnetic flowmeter and the temperature of the hot water inlet and outlet.

Temperature control

Environmental control in both greenhouses is based upon a DGT-Volmatic computer LCC 1240 which is a computer system available for commercial use. The computer is provided with a programme call routine which is a facility for applying individual control programmes, for research as well as commercial purposes.

In the control programme the diurnal period was divided into 4 zones, which took into account the time and a maximum and minimum room temperature set point (Fig. 1).

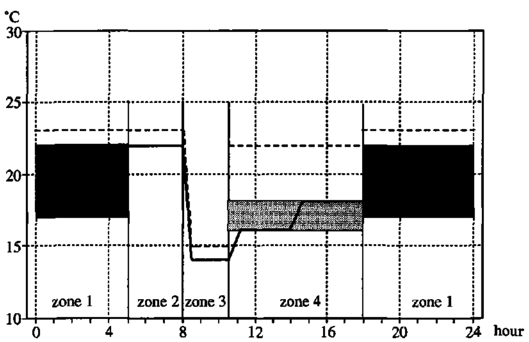

Fig. 1. The time and temperature zones of the mean temperature control. The shaded area indicates where minimum temperature set points depended on the last 168 hours' mean temperature. The lenght of the night zone 1 depends on sunset, sunrise or the application of supplementary light (long-day treatment). Zone 2 and 3 are fixed.

Three hours before and two hours after start of light period - shift beween zone 2 and 3 - were the only periods where a specific room temperature was imposed. Day temperatures in zone 4 between 16°C and 22°C depended on solar radiation. When mean room temperature lagged behind the minimum set point could be raised from 16°C to 18°C. After end of light period zone 1 the minimum room temperature set point could vary between 17°C and 22°C dependent on mean room temperature. Three hours before start of light period a fixed set point of 22°C was kept.

Experimental design

The experiment was carried out in two sequences, the first one for short-day plants from October to January and the second one for long-day plants from February to May.

Reference treatment:

- zero DIF 18°/18°C day/night room temperature set points.
- ventilation at 24°C for short-day plants 22°C for long-day plants.

Experimental treatment:

negative DIF 8°C.

zone 1: ramp of set point increase at start of dark period 3°C/h. Set point 18°C or higher, dependent on mean temperature. Ventilation 1°C over set point.

zone 2: 22°C at least 3 hours before end of dark period. Ventilation 1°C over set point.

zone 3: ramp of set point decrease at start of light period 15°C/h.

14°C at least 2 hours after start of light period. Ventilation 1°C over set point.

zone 4: set point 16°C or 18°C depending on mean room temperature. Ventilation 24°C for short-day or 22°C for long-day treatment.

mean temperature of 18.6°C based on previous 168 hours.

For experiment as well as the reference treatment:

shading screens applied during the day at an outside irradiation over 300 W/m^2.

shading screens applied during the night at an outside irradiation less than 2 W/m^2, instrument set point 200 lux.

Supplement light in zone 3 and 4 two hours

after start of light period, whenever irradiation was less than 40 μmol/m²s
long-day plants 18 hours light period
short-day plants 11 hours light period

Results

Room temperature

If we consider the time series of the room temperature on two adjacent days, where the mean temperature lags behind the first day (Fig. 1), we observe the following: at least 3 hours room temperature at 22°C and a day room temperature which seems to be 5°–6°C lower when negative DIF is applied.

Two temperature maxima occur during the night. This is because the mean temperature lags behind. The ideal mean room temperature is, however, obtained within a few hours. The second maxima occurs later, when the normal temperature programme demanding 22°C during three hours takes over.

The second day set point is pronounced lower in zone 3 due to the fact that a sufficient high mean room temperature now prevails.

This is typical for short-day plants, for which a long night period is used for regulating the mean temperature. Long-day plants on the contrary have a short night period to reach a lag in mean temperature, and therefore the night temperature will almost always be at maximum in those situations.

The fast decrease in room temperature has been given a very high priority in the temperature control programme. When we compare the room temperature one hour before daybreak with the room temperature one hour after start of light period (Table 1) we observe that the average temperature decrease has been 7.1°C, but the decrease in canopy temperature has been less, on average 5.5°C.

