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THE PHYTOTRON OF THE INSTITUTE FOR BIOLOGICAL AND CHEMICAL RESEARCH ON FIELD CROPS AND HERBAGE AT WAGENINGEN

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INTRODUCTION

There is an increasing tendency in the Netherlands to extend the fundamental basis of agricultural research. Sciences like genetics and soil physics have for a long period been in close contact with agriculture, but only recently plant physiologists have begun to collaborate with agronomists in order to ensure a better understanding of the way in which separate factors may influence growth and development.

After WENT (1949) had demonstrated the possibilities of his phytotron, the importance of such an installation was recognized in several other countries. In the Netherlands the phytotron of the Institute of Horticultural Plant Breeding was put into service in 1953 (BRAAK and SMEETS, 1956) and at the same time the foundations were laid for the two buildings of the Institute for Biological and Chemical Research on Field Crops and Herbage. This institute was primarily designed for more fundamental research in agriculture and it now has the following facilities:

1. A series of seven glasshouses in which the temperature and the relative humidity can be controlled.
2. A separate series of six completely air-conditioned growth rooms [1]) with different artificial light sources.
3. A number of cold-storage rooms.
4. A phytotron, consisting of three glasshouses and six growth rooms.

The glasshouses and rooms mentioned under 1, 2 and 3 are primarily designed for arable crops; the phytotron will be mainly used for investigations of herbage plants.

The phytotron has not been in use for long and, therefore, only a description of the general lay-out and the design of growth rooms and glasshouses will be given here. It is intended to give a critical survey of the performances of the installation in a subsequent article.

DESCRIPTION OF THE PHYTOTRON

General layout

The installation consists of three air-conditioned glasshouses and six growth rooms with artificial illumination. The layout (Fig. 1)

[1]) In this article the definitions given by HUDSON (1957) will be used throughout.

differs somewhat from that used by WENT (1957) and from the one described by BRAAK and SMEETS (1956). In these two phytotrons the glasshouses and the growth rooms are in two parallel rows with a wide corridor (atrium) in between. This, certainly, is the best arrangement to connect a number of glasshouses and growth rooms. Unfortunately, the phytotron described here had to be built as part of the chemical laboratory, and this explains the rather peculiar arrangement of glasshouses and rooms.

The plants in the phytotron should be kept free from pests and diseases. This, of course, implies that both the incoming fresh air

