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VERSLAG
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GREENHOUSE DESIGN AND ENVIRONMENT

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18 - 21 September 1973
Silsoe - U.K.

door :
Th. Strijbosch &
J.v.d. Vooren

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Symposium

GREENHOUSE DESIGN AND ENVIRONMENT

VERSLAG

Th.Strijbosch
J.v.d.Vooren

SUMMARIES

National College of Agricultural Engineering,
Silsoe, Bedfordshire, U.K.

18 - 21 September, 1973.

INTERNATIONAL SOCIETY FOR HORTICULTURAL SCIENCE

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Symposium: Greenhouse Design and Environment

Silsoe, U.K. 18-21 September 1973

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Verslag van het Symposium Greenhouse Design and Environment 1973

Het symposium werd gehouden op 18-19-20 en 21 september op het National College of Agricultural Engineering in Silsoe, Bedfordshire, England en was georganiseerd door de Commission for Horticultural Engineering van de International Society for Horticultural Science.
Er waren vertegenwoordigers uit vrijwel alle West-Europese landen, alsmede uit Canada, Israël, Japan, Nieuw Zeeland, Verenigde Staten en Zuid-Afrika.

De organisatie was uitstekend; het tijdschema werd strak gehandhaafd, terwijl ook gezorgd was voor een goede vrijetijds-besteding.

Van de vierentwintig voordrachten kan als meest opvallende worden genoemd de voordracht 'Plantgrowth optimisation using a small computer' van T. Takakura uit Japan.
In plastic groeikamers is nagegaan het verband tussen luchttemperatuur, relatieve luchtvochtigheid en CO2-concentratie enerzijds en de netto CO2-opname door de plant (fotosynthese) anderzijds (sla).
Gevonden werd dat de optimum relatie tussen temperatuur, relatieve luchtvochtigheid en de CO2-concentratie voor de maximale fotosynthese in de tijd niet constant is. Een optimum werd vastgesteld bij 40 °C, 85% rv en 1300 p p m CO_2. Beneden 25 °C werd geen invloed waargenomen van verschillen in relatieve luchtvochtigheid voorzover deze boven 60% lagen.
Afgezien van de resultaten ontleende dit onderzoek zijn belangrijkheid aan het feit dat hier de computer op zinvolle wijze in het tuinbouwkundig onderzoek is toegepast.
Het streven de computer in het onderzoek te betrekken werd ook teruggevonden in de rekenmodellen betreffende 'Heat radiation Phenoma from a Glasshouse Crop Canopy' (M.G. Amsen, Denemarken) en 'Radiation Absorbtion of Canopy Rows' (J.A. Stoffers, Nederland).
In Engeland (Lee Valley Exp. Hort. Sta, Hoddesdon) en Amerika (College of Agr. and Environmental Sci. Rutgers University, New Brunswick NJ 08903, U.S.A.) wordt opvallend veel onderzoek gedaan naar de toepassing van plastic kassen in de tuinbouw. De indruk werd verkregen dat dit onderzoek door ons op de voet moet worden gevolgd, maar dat bij de huidige stand van zaken de praktische toepassing in ons land nog weinig perspectieven biedt.
Als laatste kan worden opgemerkt dat de automatische regeling van het kasklimaat met behulp van luchtramen en warmwaterverwarming een vrijwel nederlandse aangelegenheid leek te zijn. De Engelse bijdrage beperkte zich tot de beschrijving van een lichtafhankelijke temperatuurregeling, waarbij de lichtveranderingen stapsgewijze door het apparaat worden gevolgd. Dit principe is tien jaar geleden op het Proefstation Naaldwijk verlaten voor verbeterde uitvoeringen. Bij bezoeken aan bedrijven in de praktijk bleek dat men bij de regeling van het kasklimaat gebruik maakt van eenvoudige temperatuurregelingen met een nacht- en dagniveau. Dit betreft zowel de verwarming als de ventilatie. Als reden werd opgegeven dat enerzijds meer uitgebreide apparatuur moeilijk te krijgen is, maar dat anderzijds eventuele storingen in de apparatuur door de tuinder zelf verholpen moeten worden. De organisatie van een goede storingsdienst door de leverancier (service) leek nauwelijks mogelijk ook al doordat de bedrijven ver uit elkaar liggen en dus grote afstanden moeten worden afgelegd.

