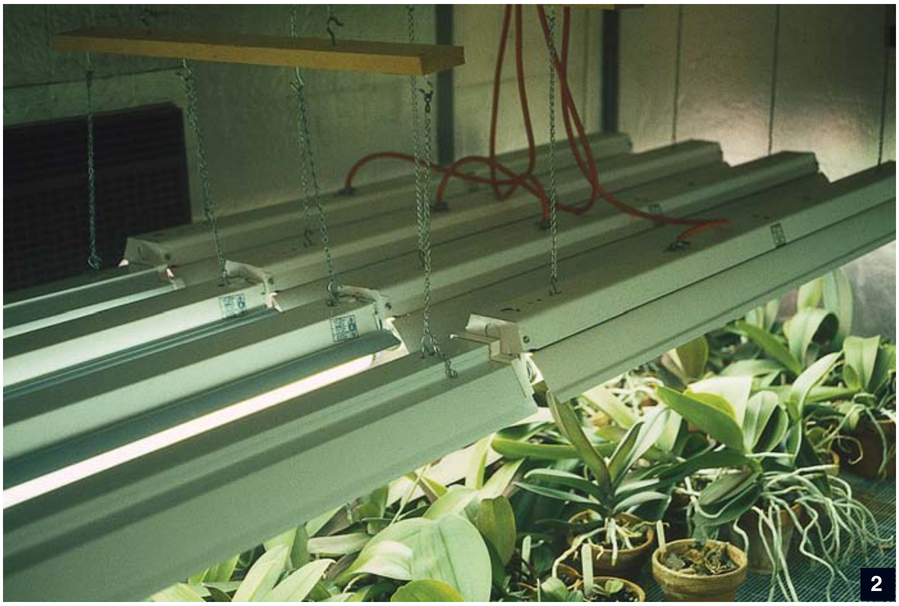
Artificial Lighting Systems

By Fred J. Bergman

Suggestions for Developign a Setup that Works for You



[1] Flasks in 2006 under 40-watt cool-white fluorescent tubes.

[2] Phalaenopsis under four fixtures, each one holding two 40-watt tubes.

AS THE PRICE OF NATURAL GAS continues to increase, it's only natural to wonder if a greenhouse is such a good idea. For those who are hooked on orchids, the alternatives are growing on windowsills or under lights. Windowsill growing is too limited for me. I have been accumulating plants since 1949 and I have far too many for any windowsill. So, early in 2007, I started considering a return to growing my orchids under lights in the basement. The result of my effort to select a good lighting system is presented here. Although many growers are convinced that a greenhouse is a must for optimum culture, a look at the available information indicates that light growing need not be a poor substitute.

LIGHT REQUIREMENTS If you search the literature for information on an orchid's light requirements, you find similar information provided by most sources. Back-tracking references and further reading suggests that many articles come from authors' simply reading articles and writing new ones. In addition, there is the problem that few writer's report the number of foot-candles provided by the light system. The difficulty in choosing a light system is also increased because lighting equipment sources do not provide foot-candle information; instead they provide only lamp output in lumens. In an effort to understand this absence, I discovered why foot-candles are not provided. The foot-candles from any light system are dependent on a number of variables, such as spacing of the lamps, distance to the lamps, reflectivity of the lamp housing, the degree to which the light is spread and the distance to the end of the lamp. There also appears to be at least one unexplained cause of variance. I did find a reference that reported that the output of a reflector is 50 to 80 percent of the input. These are some of the reasons lighting manufactures do not provide lamp output in foot-candles.

In 1983, Bob Weltz described an elaborate high-pressure-discharge-sodium (HID) system and gave a detailed map of the output in foot-candles. The lamps were 4½ feet (1.4 m) above the bench, provided 140,000 lumens and illuminated a 16-square-foot (1.5-sq-m) area with an average of 8,750 lumens per square foot. The light measured at the center of the area was 1,226 foot-candles and, at the edge of the area, 333 foot-candles; this gives an average of 780 foot-candles.

