# H o r t i c u l t u r a l   E n g i n e e r i n g

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Websites: http://cook.rutgers.edu/~roberts

http://aesop.rutgers.edu/~horteng


## Basics Principals Of Winter Ventilation

Dr. A.J.Both

### Why do you need ventilation in the winter?

Greenhouse winter ventilation is necessary to reduce the greenhouse temperature, provide humidity control, and maintain adequate carbon dioxide levels. Assuming the heating system does not overshoot the indoor target temperature, winter ventilation for temperature control is only needed when the sun's radiation overheats the greenhouse. Under normal growing conditions, leaf stomates are opened during photosynthesis allowing plants to take up carbon dioxide and, as a result, release water vapor. Therefore, the carbon dioxide concentration of the greenhouse air decreases while the humidity increases. Normally, the ambient carbon dioxide concentration ranges between 350 and 400 ppm (0.035 – 0.040%). Without the proper ventilation rate, a greenhouse crop can easily reduce the carbon dioxide concentration to 100 – 200 ppm or less, significantly reducing the rate of photosynthesis, and thus plant growth. On the other hand, high humidity levels result in 1) increased condensation on colder surfaces (e.g., greenhouse glazing material, or plant leaves when their temperature is lower than the surrounding air temperature), 2) reduced plant transpiration (which, in turn, reduces water and nutrient uptake), and 3) increased risk of disease (e.g., mildew).

### How much winter ventilation is needed?

In colder climates, the general recommendation is to install a winter ventilation capacity that is 10-15% of the maximum (summer) ventilation capacity. But what is the recommended maximum ventilation capacity? A frequently used but less appropriate design criterion is "one air exchange per minute" (where the greenhouse volume is calculated without including the air volume above the gutters). The more appropriate design criterion is "8 cfm per $ft^2$ of greenhouse area" (10 cfm per $ft^2$ for greenhouses without a thermal shade screen). This design criterion is more appropriate because the amount of solar radiation intercepted depends on greenhouse area and not volume. Note that the second design criterion is not affected by the height of the greenhouse. It is important to remember that the design criterion of 8 cfm per $ft^2$ should be increased when 1) the greenhouse location has an elevation above 1000 ft, 2) the maximum interior light intensity measures over 5000 foot candles, 3) the desired temperature increase from inlet to fan is less than 7ºF, and 4) the inlet to fan distance is less than 100 ft. Based on this information, the design winter ventilation capacity for the average greenhouse should be around 1 cfm per $ft^2$ of greenhouse area (1.3 cfm per $ft^2$ for greenhouses with a thermal shade screen).

### Winter ventilation systems

Only one ventilation system is installed providing for both winter and summer ventilation requirements by staging the (sometimes variously sized) ventilation fans. In the winter, the incoming air is (much) colder than the greenhouse air and when this cold air is allowed to reach the crop, severe plant damage can occur. Usually, a crop occupies the entire greenhouse floor area in order to maximize space utilization. Therefore, special measures are needed to prevent plant damage. It is recommended that a top-hinged ventilation window is used as air inlet (usually along an entire side-wall), and care should be taken that the incoming air has sufficient velocity (at least 700 fpm) so it mixes thoroughly with the warmer greenhouse air before it reaches the crop. If necessary, a baffle can be installed to direct incoming air upwards and away from the plants. A less common but very effective way to provide good control of inlet air velocity, ensuring proper air mixing, is the use of a differential pressure sensor (maintaining a ÄP of 0.05 – 0.10 inches of water column) to control the opening width of a ventilation window. On the other hand, a polytube air distribution system can be used. These tubes are usually installed several feet above the top of the crop canopy and along the length of the greenhouse. The tube is connected to the outside with a louvered inlet and tied shut at the other end. Once the ventilation fan turns on, incoming air inflates the tube and fresh air enters the greenhouse through holes along the entire wall of the polytube. Designed for a sufficiently high airspeed (1200 – 1800 fpm) through their holes, these polytubes ensure proper mixing before fresh air reaches the crop.

Ventilation control

The greenhouse operator decides whether to ventilate for temperature, humidity and/or carbon dioxide control. Plant requirements, including disease control, and energy costs will be the determining factors. For example, in order to dehumidify the greenhouse, the ventilation system can be turned on. This will drop the indoor temperature requiring additional heating. The additional heating further reduces the humidity but also increases energy use. It is obvious that an economic winter ventilation strategy can best be implemented with the help of a computer control system. Such a system will be able to adjust quickly and accurately to the ever-changing environment conditions with minimal input required from an already busy greenhouse grower.