Als voornaamste conclusie mag worden gesteld, dat het gebruik van de computer bij het tuinbouwkundig onderzoek zich steeds duidelijker begint af te tekenen.

Th. Strijbosch
J. v.d. Vooren

Naaldwijk, 28 september 1973

Developments in climate control

Th. Strijbosch and J. v.d. Vooren.

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Abstract

The plantphysiological demands for the greenhouse climate are described. Pipe temperature of the heating system and outside climate are used as parameters for measurement and control of airchange.

Introduction

The process, for which greenhouse climate is controlled, is in general plant growth(photosynthesis). CO_2, water, light and a certain temperature level are necessary for this process.

Carbondioxide is consumed by the leaf, so a supply is necessary. This can be provided by airchange or artificially by burning gas or oil. Airchange at a rate of 2-10 per hour depending on cropsize is necessary for sufficient photosynthesis (Whittle e.o., 1960).

Water is taken up from the soil and is removed from the plant to the surrounding air by transpiration. This transpiration is dependent on light energy and the steepness of the water vapour pressure gradient from leaf to air. This steepness is dependent on the vapour pressure deficit (Δ X) and airmovement around the leaf.

A certain temperature level is provided by
- energy supply : light energy and heating system
- energy loss : transpiration and ventilation.

Controllers of different make are in use on commercial greenhouses. They control temperature level by means of ventilators and a heating system. Some of them are also used to "control" sufficient airchange (Strijbosch, 1973) and Δ X (Heyna, 1973).

Airchange control by pipe temperature.

Supply and loss of heat in the greenhouse are equal at a constant airtemperature. A night temperature of the pipes of the heating system indicates therefore a high airchange. Consequently the ventilator opening has to be decreased. The reverse holds for a low pipe temperature.

Since the sun is another heatsupply, the pipe temperature, at which the ventilators are operating, has to be light dependent.

This control system of airchange can only be used, while the heating system is operating. This is a disadvantage for low temperature requiring crops like lettuce and carnation.

Airchange control by cutside climate.

Loss of heat in a greenhouse is dependent on windvelocity and the difference between greenhouse air temperature and outside air temperature (Businger, 1963). A minimum ventilator opening is maintained dependent on windvelocity and temperature difference. The higher windvelocity and temperature difference are, the less the ventilator opening. The reverse holds for a low windvelocity and temperature difference.

The relations between windvelocity, temperature difference and ventilator opening are considered linear for reasons of simplification.

Conclusions and discussion.

All these greenhouse climate controllers are emperical and imitating the way, the grower has controlled manually glasshouse climate for decades. The theoretical background of the relation - greenhouse climate and plantgrowth is given afterwards.

More research is needed to develop new climate controlsystems. In the near future process computers are believed to control climate.

A more scientific approach is necessary to reveal the relations between climate, greenhouse and plantgrowth.

- 3.

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MOISTURE DEFICIT CONTROLLER (Δx) FOR GREENHOUSE CLIMATE

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In Holland several types of controllers for greenhouse climate are on the market. One type, built by three firms, has the possibility of controlling the moisture deficit of the air = Δx.

Physically it is easy to prove that the drying rate, the same as transpiration, is governed by the moisture deficit Δx and the amount of absorbed radiation I, according to the following equation:

$$\text{Transpiration} = A.\Delta x + B.I.$$

The task of the controller is then to avoid too high and too low transpiration rates.

But the control system is capable of fulfilling more duties. It possesses two control circuits.

One is a light-dependent controller connected to the three-way mixing valve of the heating system and the second is the Δx-controller, connected to the ventilators.

There are built-in limits for air and pipe temperatures, which will be explained.

For most of the crops, e.g. tomatoes, cucumbers, roses, freesias and carnations, the delta-x system in our country with a moderate sea climate is working well, if the plants have enough leaf surface to provide a sufficient air humidity.

At the end some experience of the users will be given. The main reason for buying this rather expensive system (f 7.000.=) is to achieve a saving of labour and worry, with the same or an earlier crop.

COMPARATIVE MEASUREMENTS OF FAN AND PAD COOLING AND PLANT WETTING

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NETHERLANDS.

