Proceedings of the Iowa Academy of Science

Volume 68 | Annual Issue Article 7

1961

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Recommended Citation

Foley, D. C. and Horton, J. C. (1961) "The Design of Inexpensive Plant Growth Chambers," *Proceedings of the Iowa Academy of Science, 68(1),* 60-66.
Available at: https://scholarworks.uni.edu/pias/vol68/iss1/7

The Design of Inexpensive Plant Growth Chambers[1]

D. C. FOLEY AND J. C. HORTON[2]

Abstract. Inexpensive plant growth chambers can be built from standard components manufactured for other purposes. A working unit 6′ x 6′ in size assembled from a refrigerated meat storage box and general line fluorescent lamps is described. Light intensities up to 1800 ft-c at one foot and temperatures, with full light load, down to 8° C can be maintained.

The control of environment provided by plant growth chambers can be utilized by workers in all areas of botanical research. The flexibility and low cost of small chambers of the type described here are advantages not found in large rooms or units. Although cost per square foot may be greater in units of small size, multiple installations are more flexible than one large unit. This chamber was constructed primarily for routine experimentation and production of classroom material (Fig. 1).

A primary consideration in design of growth facilities is the ultimate use. Reasonable control of static conditions can be obtained without excessive costs while exact duplication of climatic conditions either cannot be achieved in small units, or costly equipment is required. Control or maintenance of light and temperature within reasonable limits is sufficient for a large portion of plant growth research. This achievement alone is a considerable improvement over the standard greenhouse installation.

SHELL

The first step in design is selection of a basic box or shell. Wood, aluminum, painted steel, or similar materials may be used, but the ease of working and insulation value make exterior grade plywood a common choice. This plywood has excellent weathering characteristics and often outlasts a similar metal structure. The box must be well insulated with a material which will not settle or absorb moisture; fiber glass or styra-foam meets these requirements. The interior surface of the chamber should have high reflectance values to scatter and diffuse the light. Baked, white enamel paint has proved satisfactory, but

[1] Journal Paper No. J-4119 of the Iowa Agricultural and Home Economics Experiment Station, Ames, Iowa. Project No. 1140.
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highly reflective aluminum adhesive papers or metal are excellent alternatives.

Small rooms can be easily adapted to growth chambers and have been used frequently. It is often more convenient to purchase commercial units with standard components such as are used for meat or vegetable storage cases. Prices for such units depend upon size, insulation and modifications required. The chamber herein described was purchased as an insulated 6′ x 6′ shell with a one-half ton compressor and evaporator for less than $900.

Lights

Light bank design is a most important step in construction. Many different illuminating devices are available, and specifica-

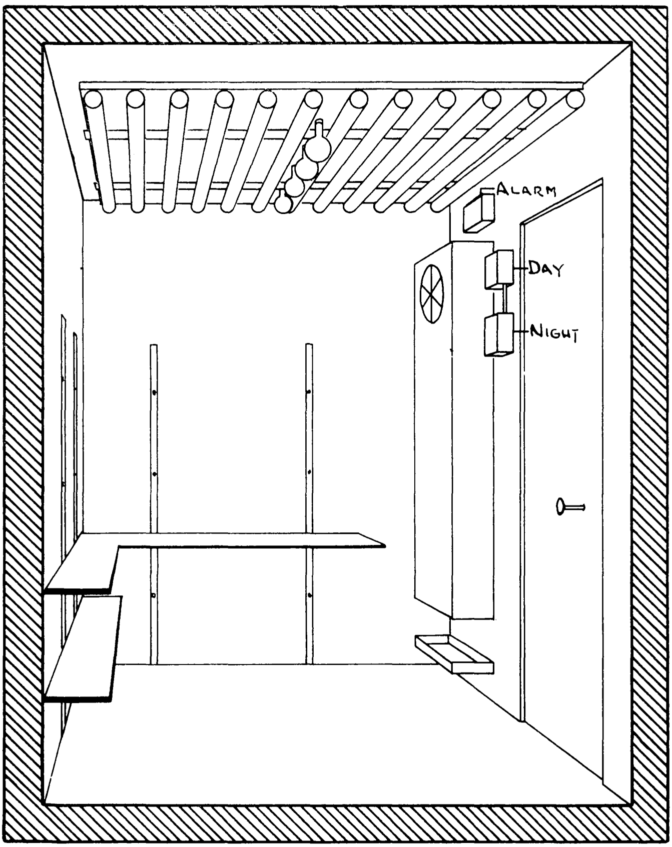

Figure 1. Diagram of internal layout of plant growth chamber (6' x 6') in Botany Hall, Iowa State University, Ames.

tions and costs can be obtained from the manufacturers. The following are typical examples of such devices:

1. Fluorescent Lights

   a. General line—Lamps which use starters and are 1″ to 2⅛″ in diameter with a range of 4 to 105 watts, outputs per bulb of 75 to 7200 lumens, and efficiencies of 20 to 65 lumens per watt. Emission is maximum between 4500 and 6000 A and decreases rapidly above and below this range.

