Chapter 14

Writing Chamber Specifications

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Introduction

There are many ways to write specifications when preparing a bid invitation or purchase contract. Each manufacturer, university, or private business has a unique method of writing them. Specifications are legally binding and, if properly written, will help prevent contractual problems after the units are put into operation. By supplying the manufacturer with all relevant information, the purchaser stands a better chance of obtaining a growth chamber that satisfies requirements.

Little has been written on specifications for growth chambers since the development of commercial growth chambers in the middle of the 20th century. One of the more complete specification guidelines was developed in 1971 by the American Institute of Biological Sciences entitled" Controlled Environment Enclosure Guidelines" (AIBS Bioinstrumentation Advisory Council, 1971). Other early publications with aids for writing specifications were prepared by Pescod et al. (1962), Downs (1975), and Tibbitts and Kozlowski (1979). A recent international workshop (Tibbitts, 1994) provided aids for lighting. Updated information on systems and controls for a broad range of enclosed facilities for plants is provided in the latest revision of the ASHRAE handbooks (ASHRAE, 1993, 1995).

There are three types of specifications—performance specifications, engineering specifications, and a combination of both. Performance specifications describe the performance expected from the unit, whereas engineering specifications describe in detail the parts to be used and the methods of assembly. Use only one type of specification when preparing a bid invitation or a purchase contract. If two types are listed, the contractor has the privilege of selecting the type that best suits his purposes.

In general, the performance specification that includes a guaranteed performance of one year or more will obtain the best operating plant growth chamber at the lowest cost.

The first items to consider are the total cost of each chamber or group of chambers, the external dimensions of the chamber, the area and height of the plant bed, the number of chambers needed for the particular experiment or plant production, and the desired location of these chambers. One or more of the standard growth chamber models may satisfy these needs without unique specifications, so obtaining current literature from the manufacturers will be helpful.

The growth chamber with the lowest cost per unit area of growing space probably will be a standard model from the assembly line. Standard sizes also can be replaced easily when they become obsolete or need major repairs. Always build flexibility into the chambers where possible because every chamber will become obsolete in time and will need to be changed. If a small part of a chamber can be changed, it will be less costly than putting in a whole new chamber. If, however, a special size or type of chamber is needed, write specifications accordingly.

The expected use of the chamber should be described briefly in the specifications. Also name the crop(s) to be grown and indicate the minimum growing area and height needed. If corn or other tall plants are to be grown, for example, specify extra chamber height. Supply a general description of the planned location of the chamber. This description should include information on the availability of air conditioning in the building, the type of electrical service (voltage, hertz, amperage, number of phases, and type of hookup), the type of water available (hot, cold, distilled, deionized, or steam), availability of compressed air or vacuum systems, and location of drains. Also provide information on the area's ceiling height, type of floors, and the width of doors, windows, and hallways through which the unit must be moved. If the chamber is to be located on an upper floor or in the basement, be sure that any doors and elevators are large enough to take the largest section of the equipment. (It is quite costly to hire a crane to lift a unit up the outside of a building and bring it through a window or a hole knocked in the wall.) If the refrigeration equipment, storage tanks, nutrient tanks, or other equipment are installed on a different floor or in a different room from the growth chambers, furnish a schematic or blueprint of the building and report the ambient temperature and humidity conditions of the location where the chamber will be operating. This general service information is not a binding part of the contract, but it will help both the user and the manufacturer avoid problems during the assembly, delivery, and operation of the chamber.

Choosing a Manufacturer

An established manufacturer probably will be the best source for obtaining a plant growth chamber. A new manufacturer, however, may have a better idea, be able to cut some manufacturing costs, or be able to service chambers locally at a lower cost than an established manufacturer could. Therefore, a new manufacturer should have a right to bid on any new chamber. Shop around for a growth chamber just as you would for any large appliance. Keep in mind, however, that a plant growth chamber contains specialized refrigeration and lighting equipment and, therefore, should be manufactured and serviced by experts.

Economics and Purchase

The lowest cost growth chambers are the standard models. Next lowest cost are those equipped with a manufacturer's standard accessories. Costs are lowered by assembly line production and by the elimination of engineering and production tooling costs associated with individual design. If standard equipment will not meet your requirements, contact manufacturers to discuss your requirements.

Overspecification

When users do not know the precise conditions with which they will be working, they often specify a greater range and tighter controls than necessary. Overspecification for growth chambers can cause high initial costs coupled with increased potential for equipment failure because "exotic" components are needed to meet the specifications. Because of the interactions between temperature and humidity, specifications involving control of both parameters result in overspecification more often than any other requirements.

