Energy Conservation for Greenhouses January 7, 2010

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Slide # Description

1 This presentation was developed by Scott Sanford, who is a Senior Outreach Specialist in the department of Biological Systems Engineering at the University of Wisconsin-Madison working in the area of energy efficiency for agriculture.
Today I'm going to cover things that you should consider in regards to heating and cooling a greenhouse, preferable, before you build it. I'll cover the affects of glazing materials, infiltration losses, reducing night time heating losses, greenhouse heating units, heat distribution, space utilization, ventilation fans, supplemental lighting on energy requirements for greenhouses. This is the first of four presentations on energy efficiency for greenhouses.

2 For most greenhouse operations that grow bedding plants, Energy will be the 3nd largest cost behind labor and plant materials. 70 to 80% of the energy will be for space heating, 10-15% will be used as electricity and the remainder for transportation.

As we look at ways to save energy, we will have to look at a balancing act between what is optimal for plant growth versus what we can afford. For example, the choice of glazing will affect light transmission needed for plant growth as well as energy requirements for keeping the green house warm. When we consider environmental factors inside the greenhouse, if greenhouse humidity is allowed to get high for long periods it can lead to fungal diseases but if we ventilate during cold weather it increases space heating. If greenhouse temperatures are reduced it saves energy but slows plant growth and takes longer to get plants to market size. The glazing with the best light transmission, glass, has the highest structure cost because of the weight and the highest energy loss but more light equals faster plant growth. So how do we marry all these issue together?

Hopefully at the end of this presentation you'll have some ideas of how to reduce energy costs without sacrificing quality.

3 Here is a quick lesson in heat loss from any structure.

Conduction heat loss is heat being conducted through a material. It is measure as a U-value or an R-value, one is the inverse of the other. A low U-value or high R-value equals a low heat transfer rate. With greenhouses we typically use U-value which has units of Btu (British Thermal Units) per hour per degree Fahrenheit per square foot of surface. Different materials have different U-values.

Convection is largely the transfer of heat from one area of a building or room to another or between air and a solid. In most commercial greenhouses, fans are being used to keep the air from stratifying so convection heat loss is not of importance.

Radiation is heat transfer between two bodies without direct contact or transport medium. Sunlight is an example of radiation heating.

Infiltration heat loss is the exchange of interior and exterior air through small leaks or holes in the building shell. The cooler air that leaks into the building has to be conditioned to maintain the greenhouse temperature.

4 These heat loss concepts apply to all types of greenhouses regardless of size or style. The top picture is a stand-alone gothic-type greenhouse, lower left is a hobby greenhouse and lower right is a large commercial greenhouse covering many acres.

5 If you are planning new greenhouses, you should consider how the type of greenhouse can affect energy consumption. A gutter connected greenhouse will have 15 to 20% less surface area therefore lower heat loss than a stand alone greenhouse based on a half acre of covered area. A gutter connected greenhouse will have better space utilization and higher labor efficiency.

Stand alone greenhouses had a 1.7 to 1.8 heat loss area to floor area but provide the ability to have isolated growing conditions which can help with disease pest control. Because of the narrow width, they can be easily ventilated naturally if roll-up side walls are used. Another advantage is that they can be heated as filled and each can be maintained with different environmental conditions. In a gutter-connected greenhouse, plastic walls could be installed so only a portion of the greenhouse is heated at a time but the heating and ventilation system needs to be designed with this in mind.

What shape would have the lowest heat loss area to floor ratio?..... Sphere. What has the next lowest ratio? … cube so a greenhouse with a square foot print will have a lower surface to floor ratio.

6 So let's put this into dollars. My example compares eight 30' x 100' greenhouse with a 5 bay 150' by 160' gutter connected greenhouse. All greenhouses are covered with double poly film that is treated with an IR inhibitor, has black fabric covering the dirt floors, covers 24,000 square feet and uses heaters with a seasonal efficiency of 78%. The stand alone greenhouses used 1793 gallons of LP gas per greenhouse for a total of 14,344 gallons for the spring growing season while the gutter-connected greenhouse used 11,929 gallon of LP for a difference of 2415 gallons or 18%.

But I'm just a small grower but plan on growing? Consider starting out with a small 1 or 2 bay gutter connected greenhouse have I can add to as my business grows. Yes, the cost is higher for the initial greenhouse but the payback will come as you grow. A sphere has the lowest surface area per enclosed area with a square/cube being next so the closer I can make the greenhouse to a square the lower my heat loss and heating bills should be.

