Final Report

Energy Conservation Opportunities for Greenhouse Structures

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Disclaimer

Estimated energy savings and implementation costs for each opportunity are based on inputs from greenhouse owners, operators and suppliers along with experience with similar applications. While the energy conservation opportunities contained in this report have been reviewed for technical accuracy, **Minnesota Department of Commerce, State Energy Office and Eugene A. Scales & Associates Inc.** do not guarantee the cost savings or reduction in total energy use presented in the recommendations. The **Minnesota Department of Commerce, State Energy Office and Eugene A. Scales & Associates Inc.** shall, in no event, be liable in the event that potential energy savings are not achieved.

Specific manufacturers of coverings, thermal blankets, heating systems, etc., are identified in the body of this report. The report uses equipment models and costs to develop representative paybacks on energy saving opportunities. Manufacturers identified in the report are provided for informational purposes only and are not to be construed as recommendations.

Section 1

Introduction & Overview

This report identifies and quantifies energy conservation strategies for greenhouse structures; both new and retrofit opportunities. Greenhouses provide an environment for plant growth that includes controlled temperature, humidity, ventilation, lighting and CO2 control. Different plants require different combinations and variable amounts of these environmental controlled requirements. Winter conditions in Minnesota provide a challenge in maintaining an environment conducive to plant growth.

The primary objectives of this analysis are:

- Determine conservation strategies providing paybacks of less than 10 years that would facilitate compliance with the Minnesota State Energy Code for new greenhouse structures (Minnesota Rules, Part 7676.0900, Subpart 1, Items B and C).
- Provide a resource for suppliers, owners and operators of new and existing structures to identify and understand the value of energy conservation opportunities for greenhouse structures.

A simulation was developed to analyze conservation strategies. This approach was used to analyze the interactions of the strategies. The simulation considered cover material, heating systems, insulation, lighting, occupants, space conditions and operating schedules. Weather and solar data are based on conditions found in the Minneapolis and St. Paul Minnesota region.

A basic greenhouse structure with two-ply polyethylene covering was analyzed for two operating schedules:

- A greenhouse - operating all year. This is typical of many greenhouse structures currently found in the Minnesota.

- A greenhouse - operating only during the period of February though the summer months.

These extremes in operating schedules provide a range of simple paybacks for the conservation strategies analyzed so that owners and operators can better understand the feasibility of each and compare the relative economics of implementation.

The analysis also addresses opportunities applicable to larger greenhouse structures such as multiple units served by a central heating plant.

Section 2

Executive Summary

Introduction

Energy conservation strategies for greenhouse structures were analyzed separately and in selected combinations for the baseline structure operating year around and for the period February through the early fall months. The baseline structure was a 30' wide by 96' long by 8' high sides structure with 2 ply polyethylene covering and orientated east west along the long dimension. Energy and cost savings, installation costs and simple paybacks are summarized in Table 2 – 1 for opportunities evaluated singly and Table 2 – 2 for Integrated opportunities. The opportunities summarized in Table 2 – 1 also assumes that the structure has power vented heaters.

Energy Use and Supply

Space heating is the major energy use in greenhouse structures. A significant amount of heating energy required is supplied by solar heat gain as indicated below for full and partial year operation. Power for lighting and fan motors are the other energy use needs. Percentages of energy required for each use and sources that supply the required energy are summarized below.

Percentage of Energy Required/Supplied	**Full Yr**	**Partial Yr**
Energy Required For (Usage)		
Natural Gas Energy Required		
Space & Infiltration Air Heating	93.2%	97.4%
Electric Energy Required		
Motors	1.8%	2.6%
Lighting	5.0%	<.1%
Totals	100.0%	100.0%
Energy Supplied By (Source)		
Solar	35.9%	40.7%
Natural Gas	57.2%	56.5%
Electrical	6.8%	2.6%
People	.1%	.2%
Totals	100.0%	100.0%

Strategies for reducing heating energy and costs include:

Low Cost High Impact Opportunities

Energy Efficient Heating Systems – Unit heating systems with power vented exhaust as opposed to atmospherically vented systems stop airflow through the flue when the unit is not operating. Continuous airflow through the exhaust system during non-operating times allows the heating system to cool down. Warm air is vented out of the structure. The net result is that the seasonal efficiency of the heating system is reduced and excess energy is used.

Insulation on Walls – Insulation added to the North and East Walls during the winter months reduces heat loss and has a minimal impact on solar heat gain and transmission. Insulation panels, consisting of R-10 extruded polystyrene, put in place during the fall and taken out in the spring.

Infrared Anti-Condensate (IRAC) Covering – Installing a layer of IRAC film on the inside layer of the two ply covering reduces radiation during nighttime hours and heat loss from warm objects in the greenhouse. Anti condensate features of the film also disperse condensation and reduce dripping.

Night Setback Temperature Controls – If plant types grown can accommodate reduced temperatures during nighttime periods, significant energy and cost savings can be achieved.

High Impact High Cost Opportunities

Thermal Blankets – Thermal blankets can achieve significant energy savings. Thermal blankets act like thermal barriers within the greenhouse, reducing the amount of space that needs to be heated and radiant losses during nighttime hours.

Double Ply Polycarbonate Covering – This covering material greatly reduces heat loss and has a life expectancy of up to 20 years; 5 times longer than polyethylene. In addition to energy savings, the covering will require less maintenance over the years.

Section 4 also contains information on other energy and water saving opportunities including:

- Sewer Refunds
- Energy Efficient Lighting for Office and Storage Area
- Energy Efficient Motors

Table 2 – 1, Summary of Energy Conservation Opportunities

Energy Conservation Opportunity	Energy Savings (MCF)	Energy Cost Save ($)	Opportunity Costs ($)	Simple Payback (Years)
Heating Systems - Full Year				
Power Vented Heaters	143	$858	$880	1.03
Direct Vent Heaters	160	$960	$4,170	4.34
Heating Systems - Partial Year				
Power Vented Heaters	61	$366	$880	2.40
Direct Vent Heaters	69	$414	$4,170	10.07
Covering - Full Year				
Twin Wall Polycarbonate	127	$762	$12,725	16.70
Double Ply Film - Poly Outer, IRAC Inner	225	$1,350	$100	0.07
Coverings - Partial Year				
Twin Wall Polycarbonate	37	$222	$12,725	57.32
Double Ply Film - Poly Outer, IRAC Inner	75	$450	$100	0.22
Wall Insulation - Full Year				
R-5 Insulation	110	$660	$280	0.42
R-10 Insulation	127	$762	$280	0.37
Wall Insulation - Partial Year				
R-5 Insulation	42	$252	$280	1.11
R-10 Insulation	47	$282	$280	0.99
Thermal Blanket - Full Year	308	$1,848	$13,750	7.44
Thermal Blanket - Partial Year	108	$648	$13,750	21.22
Night Setback - Full Year				
5 F Setback	103	$618	$350	0.57
10 F Setback	191	$1,146	$350	0.31
Night Setback - Partial Year				
5 F Setback	44	$264	$350	1.33
10 F Setback	85	$510	$350	0.69

