INSTITUUT VOOR TUINBOUWTECHNIEK
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DEVELOPMENTS IN THE CONTROL OF THE GLASSHOUSE CLIMATE

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1. Introduction.

The cultivation of horticultural crops is gradually becoming an industrial process. With technical progress a better control of the glasshouse climate is possible, economically justified by social change.
The realization of a complete controlled cultivation with a planned production, is, however, still greatly hampered by the lack of exact knowledge about the requirements of the crop.
Higher yields are very important; in a comparison of holdings following a method of factor analysis, Meijaard (9) found that the differences in the net results of the holdings are mainly determined by earliness and yield.
The requirements of the crop are very complicated because often various physiological processes have to be controlled at the same time. In addition, we are concerned with interactions between the crop and the climate inside the house and outside.
In climate research, a programme of requirements is drawn up step by step from data derived from horticultural, physiological and climatological investigations. These specified conditions are then more or less accurately implemented and tested in practice, the findings of which lead to a better formulation of the requirements, and so on.
Whether this is the quickest way is questionable but it remains a fact that there is just too little research capacity to arrive at a systematic approach. Abroad also, very little is being done in this field. However, more efficient research methods are being looked into, such as, the use of calculation models (for instance, used to calculate the temperature and humidity, for varying radiation intensities in high and low houses (8) and for soil heating research (5)), multi-factoral experiments (the comparison of crop reactions to a series of climates), simultaneous measurements of the climaticconditions (7) and the activities of the plants.

An intensive testing of the findings under practical circumstances remains necessary, which is a difficult and time consuming job. At this stage the modern control systems are indispensible in realizing the climate regimes to be investigated, which still must be considered as "prototype".
The effect of differential ventilation, that is to say, the ventilators are further opened as the temperature rises, and the consequent specification for the equipment, for example, could only be studied when automated vent systems became available. The result of this research has led to considerable improvement of the original equipment. So far as the glasshouse climate is concerned, the control systems and control equipment advanced in the last years are in essence but an expedient to the further investigation of the desired glasshouse climate and the regulation of it. The supposition, that first horticulturists should formulate the (climate) conditions to enable the technicians to develop the suitable equipment, is misleading: the technicians should be involved in the research at a much earlier stage.

2. Requirements of the glasshouse climate.

In the Netherlands intensive experiments have been carried out on the control of the glasshouse climate for tomatoes in particular. Recently, more consideration has been given to lettuce, carnations and freesias. In these experiments, it was attempted by means of new control equipment and technical aids to get more insight into the climatic requirements of the crop. The findings with tomato are undoubtedly applicable to other crops after the necessary modifications.
Although research findings have contributed to improving the supply pattern of tomatoes, the supply still fluctuates rather much due to inadequate control of growth and fruiting.
For many years, temperature has been the sole parameter for climate control.

The phenomenon of thermo-periodicity described by Went is further worked out by Verkerk (15), who showed, for tomatoes, that the relation between photosynthesis on one side, and growth and respiration on the other, strongly depends on the relation between light and temperature. Under low light conditions, a lowering of the night temperature is a means of slowing down respiration and growth (in the dark), so that the net assimilation surplus can be directed to the desired (generative) development of the crop, such as truss formation and fruit set.
The light-dependent regulation of temperature, matching increasing light intensity with higher temperature, is based on this concept. But how logical this principle appears, it still has not found wide-spread application, mainly because exact data regarding the relationships are lacking.
Especially during the last years it has become clearer that the room temperature forms a too limited basis for the regulation of the climate.
It is well known that a certain desired temperature can be realized in different ways, for example by over-ventilating and excessive heating or by limited ventilation and normal heating. But under these two sets of conditions, two completely different crops emerge, respectively a "sturdy" and a "leggy" crop, that is, plants that differ in their moisture content. A subtle control of the moisture condition of the plants through increased transpiration, especially in the dark winter months, is very important. Later, in strong sunlight by contrast, transpiration must be limited. It must be stressed that sharp fluctuations in the transpiration conditions can have serious effects on the crop. In this connection it has been argued that conditions during only 5% of the time are decisive for the (qualitative) success or otherwise of the culture. For example, for tomatoes, it has been observed that a rapid and substantial increase in transpiration, interrupts the growth rhythm, through which virus infection may become manifest and one or two trusses fail to set. (13, 16).
Under these circumstances lettuce can suffer tipburn and flowers loss of quality (splitting of carnations).