7 The general recommendation is to orient single span greenhouses with the length east/west and gutter connected /multiple bay greenhouses north/south. Why? Orienting the greenhouse east/west provides the most surface exposure to the winter sun however if the gutter

connected greenhouse were faced east/west the shadow cast by the gutters would be basically stationary, causing lower growth in that area of the greenhouse.

8 Let's look at the difference between a single pane and a double pane glazing. Glass is the original greenhouse covering while a majority of new greenhouses use double layer of polyethylene film glazing. Glass has the disadvantage of high heat loss, but has the highest light transmittance which is important because light equals plant growth. Glass has long life, often outlasting the structure holding it up but requires a higher cost structure due to it's weigh. A double layer polyethylene film glazing has about half the heat loss of glass but has the shortest life, 3-4 years and about 10% to 15% less light transmission than glass. It's low cost and light weight which results in low cost structures are advantages.

9 Here is a table of the different glazing types with the % light transmission, % Thermal Transmittance, which I'll talk about in a minute, Conduction heat loss, estimated life and flammability. As you can see from the table most single pane materials have a light transmission about 90% but when the second layer of glazing is added the % light transmittance is reduced to about 78-80%. The same is true of conduction heat loss. Glass is not a bad material as far as heat loss is concerned, looking at the 4th column of the table you see that any single pane material has a U-value of about 1.1 Btu per hour per degree Fahrenheit per square foot. The same is true of double glaze materials, they range from 0.5 to 0.7. The fifth column indicates the expected life of different materials and column 6 lists the flammability potential if exposed to a flame. Many insurance companies require low flammable materials be used for glazing and exposed insulation. The third column is Thermal Transmittance or long wave radiation loss, you can see that most materials have low transmittance except polyethylene films. We'll talk more about this in a few slides.

10 Let's look at a pictorial of how this works. On the left with have a greenhouse with a glass or ridge plastic glazing. The sunlight passes through the glazing and heats the plants, soil and structure. When the objects re-radiate the heat, the glazing reflects it back into the greenhouse. The center illustration depicts a greenhouse with a polyethylene film. The sunlight passes though the film, warms the objects inside the greenhouse but then the re-radiated heat passes back through the film. The one exception to this is if condensation collects on the glazing, it will reduce the amount of IR radiation leaving the greenhouse but also reduces the amount of sunlight entering the greenhouse.

11 Lets talk about radiation for a minute. There are two types radiation we are concerned with; solar or short wave radiation which is sunlight and is absorbed by the plants, soil and greenhouse structure, warming these items up. Once heated above the surrounding ambient temperature, the plants, soil and greenhouse will re-radiate heat out, which is long wave or infrared (IR) radiation. This is particularly an issue on clear cold nights. Glass and rigid plastic glazing inhibit the loss of IR radiation, to less than 4% while polyethylene films have IR radiation losses of about 50%.

12 Polyethylene film manufacturers have developed films that reduce the infrared radiation losses through polyethylene films. These films typically reduce losses by 15 to 20%. The cost of the films with the IR additive cost about 1.5¢ more than a standard film or about $10 per year for

a 30 x 96 greenhouse. On a double layer poly greenhouse, the IR film would be placed on the inside and a standard film used on the outside. There is no light transmittance loss with these films and in fact they help to diffuse the light which can result in fuller more even crop growth. The payback on using the IR film versus a standard film is about 2 to 3 months in northern climates. Most film manufacturer's only make one product that contains the IR additive and is often combined with a condensate control addition to reduce condensate beading on the film. The slide lists some of the major manufacturers and their products that contain an IR additive.

13 Factors affected solar gain. Remember a percent increase in light equals a percent increase in plant growth so a little can make a difference. The difference in light transmittance between a single and double glaze material can vary from 75% to 94%, so material selection will have an affect. In previous slides I mentioned condensation, it can reduce light at the plant level by up to 30%. Film manufacturers make films with additives to reduce the surface tension so any condensation will sheet off. In fact, some greenhouse structures are made with small gutters incorporated into the purlins to collect the condensation and route it via gutters in the structure frame to the ground so it doesn't drip on the plants and cause quality issues. A gothic style roof, with it's steeper pitch, is recommend for Wisconsin to aid shedding condensation inside and snow outside.
Another factor that can affect light levels in greenhouses is dust collection on glazing. Some manufacturers also have films that inhibit dust from adhering to poly glazing to improve light levels. I suspect that this isn't a large issue in Wisconsin.

