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UNIVERSITY OF ALASKA FAIRBANKS

Controlling the Greenhouse Environment

There are many opportunities and approaches for producing crops in greenhouses. In the planning phase, decisions need to be made on greenhouse layout and design. A suitable location needs to be identified before the greenhouse can be constructed. When the greenhouse space becomes available and suitable crops, varieties and growing systems have been determined, focus needs to be directed to maintaining and controlling a suitable greenhouse environment. The greenhouse as a controlled environment is an opportunity for Alaska high energy costs for heating and electricity. Nationally, heating constitutes 65 to 85 percent of annual energy cost for a year-round commercial greenhouse (Runkle and Both, 2011).

As solar heat in the form of light enters the greenhouse, objects absorb it and reradiate it into the greenhouse environment (the greenhouse effect). Glass or rigid plastic greenhouse covering materials are optimal for trapping as much as 96 percent of thermal radiation, while single-layer polyethylene is less efficient, with more than 50 percent of the thermal radiation escaping. Polyethylene plastic that contains radiation-absorbing (IR-absorbing) materials improves retention of thermal radiation by approximately 20 percent (Bartok, 2001). To improve heat retention, IR-polyethylene plastic should be considered, although local availability may be limited (check with local commercial greenhouse operators). Inflated double-layered polyethylene plastic is commonly used in Alaska and is 40 percent more efficient in retaining heat than single-layer polyethylene (Nelson, 2012). In either case, the polyethylene plastic should contain a UV inhibitor or it is unlikely to last more than one season. If on a tight budget, check with local Alaska greenhouse operators who use UV-inhibited polyethylene plastic. Used plastic can often be purchased for a fraction of the original cost and provides several years of excellent service to a greenhouse gardener.

Heat loss from a greenhouse occurs through convection, conduction or radiation. Convection is the transfer of heat through circulation and mixing of warm air with colder air. Conduction is the movement of heat between or through objects such as a metal rod or a greenhouse covering material. Radiation is the movement of heat from a warm to a colder object without the need for a medium such as air (convection) or direct contact between or through objects (conduction).

When the air outside is colder, a greenhouse loses heat through conduction across the covering material. e amount of heat loss depends on the conductive characteristics of the covering material. Outside air in contact with the warmer covering material is continuously mixed to remove heat through convection. Air exchange or in ltration through greenhouse cracks, small openings and gaps around doors, equipment and other greenhouse features, is another form of convective heat transfer. Although radiation is important for solar heating of a greenhouse, thermal radiation is of minor importance for heat loss from a greenhouse. Wind, on the other hand, signi cantly increases heat loss, and the greenhouse heating requiremen h7p>deou-4.5 beauswcin-4.5 de ee

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auger. Local availability of pellets may be an issue or justification.

Fuel heaters (oil, kerosene, white gas or diesel) are not recommended for use in greenhouses unless adequate ventilation is provided. However, with frequent cleaning and maintenance, portable kerosene heaters that burn K-1 grade kerosene may be used successfully. For smaller greenhouses, kerosene heaters are especially well suited for emergency situations. Oil-fired furnaces are often too large to fit into the greenhouse design and structure. If used to heat other buildings as well as the greenhouse, such as a home, work area or storage facility, an oil-fired boiler can be advantageous.

When selecting a greenhouse heating system, the amount of heat for maintaining the desired greenhouse temperature needs to be known. Greenhouse covering materials are rated for their heat conductive properties. The U-value is a measure of heat transmission through a material. The higher the U-value, the less insulation the covering material provides. Table 1 lists U-values for some popular greenhouse covering and wall materials. In contrast to the U-value, the R-value is the insulative coefficient of a material and the inverse of the U-value. By matching the greenhouse heating requirement (calculated as the hourly heat loss) with the heater output in Btu/hour, a correctly sized heater can be chosen (make sure to use heater output and not the input value). British thermal units (Btu) are commonly used to measure energy and represent the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Using the information in Table 2 and the square footage of the greenhouse (length × width), the heating requirement can quickly be estimated. For example, a 12-foot by 16-foot freestanding greenhouse has a floor area of 192 square feet. U0.5 (i (q)10 (u)-c7MCID 2030.5 (g1 set.) (in

A more accurate method (Kramer, 2013) for calculating heat loss in a greenhouse is the formula HL (heat loss) = SA (surface area of the greenhouse covering) × U (heat loss factor of covering material) × TD (difference between highest inside and lowest outside temperature). Examples 1 and 2 illustrate the use of this formula for calculating the heat loss in a lean-to greenhouse (Example 1) and in a freestanding greenhouse (Example 2).

