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The effect of energy saving on growth and development of different types of pot plants (season 1984-1985)

Virkning af energibesparelser på vækst og udvikling af forskellige potteplanter (sæson 1984-1985)

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Summary

This paper presents the results of a series of experiments concerning growth response of five different pot plants in five different greenhouses. The effect of permanent insulation, which has been investigated in previous experiments, did not differ from what has been found so far.

The effect of air humidity control by heat input resulted in high, vigorous growth. On the other hand most species had shorter production time and an increase in number of flowers.

The effect of slatted benches as compared to ordinary benches showed a more compressed growth and a shorter growth period. The plants were sturdier and less vulnerable to transport and handling as compared to those grown on traditional benches. The effect of flooded benches as compared to dry capillary benches showed no significant difference between the two treatments.

Key words: Greenhouses, insulation, air humidity control, bench type, irrigation system, energy consumption, pot plants.

Resumé

I denne beretning behandles resultaterne af fire undersøgelser på fem potteplanter, i fem forsøgsvæksthuse. For disse planter blev energiforbrug, produktionstid, kvalitet samt frisk- og tørvægt registreret.

I permanent isolerede væksthuse, som er blevet undersøgt her på stedet ved flere lejligheder, blev ikke fundet forskelle i forhold til tidligere resultater. Forøgelse af temperaturen uden at ventilere ved fugtighedskontrol i væksthuse gav både en højere temperatur, en højere luftfugtighed og et højere energiforbrug pr. plante, end forventet. Desuden blev planterne løse i væksten og derved mere sårbare for skader under transport.

Rendeborde sammenlignet med traditionelle borde gav en mere tæt og fast vækst og et noget forkortet vækstperiode. Planternes reaktion på ebbe-/flodvanding sammenlignet med traditionelle borde dækket med vattex viste ingen signifikante forskelle mellem de to behandlinger.

Nøgleord: Væksthuse, isolering, luftfugtighedsstyring, bordtyper, vandingssystem, energiforbrug, potteplanter.

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Introduction

The effect of insulation, equipment or humidity control in a greenhouse will not only have an impact upon the energy consumption, but also upon the environment inside the greenhouse and consequently upon plant growth and quality. The choice of greenhouse cladding, equipment or humidity control is therefore not only a question of energy saving but finally a question of plant response.

The experiments with energy saving which started in this department in 1978 had therefore two main purposes. In the first place to investigate which type of greenhouse insulation resulted in the highest energy saving, secondly to collect information on environmental and biological factors which might help to explain how to secure plant growth of an acceptable quality in those greenhouses.

For these purposes the Ministry of Energy supported the building of an experimental unit consisting of five greenhouses. The results of the first series of experiments by *Bjerre* and *Amsen* (6) showed that for some species of pot plants permanent insulation is an attractive alternative.

The experiments, which are reported in this paper, will not only compare insulation, but also types of benches, irrigation systems and air humidity control mode which are all expected to have a beneficial effect on energy saving. This paper reports on the results of plant growth only. For the results of the total energy consumption and environmental parameters, see *Nielsen et al.* (9).

Materials and methods

Research facilities

The experiment was carried out at the Department of Horticultural Engineering, Årslev, approx. 12 km south of Odense, Denmark. For the purpose five east-west orientated greenhouses, which differed in cladding or equipment, were used. The ground surface is 21.5 m × 8 m. The differences in cladding, equipment and environmental control routines are shown in Table 1. For a detailed description of insulation, heating system, room temperature control, bench temperature control, carbondioxide supply and data collection, see *Amsen* and *Nielsen* (1).

Experiment

The experiment took place from the 15 August 1984 until 30 April 1985. The minimum room temperature set point for heating was 18°C and the maximum room temperature set point for ventilation was 28°C. Relative air humidity (RH) control set point was 92% RH. The set point for root-zone temperature was minimum 20°C.

All greenhouses are equipped with shading-screens which are drawn whenever the outside irradiation exceeds 210 w/m^2.