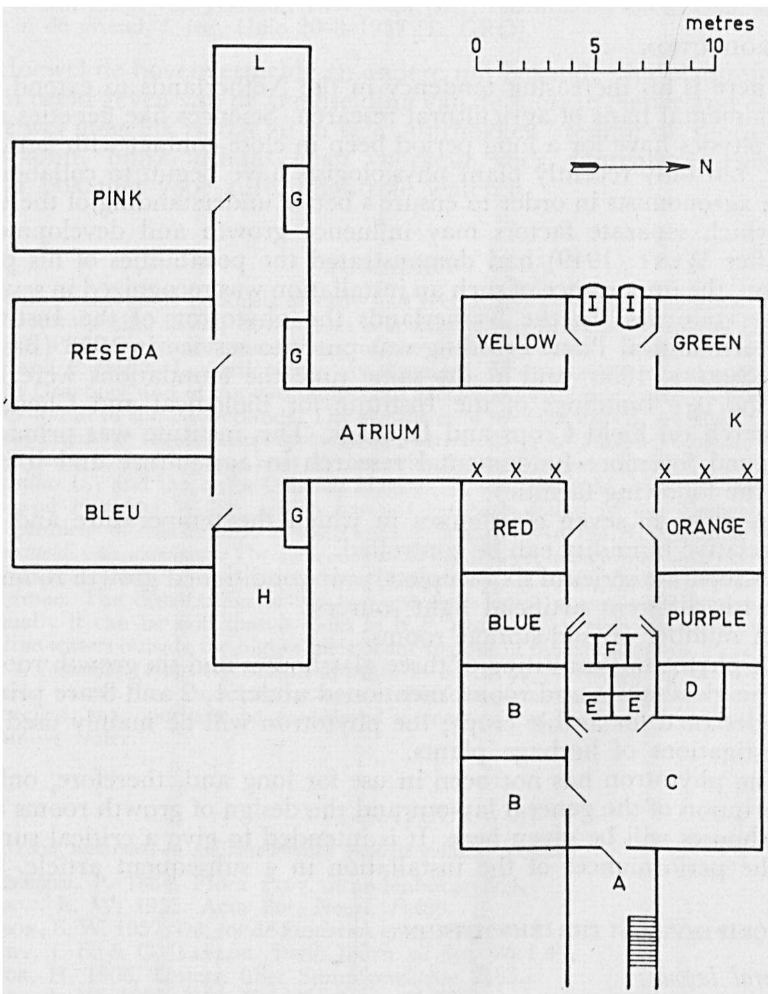

Fig. 1. General lay out of the phytotron. A, corridor with staircase to basement; B, sitting room; C, laboratory; D, weighing room; E, entrance to phytotron proper; F, lavatory; G, air conditioning duct for glasshouse; H, machine room for glasshouses; I, sterilizing unit; K, photography room; L, potting room; x, tap for nutrient solution.

and plants, pots, soil and gravel have to be freed from adhering living organisms. Also several precautions are essential for the personnel working in the unit (see below).

The phytotron can only be entered at E (Fig. 1). Both of these entrance rooms are provided with two ultraviolet lamps, which remain turned on as long as nobody is in the rooms. Persons may take a shower here, but *must* wash hands and face, change their upper clothes and shoes, and cover their hair before entering the phytotron.

Just on the opposite side of the entrance is a sterilizer (I), which consists of two separate containers for sterilizing pots, sand, soil, gravel etc. The containers are cylindrical, 1.30 m long, with a diameter of 0.86 m. They can be opened either from the inside or from the outside of the building. A separate steam generator can produce 40 kg steam per hour. Sterilization is carried out at a pressure of 2 kg/cm^2 (= 120° C). The time of sterilizing depends on the material in the container. The inner door is provided with a valve to permit the entrance of air after sterilization, thus avoiding a vacuum in the container after the steam supply is cut off. To avoid the entrance of steam into the atrium, the inner door is opened after the temperature has dropped to about room temperature.

Ideally plants are grown in the phytotron from decontaminated seeds; in cases where mature plants have to be brought in they are sprayed with parathion or a similar agent and put under regular control for some time.

A description of the glasshouses and the growth rooms and filter installations are given below.

The glasshouses

The glasshouses are situated at the south side of the building. They are of the usual shape, and each has a floor area of 8 x 4 metres The wooden glazing bars of the roof are 75 cm apart; by using hammered glass, shadows of bars and other opaque subjects are avoided. The light intensity inside the glasshouse is about 76 % of that outside (measured on a day with overcast sky). There are no fixed benches or tables; all plants are placed on trolleys.

The lowest temperature that can be reached, varies with the glasshouse and the time of the year. During summer temperatures of 25, 20 and 15° C can be maintained, provided that the outside temperature does not rise above 25° C. This temperature is reached in Wageningen only 24 days a year on the average. During winter the temperatures can be kept at 20, 15 and 10° C when the outdoor temperature is not lower than — 10° C.

As in WENT's system (1957), both the glasshouses and the growth rooms are designated by means of different colours (Fig. 1, Table I). For the growth rooms the spectral colours used range from red (warmest room) to purple (coldest room). For the glasshouses three colours are also used running from reddish to bluish, thus using the colour temperature association for both glasshouses and rooms. (Bleu is a Dutch word for light blue.)

In the two glasshouses with the higher temperatures the cooling is accomplished by means of well water flowing through a cooler in the air circulation system (Fig. 2b and below); in the third glasshouse artificial cooling with freon is used, the air passing through a similar type of cooler.