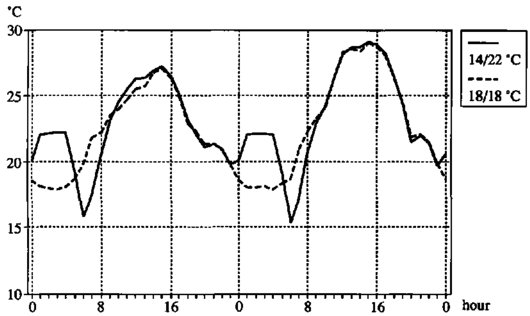

Fig. 3. The time series of room temperature in two greenhouses (7-8 May 1990, long-day plants), one with zero DIF and one with negative DIF. Note that room temperatures at day are identical, apart from a few hours just after sunrise. At night the forced high temperature is the cause of a higher mean temperature (see text).

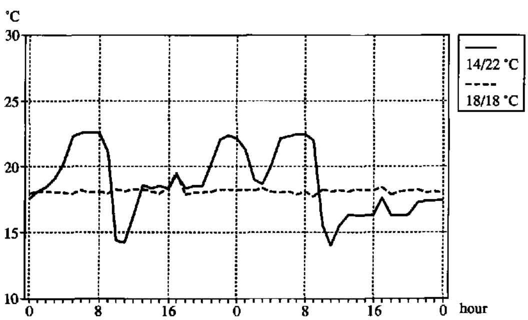

Fig. 2. The time series of room temperature in two greenhouses (4-5 January 1990, short-day plants), one with zero DIF and one with negative DIF. Note the fast decrease of room temperature due to ventilation, the pronounced lower room temperature during day before noon and the two maxima occurring at night (see text).

Table 1. The decrease in room- and canopy temperatures from one hour before sunrise until one hour after. Note that decrease in canopy temperature is less than decrease in room temperature.

Temperature decrease °C	Room %	Canopy %
0 - 1		0.4
1 - 2		0.
2 - 3		0.5
3 - 4		10.8
4 - 5		20.6
5 - 6	4.4	34.8
6 - 7	44.3	26.0
7 - 8	41.9	6.4
8 <	9.4	0.5

Table 2. Energy consumption in two greenhouses. Both long-day and short-day treatment show an increase in energy consumption due to a forced room temperature decrease by ventilation at the start of the light period.

	Zero DIF	Negative DIF	
Short-day	w/m^2	w/m^2	%
Oct.-Jan.	108	122	+13
Long-day			
Feb.-May	73	79	+ 9

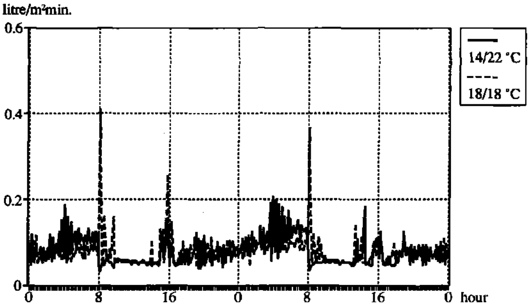

Fig. 5. Hot water flow in two greenhouses, one with zero DIF and one with negative DIF. Note the severe hot water consumption peaks in the greenhouse with zero DIF.

Energy consumption

The beneficial aspect of negative DIF on growth (e.g. to reduce the application of growth retardants) lead us to try a strategy where the reduction in room temperature at sunrise was given high priority. The fast decrease of room temperature was obtained by excessive ventilation at the start of the light period. In the negative DIF programme ventilation was active for 352 hours in the morning hours as compared to 22 hours in the zero DIF programme. The loss of energy from ventilation could not be counteracted by mean room temperature control programme. The result clearly shows an increased energy consumption (Table 2).

Energy consumption peaks

The striking point are the pronounced energy consumption peaks, with a traditional temperature control (Fig. 3). Due to a forced room temperature reduction by ventilating in the morning a higher energy consumption is found by negative DIF.