Technical Requirements

Construction

The wall materials and finish should be specified. White, baked-on enamel, epoxy paint, aluminized Mylar, or other reflecting surface normally is used on the inside wall and a natural finish or an enamel on the outside walls. If the laboratory has a particular interior decoration scheme and a certain color is needed, specify that color, but realize that cost will increase significantly for reach-in growth chambers. The walls normally are made of foam or fiber glass insulation, with wood or metal framing. Foamed-in-place polyurethane has greater insulating value per inch of thickness than does fiber glass or other insulation materials.

Dimensions. When specifying the size of a growth chamber, allow adequate space around it for placement and repair. Leave space behind each unit for easy service access. This extra space will also allow room for plumbing and electric lines, working lights, and electrical service outlets for hand tools. Specify the minimum inside dimensions, which should include the length and width of the chamber floor and the height of the growing area. Also specify the length and width of the floor and the clear height of the chamber. These dimensions should be supplied for both reach-in and walk-in growth chambers.

Plant bed. Some plant beds are designed to be stationary, and others are movable. A convenient way of adjusting the growth height is desirable to compensate for a decrease in photosynthetic photon flux (PPF) or to maintain a constant distance from the top of the plant to the lamp bank. If the plant bed is stationary, the growth height variance can be obtained by using one or more movable lamp banks. The movable plant beds either use shelf brackets or are equipped with a hand crank and winch. Specify the type wanted.

Doors and seals. The seal around the door prevents leakage of light and CO_2 or other gases into or out of the chamber. It also contains the conditioned air. Specify that the seal must be opaque to light. If an inspection window is desired in the growth chamber door, so specify, but remember that the cover over the window could be opened accidentally, allowing light to reach the plants during the dark period. This problem can be effectively solved by installing 2-way mirrored glass.

Access ports. It is usually desirable to have one or more access ports in each chamber to allow instrument leads to be placed inside the chamber and to provide a means for adding water, CO_2, or other gases to the growing area. Ports must be lighttight to avoid photoperiod problems.

Barrier. The use of a barrier between the lamps and the growing area reduces the heat load from the lamps and the PPF. Some chambers employ a barrier and others do not. Each arrangement has advantages. In a chamber without a barrier, air normally flows from below the plants up through the hot lamps and back to the cooling coils. This airflow pattern ensures that the hottest air reaches the cooling coils and the heat is carried away from the chamber.

In a chamber with a barrier, two areas need cooling—the lamp back and the plant growing area. In some chambers, the refrigeration unit cools the lamp bank and the growing area. In other chambers, the refrigeration unit cools only the growing area. The lamp bank is cooled by an auxiliary system, exhausting its heat to the surrounding space or ducting to the outdoors. Because the exhaust type of design obviously requires introduction of make-up air to the lamp bank, the temperature of that air must be considered. If the make-up air temperature is above 24°C, lamp intensity will decline.

When the barrier is clean, it reduces the light transmission by about 10 percent. If it becomes dirty, as it often does, the reduction will be greater. Barriers should be easy to remove for cleaning and for replacement of lamps. For the nonbarrier type growth chambers fitted with fluorescent lamps, it will be necessary to utilize low temperature lamps when the growing area is below 10°C. Most fluorescent lamps are designed such that the optimum output is obtained when the lamp ends are approximately at 40°C. Through the use of a design internal to the fluorescent tube to assist in raising the lamp end to 40°C, lamps are available for operation over three air temperature ranges at which 90% to 100% intensity will be achieved (-12°C to +16°C, -1°C to +21°C, and 10°C to 32°C).

Floors and drains. The floor should be of galvanized metal, stainless steel, or other durable substance. If caustic chemicals will be used in the chamber, it may be desirable to specify stainless steel. For growth rooms, the available building floor may be suitable. For safety, walkways should be coated with an abrasive.

The drain for the growth chamber is normally placed in the floor. Specify a drain location that will be easy to reach so the drain can be cleaned out without removing the plants.

In a chamber where the soil will be watered by spray nozzles or individual watering tubes, it is desirable to have some way of draining away the excess water from the containers. The drain should be at least as big as that for a kitchen sink to prevent stoppage from soil or plant debris. It also should have a water-sealed trap to restrict gas flow into or out of the chamber. An external floor drain is needed in addition to the one inside. The floor around and under the chamber should slope toward this external floor drain.

Refrigeration Systems

Three main types of refrigeration systems are used in growth chambers today: direct expansion utilizing solenoid valve(s) for diverting refrigerant flow on demand of the temperature controller; direct expansion with a proportional valve and temperature controller; and secondary cooling. The first system probably costs less initially, but the second and third types are the most desirable for a growth chamber because they allow only slight temperature and humidity fluctuations inasmuch as the temperature approaches a modulated line and stays at the preset temperature.