The air temperature in the glasshouses can also be kept down by spraying the roof with well water. This is accomplished by means of two plastic tubes, which both run alongside the ridge of the roof and bend down at its southern end. In this manner both the roof and the vertical end wall can be sprayed with water. The water layer thus formed is only a few millimetres thick, and does not filter out much of the infra red radiation, but keeps the glass cool. It has already been proved that this system of roof spraying is fairly effective (SPOELSTRA, 1957).

As water from a well is available in unlimited quantities, the water runs into the drains after having passed the coolers or the sprayers. At first it was intended to use the same water for the roof spray and the cooler, but its iron content turned out to be so high that iron was precipitated on the glass. Fortunately water of a lower iron content is present in another soil layer, but the capacity of this layer is much less, so that now two separate wells are used; one for the coolers, the other for the roof spray.

The three glasshouses are heated by means of radiators connected to the normal warm-water heating system of the building. These radiators are also placed in the air-circulation system (Fig. 2b).

Humidifying the air is possible by means of water sprays in the air-circulation system, just where the air enters the glasshouse (Fig. 2c). With rather fine nozzles and a high pressure (6 atm) a very fine mist is formed. When the humidity needs not to be kept constant, the humidifying system can be used as an additional cooling system on very hot days.

As a glasshouse is not insulated from its surroundings, there are usually rather long periods during which it has either to be cooled or to be heated, depending on the energy entering or leaving the glasshouse. Therefore the temperature is regulated by two contact thermometers instead of one. Both are mounted on a small panel suspended in the greenhouse and facing north. These regulators can be set at the desired temperature; one operates the pump in the well water line, the other a motor valve in the heating system, which, in turn, operates a pump.

The relative humidity is regulated with a Honeywell humidistat mounted on the same panel as the thermoregulators. It operates a valve in the water spray line. It is not possible to dry the air and therefore occasionally the humidity may exceed the desired level. Thus, when the influence of relative humidity on plant growth is tested, experiments have to be carried out in the growth rooms. The purpose of the installation is mainly to prevent a very low humidity of the entering air, and to cool the air on very hot days. It is not possible to control the relative humidity with a wet bulb thermoregulator,