Table 2 – 2, Summary of Integrated Conservation Opportunities

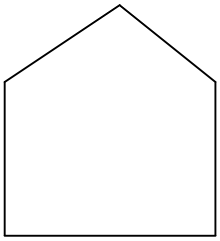
Integrated Strategy	Heating Energy (MCF)	Energy Savings (MCF)	Cost Savings ($)	Total Strategy Cost ($)	Simple Payback (Yrs)
Full Year Operation					
Baseline with Power Vented Heater	713				
+ IRAC Film	488	225	1350	100	0.07
+ R-10 Insulation on N/E Wall	410	303	1818	380	0.21
+ Setback Thermostat (10F)	292	421	2526	730	0.29
Baseline with Power Vented Heater	713				
+ Thermal Blanket	316	397	2382	13,750	5.77
+ R-10 Insulation on N/E Wall	263	450	2700	14,030	5.20
+ Setback Thermostat (10F)	181	532	3192	14,380	4.51
Partial Year Operation					
Baseline with Power Vented Heater	304				
+ IRAC Film	229	75	450	100	0.22
+ R-10 Insulation on N/E Wall	199	105	630	380	0.60
+ Setback Thermostat (10F)	142	162	972	730	0.75
Baseline with Power Vented Heater	304				
+ Thermal Blanket	153	151	906	13,750	15.18
+ R-10 Insulation on N/E Wall	135	169	1014	14,030	13.84
+ Setback Thermostat (10F)	96	208	1248	14,380	11.52

Section 3

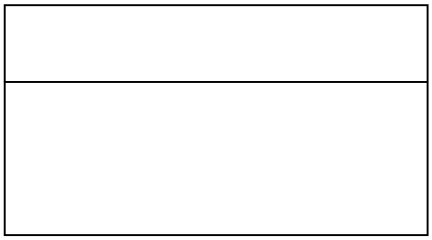
Baseline Greenhouse Structure

Structure Description/Orientation

The baseline greenhouse structure used to evaluate energy conservation strategies is a representative single structure 30’ wide and 96’ long, orientated east/west along the long axis. The structure would have an open gable or hoop roof, as illustrated below, and vertical sides. Framing is aluminum tubing with cemented in ground anchor posts.



30 Ft Wide
8 Ft Sides
13.5 Ft High



96 Ft Long

Surface Areas	Square feet
Roof (North Slope)	1,536
Roof (South Slope)	1,536
East Wall	322.5
West Wall	322.5
North Vertical Wall	768
South Vertical Wall	768
Total Surface Area	5,253
Floor Area	2,880 Sq Ft
Volume	30,960 Cu Ft

Solar Radiation

The greenhouse structure is assumed to be sited in an open area. Thus, the total or global amount of solar radiation would include direct and diffuse (i.e. sky and ground reflection) components.

Orientation

The baseline structure is assumed to be orientated with the long dimension along the east/west direction to maximize solar gain.

Solar Radiation

Average solar heat gain, by month, for the Minneapolis/St. Paul area for horizontal and north, south, east and west surfaces published by the National Solar Research Lab was used.

Operational Schedules

Two operational scenarios are analyzed to provide a range of the economics of energy conservation.

- Operation all year

- Partial year operation from February through the summer months

Covering

The baseline structure is covered with double ply polyethylene having solar transmissivity and R values of:

- Solar Transmissivity = .83 (% visible light)
- R Value = 1.43 sq ft Hr Sq Ft/BTU

The structure has a small inflation fan to create an air pocket between polyethylene sheets.

Internal Lighting System

Lighting consists of:

- Twenty-two 400 watt high pressure sodium fixtures, manually controlled during the evening hours during plant growth periods.

- Greenhouses that operate all year have lighting. Those operating from February through summer have no photoperiod lighting.

Infiltration

One air change per hour (i.e. 516 cubic feet per minute (cfm))

Indoor Temperature

68 F Constant

Insulation

No insulation on walls or perimeter areas around floor.

Internal Heating & Ventilating Systems

Heating Systems

Gas fired unit heaters, atmospherically vented, 65% seasonal efficiency, single stage gas and temperature control. Fan operates when burner is on.

Horizontal Circulation Fans

Four circulation fans with manual on/off, 2600 cfm and 1/10 HP. Circulation fans operate continuously during winter months to minimize temperature stratification.

Exhaust Fans

Two general exhaust fans, ¾ HP, two speed, temperature controlled with manual override, interlock with intake dampers 16,500/1,000 cfm.

One continuous exhaust fan, 1/3 HP, two speed, manual control, 1,100/1,600 cfm.

Baseline Structure Energy Use

Baseline structure energy use for each of the two operational scenarios is summarized in Tables 3-1 (all year operation) and 3-2 (February through summer). These tables represent heat loss through the greenhouse covering (i.e. conduction), heat required for infiltration and ventilation air, internal heat gains from lighting and motors and solar heat gain.

Simulation of the baseline structures indicate that 85% to 95% of the energy used in greenhouse structures is for space heating and ventilation. Ventilation includes infiltration of outdoor air into the structure. Required energy is:

Full Year Operation

Space Heating	467 MMBTU
Ventilation Air Heating	89 MMBTU
Total	556 MMBTU (Million BTU)

Partial Year Operation (February through Summer)

Space Heating	203 MMBTU
Ventilation Air Heating	34 MMBTU
Total	237 MMBTU

The tables also indicate the sources of energy that provide the required heating. Solar energy provides a large percentage of the heating and ventilation load.

Full Year Operation	349 MMBTU (36%)
February through Summer Operation	171 MMBTU (41%)

Energy costs are based on natural gas at $6.00/MCF (i.e. $0.60 per therm), electric demand costs at $7.00/kW and electric energy use at $0.045/kWh.

The tables do not contain data on radiant heat losses from plants and warm objects within the greenhouse. Radiant heat losses are difficult to determine. The approach used by many manufacturers has been to install systems and components that reduce radiant heat loss (e.g. thermal blankets and IR covering materials). Energy use and savings were determined by comparing similar or the same greenhouse structures with and without the component.