For a small installation, the direct-expansion proportional valve system usually is the most desirable, but if there is to be a large quantity of growth chambers, a secondary cooling system via a central chiller may be desirable. In this system, one or two large compressors, which are more efficient than small compressors, are used to refrigerate a cooling medium (water and glycol) that is circulated through the building, and each chamber is connected to the supply and return lines from the central chiller.

Capacity. The capacity, or size, of the condensing unit (compressor, condenser, receiver) will be determined by such factors as radiation heat load, wall and floor area, volume, growing area temperature, and ambient temperature. Specifications should describe needed performance so the manufacturer and/or supplier can furnish the correct size. To provide the required capacity, a condensing unit that is to operate in a hot area will need different design considerations (i.e., compressor size, condenser size, motor cooling, etc.) from one that is to operate in a cool area. Therefore, the location of the condensing unit is important and should be included in the specifications. If the compressor is to be placed on the roof or outdoors, so indicate because most condensing units are not designed to operate at temperatures below 13°C or above 33°C. It must be specified when roof-top or outdoor operation is necessary to ensure that the condensing unit is designed and equipped with the necessary controls and protections for the application.

The size of the cooling coil and the capacity of the blower are important. Most refrigeration systems are designed to have an 8°C temperature difference (TD) between the air entering the coil and the air leaving the coil. This temperature difference helps remove moisture. If a high humidity is needed in the chambers, the coil must be larger than the one normally used in order to reduce the TD. Performance specifications should be written so that the manufacturer will furnish the correct coil and blower to meet the chamber's requirements. Don't try to specify the coil size or the TD because the coil provided may not operate to meet performance requirements. The material of the coil should be specified, however, because if pollutants will be used, the coil should be made of either stainless steel or epoxy-coated metal. Pollutants, such as sulfur dioxide, corrode and destroy aluminum coils.

If the lamp bank is to be cooled separately from the growth chamber's refrigeration unit, the coil sizes and the refrigeration capacity must match the heat load created by the lamps.

Standby refrigeration. If it is necessary to keep a plant growth chamber operating continuously, a standby refrigeration system should be purchased initially. The capacity of the standby system must be as large as that of the primary unit, and the refrigeration piping must be installed in parallel so that the system can be put into operation automatically by solenoid valves or manually by opening and/or closing hand valves. If an installed standby system is too expensive, have a new compressor and other refrigeration parts for a standby system in stock so that they can be installed immediately. Provision for a standby system also is important if several identical chambers are to be used at one laboratory or group of laboratories. Standby electric power generation equipment should be installed if possible. It should be sized to operate the refrigerator equipment and the low-level lighting for photoperiod control, along with electric controls, recorders, and other necessary auxiliary equipment.

Lighting

Many types of lamps are available for lighting plant growth chambers (Canham, 1966; Tibbitts, 1994). If you will need a special type of lamp or control—for example, to turn the lamps on for a few seconds in the middle of the night—this requirement should be included in your specifications. Lamp banks can be specified either by performance or by the number and types of lamps. Most manufacturers give lighting specifications in terms of number, loading, and type of lamps. When you specify a PPF, it should include the distance from the lamp bank at which it is required. Fluorescent lamps can lose up to 10% of their output during the first 100 hours of operation after which the decline is at a much slower rate. Therefore, it is helpful to require that the intensity be met with 100-hour-old lamps. Charts, curves, and tables available from lamp manufacturers provide anticipated output decline over thousands of hours. Many factors affect the output and life of lamps, such as the number and length of burning cycles.

It may be desirable to install new lamps at a later date if a better type becomes available, but no new lamps should be installed that would produce more heat than those in the original installation because the capacity of the chamber's refrigeration system probably will not be adequate. It is possible that more efficient lamps than those currently being used will be made available to provide more irradiation in the visible and plant-response range of 400 to 750 nm, and with less heat. Contact the growth chamber manufacturer before changing lamp types because the lamp canopy not only supports the lamps but is an integral part of the airflow design in many chambers, and modification may result in adverse performance.

Normally, the desired ratio of red photons to far-red photons is obtained by using incandescent lamps as a supplemental radiation source. Whenever possible, controls for photosynthesis lighting should be separate from the photoperiod lighting.

A high-temperature cutout should be provided in the lamp chambers so that the temperature will not rise above a preset level if the refrigeration or the cooling fan goes off. If the lights are not cut off automatically, the plants may be killed or the electric wire installation may melt and start a fire.

