Danish Research Service for Plant and Soil Science
Research Centre for Horticulture
Department of Horticultural Engineering
DK-5792 Årslev

Report no. 2094

Reduction of energy consumption peaks in a greenhouse by computer control

Udjævning af energiforbrugsspidser i væksthus ved hjælp af klimacomputer

MARIUS G. AMSEN, OTTO FRØSIG NIELSEN and LARS H. JACOBSEN

Summary

The results of using a computer for environmental control in one greenhouse is in this paper compared with using modified analogue control equipment in another one. Energy consumption peaks can be almost prevented by properly applying the computer control and strategy. Both treatments were based upon negative DIF, i.e. low day and high night minimum set points (14°C/22°C) for room temperature.

No difference in production time and quality was observed in six different pot plant species. Only *Kalanchoë* showed significant increase in fresh weight and dry weight.

By applying computer control, the lack of flexibility of analogue control can be avoided by applying computer control and a more accurate room temperature control can be obtained.

Key words: Greenhouse heating, energy comsumption peaks, district heating, pot plants, computer control, negative DIF.

Resumé

Undersøgelsen tager udgangspunkt i traditionelt (analogt) klimareguleringsudstyr magen til det, som findes i danske erhvervsgartnerier, og sammenligner det med en klimaregulering baseret på digital teknik – klimacomputer.

Undersøgelsen er delt i to. En del, som omtaler resultaterne af den tekniske undersøgelse og udvælger en egnet klimastyring, samt en del, der behandler virkningen af denne klimastyring på en række udvalgte potteplanter.

Undersøgelsen viste, at man ved hjælp af en klimacomputer opnår en næsten perfekt udjævning af energispidserne såvel om morgenen som om aftenen.

Lav dag og høj nat (negativ DIF) rumtemperatur setpunkter blev anvendt i begge behandlinger. Bortset fra *Kalanchoë,* der gav en højere friskvægt og tørstoftilvækst, fandtes der praktisk talt ingen forskel i produktionstid og kvalitet af seks forskellige potteplantearter dyrket ved de to systemer.

Nøgleord: Væksthusopvarmning, energiforbrugsspidser, fjernvarme, potteplanter, computerstyring, negativ DIF.

Introduction

The Danish Ministry of Energy formed a working group to look into some of the difficulties which arise when heat for large numbers of greenhouse nurseries is supplied by district heating.

A series of experiments were carried out to investigate the possibilities of adapting greenhouse heating to the restrictions of heat supply from district heating.

It is often suggested that energy for heating greenhouses should be supplied by district heating or waste heat from power production. The combination of large areas of greenhouses and district heating raises some unexpected and unwanted side effects (1), however, unless special precautions are taken.

As shown in the previous experiments negative DIF (i.e. low day and high night set points for room temperature – 14°C/22°C) proved an adequate way to avoid heat consumption peaks in the morning and to reduce the peaks in the evening (2).

Even if a difference of 6°C may suffice from a biological point of view, 8°C was chosen in our experiments in order to investigate the potentials for suppression of energy consumption peaks.

Environmental control based on the modified analogue equipment which was applied in the previous experiments suffers from a lack of flexibility. It was based upon a thermostat control modified with a device which prolonged the opening time of the mixing valves from 4 to 140 minutes from closed to open. It was a cheap way to reduce the energy consumption peaks in the afternoon. But the device does interfere with the heat demand both when wanted but also when not wanted. The reduced opening speed of the mixing valves might result in energy demand during day time resulting in room temperatures which were too low. Furthermore the reduced opening speed of the mixing valve could not totally prevent heat consumption peaks in the evening hours.

The computer has facilities which overcome some of the drawbacks of the modified analogue system. The slope of the set point change – the ramp function – can be adjusted. This makes it possible to provide a smooth change from night to day or from day to night room temperatures with a minimum of distortion in the energy supply.

With computer the ramp function at dawn or at dusk need not to be identical. Except for dawn and dusk the ramp functions will not interfere with normal temperature control as experienced by the modified analogue control in the previous experiment.