To improve the thermal abilities of the greenhouses the shading screens were drawn at night, when the light intensity i lower than 5 w/m^2 (set point 100 lux). In the greenhouses clad with single glass (no. 1 and 4) the shading screens were drawn together with the thermal screens at night.

The plants are supplied with pure carbondioxide and the concentration controlled at 800 cm^3/m^3. The supply started at sunrise and stopped at sunset or whenever the vents were open.

Watering and fertilization: The diluted fertilizer was applied and water was supplied with 1 mm whenever 0.8 mm evaporation was recorded by an evaporimeter. The concentration of the nutrient solution with a stabilized pH of 6.5 and

Table 1. Strategy and equipment

Greenhouse no.	1	2	3	4	6
Cladding	single glass	2 layer glass	2 layer PMMA	single glass	2 layer PMMA
Heating system	standard	reduced	reduced	standard	extended
First priority	top & wall heating	top & wall heating	top & wall heating	floor heating	top & wall heating
Humidity control	venti-lating	heating	venti-lating	venti-lating	venti-lating
Benches	closed benches	closed benches	closed benches	slatted benches	closed benches
Irrigation	dry ca-pillary	dry ca-pillary	dry ca-pillary	plooded benches	flooded benches

a conductivity of 1.6 ms was 1.5 pro mille.

Plant species: Five species of pot plants were included in the experiment.

Begonia (Begonia lorraine × *cheimantha* 'Rød Virum'), chrysanthemum *(Dendranthema morifolium* 'Cirkus'), *Hedera (Hedera helix* 'Anne Marie'), *Kalanchoë (Kalanchoë blossfeldiana* 'Anne Marie') and *Saintpaulia (Saintpaulia ionantha* 'Rhapsodie'). The plants were propagated in commercial nurseries and started in the experiment as rooted cuttings.

Growth retarding: Chrysanthemum was sprayed twice with diaminozide 2.55 g/l a.a. *Kalanchoë* was treated four times with diaminozide 1.70-2.55 g/l a.a.

Data sampling: The production time is defined as the time for each individual plant from the beginning of the experiment until it reaches a criterion for sale. This is defined as follows: *Begonia;* ten open flowers. Chrysanthemum; the second flower half open. *Hedera;* three vines longer than 20 cm. *Kalanchoë;* four open flowers. *Saintpaulia;* four inflorescences with at least one flower.

Production time: The production time is defined as the period where 50% of the plants had reached the criterion for sale.

Recordings

Whenever a plant reached the criterion for sale, different recordings were made depending on the plant species. Energy consumption, fresh weight increase and dry matter increase were estimated for all plant species.

Statistics

Four movable benches 18 m × 1.6 m are installed in each greenhouse. Only the two benches in the middle of the greenhouse were used for experimental purposes. Each bench was divided into two equal sections acting as replicates; four replicates per greenhouse. Each section contained five plots representing one pot plant species. The pattern of the plots was identical in the five greenhouses. Each plot contained 50 plants, but only ten plants in each plot were used for recording. From a statistical point of view, the experiment suffers from restrictions, due to the fact that only one greenhouse per treatment is available. As a result of this the effect of greenhouse and locality cannot be separated. This should be taken into account while interpreting the results. Least significant difference (LSD) is calculated at the 95 per cent level by an analysis of variance.

Results

Insulation

Greenhouse no. 1 and 3.
No. 1. Single glass and thermal screens,
No. 3. 2 layers of PMMA,

Energy consumption: A reduction in energy consumption ranging from 0 *(Hedera)* up to 24% (*Saintpaulia* 2) was found. Especially in crops with a long production time the energy reduction has been noticeable (Table 3, column 1 and 3).

Quality: Apart from *Begonia* no significant differences are found when comparing mobile and permanent insulation. (Table 4, column 1 and 3).

Plant height: Begonia and chrysanthemum showed opposite effects, whereas the mean values displayed a tendency towards higher plants in the PMMA-house (Table 6, column 1 and 3).

Dry matter increase: Also the dry matter increase shows a significant lower value for three of the five observations for plants grown in the greenhouse with permanent insulation (Table 8, column 1 and 3).