14 On double Poly film covered greenhouses it is not uncommon to find condensation or water pooling in the air pocket between the films. This is often caused by using inside greenhouse air that is high in moisture. The problem can be reduced adding some ducting to drawn outside air into the blower intake. Cold air holds less humidity than warm air so there will be less moisture to condense. To maintain the maximum insulation value, the roof or wall sections need to be inflated properly. The film can get pinched as it is pulled over a roof peak or across a purlin as the film transitions to the side walls. To maintain proper inflation, a jumper can be installed to provide an un-restricted flow path for the air.

15 The type of glazing material can affect infiltration losses in a greenhouse. This is principally a result of the number of joints in the glazing. Glass glazed greenhouses are typically the worst and double poly films are the best. The infiltration rate is expressed in air changes per hour; 2 air changes per hour means that the air in the greenhouse is heated and replaced twice. Older construction greenhouses typically have higher infiltration rates than new construction.

16 How do we build a wind break. An immediate option is to build some type of wall or high snow fence but this is often not economical or practical. A more permanent option is to plant a wind break with trees and bushes. A mix of evergreen and deciduous trees of different varieties is recommend so if there is a disease issue you don't loss the whole wind break. A recommendation for a fast growing wind break is to use hybrid poplar and white pine along with a mixture of other slower growing trees. The wind break should be planted to break the prevailing winds which for Wisconsin is from the west and north during the heating months. The wind break should be located 4 to 6 time the mature height of the trees upwind of the greenhouses.

17 Infiltration leaks come from a variety of locations in the shell of the greenhouse structure. Around roof and wall vents, cover connection to foundation, lap seals in glass greenhouses, weather stripping and door sills, ventilation louvers to name a few. Covering unused ventilation fans with plastic or foam, putting a plastic film over a rollup door and making sure the soil covers at least half the sill board can reduce infiltration. If you're dealing with an older leaky glass glazed greenhouse, covering it with a single or double layer of poly film can save up to 40% in energy costs. Doing some maintenance on the shell of the greenhouse can save 3 to 10% in heating costs.

18 Insulating the walls up to the plant height can reduce heat loss without affecting plant growth. The walls could be 2 x 4 framed with an inch of foam board or another construction method to reduce the U-value of the wall. If insulation is used against the current glazing, it needs to be sealed to the glazing so there is no air movement from behind the insulation. North walls don't allow direct sunlight to enter the greenhouse but do allow diffuse light to enter. Some recommend that the north wall be translucent, others insist that the amount of diffuse light is small compared to the heat loss. In general, it is recommended to insulate all opaque surfaces on the north wall. The perimeter should also be insulated especial with new construction if plants are to be grown on the ground. It hasn't been economical from an energy cost stand point to insulate the perimeter of an existing greenhouse due to the higher installation cost. However if plants are being grown on the ground, insulation may decrease production time and save labor as well as energy. Word of caution, Foam board is flammable and should be kept away from heat sources and covered with a non-flammable covering to from fire and UV degradation.

19 We will cover Thermal/Shade curtains in more detail in the next presentation. They provide one of the best options for a substantial reduction in heating fuel usage – 30 to 50% annually.

20 There are several differences between unit heaters that have not been well publicized and there are some new higher efficiency units available. Unit heaters are very popular because they are low cost, have low installation costs, very reliable and are easily staged. It is highly recommended that in any greenhouse there are multiple heaters to reduce the chance of a "No Heat" situation. If one heater fails, the remaining heaters need to be able to keep the greenhouse temperature high enough to keep from killing the plants.

21 There are four main types of vented unit heaters. The first type is a gravity vented heater (upper right) which will have a large diameter exhaust vent connected to an outside vent. The second type is a power vented heater (lower right). It has a small blower in the exhaust vent that meters the air for combustion. When it is not operating it blocks free movement of the air. The third heater type is a separated combustion (left) which has a blower as well as an air intake for combustion air. If you see two pipes coming from outside a building to the unit heater, it's likely a separated combustion unit. The combustion chamber is fully isolated to the outside.