When describing her basement greenhouse, Kleiman (2007) reported operating the lights 12 to 13 hours during the autumn and winter, and 14 to 15 hours during spring and summer. The main light source is a 1,000 watt metal halide HID on a 9-foot (2.75-m) track. According to Kleiman, the system lights an area 7½ feet (2.3 m) wide. With a 9-foot (2.75-m) track, the system will light 124 square feet (11.5 sq m). The output of most 1,000-watt metal-halide HID lamps is 96,600 lumens. The average light intensity of Kleiman's system is 779 lumens per square foot. Other literature contained articles reporting light 6 inches (15 cm) below a four-lamp fluorescent fixture of about 1,000 foot-candles. The same articles further state that 1,000 foot-candles were sufficient to grow and bloom many orchids. An outdated agricultural bulletin states that 1,000 to 2,000 foot-candles should be sufficient to grow and bloom most crops. The same bulletin stated that a room measuring 9 × 12 feet (2.75 × 3.5 m) with reflective walls and 24 daylight and cool white (50/50 mix) of fluorescents provided 1,200 to 2,700 foot-candles. Another article reported a light intensity beneath four enhanced white tubes as 1,085 foot-candles 6 inches (15 cm) below the tubes, and 789 foot-candles at a distance of 12 inches (30 cm).

I measured the output from a strip light holding two cool-white fluorescent tubes (T-12, 40 watt, 48 inches [1.2 m] long, output 3,050 lumens). The measurement taken 6 inches (15 cm) below the center of the tubes was 630 foot-candles and at 12 inches (30 cm) 360 foot-candles. When the light from two strip lights holding a total of four tubes was measured in the center, it was 1,250 foot-candles at 6 inches (15 cm) and 780 foot-candles at 12 (30 cm), which are in good agreement with published values. When the two-lamp output is compared with the four-lamp output, it indicates a benefit from increasing the number of tubes. There is an increase in light intensity across the entire array. This increase occurs because light from each tube radiates down at approximately 120 degrees. This causes light in an area to come from more and more tubes as distance increases from the fixtures. This effect moderates the decrease in light experienced as tube distance is increased. To further check this effect, four strip lights, each holding two tubes for a total of eight tubes, were assembled side by side. The voltage and amperage measurements indicated a total power consumption of 320 watts.

This was a surprise because either my meters are off or the power dissipated by the solid state ballasts is minimal. Scanning the eight-tube output with a light meter produced the second pleasant surprise. At 1 inch (2.5 cm) from the tubes' surface, the intensity was 3,100 foot-candles and at 3 inches (7.5 cm) it had only decreased to 3,000 foot-candles. I next scanned the area under the lamps at 6 inches (15 cm) and found a uniform intensity of 2,000 foot-candles for the entire area under the lamps, with the exception of a 2-inch (5-cm) strip around the perimeter. At 12 inches (30 cm), the light had decreased to 1,500 foot-candles and at 22 inches (55 cm) to 580 foot-candles. In an effort to maximize the output, I covered the lamp fixture with bright aluminum foil but the reading was unchanged. A foot-candle scan with changing numbers of lamps confirmed that the number of tubes has a significant impact. I found that at 3 inches (7.5 cm) with only six tubes the output was only 2,010 foot-candles, with four tubes 1,080 foot-candles, and with two tubes 1,020 foot-candles.

It is obvious that the ability to predict foot-candles from the lumen output of lamps would be helpful. To determine if this were possible, lamps in the array where changed to Ecolux Sunshine tubes with an output of 2,250 lumens. With two tubes, the output at 3 inches (7.5 cm) was 850 foot-candles. This was calculated (lamp output in foot-candles divided by lamp output in lumens × 100) to be 37.8 percent of the lamp value in lumens. For the lamps having an output of 3,050 lumens, the value was 33.4 percent. If it is possible to predict the output, this approach does not appear promising.