Dry matter content: An ambiguous result shows a higher dry matter content for *Kalanchoë,* but a lower dry matter content in *Saintpaulia* 1 in the greenhouse with mobile insulation (Table 9, column 1 and 3).

Air humidity: For all months, apart from day values in September, the relative air humidity in the insulated houses was 5-10% higher at night as well as day. The results can be studied in detail in (9, Fig. 10 p. 23).

Air humidity control

Greenhouse no. 2 and 3.

Humidistat set point 92% relative air humidity (RH) in both greenhouses.

No. 2. air humidity control by heating only.
No. 3. air humidity control by ventilation.

Production time: Significantly shorter production time is observed in *Begonia, Saintpaulia* 1 and 2 when the mode of humidity control is heating only. However, the production time of chrysanthemum is contradictory to the other pot plant species (Table 2, column 2 and 3).

Energy consumption: The energy consumption increase per produced plant ranges from 1 (*Saintpaulia* 2) until 45 *(Hedera)* % when ventilation is omitted. Also from this point of view the ventilation humidity control must be preferred (Table 3, column 2 and 3).

Quality: Begonia and *Saintpaulia* showed a remarkable improvement in quality when ventilation humidity control is applied. This may indi-

Table 2. Production time, days

Greenhouse no.	1	2	3	4	6	LSD
Insulation	+		+			
Air humidity control		+	+			
Benches	+			+		
Irrigation			+		+	
Begonia	87	83	87	88	90	2
Chrysanthemum	60	67	63	58	61	3
Hedera	44	51	44	40	46	ns
Kalanchoë	98	97	97	98	95	ns
Saintpaulia 1	71	56	64	68	65	7
Saintpaulia 2	87	81	87	94	82	7

Table 3. Energy consumption, Mjoule per plant

Greenhouse no.	1	2	3	4	6
Insulation	+		+		
Air humidity control		+	+		
Benches	+			+	
Irrigation			+		+
Begonia	20.4	17.6	16.9	17.6	17.8
Chrysanthemum	7.6	7.8	6.7	6.1	6.3
Hedera	2.2	3.5	2.2	1.5	2.9
Kalanchoë	36.7	29.3	27.1	31.3	27.1
Saintpaulia 1	4.5	3.5	3.5	3.4	3.3
Saintpaulia 2	25.0	18.7	18.9	23.6	17.8

Table 4. Quality, 1-5, 5 best.

Greenhouse no.	1	2	3	4	6	LSD
Insulation	+		+			
Air humidity control		+	+			
Benches	+			+		
Irrigation			+		+	
Begonia	3.3	1.8	2.8	3.7	3.0	0.4
Chrysanthemum	3.2	3.2	3.2	3.8	3.0	ns
Kalanchoë	3.5	3.5	3.5	4.3	3.8	0.4
Saintpaulia 1	3.7	4.0	3.7	3.5	3.7	ns
Saintpaulia 2	3.5	3.0	3.5	4.2	3.3	0.4

Table 5. Number of flowers and buds or inflorescences.

Greenhouse no.	1	2	3	4	6	LSD	
Insulation	+		+				
Air humidity control		+	+				
Benches	+			+			
Irrigation			+		+		
Chrysanthemum	19	23	19	19	18	3	flowers & buds
Kalanchoë	10	8	7	13	9	2	inflorescences
Saintpaulia 1	36	42	37	34	37	3	flowers & buds
Saintpaulia 1	13	11	12	13	12	ns	inflorescences
Saintpaulia 2	28	28	25	27	26	ns	flowers & buds
Saintpaulia 2	10	10	10	10	11	ns	inflorescences

Table 6. Plant height, cm.