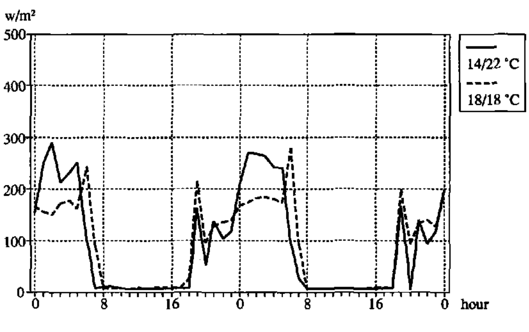

Fig. 4. The time series of energy consumption on two adjacent days in two greenhouses, one with zero DIF and one with negative DIF. The demand for a high room temperature three hours before the start of the light period results in a high energy consumption. Note that energy consumption peaks are not found when negative DIF is applied (see text).

Hot water flow

For nurseries connected to district heating the time series of the water flow is of more interest than energy consumption. Fig. 5, shows the water flow on two adjacent days in January. Severe hot water consumption peaks in very short periods are seen where negative DIF is not applied (Fig. 5).

Air humidity

The level of air humidity has two major impacts upon plant growth. Low levels promote transpiration, high levels promote fungi spore germination. Therefore the time series of the air humidity content in respect to those two items is of major interest for plant growing in protected cultivation.

For fungi spore germination periods where the difference between leaf temperature and dew point temperature becomes less than 1°C - the state of near condensation - in a period of more than two hours is of danger in respect to fungi spore germination.

In the following analyses we have counted the periods, where the difference of leaf temperature and dew point temperature was less than 1°C (Table 3).

Table 3. The number of periods, where the difference between leaf and dew point temperature (T_l - T_d) has been less than 1 or 2°C.

T_l - T_d	Number of hours before sunset						
	6	5	4	3	2	1	0
	Number of periods						
0 - 1°C	0	1	2	4	4	13	1
0 - 2°C	20	16	17	32	58	87	20

The interval between 0°C and 1°C is assumed to be a critical difference where fungi spores germinate. This occurs most often one hour before sunset. From this point of view prophylactic measurement must be carried out at that time.

Canopy temperature

Canopy temperature is the ultimate temperature to which the plants react. The difference between the air and leaf temperature indicates where an expected reaction of the plants does not occur due to a discrepancy from the room temperature - which is the controlled media - and the tissue temperature, which is the reacting media (Table 4 and Fig. 7).

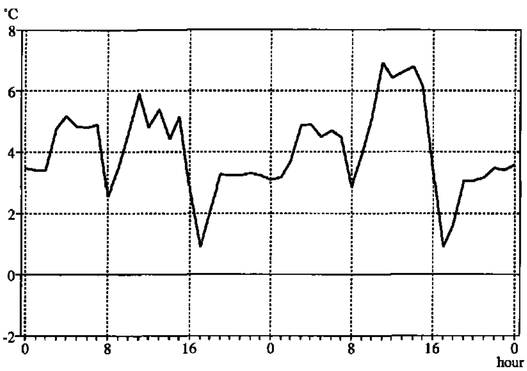

Fig. 6. Difference between leaf- and dew point temperature on a sunny day. Note that differences become small in the late afternoon.

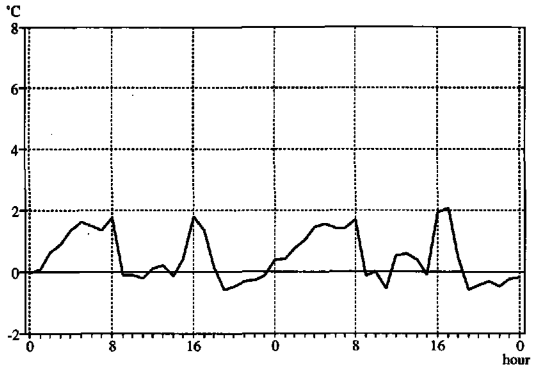

Fig. 7. Difference between air- and leaf temperature. Note that large differences are prevailing during night time.

Discussion

Programme call

The programme call routine (3, 6) proved its applicability. Due to this facility it was possible to combine negative DIF, mean room temperature control, supplementary light and short-day or long-day control.

Table 4. The number of periods of one hour, where the difference between leaf- and room temperature (T1 - Tr) has been in the indicated classes. Before sunrise app. 90 per cent of the leaf temperatures have been between 1 and 3°C lower than room temperature, thus reducing the effect of negative DIF.