Carbon Dioxide Control Systems

In preparing CO_2 specifications for a growth chamber, state whether the chamber will be sealed to retain CO_2 and to exclude outside air. To fulfill this requirement, no fans should be installed to add outside air. If these fans are required for experiments, a means should be provided for sealing the air inlets and outlets. The CO_2 should be fed into the growth chamber in such a way that it will be diffused in the area of the circulation fan before being introduced to the plants. This diffusion will eliminate any clouds of high-density CO_2. The control system should be installed with capability to add or remove CO_2 during either the light or dark periods, or during both.

Ventilation System

More controversy occurs between growth chamber manufacturers and users about the direction of airflow than about almost any other factor of the system. Air must be moved to carry heat away from the plant, to carry CO_2 to the plant, and to maintain minimum temperature gradients, both vertical and horizontal, within the chamber. Any airflow rate and direction that can accomplish these objectives probably will be satisfactory.

Air movement. The air moving over the plants interacts with light and heat radiation, relative humidity, and plant transpiration to form micro-environments throughout the plant-growing area. Therefore, it is necessary to hold the airflow constant over the whole growing area. To do this, the rate of airflow must be high enough to pressurize the air and distribute it evenly across the plant bed. If the rate of airflow is too low, there will be too great a temperature rise, and the air will move in puffs or along channels. If the rate is too high, the plant leaves may dry out or be physically damaged. The airflow through the plants should be not less than 0.15 m s^{-1} (30 fpm) and not more than 0.50 m s^{-1} (100 fpm). Avoid specifying air movement in air changes per minute because chamber configuration will influence the air flow per square meter of growing surface. For example, tall chambers and short chambers with the same growing surface will have different air flow rates if air movement is based on air changes per unit time.

Makeup air. Unless provisions are made for CO_2, it will be essential to specify a certain amount of outside makeup air. This can be accomplished with a small positive blower to force this air into the chamber. Or, some growth chamber manufacturers use the internal blowers to draw the outside air into the chamber at a point where it is mixed with the chamber air before entering the growth area. A small amount of makeup air will bring in CO_2, and exhaust air will help carry out impurities such as ethylene and ozone. Remember, however, that the cost of conditioning every cubic meter of makeup air will be high because the air must be brought to the same temperature and relative humidity as the air inside the chamber. Therefore, keep the percentage of makeup air to a minimum. Of course, some makeup air is required for normal plant growth in chambers that rely on ambient CO_2. This is helped, in most standard commercial chambers, by the fact that the chambers have a significant leakage and exchange with surrounding air.

Filtering. If the growth chambers have been specifically constructed with tight sealing to study air pollution, specify that filters be provided to remove all air pollutants from the makeup air. Most pollutants can be filtered out by using first a coarse furnace filter to remove the particles of dirt and debris, and then a charcoal or potassium permanganate filter to remove objectionable gases. Fine or absolute filters are available to eliminate bacteria when such a requirement exists. Remember that extra power is required to force the air through the small pores of such filters. To prevent the infiltration of polluted ambient air into the chamber, the entire chamber air circulation system must be operated at a positive pressure.

Electricity

The electrical supply should be specified in volts, hertz (cycles), number of phases, and types of hookup (for example: 208 V/60 Hz/3 Ph/4-wire "Y"). If an electric supply is already installed, the available amperage should also be indicated.

Water, Steam, Pressurized Air, and Vacuum

The size of water supply pipes and drains and the distance of each from the intended installation area should be specified. If distilled or deionized water is available in the area where the plant growth chamber will be installed, the available flow in gallons per hour or liters per minute should be specified. Distilled or deionized water can be used for humidification, nutrient solutions, leaching of soil, and, if available in sufficient quantity, the cooling tower.

If steam is available, indicate the size of line and its pressure. The manufacturer will need this information if steam is to be used for heating or humidifying the chambers.

Describe any available pressurized air and vacuum systems so the manufacturer can make use of these systems if necessary. Pressurized air used in controls and for plant experiments must be free of oil and other impurities.

Scope

Installation

Specify who is to do the installation—the manufacturer, the purchaser, or both—and how much each is expected to do. If the purchaser has an installation crew available, they might be able to install the equipment more economically than the manufacturer.

Standards of Performance and Acceptance

Although requiring exact tolerances could increase the cost of the original bid, it may be desirable to list acceptable tolerances. Specify who will do the testing, the type of test equipment, and the acceptable variations. Because no two chambers operate exactly alike, the manufacturer's specified data may not describe the way that a particular unit will operate.

Guarantee

The guarantee on a product is only as good as the manufacturer and only as binding as the accepted specifications. Most guarantees become void if the product is misused. Therefore, take care to handle the growth chamber and its equipment properly. Most warranty periods are for one year, but the commencement date may vary between date of shipment and date of installation, so the type wanted should be specified.