Section 4 and Appendixes C & D provide additional information on thermal blankets and infrared films that reduce radiant heat losses. Through measurements of energy use in greenhouses with this technologies, space heating requirements have been shown to be reduced by:

Thermal Blankets	30% to 70%
IR Films	30%

Table 3 – 1, Baseline Greenhouse, Full Year Operation

Energy Use

Usage	kW	kWh	MMBTU	% Use
Electric				
Motors	1.60	5,001	17	2.7%
Lights	10.23	14,424	49	7.9%
Heating				
Envelop			467	75.0%
			89	14.4%
Ventilation				
Totals			623	

Energy Sources & Costs

Sources	MMBTU	%	kW	kWh	Costs ($)
Solar	349	35.9%			$0
Heating	467	48.0%			$4,310
Ventilation	89	9.2%			$826
Lights	49	5.1%	10.23	14,424	$1,308
People	1	0.1%			$0
Motors	17	1.8%	1.60	5,001	$385
Totals	973	100%	11.83	19,425	$6,828

Table 3 – 2, Baseline Greenhouse, Partial Year Operation

Energy Use

Usage	kW	kWh	MMBTU	% use
Electric				
Motors	1.60	3,304	11	4.5%
Lights	0	0	0	0.0%
Heating				
Envelop			203	81.7%
			34	13.7%
Ventilation				
Totals			248	

Energy Sources & Costs

Sources	MMBTU	%	kW	kWh	Costs ($)
Solar	171	40.7%			$0
Heating	203	48.3%			$1,872
Ventilation	34	8.1%			$315
Lights	0	0.0%	0.00	0	$0
People	1	0.2%			$0
Motors	11	2.7%	1.60	3,304	$303
Totals	420	100%	1.60	3,304	$2,490

Section 4

Analysis of Energy Saving Opportunities

Introduction

This section identifies and analyzes feasible energy saving opportunities for both new and retrofit on existing greenhouse structures. These opportunities are analyzed singly and in selected combinations.

Energy saving opportunities is evaluated individually with respect to a baseline structure and for selected combinations. A fixed energy cost structure - $6.00/MCF natural gas, $7.00/KW electric demand and $0.045/KWH electric energy use is used to determine paybacks. Sales tax of 6.5% is included in the payback analysis of electric cost savings. Energy savings are identified for each opportunity such that the analysis can be customized for different rate structures.

Detailed data and costs on opportunities such as coverings, heating systems and thermal blanket costs are contained in the attached appendixes.

Utility Rebates

Electric/Gas Utilities

Utility rebates are often available for energy efficient equipment, systems and controls. Readers are encouraged to check with their local gas and electric utilities for prescriptive and custom efficiency rebates on new and retrofit equipment, systems and controls that save energy. Examples of applicable rebates that may be available from your utilities include:

- High intensity discharge lighting such as high-pressure sodium, metal halide or pulse start metal halide.
- T5 and T8 lamps and electronic ballasts
- Compact fluorescent lamps
- High efficiency heating systems such as power vented unit heaters and condensing boilers
- High efficiency unit heaters such as power vented or direct vented combustion models
- Systems that control space temperatures and shut off equipment
- Systems that control lighting
- Thermal blankets
- Perimeter and wall Insulation
- Steam trap surveys and new or rebuilt steam traps

Water Utilities

Many city and municipal water utilities offer refunds for sewer charges for water that evaporates and does not return to the sewer. These rebates and additional information about sub-metering requirements are further explained in this section of the report. Readers are encouraged to check with their local water utility for further information.

Heating Systems

A typical heating system used in greenhouse is a unit heater with propeller or blower fans controlled by a thermostat. Appendix A provides detailed descriptions.

Three units having different efficiencies are evaluated:

Atmospherically Vented – The baseline greenhouse structure is assumed to have a atmospherically vented heating system with a seasonal efficiency of 65%.

Power Vented – Combustion air is metered through the unit by a separate fan. When the unit is off, air venting is shut off. The unit has intermitted spark ignition. Seasonal efficiency is 78%.

Direct Vented – Combustion air is taken from the outside and vented to the outside. Unit designs allow some heat recovery from flue gas. The unit has intermittent spark ignition. Seasonal efficiency is 80%.

Each unit heating system type is assumed to have a single stage gas control and thermostat. Unit heaters can optionally burn propane for little or no additional cost. Oil fired models are available, but costs are high.

Number/Size of Heating Systems

The number and size of heating systems required is determined by the design-heating load for the structure. That is, the amount of heating energy required on a day when outdoor temperatures are –20 F, indoor air temperatures are 70 F and infiltration is about one air change per hour (i.e. 516 cfm) Simulations indicate a design heating load of 381,000 BTUH. Therefore, the heating systems and costs selected from Table A - 1, Appendix A are:

Atmospherically Vented	List Costs
1 Heater 200,000 BTU Output	$ 1,350
1 Heater 200,000 BTU Output	$ 1,350
Total	$ 2,700

Powered Vented

1 Heater 200,000 BTU Output	$ 1,755
1 Heater 200,000 BTU Output	$ 1,755
Total	$ 3,510

Direct Vented

1 Heater 229,600 BTU Output	$ 3,590
1 Heater 184,500 BTUU Output	$ 3,280
Total	$ 6,870

Table 4 -1 illustrates heating energy savings and costs and the economics of purchasing unit heaters with high thermal and seasonal efficiencies. Benefits are determined for both year around operation and partial year operation.

Incremental costs indicated in Table 4 - 1 do not include installation costs since these costs are approximately the same for each type of natural gas or propane heating system. Design heating capacities and are the same for both full and partial year operation. Oil fired heating systems are not analyzed in this report. However, typical costs are about 2.25 times higher.

The results indicate that additional costs of a power vented unit heater have a relatively short payback, even for greenhouses that operate a portion of the year. The results apply to both new and retrofit opportunities.

Table 4 – 1, Energy Efficient Heating Options

Structure Description	Heating Energy (MMBTU)	Gas Energy (MCF)	Heat System Cost ($)	Heating System ($)	Energy Cost Save ($)	Increment Equip Cost ($)	Simple Payback (Years)
<u>Full Year Operation</u>							
Atmospherically Vented Heaters	556	855	$2,700	$5,132			
Power Vented Heaters	556	713	$3,580	$4,277	$855	$880	1.03
Direct Vented Heaters	556	695	$6,870	$4,170	$962	$4,170	4.33
<u>February - Summer Operation</u>							
Atmospherically Vented Heaters	237	365	$2,700	$2,188			
Power Vented Heaters	237	304	$3,580	$1,823	$365	$880	2.41
Direct Vented Heaters	237	296	$6,870	$1,778	$410	$4,170	10.17

Covering Materials

Many transparent and translucent materials are used for greenhouse coverings including:

- Glass
- Polyethylene (Single and Double Layer)
- Polycarbonate (Single, Double and Triple Layer)
- Fiberglass
- Acrylic
- Selected Combinations of coverings (e.g. polyethylene over single pane glass)

Each has slightly different characteristics of insulation values, visible and infrared light transmittance, life expectancy and cost as indicated below. Double Ply Polyethylene is the baseline greenhouse covering used in this analysis.