T_l - T_r	Number of hours before start of			at light	after period		
	3	2	1	0	1	2	3
°C	number of periods, %						
3 - 4	0	0	0	0	0	1	1
2 - 3	0	0	0	0	8	7	1
1 - 2	0	0	0	6	9	12	15
0 - 1	0	0	0	3	15	15	26
-1 - 0	2	2	2	11	36	44	33
-2 - (-1)	47	54	55	44	33	20	21
-3 - (-2)	41	33	32	30	0	1	4
-4 - (-3)	11	12	11	6	0	0	0

Room temperature

The difference in the time series of the room temperature in the two treatments is a result of three different approaches in the mean room temperature programme.

- The difference between zero and negative DIF programme
- The provoked temperature reduction at sunrise, by ventilation
- The attempt of the programme to regain a lag in mean room temperature, according to the mean room temperature control.

Mean room temperature

To obtain a growth retarding effect of negative DIF on plant development, the decrease from night to day temperature is believed to be crucial for the result (5, 7, 8, 10, 11, 12). Therefore great care was taken to obtain a fast decrease in room temperature at the start of the light period. This implied opening the vents, whenever necessary. When we compare the number of hours where vents have been opened in connection with this temperature decrease we find a considerably higher frequency than in the reference treatment.

Regaining the desired mean room temperature - 18.6°C - has resulted in a rise of room temperatures at the beginning of the night and as soon as the desired mean temperature was obtained a decrease. Three hours before the start of the light period the room temperature was increased again to the demanded 22°C (Fig. 2). This change between high and low room temperature during the dark period is not desirable and a mistake in the strategy. This must be improved in future routines.

Conclusion

Negative DIF

The high priority of a fast temperature decrease at the start of the light period resulted in an undesired high energy consumption.

Mean room temperature control

Within the limit of 168 hours it has been possible to keep the mean room temperature to a high degree of accuracy during winter time. But in late spring when solar radiation dominates room temperature, however, the mean room temperatures in both treatments increase.

Programme call

Programme call routine has proven its applicability in this experiment, however, several improvements have to be made to overcome energy waste, and undesirable raise and fall in room temperatures within short time during the night.

References

1. *Amsen, M. G. & Nielsen, O. F.* 1988. Simple techniques for reduction of energy consumption peaks in greenhouses. Tidsskr. Planteavl 93, 27-36.
2. *Amsen, M. G. & Nielsen, O. F.* 1990. Reduction of energy consumption peaks in a greenhouse by computer control. Tidsskr. Planteavl 94, 431-440.
3. *Borland International, Inc.* 1988. Turbo Pascal Version 5.0. Reference Manual, 654 pp.
4. *Cockshull, K.; Hand, D. & Langton, A.* 1986. GCRI finds new ways to cut heating bills on ayr crops. Grower 105, 77-83.
5. *Hendriks, L. & Scharpf, H. C.* 1985. Nachtabsenkung bei Topf Chrysanthemen - lieber nicht. Gb+Gw 88, 1362-63.
6. *Ehlers, N.* 1991. Interfacing crop models to standard software for greenhouse climate control. Ecological modelling (accepted for publication).
7. *Erwin, J. E.; Heins, R. D., & Karlsson, M. G.* 1987. Thermomorphogenesis in *Lilium longiflorum.* Amer. J. Bot. 76, 47-52.
8. *Heuvelink, E.* 1988. Influence of day and night temperature on the growth of young tomato plants. Sci. Hort. 38, 11-22.
9. *Jacobsen, L. H.; Amsen, M. G. & Nielsen, O. F.* 1991. Negative DIF: Mean room temperature control and its effect on short-day plants. Tidsskr. Planteavl 95, 441-447.
10. *Moe, R. & Heins, R. D.* 1989. Control of plant morphogenesis and flowering by light quality and temperature. Acta. Hort. 272, 81-89.
11. *Mortensen, L. M. & Moe, R.* 1987. Effect of fluctuating temperature on growth and flowering of *Chrysanthemum morifolium* Ramat. Gartenbauwissenschaft 52 (6), 260-263.

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