Delivery Requirements

Most growth chambers are shipped by commercial carriers and are delivered by the truck driver to the receiving area. If specific requirements must be met—delivery to a certain building on a certain date, or knocking the chamber down to a certain size or weight so that it can be accommodated by the elevators or doors through which it must be moved—such requirements should be included in the original specifications. If the costs of a special procedure will be excessive, the manufacturer can list these costs separately. Then the purchasers will be able to determine how to handle the cost.

Modifications

Minor modifications usually can be made by either the manufacturer or the purchaser. Often the purchaser can modify a standard unit at the place of use. It is usually faster and more economical to obtain standard growth chambers on approved purchase schedules than it is to obtain modified chambers that must go out on bid.

Sample Specifications

The following sample specifications are published for guidance only. They are not intended to be used to purchase any particular chamber for any particular use, but rather an as aid in writing specifications that will fit your particular needs and that will give all necessary information.

I. Requirements

The research conducted in the ____ laboratory at ______ requires accurate and reproducible controlled environments for physiological studies on horticultural crops such as lettuce, tomatoes, petunias, marigolds, birch, crabapples, and selected experimental species, and on field crops such as clover, alfalfa, soybeans, wheat, oats, and corn.

For the proposed physiological research, accurate control of light intensity, day length, temperature, relative humidity, carbon dioxide (below and above atmospheric concentration), and airflow is needed. In addition, the environment must be scrubbed for excessive concentrations (above atmospheric) of undesired gases such as ethylene, ozone, sulfur dioxide, and carbon monoxide.

For purposes of definition, the words "growth chamber" will mean the total system, and the words "growing area" will mean the volume within the growth chamber where plants are grown. "Growth height" is the maximum distance between the light barrier or lamp bank and the floor or shelf on which the plants sit.

A minimum of four separate but identical plant growth chambers is required. To satisfy the research requirement of the laboratory, each controlled-environment chamber must meet the following performance and technical requirements.

II. Physical Construction

A. Materials

Because the growth chamber is subjected to high humidities, it must be constructed of rustproof materials such as aluminum, stainless or coated steel, or plastic.

B. Size

Specify the maximum *exterior* dimensions (length, width, and height), growing area, and growth height. External dimensions will differ significantly from those of the growing area so as to accommodate the air handling equipment, light bank(s), cooling coils, etc. Consider the dimensions of existing doors, and do not hesitate to require a site visit from the manufacturer to address concerns.

C. Interior and Exterior Finish

Specify the type of finish wanted on the interior walls; it must provide uniformly high reflection of the light source. The surface should be of a material or coating that will not corrode, fade, yellow, or otherwise lose its reflective ability after several years of service. The exterior finish should be specified to ensure good quality (i.e., polished aluminum, baked enamel, etc.).

D. Insulation

Expanded polyurethane insulation is highly recommended for all walk-in growth chambers and for reach-in chambers with extreme temperature requirements. Normally, however, the type of insulation for reach-in chambers sold by established manufacturers is of no concern because these chambers are small and operate at near-ambient temperatures. Several types of insulation are presently utilized by growth chamber manufacturers (expanded polyurethane, glass fiber, and expanded polystyrene). The type with the lowest thermal conductivity "k factor" (defined as the rate of heat transfer that occurs through the insulation, in units of BTU/hour/square foot/degree Fahrenheit of temperature differential between the inside and outside of the growth chamber per inch of thickness) is expanded polyurethane, with an approximate k factor of 0.10 to 0.11. Glass fiber and expanded polystyrene have k factors of approximately

0.22 to 0.25. The k factor is used in determining the required wall thickness to arrive at a satisfactory overall thermal resistance "R."

E. Floors

1.The growth chamber must have a floor that will provide for the collection and removal, by means of a drain, of condensed or spilled water and of dirt, leaves, and other small particles of debris that are products of the experimental process. The growth chamber floor may be built into the purchaser's building floor. If so, list the dimensions, structural characteristics, and location of drains in the specifications. Because the floor will be exposed to water, soil, and plant matter, it must be made of material that will not rust, corrode, or otherwise deteriorate under normal use.

2.With loading evenly distributed, a reach-in growth chamber plant bed (bench) must support a load of at least 244 kg/m^2 (50 lbs/ft^2). The minimum load to be supported by a walk-in growth chamber plant bed must be 732 kg/m^2 (150 lbs/ft^2). Because it is desirable to adjust the growth height (distance between the plants and the light source) to accommodate plant size, the plant bed must be adjustable from the specified growth height to within 30 cm (12 in) of the light source. Following are three methods of growth height adjustment; specify the desired method. 1) Wall-mounted pilasters and shelf brackets. Unless making only a very small adjustment, it is necessary to remove the plants completely from the plant bed, adjust the shelf brackets to desired height, and return the plants. 2) Winch-adjustable plant bed. This design eliminates the requirement of removing the plants to make a growth height adjustment. The growth chamber environment may be disturbed considerably, however, unless the user has access to the winch without entering the growth chamber. 3) Movable, counter-balanced lamp bank. This design eliminates any movement of the plants because the plant bed location remains unchanged. The lamp bank is moved manually to the desired height.