   b. Slim line—Instant start lamps about 1″ in diameter, and approximately equal in efficiency and spectral energy distribution to the general line. Advantages are ability to place more bulbs in a given space, and extra loading to increase bulb output.

   c. VHO, Power Groove—Instant start bulbs with an efficiency of over 70 lumens per watt, and approximately the same spectral energy distribution as other fluorescent lamps.

   d. Mercury vapor—Lamp efficiency is 56 lumens per watt with high loading per bulb at increased temperatures, and usually used as single point source of light. A 1,000 watt light bulb delivers about 62,000 lumens with spectral distribution as peaks at approximately 5,500 and 5,800 A with lower amounts in the other areas.

2. Incandescent

   A wide range of wattage and shapes is available but emission is only 16 to 18 lumens per watt. Filament radiation is: light about 20 per cent, infrared about 72 per cent. Spectral energy distribution is primarily between 5,000 and 7,600 A, chief advantage is low cost.

3. Sodium—A narrow spectral range (5,889–5,895 A) but highly efficient lamp (100 lumens per watt). Used as single lamps and require a long period of warm-up.

In general, maximum light intensity available is desired and design considerations must weigh cost against light intensity. A general rule is the longer the fluorescent tube which can be used, the cheaper the cost per lumen. Additional considerations include bulb replacement, starter replacement and life of tubes. Output of fluorescent tubes decreases rapidly during the first 100 hours and slowly during the remainder of bulb life of about 7,500 hours. In the unit described, bulbs are replaced about once a year.

General line fluorescent bulbs, 60″, 90 watt, T12, fit the internal dimensions of a 6′ x 6′ chamber. Only 12 were used although space for more was available. In other designs, the number of bulbs was increased with a corresponding increase in light on the bench. However, crowding causes the bulbs to overheat and results in a decrease of lamp efficiency and frequent starter failure. An aluminum pan was constructed for holding wiring, starters and sockets and fastened to the ceiling in an easily demountable fashion. The ballasts were enclosed in a perforated box outside the unit to permit adequate air circulation and to prevent tampering. Thus the high heat source represented by the ballasts was removed from the interior to reduce the heat load.

Spectral energy distribution of fluorescent lights is maximum in the yellow-green region and insufficient red is available for plant growth. Consequently, a balance of fluorescent and incandescent light is required. Differences exist between types of fluorescent lamps but warm white bulbs supplemented by incandescent produce excellent plant growth. A watt ratio of 10 fluorescent to 1 incandescent is often used but Went (1957) suggests a ratio of 10:1 or 20:1 fluorescent lumens to incandescent lumens. If specific wave lengths are required, the simplest solution is use of filters, but reduced intensities result.

At the present, light intensities of 1,500 to 1,800 ft-c can be obtained for a reasonable cost, intensities to 4,000 ft-c can be obtained at moderate cost and intensities beyond 4,000 may be achieved with a sacrifice of lamp efficiency and at considerable cost. In the described chamber, twelve 90 watt fluorescent tubes produce about 1,800 ft-c at 12″ from the bulbs. This intensity decreased to approximately 1,200 ft-c after a year. It would have been possible to double the number of bulbs in the same space and realize about a 75 per cent increase in light output. This would also necessitate an increase in refrigerative capacity since the light bank is the major source of heat within the growth chamber.

Thermal barriers can be used to solve this problem of lamp temperature and heat load. The barriers do not, however, keep bulb heat from the chamber but rather allow a separate air circulation system to cool the lamps. Much of the lamp heat is radiant. The rate (R) of this energy radiation per unit area at temperature (T) is given by $R = ebT^4$. Since e is emissivity and b is a constant, the rate of energy radiated is proportional to the fourth power of the absolute temperature of the bulb. Therefore, operating the bulbs at the proper temperature reduces the amount of radiant heat by lowering the absolute temperature. Barriers cause a 10 percent decrease in light transmission and require frequent cleanings.

The choice of electrical control equipment for lights is dictated by size of the lighting system. In installations with a small number of lamps, time clocks alone will suffice. In installations where more than 14 VHO (96″) lamps are installed it is advisable to use power relays. The 12 lamps used in this unit require about 19 amperes which can be handled adequately by time clocks. Variable light levels can be obtained with electronic dimmers at additional expense and with special control equipment. A cheaper and less elegant method is to use clock controlled modules of two or more bulbs. Light levels in this chamber are achieved by using switches to place the fluorescent units on either of the two time clocks. It is thus possible to switch in successive modules of light and to obtain a fairly smooth increase in light intensity by these means (Fig. 2).