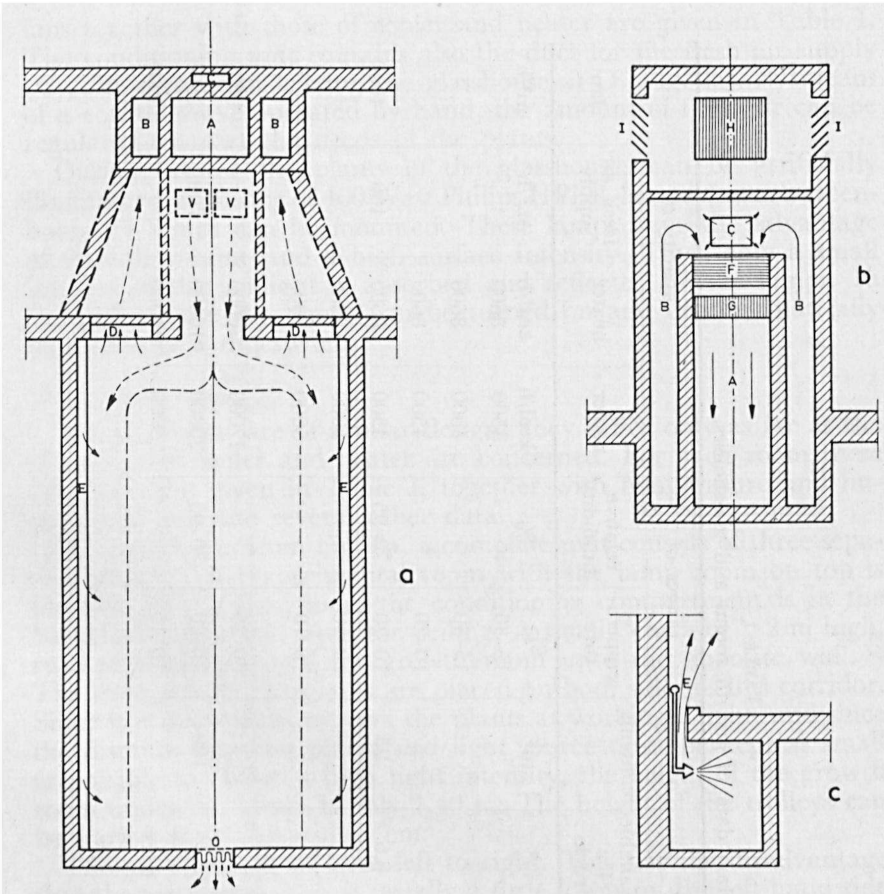

Fig. 2. a. Air-circulation system in glasshouse; b. Cross section through air-conditioning system (G, Fig. 1); c. Air-supply duct with water spray. A, air-supply duct with heater (F) and cooler (G); B, duct leading from glasshouse to conditioning apparatus; C, fresh air supply duct; D, opening for air leaving the glasshouse; E, longitudinal slit for air entering the glasshouse; H, cooler for the atrium; I, dampers to regulate the atrium cooling; V, fan.

as is done in the growth rooms, since the glasshouse temperature can only be kept within fairly wide limits.

The air is circulated by means of two fans in the air duct (V, Fig. 2a). Air is blown into the glasshouse through two long and narrow slits in the floor alongside the longer walls (E). There are two openings (D) at either side of the door, just above the floor by which the air leaves the glasshouse and enters a channel which runs below the corridor floor from the glasshouse to the conditioning unit. It is then drawn through a cooler (G) and a heater (F) after which it passes again through a channel under the corridor floor. This channel splits up into two ducts leading to the long slits in the floor in which the nozzles for humidifying are mounted (Fig. 2c). The capacity of the

TABLE I

Main data of growth rooms and glasshouses.

nr.	colour indication	surface		contents	ranges of		capacity of			
		of floor	available for trucks		temperature	relative humidity	cooler	heater	fresh air supply	fan
		m²	m²	m²	°C	%	kcal/h	kcal/h	m²/h	m²/h
1	red				15–30		4500	8600		
2	orange . . .				15–30		4500	8600		
3	yellow				10–20		4500	8600		
4	green	15.7	8.6	25	10–20	70–95	4500	8600	400	4000
5	blue				0–10		5000	5600		
6	purple				0–10		5000	5600		
7	pink				20–25		17000	20000		9000
8	reseda	32.0	15.1	100	15–20	70–95	20000	16000	700	12600
9	bleu				10–15		25000	10000		9000

fans together with those of cooler and heater are given in Table I. The conditioning unit contains also the duct for the fresh air supply (C), the surplus air leaving the glasshouse at O (Fig. 2a). By means of a control valve operated by hand, the amount of fresh air can be regulated to meet the needs of the plants.

During winter the plants in the glasshouses can be artificially illuminated by means of 400 Watt Philips HPLR-lamps. In each greenhouse 24 lamps can be mounted. These lamps have the advantage of a small volume and a high surface intensity. Thus, only a small fraction of the sunlight is absorbed and reflected by the lamps. In each glasshouse the lamps can be turned on and off automatically by means of a timeswitch.

The growth rooms

The six rooms are of similar design; they differ only as far as the capacities of cooler and heater are concerned. For each room these capacities are given in Table I, together with temperature and humidity ranges and several other data.

As can be seen from Fig. 3a, a complete unit consists of three separate rooms. The experimental room with the lamp room on top is situated on the first floor; the conditioning compartment is in the basement, suspended from the ceiling. A small "corridor", 2 m high, runs from the door of the growth room unto the opposite wall. [1]) The trolleys with the plants are placed on both sides of this corridor. Since it is convenient to have the plants at working height, and since the distance between plants and light source must be kept as small as possible to obtain a high light intensity, the height of the growth room under the lamps is only 1.40 m. The height of the trolleys can be varied from 70 to 110 cm.