The experiment is divided into two parts. A preliminary investigation, without plants, where different means and ways are tested. The main experiment, where the most suitable result from the preliminary investigation is applied in a larger scale experiments including plants.

It is the aim of this paper to show that a reduction of energy consumption peaks can be obtained by taking advantage of those abilities of computer control.

Materials and methods

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

Heating system

The heating system 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 designed heat output is 83 kW. The floor heating system consists of 12 pipes, 0.5 m above the ground level.

Environmental control

Environmental control in the reference treatment is based upon analogue control equipment (DGT-Volmatic Lumix Combi LC 21), which is similar to the equipment traditionally used in commercial nurseries in Denmark. The opening time for the mixing valve was modified from the normal 4 minutes to 140 minutes.

The evironmental control in the other treatment is based on a DGT-Volmatic computer LCC 1240, which is available for commercial use.

Aspirated screen

Dry and wet bulb temperatures for room temperature and air humidity are measure by pt 100 thermo sensors placed in an aspirated screen exposed to an air velocity of approximately one meter per second. The sensors for the thermostat and the hygrostat are also placed in the aspirated screen.

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

Shading screens

The greenhouses are equipped with shading screens (Ludvig Svensson No. 15), which are drawn along the greenhouse, and theoretically reduce irradiation by 55 per cent.

The screens are also applied during the night as thermal screens.

Benches

Each greenhouse is equipped with four movable benches, 1.6 × 18 m. The benches are equipped with a capillary irrigation system.

During the experiment pot plants were grown on the benches.

Data sampling

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

Energy consumption

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

Experimental plan

The experiment was carried out from 11 January until 1 May 1989, with:
Reference treatment:

- analogue control equipment.
- reduced opening speed of mixing valves (140 minutes from closed to open).

Experiment treatment:

- computer control equipment.
- slope of set point change at sunrise –10°C/h.
- slope of set point change at sunset 2°C/h.
- normal opening speed of mixing valves (4 minutes from closed to open).

For experiment as well as the reference treatment:

- negative DIF: 14°C/22°C, day/night minimum room temperature set point.
- ventilation at 28°C room temperature.
- 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 5 W/m^2.

Plant experiment

The experiment was performed with six species of pot plants:

- *Begonia (Begonia elatior*-hybrid 'Schwabenland'), five weeks old rooted cuttings.
- *Chrysanthemum (Dendranthema grandiflora* 'Garland'), two weeks old rooted cuttings pinched once.
- *Hedera (Hedera helix* 'Susanne'), five weeks old rooted cuttings.
- *Hibiscus (Hibiscus rosa-sinensis,* red) twelve weeks old cuttings, with three cuttings per pot.
- *Kalanchoë (Kalanchoë blossfeldiana* 'Pollux', seven weeks old cuttings, pinched two weeks before start of experiment.
- *Radermachera (Radermachera sinica),* nine weeks old seedlings.

Most plants were treated with growth retardents, as previous experiments (5) had shown that this was necessary to obtain adequate sales quality. The treatments as well as initial and final plant densities are shown in Table 1.

Table 1. Treatment with growth retardents and initial and final plant density.

Plant species	Growth retarding		Pots per m^2
Begonia	1‰ CCC	1x	50→20
Chrysanthemum	3‰ alar	2x	45
Hibiscus	0.4‰ CCC	4x	50→25
Hedera	not treated		89→59
Kalanchoë	3‰ alar	1x	45
Radermachera	0.8‰ alar	3x	22

Recordings

Whenever a plant had reached the criterion for sale, different recordings were made.

- Plant height from the pot rim and quality.
- The following specific recordings were made:
- *Chrysanthemum,* number of flowers and buds showing colour.
- *Begonia,* height of inflorescences.
- *Kalanchoë,* height of inflorescences.
- *Hedera,* number of leaves on the second longest vine, used for computing the internode length.
- *Hibiscus,* number of buds and laterals.
- *Radermachera,* registration of all plants was performed on the same day, 103 days after start of experiment.