Table B – 1, Appendix B provides typical greenhouse coverings used in Minnesota and associated solar transmission, insulation values and costs per square foot. Properties and costs vary by manufacturer. Typical coverings are identified in Table 4 – 2.

Table 4 – 2, Selected Greenhouse Covering Materials

Material	Life (Years)	U Value	R Value	Transmittance Solar % Visible Light	IR Thermal (%)	Cost Sq Ft ($)
Single Pane Glass	>20	0.91	1.1	90	<3	
Single Ply Polyethylene	4	1.10	0.91	87	50	$0.09
Double Ply Polyethylene	4	0.70	1.43	78	50	$0.18
Single Wall Polycarbonate	20	1.10	0.91	90	<3	$1.30
Twin Wall Polycarbonate	20	0.60	1.67	83	<23	$2.10
IRAC Inner, Poly Outer	4	0.50	2	76.5		$0.20

Covering tradeoff considerations can be evaluated on the basis of more than energy and lowest costs. Longer life expectancies of the hard coverings will save on-going maintenance and replacement costs. Tables 4 – 3 and 4 – 4 illustrate the costs benefits of selected coverings. Since the results are sensitive to heating system efficiencies, the results are illustrated for two heating systems; atmospherically vented and power vented.

The tables also illustrate energy use and costs for two-selected single ply coverings of polyethylene and polycarbonate. An infrared anti-condensate (IRAC) covering material is also analyzed . The combination includes an outer layer of clear polyethylene and inner layer of IRAC film.

IRAC covering material and infrared reduction benefits are discussed in Appendix D. A main benefit is the reduction of infrared heat loss to clear skies during nighttime hours. Benefits cited by one manufacturer are a 30% heating energy savings. In addition, newer films have improved solar transmittance values approaching clear polyethylene coverings.

The covering was evaluated on the basis of an advertised 30% reduction in heat loss with respect to a double ply polyethylene covering having a U value of .7 BTU/Sq Ft hr F. A 30% reduction would result in a U value of .5 BTU/sq ft hr F. This represents a two-ply covering consisting of clear polyethylene on the outer layer and IRAC film on the inner layer. The layers are separated by an air space.

The other issue is life cycle costs associated with covering materials such as polycarbonate that have an expected life of 20 years or about 5 times the life of 2 ply polyethylene. If evaluated on a comparable basis (i.e. assuming no inflation in energy costs), the following simple paybacks over 20 years are available:

Energy Savings ($)	Material costs ($)	Simple Payback (yrs)
$1,540	$ 4,950	3.20
$15,240	$ 14,500	0.95

Thus, for those evaluating covering options over a longer period of ownership, paying more initial construction costs will provide greater benefits over time. If other factors such as replacement time and cost were added to the analysis, the difference in paybacks would be larger.

Table 4 – 3, Selected Greenhouse Covering Material, (Atmospherically Vented Furnace)

Structure Description	Heating (MMBTU)	Natural Gas (MCF)	Cost ($) Heating	Net Save Heating ($)	Material Cost ($)	Simple Payback (Years)
<u>Full Year Operation</u>						
Single Ply Polyethylene	914	1,406	$8,437		$1,250	
Single Ply Polycarbonate	904	1,391	$8,345	$92	$10,050	95.33
Double Ply Polyethylene	556	855	$5,132		$1,775	
Twin Wall Polycarbonate	457	703	$4,218	$914	$14,500	13.92
Double Ply IRAC Film (Inner Layer, Polyethylene Outer)	381	586	$3,517	$1,615	$1,875	0.06
<u>February - Summer Operation</u>						
Single Ply Polyethylene	370	569	$3,415		$1,250	
Single Ply Polycarbonate	366	563	$3,378	$37	$10,050	238.33
Double Ply Polyethylene	237	365	$2,188		$1,775	
Twin Wall Polycarbonate	208	320	$1,920	$268	$14,500	47.54
Double Ply IRAC Film (Inner Layer, Polyethylene Outer)	179	275	$1,652	$535	$1,875	0.19

Notes:
1 - Area of Covering Material = 5,253 Sq Ft
2 - Cost of Material includes clamping systems and or additional structure supports
3 - Assumes installation by Owner/Operator

Table 4 – 4, Selected Greenhouse Covering Material, (Power Vented Furnace)

Structure Description	Heating (MMBTU)	Natural Gas (MCF)	Cost ($) Heating	Net Save Heating ($)	Material Cost ($)	Simple Payback (Years)
<u>Full Year Operation</u>						
Single Ply Polyethylene	914	1,172	$7,031		$1,250	
Single Ply Polycarbonate	904	1,159	$6,954	$77	$10,050	114.40
Double Ply Polyethylene	556	713	$4,277		$1,775	
Twin Wall Polycarbonate	457	586	$3,515	$762	$14,500	16.71
Double Ply IRAC Film (Inner Layer, Polyethylene Outer)	381	488	$2,931	$1,346	$1,875	0.07
<u>February - Summer Operation</u>						
Single Ply Polyethylene	370	474	$2,846		$1,250	
Single Ply Polycarbonate	366	469	$2,815	$31	$10,050	286.00
Double Ply Polyethylene	237	304	$1,823		$1,775	
Twin Wall Polycarbonate	208	267	$1,600	$223	$14,500	57.04
Double Ply IRAC Film (Inner Layer, Polyethylene Outer)	179	229	$1,377	$446	$1,875	0.22

Notes:

1 - Area of Covering Material = 5,253 Sq Ft

2 - Cost of Material includes clamping systems and or additional structure supports

3 - Assumes installation by Owner/Operator

Insulation of Walls

Additional insulation can be temporarily installed on the structure sidewalls to save heating energy (Appendix C). Areas where additional panels can be installed on the baseline structure while minimizing loss of solar gain are:

- North Wall – 8 Feet High Wall x 96 Feet Long (768 Sq Ft)
- East Wall – 8 Feet Wall x 30 Feet Long (240 Sq Ft)

The type of insulation installed is assumed to be 4' wide x 8' high polystyrene panels along the wall and held in place by a simple clamps connected to structure supports. Two insulation scenarios for the baseline structure are evaluated.