F. Doors and Seals

Specify the number of hinged access doors required to provide adequate access to the growing area. Include the minimum width and height of each opening. To allow for observation of the plants in the growing area without exposing them to the ambient atmosphere, the access door must have a window that can be made light tight by adding a hinged cover.

G. Lamp Bank

Specify the maximum PPF required at a given distance from the lamps, the anticipated temperature range requiring this intensity, and the type of lamps (i.e., cool-white fluorescent/incandescent mixture, etc.). It is desirable to maintain the intensity at a near-constant level, so select a growth chamber design that best suits your requirements. Two types are available, barrier and nonbarrier, each having its advantages and disadvantages. The primary advantages of the barrier type is that there is less long wave radiant heating of plants, and when using fluorescent lamps, the temperature of the lamps, and thus photon output, can be maintained more constant. Nonbarrier lamp banks are now available that can accommodate filters for spectral studies and still allow enough airflow to remove lamp heat.

If a barrier design is wanted, specify that the lamp bank be completely sealed from the growing area and designed so that the lamps are easily accessible for changing.

H. Other Access Areas

A minimum of two access holes must be supplied to the growth chamber for water, instrument leads, and gas supplies. Each hole must be at least 5 cm in diameter, or equivalent area. These holes must be capable of being completely sealed against gas and light transfer, as described earlier.

I. Growth Chamber Sealing

The mixture of gases, mainly the proportion of CO_2 in the growth chamber, will differ from that normally found in the atmosphere. The growth chamber needs to be sealed to restrict the transfer of gas in or out of the chamber. The seal must be capable of maintaining a differential pressure of plus or minus 1.25 cm of water between the growth chamber and its surrounding air. For controlled CO_2 studies, the air system must be capable of being sealed to lose no more than 10 µmol mol^{-1} of CO_2 per minute at a differential of 500 µmol mol^{-1} of CO_2 between the chamber and the surrounding air.

III. Environmental Control

Temperature, humidity, light, and CO_2 must be controlled well enough to maintain the environment required for the research.

A. Temperature

See Item V (Controls and Other Equipment) for programming and control. Specify the required growth chamber temperature range (i.e., 5° to 45°C with no lights; 10° to 45°C with all lights on) and the maximum differential, such as $\pm$ 0.5°C.

Specify the maximum temperature variation across the growing area, usually defined as uniformity on a horizontal plane. A typical uniformity requirement is $\pm$ 0.5°C with or without the lamps.

The maximum vertical temperature gradient is difficult to specify because it will be a result of a combination of factors (i.e., airflow velocity, lighting intensity, growing area, growing height, temperature control, and humidity control), all of which must be included in your specifications. The typical temperature gradient to be expected in a growth chamber of standard design with a source of 340 µmolm^{-2}s^{-1} is an increase of 1.5°C from the plant bed (152 cm from the lamp canopy) to within 30 cm of the lamp canopy as measured with an aspirated shielded thermocouple.

B. Humidity

See Item V (Controls and Other Equipment) for programming and control. Specify the required relative humidity range. This requirement will affect the equipment cost considerably. Therefore, it is important that relative humidity range be specified in such a manner that a manufacturer does not overdesign, which results in unnecessary costs, yet the equipment meets your requirements. Because temperature and relative humidity are directly related, a specification such as 50% to 90% with a control of $\pm$ 5% is not a good specification without further clarification. Be certain to specify the growth chamber temperature range over which the specified relative humidities are expected (with lamps on, off, or both). If only additive humidities are of concern, the specifications would read "additive to 90% with a control of $\pm$ 5%." It is necessary, however, to include the maximum growth chamber temperature and lighting conditions at which the maximum relative humidity is required.

C. Light

See Item V (Alarm System and Other Equipment) for programming and control. Specify the required PPF and the distance from the lamps, such as 340 $\mu molm^{-2}s^{-1}$, 60 cm from the lamp bank or barrier. If a mixture of fluorescent and incandescent lamps is desired, stipulate that the PPF be reached with fluorescent lamps operated for at least 100 hours. Uniformity of PPF at a specified level over the plant bed should be included. Use a statement such as "The PPF on a horizontal plane extending to within 15 cm of the walls must not vary from the average PPF by more than 10%."