22 The newest heater is a high efficiency condensing unit. This has an outside air intake and exhaust which are often PVC plastic pipe and has a condensate drain. It is basically a separated

combustion heater with an extra heat exchanger to condense the moisture out of the flue/exhaust gases. This type of heater has efficiencies in the 90 to 95% range.

23 The four types included Gravity vented, power vented, separated combustion and high efficiency condensing separated combustion unit heaters. Gravity vented heaters rely on the buoyancy of the combustion gases and wind passing the vent to exhaust the products of combustion outside the greenhouse. These are the least costly of the unit heaters and have a thermal efficiency of 80%. A power-vented has a small fan that meters the proper amount of air for combustion and exhausts the flue gases. The exhaust vent pipe can be exhausted horizontally which reduces installation costs. These heaters have a thermal efficiency of 80%. A separated combustion unit heater is a power-vented heater that has a sealed air intake so all combustion air is drawn from outside. Using outside air allows the heater to be operated in tight structures with low infiltration without the concern of flue gases being drawn into the greenhouse. Separated combustion heaters have a thermal efficiency to 80%. The last vented heater is a high efficiency condensing separated combustion heater. These heaters have all the features of a separated combustion heater but have an additional heat exchanger to squeeze some additional energy by condensing some of the water vapor out of the flue gas. These heaters have a thermal efficiency of greater than 90%. Looking at the thermal efficiencies and manufacturer's list prices, there is no obvious advantage of a power vent heater or a separated combustion heater over a gravity vented heater. There is a 13 % point difference between the gravity vent and the HE condensing unit heater but at almost 2.5 times the cost. The prices listed here are for heaters with stainless steel heat exchanges which adds $400 to $500 to the cost of the heater versus using the standard aluminized steel heat exchanger. Manufacturer's warranty the aluminized heat exchanger for 10 years unless it's used in a greenhouse in which case the warranty is reduced to 1 year. This is because the high humidity and chemicals used in greenhouses can rapidly deteriorate the heat exchanger. If a stainless steel heat exchanger is used, a 10 year warranty is available so for a $500 investment, the warranty is extended by 9 years. Now let's investigate the heater efficiency differences further.

24 The thermal efficiency is widely published and can be calculated from information on the heater label but the season efficiency which is the right hand column is the real efficiency of these heaters. The gravity-vented unit heater has the lowest season efficiency at 65% because when the heater is not in use heated air from inside the greenhouse is continuously being drawn out of the greenhouse by thermal buoyancy or pressure differences caused by the wind. The power-vented unit heater has a seasonal efficiency 13% points higher, at 78%, than the gravity vented heater and costs about 5% more. The power vent fan blocks air from flowing out the vent pipe when the heater is not in use so it reduces loss. The separated combustion heater has a seasonal efficiency of 80% which indicates that using the air in the greenhouse for combustion air results in about a 2% loss. The high-efficiency condensing unit heater has a seasonal efficiency of 93% which is 28% higher than a gravity vented heater but its cost is considerably higher. The point here is that the seasonal efficiency is much more important in the selection of a heater than the thermal efficiency but unfortunately few manufacturers publish this data.

25 To visualize the differences, let's look at a case study for a typical stand alone 30 foot by 96 foot greenhouse with double poly glazing located in the Madison Wisconsin area. We'll assume all parameters and costs are the same except for the heater type being used. The growing

season will be from February 1st to June. The greenhouse requires two LP heaters to maintain the 68°F day-time and 60°F night-time temperature all except for some unseasonably cold nights. One heater can supply all of the heat about 80 percent of the time. An LP gas cost of $1.50 per gallon was used.