**This article was prepared for Grower Talks magazine.**

**Design of Greenhouse Systems Short Course**
January 8-9, 2001
Cook College, New Brunswick, NJ

**PROGRAM**

**Monday January 8, 2001**

| | |
|---|---|
| 8:00 am | Arrival and Registration |
| 8:30 am | Introduction and Overview of Major Greenhouse Components<br>Dr. A.J. Both |
| 9:30 am | General Design and Glazing Choices<br>Professor Emeritus William Roberts |
| **10:30 am** | **Break** |
| 10:45 am | Heating<br>Professor Emeritus William Roberts |
| 11:30 am | Ventilation and Cooling<br>Dr. A.J. Both |
| **12:15 pm** | **Lunch** |
| 1:00 pm | General Crop Issues<br>Professor George Wulster |
| 2:00 pm | Irrigation and Watering<br>Mr. Ralph Freeman |
| **3:00 pm** | **Break** |
| 3:15 pm | Supplemental Lighting and Shading<br>Dr. A.J. Both |
| 4:00 pm | Open-Roof Greenhouses<br>Professor Emeritus William Roberts |
| 4:30 pm | Building an Open-Roof Greenhouse with Heated Ebb and Flood Floor Irrigation System<br>Mr. Eugene Reiss |
| **5:00 pm** | **Adjourn** |

**Tuesday January 9, 2001**

| | |
|---|---|
| 8:30 am | Root Zone Heating<br>Professor Emeritus William Roberts |
| 9:30 am | Developing a Master Plan for Greenhouse Expansion and Orderly Growth<br>Mr. John Hoogeboom |
| **10:30 am** | **Break** |
| 10:45 am | Insect Screening<br>Professor David Mears |
| 11:30 am | Controlled Environment Agriculture Abroad Mr. John Hoogeboom |
| **12:00 pm** | Greenhouse Bus Tour<br>**Lunch on the Bus**<br>Open-Roof Greenhouse<br>Kube Pak Corporation<br>Burlington Tomato Greenhouse |
| **5:00 pm** | Tour returns, **Adjourn** |

**To register call 732 932 8451**

# How Do You Choose a Greenhouse

## "Greenhouse Design and Construction"

William J. Roberts Professor Emeritus
Rutgers University and Former Director CCEA

(**Continued from Hort Eng'g VolXV no 3-4)**

There are many pieces to a greenhouse production system puzzle. The diagram in Figure 1 graphically portrays some of the inputs and outputs that need to be considered when planning an expansion to a greenhouse production system. Each of the items mentioned needs to be considered. Some items such as heat have arrows going in both directions. Residue is an item often forgotten. Some items are easier to handle than others because they flow, such as water and air. Others require manual labor and storage facilities. Deciding upon a growing system will determine how the materials are required to move and be moved throughout the greenhouse. Cost effectiveness, that is labor versus initial capital expenses, of the system may help make the final decision. Thinking of the greenhouse as a system, that is planning how each item moves, can help forestall subsequent problems.

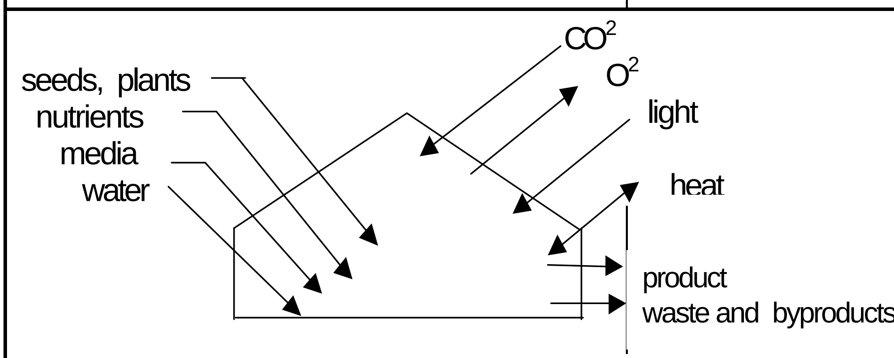


Figure 1 Parameters required for a greenhouse production

## Key Components for Greenhouse Facilities

### The Foundation

With new environmental regulations limiting run-off from greenhouses it is becoming increasingly beneficial to construct a solid concrete foundation for the greenhouse. The walls must extend below frostline and should be 8" wide. Interior walkways should be 4" thick and at least 10 feet wide for vehicle travel.

### The Structure

The type of structure should be based upon the growing system, the level of automation, the crops to be grown and the overall physical arrangement possible on the site. These choices determine bay width and length, gutter height, glazing, and type of ventilation. Hanging baskets can determine gutter height and irrigation booms can require special clearances.