How much light is desirable? During the summer, plants in my greenhouse receive 3,750 foot-candles. Hager (1977) reported he obtained rapid growth of cattleya seedlings at 4,000 foot-candles. It appears that artificial light at levels higher than generally provided could be beneficial, levels considerably above the frequently cited 1,000 foot-candles. But I have grown and flowered phalaenopsis that received only 200 foot-candles. Wang (1998) studied the effect of light intensity on the flowering of phalaenopsis and found that 100 to 200 foot-candles were sufficient to produce optimum blooming during spike induction. However, I am proceeding with the idea that the goal should be to obtain as much light as possible. If this amount of light proves to be excessive, the lights can either be raised or some of the tubes removed.

The trouble with foot-candles and lumens is they are different units. Foot-candles measure intensity and lumens measure quantity. Trying to get from one to the other is like explaining how many miles in a gallon of water.

CHOOSING A SYSTEM When selecting an artificial light system, why do so many growers choose a high pressure sodium (HID) discharge system? Could it be that most growers who select a fluorescent light system are looking for the least expensive system? Or is it that many believe that the most expensive system must be the best? One problem usually ignored is that the HID output contains significant infra-red radiation. This radiation heats foliage, making it necessary to keep the lamp high above the plants. Raising the lights partly overcomes the heat problem and increases the growing area but it also decreases the light intensity. Even with the HID raised, it is frequently necessary to provide significant amounts of ventilation or mechanical cooling to keep the plants cool. Growing in New York City, Weltz (1983) did not report how much refrigeration he occasionally used, but said it required a large unit. In contrast, most growers report that fluorescents are cool enough to make it possible to lower the lamps until they almost touch the foliage without any burning. Considering the heat problem with HID it seemed prudent to consider growing under fluorescent lights.

Can anything be gained by using high output (HO or VHO) fluorescent lamps? I found a two-tube solid-state ballast fixture listed at one source. Each HO tube will provide 4,950 lumens for a total of 9,900 lumens per fixture. The fixture measures 4 × 46 inches (10 × 115 cm) so it would be possible to gang 11 fixtures to provide 108,900 lumens, or 6,800 lumens per square foot. There does not appear to be any HO or VHO lamp fixtures that use solid-state ballasts. Because of this, the use of either a VO or VHO system would encounter similar heat problems associated with HID.

Standard fluorescent lamps come in three diameters designated as T5, T8 and T12. The number is an expression of the diameter in increments of 1/8 inch (3 mm). A T5 is 5 × 1/8 or 5/8 inches (12.5 × .3 or 1.5 cm) in diameter, a T8 is 8 × 1/8 or 1 inch (20 × .3 or 2.5 cm) in diameter and a T12 is 12 × 1/8 or 1½ inches (30 × .3 or 3.75 cm) in diameter. A check of catalogs located white T5 lamps that produce 2,900 to 5,000 lumens, T8 lamps that produce 2,800 to 3,100 lumens, and T12 lamps that produce 1,500 to 3,400 lumens. Before you make a final selection, consider reading the excellent review of fluorescent tubes by Sandrick (1979).

There are high bay fixtures available that hold six to eight cool-white T5 lamps and produce a total output in an eight-lamp version that provides 40,000 lumens. The main disadvantage of this system is that it lights an area of only about 6 square feet (.6 sq m). This unit provides illumination equal to about 6,700 lumens per square foot. There are many different T5 tubes available, but only one tube provides 5,000 lumens per tube.

WIDTH OF THE UNIT An alternate to the high bay fixture would be to gang T8 or T12 lamps. To decide how wide a lighting unit should be, I considered optimum bench spacing. For most people, a bench 3 feet (.9 m) across is about as far as they can comfortably reach. This means that two-sided benches with a 2- or 3-foot (60 or 90 cm) walkway or a 6-foot (1.8 m) bench with 2- to 3-foot (60 to 90 cm) sidewalk is the optimum configuration. Either arrangement produces the same ratio of walk to growing area. The growing area would have to be increased to two 6-foot (1.8 m) benches before obtaining an improvement in the ratio. An area in the basement holding two benches 6 feet (1.8 m) wide is out of the question for most growers, including myself. T8 and T12 lamps are available at any store that carries lighting supplies, such as big-box stores, hardware stores, drug stores, wholesales clubs, electrical suppliers, greenhouse and gardening suppliers, advertisers in *Orchids*, mail-order sources, etc.