The air stream goes from left to right. This has the disadvantage that the air temperature is usually a little lower on the left hand side than on the right hand side, and consequently the relative humidity a little higher. As the light intensity and wind velocity also vary throughout the room, the position of the trolleys with the plants is changed every day.

The growth room and the conditioning room are insulated by means of a layer of cork. The glass panels beneath the lamps consist of two layers of glass with dry air in between (so called thermopane).

The temperature in each room is regulated by means of two contact thermometers. When the temperature becomes too high, one of these starts the compressor of the cooling machine; when the temperature becomes too low, the other thermometer starts the electrical heater. By using two thermometers instead of one, it is possible to establish a temperature interval in which neither the cooler nor the heater works. This saves considerably on the operating costs of the rooms. When the lamps are not turned on, there are very small temperature differences at different places in the room. These differences are

[1]) To avoid confusion, the corridor which interconnects rooms and glasshouses will be called atrium (WENT, 1957).

about ½° C and it is obvious that with these differences in temperature a difference of 0.2° C between the contact thermometers can easily be accepted. When the lamps are turned on the temperature difference between the incoming and outgoing air increases somewhat. It is only when the room temperature is 10° C or less that the difference may exceed 2° C. The temperature differences around the plants are much smaller and never exceed 1° C, except for a very thin air layer underneath the glass panel.

The relative humidity is regulated by means of wet-bulb contact thermometers. When the relative humidity is below the preset value, one of these operates the water sprays; when it is above it, the other thermometer operates the compressor of the cooling machine in order to dry the air by cooling it. As a consequence, the capacity of the heater has to exceed that of the cooler, since otherwise it would not be possible to keep the room at the required temperature.

Apart from these four thermometers there are two other contact thermometers which operate the alarm system. One of these is set 1° C higher than the required temperature, the other one 1° C lower. As soon as the temperature exceeds this range, a claxon is operated during working hours, and a bell in the house of the chief gardener out of working hours. By means of indicator lights on the control panels the cause can easily be traced.

The same system is used in the glasshouses, but here the alarm system works when the temperature is more than 5° C above or below the set value. In case electricity mains fail, a set of batteries automatically delivers the power for the alarm system. A standby generator to keep the whole installation working is not available, so that the plants will have to be removed from the glasshouses if the electricity should fail during bright days. Since a prolonged failure of electricity occurs only occasionally and bright days are not very frequent in the Dutch climate, the chance that both would occur at the same time is rather low.

The lamp room can be entered through a small door in the atrium, just above the entrance to the growth room. The lamps are Philips 400 Watt HPL lamps, i.e. a high pressure mercury vapour lamp, in which the ultra-violet spectral lines below 3000 Å are transformed into visible light by means of a glass bulb covered on the inside with a fluorescent paint. Besides the visible mercury lines this lamp gives a continuous spectrum with a maximum around 6600 Å. The plants grow much better under these lamps than under the normal mercury vapour lamps, since the effect of the rather large amount of near infra-red radiation on plant elongation is compensated by a high amount of red radiation (WASSINK *et al.*, 1950).

Six of these lamps are mounted together on a frame (H, Fig. 3a). The position of the lamps on the frame can be changed in two directions to ensure the best distribution of the light in the growth room below. The frame is covered with a metal sheet, painted dull white on its lower side to reflect and disperse the light, and black on the upper side to dissipate the heat into the lamp room. Two frames on