Due to more transpiration than to supply in the warmer season - with the maximum available light - the water economy of several crops is often not in a good condition.

Growers with year-round blueprint growing are interested in systems to avoid this.

In a specially erected greenhouse at the Institute of Horticultural Engineering measurements were carried out with two ventilation methods - Fan-and-Pad cooling and Plant wetting.

Energy balances are calculated based on the measurements.

At the same time the plant response (water potential and leaf-thickness) was measured.

Some graphs show the energy balance and plant response, and some conclusions are drawn from the characteristics of the applied systems.

DEVELOPMENTS IN GLASSHOUSE CLIMATE CONTROL

BY TH. STRIJBOSCH & J. VAN DE VOOREN, RESEARCH STATION FOR VEGETABLE & FRUIT CROPS UNDER GLASS, NAALDWIJK, NETHERLANDS.

Ventilating and heating are not only used to control the air temperature in glasshouses, but also to control the air exchange, which is necessary for the supply of CO_2 (photosynthesis) to, and for the removal of water vapour (transpiration) from, the plant. The direct measurement of air exchange is impossible in commercial glasshouses. Therefore this factor has to be derived from other variables:

1. Pipe temperature. Supply and loss of heat are equal at a constant air temperature. Consequently a high temperature of the pipes of the heating system indicates a high air exchange : ventilation has to be decreased. The reverse holds for a low pipe temperature. Pipe temperature has to be light-dependent, since heat supply is also provided by the sun.

   This control system can only be used while the heating system is operating.

2. Wind velocity and outside temperature. The heat loss is dependent on wind velocity and the difference between outside and inside temperature (Δ t). Consequently air exchange is related to those factors, which partially control ventilation.

3. Air humidity. The plant produces water vapour by transpiration. At a constant transpiration increasing air humidity indicates decreasing air exchange : ventilating has to be increased. The reverse holds for decreasing air humidity. This is measured and controlled by the vapour pressure deficit (Δ x).

At the moment glasshouse climate controllers, based on one of the preceding principles, are used in Holland.

THE DESIGN OF DUCTED AIR HEATING SYSTEMS

by B. J. Bailey, National Institute for
Horticultural Engineering, Silsoe, U.K.

In the ducted air type of glasshouse heating system inflatable perforated polyethylene ducts are used to distribute warm air throughout the glasshouse. To produce uniformity of temperature the ducts must have uniform heat output in the body of the glasshouse but supply extra heat around the periphery. The total heat output of a duct is partly by transfer through the duct wall and partly by the discharge of heated air through the perforations. Heat transfer theory can be used to calculate the heat supplied by radiation and convection from the duct wall. The difference between this and the required output must be supplied by air discharge. The discharge of air through a perforation is dependent on the discharge coefficient and the static pressure difference existing across it. Measurements of the former have shown it is not constant but dependent on the static and velocity pressures of the air within the duct. In short ducts the static pressure rises monotonically from the entrance, while in long ducts there is at first a decrease and then a small increase towards the duct end. The decrease is caused by friction with the duct wall and can be calculated; the increase occurs because of the loss of momentum along the duct, and can be predicted by using the static regain coefficient. The latter has been determined experimentally and is dependent on the ratio of hole to duct area and on the velocities upstream and downstream of the hole. Using this information the area and spacing of perforations necessary to provide the required heat output can be calculated. This procedure has been used to design ducts 60m in length to heat a glasshouse which contained a tomato crop. The resulting temperature distribution showed a mean standard deviation of 0.8 C.

"An Inexpensive Greenhouse Vent Controller"

by W. J. Roberts, Rutgers University,
New Brunswick, U.S.A.

In the United States most plastic film greenhouses are ventilated mechanically with fans and motor operated louvers. In many respects, it is desirable to control the opening dimensions so that uniform velocity can be maintained. As flow increases with additional fans, the openings or inlets should be increased accordingly. Existing modulating controls used in glass houses could adequately perform this function but their cost is high in relation to the initial cost of the house itself.

The design of this control is an attempt to perform the task of opening the window in steps. Standard capillary bulb thermostats and cam operated microswitches in conjuncion with appropriate relays and switches were used.

