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Negative DIF: The effect of temperature drop prior to light period on environment and energy consumption under short day conditions in greenhouses (I)

Negativ DIF: Virkningen af temperaturfald før lysperioden på klima og energiforbrug under kortdagsforhold i væksthuse (I)

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Summary

From October 1990 to January 1991 an experiment was carried out with negative DIF under short day conditions, 10.5 hours. The effect of a traditional room temperature programme with fixed room temperature set points day/night (18/18°C) was compared with a negative DIF programme day/-night (16/22°C). To preserve maxim of energy a 168 hours mean room temperature programme was applied, which moves energy consumption to the night period, when the greenhouse was insulated by screens. In order to preserve energy and to obtain a longer period with a low room temperature, the drop in room temperature was applied 3 hours prior to the light period.

During the light period supplementary light was applied whenever outside irradiation was less than 40 μmol/m^{2}s. High priority of negative DIF with a fast decrease in room temperature necessitates ventilation of warm air at sunrise.

Due to this an increased energy consumption of 7 per cent was found compared to a traditional (18/18°C) room temperature programme.

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

Resumé

Fra oktober 1990 til januar 1991 blev der udført et forsøg under kortdagsforhold, 10,5 timer, der sammenlignede virkningen af 2 rumtemperaturstyringsprogrammer: et traditionelt med faste setpunkter for dag/nat (18/18°C) blev sammenlignet med et negativ DIF dag/nat (16/22°C) kombineret med gennemsnitstemperaturstyring over de sidste 168 timer. I lysperioden anvendtes tilskudslys, når lysintensiteten ude var mindre end 40 μmol/m^{2}s. Tilskudslys af højtryks-natriumlamper med en installeret effekt på 30 W/m^2 og målt til 40 μmol/m^{2}s i plantehøjde. 3 timer før lysperioden sænkedes setpunktet fra det høje natniveau 22°C til 16°C.

Forsøget omfattede dyrkning af kortdagsplanter – 10,5 timer dag – i efterårssæsonen (oktober-januar).

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Høj prioritering af negativ DIF, der kræver udluftning af varm luft, medfører 7% højere energiforbrug end ved et traditionelt temperaturprogram.

Anvendelse af middeltemperaturregulering, der fortrinsvis anvender varme i de perioder, hvor gardiner er trukket for, har ikke kunnet forhindre det højere energiforbrug.

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

Introduction

Energy consumption peaks which are a special problem when many commercial greenhouse nurseries are connected to district heating have been discussed in previous papers and will not be repeated here. Some difficulties can be solved by reducing energy consumption peaks at sunrise and sunset by applying high night and low room temperatures (1, 2, 3).

The specific topics reviewed in this experiment may be summarized as follows,

- avoiding energy consumption peaks in morning and evening hours.
- negative DIF room temperature programme.
- preserving energy by reducing room temperature 3 hours prior to light period.
- move of energy consumption to night periods by moving average mean temperature control.
- supplementary light application dependent on low electricity tax periods.

The main target of the experiment is to prove that it is possible to combine the above mentioned conditions into simple temperature control routines.

Some of the aspects may appear to be contradictory as the requirements for plant development and energy conservation are incompatible. 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, 3, 5).

A fast decrease in room temperature in the morning, which was believed to be essential in order to obtain a maximum morphogenetic effect, is not in agreement with a desire for a reduced energy consumption. Therefore the reduction of room temperature was set to be activated 3 hours prior to start of the light period.

Apart from avoiding energy consumption peaks in the morning and in the evening, the negative DIF programme was given a very high priority due to its expected morphogenetic effect on plant development. The effect of this priority on the energy consumption is important when evaluating the final results of the experiment.

The experimental design of the room temperature programme was based upon,

- at least 3 hours at 22°C prior to the low temperature (16°C) period.
- at least 2 hours at 16°C after the high temperature (22°C) period.
- room temperature should not exceed 22°C during the light period.
- average room temperature of 18.6°C based upon the previous 168 hours measurements.

Computer control has pronounced advantages compared to traditional analogue control systems due to a free choice of ramp functions when changing set points.

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 (4, 7), which is a facility for applying individual control programmes, for research as well as for commercial purposes.

The combinations of the specially designed control programme for this experiment would not have been so convenient if this programme control had not been installed.

The application of these facilities in combination with the standard control routines will be discussed and demonstrated. 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 (11).