### Ventilation and Cooling System

Ventilation systems can be either mechanical or natural with natural being determined mostly by site because of wind considerations. Natural ventilation through side walls is becoming a popular choice but its appropriateness depends on crops being grown, location, and automation potential. Open roof greenhouses are taking the industry by storm. Performance for cooling is outstanding.

### Heating System

The heating system should be selected based on personal choice and the crop being grown. The initial cost is important but may not be the most important consideration. A uniform crop is a necessity for some growing systems, and the heating and ventilation systems are major players in producing a uniform crop. Heating systems that give good temperature uniformity are preferred.

### Thermal Screens or Curtain Systems

A thermal screen that doubles for

summer shading is one of the best investments a grower can make. The greenhouse structure must be able to accommodate a thermal screen. If the installation cannot be made at the beginning of the project, the design must include the provisions for it to be added without expensive modification or alteration to the greenhouse at a later date.

**Growing Systems**

Efficient use of greenhouse space and the cost and energy savings realized are a major considerations for growers. Being able to fill and empty the greenhouse efficiently and quickly is an important consideration. The bedding plant industry is a good example of how mechanization has developed and each piece of required equipment works within a system to achieve the desired goal of efficient movement and reduced time, and cost.

**Environmental Control System**

Quality analog and computer systems are available that accurately sense and control both aerial and soil temperatures. Computer systems have the advantage of recording data for subsequent use in evaluating plant performance or identifying problems with the growing system.

**Adequate Water Supply**

In siting the greenhouse consideration must be given to the water supply. Is there an adequate water supply? Water availability via certification should be determined prior to the site purchase and/or greenhouse construction or the grower will risk not obtaining a water certification for the volume of water needed.

**Irrigation Systems**

Irrigation systems vary in design and layout. Automation is a major consideration, a greenhouse design should be chosen that allows for future installations of automatic control and equipment. The fertilizer injection system must be compatible with the installed irrigation system and must be understood by the operator so that expectations of its performance are realized.

**Utilities Installations**

The installation and availability of common utilities, (water, fuel and electricity), is of utmost importance, particularly when thinking about capacity for future expansion. The use of appropriate electrical installation practices within the greenhouse can forestall future safety and operation problems as well as maintenance and breakdown situations. Each electrical installation should have provisions for the addition of an emergency generation system, preferably to be installed when the greenhouse is constructed.

Selecting a Greenhouse requires much thought and a good master plan composed of many components. Considerable thought and evaluation has to be made before the plan is completed and before the intended program of growth or expansion is undertaken. The important issues include a business plan, a site evaluation, an evaluation of the type of growing structures, equipment desired and required and the impact the expansion might have on the community at large. The listed references contain information helpful in preparing a master plan for the grower who would like to erect new facilities or enlarge current ones. My former co-worker gave me good advice when he said to me, ***"Don't sew a shirt to a button."*** Growers who are the most unhappy after a change are those who altered existing facilities, tried to make them work, and ended up spending as much money as if they had built new, without the benefit of a new facility. Make mistakes on paper. Think, plan and consult with those who can help you make an admirable facility which will be a joy to operate.

References:
1. Bartok, John *"Develop a facilities master plan - before you expand"*
Greenhouse Management and Production, April 1996

2. Brumfield, Dr. Robin *'Greenhouse Systems Costs,"* NRAES 72 Greenhouse Systems, Automation, Culture and Environment, Proceedings of International Conference, ACE-SYS New Brunswick, NJ July 1994

3. Roberts, William J. *'Greenhouse Structures for Controlled Environment"* Bedding Plant IV, Chapter 17, page 215, J. Holcomb Editor

4. Roberts, William J. "Creating a Master Plan for Greenhouse Operations" Rutgers Cooperative Extension Publication E221, 1998.

***Paper to be presented at the Grow Your Greenhouse Conference, Nov 9-10, 2000 Batavia,NY. Organized by Cornell University***

## Which Fuel Should I Use?

Fuel prices are again becoming a significant cost for greenhouse growers. The question is often asked, “Which Fuel should I use.” For some growers the question is not an option because their heating plant will only use one fuel but for others there can be some choices.

There are two items to consider when considering a fuel choice. One, of course is the cost per unit of the fuel and the second is the heating potential from that unit of fuel. In general terms fuel oil has a heating capacity of 140,000 Btu/gallon. Natural gas is sold by the therm which is 100,000 Btu and propane has approximately 90,000 Btu/gallon. To these numbers an efficiency of operation has to be applied. If we assume that the oil delivery system is 71.5% then a gallon of oil will yield 100,000 Btu/gal, a number easy to work with. If we assume the gas burning equipment operates at 75% efficiency then a therm of natural gas will yield 75,000 Btu/therm and a gallon of propane will yield 67,500 Btu/gallon.