Statistics

Only the two benches in the middle of the greenhouse were used for experimental purposes. Each bench was divided into two equal sections which acted as replicates. Thus, there were four replicates per greenhouse.

Each section contained six plots, which were randomized. The pattern of the plots was identical in the two greenhouses. Each plot contained 50 plants and ten plants in each plot were used for recording.

Because only one greenhouse per treatment was available, the effect of greenhouse and locality cannot be statistically separated.

Results

Preliminary experiments

Ramp function

The decrease at sunrise and the increase at sunset of the set point for room temperatures (ramp function) has been the subject of separate investigations in the month of June until September. In order to obtain sufficient heat consumption, extraordinary high room temperatures have been applied, 30°C/38°C day/night and ventilation at 40°C/48°C.

For the sunrise situation four different ramp (e.g. room temperature decrease) values have been investigated, Fig. 1.

The effect can be summarized as: The less steep the ramp is, the higher is the energy consumption peak that will occur in the morning. In order to avoid energy consumption peaks in the morning a steep ramp must therefore be recommended.

A better reduction in the heat consumption peaks is obtained when the ramp function is activated before the screens are opened in the morning.

In the main experiment the opening of the screens in the morning was delayed 15 minutes and a ramp of –10°C/hour was applied.

The energy consumption at sunset is a result of three successive incidents:

1. the raise in heat demand shortly before sunset due to decreasing natural irradiation.
2. the closing of the thermal screens.
3. the increase of the set point.

All three will have an effect upon the progress of the energy consumption.

The decrease in irradiation will call upon an increase in energy consumption. The closing of the screens will, on the other hand, result in a de-

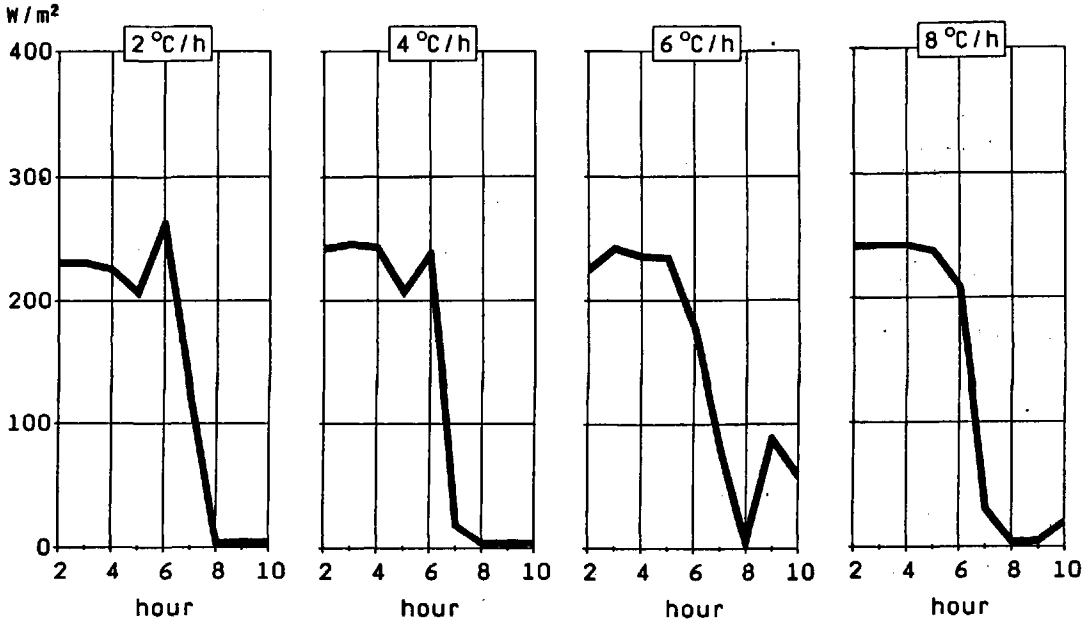

Fig. 1. Time dependent energy consumption when different ramp functions for temperature decrease at daybreak are used. Note that 2°C per hour shows a noticeable peak, which disappears when a set point decrease of 8°C per hour is used.