Materials and methods

Greenhouses and data acquisition

The experiment was carried out during the winter season October 1990–January 1991 at the Department of Horticultural Engineering, Aarslev. 2 identical east-west orientated greenhouses clad with single glass and an area of 8×21.5 square metres were used.

A more detailed description of the facilities and data acquisition has been reported in previous papers and will therefore not be repeated here (1,2,3).

Temperature control

Light period

The start point for the light period was fundamental for generating the temperature control routine.

In Denmark the price of electricity depends on the period in which it is used. In the low rated zone between 9.00 p.m.–6.30 a.m. the price is 0.19 DKK/kWh, in the medium rated zones between 6.30 a.m.–7.30 a.m. and 12.00 a.m.–9.00 p.m. the price is 0.33 DKK/kWh, and in the peak rated zone between 7.30 a.m.–12.00 a.m. and 5.00–6.30 p.m. the price is 0.58 DKK/kWh. Therefore great care was taken to avoid supplementary light in the peak rated zones when designing the control programme.

The light period had a length of 10.5 hours and started 13.5 hours after natural sunset. As a result the light period began even earlier during the decreasing day length in the autumn. To prevent use of supplementary light in the peak rated zone between 5.00–6.30 hours p.m. sunsets later than 5.00 p.m. was overruled. In the light period the supplementary light was turned on whenever outside light intensity was lower than 40 μmol/m^{2}s. Once the supplementary light was turned off between 6.30 and 12.00 hours a.m. it was not turned on again until 12.00 a.m.

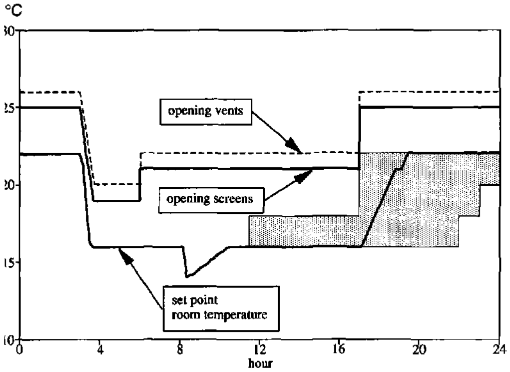

Fig. 1. The time and temperature zones of the mean temperature control. The area between over and lower limit indicates the space for the minimum temperature set points depended on the previous 168 hours' mean temperature.

Low temperature period

The progress of the set points are shown schematically in Fig. 1.

3 successive ways, with falling priority, were applied to reduce room temperature and controlled by a ramp function of 15 °C/h.

First priority :	reducing temperature of heating system.
Second priority:	opening screens whenever the actual room temperature was 3°C higher than the set point.
Third priority :	opening vents whenever the actual room temperature was 4°C higher than the set point.

Whenever the decrease of the room temperature was slower than the ramp function the method with the lower priority was set into function.

Whenever the decrease in room temperature was faster than the ramp function the method with the highest priority was set out of function.

By doing so the method with the smallest loss of energy had the highest priority and the reduction of the room temperature could be performed with the highest possible energy preservation.

The reduction of room temperature started 3 hours prior to the light period.

To prevent a peak in energy consumption, when the screens were removed at sunrise an extra drop of 2°C in the set point was included in the control programme. This drop is cancelled by a ramp function of 1°C/h.

High temperature period

The high temperature period always occurred during the dark period when vents were closed and the screens were drawn. It was controlled by the programme call and by a ramp function of 3°C/h.

Mean temperature control 16°C< T <22°C

The mean room temperature was controlled by a set point calculated from a 168 hours moving average. The correction zone available to correct the mean room temperature was the last 5.5 hours of the light period where the set point can be set between 16°C and 18°C and the first 5.5 hours of the dark period where the set point can be set between 16°C and 22°C.

Any raise in room temperature set point was restricted by a ramp function of 3°C/h. In order to obtain the final temperature of 22°C at the end of the dark period a stepwise raise of the minimum temperature from 18°C to 20°C for the last 2 hours was applied.

3 successive ways with increasing priority were applied in order to increase the mean room temperature.

First priority :	close vents for room temperatures lower than 22°C.
Second priority:	close screens (only during dark period).
Third priority :	increase pipe temperatures.