There are other considerations when making these decisions. Gas operating equipment is usually more inexpensive to purchase. Oil burning equipment can require more maintenance in some cases. Oil storage must be such that it is unaffected by extremely low temperatures or special additives have to be used during periods of extreme cold weather. Availability and reliability of heating contractors for maintenance and service is also an important consideration.

Applying unit costs to these numbers will give operating cost comparisons. If we assume that oil is $1.25 per gallon than it will produce 80,000 Btu/Dollar. Natural gas at $.90 per therm will produce 83,300 Btu per dollar. With propane at $1.00 per gallon it will yield 67,500 Btu/dollar. For these assumption the following is true:

| Fuel | Cost | Btu/dollar |
|---|---|---|
| Natural gas | $0.90 | 83,300 |
| Propane | $1.00 | 67,500 |
| Fuel oil | $1.25 | 80,000 |

A grower can substitute the prices available at the current time and make a decision about the fuel to use if his heating plant can accept different fuels. A grower can also receive assurances from equipment contractors concerning the efficiency of the heating equipment. If the heating efficiencies are higher than assumed in this example then the corrections can easily be made. For instance, some oil burners are listed as operating at higher than 71.5% efficiency and some gas equipment is listed at 80% efficiency. Using the numbers in this example gives a conservative approach to the real question of which fuel to use.

When dealing with energy use for heating there are several options for savinf energy and reducing costs. One of these is managing the fuel use. When designing new facilities it is a good time to consider the installation of a heating plant which will use either gas or oil. The change from fuel to fuel is usually straightforward and it gives the grower another management option to control energy costs by using whichever fuel is least expensive at the moment.

## Outstanding Agricultural Achievementof the 20th Century

**Recently the Horticultural Engineering program at Rutgers was recognized as one of the five outstanding achievements in agricultural Engineering for the 20th century.**

ASAE, The Society for engineering in agricultural, food and biological systems, recently conducted a nationwide survey to determine the outstanding achievements for the 20th century among the areas in which Agricultural engineers have traditionally worked. Our program was recognized in the area of Structures and Environment. The following text is from the Agricultural Engineering Society Journal, Resource, and March 2000 edition.

"Integrated System for Low-Cost and Low-Energy Greenhouses"

"Three concepts have been integrated to develop low-cost greenhouse structures and environmental control systems that require little energy for winter heating relative to classical systems.(1) the air-inflated double-layer polyethylene greenhouse;(2) movable thermal insulation for greenhouses and (3) root zone heating systems for production greenhouse. Work on the air-inflated double-layer polyethylene system was initiated at Rutgers University in 1965. The innovation was quickly adopted for commercial use and became the basis for a rapid expansion in plastic greenhouse acreage. Today about 64 percent of commercial greenhouses in the United States and Canada utilize this system, and all major greenhouse structure supply firms offer frames designed for double-polyethylene covering. The studies on the effects of greenhouse curtain materials for energy conservation were conducted in the late 1960's. By the end of the 1970's, several commercial suppliers were providing greenhouse curtain materials and the mechanisms to deploy them. It was also in the late 1960's that research was undertaken at Rutgers on the methods of using relatively low temperature but warm water for the beneficial heating of the root zone of the plant. A number of systems were designed to utilize various heat sources and warm water distribution systems in greenhouse floors or under benches. Today all three systems are in wide-spread commercial use, not always as a totally integrated system, though it often is the case."

Eco-Complex Research Greenhouse which features the design innovations mentioned in the citing of the program as one of the top five in the 20th century.

**Design of Greenhouse Systems**
**Short Course**
**January 8-9, 2001**
**Cook College Campus**
**Rutgers University**
**New Brunswick, NJ 08901**

**Course Coordinator Dr. A.J. Both**

**To Register Call**
**Margaret Stegmann**
**732 932 8451**
**Margs76@hotmail.com**

***See Program on Page 2***

## Greenhouse Design Check List

**Permits**

**Site Preparation**
- Leveling
- Drainage

**Greenhouse Foundation**
- Perimeter knee wall
- Walk ways
- Concrete floors
- Splash ways for roof runoff
- soil bearing capacity
- Interior post design

**Utility Provisions**
- Electricity
- Potable Water
- Irrigation water
- Telephone
- Natural Gas
- LP Gas storage tank
- Fuel oil storage tank
- Sewage system