The optimum artificial orchid growing light is ganged fluorescent lights. The secret is to gang two-lamp strip lights without reflectors into units containing a minimum of four or more strips.

With this in mind, consideration was given to lighting systems for a 3-foot- (.9-m-) and a 6-foot- (1.8-m-) wide bench. I elected to examine systems for a 3-foot (.9-m) bench that would be 2 feet (60 cm) wide and a system for the 6-foot (1.8 m) bench that would be 4 feet (1.2 m) wide. The 4 × 4 array would hold 10 strip lights with each strip holding two lamps. Each of the 20 lamps would provide 3,100 lumens for a total of 62,000 lumens per array or 3,875 lumens per square foot. For those unfamiliar with strip lights, they are simple rectangular boxes containing a ballast, sockets for tubes and no reflector. I checked the output of a single two-lamp fixture with T8 lamps and found the output to be about the same as obtained with T12 lamps. It may have been a little different, but my General Electric type 213 light meter provides numbers in large increments. As was the case with the T12 lamps, the wattage of the T8 was equal to their stated 32 watts per lamp. If the fixtures are loaded with the best T8 lamps the array will provide the same light as a T12 array. The T8 lamp consumes only 32 watts instead of the 40 watts of the T12, and with both lamps providing the same lumens the economy of using the T8 lamps is obvious.

Most enhanced spectrum lamps are available only in a T12 configuration. Which are most important: total lumens or spectral distribution? A convincing answer, one of value, to this question was not found in the literature. This would show if there is anything to be gained from using special lamps, lamps that are as a rule more expensive to purchase and operate.

COST OF A SYSTEM For price comparison purposes, I made a quick summary of the costs associated with constructing a greenhouse. It is different from 1956, when my first greenhouse was constructed. It appears that the cost for a 10 × 12-foot (3 × 3.5-m) greenhouse, including a materials kit, foundation, heating system and a back-up heating system and a fan should be about $5,000, providing you do most of the work. Adding the cost of installing gas, electricity and water could add about $4,000 for contractor fees. This size of greenhouse will hold two 3 × 12-foot (.9 × 3.5-m) benches for a total of 36 square feet (3.3 sq m) of bench space. Construction costs would average about $250 per square foot. The utilities will cost around $4 a square foot or $480 a year; $13.30 per year per square foot or $1.10 per square foot of bench space per month.

The cost of the various lighting systems was calculated to help in the final selection, although the costs of suspending the system, a system for raising the lights and the wiring were not included. Electrical outlets sufficient to supply the system so wiring can be accomplished using outlet strips and a time clock would cost about $50. A method of raising the lights is probably desirable because the lamps should be operated as close to the plants as possible. As an aid to the selection, annual operating costs were calculated that included electricity and lamp replacement. Operating costs were calculated assuming a 16-hour day all year long and electricity at 7 cents a kilowatt hour. Costs were calculated using the area directly under the lamps (the 4 × 4 array covering 16 square feet (1.5 sq m).

A HID 1,000-watt system costs approximately $400 and with a light track around $650. This comes to $18 to $25 a square foot. The lamp replacement cost will run $18.60 per year. The system consumes 1,144 watts for a cost of $468 a year, which gives a total costs for lamps and their operation is $487 or $30.44 a year per square foot.