26 Now lets look at the economics of these heaters using the gravity vented unit heater as the base case. The first column in this table is the heater type. There is some differences in the individual heater capacity ratings but this doesn't have an affect on the fuel consumption. The second column shows the incremental cost difference for two heaters. The third column is an estimate of the LP gas consumption based on a mathematical model that uses 30 year average weather data to calculate greenhouse heat loss. The % Fuel Savings column is the percentage fuel difference using the gravity vent heater as the base case. The Fuel Cost Savings column is the gallons of LP gas difference from the gravity vented heater multiplied by the fuel cost of $1.50 per gallon. The far left column is the Simple Payback in years. Payback is the incremental cost divided by the fuel savings. Looking at the payback column, the Power-vented heater will pay for its incremental cost difference in 0.3 years however the heating season is only 120 days of the years so 0.3 of 120 days is 39 days. Based on this analysis one should always purchase a Power-vented heater rather than a gravity vented heater based on the short payback. The Separated-Combustion heater saves 3% more fuel than the Power-Vented heater but has a longer payback of 4.6 years, still not a bad payback. The HE condensing heater saves 30% more energy than the gravity vented heater, 11% more than the Separated-Combustion unit but has a much higher incremental cost but the payback to 3.5 years because of the higher energy savings. This is a better investment than the separated combustion heater but maybe a higher cost than many would like. However if we consider that 80% of the heating could be a supplied by one heater and 20% of the heating supplied by a second heater then using one High-Efficiency Condensing heater as the primary heater and a Power-Vented heater as the secondary heater (set at a lower thermostat setting) the combined payback would be 2.0 years or a 50% return on investment, which would be a very reasonable investment for any grower. Two heating units are recommended for any greenhouse so there is built in backup should one heater fail.

27 If you currently have gravity vented heaters, all hope is not lost. Some manufacturers offer a kit to convert a gravity vented heater to a power-vent. The efficiency improvement will pay for the kit in a year or two.

28 Non vented heater are often advertised as being 100% efficient because all the products of respiration are exhausted into the greenhouse. However 8% of the energy is converted to water vapor which lowers the efficiency to 92%. Fresh air intakes or a minimum ventilation rate is required when using non-vented heaters to ensure adequate oxygen levels for complete combustion and to maintain good air quality for plants and people. The fresh air that enters the greenhouse has to be heated which also decreases the overall efficiency. This efficiency is temperature related, colder outside air temperatures result in more energy being used to heat the incoming air lowering overall efficiency. In the upper Midwest an non-vented heater will have a seasonal efficiency of 78-80% about the same as a power-vented or separated combustion heater. Some non-vented heaters have a fresh air inlet connected directly to the heaters which would improve the efficiency while other non-vented heaters require the heater be interlinked with an exhaust fan and inlet louver so fresh air is entering the greenhouse when the heater is

firing. If a greenhouse is very tight, oxygen levels can be depleted or flue gases can get pulled back into the greenhouse during periods of high heating needs. Non-vented heaters do a great job of increasing CO_2 which is good for plants during the day but about 80% of the heating occurs at night when plants are not using CO_2 so some of the benefit is loss. Water vapor is a product of combustion which is all discharged into the greenhouse with a non-vented heater. For every gallon of LP gas or Therm of Natural gas, 1.5 pounds of water is added to the air. This increase in humidity maybe beneficial for some types of plants but for most bedding plants grown in Wisconsin this can be a negative do to increased risk of disease problems and increased condensation on glazing, reducing light. One suggestion for the use of a non-vented unit heater is to pair the units with vented heaters. The vented heater would be the primary heater at night while during the day the non-vented heater would be the primary heater when CO_2 is consumed by the plants. It is generally recommended that 1 square inch of air intake area per 1000 to 2000 Btu/hr of furnace capacity be provided to ensure proper oxygen levels. This would equate to a 12" diameter opening for a 250,000 Btu/hr heater. Properly managed, non-vented heaters work well but there are some increased risks compared to using vented unit heaters.

29 Non-electric unit heater can be gravity vented or non-vented. They rely on convection air movement to distribute the heat, have low capacities so many will be needed per greenhouse depending on the size. The non-vented versions will require venting to provide combustion air. They are most suitable for hobby greenhouses without electricity. They are available with either single stage or set-back thermostats for day / night temperature differentials that operate on batteries.

30 Portable unit heaters which burn kerosene or fuel oil should never be used in greenhouses. These heaters are design for open spaces and have a higher tendency to produce greater amounts of ethylene and sulfur dioxide. If you must use this type of heater, it should be for emergency situations only, LP or natural gas fired and a vent or door should be opened to provide enough oxygen. Some plants are susceptible to injury from ethylene and sulfur dioxide that are products of combustion. Tomatoes, cucumbers, lettuce, melons, peppers, tobacco, some flowers, and bedding plants are susceptible to ethylene gas. Sulfur dioxide exposure can cause leaf curling and/or necrotic spots on leaves. The affect may not be apparent for several weeks.