The ratio of lamp types in wattage should be specified as required for your research. If fluorescent and incandescent lamps are to be used, a typical requirement is 25% wattage of incandescent to 100% wattage of fluorescent. The ratio in wattage also should be specified when using two types of high intensity discharge (HID) lamps.

If a number of lamps are specified, the quantity should be given as a minimum of each type to clarify that provision of this quantity does not preclude meeting other portions of your lighting specification.

D. Airflow

The direction and velocity of the growth chamber airflow must be specified. These requirements are determined by a combination of your research requirements and other requirements stipulated by the entire growth chamber's specifications. Typically either a downward or upward direction of air flow is recommended. To be effective, a side-to-side airflow requires a velocity that can damage most plants. Usually, an airflow between 0.15 and 0.36 ms^{-1} will be sufficient for good uniformity without damaging the plants. Also, some type of airflow uniformity should be specified, and it is not unrealistic to require that the velocity vary no more than 5% from the average over a horizontal plane.

The growth chamber should also be equipped with an inlet to add fresh air. The quantity of fresh air needed depends mainly on the growth chamber size. Do not specify a larger quantity than required because fresh air can add a considerable load to the refrigeration system. Further, it is desirable for the fresh air to enter at a point where it will thoroughly mix with the conditioned air before being introduced to the growing area.

E. Control of CO_2 and Other Gases

If your research requires the addition of CO_2 or other gases, even if your facility is providing the control(s), it is necessary that this requirement be specified. This requirement usually entails more than just the control(s), such as special gasketing, special fresh air inlet damper, etc., all of which can usually be provided with the growth chamber at the time of manufacture at a lower cost than on-site modifications.

IV. Controls, Monitoring, and Recording

Reliability of the control system is of utmost importance to successfully complete your research. Thus, it is important to include in the specifications wording that will ensure that the controller(s) is of high quality and a proven design.

A diurnal cycle (day-night) for temperature and lighting is a minimum requirement for nearly all plant growth. Some research requires additional changes; therefore, it will be necessary to specify those requirements. Because there is a direct relationship between temperature and relative humidity, there should be a way to change the relative humidity cycle seperately from the temperature cycle. Further, independent control of the different lamp types is desired.

Most growth chamber manufacturers install, or have available, computer controllers for setting and maintaining environmental conditions within the chambers. The computer controllers should provide a wide flexibility for timing of set point changes to meet experimental requirements including close simulation of the daily changes in the outside environment.

The computer controllers mounted on the growth chambers should provide a digital display of the set points and the present level of conditions in the chambers. In addition, there should be an output connection to permit attachment of the chamber computer to a separate host computer for continuous monitoring of conditions in the chamber for summarization of conditions maintained over different time intervals. It would be of significant advantage if the chamber controller also had capability and capacity to store data and print out daily and weekly summaries of the controlled parameters. For data summarization, averages of 10 minute samplings are adequate, whereas for evaluating system operations and problems, plottings of one minute samplings are desirable.

The computers on each chamber should have the capability of being programmed from a host computer to permit programming and operation from a central location, but each chamber computer should have the necessary memory capacity to maintain control of the chamber if the host computer is not operating.

The monitoring computer should be energized by an electrical system separate from that of the growth chamber and, if possible, should be powered by a non-interruptable battery supply in the event of total electrical power loss to the chambers so that environmental conditions during a power failure can be obtained.

If electro-mechanical systems are used for control of the chambers, the system should provide as a minimum 1) temperature control with two set points (24-hour clock with trippers or establishing light/dark or diurnal cycles) and 2) lighting control with two time clocks available for the high intensity photosynthetic lighting (to permit operation of only one-half of the lamps) and a third time clock for controlling incandescent lamps for low intensity photoperiod control. If humidity control is desired, controllers similar to the temperature controllers should be installed.

When the chamber is not controlled by a computerized controller, data monitoring and recording can be undertaken most effectively by purchasing separate environmental data loggers that can be attached or downloaded to computers.

V. Alarm Systems and Other Equipment

Some type of alarm system is always desirable. Each growth chamber control panel should have a visual and audible alarm that is triggered by the high and/or low limit control(s) if their temperature setting is violated. A set of "dry" contacts can be specified for connection to a remote alarm system, energized by an electrical system separate from that of the growth chamber(s). Consideration should be given to attaching the alarm system to a modem that will automatically dial and alert a maintenance person.

Other Equipment: The controls, relays, or solid-state components, such as circuit boards and circuit breakers, should be easily accessible for service. Ideally, access can be gained through hinged panels; some components, however, will require the removal of a few screws, unless one is willing to absorb potentially high costs for special design. The design of lamp ballast racks should be considered carefully when writing specifications. In addition to easy access, specify that the lamp ballasts must admit forced air for cooling. Because growth chamber manufacturers must place the ballasts in such a manner as to conserve space, ballast cooling by natural air convection often is not sufficient.