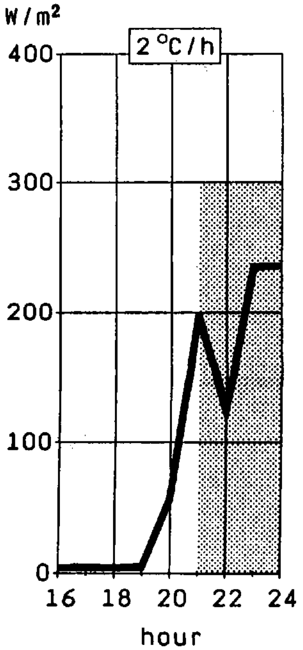

Fig. 2. Time dependent energy consumption at end of day. Note the short decrease in energy consumption due to the screens being closed at 21 hours.

crease in energy consumption, hence the little peak observed at sunset, see Fig. 2. This phenomena is typical for days with high irradiation and zero energy consumption.

An overshoot or peak in the energy consumption will occur when the ramp is too steep (e.g. >2°C/h). A large deviation between the room and the set point temperature will result in too much opening of the mixing valves.

The steeper the ramp, the more pronounced the overshoot, Fig. 3. In the main experiment therefore an evening ramp of 2°C/h was chosen.

Main experiment

Room temperature

A typical profile of room temperatures is shown in Fig. 4. The room temperatures follow the ramp very closely.

There is, however, a pronounced difference between the two treatments at sunset. The control provided by the analogue system results in a steeper rise in room temperature than the computer system. This is the effect of the ramp function. As the analogue system is asking for a temperature rise, the set point will already be at the night

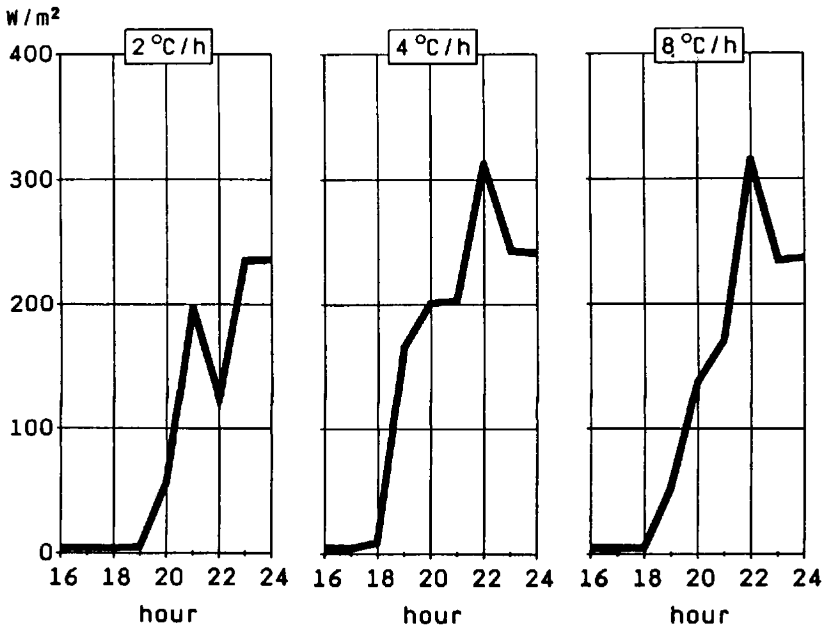

Fig. 3. Time dependent energy consumption when different ramp functions for temperature increase at the end of the day are used. Note that 8°C per hour shows a pronounced peak, which disappears when a set point increase of 2°C per hour is used.