31 The location where the heat is distributed into the greenhouse can save energy. If the heater is discharging the heated air in the gable, then the whole greenhouse has to be heated to get the plants to the desired temperature. If the heat is distributed in the floor and the plants are grown on the floor, it creates a micro-climate so the whole greenhouse doesn't have to be heated up to provide the proper environment for plant growth. The energy savings from floor heating or under-bench heating is equivalent to turning down the thermostat about 5-10°F. If hydronic floor heating is used, a unit heater will be required to maintain greenhouse temperature during cold spells.

A study of bottom heating of hot house tomatoes found a 7% increase in yields compared to conventional heating systems. Bottom heating can save up to 20 to 25% in heating costs. Photo shows hydronic bench top heating with the supply and return lines running along the greenhouse wall.

32 If forced air unit heaters are used, the same advantage can be accomplished by distributing the air under the bench. This picture shows a duct extending from the heater to below the bench. A poly-tube can be connected to the duct to aid in distributing the air uniformly under the bench. A blower type heater needs to be used for this application instead of a propeller fan due to higher static pressures created by the ducts and poly-tube.

33 Here are some examples of grower-built under-bench heating systems on the right and a commercially available system on movable benches on the left.

34 Here are some photos of a natural convection hydronic under-bench heating system in an Amish greenhouse. The supply pipe from the boiler is overhead and goes to the far end of the greenhouse. The supply pipe is connected to a distribution pipe with pipes dropping to the floor under the benches. At the near end of the greenhouse the pipes are connected to a return pipe that runs along the floor back to the boiler. I'm not sure this system is very efficient but it shows a way to do under bench heating.

35 Maintenance of heating equipment will reduce heating costs. Cleaning heat exchangers, tuning up burners, calibrating thermostats, steam trap maintenance and lubricating motor and fans can reduce heating costs up to 20%. Much of the savings can come from soot removal on heat transfer surfaces in tube boilers which can reduce fuel consumption by up to 10%. If you have a central heating system, insulating pipes and ductwork in the head house will also conserve energy.

As mentioned earlier air intakes for unit heater is important for proper combustion of fuel, this is also important for boilers.

36 For greenhouses who want to use a hydronic system to do under bench heating, there are several high efficiency heaters available. One type is modulating boilers that have thermal efficiencies above 90% some as high as 98%. There are also several high efficiency water heater that are suitable for smaller greenhouses that have efficiencies above 90%. These boilers can be used as "Add-On" boilers to an existing system where the High Efficiency boiler is set to be the primary boiler and the old boiler is the secondary boiler. Therefore if the new boilers can't keep up with the heating requirement, the old boiler will kick in. This require a controller that can control multiple heaters. There will be an offset between the new boiler set point and the old boiler set point so the old boiler will only operate in very cold conditions. With this type of setup the high efficiency boiler can be smaller than needed to cover the maximum heating requirement – 80% of maximum would typically be an economical size. There are numerous manufacturers of high efficiency boilers available. For small greenhouses a high efficiency water heater can also be used instead of a boiler.

37 Here are some examples of water to air heat exchangers that can be used with high efficiency boilers to distribute heat in a greenhouse. They can be located overhead or under bench.

38 Radiant heaters can also reduce energy use because they heat the plants but not the air directly reducing the overall energy use. Radiant heaters are not widely used in greenhouses. One

issue is if not properly setup or controlled they can burn the plant leaves. There can also be a large variation in the heat output over the length of the heat pipe so choosing a system with even heat distribution will be important. Radiant heaters are a great choice for loading docks, work areas such as for transplanting and seeding or warehouse areas. Manufacturer Roberts Gordon offers a free publication entitled Gas-Fired Infrared Heating for Greenhouses at their web site www.greenhouse-heater.com.

39 Environmental control systems can be used to control heaters, fans, louvers, irrigation systems, lighting and CO2 enrichment so that the system work together. It is also important to maintain for accurate control, thermostats should be calibrated annually. Control system will ensure systems are not competing such as having the heaters on while the fan is running. Control systems can also be tied to real-time weather data to anticipate heating and ventilation needs thus saving energy and providing accurate control. DIF is the difference between day and night temperature settings. Plants respond to the average daily temperatures not absolute so a greenhouse that is kept at 65F constantly will yield the same growth as one that is 70F during the day and 60F at night. From an energy stand point, reducing the temperature at night well save 5% in energy costs.