Additional Insulation Scenario 1 - 1 " Polystyrene Panel

- R = 5.0 Sq Ft Hr F/BTU (U = .2)
- Insulated Area of 1008 Sq Ft (19.2% of Surface Area)
- Net Structure R Value increased from R = 1.43 to R = 2.47

Additional Insulation Scenario 2 - 2 " Polystyrene Panel

- R = 10.0 Sq Ft Hr F/BTU (U = .2)
- Insulated Area of 1008 Sq Ft (19.2% of Surface Area)
- Net Structure R Value increased from R = 1.43 to R = 3.51

Energy and cost savings are summarized in Table 4 – 4 and 4 – 5. The analysis indicated that the additional insulation decreased the heating load by:

R – 5 Insulation

Full Year Operation	15.5%
Partial Year Operation	13.8%

R –10 Insulation

Full Year Operation	17.8%
Partial Year Operation	15.6%

The resulting paybacks on installing the additional insulation are less than one year.

Another benefit of installing insulation (i.e. on a permanent or annual basis) is the decrease in design heating capacity as indicated below:

Structure/Insulation	Design Heat Load (BTUH)
Baseline	381,000
Baseline + R -5	328,000
Baseline + R -10	321,000

The capacity of the unit heaters installed can be reduced, resulting in lower initial structure costs. A comparison to the baseline heating capacity for two different heating system efficiencies is illustrated below.

Structure/Insulation	Cost of Unit Heaters		Savings
	2 Ply Cov	2 Ply + R5/10	
Baseline			
Atmospherically Vented	$2,700	$2,420	$280
Power Vented	$3,500	$3,180	$320

The above analysis assumes that the added insulation would be installed each year or left in place all year. Of interest is that the savings from reduced heating system costs are about the same as the cost of the insulation. The design heating loads between R – 5 and R – 10 insulation did not warrant a smaller unit heater.

Table 4 – 4, Insulation with 1” (R-5) Polystyrene Panels

Operational Scenario	Baseline Structure		Insulated Structure	
	(MMBTU)	(MCF)	(MMBTU)	(MCF)
Atmospherically Vented Heaters (65% Seasonal Eff)				
Full Year	556	855	470	723
Partial Year	237	365	204	314
Power Vented (78% Seasonal Eff)				
Full Year	556	713	470	603
Partial Year	237	304	204	262

Operational Scenario	Savings (MCF)	Cost Save ($)	Insulation Cost ($)	Simple PB (Yrs)
Atmospherically Vented Heaters				
Full Year	132	$794	$280	0.35
Partial Year	51	$305	$280	0.92
Power Vented				
Full Year	110	$662	$280	0.42
Partial Year	42	$254	$280	1.10

Table 4 – 5, Insulation with 2" (R-10) Polystyrene Panels

Operational Scenario	Baseline Structure (MMBTU)	Baseline Structure (MCF)	Insulated Structure (MMBTU)	Insulated Structure (MCF)
<u>Atmospherically Vented Heaters (65% Seasonal Eff)</u>				
Full Year	556	855	457	703
Partial Year	237	365	200	308
<u>Power Vented (78% Seasonal Eff)</u>				
Full Year	556	713	457	586
Partial Year	237	304	200	256

Operational Scenario	Savings (MCF)	Cost Save ($)	Insulation Cost ($)	Simple PB (Yrs)
<u>Atmospherically Vented Heaters</u>				
Full Year	152	$914	$280	0.31
Partial Year	57	$342	$280	0.82
<u>Power Vented</u>				
Full Year	127	$762	$280	0.37
Partial Year	47	$285	$280	0.98

Thermal Blankets

Description

Thermal blankets are used as an internal cover for plants and creates a “envelop” within the greenhouse structure much like a home with an attic. Thermal blankets reduce energy use in three ways:

- Reduce the amount of greenhouse volume that requires heating.
- The additional insulation values of the blanket material provide thermal resistance. The amount is dependent on the material and is difficult to predict because of the characteristic of the material.
- Radiant heat loss reduction is the largest benefit. Warm plant surfaces radiate energy. The net energy exchange is the rate of emission of the surface (emissivity), temperature and surface area. A thermal blanket blocks and thus reduces the radiation. The reduction is dependent on the blanket material and its emissivity. A good material is one that has low emissivity (i.e. high reflectivity) on the surface facing the outer cover and is highly reflective on the inner surface facing the plants. Since heat loss is a direct function of emissivity, blanket materials having aluminized surfaces with low emissivity values minimize heat loss.

Since thermal blankets also serve to shade crops, the material tends to be porous (e.g. woven materials). Porous blankets allow moisture to drain and allow some heat to escape. Non-porous materials, such as polyethylene trap water and condensation and block out light (i.e. depends on material) that reduces heat retention during daylight hours. Aluminized material provides a compromise between the two extremes; reflecting sunlight during the day and reducing heat loss at night.

As indicated in Appendix D, the radiant heat loss calculations are dependent on temperatures and emissivity values that are difficult to determine and vary by plant type, greenhouse covering and outdoor temperatures.

Published information on heat loss savings for greenhouse’s having thermal blankets have been determined by installing thermal blankets, measuring or recording energy use over a period of time or season and adjusting the overall U value of the greenhouse covering thermal blanket combination.

Installation & Retrofit

Installation on a new structure is the most optimal since the blanket and drive system can be installed on overhead structural supports before other components such as fans and lights are attached. Thermal blankets can be retrofit on existing greenhouse structures. The main issue is that existing equipment and systems mounted on the ceiling supports (e.g., lighting fixtures, piping, fans, heaters) may have to be re-moved and re-mounted.

Insulation Values of Installed Thermal Blanket Material

Insulation values published in Greenhouse Engineering publications provide net insulation values for selected combinations of thermal blankets material and single glass glazing. These are summarized in Table 4 - 6.

Table 4 - 6, Insulation Values of Selected Greenhouse Single Pane Glass Covering/Thermal Blanket Combinations

Blanket Description	Net U Value BTU/Sq Ft Hr F	Net R Value Sq Ft Hr F/BTU
Single Glass Glazing	1.1	0.91
Aluminized Polyethylene Tubes	0.54	1.85
White-White Spun Bonded Polyolefin Film	0.51	1.96
Heavy Weight Grey White Spun Bonded Film	0.43	2.33
Light Weight Grey White Spun Bonded Film	0.56	1.79
Clear Polyethylene Film	0.45	2.22
Black Polyethylene Film	0.48	2.08
Aluminum Foil-clear Vinyl Film Laminate	0.4	2.50
Aluminum Foil - Black Vinyl Film	0.63	1.59
Aluminum Fabric	0.39	2.56

One manufacturer of thermal blanket material publishes energy saving potential for their product (e.g. L.S. Svenson). Published energy saving data ranges from 47% to 72% for the XLS10 to XLS18 material, which is aluminum foil with clear vinyl film laminate. The different energy savings are functions of the percentage blanket area covered by the aluminum foil.