Greenhouse no.	1	2	3	4	6	LSD	Height until:
Insulation	+		+				
Air humidity control		+	+				
Benches	+			+			
Irrigation			+		+		
Begonia	25.4	27.5	26.9	24.0	27.3	1.3	infloresscences
Chrysanthemum	14.8	12.3	13.8	15.6	15.0	0.9	inflorescences
Kalanchoë	9.7	9.9	9.7	10.4	9.9	ns	top of leaves
Kalanchoë	11.8	11.9	12.4	14.2	14.7	0.9	inloresscences
Saintpaulia 1	6.7	6.9	6.9	5.5	6.4	0.7	top of leaves
Saintpaulia 1	9.9	9.8	10.0	9.2	10.1	ns	inflorescences
Saintpaulia 2	5.9	6.4	6.4	5.2	5.8	ns	top of leaves
Saintpaulia 2	9.5	9.7	9.8	9.0	9.8	ns	inflorescences

Table 7. Fresh weight increase, g per plant.

Greenhouse no.	1	2	3	4	6	LSD
Insulation	+		+			
Air humidity control		+	+			
Benches	+			+		
Irrigation			+		+	
Begonia	91	80	86	94	95	7.7
Chrysanthemum	21	18	19	27	20	2.5
Hedera	15	17	15	16	17	1.0
Kalanchoë	96	83	82	113	95	10.6
Saintpaulia 1	72	61	68	59	63	5.6
Saintpaulia 2	53	50	46	55	49	ns

Table 8. Dry matter increase, g per plant

Greenhouse no.	1	2	3	4	6	LSD
Insulation	+		+			
Air humidity control		+	+			
Benches	+			+		
Irrigation			+		+	
Begonia	6.6	5.8	6.0	6.8	6.6	0.5
Chrysanthemum	2.2	1.8	1.9	2.9	2.1	0.2
Hedera	2.9	3.3	2.9	3.0	3.2	0.2
Kalanchoë	5.3	4.4	4.5	6.5	5.4	0.6
Saintpaulia 1	3.8	3.0	3.4	3.4	3.4	0.3
Saintpaulia 2	2.4	2.3	2.1	2.9	2.3	0.4

Table 9. Dry matter content, %.

Greenhouse no.	1	2	3	4	6	LSD
Insulation	+		+			
Air humidity control		+	+			
Benches	+			+		
Irrigation			+		+	
Begonia	7.2	7.3	7.0	7.3	6.9	0.3
Chrysanthemum	10.3	10.0	10.3	10.5	10.3	ns
Hedera	18.4	18.3	18.3	18.6	18.6	ns
Kalanchoë	5.5	5.2	5.8	5.7	5.6	0.1
Saintpaulia 1	5.3	4.9	5.0	5.8	5.4	0.3
Saintpaulia 2	4.5	4.6	4.6	5.2	4.7	0.3

cate that *Begonia* prefer a less humid climate to develop good quality. Also *Saintpaulia* 2 showed identical response. Else no significant difference was found between the mode of humidity control (Table 4, column 2 and 3).

Number of flowers and buds, cq. inflorescences: The number of flowers and buds shows a significant increase for chrysanthemum and *Saintpaulia* 1 when ventilation is not applied. This supports the impression of quality (Table 5, column 2 and 3).

Plant height: Only chrysanthemum showed significantly higher plants when ventilation humidity control is applied (Table 6, column 2 and 3).

Dry matter increase: Begonia and *Kalanchoë* do respond oppositely (Table 8, column 2 and 3). Dry matter content. Here also the results are ambiguous. The high humidity did not result in a lower dry matter content for *Begonia* (Table 9, column 2 and 3).

In September and April the heating strategy resulted in approx. 2-3% higher relative humidity. In midwinter the difference increased to approx. 5%. The same pattern was seen both night and day (9, Fig. 21 p. 36).

Bench types

Greenhouse no. 1 and 4.

No. 1. Dry capillary solid benches, bench heating. Top and wall heating first priority.

No. 4. Slatted benches, no bench heating. Bottom heating first priority.

Production time: Only *Saintpaulia* 2 responded with a delayed production time on slatted benches. No significant differences were found for the other pot plant species (Table 2, column 1 and 4).

Energy consumption: In general a reduced amount of energy is observed when slatted benches are applied, ranging from 6% (*Saintpaulia* 2) up to 32% (*Hedera*). It is the reduced production time which is the main cause for the difference (Table 3, column 1 and 4).