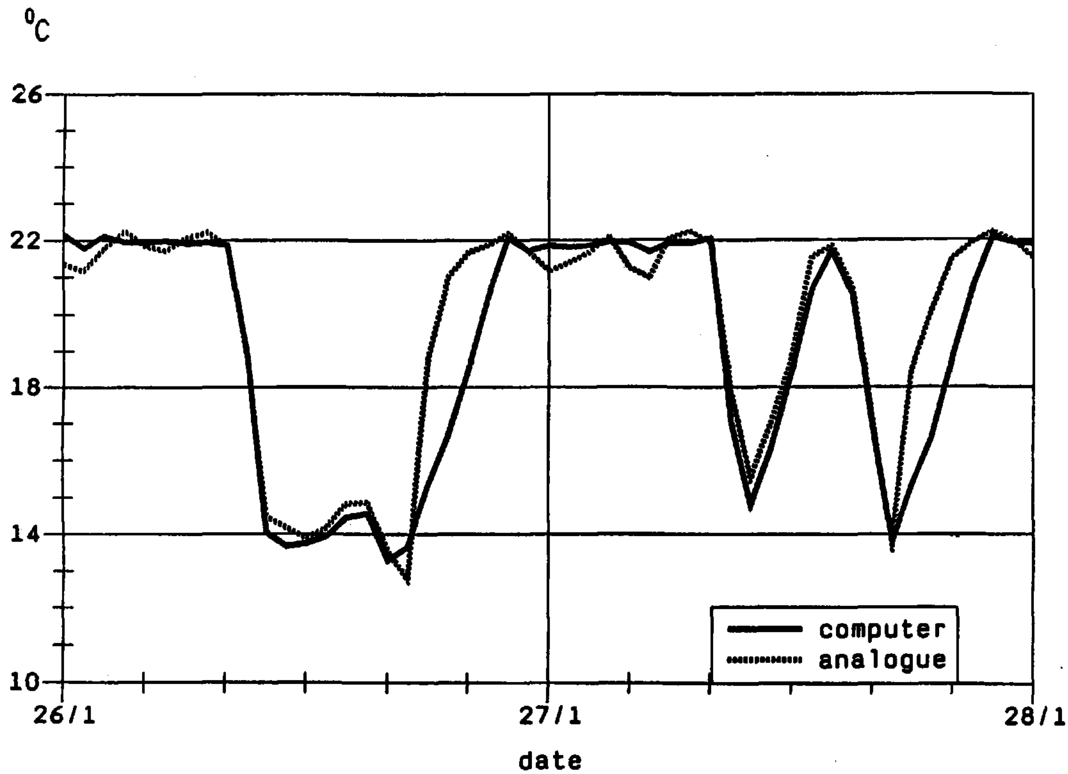

Fig. 4. Time dependent room temperature in two greenhouses, one with analogue and one with computer control. Note a steeper increase in room temperature at night in the greenhouse with the modified analogue control, this will have an effect on the energy consumption.

value (22°C) and the energy demand will be maximum. The reduced opening speed of the valves cannot quite avoid a peak, Fig. 5.

In computer control the set point rises with 2°C per hour and a lower slope is the result.

A lag in room temperature by computer control is seen in the evening.

Mean room temperature

The occasional too low room temperature in the greenhouse with computer control will result in a lower mean temperature. During the whole experimental period from 17 January until 1 May 1989 it amounts to 0.5°C. The difference is, however, a result of a very short period where the room temperature in the analogue control is ahead as compared to computer control, Fig. 6.

Energy consumption

The typical difference between the two treatments is shown in Fig. 5. The evening peak experienced with the analogue system has been avoided with computer control.

Plant experiment

Production time

The production time is expressed by the mean date at which each plant reached the criterion for sale. The criterion for sale is defined for each plant species as follows:

Begonia, two open flowers.

Chrysanthemum, second ring of disc flowers open.

Hibiscus, one open flower.

Hedera, three vines longer than 20 cm.

Kalanchoë, two open flowers.

As can be seen from Table 2, there was no significant difference in production time for any of the plant species in the experiment.