40 The more plants that can be grown in the space we are heating, the better we are utilizing the heat. On the left is the traditional bench layout with benches running longitudinal in the greenhouse which provides growing area of 59% of the total floor area. The center layout is a peninsula layout which provides 69% of the space as growing area. Moveable benches can increase the growing space to 81%. Both the longitudinal and the peninsula bench layout can be used for retail as well as growing while the movable benches are strictly for growing space. However is rolling carts are used as movable benches, some of the carts could be removed and the remaining carts arranged in a peninsula pattern for retail sales.

41 Here is an example of rolling bench tops. The bench tops roll on pipes that run the length of the bench which are supported by frames embedded in the ground. The bench top can roll to the right or left, opening a work path as shown in the center of the photo. This grower has under-bench heating and bench top micro irrigation incorporated with this movable bench system.

42 Most growers do a good job of space utilization by growing plants on benches with hanging baskets overhead. There are also racking systems that can increase plant density.

43 There are two types of commercially available hanging basket systems. On the left is a cable type system that can be used to suspend baskets from three heights. In the center of the left photo (red arrow) is an automatic watering systems applying water to a basket. On the right is a pipe system that is moved with a rack and pinion drive to move the plants past the watering device. The disadvantage of this type is that the baskets can only cover half the ceiling area if the automatic watering system is used. Both are examples of vertical growing systems.

44 Circulation fans can be important in reducing cold spots, keeping condensation from forming on the glazing and moving warm air near the roof down to the plant level. There are several different styles of fans that can be used: paddle fans, jet blowers and basket fans.

45 The efficiency of ventilation fan is measured as cubic feet per minute per watt or air flow per unit of energy and can vary widely. A 48” fan with similar equipment can range from 12 to 27 cfm/watt. Fortunately, there is independent testing of fans by two organizations: BESS Lab of the University of Illinois and Air Movement & Control Association. Both organizations published data and make data available on-line. In general, the larger the fan diameter, the higher the fan efficiency. If purchasing fans for ventilation, aim for efficiency ratings of 20 cfm/watt at a 0.05” static pressure for 36” or larger fans.

46 Small motors are typically not very efficient but some companies do make high efficiency motors. Many of the fan manufacturers use high efficiency motors as a way to increase the fan efficiency so if you need to replace a fan motor the motor efficiency should be considered. Typically, it is only cost justified purchase a HE motor for applications that run 50% or more of the time.

47 Maintenance on fans are often neglected. The two most common maintenance issues are shutters that don’t open or close properly and loose belts. Shutters that don’t open can reduce air flow by up to 40% while loose belts can reduce air flow by 30%. At the start of the ventilation season (April) check the louvers for free operation and lubricate the joints with a dry lubricant like graphite. Do not use oils as they will just attract dirt faster and cause the shutters to work improperly sooner. Belt condition and tension should be checked several times during the growing season when time is hard to find. I recommend purchasing fans with automatic belt tensioners or retrofit existing fans with automatic tensioners so that a once a season check of the belt condition and tension would be all that is needed. Another point is to remove trees, shrubs, or other objects that impede air flow from in front of the fan discharge. There may be some motors or belt tension devices that may require lubrication although most motors sold today have sealed bearings. Motors used for fans in greenhouses should have totally enclosed housings to keep moisture and dust out.

48 Summer Ventilation can be reduced using shade or thermal curtains as discussed earlier. These can lower air temperatures in the greenhouse by 10°F. Other options for controlling greenhouse temperatures during the summer include evaporative cooling or misting to reduce air temperature.
Natural ventilation can be utilized with roll-up side walls and roof vents or open roof designs. Variable speed controls on fans can allow lower ventilation rates during the winter so large temperature swings are lessened and higher speeds in the summer. The greenhouse pictured is a newer open-roof design.

49 One of the new styles of greenhouses is an opening roof design. The gable roof section can be opened allowing a large unrestricted vent area compared to a ridge or gable vent system. The convection air movement provides enough ventilation that this ½ acre greenhouse doesn’t use any ventilation exhaust fans. One disadvantage with this system is the large amount of seams that could increase infiltration losses compared to other vent systems.