Reference treatment:

- zero DIF 18/18°C day/night room temperature set points.
- ventilation at 22°C

For experimental as well as for referential treatment,

- shading screens were drawn during the day at an outside irradiation above 300 W/m^2.
- shading screens were drawn during the night at an outside irradiation of less than 2 W/m^2, instrument set point 200 lux.
- supplementary light period 10.5 hours, whenever irradiation was less than 40 μmol/m^{2}s.

Results

Room temperature

The time series of the room temperature on 2 adjacent days of the 2 treatments are shown in Fig. 2. For the reference treatment irradiation during the day increased the room temperature till above 18°C.

In the experimental treatment the shift between the high night temperature and the low morning temperature can be seen clearly. Due to a low mean room temperature the high night temperature of 22°C was extended from 3-7 hours.

The set point for the room temperature when the mean temperature lacked behind was independent of the disappearing value 168 hours before and would always be replaced by the highest value within the allowed limits in the correction zone.

When the mean room temperature was too high the disappearing value would be replaced by a minimum value (16°C).

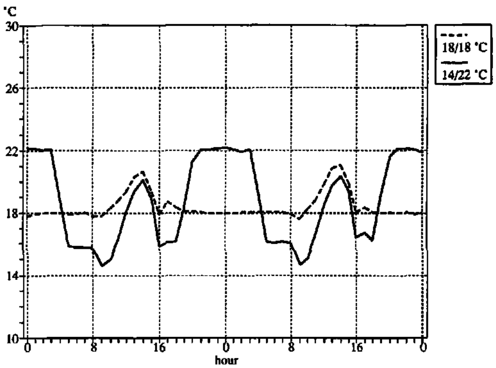

Fig. 2. The time series of room temperature in 2 greenhouses (17-18 January 1991), 1 with zero DIF and 1 with negative DIF. Note the pronounced lower room temperature during day.

In order to obtain a sufficient drop in room temperature at 3.00 a.m. both days it was necessary to open the screens for about 30 minutes. On the other hand it was not necessary to open the vents.

The extra temperature reduction of 2°C in order to avoid energy consumption peaks when screens were removed at sunrise, could be recognized clearly at 8.00 a.m.

The average room temperatures for the whole experimental period were 18.3°C for the referential treatment and 18.6°C for the experimental one.

Energy consumption

The energy consumption with negative DIF was 7

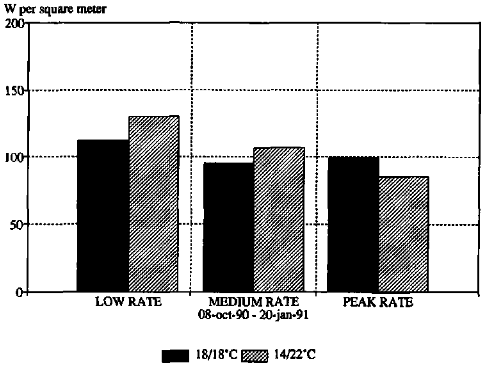

Fig. 3. The energy consumption pattern, where the consumption is divided into the 3 zones: low rate, medium rate and peak rate.

Table 1. The decrease in room- and canopy temperatures from 1 hour prior to room temperature drop 22°C/16°C until 1 hour after. Note that decrease in canopy temperature is less than decrease in room temperature.

Temperature decrease °C	October-January	
	room per cent	canopy per cent
0 - 1		
1 - 2		
2 - 3		2.0
3 - 4	4.0	18.2
4 - 5	42.4	60.6
5 - 6	46.5	17.2
6 - 7	5.1	2.0
7 - 8	2.0	
8 - 9		
9 - 10		

per cent higher compared with the referential treatment. This higher energy consumption was caused by the need to ventilate and the need to open screens in order to obtain a sufficient quick drop in room temperature –15°C/h.

In the negative DIF treatment vents were opened 38 times (13 hours) and screens opened 99 times (88 hours).

As a consequence the negative DIF programme was able to move the bulk of energy consumption from the day time towards the night time (Fig. 3).

Table 2. Energy consumption in the 2 greenhouses.

	zero DIF	negative DIF	
	energy consumption W/m^2	energy consumption W/m^2	per cent
short-day Oct—Jan	108	116	+7

Energy consumption peaks

The essential point was (Fig. 4) the pronounced energy consumption peaks with a traditional temperature control. The energy consumption peaks in the negative DIF treatment were levelled out and replaced by a constantly high energy consumption during the dark period.