3. Control of the glasshouse climate.

Research into the glasshouse climate has not stagnated by the lack of formulated plant requirements. Control systems have been evolved which regulate heating and ventilation not only to maintain set air temperatures, but also to regulate the transpiration of the crop, especially to eliminate sharp transitions. Two control systems will be outlined.

3.1. Heating with hot pipes and ventilation.

This new approach is further worked out for tomato by Strijbosch and others (13) who attempted to reproduce and incorporate into a control system the "touch" of the good grower. This has resulted in a control system ("Strijbosch" or "Meerel" system) whereby the air temperature is controlled dependent on light, i.e. a higher temperature is set with increasing light intensity. The desired room temperature is achieved by a certain temperature of the heating water (the pipe temperature) combined with a certain degree of ventilation. Ventilation is directly controlled by the pipe temperature; if the pipe temperature falls below the set value, the ventilators are opened.
The pipe temperature at which the ventilators are opened is adjustable, dependent on the light intensity; it is lower when the light intensity is high because then the need to stimulate transpiration declines sharply (see table).

Climate control system Strijbosch.
simplified example.

	night	day without sun	day with sun
desired room temperature	16°C	20°C	25°C
vents open at pipe temperature below	55°C	55°C	40°C

The basis for this control system is the fact that heat loss and moisture loss are linked up. When loss of heat, and therefore of moisture, is minimal, for instance in dark damp still weather, ventilation is increased stimulating the transpiration of the crop. When the loss is high, the vents remain closed longer, to slow down the transpiration. The details of this control system which are mainly aimed at preventing extreme conditions are not considered here; if for instance, the temperature in the house is too high the pipe temperature is lowered before the ventilators are opened.

A characteristic of the system is the inertness in the opening of the vents when the light intensity increases rapidly because of the slow cooling down of the water in the pipes. This checks large and sharp fluctuations in the glasshouse climate.

3.2. Vapour-pressure deficit control system.

Subsequently van Drenth of the Institute of horticultural engineering has designed a control system which more directly influences the transpiration of the crop via the evaporative power of the air in the glasshouse (3).

This system is called the vapour pressure deficit or Δx system. (illustration 1). The starting point is the fact that the transpiration of the crop depends mainly on the vapour pressure deficit Δx, that is to say, the difference in moisture content (in grams water vapour per kg dry air) of the saturated air at the prevailing temperature and the actual moisture content of the glasshouse air. (illustration 2).

The greater Δx, the dryer the air, and the greater stimulation of transpiration; a small Δx, thus a small moisture deficit, on the other hand, inhibits the transpiration.

The moisture content of the air in the house, can within certain limits be controlled by heating and ventilation.

In this system the temperature control in the house also depends on light intensity, that is to say, there is a set night temperature and the day temperature increases with light intensity. The control of the vapour pressure deficit via the vent opening is entirely independent of this temperature control. The vapour pressure deficit at which the vents are opened, is adjustable and can also be controlled by the light intensity. (see table).

Climate control, Δx system (simplified example).

	night	day without sun	day with sun
desired room temperature	16°C	20°C	25°C
Vents open at a vapour pressure deficit (grams water per kg air) lower than:	4.3	4.3	5,0

This system also is designed to prevent sharp fluctuations in transpiration whereby it should be noted that the moisture in the glasshouse air is largely brought in by the plants themselves. A few additional provisions are the minimum pipe temperature adjustment, the opening of the ventilators above a maximum room temperature irrespective of the vapour pressure deficit and the closing of the ventilators for low outside temperatures.
Especially the last of these control systems which are obviously still in the experimental stage, is clearly based on interaction between climate and the crop. In experiments and in practice the results with these systems are promising.

4. Control of the climatic factors.

To regulate the glasshouse climate, the different climatic factors must be controlled, that is to say, they should be maintained at a desired level. This is by no means the case for the light intensity, the light is a fluctuating factor that can hardly be influenced.

When considering the whole plant, the light is throughout the whole year a minimum factor.
The availability of the natural light level can be improved; in this connection reference can be made for example to the research of Stoffers (12), from which it appears that for the Venlo houses in the Netherlands, the roof angle between 20 and 30° is not so relevant, but it is the orientation of the ridge that is important; an east-west direction being the best. At present attention is being paid to the form and construction of the glasshouse roof, for example, with roofs of semicircular rigid plastic sheeting.