Comparing the calculated heating requirements, the simple method (Table 2) resulted in an overestimation of approximately 6,000 Btu/hour for the 12-foot by 16-foot greenhouse. The example of the lean-to greenhouse also results in a similar overestimation using the method in Table 2. Although the estimates differ, the simpler formula is still a useful tool for making a rough assessment of the heating requirements for various types of greenhouses.

Planning for abnormally low outside temperatures can make the difference between saving or losing a crop and protecting the greenhouse structure. In Alaska, a slightly oversized heater is always better than an undersized heat source. A backup system is crucial for year-round

Example 1. 12-x 16-foot lean-to greenhouse (adapted from *Greenhouses for Homeowners and Gardeners*, NRAES-137)

Surface area:

End walls: 2 x 6 . x 12 . = 144 sq. .
Sidewall: 6 . x 16 . = 96 sq. .
Peaks (endwalls) = 2 x 0.5 x 12 . x 6 . = 72 sq. .
Roof: 13.4 . (a2 + b2 = c2) x 16 . = 214.4 sq. .
Total: 526.4 sq. .

Heat Loss (HL) = Surface Area (sq. .) of greenhouse (SA) x U factor (U) x Temperature di erence between minimum outside and 60°F inside (standard) (TD)

Given:

SA = 526.4 sq. .
U-value (single layer polycarbonate – Table 10) = 1.2
TD= 60°F [desired inside temperature] + 30 (-30°F) = 90
Heat Loss = 526.4 x 1.2 x 90 = 56,851 Btu/hr.

Example 2. 12- x 16-foot freestanding greenhouse (adapted with permission from *Greenhouses for Homeowners and Gardeners*, NRAES-137).

Surface area:

Ends: 2 x 6 . x 12 . = 144 sq. .
Sides: 2 x 6 . x 16 . = 192 sq. .
Peaks (end walls): 2 x 0.5 x 12 . x 3 . = 36 sq. .
Roof: 2 . x 6.7 . (a2 + b2 = c2) x 16 . = 214.4 sq. .
Total: 586.4 sq. .

Heat Loss (HL) = Surface area (sq. .) of greenhouse (SA) x U factor (U) x Temperature di erence between minimum outside and 60°F inside (standard) (TD)

Given:

SA=586.4 sq. .
U-value (single layer polycarbonate – Table 10) = 1.2
TD= 60°F [desired inside temperature] + 30 (-30°F) = 90
Heat Loss = 586.4 x 1.2 x 90 = 63,331 Btu/hr.

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Water/Air Temperature	Btu Stored	
	1-Gallon Jug	5-Gallon Jug
60ºF	83	417
70	167	834
80	250	1,251
90	334	1,668
	30-Gallon Barrel	55-Gallon Barrel
60ºF	2,500	4,590
70	5,000	9,170
80	7,500	13,760
90	10,000	18,340
	Concrete/ Concrete Block	Brick
60ºF	224/cubic foot	271
70	448	542
80	672	813
90	896	1,084

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Cooling

Need for air movement in the greenhouse

There are two primary reasons air flow is necessary in greenhouses: (1) to remove excess heat through ventilation as the temperature rises, replacing hot air with cooler air, and (2) to control relative humidity and carbon dioxide within the plant canopy. A single system can serve both needs in smaller greenhouses, while separate exhaust and circulation systems are common in larger-sized greenhouses. Separate systems need to be carefully coordinated and adjusted to work together instead of counteracting each other Air movement systems range from simple, do-it-yourself arrangements to professionally designed, installed and integrated computer controlled systems.

Temperature Control Systems (Ventilation)

As the sun warms the greenhouse, temperature rises rapidly. Without a method of removing excess heat, the temperature may increase to levels detrimental for crop growth. The purpose of the ventilation system is to prevent temperature increases and heat buildup by replacing the hot air with cooler outside air.