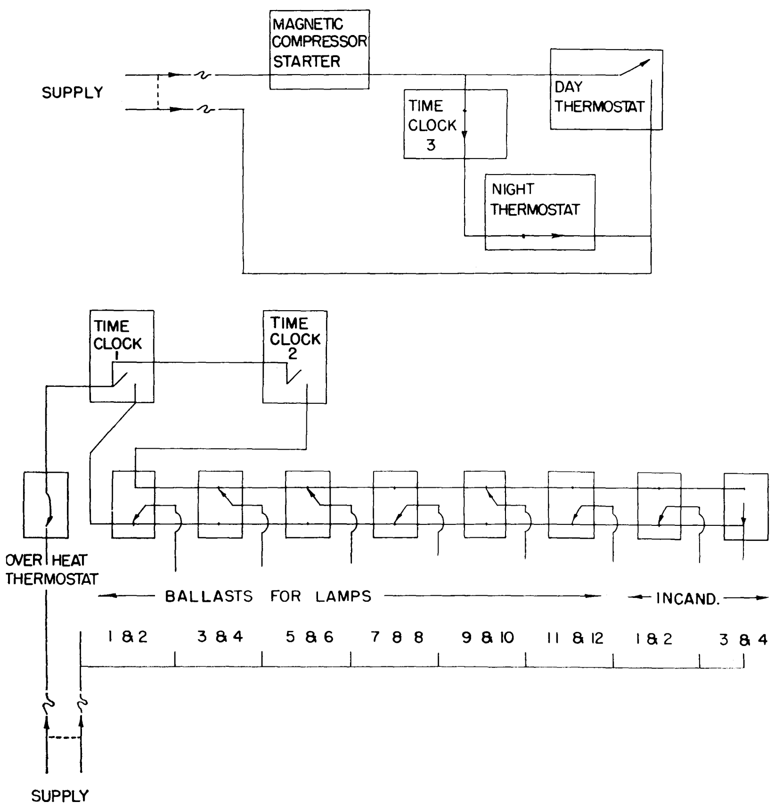

Figure 2. Wiring diagram for lights and refrigeration in plant growth chamber (6′ x 6′).

Cooling

The large quantities of heat released in the production of light and movement of the air require adequate refrigerating capacity. Essential to understanding the design of cooling requirements is knowledge that approximately 40 per cent of the heat produced by the bulbs is radiant energy. This radiant energy is converted into heat which can be removed by the refrigeration system. Since much of the conversion is at the bench, pot container, or plant leaf surface, adequate air must move across these areas to remove this heat. The energy produced by fan motors and heating coils is primarily conducted and convected heat. Preference in refrigeration units is for a hermetically sealed unit with an attached air cooled condenser or with a remote air or water cooled condenser. Many capacities are available and little servicing is required after installation. Evaporators also are available in a multiplicity of types. Many installations use an enclosed blower mullion unit with an evaporator temperature of about 40° to 45°F. In the unit described, a one-half ton compressor and condenser unit, and a one-half ton capacity blower-type evaporator coil are used. Air circulation from one evaporator is not optimum, and use of another evaporator or blower and dummy shell would correct this fault. A good balance exists between the heat load and the refrigerative capacity available, and temperatures of 45°F are possible with all lights on.

Since lights and motors generate heat, variation of chamber temperature is achieved by control of the cooling unit. Temperature control can be accomplished in three ways: intermediate heat exchange, hot gas by-pass cycling, or compressor cycling. Use of an intermediate heat exchanger permits close temperature control but is expensive and not adapted to rapid temperature changes. A hot gas by-pass cycles the refrigerant around evaporators, thus the compressor operates continuously. In this chamber, short cycling of the compressor is used wherein the compressor operates for short periods removing small aliquots of heat. This system is cheapest and easiest to use, and the overall effect is fair temperature control. The on-off compressor operation is regulated by two thermostats in parallel. Since the thermostat with the lower setting controls the compressor, inserting a time clock permits alternate operation. As many thermostats and time clocks may be wired in parallel as required for multiple operations and the lowest-set thermostat in the circuit will control the temperature. This system has the advantage of inexpensive components and has been, in our experience, trouble-free.

Platform

The supporting device for plants and plant containers must be adjustable and offer minimum resistance to air flow. A flexible arrangement was made by placing standards along the walls in which brackets could be engaged to support a bench or shelves of expanded metal. This arrangement proved very satisfactory in accommodating a wide range of bench shapes and sizes.

Additional Features

An important safety device is an over-heat thermostat placed near the ceiling to interrupt the light circuits in the event of refrigeration failure. An intermediate relay was used to break the light circuit and energize a bell. When one such failure occurred before this feature was added, the chamber temperature increased rapidly to 85°C. Although refrigeration failures are rare, this device can prevent loss of an experiment.

This chamber has been used for about three years and has proven its ability to perform under adverse conditions without serious malfunction or excessive operating expense.

The costs were:

Shell and refrigeration unit	$ 850.00
Light bank, switches, and wiring	600.00
Total	$1,450.00

Savings can be effected by using a less flexible light system or use of a wooden bench. There are approximately 25 square feet of usable surface at a cost of about $55 per square foot. This figure compares favorably with the cost of similar commercial units.

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