The temperature in a glasshouse can be controlled only up to a certain extent; in strong sunlight the temperature often rises higher than is desirable. A choice must then be made between ventilation whereby the humidity sharply decreases and not ventilating, in which case the temperature may rise too high, but in combination with a high humidity.
With high radiation intensity, the CO_2 concentration presents a problem too: the CO_2 requirement is then at its maximum, but with much ventilation, an artificial increase of the CO_2 level above the natural level of 0.03% is no longer possible. It must be noted here that with an increased CO_2 level, the plant temperature may, or even should be considerable higher, as appears from the nearly classic cucumber curve of Gaastra (4).
More knowledge of this CO_2 effect is urgently needed for it is clear that it has important consequences for ventilation with rising temperature.
The factor soil has not been considered; in general when considering the climate above the soil, the soil is taken to be a non-limiting factor.
However, with a subtler climate regulation in the house, the root environment plays a more limiting role. Especially the inertness of the soil as for changing temperature can be restricting, hence a renewed interest in "container" cultivation. (1).

4.1. The prevention of high temperatures.

As an illustration of the technical possibilities a few new developments are discussed in connection with the prevention of a too high temperature, based on the principle of evaporative cooling.
Cutting down the radiation by shading, by "white washing" has fallen into disuse because it is laborious and a permanent chalk screen is definitely unfavourable to growth and production. Mechanical shading by means of (artificial) material is a good, but an expensive solution and is applied on a small scale in the Netherlands for pot plants. Shading by means of coloured liquids over the roof appears to be too expensive and unreliable in the Netherlands.

4.2. Roof-sprinkling.

A recent method of glasshouse cooling is the use of sprinklers on the roof. In recent years many so called roof sprinklers have been installed to clean the roof of the house to improve transparency.
In practice it appears that when spraying in warm sunny weather with the ventilators opened, a considerable lowering of the temperature and increase in moisture content in the glasshouse can be obtained. The outside air that enters the glasshouse via a water curtain, is moistened and cooled above the glasshouse because the necessary heat of evaporation is withdrawn from the air (6). The cooling effect lies between 3 - 5^{o}C.

4.3. Fan and Pad cooling.

Another principle of evaporative cooling has long been known in the U.S. where the "fan and pad cooling" method has been developed. By drawing the outside air through wet pads the humidity of the air is raised, while the extracted evaporation heat lowers the air temperature. Although less effective in moist sea climates than in arid areas, this form of climate control is now receiving more attention.

Glasshouse firms became interested not only with a view to their export, but also on account of the necessity for quality improvements in floriculture. Evaporative cooling is most effective in sunny dry weather, that is to say, under the most adverse weather conditions for the quality of many flowers. A general objection to fan cooling is the horizontal temperature gradient. On the other hand, under these extreme weather conditions, any fall in temperature may improve the climate considerably, even though the entire house is not cooled evenly. Especially now that the cost of fans is more reasonable and also on account of the low electricity consumption, the limitations of this cooling system may be more than compensated by the advantages,namely an effective cooling during the (short) periods that the quality of the crop is very vulnerable. Moreover, with ventilators, ventilation and cooling can be far better mechanised.

Extensive measurements are being carried out in an experimental glasshouse in Aalsmeer by the Research Station for Floriculture and the Institute for Horticultural Engineering (I.T.T.). A commercial installation of 2.000 m^2 for roses is at present also in use in Aalsmeer. (illustration 3 and 4).

4.4. Sprinkling of the crop.

Yet another type of evaporation cooling is moistening the crop. Cooling by sprinkling is already in use for mist propagation of cuttings. Seemann (10) has demonstrated that sprinkling the leaves can lower the leaf temperature.

In Michigan plant misting of (outdoor) tomatoes has been applied by VandenBrink and Carolus (14). The specifications are that the water should be sprayed evenly over the area in small quantities (0.5 - 1.0 mm per hour) in not too fine drops. Carolus c.s. (2) conclude that the optimum water balance of a plant can more easily be achieved by regulating the transpiration, i.e. by the humidity of the air, than by a control of the water uptake, i.e. by watering the soil.

At the Institute of Horticultural Engineering Spoelstra has developed a sprinkler which meets these requirements and also can be applied to maintain the moisture level of the soil (11). The water is spread by centrifugal force; the sprinkler basically consists of a small centrifugal pump driven by a small electromotor. Depending on the water supply the precipitation rate is suitable for misting (average 1,0 mm/hour) and for irrigation (average precipitation rate 5.0 mm/hour). See illustration 5.
Recent experiments have indeed shown that tomato plants sprinkled in this way, transpire considerably less than the control plants.
Misting may offer a possibility for growing glasshouse lettuce in the summer.