VI. Operating Conditions

It is important to list design temperature, or ambient air temperature(s) surrounding the growth chamber, anticipated throughout the year. Avoid listing a design temperature greater than is required. If the growth chamber(s) is to be installed in an air-conditioned room, there will be no need for listing a design temperature greater than 13°C minimum to 33°C maximum, including the anticipated relative humidity range, unless unusual conditions prevail.

If the growth chamber(s) will be installed in a location requiring performance at extreme conditions, clearly specify the conditions. If the location will be outdoors or only partly enclosed, a site visit by the manufacturer should be required before bidding.

VII. Installation

Inasmuch as installation can be a significant portion of the total equipment cost, careful consideration should be given at the time of specification. The installation requirements depend on a number of factors, many of which are unique to your purchase (i.e., reach-in or walk-in growth chamber[s], quantity of growth chambers, personnel from your facility available to assist, availability of necessary handling equipment, etc.) and all of which contribute to the type of installation best suited to your requirements.

The following are three commonly utilized methods (not listed in any order of preference) to accomplish the installation: 1) Installation *not* included as part of the purchase. This is a very common practice when purchasing a small growth chamber(s) that requires little, if any, on-site assembly. This installation approach can also be utilized for installation of larger growth chambers when there are personnel available who are familiar with the type of growth chamber. 2) *Supervision only* by the growth chamber manufacturer. This is a good approach if your facility has, or can acquire, personnel to perform the installation work accompanied by supervision from the manufacturer. If you opt for supervision only by the manufacturer, the wording should be such as to ensure that the supervisor provided will be one with a technical background and/or experienced with installations, such as a direct employee of the growth chamber manufacturer or one of their factory-trained service organizations. 3) *Installation* by the growth chamber manufacturer. This type of installation is usually reserved for the more complex and/or larger type of growth chamber(s). It is also utilized when the job site is such that some disassembly and reassembly of the growth chamber is required to move it into place, as any possible effect on warranties will be eliminated, with the manufacturer responsible for the required work. It is a good practice to require a site visit when including this type of installation in the specifications. Other items that should be included in the specifications are a) start-up and checkout of the equipment and b) operating instructions including recommended maintenance for the staff responsible for the management of the growth chambers..

VIII. Standard of Performance and Acceptance of Equipment

In this section, requirements can be listed that must be met for the equipment to gain acceptance. This section can be as simple as citing satisfactory completion of previous portion(s) listed by the specifications as constituting acceptance, additional testing, or additional item(s) unique to your requirements.

IX. Tests During Acceptance Period

Acceptance testing can add significant cost to the purchase. Therefore, make sure that the only testing required for the growth chamber manufacturer to gain acceptance is both required and reasonable. One method of determining the amount of acceptance testing is to consider the type of equipment specified (i.e., standard production model versus custom design).

When the equipment to be purchased is a standard model, only a small amount of testing usually is required to gain acceptance (i.e., temperature control at the low, midpoint, and high end of the specified range and relative humidity control at the three temperature test points). While this testing is underway, check other items of concern yourself, such as light intensity, uniformity, etc. Since the manufacturer's representative will be present at this time anyway, this provides an opportunity to obtain assistance if any questions or problems arise.

When the specifications require custom manufactured equipment, more extensive acceptance testing unique to your requirements will be needed. These testing requirements must also be realistic. Remember, it will be less costly to perform the testing with your personnel and equipment.

X. Warranty

Standard warranties differ slightly among established growth chamber manufacturers, although all should be valid for 1 year. The terms of the warranty period can usually be modified slightly with little or no additional cost.

The warranty period and/or requirements should be clearly specified, but they must also be realistic and reasonable. Other than during the initial start-up period, it is doubtful that any manufacturer will bid (without detailing certain exception[s]) on a job that requires them to guarantee uninterrupted performance.

Conclusions

A growth chamber is composed of a fairly complex mixture of components, such as electrical, refrigeration, plumbing, and air-handling. As part of the overall design and assembly leading to the manufacture of the completed growth chamber, it is the responsibility of the growth chamber manufacturer to select high-quality components. Some growth chamber manufacturers have complete control over the design and manufacture of their microprocessors; others acquire them from outside sources.

As indicated by the paragraph titled "Choosing a Manufacturer," one should shop around when considering purchase of a growth chamber. Ideally, this would include discussions with users of equipment with requirements similar to yours at various locations. Reliability and performance of the equipment obviously are important, but response to warranty and/or service responsibilities also should be considered.

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