Hot water flow

For glasshouse nurseries connected to district heating the time series of the water flow was of greater interest than the energy consumption. Fig. 5 shows the water flow on 2 adjacent days in January. Severe hot water consumption peaks in very short periods at sunrise were seen where a traditional temperature control was applied.

Air humidity

The level of air humidity has 2 major impacts upon

Table 3. Frequency table of differences between leaf– and dew point temperatures(T_l-T_d).

	Number of hours before and after room temperature drop						
	before				after		
T_l-T_d	3	2	1	0	1	2	3
°C	Number of periods						
–2(-1)							
–1-0							
0-1				1			
1-2			1	12	8	10	1
2-3	4	4	7	23	35	25	17
3-4	16	11	9	32	32	34	33
4-5	22	25	29	21	16	20	31
5-6	30	31	36	8	7	9	11
6-7	20	26	14	1	1	1	5
7-8	4	4	3				
8-9	1						
9-10							
10-11							

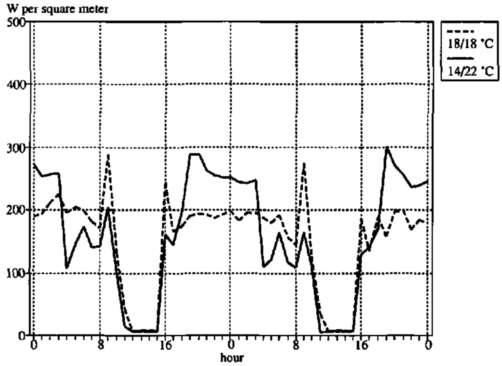

Fig. 4. The time series of energy consumption on 2 adjacent days in 2 greenhouses, 1 with zero DIF and 1 with negative DIF. The demand for a high room temperature in the dark period results in a high energy consumption. Note that energy consumption peaks are not found when negative DIF is applied (see text).

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 2 items were of interest for plant growth in protected cultivation.

Periods when the difference between leaf temperature and dew point temperature became less than 1°C for more than 2 hours might indicate a risk of fungi spore germination.

When a room temperature drop was imposed it is possible that the favourable conditions for fungi spore germination may increase. However, Table 3 shows that differences of less than 1°C hardly ever occur. Furthermore it shows that small differences tended to occur during the hours after the drop in room temperature.

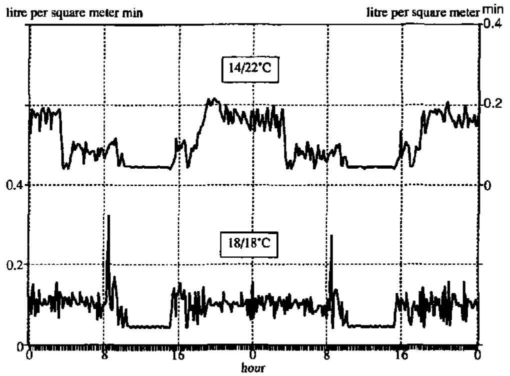

Fig. 5. Hot water flow in 2 greenhouses, 1 with zero DIF and 1 with negative DIF. Note the severe hot water consumption peaks in the greenhouse with zero DIF.

In the period with a demand for high room temperature the irradiation from the heating pipes increased. This increased radiation to the plant canopy resulted in a higher leaf temperature and consequently in an increased difference between leaf and dew point temperature.

Opening of the screens during the night or morning hours also resulted in a lower leaf temperature. On the other hand, however, condensation of air humidity on the cold glass reduced the dew point temperature.

The time series of the differences between leaf and dew point temperature (Fig. 6) show that the risk for small differences was more pronounced in the late afternoon.

Canopy temperature

Canopy temperature is the ultimate temperature to which the plants react. The difference between the leaf and the air 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 (see Table 4 and Fig. 7).

The negative DIF effect, expressed as the room temperature drop from 1 hour before till 1 hour after start of light period has been 5.1°C on average (Table 1). The drop in canopy temperature, however, was less than 4.5°C.