The control box or black box is mounted so that eight rotary cam operated single pole-double throw switches can be controlled on a one to one ratio with the shaft which operates the window linkage.

The sequence of operation would be as follows: The thermostat would call for ventilation and the motor operator would start opening the window. After the shaft had turned a predetermined number of degrees, the first micro or limit switch would turn off the motor. As the temperature continued to rise, the second thermostat would tell the window to open until the second limit switch would stop it. The same procedure is followed for 2 more open positions with a separate circuit to close the window in a similar fashion.

Seven units were installed in the Spring of 1973 and to date have proven successful.

DETERMINATION OF GLASSHOUSE HEAT REQUIREMENTS FROM TEMPERATURE AND WIND RECORDS

by T. O'Flaherty, Glasshouse and Vegetable Crops Research Station, Kinsealy, Eire.

Glasshouse heat requirements have been estimated from an analysis of hourly readings of temperature and windspeed. The readings cover the months November to March in five successive winters, at three meteorological stations in England and three in Ireland.

The analysis examines the heating system capacity needed in each region to meet peak demand to within specified limits. It proposes a criterion for evaluating the external design temperature and thermal transmittance (U-value) to be used in different regions in the design of glasshouse heating systems. The criterion is used to derive values of these quantities for the six places included in the study. Total winter fuel consumption for the six regions is also compared.

The results demonstrate the important influence of wind on glasshouse heat demand. Winter temperatures are generally lower in England than in Ireland, but greater windspeeds in Ireland tend to cancel this advantage.

EFFECT OF VENTILATOR OPENING AREA ON TEMPERATURE RISE IN GLASSHOUSES

By R. A. J. White, Horticultural Research Centre,
Levin, New Zealand.

The effect of ventilator opening areas between 6 and 27% of the floor area on glasshouse air temperature rise above outside air temperature was compared in two experiments in 12 identical glasshouses, with uniform cover crops in bright sunshine. The use of roof and side ventilators was compared with using roof ventilators only (with same total ventilation areas in the range 6 - 15%) and significantly reduced temperature rise. Temperature rise in glasshouses, using both roof and side ventilators, was best fitted to the model $\log \Delta t = a - bv$ (Δt is temperature rise and v is ventilator opening as % floor area) and accounted for 92.4% of the variation. The model predicts a reduction of about 0.1 °C (0.2 °F) for each 1% increase in ventilator opening above 15%, falling to 0.05 °C (0.1 °F) per 1% above 27% ventilator opening. The model could not be used to predict the temperature rise in any particular glasshouse in the block of 12 glasshouses used for the experiment as the position of the glasshouses within the block and the direction of the wind also affected the observed temperature rise. The results are discussed with reference to subsequent experience in this block of glasshouses.

SOME ASPECTS OF ENERGY BALANCE IN GREENHOUSES

N. LEVAV & L.G. MORRIS, VOLCANI CENTRE, BET DAGAN, ISRAEL

The FAO High Value Crops Project is experimenting on this subject with a view to deriving a mathematical model which will have useful application in practice.

Studies concern the heat and water balance of a glasshouse during night time heating with a piped hot water system and also while cooling by day using forced ventilation.

The paper will report on progress so far.

AIR FLOW AND TEMPERATURE DISTRIBUTION IN GREENHOUSES WITH FAN VENTILATION

BY J.S. WOLFE & R.F. COTTON, NATIONAL INSTITUTE OF AGRICULTURAL ENGINEERING, SILSOE, U.K.

Observations of air flow in glasshouses with exhaust fan ventilation have shown that the pattern of flow is not a uniformly deep stream moving directly from inlet to fans, but is more complex and largely determined by the configuration of the inlet and to some extent by that of the roof. A crop or other resistance to flow in the house also influences the flow pattern. Detailed flow patterns have been determined for a number of inlet configurations, both without a crop in the house and with different heights of crop, and the implications of these patterns for temperature distribution are discussed.

Temperature measurements have been made in greenhouses and greenhouse compartments with exhaust fan ventilation. Temperature rise from inlet to fans and temperature lift midway between inlet and fans are linearly related to solar radiation intensity. Temperature rise differed from the value calculated from theory by different amounts in differing circumstances, and possible causes considered are air leakage through the cladding reducing the effective ventilation rate, the orientation of the crop rows affecting the air flow pattern and the cooling effectiveness, and the validity of the factor used in the calculation for the proportion of the solar radiation received in the glasshouse used in sensible heating of the air.