Quality: All species showed a better quality on slatted benches, though only significantly for *Begonia, Kalanchoë* and *Saintpaulia* 2. (Table 4, column 1 and 4).

Number of flowers cq. inflorescences: A significantly higher number of inflorescences was found for *Kalanchoë* on slatted benches (Table 5, column 1 and 4). No remarkable differences were found for the other species. No general statement can be made, the five species showed no clear tendency. *Kalanchoë* had significantly higher inflorescences on slatted benches, the opposite effect though less pronounced was seen for *Begonia* and *Saintpaulia.* (Table 5, column 1 and 4).

Dry matter increase: A significantly higher dry matter increase was found for *Kalanchoë* on slatted benches, the other species except *Saintpaulia* 1 showed higher mean values too (Table 8, column 1 and 4).

Air humidity: A remarkable decrease in RH is observed for slatted benches, especially in the winther months at night by *Nielsen et al.* (9).

Irrigation system

Greenhouse no. 3 and 6.

No. 3. Dry capillary benches.

No. 6. Flooded benches.

Production time: Only *Begonia* had a significantly negative response to flooded benches with a slightly increased production time. No remarkable difference was found for the other species (Table 2, column 3 and 6).

Energy consumption: A lower energy consumption per produced plant was expected due to a lower evaporation from the dry bench surfaces. But the treatments were fairly similar in that aspect (Table 3, column 3 and 6).

Quality: Only *Kalanchoë* responded with a significantly better quality on flooded benches. For the other species the quality was equal (Table 4, column 3 and 6).

Number of flowers cq. inflorescences: Again *Kalanchoë* responded with a higher number of inflorescences on flooded benches. Chrysanthemum and *Saintpaulia* were much alike (Table 5, column 3 and 6).

Plant height: Apart from *Kalanchoë* inflorescence height, *Begonia* and chrysanthemum did not respond positively to flooded benches (Table 6, column 3 and 6).

Fresh weight increase: A substantial and significant raise in fresh weight increase was found for *Begonia, Hedera* and *Kalanchoë* in favour of flooded benches (Table 7, column 3 and 6).

Dry matter increase: Not unexpectedly the dry matter increase showed the same pattern as fresh weight increase (Table 8, column 3 and 6).

Air humidity: A slightly lower air humidity can be seen during the night, when flooded benches are applied. The effect is most pronounced in the winter months. In daytime there is no difference apart from December, January and February where flooded benches had a slightly higher RH. No reasonable explanation can be offered for this last observation (9).

Discussion

The present experiment is no. 5 in a series which was carried out in the same experimental unit. Data from the first season 79/80 (4) report only on results for two layers of PMMA (double acryl). In some cases plant quality was improved, *Dieffenbachia* for instance.

Saintpaulia had a less compressed growth and production time for chrysanthemum was increased by a few days. Further the first experiment was combined with three different spacings, and the result showed that plants could be grown with the same number of plants pr. m^2 under a double layer of PMMA without losses in quality in spite of light reduction. The first season the greenhouse clad with PMMA was compared to a glasshouse clad with single glass without shading or thermal screens.

Results from the season (80/81) and (81/82) reported by *Bjerre* and *Amsen* (6) displayed similar results. The same seven pot plant species are used. Double PMMA and thermal screens (Peritherm) generally increased dry matter production, whereas double glass had a lower dry matter production than the reference house.

Production time was slightly shorter or equal for all the insulated greenhouses as compared to greenhouses clad with single glass. With respect to quality, double glass and double PMMA generally produced plants of good quality. A tendency towards a less compressed growth could be seen, but the two seasons were different in that aspect.

The present experiment took place in 84/85 to investigate how the insulation systems worked in combination with new bench types, altered air humidity control and irrigation systems. The aim was to reduce energy consumption and to investigate how air humidity was affected.