The baseline building used for comparison in this analysis has a covering of 2 ply polyethylene (i.e. U = .69). A comparative range of net U values from .41 BTU/Sq Ft hr F (40% save) to .28 BTU/Sq Ft hr F (60% save) are used in the analysis illustrated in Tables 4 - 7 and 4 - 8. Paybacks range from 4.5 to 7.5 years, for full year operation. Payback on partial year operation ranges from 12.3 to 21.8 years.

Cost of Thermal Blankets

Costs of an installed thermal blanket for a new baseline structure are about $14,750 for the baseline structure. The tables below indicate the same cost for both of the thermal blanket materials analyzed. Thermal blanket cloth material portion of the total costs is about 10%. The main costs are the hardware and controls and installation. Users should consider material with higher energy savings if shading is not an issue.

Table 4 – 7, Thermal Blanket (40% Heat Save)

Structure Description	Heating (MMBTU)	Natural Gas (MCF)	Cost ($) Heating	Net Save ($)	Initial Cost ($)	Simple Payback (Years)
Full Year Operation						
Baseline Structure W/O Blanket	556					
Atmospherically Vented Heaters		855	$5,132			
Power Vented Heaters		713	$4,277			
Direct Vented Heaters		695	$4,170			
Baseline Structure With Blanket	316					
Atmospherically Vented Heaters		486	$2,917	$2,215	$13,750	6.21
Power Vented Heaters		405	$2,431	$1,846	$13,750	7.45
Direct Vented Heaters		395	$2,370	$1,800	$13,750	7.64
February - Summer Operation						
Baseline Structure W/O Blanket	237					
Atmospherically Vented Heaters		365	$2,188			
Power Vented Heaters		304	$1,823			
Direct Vented Heaters		296	$1,778			
Baseline Structure With Blanket	153					
Atmospherically Vented Heaters		235	$1,412	$775	$13,750	17.73
Power Vented Heaters		196	$1,177	$646	$13,750	21.28
Direct Vented Heaters		191	$1,148	$630	$13,750	21.83

Table 4 – 8, Thermal Blanket (60% Heat Save)

Structure Description	Heating (MMBTU)	Natural Gas (MCF)	Cost ($) Heating	Net Save ($)	Initial Cost ($)	Simple Payback (Years)
<u>Full Year Operation</u>						
Baseline Structure W/O Blanket	556					
Atmospherically Vented Heaters		855	$5,132			
Power Vented Heaters		713	$4,277			
Direct Vented Heaters		695	$4,170			
Baseline Structure With Blanket	230					
Atmospherically Vented Heaters		354	$2,123	$3,009	$13,750	4.57
Power Vented Heaters		295	$1,769	$2,508	$13,750	5.48
Direct Vented Heaters		288	$1,725	$2,445	$13,750	5.62
<u>February - Summer Operation</u>						
Baseline Structure W/O Blanket	237					
Atmospherically Vented Heaters		365	$2,188			
Power Vented Heaters		304	$1,823			
Direct Vented Heaters		296	$1,778			
Baseline Structure With Blanket	116					
Atmospherically Vented Heaters		178	$1,071	$1,117	$13,750	12.31
Power Vented Heaters		149	$892	$931	$13,750	14.77
Direct Vented Heaters		145	$870	$908	$13,750	15.15

Control Systems

Control systems are available to perform a number functions to optimize greenhouse operation including the following basic functions:

Heating system Control
Space Temperature Control
Start/Stop of Equipment and Systems (e.g. exhaust, circulation fans, thermal blankets and lighting)

Appendix F provides additional information on control systems and costs.

Functions applicable to saving energy in the baseline greenhouse structure are:

- Temperature control as a function of time of day, especially night setback. Note that temperature setback is dependent on type of crop and growth cycle and may not be applicable to all greenhouse operations.
- Lighting system start/stop control.

The following analysis illustrates energy savings for:

- Temperature Setback - Two setback strategies; a 5 F setback and a 10 F setback during nighttime hours.
- Lighting System Control – Assumes that typical savings of 10% in optimal start stop times can be achieved.

Paybacks are provided for two approaches, simple setback thermostats and timers and a basic control system.

Night Setback

Tables 4 – 9 and Table 4 – 10 provides potential energy and cost savings from reducing night time space temperatures during the period 9 PM to 8 AM for 5 F and 10 F temperature setbacks. Table 4 – 9 provides paybacks for a simple programmable thermostat and Table 4 – 10 for a basic control system.

Lighting Control

Lighting controls reduce lighting energy use, but increase nighttime heating energy. Potential energy and cost savings from reduced lighting energy using simple mechanical timers can be illustrated as follows:

Energy Use/Costs	Baseline Structure	Baseline Structure with Lighting Control
Lighting		
Energy Use kWh	14,424	13,043
Cost	$1,308	$1,241
Heating		
Heating Energy MCF	713	719
Cost	$4,277	$4,315
Net Savings		$ 38

Installed timers costs (two totaling about $620, Appendix F) would have a payback exceeding 10 years.

Table 4 – 9, Night Temperature Setback (5 F & 10 F) with Setback Thermostat

Operational Scenario	Baseline Energy (MCF)	Energy Use 5 F Setback (MCF)	Energy Saving (MCF)	Energy Use 10 F Setback (MCF)	Energy Saving (MCF)
Atmospherically Vented Heaters (65% Sesonal Eff)					
Full Year	885	732	153	625	260
Partial Year	365	313	52	264	101
Power Vented (78% Seasonal Eff)					
Full Year	713	610	103	522	191
Partial Year	304	260	44	219	85

Operational Scenario	Cost Save 5 F Setback ($)	Cost Save 10 F Setback ($)	Installed Cost ($)	Simple Payback 5 F (Yrs)	Simple Payback 10 F (Yrs)
Atmospherically Vented Heaters					
Full Year	$918	$1,560	$350	0.38	0.22
Partial Year	$312	$606	$350	1.12	0.58
Power Vented					
Full Year	$618	$1,146	$350	0.57	0.31
Partial Year	$264	$510	$350	1.33	0.69