Temperature does not rise linearly between inlet and fans, and is higher at or above the top of the crop canopy than within it. Thus the temperature lift at the middle of the house bears a varying relationship to the temperature rise, depending on the height of the measuring position in relation to that of the crop, and possibly on the structure of the crop canopy and the airflow patte

Some evidence has been obtained that with fans up to 50 ft (15.3m) apart there is adequate ventilation midway between them.

RADIATION ABSORBTION OF CANOPY ROWS

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WAGENINGEN - NETHERLANDS.

Canopy rows, are taken to be rows of infinite length, with a definite centre-to-centre distance, height and width simplified to a rectangular shape.

The radiation absorbtion, short and long wave, is computed for different geometrical arrangements, different directions of the sun, different directions to diffuse radiation ratios and different amounts of reflection of the bottom.

In all cases the following assumptions are used:

a) isotopic canopy (spherical leaf distribution and equal density of leaves in the canopy);

b) isotopic scattering of the light;

c) the photosynthesis P as a function of light L is describable by $P = E \cdot L \left(\frac{EL}{A} + 1\right)^{-1}$ where E and A are constants. This makes a general dimensionless (and thus independant of the plant as far as the assumptions are correct) description possible of a photosynthetic profit as a function of a dimensionless light value.

CONTROLLED ENVIRONMENTS FOR SCIENTIFIC RESEARCH AND HORTICULTURAL PRACTICE

by

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After discussing the complexity of the reactions of plants to environmental factors which vary in a number of ways - leading to as many as 56 main reactions to aerial factors and 36 to the root environment - the importance of using Phytotrons and "Phytotronics" to provide the information needed by horticulturists is underlined. The main features of a large number of phytotrons throughout the world are compared and the difficulties of transferring results from phytotrons to greenhouse or field horticulture are considered. Finally the control requirements for the more important environmental factors are discussed.

THE ENERGY BALANCE OF AN AIR INFLATED POLYETHYLENE GREENHOUSE

Elisabeth Slack* and J. A. Clark**

Greenhouses covered with plastic film offer an attractive alternative to the traditional rigid glasshouse, principally because of their lower capital costs, and because their short life and consequent mobility eases problems of crop rotation in the greenhouse. The environment of the glasshouse is better documented than that of plastic houses, and among the plastic houses the air inflated bubble house has received comparatively little attention despite its appealing mechanical simplicity. This paper describes measurements of the energy balance of a polyethylene film bubble house at Sutton Bonington, Leics., England, made in September and October 1970. The net radiation in the house and the fluxes of sensible heat and latent heat related to ventilation of the house, together with ground storage, were used to estimate hourly averages of the component fluxes in the energy balance of the house and the partition of heat between them.

The energy balance of the house and the diurnal temperature cycles within it both exhibit features which contrast with the glasshouse, and which are consistent with other authors observations on the limitations of the plastic film house as a plant environment. Daytime temperatures in the house were above those outside, but the high rate of ventilation required to support the house depressed air temperatures in the important night period to levels not significantly different from those outside. The bubble house appears to be best suited to sites where water supply rather than low temperature is the limiting physical factor for plant growth.

(* Long Ashton, ** Sutton Bonington, University of Nottingham)

HEAT RADIATION PHENOMENA FROM A GLASSHOUSE CROP CANOPY

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1. In a simple model the following assumptions are made:

.1 positive radiation flux from plant canopy to screen (e.g. glass roof)

.2 plant temperature (T_d) and sky temperature (T_a) are not affected by glasshouse type or = material.

.3 heat radiation from a plant canopy to the sky is described by

$$dH_o = S(T_d{}^4 - T_a{}^4) = 4\,S\,\bar{T}_o^3\,dT_o = U_o dT_o$$

.4 The reducing effect of glasshouse type or -material is expressed as fraction of dH_o.

2. The screen acts as optical black (e = 1) and has a heat conductivity (L) so high that temperatures on the front and back sides are identical ($dT_h = 0$).