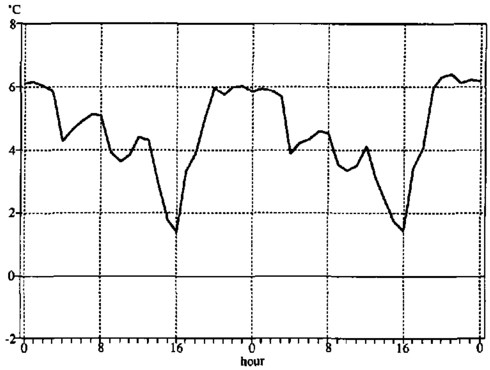

Fig. 6. Difference between leaf– and dew point temperature on a sunny day. Note that differences become small in the late afternoon.

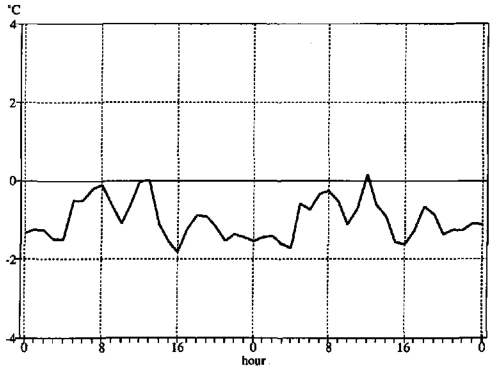

Fig. 7. Difference between leaf- and room temperature.

Discussion

Programme call

The programme call routine (4, 7) proved its applicability. Due to this facility it was possible to combine negative DIF, mean room temperature control, and supplementary light with short and long day conditions.

It is the second period with programme call in use. Efforts were made to correct unwanted side effects from the first period.

The unwanted side effect of the mean temperature control, which resulted in 2 maxima in the night hours was corrected (3).

In order to avoid too steep an increase in the inlet temperature to the heating system, it was controlled by a maximum permissible ramp function of 15°C/h.

Energy consumption

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 (6,8,9,10,12,13). However, previous experiments show that the drop in temperature has no necessary link to the change from dark to light period.

In this experiment therefore the temperature reduction to the low temperature period was started 3 hours prior to the light period.

In this way advantage could be taken of the cold atmospheric conditions in order to reduce room temperature with a minimum of energy waste.

The previous experiment (3), where the room temperature reduction at sunrise was given a very high priority, resulted in a pronounced energy increase of 12 per cent. In this experiment the reduction in room temperature was moved to 3 hours prior to the light period hoping that the cold night situation would help to a quick temperature drop, and to avoid provoked cooling by ventilation or opening of the screens. In spite of those precautions there was still an increase of energy consumption of 7 per cent compared to reference treatment.

From an energy consumption point of view the high priority of the temperature drop in the morning hours should be taken into consideration when the morphogenetic effect on plant growth is validated.

Energy consumption peaks and hot water flow

As for all previous experiments (1,2,3) negative DIF

Table 4. Frequency table of differences between leaf- and room temperature (T_l-T_r).

	Number of hours before and after room temperature drop									
	before				after					
T_l-T_r	3	2	1	0	1	2	3	4	5	6
°C	Number of periods [%]									
4-5										
3-4								1		
2-3							2		2	1
1-2	2	2	2		4	5	14	15	13	12
0-1	6	4	6	7	45	46	54	48	44	41
-1-0	68	75	64	35	38	39	30	34	33	33
-2(-1)	24	17	28	54	13	10		2	8	13
-3(-2)	2		4							
-4(-3)										

programs showed to be able to avoid energy consumption peaks. However, one should be well aware that in this programme an extra room temperature drop of 2°C was implied, when screens were removed at sunrise. Both energy consumption peaks and water flow peaks were totally suppressed.

Mean temperature control

The practical application of the mean temperature control showed disadvantages. The moving mean room temperature control strategy resulted in unstable set point calculations. The new values very much depended on the value which was expelled. Both small and high values caused instability and should be replaced by values, which could be far from the actual values.

The difference in the time series of the room temperature in the 2 treatments is a result of 3 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 lack in mean room temperature, according to the mean room temperature control

For the future mean room temperature control another strategy based upon the means of the whole experimental period is preferred in order to avoid the mentioned instabilities.

Conclusion

The questions asked in the introduction are concluded as follows,

It is possible to avoid energy consumption peaks in the morning and the evening hours.

It is possible to apply the negative DIF room temperature programme, but at the expenses of an increased energy consumption of 7 per cent.

It is possible to preserve energy by reducing room temperature 3 hours prior to the light period.

It is possible to move energy consumption to night periods by moving the average mean temperature control.

The supplementary light application depending on low electricity tax periods has not interfered with the experimental strategy.

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