Table 4 – 10, Night Temperature Setback (5 F & 10 F) with Basic Controller

Operational Scenario	Baseline Energy (MCF)	Energy Use 5 F Setback (MCF)	Energy Saving (MCF)	Energy Use 10 F Setback (MCF)	Energy Saving (MCF)
Atmospherically Vented Heaters (65% Sesonal Eff)					
Full Year	885	732	153	625	260
Partial Year	365	313	52	264	101
Power Vented (78% Seasonal Eff)					
Full Year	713	610	103	522	191
Partial Year	304	260	44	219	85

Operational Scenario	Cost Save 5 F Setback ($)	Cost Save 10 F Setback ($)	Installed Cost ($)	Simple Payback 5 F (Yrs)	Simple Payback 10 F (Yrs)
Atmospherically Vented Heaters					
Full Year	$918	$1,560	$2,500	2.72	1.60
Partial Year	$312	$606	$2,500	8.01	4.13
Power Vented					
Full Year	$618	$1,146	$2,500	4.05	2.18
Partial Year	$264	$510	$2,500	9.47	4.90

Mixed Strategy Opportunities

Combinations of individual energy saving opportunities can be analyzed to determine the benefits of mixed or integrated conservation strategies. The following selected combinations are illustrated for full year operation.

- Baseline with power vented heater
- Baseline with power vented heater + IRAC Film on inner layer
- Baseline with power vented heater + IRAC Film on inner layer + Insulation on North & East Walls
- Baseline with power vented heater + IRAC Film on inner layer + Insulation on North & East Walls + Night Setback of 10 F

- Baseline with power vented heater
- Baseline with power vented heater + Thermal Blanket
- Baseline with power vented heater + Thermal Blanket + Insulation on North & East Walls
- Baseline with power vented heater + Thermal Blanket + Insulation on North & East Walls + Night Setback of 10 F

These basic combinations were analyzed for the baseline greenhouse structure with power vented unit heaters for year around operation. The results of the analysis are contained in Tables 4 - 11. Note that IRAC film costs are incremental costs over polyethylene and that total strategy costs are accumulative.

Table 4 – 11, Mixed Integrated Conservation Strategies

Integrated Startegy	Heating Energy (MCF)	Energy Savings (MCF)	Cost Savings ($)	Total Strategy Cost ($)	Simple Payback (Yrs)
<u>Full Year Operation</u>					
Baseline with Vented Heater	713				
+ IRAC Film	488	225	1350	100	0.07
+ R-10 Insulation on N/E Wall	410	303	1818	380	0.21
+ Setback Thermostat (10F)	292	421	2526	730	0.29
Baseline with Vented Heater	713				
+ Thermal Blanket	316	397	2382	13,750	5.77
+ R-10 Insulation on N/E Wall	263	450	2700	14,030	5.20
+ Setback Thermostat (10F)	181	532	3192	14,380	4.51
<u>Partial Year Operation</u>					
Baseline with Vented Heater	304				
+ IRAC Film	229	75	450	100	0.22
+ R-10 Insulation on N/E Wall	199	105	630	380	0.60
+ Setback Thermostat (10F)	142	162	972	730	0.75
Baseline with Vented Heater	304				
+ Thermal Blanket	153	151	906	13,750	15.18
+ R-10 Insulation on N/E Wall	135	169	1014	14,030	13.84
+ Setback Thermostat (10F)	96	208	1248	14,380	11.52

Energy Saving Strategies Applicable to General Greenhouse Operations

The following energy conservation strategies are applicable to new and or retrofit opportunities typically encountered in greenhouses or adjoining structures such as office and storage areas.

Water Cost Saving Opportunities

The amount of water used in a greenhouse will vary depending on area, plant type, time of year, weather and heating ventilation system. Water used in greenhouses may be eligible for a sewer surcharge rebate since it does not return to the sanitary sewer. The reader should check with their local water utility for potential surcharge rebates.

Sewer surcharges for water are available from many communities for applications such as commercial lawn sprinklers, and cooling tower makeup water. Typically, the following is required for a sewer surcharge rebate:

Water must be purchased from the local water utility.
The local water utility has a sewer surcharge. Typically, sewer surcharges are 50% to 60% of the total charge.
Water used for applications qualifying for sewer surcharge rebates must be metered separately or sub-metered off the general building service. Note that some water utilities have specific qualifications for meter types that must be used.

Typical Amounts of Water Required for Plants

Estimates of maximum daily water requirements for selected different crops were obtained from Greenhouse Engineering and are based on a per square foot area of the greenhouse floor. These include:

Crop Description	Gallons/Sq Ft Day
Bench Crops	= .4
Bedding/Pot Plants	= .5
Mums/Hydrangea	= 1.5
Roses	= .7
Tomatoes	= .25

Total Annual Requirement Estimates

The following provide an estimate of the total amounts of water required based on a greenhouse footprint of 30’ x 96’ or 2,880 sq ft. The analysis is used for illustrative purposes and provides sewer rebate amounts.

	.25 gal/sq ft	1.5 gal/sq ft
Daily Range	720	4,320
Annual Range (180 days)	129,600 gal	777,600 gal

Water/Sewer Rates

Water/sewer rates for Minneapolis and St. Paul, Minnesota (2003) were used to provide a range of estimated surcharge amounts.

City of Minneapolis, Minnesota

• Water	$ 2.95/1,000 Gal
• Sewer	$ 4.38/1,000 Gal

City of St. Paul, Minnesota

• Water	$ 2.03/1,000 Gal
• Sewer	$ 3.23/1,000 Gal

Sewer Surcharge Rebates

City	Range of Refund
Minneapolis	$569 - $3,407
St. Paul	$420 - $2,513

Installed cost of Water Meter

The installed cost of the water meter can depend on a number of factors. A worst-case scenario is that an additional water meter with backflow preventer would have to be installed. Estimated installed costs are $1,500. Payback ranges are:

Minneapolis	.5 to 2.6 years
St. Paul	.6 to 3.5 years

The reader is cautioned to check with their local utility for availability of potential surcharge rebates and rules governing installation and meter types.

Energy Saving Lighting Opportunities

Greenhouse structures and adjoining office/storage facilities use a variety of lighting systems. The following illustrates comparative energy use and costs for common opportunities in the following two areas.

Greenhouse and Storage Areas

- Pulse Start Metal Halide Fixtures
- High/Low Bay T8 Fluorescent Fixtures

Office Areas

- Fluorescent fixtures having 4' T8 lamps and electronic ballast instead of T12 lamps
- Compact Fluorescent Lamps in fixtures having incandescent lamps
- Light Emitting Diode (LED) Exit Signs

Greenhouse and Storage Areas

Pulse Start Metal Halide Fixtures and Retrofits

A common lighting fixture used in greenhouse storage areas and sometimes in greenhouses for photoperiod light is a 400-watt metal halide fixture. Although high-pressure sodium is more common, this lighting technology, a variation of standard metal halide technology, has been available for about 5-6 years. Recent additions to the product line have included larger wattage 750, 875, 1000 and 2000-watt fixtures.