50 Natural ventilation works on the principle of thermal buoyancy (hot air rises). With openings in the side walls and roof vents or an open roof design, the cooler air enters the greenhouse through the side wall vents to replace the hot air that has exited through the roof

vents – convection air flow. The greater the distance between the inlet and outlet the higher the potential air flow rate. Single span greenhouses can often get adequate cooling with just side wall vents.

51 Roll up side walls or curtain side walls work especially well for freestanding single span greenhouses for summer ventilation. However, they have very high infiltration rates due to the loose fit increasing winter heating. The side wall curtains are often made from single glazing materials resulting in high conduction losses. It is recommended that the curtains or rollup sidewalls be sealed with a sheet of poly film from the inside for the winter to reduce infiltration and conduction heat loss.

52 For non-electric applications, pneumatic vent controls can be used to open and close vents for temperature control.

53 Supplemental lighting can be used to shorten time to market which means grower might be able to delay starting plants which results in less heating or be able to better predict time to market, higher quality plants or earlier flowering. T-8 fluorescent lamps are recommended for growing chambers while high intensity discharge lamps are recommended for greenhouse. There are two types of HID lamps used in greenhouses High Pressure Sodium and Pulse Start Metal Halide lamps. High Pressure Sodium lamps are the most efficient lamps and emit a yellow/orange light. A Pulse Start Metal Halide emits a bluish/white light. Typically in greenhouses either high pressure sodium lamps are used or a 50:50 mix of both types of lights. Lights should be controlled with timers or better yet a light integral controller that measures the sunlight entering the greenhouse daily and controls the lights provide supplemental light to reach a minimum daily light integral.

54 I often get the question "I want information on a solar greenhouses" and I usually respond that greenhouses are already solar, what do you really want to know. What they are usually thinking about is eliminating the need to heat by adding thermal mass to a greenhouse or thinking of an active solar system. Thermal mass can aid in replacing about 25% or more of night time heating if the temperature in the greenhouse is allowed to vary. During the day the greenhouse temperature needs to rise to add heat to the thermal mass and at night the greenhouse temperature has to be allow to decrease to get the energy out of the thermal mass. This may result in a wider temperature variation than is normally recommend, depending on the plants being grown. Otherwise the thermal mass just increases the heating load or response time to increase greenhouse temperature because the thermal mass has to be heated up to get the air temperature to increase. Active thermal solar systems for a greenhouse typically aren't economical. If you're interested in a solar greenhouse I'd suggest you start with the book "Solviva" by Anna Edey or Passive Solar Energy Handbook by Edward Mazria.

55 This is an illustration of the typical passive solar greenhouse for winter time plant production. The north roof and north, east and west walls are well insulated. The glazing is facing south and tilted at approximately the same angle as the latitude (~45 degrees). The greenhouse will contain some thermal mass to absorb heat during the day and re-radiate it into the greenhouse at night. The glazing is covered by an energy curtain at night to further retain heat.

56 During the winter the sun is low in the south sky and will penetrate to the back of the greenhouse and heat thermal mass along the north wall. During the summer the sun is high in the sky and won't reach the back which helps to moderate temperatures.

57 An example of a passive solar designed greenhouse in Western Pennsylvania. A wood burner is used for supplemental heating.

58 This is another example in Colorado. This one appears to have two growing levels.

59 This photo show some of the thermal mass, 55 gallon drums, painted black and filled with water. This wall doubles as a place to grow some plants.

60 This is a tool that has been designed by UW-Madison for the USDA. It can be used to estimate the energy use for greenhouses and the potential savings from many of the technologies discussed in this presentation. I think you'll find it helpful for teaching and consulting with clients. If you have any questions or suggestion for the site, please contact me.

61 Some reference that will be of assistance. You'll find information and links on greenhouse and other Agricultural enterprises at the Wisconsin Energy Efficiency web site, the address is on the slide. Two other publications are the "Energy conservation for Commercial Greenhouse", which much of this talk was based on, and Greenhouse Engineering. Both of these publications are available from NRAES, Natural Resource and Agricultural Engineering Service located at Cornell University. I already mentioned Lighting up Profits a few slides back. And final the National Greenhouse Manufacturers Association's web site has some publications and downloads on different energy conserving equipment.

62 I thank you for your attention and hope you found this presentation helpful. If anyone has question, you are welcome to contact me. You are welcome to modify this presentation as you'd like for your purposes.