5. Conclusion.

The control systems and aids for the control of the glasshouse climate discussed here are engineering developments applied to horticultural crops. This research has already yielded important climatological information.
The evaluation of the horticultural merits is lagging behind mainly due to the complexity of the physical and physiological processes concerned. The common parameter used to evaluate treatment effects, namely the yield, is inadequate because it only represents the integral and ultimate effect.
For the grower this is most important, but the ultimate yield does not reveal the effect of a certain treatment at a particular time, which is what matters to the research worker.
That is why research techniques are being developed involving the simultaneous registration of both environmental and crop response. This approach has already been adopted in a joint project; crop responses measured are: leaf temperature, stomatal opening and the rate of transpiration.

6. Summary.

The control of the glasshouse climate is no longer limited to the maintenance of a set room temperature but extented to the regulation of the transpiration of the crop via the evaporative power of the air. In dull weather the transpiration has to be stimulated to achieve the desired development of the crop and during periods of high incident radiation the transpiration has to be limited.

In the Strijbosch or Meerel system the air temperature is controlled depending on the light intensity; the desired (minimum) temperature of the water (pipe temperature) lowers with increasing light intensity. Ventilators are opened if the ambient temperature is too high and the pipe temperature is lower than desired for the prevailing light intensity.

The "vapour pressure deficit" or "Δx-system" also controls the air temperature depending on radiation level, but the ventilation is controlled directly by the vapour pressure deficit of the air; if this deficit becomes too small the ventilators are opened.

The control of the climate factors in a glasshouse is still only possible to a limited extent. Some recent developments in preventing high air temperatures are based on evaporative cooling: sprinkling over the roofs when the ventilators are opened; fan and pad cooling and moistening the crop by sprinkling at a low precipitation rate.

In testing the horticultural merits of control systems etc., the final yield proved to be a too rough criterion for determining the effect of specific treatments at a certain moment. Therefore more direct measurements of the crop response are used, such as the leaf temperature, the opening of the stomata and the actual transpiration rate.

7. Literature cited.

1. Berkel, N. van: Containerteelt bij tomaten. Groenten en Fruit 24, 1968: 77,81.

2. Carolus, R.L. A.E. Erickson, E.H. Kidder, R.Z. Wheaton. The interaction of climate and soil moisture on water use, growth and development of the tomato. Mich. State Univ.Agric.Exp.Sta East Lansing. Quart. Bull. 47, 1965: 542 - 581.

3. Drenth, A. van en S.H.Achterberg: Regelsysteem voor het kasklimaat. Beschrijving van een vocht-deficit-regeling. I.T.T. publicatie 52, 1969.

4. Gaastra, P. Fysiologische aspecten van de toepassing van koolzuur. Meded.Dir.Tuinb. 27, 1964: 369 - 377.

5. Heijna, B.J. Warmtetechnische aspecten van grond-verwarming. Meded.Dir.Tuinb. 31, 1968: 38 - 49.

6. Holsteijn, G.P.A. van en W. van Eindhoven: Eendaks-besproeier biedt verschillende toepassings-mogelijkheden. Groenten en Fruit 24, 1968: 15, 17.

7. Koppe, R. en D. Bokhorst. Energie-, vocht- en CO_2-huishouding in kassen. I.T.T. Publikatie 21, 1967: 26 pp.

8. Koppe, R. en J.A.Stoffers: Berekening van temperatuur-fluctuaties in kassen bij wisselende instraling en van luchtvochtigheids-fluctuaties bij wisselende waterdamp-toevoer. Kassen en Kasklimaat. I.T.T. Publ. 13: 81 - 94.

9. Meijaard, D. : Verschillen in bedrijfsuitkomsten in de glastuinbouw. Meded.Dir.Tuinb. 28, 1965: 188 - 193.

10. Seemann, J. Ein Beitrag zum Problem der Kühlung von Gewächshäusern während des Sommers mit einfachen Verfahren. Gartenbauwissenschaft 27, 1962: 33 - 44.