Bailey (2) expresses the idea that growing plants in an insulated greenhouse is a question about knowing how macroclimate influences microclimate. In a single glass greenhouse the grower knew by experience which air temperature should be chosen, how the limits for air humidity should be, depending on crop and outdoor temperature.

The double glazing gave rise to another climate, thus air temperature and relative air humidity measured in a single glasshouse would cause a different microclimate when transferred to a greenhouse with double glazing.

A higher air humidity was one of the most conspicuous changes caused by insulation, and much work has been done to find out how plant growth has been affected.

Cockshull (7) says that the effect of a VPD (vapor pressure deficit) lower than 0.25 kpa seems to be problematic for water uptake. *Bailey* (2) claimed high air humidity slows down transpiration, and low transpiration might cause plants of low quality. *Bakker et al.* (3) grew cucumbers under varied air humidities. VPD was between 0.57-0.91 kpa in daytime and 0.26-0.66 kpa at night. Both yield and vegetative growth (sideshoots) was promoted by high humidity. Although the presented results do not indicate lower quality *Bakker et al.* (3) claims that low VPD gave poorer quality and signs of calcium deficit. *Stanghellini* (10) is developing a method for appraisal of the transpiration rate of a greenhouse canopy, as a physical process affected by microclimate.

She states the fact that transpiration is not a simple process solely governed by air humidity, and she further claims that higher VPD than 0.3 kpa does not increase transpiration. *Cockshull* (8) reports on calcium deficits in young tomato plants when VPD is lower than 0.1 kpa, on the other hand however the moist conditions also increased growth.

To make a comparison of the air humidity conditions in this experiment the humidistat set point started ventilation at 92% relative humidity which is close to a VPD of 0.2 kpa. at 18°C room temperature.

Many other scientists could be mentioned, but this ought to be sufficient to state the fact that insulation might limit water uptake and thereby nutrient uptake. The introduction of the term VPD instead of relative air humidity must be considered to be a progress, because it makes it possible to compare humidity indifferently insulated greenhouses, since temperature differences between canopy and air temperature can be taken into account.

Therefore comparisons would be much easier in the future if a VPD was calculated from water content in the air and the temperature of the canopy.

In our experiment no signs of calcium deficiencies such as small leaves or death of growing points were observed.

When insulation of greenhouses started it was the general opinion that insulation would increase fungal diseases. Actually very few papers report on such problems, and our experiment too indicates that this fear was unfounded. A reason might be the increasing understanding of microclimate, in other words plants benefit from the right tissue temperature, not from the air temperature measured one meter above the plants. As a consequence good bench heating equipment has been installed in modern pot plant nurseries and thereby a higher tissue temperature can be maintained at a lower air temperature. *Vogelezang* (11) compared production of *Saintpaulia* on heated versus unheated benches. If root-zone temperature was kept at 26°C, leaf and growing point temperature would be as high as 24°C, whereas air temperature was only 18°C. It is reported that high bench temperature shortens production time by 25% in wintertime and spring, without reduction in quality. It is evident that keeping canopy temperature above air temperature no condensation will take place.

In our experiment slatted benches (greenhouse no. 4) were tested as an alternative to heated benches (1). As opposed to the standard of reference (greenhouse no. 1), first priority was given to the bottom heating. It was believed that warm air streaming through the plant canopy would heat the plants and keep them dry. Plant production responded very positively to this strategy, quality and dry matter production rose and energy consumption per plant was reduced by 15% on average. Root zone temperature and leaf temperature were not recorded in detail, leaf temperature showed a lower value for slatted benches, but the different priority of heating systems in the two houses makes it absurd to compare the leaf temperatures. Equal leaf temperatures do not necessarely garantee equal tissue temperatures, as different temperature gradients in the plant canopy may prevail according to different heating strategy. Evaporation from bench surface should be avoided, as energy is lost due to humidity control by ventilation.

Weel (12) found that 25% less water was used when the wet capillary mat was covered with a plastic liner between the pots. Furthermore root zone temperature rose by 1.5°C. Similar observations were made by *Bjerre* (5) using a perforated plastic liner. In that case evaporation from the bench surface was reduced by 70% compared to an uncovered wet surface, root zone temperature was increased by 1°C. Removal of this undesired evaporation will hardly be detectable, as plants in response increase their transpiration.