Room temperature

The difference between the two treatments in mean room temperature is dependent on the length of the growing period. The observed differences are mainly due to a difference in the control systems – analogue or digital. Each system has its own dynamic performance and characteristic re-

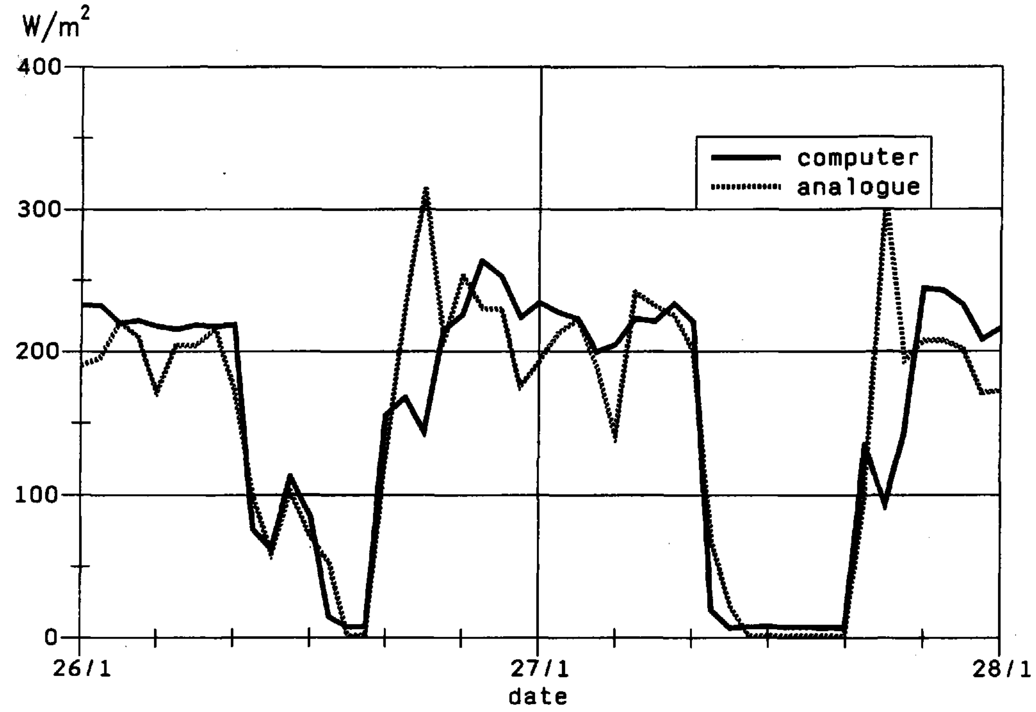

Fig. 5. Time dependent energy consumption in two greenhouses, one with analogue and one with computer control. Note a pronounced peak at night in the greenhouse with the modified analogue control, this is due to a lack of evening ramp.