**Greenhouse Structure**
- Roof glazing
- Side wall glazing
- End wall glazing

**Ventilation and Cooling Systems**
- Gable ventilation system
- Exhaust fans
- Pad system
- Roof ventilation system
- Natural ventilation system
- Open Roof Design
- Horizontal air flow fans
- Fog cooling system

**Curtain Systems**
- Energy retention systems thermal screens
- Inside shade system
- External shade system
- Gable shade system
- Black out system/day length control

**Environmental Control Units**
- Analog controllers
- Computer based controllers
- Alarm systems

**Electrical Installations**
- Service Entrance equipment
- Stand-by power generator
- Interface panels

**Heating Systems**
- Gas fired unit heater
- Oil fired unit heater
- Hot water unit heater
- Hot water boiler unit
- Perimeter piped hot water system
- Overhead piped hot water system
- Under-bench system piped hot water
- In-floor system piped hot water
- Pipe/rail heating system

**Irrigation Systems**
- Hand watering
- Overhead spray nozzle
- Floor sprinkler
- Irrigation boom (movable)
- Low level spray nozzle
- Flooded floor
- Drip irrigation

**Fertilizer Injection Equipment**
- Proportioners
- Injection units
- Liquid fertilizer injection system

**CO2 Injection units**
- Pure CO2 distribution system
- CO2 burners
- Flue gas CO2 extraction system

**Greenhouse Lighting**
- Supplementary lighting system
- Cyclic lighting system
- Walk-way and security lighting
- Day length control

**Growing Systems**
- Greenhouse floor
- Flooded greenhouse floor
- Fixed tables or benches
- Rolling tables
- Mobile or transportable tables
- Hanging basket systems
- Vegetable growing system

**Misc Installations Equipment**

**Site Finishing**

*Courtesy John Hoogeboom, CEO*
*Agronomico International, Hendersonville, North Carolina*

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## Design of Greenhouse Systems
**January 8 and 9, 2001**

This popular greenhouse engineering and environmental control short course will again be offered. Dr. AJ. Both, your editor, is the course coordinator and will be giving several presentations during the 1 1/2 days of lectures and demonstrations. The course will feature a one-half day tour to our new open-roof greenhouse, Kube Pak Corporation, and the Burlington County Resource Recovery Greenhouse which is operating on methane gas produced at the adjacent landfill Watch for registration information which will soon be announced. General information and course content is available now from your editor, AJ. Both. Mark the dates on your calendar and plan to attend this very informative course.

To register call Margaret Stegmann
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## Receive Horticultural Engineering via the Internet

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Thanks to those of you who have elected to receive this newsletter via the internet. Our hope is that many more of you will want to make use of the website and eliminate the need for us to send you a hard copy.

Thanks for helping us save the duplicating, postage, and handling costs, particularly since our staff has been greatly diminished.

We will send an e-mail announcing each new Horticultural Engineering Newsletter as it is posted on the web site.

Supplemental Lighting Strategy for Greenhouse Strawberrie Production

Joshua S. Gottdenker, Gene A Giacomelli, and Edward Durner

Abstract of a paper presented
at the 15th International Congress for Plastics in
Agriculture and the 29th National Agricultural Plastics Congress
September 24-27, Hershey, PA

**ABSTRACT** Controlled environment, hydroponic, greenhouse cultivation of Sweet Charlie strawberries is an effective method to target niche winter markets in the Northern US between October and June. Plants were conditioned in an environmentally controlled growth chamber and transplanted into 15 cm plastic pots on ebb and flood benches in a greenhouse on September 1. Fresh fruit yields were measured within daily light integral (DLI) treatments of 12, 9, 6 moles $m^2$ per day. Which were achieved by supplementing natural sunlight with high pressure sodium (HPS) artificial lamps. For comparison, the control consisted of only natural lighting. All treatments were exposed to incandescent night interruption for three hours at midnight, to ensure that long day conditions and plant reproductive stage would be maintained. High intensity discharge HPS supplemental lighting can help accelerate fruit maturation, which assists in targeting specific harvest dates. However, such lighting may not be needed for maintaining high total, late season yields. Total yields averaged between 111-127 grams per plant from October through January with a density off 11 plants per square meter, for all treatments. The economic value of the supplemental lighting treatments was determined by comparing the capitol and operational costs of the supplemental lighting with the increase in return that ensued. The results indicated that regardless of the amount of supplemental lighting, an economically viable system would need to provide at least a three fold increase of planting density, unless per plant yield can be significantly increased. Previous research has shown that comparable yields per plant are possible at 32 plants per square meter. Chocolate covered strawberries provide an interesting value added opportunity for high-quality fresh grown strawberries, which could drastically improve economic viability of the system.

Copies of the 600 page proceedings are available from:

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