11. Spoelstra, P.A. en W. Broekhuizen. Ontwikkeling van een sproeier voor gewasbevochtiging. Publikatie I.T.T. - 1969: 5 pp

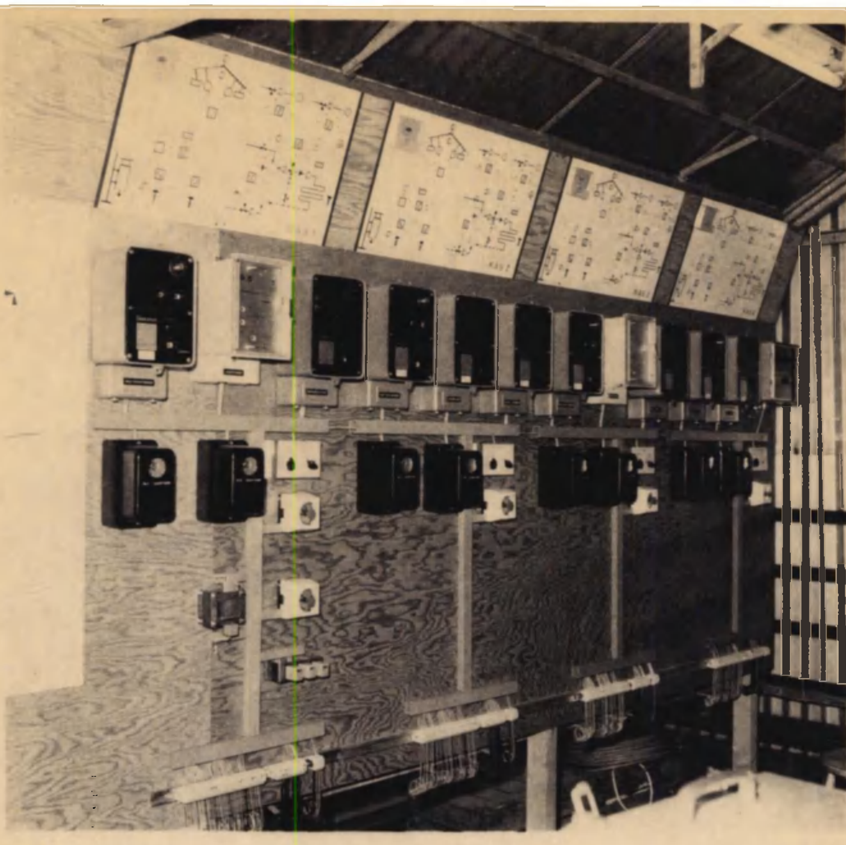
12. Stoffers, J.A. Licht en dakhelling van warenhuizen. Meded.Dir.Tuinb. 31, 1968: 17 - 21.

13. Strijbosch, Th.: Ventilatie en verwarming van tomatenkassen. Meded.Dir.Tuinb. 29, 1966 : 364 - 371.

14. VanDenBrink, C. and R.L. Carolus: Removal of atmospheric stresses from plants by overhead sprinkler irrigation. Mich. Agric. Exp. Sta. Mich. State Univ. East Lansing. Quart. Bull. 47, 1965 : 358 - 363.

15. Verkerk, K.: Temperature, light and the tomato. Meded. Landbouwhogeschool 55 (4) 1955: 176 - 224.

16. Vijverberg, A.J. en Th. Strijbosch: Ontwikkelingen in de klimaatregeling bij tomaat en sla. Meded.Dir.Tuinb. 31, 1968 : 472 - 475.

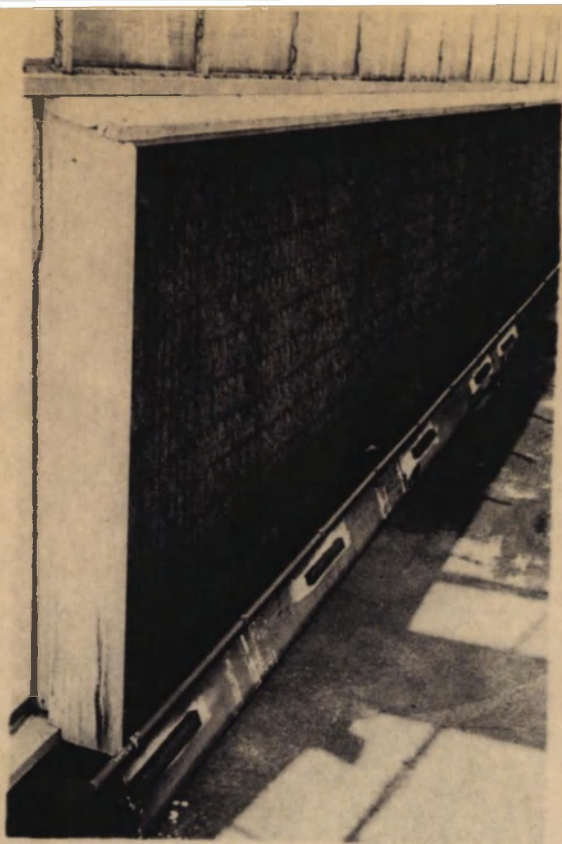


Afb. 1
Regelpaneel met vier experimentele vochtdeficitregelaars. Op de regelschema's wordt door lampjes aangegeven welke onderdelen in bedrijf zijn.