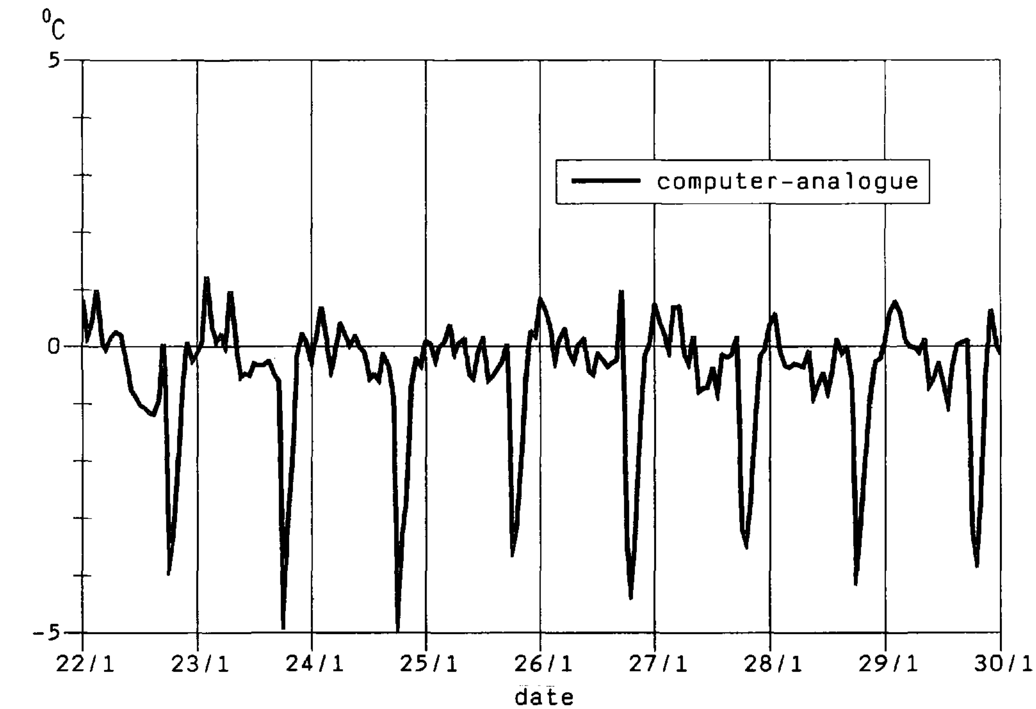

Fig. 6. Difference between room temperature from greenhouse with computer – analogue control system. Note that room temperature with computer control lags behind, due to a controlled set point ramp of 2°C/hr.

Table 2. Production time.

Plant species	Production time, days	
	analogue	computer
Begonia	70	70 ns.
Chrysanthemum	59	60 ns.
Hibiscus	107	110 ns.
Hedera	73	71 ns.
Kalanchoë	79	79 ns.
Radermachera	103	103 ns.

sponses to changes. In general a 0.5°C higher room temperature has been found, Table 3, using the analogue control system.

The temperature difference exists, however, primary for a very short period – 1 hour – and has a very considerable difference – from 3°C–6°C, see Fig. 6, it will hardly have the effect on growth as a constant higher temperature of 0.5°C.

Energy consumption
Energy consumption is related to each plant species and is a result of temperature control and production time. It expressed the amount of energy which is used in a particular treatment during a particular period. There has not been a significant difference in energy consumption in spite of a higher mean temperature while applying analogue control.

Plant quality
Quality at time of sale was an assessment of a visual impression of the whole plant.

In general a very satisfactory quality was obtained in both treatments and no significant difference was observed, Table 4.

The length of internodes of *Hedera* was 20 mm in both treatments.

Number of flowers and buds
In the flowering species of *Chrysanthemum* and *Hibiscus,* no influence has been detected with regard to the flowering abilities. Neither has the number of laterals in *Hibiscus* been affected, Table 5.

Fresh weight and dry weight
Apart from Kalanchoë there has not been found a significant difference, neither in fresh weight nor in dry weight increase in any of the plants in the experiment, Table 6. This is in good accordance with most other abilities recorded in this experiment.

Table 3. Energy consumption, Mj/plant, and mean room temperature, °C.

Plant species	Energy consumption		Mean temperature, °C	
	analogue	computer	analogue	computer
Begonia	34.5	34.2 ns.	19.8	19.3
Chrysanthemum	14.1	14.4 ns.	19.5	19.0
Hibiscus	37.8	37.2 ns.	20.1	19.6
Hedera	12.4	12.0 ns.	19.8	19.3
Kalanchoë	16.6	16.4 ns.	20.0	19.5
Radermachera	44.3	43.7 ns.	20.0	19.6

Table 4. Plant quality and plant height, cm.

Plant species	Quality, 5 = best		Plant height	
	analogue	computer	analogue	computer
Begonia	4.5	4.1 ns.	19	19 ns.
Chrysanthemum	4.5	4.7 ns.	16	16 ns.
Hibiscus	4.8	4.8 ns.	25	23 ns.
Hedera	5.0	5.0 ns.	–	–
Kalanchoë	4.8	5.0 ns.	18	19 ns.
Radermachera	5.0	5.0 ns.	34	32 ns.