.1 The effect of screen number

$$dH_n = \frac{1}{n+1}\; dH_o = \frac{Uo}{n+1} dT_o$$

3. The screen acts as optical grey ($e \neq 1$) but ($dT_h = 0$)

.1 Transmitting screens ($t = 1 - e$)

$$dH_t = \frac{1+t}{2}\; dH_o = \frac{1+t}{2}\; U_o dT_o$$

.2 Reflecting screens: ($r = 1 - e$)

$$dH_r = \frac{1-r}{2} dH_o = \frac{1-r}{2}\; U_o dT_o$$

4. The screen acts as optical black (e = 1) but temperatures on the front and back sides of the screen differ ($dT_h \neq 0$)

.1 $$dH_L = \frac{1}{2}\left(1 - \frac{1}{1 + \frac{2L}{U_h\, dz}}\right) U_o dT_o$$

PLANT GROWTH OPTIMIZATION USING A SMALL COMPUTER

BY TADASHI TAKAKURA, COLLEGE OF HORTICULTURE, CHIBA UNIVERSITY, JAPAN

Direct Digital Control (DDC) of plant growth process is more effective and sophisticated procedure than any conventional analog control. As a preliminary step, the concept of on-line process control has been applied to the plant assimilation which can be considered one of the main dynamic processes in plant growth.

The process optimization is effected directly without recourse to any mathematical model, assuming CO_2 uptake by plants is unimodal. In order to get the maximum value of CO_2 uptake, air temperature, relative humidity and CO_2 concentration in the plant growing chamber are changed under the scheme of steepest ascent or the complex method in the daytime.

Process simulation without using actual plants has pronounced the adequate values of step size and direction in each method as well as the pattern of pursuing the time dependent optimum.

The result of leaf lettuces grown for five days under a constant light intensity elucidates the basic pattern which Heath (1969) suggested. Optimum condition for maximum CO_2 uptake changes considerably with time and its daily course is not consistent.

All control programs are made in the mixed mode of FORTRAN AND SABR which allows us to make our own control programmes using any I/O device very efficiently.

LIGHT-DEPENDENT TEMPERATURE PROGRAMMES FOR EARLY-SOWN TOMATOES

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Most, if not all, November-sown tomato crops in Britain are produced by what has become known as the "Blue-print" method. The essential features of this method are the maintenance of a three-fold level of CO_2 enrichment and the control of day and night air temperatures at set levels throughout different plant growth stages irrespective of day to day fluctuations in the light climate.

While it is generally accepted that highly profitable crops can be produced by this method it may be questioned whether even greater profitability could be obtained by modulating the daytime air temperature to accord with short-term changes in radiation receipt.

A modified version of the light-modulated greenhouse controller, developed by Bowman and Weaving (1970) has been constructed at the Glasshouse Crops Research Institute. This instrument has been used to effect light-dependent temperature control in an experiment designed to test the value of such a control system by comparison with single-level temperature control as embodied in the "Blue-print" method.

Some of the problems which necessitated modification of the original design are discussed and details of the instrument as constructed and the glasshouse heating and control systems are given.

The various temperature treatments included in the experiment are discussed and some of the physical data collected during the early stages of the experiment are presented.

"Air Inflated and Air Supported Greenhouses"

by W. J. Roberts.
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The use of air between double film-covered greenhouses has greatly enhanced their acceptability. Keeping the film rigid provides longer life of the film and greatly reduces labor of recovering. The double layer provides a reduction in heating costs and condensation problems. From a design point of view, rafters or supports no longer need to be 4' on centers to provide a means for attaching or holding down the film.

Our work in this area was initiated in 1965 in an attempt to reduce labor of covering. The first unit constructed was a pipe frame house covered with two layers of film. The two layers of film were forced apart by a small blower developing approximately 0.2 inch of static pressure. The outer layer of film formed an arch approximately 2" above the frames of the house which were located 6' on centers. The inner layer of film was forced down over the frames by the pressure. This effect gave the appearance of a curved, tufted air mattress. The end frames were laminated curved wooden arches to provide attachment for the plastic film.

The results were more than we had hoped for. The entire house 24' x 48' was erected and covered in less than 2½ hours with no difficulty. The plastic was rigid, did not move in the wind and was pleasing to look at.