Smaller greenhouses can be adequately ventilated by leaving doors and windows open or by removing sections of the covering (Picture 1). By properly orienting the greenhouse to take advantage of local wind patterns, summer winds may be captured and vented into the greenhouse for cooling For medium- and large-sized greenhouses, however, air movement and ventilation needs must be met with a combination of active and passive systems.

Picture 1. Door vents and high ceilings in small greenhouses can provide adequate ventilation.

Passive ventilation systems operate on the principle that air expands when heated, increasing the pressure in the greenhouse. To release pressure, air is pushed through vents or other openings in the structure and replaced with air pulled or pushed by wind through other openings in the greenhouse. In Alaska, the greenhouse air heats up rapidly during days with intense spring and summer solar radiation. With a passive ventilation system, hot air flows out of vents positioned in the greenhouse roof or end walls. Cooler air is brought in through side vents (or other uncontrolled openings) to replace the hot air and lower the interior temperature (Figure 1; Bartok, 2000). Vents along part or the entire length of the roof ridge can be an efficient greenhouse ventilation system (Picture 2). The passive ridge-vent

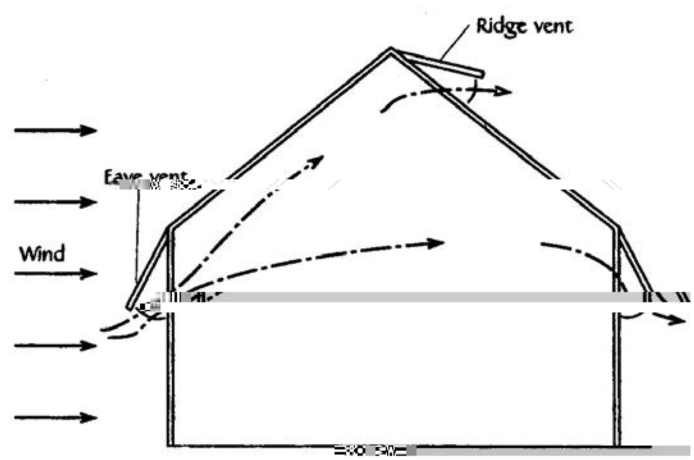

Figure 1. Passive ventilation of hot air through ridge (top) vents with cooler replacement air entering through side vents. Adapted with permission from Greenhouses for Home

(cfm). e fan output is recorded and indicated as cfm under no air resistance (free air) and as one or several static pressure values measured in inches of water column. e static pressure value takes into account friction created by, for instance, air passing through a louvered vent. The manufacturer should provide technical speci cations for the fan capacity at various static pressures. Fan capacity ratings at ⅛ inch (0.125 inch), rather than no static pressure, should be used for Alaska greenhouses. If insect screening or evaporative cooling pads are used, fan ratings of ¼ inch (0.250 inch) or greater static pressure need to be considered. Typical fan performance under two static pressure values are summarized in Table 6.

For Alaska, an acceptable standard of air movement is 12 cfm for each square foot of greenhouse oor area. As an example, Picture 4 shows a greenhouse measuring 16 feet by 24 feet, with a oor area of 384 square feet. Multiplying 384 square feet by 12 cfm per square foot results in 4,608 cfm, the required fan capacity to adequately ventilate this greenhouse using an exhaust fan and louvered vent system. Since the need for ventilation varies throughout the seaiosexarinen--2.9 (a Td 0 T.3 (e n1

Vents opening downwind and fans exhausting with pre-

8 feet above the floor (Bartok, 2000). Oscillating fans that move air through the plant canopy can improve air circulation in smaller greenhouses.

Humidity Control

A secondary role of the ventilation system is to eliminate excess humidity. If not properly vented, excess humidity condenses on the leaf surface where it can enhance disease problems. It can also condense on the greenhouse structure where it may reduce light transmission and on the wattage and type of gas mixture, the halogen version can be 30 to 60 percent more energy efficient (lumens per watt of electrical energy) than the traditional incandescent bulb. The lifetime of the bulb is often more than double the number of hours expected for a traditional incandescent bulb.