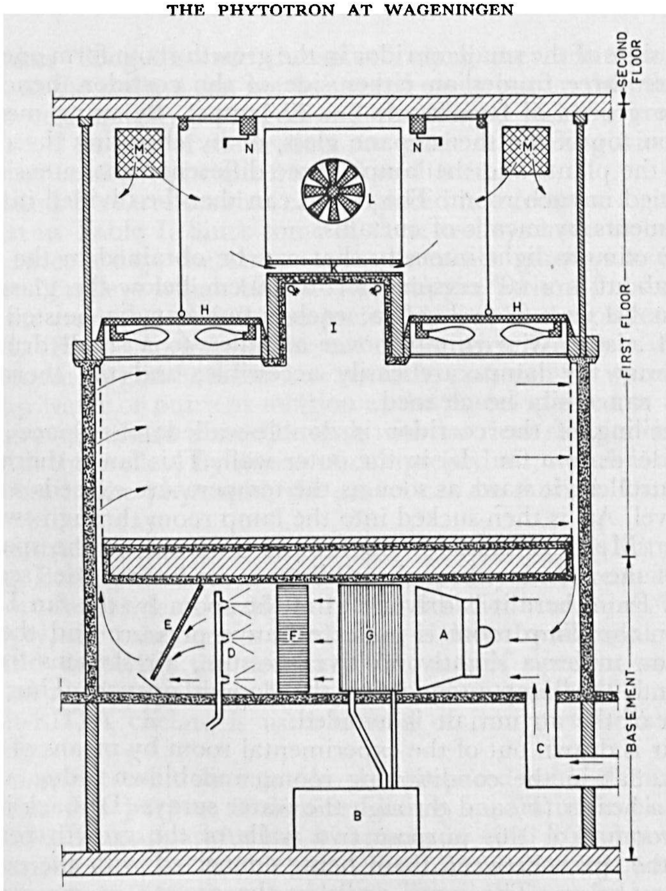

Fig. 3a

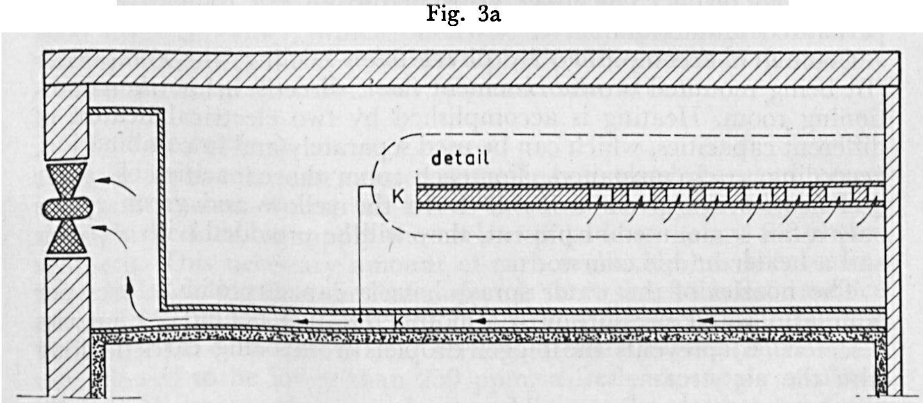

Fig. 3b

Fig. 3. a. Cross section through a growth room; b. Removal of the warm air from the lamp room. A, fan; B, freon compressor; C, fresh air supply duct; D, water spray; E, screen; F, heater; G, cooler; H, lamp frame; I, corridor; K, double-walled ceiling in the corridor; L, fan; M, opening through which fresh air enters the lamp room; N, winding drum for lamp frame.

opposite sides of the small corridor in the growth room form one group. There are three frames on either side of the corridor, hence there are three groups of two frames (= 12 lamps). By using mesh wire screens on top of the thermopane glass, or by changing the distance between the plants and the lamps, three different light intensities can be obtained in each room. The rooms can then be divided into three compartments by means of curtains.

The maximum light intensity that can be obtained in the growth room is about 8×10^5 ergs/cm^2 sec. at 30 cm below the glass panel.

As can be seen from Fig. 3a, each frame can be hoisted up by means of a steel wire running over a pulley to a small drum (N). In this way the lamps are easily accessible, and the thermopane windows can easily be cleaned.