This principle has been applied to all sizes and shapes of conventional plastic covered houses. It is used on hobby houses as well as on ranges covering over 9 acres. New and exciting designs have been tried and only the imagination limits the possibilities of providing good greenhouse design and environment, attractively and inexpensively.

A MULTI-BAY INFLATED HOUSE

by M.L. Banks. Church Farm, Kington Langley, U.K.

An experimental house comprising six bays, each 150 ft. (46 m) long x 35 ft. (10.7 m) wide and covering 0.75 acre (0.31 ha), was designed and constructed.

1) To demonstrate that such a structure was cheap and easy to erect, using large sheet film to maximum advantage,

2) using a high-tensile steel matrix to stress the structure, to provide crop support, and to minimise structural movement between the bays due to aerodynamic forces and

3) to investigate the problems associated with growing a variety of crops with widely differing environmental requirements.

600 g. (150 μ) polyethylene film was used, in rolls 120 ft. (40 m) x 36 ft. (11 m). Valley gutters were formed by bolting 8 in x $1\frac{1}{2}$ in (200 x 38 mm) planks onto 4 in. x 2 in. (100 x 50 mm) posts concreted into the ground at 15 ft. (4.6 m) centres. The roof sheeting was battened to this using cord rolled in the film. The walls sloped outwards 20° and consisted of 2 in. x 2 in (50 x 50 mm) posts at 5ft. (1.5 m) centres, covered with film by battening at the top and bottom, the bottom edge being buried. A polypropylene net of 30 in. (760 mm) mesh covered the roof and was fixed to the valley gutters with hook bolts. 30 in (760 mm) dia. propeller fans of 9000 $ft.^3/min$ (280 m^3/min) were used for ventilation, one per bay, giving a ventilation rate of approx. 2 $ft.^3/ft^2/min$ (0.6 $m^3/m^2/min$). This has been found adequate if the house is damped down hourly.

An inflation pressure of 0.16 in. (4 mm) w.g. is used, which is increased to 0.3 - 0.5 in (8 - 12 mm) in high wind conditions. The structure has successfully weathered wind of 36 knots gusting to 45 knots but failure has occurred at windspeeds in excess of this. To achieve greater reliability would require thicker film and a stronger and more expensive structure. A similar structure is being evaluated in Worcestershire. Crops grown successfully include Spring lettuce, self-blanching celery, peppers, aubergines, tomatoes and cucumbers. It is concluded that it is possible to construct lamp protected cragging areas using air inflated structures with high-tensile wire stressing. Such structures will withstand average weather conditions but will fail in gale-force winds.

It has been proved that the atmospheric conditions aimed at can be achieved in all temperature and weather conditions and that crops grow well. An electronic method of linking heating and ventilation to humidity will ensure ideal conditions.

FULL-SCALE GLASSHOUSE WIND LOAD MEASUREMENTS

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Efficient structural design can only be attained if an adequate knowledge exists of the loads to which the structure will be subjected. Of the major loads on glasshouses - snow, crop and wind - the last is most poorly defined at present. Because of the nature of recurrence of strong winds some uncertainty in estimating maximum wind loads is inevitable. The aerodynamic aspects of a building's response to known winds are also poorly defined but are however amenable to experimental determination.

During periods of strong winds measurements have been taken on a number of glasshouses of the free stream wind pressure and direction together with the resulting pressures at 48 points distributed over each house. These data have been used to derive pressure coefficients, which relate wind loads to wind pressures, for the various glasshouse surfaces. Accurate values of pressure coefficients allow design loads to be calculated using design wind speeds predicted from meteorological records.

The instrumentation for the experimental work is described together with the method of data analysis and preliminary results are presented.

TYPE AND ORIENTATION OF GLASSHOUSE STRUCTURES

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Ever since commercial glasshouses have been supported by a metal superstructure there has been a difference of opinion between growers who have either favoured a multispan structure of Dutch origin or the more expensive clear, widespan type preferred in Denmark. In 1969 four ¼-acre houses (0.1 ha) were erected at Efford Experimental Horticulture Station, Lymington, Hampshire, to determine the most efficient type of glasshouse for crop production and assess the type of house which can be managed at the lowest cost. In addition, detailed total solar radiation measurements were taken in each house and compared with the outside.