In our experiment a comparison between flooded benches and dry capillary benches was made, to see if the total dry bench surface of the flooded bench system would be advantageous.

Apart from a slightly higher dry matter production, quality, production time, energy per plant and number of buds and flowers were equal for the two systems.

The last to be mentioned in this discussion is the air humidity control system. Raising temperature instead of ventilating resulted in longer production time, plants of poorer quality and an increased energy consumption per plant in spite of a 0.6°C higher air temperature. Furthermore the heating strategy resulted in a higher air humidity. An explanation might be that transpiration rate and thus water uptake was reduced by the high humidity, however, an investigation would require recordings of water consumption.

Conclusion

In this final passage we will see which of the applied systems can be recommended for each individual plant species. This evaluation is only based on quality (Table 4), energy consumption per plant (Table 3) and production time (Table 2). When differences are expressed as a percentage the reference house is always set at 100%. The first greenhouse mentioned in the parenthesis is always the reference, and further, if a character is not mentioned in the evaluation it just means no difference.

Begonia

Insulation (greenhouse no. 1 and 3): Reduced quality, but on the other hand reduced energy consumption.

Air humidity control (greenhouse no. 3 and 2): Poor quality, can not be recommended.

Bench types (greenhouse no. 1 and 4): Improved quality and lower energy consumption.

Irrigation system (greenhouse 3 and 6): Same quality, but energy consumption and production time were slightly increased.

Chrysanthemum

Insulation (greenhouse no. 1 and 3): Same quality, energy consumption was reduced by 10%.

Air humidity control (greenhouse no. 3 and 2): Same quality, higher energy consumption and longer production time.

Bench type (greenhouse no. 1 and 4): Slightly improved quality, 20% lower energy consumption.

Irrigation system (greenhouse no. 3 and 6): same quality, 5% reduction in energy consumption.

Hedera

Insulation (greenhouse no. 1 and 3): No differences.

Air humidity control (greenhouse no. 3 and 2): Same plant size, energy consumption was increased by 60% and production time was prolonged.

Bench type (greenhouse no. 1 and 4): Same plant size, energy consumption was reduced by 32%, and production time was 4 days shorter.

Irrigation system (greenhouse no. 3 and 6): Slightly bigger plants, 22% higher energy consumption.

Kalanchoë

Insulation (greenhouse no. 1 and 3): Same quality, 26% lower energy consumption.

Air humidity control (greenhouse no. 3 and 2): No differences.

Bench type (greenhouse no. 1 and 4): Improved quality, 15% lower energy consumption.

Irrigation system (greenhouse no. 3 and 6): Slightly improved quality, no differences in production time and energy consumption.

Saintpaulia 1

Insulation (greenhouse no. 1 and 3): Same quality, 22% lower energy consumption and shorter production time.

Air humidity control (greenhouse no. 3 and 2): Same quality, same energy consumption and shorter production time.

Bench type (greenhouse no. 1 and 4): Same quality, 24% lower energy consumption.

Irrigation system (greenhouse no. 3 and 6): Same quality, 6% lower energy consumption.

Saintpaulia 2

Insulation (greenhouse no. 1 and 3): Same quality, 24% lower energy consumption.

Air humidity control (greenhouse no. 3 and 2): Lower quality, same production time, but 6 days shorter production time.

Bench type (greenhouse no. 1 and 4): Improved quality, slightly lower energy consumption, but 7 days longer production time.

Irrigation system (greenhouse no. 3 and 6): Same quality, slightly lower energy consumption and 5 days shorter production time.

In good accordance with previous experiments, the use of double PMMA as cladding material proved advantageous. Slatted benches combined with a heating strategy where bottom heating had first priority were very successful too. Although the combined effect of these two systems has not been investigated yet it might be an attractive alternative.

For most of the plant species flooded benches improved quality a little, whereas air humidity control by heating cannot be recommended.

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