Information on a VHO (very high output) lamp system came from earlier work. A 215 watt unit 96 inches (2.4 m) long contained two power grove cool-white lamps, each producing 6,000 lumens or 12,000 lumens per fixture. A fixture will provide light for an area of about 12 square feet (1.1 sq m). At 6 inches (15 cm) a fixture provided 1,630 foot-candles; at 9 inches (22 cm) 1,250 foot-candles; at 12 inches (30 cm) 870 foot-candles; and at 48 inches (1.2 m) 200 foot-candles. A 48-inch- (1.2-m-) long HO two-lamp unit provided 1,200 foot-candles at 6 inches (15 cm) and 680 foot-candles at 12 inches (30 cm). I monitored the output of a lamp over its 10,000 hour life and found that the output was above 95 percent for the entire life, considerably more than the frequently reported one year. The HO and VHO systems produce less heat than HID, but are available only with magnetic ballasts. A two-lamp unit using 96-inch- (2.4 m-) long tubes consumes 442 watts and costs $180 a year to operate. The fixtures cost $160 each and the tubes cost $30 each or $35.30 a year for each two-bulb fixture for a total cost of $215 a year; $1.50 per square foot per year.

The high bay fixture costs $212.50 to light a 6-foot (1.6-m) area, which comes to $35.42 per square foot. The annual operating cost would be $176.60 a year and the tubes would run $23.31 per year. Total operating costs would be $199.92 a year, $16.66 a month or

2.78 a month per square foot. I found a T8 two-lamp strip light for $26.88 so a 4 × 4 array would cost $268.80 or $16.80 per square foot. The annual cost for tube replacement would be $20.18 and for electricity $216.63. The total operating cost would be $236.81 a year, $19.73 per month or $1.23 a month per square foot. The costs per square foot would be the same for either the 2 × 4-foot or 4 × 4-foot array. A T12 two-lamp fixture is available for $19.88, so a 4 × 4 array would cost $198.80. Twenty lamps at $3.45 each would total $69 and with a life of 3.42 years the annual costs for tube replacement would be $20.18. Electrical costs would be $327 per year or $27.25 per month. This totals $ 28.93 per month or $1.81 per month per square foot. The only reason for choosing T12 lamps is that T5 and T8 lamps are available only in white, daylight, and cool white and enhanced versions. It would take 10 years of the lower operating costs to recover the $70 saved using T8 lamps. The T8 and T12 systems are clearly superior since they have the lowest installation costs and the lowest operational costs. The conclusion is obvious considering that fluorescents provide 3,000 foot-candles compared with the 1,225 foot-candles provided by the more expensive HID.

BENEFITS OF LIGHTS Are there any good reasons to pursue growing orchids under lights? The greenhouse we discussed earlier costs around $9,000 for 36 square feet (3.3 sq m) of bench. If you add the costs of a floor, walks and other needs, and invest the total in a money market, it should produce $30 to $40 a month in interest. The interest plus operating costs should equal about $70 a month. For comparison purposes, the light system that provides 36 square feet of bench space at $1.23 a square foot will cost $44.28 a month. This means you will be ahead $25.72 a month.

In conclusion, it appears that the optimum artificial orchid growing light is ganged fluorescent lights. The secret is to gang two-lamp strip lights without reflectors into units containing a minimum of four or more strips. Each strip measuring 4½ × 48 inches (11 × 120 cm) when ganged (placed side by side) will produce an eight-lamp fixture that is 48 × 17 inches (120 × 42 cm). More units can be ganged to produce larger units, but it is recommended you limit the size to a 10-fixture unit which would be 4 foot square (.4 sq m). Your plants can be grown close to the lights and at 3 inches (7.5 cm) the lights will provide at least 3,000 foot-candles and at 6 inches (15 cm) 2,000 foot-candles. This is several times the light available using HID and it is close to the light available in a greenhouse; sufficient to grow and bloom most orchids. Either T8 or T12 lamps can be used, with the T8 lamps being slightly more efficient.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[3] In 1953, the author grew cattleyas under 40-watt tubes. The incandescent lamps served as ballasts, not to extend the spectrum.

[4] Flasks positioned beneath 40-watt fluorescent tubes with bulb ballasts in 1953.

References

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