Four experimental vapour pressure deficit controllers.

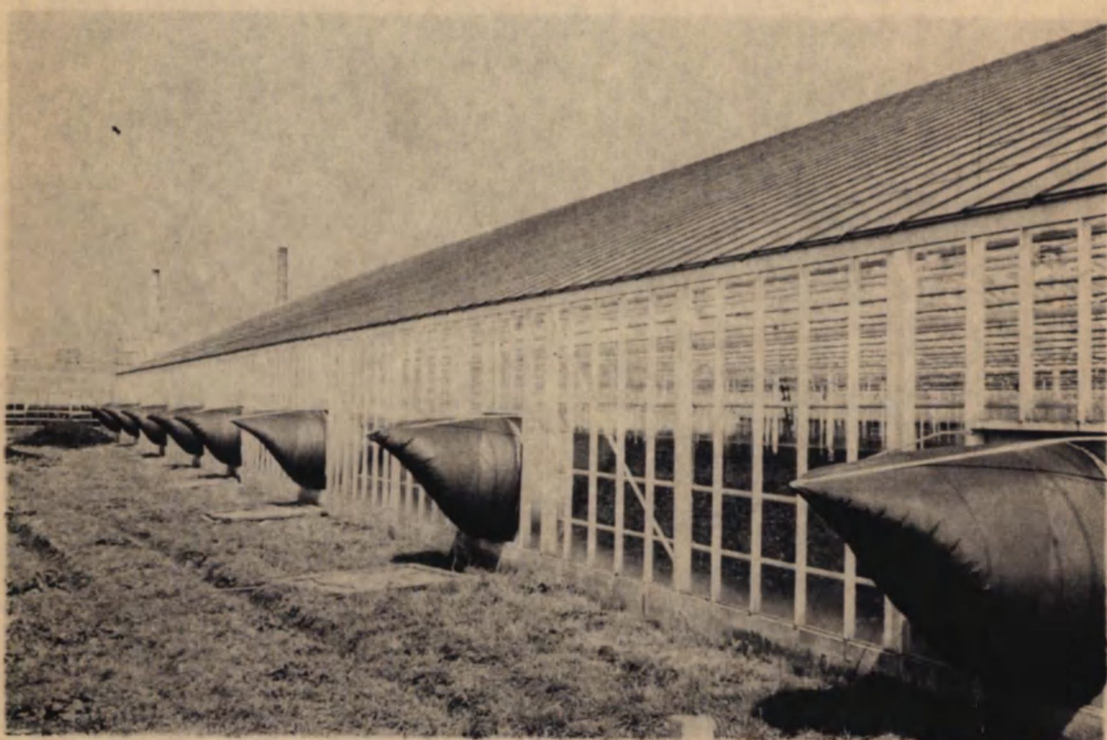
Afb. 2
Geventileerde en tegen straling geisoleerde meetkast met natte en droge thermokoppels voor het bepalen van het vochtdeficit.

Aspirated box containing wet and dry thermocouples for determing the vapour pressure deficit.



Afb. 3
Watermatkoeling; wand met bevochtigde mat (cocos vezels) waar de lucht door naar binnen wordt gezogen.

Fan and pad cooling; pad of coco fibres through which the air enters the glasshouse.



Afb. 4
Watermatkoeling; wand met ventilatoren en (hier uit staande) afsluithoezen.

Fan and pad cooling; wall with fans and nylon flabe to shut off the fan outlet.

Afb. 5

Centrifugaalsproeier voor gewasbevochtiging. Het te versproeien water loopt vrij vanuit het leidingnet in een beker, die met een verlengas is gckoppeld aan de electromotor (90 W – 2800 omwentelingen per minuut). Op de beker is een sproeipijp aangebracht, die het water verspreidt.

Centrifugal sprinkler for moistening the crop. Water from the main supply flows into cup, which is rotated by an electromotor (90 W – 2800 r.p.m.). In the cup the sprinkler is mounted. Precipitation rate 1–5 mm/hr over 50 m^2.