Fluorescent

Fluorescent bulbs give off more uniform light than incandescent lamps. Fluorescent bulbs are available in 28- to 225-watt configurations and are often mounted in banks to cover larger growing areas. Home gardeners use fluorescent bulbs to start

High-Intensity Discharge (HID)

High-intensity discharge lamps are more costly to purchase and operate but o er the highest quality output of available grow-light options. High-pressure sodium (HPS) lamps are the most commonly used HID xtures in commercial greenhouses. HPS lamps provide a large portion of yellow-orange light but are limited in the shorter, blue wavelengths. Metal halide (MH) lamps have a more balanced spectrum and may be preferred in completely controlled environments or growing conditions with high dependence on supplemented light. MH lamps are sometimes used in combination with HPS lamps in greenhouses.

 e HPS lamps are slightly more e cient in transforming electric energy to light for plant growth than the MH lamps; they are, therefore, recommended over MH lamps for supplemental light applications in commercial greenhouses. HPS lamps come in various suitable wattage levels, from 400 to 1,000 watts, for greenhouse applications. e choice of HPS lamp type and wattage is dependent on crop needs, available natural light and the greenhouse design.

HID light xtures have a bulb, re ector, ballast and capacitor (Picture 6). e bulb functions at a high

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to work well since even low levels of natural light are su cient to complement the spectrum.

LEDs or similar technologies are likely to become the major source of greenhouse lighting in the future. e LED technology is still in development, with the expectation of major advances in energy e ciency, light output, xture design and greenhouse applications. At

When the main purpose of supplemental lighting is to enhance plant growth, several factors need to be considered, such as crop requirements, desired intensity and quality, uniformity (number of required fixtures), operating costs and financial return on the investment. Several units and methods are used to measure available light. Foot-candles are a common measurement unit of light. Foot-candles and the unit "lux," commonly used photosynthetic active radiation (PAR) in the 400 to 700 nm range is of primary interest.

PAR levels can be measured in several units, including foot-candles, although the most appropriate unit for plant growth is micro-mol (µmol) per square meter (m^2) and second (s), or $\mu mol \cdot m^{-2} \cdot s^{-1}$. This quantum, or photon, unit measures the number of photons or light particles that appear on one square meter (10.8 square feet) every second. Another common light and PAR unit is watt per square meter (W/m^2) for measuring the energy in the photons falling on one square meter each second. PAR comparisons and conversions for HPS, metal halide and sunlight are offered in Table 13.

Instantaneous light measurements are helpful in showing the amount of available light at the time the reading is made. Since natural light is continuously changing during the day, a single measurement may not give a good indication of the total daily light available for crop growth. Therefore, the total amount of light provided during a day is expressed as the daily light integral (DLI). The DLI is a measure of the number of light particles or photons available to plants during 24 hours, or a day.

The commonly used unit for DLI is moles per square meter and day or $mol \cdot m^{-2} \cdot day^{-1}$. Plant growth, development, rate of maturation, yield and quality depend on DLI and provide information for determining when supplemental lighting or shading may be needed. During the long days of the Alaska summer, the natural DLI o en reaches 60 mol/m^2 and day, while in the winter DLI o en drops below 2 mol/m^2 and day.

e selection of light xtures for supplemental lighting depends on how they are to be used. First, consider the minimum light requirement for producing a certain crop (Table 11), then nd out the energy values for the intended light xtures (Table 14).

To determine the required number of lamp xtures, multiply the desired light level by the illuminated area and then divide this by the e ective ux of the selected light source. e e ective ux is approximately 80 percent of the rated ux for HID lamps. For incandescent and uorescent lamps, e ective ux varies from 50 to 70 percent depending on the type of re ector.

Growing lettuce seedlings at a light level of 25 watts per square meter (960 foot-candles) in a 1.5- by 3-meter area (4.5 square meters, or 48.4 square feet) would require a total of 25 watts per square meter multiplied by 4.5 square meters, or 112.5 watts of light. If using 400-watt HPS lamps, the e ective ux is 38.4 (Table 14). e number of light xtures needed to provide the desired light level for the 4.5-square meter area is 112.5 watts divided by 38.4, which equals 2.93, or three 400-watt HPS xtures.

e cost for operating HID lamps can lyath0.0973(48.4 6 -1.-)-2.y th0.0n 73(48.4 6 -13W83.2 (a)ID 1845 a n94f 25

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