Table 5. Flowers, buds and laterals.

Plant species	Analogue	Computer
Chrysanthemum		
flowers, buds	12	13 ns.
Hibiscus		
buds, total	22	20 ns.
with colour	4.3	4.1 ns.
laterals	5.3	5.7 ns.

Discussion and conclusion

The previous experiment (5) has shown that no great difference in plant quality was found when applying negative DIF by a modified analogue system as compared with a zero dif. temperature program.

The aim of this experiment was to show whether an improved temperature control as possible by computer may have an effect on plant growth and quality. From this point of view it was obvious that a comparison between two different systems – analogue and digital – was of interest. The computer has far more facilities for adapting the temperature program to specific situations than the modified analogue system.

In this experiment, where the temperature program (14°C/22°C) was identical in both treatments, no important differences were found.

Even the slightly higher average room temperature (+ 0.5°C) with analogue control has not reduced production time, as could have been expected (7, 8). This is because the difference in mean temperature is a results from only one daily room temperature peak of 3°C–6°C for less then one hour.

The room temperature peak has not, however, resulted in a significant increase in energy consumption.

The general advantages of growing with negative DIF (e.g. shorter internodes) cannot be demonstrated in this experiment but should be kept in mind (4, 6, 8).

In general there has not been a statistical difference in dry weight and fresh weight increase. It is therefore surprising that the fresh weight and dry weight increase for *Kalanchoë* is highest in the treatment with the lowest mean room temperature – computer control.

It has not been possible to detect any difference in plant growth and development between the two treatments, analogue and computer control. The application of computer has not improved the results obtained by analogue control. This holds for plant quality, production time as well as energy consumption. The improvements in computer control are to be found in a more precise temperature control and a better suppression of the energy peaks in the evening.

References

1. *Amsen, M. G. Nielsen, O. F. & Strøm, J. S.* 1985. Tomaterne skal lære at gemme på lyset. Ingeniøren 38, 8-9.
2. *Amsen, M. G. & Nielsen, O. F.* 1988. Simple techniques for reduction of energy consumption peaks in greenhouses. Tidsskr. Planteavl 93, 27-36.
3. *Cockshull, K., Hand, D. & Langton, A.* 1986. GCRI finds new ways to cut heating bills on ayr crops. Grower 105, 77–83.
4. *Erwin, J. E., Heins, R. D. & Karlsson, M. G.* 1987. Thermomorphogenesis in *Lilium longiflorum*. Amer. J. Bot. 76, 47-52.

Table 6. Fresh weight and dry weight increase, g.

Plant species	Fresh weight		Dry weight	
	analogue	computer	analogue	computer
Begonia	106	106 ns.	9.0	9.7 ns.
Chrysanthemum	26	27 ns.	3.1	3.0 ns.
Hibiscus	106	104 ns.	19.6	21.3 ns.
Hedera	18	19 ns.	3.4	3.5 ns.
Kalanchoë	184	205 *	9.7	11.6 *
Radermachera	62	63 ns.	13.4	14.2 ns.

* significant at the 95% level

5. *Jacobsen, L. H., Adriansen, E., Amsen, M. G. & Nielsen, O. F.* 1988. The response of pot plants to reduction of energy consumption peaks in greenhouses. Tidsskr. Planteavl 93, 37-43.
6. *Hendriks, L. & Scharpf H. C.* 1985. Nacht-absenkung bei Topf Chrysanthemen – lieber nicht. Gb+Gw 88, 1362-1363.
7. *Lepage, I., De Jong, J. & Smeets, L.* 1984. Effect of day and night temperatures during short photoperiods on growth and flowering of *Chrysanthemum morifolium* Ramat. Sci. Hort. 22, 373-381.
8. *Moe, R. & Heins, R. D.* (1990). Control of plant morphogenesis and flowering by light quality and temperature. Acta. Hort. 272.

Manuscript received 11 June 1990.