The four houses are:

1. 10' 6" (3.2 m) bay Venlo type multispan 105 ft x 100 ft (32 m x 31 m) orientated North-South
2. Identical structure to 1 but orientated East-West
3. Clearspan of conventional design 180 x 65 ft (55 x 20 m) orientated East-West
4. Clearspan with mansard shaped roof 180 x 65 ft (55 x 20 m) orientated East-West

Three tomato crops, sown in November, were grown in the years 1970-72 followed by a successional sowing of lettuce during the winter of 1972/73.

The tomato crop yields showed an initial advantage in favour of the clearspan houses. After six weeks of picking the yield from the plants in the E-W orientated multispan had caught up and by the end of the cropping season had given higher yields and financial returns than either of the clearspan houses. The plants in the N-S orientated house did not yield as well as those in the other three houses.

The lettuce cropping pattern again showed an advantage to the plants in the clearspan houses during the poorest light period in December and January. Marketable lettuce matured 14 days earlier in the two clearspan houses than those in the N-S multispan house and 7 days earlier than those in the E-W multispan. There were no differences in the date of maturity in the four houses after the spring equinox.

P.T.O.

Solar radiation measurements have correlated well with crop response. In overcast conditions there was very little difference between the four houses at any time during the year. In bright conditions the clearspan houses transmitted more light during the winter period than either of the multispan houses. In the period March-September the E-W orientated multispan gave a higher light transmission than N-S orientated multispan or the clearspan houses.

STANDARDISATION OF DESIGNS AND EQUIPMENT

by K. C. Cokeley and E. T. Wall
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Growers, and their Advisers, are faced with a bewildering array of basic equipment from which to choose when planning to build or re-build a property. If the choice is restricted to an individual country the range is quite wide but if the choice is open (e.g. within the E.E.C. for a European grower) the range is immense.

The majority of growers naturally want the best buy within the confines of their personal financial position and expect help from their Advisers in making a choice. The Advisers' knowledge of the equipment available is normally limited. It is limited not only in the sense that it would tend to be restricted to certain manufacturers, probably within their own particular country, but also in the parameters which are required to establish the 'best buy'. These parameters would be installed initial cost, overall efficiency, normal life expectancy, annual maintenance costs and availability of spares. It is fair to say that it is only the installed initial cost that is generally known. Advisers with long experience may have knowledge of other parameters for particular items of equipment but today's rapid changes (very often these changes appear to occur for competitive reasons between manufacturers rather than better service to the customer) tend to ensure that long experience is never obtained.

The concept to be proposed therefore is that there is a need for equipment standardisation within the growing industry in order to ensure that good basic designs are available at competitive prices. It is further suggested that such standardisation is necessary if future maintenance cost and labour requirements are to be reduced to a minimum and future labour saving machines are to be quickly and widely introduced.

AN INFLATED PLASTICS ROOF FOR A MULTISPAN GREENHOUSE

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A greenhouse incorporating a double-layer inflated roof offers the possibility of worthwhile fuel saving, minimum loss of light due to structural members, easy access and such a structure is readily fan-ventilated. Against these advantages must be set the problems of large forces in the structural members, loss of light reflected by the second plastics film and the difficulty of handling large areas of film plastic during construction or re-cladding.

Consideration is given to the forces existing in curved films and in the supporting structure, in relation to weather and crop loads. Experimental forms of inflated roof greenhouse are described and some results quoted for heat loss and light transmission.

ROOT TEMPERATURE AND GLASSHOUSE TOMATO PRODUCTION

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LITTLEHAMPTON, ENGLAND

Equipment will be described for controlling root temperature in controlled environment cabinets. The influence of root temperature on tomato growth in controlled environment cabinets will be discussed. A cheap method of controlling root temperature in commercial crops of glasshouse tomatoes will be described.

A SET OF REFRIGERATED GREENHOUSES FOR CROP ENVIRONMENT RESEARCH

L.G. MORRIS & N. LEVAV, VOLCANI CENTRE, BEL DAGAN, ISRAEL.

The plans for these greenhouses and the philosophy of their use for crop research were described at the I.S.H.S. Symposium "Greenhouse Climate : Evaluation of Research Methods", Naaldwijk, May 1971.

This paper will give further information on the design and construction of these greenhouses.