The ceiling of the corridor is double-walled; the space (K) in between leads to a fan (L) in the outer wall. This fan is thermostatically controlled; it starts as soon as the temperature exceeds a certain preset level. Air is then sucked into the lamp room through two other openings (M) in the outer wall. From here it enters the space (K) on top of the corridor through openings in its lateral side (see detail Fig. 3b). From here it is driven out of the room by the fan L. Since the air in the lamp room is under negative pressure and the air in the atrium under a slightly positive pressure, air streams from the atrium into the lamp room when the door is opened. Thus contamination of the atrium air is avoided.

The air is drawn out of the experimental room by means of the fan (A) (Fig. 3a) in the conditioning room, and blown along a cooler (G) and a heater (F) and through the water sprays (D) back into the growth room. For this purpose two walls of the growth room are double, the space between them being connected with the conditioning room below. The inner walls in the growth rooms consist of perforated aluminium.

Cooling is accomplished by direct freon cooling, the compressor (B) being mounted on the basement floor, directly below the conditioning room. Heating is accomplished by two electrical heaters of different capacities, which can be used separately and in combination, according to circumstances. For each room the capacities of cooler and heaters are given in Table I. In the yellow and green rooms only a fan is mounted at present, they will be provided with a cooler and a heater in due course.

The nozzles of the water sprays have a capacity of 5.2 litres per hour at a water pressure of 6 atmospheres. Just behind the nozzles a screen (E) prevents the bigger droplets from being carried along with the air stream.

The atrium

The atrium serves mainly for potting, watering and transport purposes. The pots with plants are invariably placed on trolleys to facilitate transport. These trolleys have a table surface of 60×120 cm, and can be moved in all directions since they have four castors.

This makes "long distance transport" along the atrium somewhat difficult, as the trolleys can not be steered easily but on the other hand they are very quickly arranged and rearranged inside a room or a glasshouse. The tops of the trolleys are made of a strong wire netting and are adjustable in height from 70 to 110 cm.

The number of trolleys that can be placed in a room or a glasshouse are given in Table I. Since some of these trolleys have to be moved at least twice a day, the atrium must be rather spacious to facilitate transport. Trolleys which have to wait in the atrium for some time during the transport period, are preferably put in the places marked K and L (Fig. 1) to have them out of the way. On their way from growth room to glasshouse or *vice versa* the pots can be watered with either tap water or nutrient solution at the places marked × (Fig. 1). Where gravel culture is used, a tank with nutrient solution is carried along with the trolley. By means of compressed air, which is available everywhere in the phytotron, the gravel can be flushed. Usually this is done twice a day.

The nutrient solution is stored in two tanks in the attic of the building. Both tanks have a 2000 litres capacity and are coated with plastic on the inside. Usually only one tank is in use; just before it gets empty, the other one is filled. This is done by filling it with tap water and dissolving the necessary amounts of nutrient salts. The Hoagland nutrient solution is used throughout, with A–Z addition, but iron-EDTA chelate is used instead of iron tartrate and given separately.

The nutrient solution can also be prepared with demineralised water. For this purpose a demineralizing apparatus is placed also in the attic. This apparatus has a capacity of 4000 litres between two regenerations, and it is able to deliver demineralized water at a maximal rate of 2000 litres per hour. The water can be stored in a 1000 litres container, which otherwise is the same as the nutrient solution tanks. From this container a plastic tube goes to both nutrient solution tanks, to the laboratory (C) and to the atrium.

The fresh air supply

As the air circulates in a closed system in both glasshouses and rooms, a certain amount of fresh air has to be introduced, especially during the light periods, to supply the carbon dioxide necessary for photosynthesis. This necessary amount of carbon dioxide has been calculated by assuming that the leaf surface is three times the floor surface covered by the plants, and that the carbon dioxide consumption is 100 mm^3 for each cm^2 of leaf surface. If the CO_2-concentration is not allowed to be lower than 250 ppm, a fresh air supply of about 20 times the room volume per hour and 8 times the glasshouse volume per hour is required.

The amount of dry matter produced in a given time under artificial illumination with a sufficient CO_2-supply has also been used as a basis for calculation. Using the data of a preliminary experiment, a rate of 6 times the room volume per hour was obtained.

Taking into account that the air circulation system is not completely airtight, and that a rate of 20 times the room volume per hour is the highest possible value, the actual rate has been fixed at 16 times the room volume per hour and 7 times the glasshouse volume per hour.

The phytotron is only partly occupied by plants to leave place for rearrangements, and it is not necessary to supply all the rooms and the glasshouses with the maximum amount of fresh air at the same time. Therefore the necessary amount of fresh air has been estimated on 3500 m^3 per hour instead of the total amount of 5000 m^3.

The way in which this amount of fresh air is introduced into the phytotron can be seen on Fig. 4. A big centrifugal fan (A) of the required capacity drives outside air along a heater (F), a cooler (G) and a filter (B) in which the air is decontaminated as far as possible.

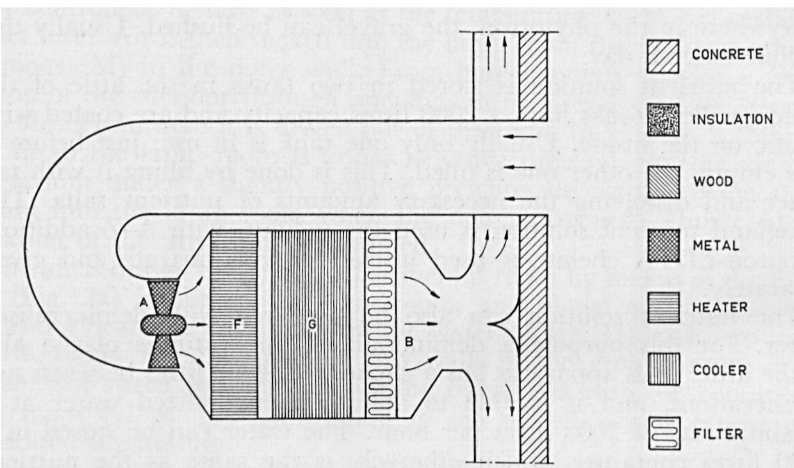

Fig. 4. Fresh-air supply duct with preconditioning and filter apparatus. A, fan; B, filter; F, heater; G, "Raschig" cooler.

The heater consists of a hot water radiator connected to the central heating system of the building. The cooler is a so called "Raschig"-cooler, in which a stream of water runs over porous earthenware rings in a direction perpendicular to the air stream. The temperature of the well water used here is about 9° C during winter time and about 12° C in the summer. The cooler is used continuously to free the incoming air of the greater part of its contaminants, the heater is used only in winter time when the outside air temperature is too low. The heater is thermostatically controlled; its capacity is given in Table I.

The filter consists of several layers of very fine fabric wetted with germisan to kill all living organisms which are filtered out of the air stream.

After having passed the filter the air is led into two main supply ducts leading to the rooms, the glasshouses and the atrium. The place of entrance of fresh air into the air-circulation system can be seen from the Figures 2b and 3a (C).

The whole fresh-air supply system is mounted in the basement. In the ducts leading to the separate rooms and glasshouses a calibrated valve can be set at the amount of fresh air that is needed. Since the amount of air entering a room will depend also on the position of the valves in the other supply ducts, it is not easy to keep the supply at exactly the same rate for an extended period of time. However, it may be assumed that the carbon dioxide supply will in most cases be more than sufficient, so that a careful regulation of the fresh air supply is not necessary.

ACKNOWLEDGEMENTS

The construction of a complex installation like this phytotron is certainly not an easy task to accomplice. I deeply appreciate the constant interest of everybody concerned in its construction.

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SUMMARY

A detailed description is given of the phytotron of the Institute for Biological and Chemical Research on Field Crops and Herbage as far as general planning and the air conditioning of growth rooms and glasshouses is concerned. The main data are given in Table I; (the building costs can be found in the appendix.)

The performances of the phytotron will be dealt with in a subsequent article.

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