Pulse start fixtures offer many features including lower lumen depreciation. This provides an opportunity to use lower wattage lamps that provide equal or greater lighting levels with less energy use. Use of a pulse start fixture also provides the opportunity to design a lighting system that requires fewer fixtures.

Unfortunately, large wattage pulse start metal halide lamps are limited to base up configurations (e.g. light must hand down) at the current time. One manufacturer, Sylvania, manufacturers a 750 watt pulse start lamp for horizontal configuration. Large pulse start metal halide lamps for universal and/or horizontal configuration are expected to be available in the near future (i.e. 1- 2 years) as the market matures.

Pulse start metal halide fixtures for new structures and retrofit applications are currently limited to replacement or retrofit for the current fixtures if base up lamps are used.

Costs

New pulse start fixtures cost about 15% to 20% more than standard metal halide fixtures.

Pulse Start Retrofit Examples

Two opportunities are analyzed to illustrate the benefits of pulse start lighting. Operating hours are assumed to be 2,500 hours per year.

Retrofit Existing 400 Watt Metal Halide with 320 Watt Pulse Start Lamp and Ballast

Energy Savings

Demand (kW)

(460 – 365) Watts = .095 kW

Energy Use (kWh)

.095 kW x 2,500 hrs/yr = 238 kWh

Cost Savings

Demand

.095 kW x $7.00 x 12 mo =$ 7.98

Energy Use

238 kWh x $0.045/kWh =$ 10.71

Sales Tax @ 6.5% =$ 1.21

Total Annual Save =$ 19.90

Costs
Lamp and Ballast =$ 75.00
Estimated Labor =$ 80.00

Total =$ 155.00

Simple Payback
$155/$19.90 = 7.8 years

Install 320 Watt Pulse Start Fixtures – New Construction

Incremental Cost =$ 55.00

Note that labor costs would be the same as installing a standard 400-watt metal halide fixture.

Simple Payback

$55/$19.90 = 2.8 years

High/Low Bay T8 Fluorescent Fixtures

Lighting fixtures used for greenhouse photoperiod lighting tend to be compact fixtures with reflectors that are hung from overhead support structures. Height above the plants and spacing are important considerations. High-pressure sodium lamps are typical, but metal halide lamps are also available.

A recent innovation is a T8 fixture having six (6) 32 watt 4’ lamps, electronic ballast with optional reflector. These fixtures provide approximately the same amount of lumens as a 400-watt metal halide, but use substantially less energy (e.g. about 224 watts/fixture) and have about the same expected life. They were designed to replace standard high/low bay 400-watt metal halide fixtures. Thus, they would be directly applicable for storage areas and potentially for photoperiod lighting. Costs are about $100 more per fixture than a standard 400-watt metal halide fixture. The following illustrates the benefits of installing these fixtures in a new application, 2,500 operational hours per year are assumed.

Energy Savings

Demand (kW)

(460 – 224) watts = .236 kW

Energy Use (kWh)

.236 kW x 2,500 hrs/yr = 509 kWh

Cost Savings

Demand

.236 x $7.00/mo x 12 mo =$ 19.82

Energy Use (kWh)

590 kWh x $0.045 =$ 26.55

Sales Tax @ 6.5% =$ 3.01

Total Annual Savings =$ 49.38

Incremental Cost =$ 100.00

Simple Payback = 2 years

Office Areas

T8 Lighting

Fluorescent fixtures having T8 lamps with electronic ballasts are a common retrofit for existing fluorescent fixtures having T12 lamps and older style magnetic ballasts. Benefits include:

- Energy savings up to 40%, depending on the number of lamps per fixture
- Increased lighting levels because of decreased lumen depreciation. That is, the lighting output of all fluorescent lamps decreases over time. Light from T8 lamps does not decrease as much as T12 lamps, so the light output remains high.

T8 lighting technology is about 10-12 years old. Cost of new fixtures having T8 lamps and electronic ballasts is about the same, or less, than similar fixtures having T12 lamps.

The following illustrates energy and cost savings from retrofitting a four-lamp fixture operating 2,500 hours per year.

Energy Savings

Demand (kW)
(178-109) watts = .071 kW

Energy Use Savings (kWh)

.071 kW x 2,500 hrs/yr = 178 kWh

Cost Savings

Demand

.071 kW x $71/kW x 12 mo =$ 5.96

Energy Use

178 kWh x $0.045/kWh =$ 8.01

Sales Tax at 6.5% =$ 0.91

Total Annual Save =$ 14.06

Retrofit Costs
Ballast =$ 24.00
4 T8 Lamps @ $2.25 =$ 9.00
Labor @ $25/fixture =$ 25.00
Lamp/Ballast Disposal =$ 5.00

Total Cost =$ 63.00

Simple Payback = 4.5 years

Compact Fluorescent Lamps

Compact fluorescent lamps are direct replacements for incandescent lamps in typical office fixtures including table lamps and recessed ceiling fixtures. Advances in the technology and physical packaging of the lamps have resulted in lamps that can fit in most any fixture and still maintain acceptable light levels and appearance.

Compact fluorescent lamps save about 60% of the energy used by a comparable sized incandescent lamp and have an expected life approaching 10,000 hours. The following illustrates the benefits of replacing a 75-watt incandescent lamp with a 23-watt compact fluorescent lamp, 2500 operational hours per year are assumed.

Energy Savings

Demand (kW)

(75-23) watts = .052 kW

Energy Use (kWh)

.052 kW x 2500 hrs/yr = 130 kWh

Cost Savings

.052 kW x $7.00/mo =$ 4.37
130 kWh x $0.045/kWh =$ 5.85

Sales Tax @ 6.5% =$ 0.66

Total Annual Save =$ 6.51

Cost of Compact Fluorescent Lamp

Costs of compact fluorescent lamps have dropped considerably and can now be purchased at lighting companies, home improvement stores and hardware stores.

Costs vary considerably, but $3 - $4 per lamp is typical.

Simple Payback

$3.50/$4.51 = .5 years

Light Emitting Diode (LED) Retrofits of Exit Signs

LED exits signs consume about 2 watts of power as opposed to exit signs having incandescent (two 15 – 20 watt) or fluorescent (two 5 – 7 watt) lamps. Since they also have an expected life of 25 years plus, they provide on-going maintenance savings.

The existing state of Minnesota Energy Code limits exit sign power to 5 watts per side on new structures.

LED kits can be retrofit on existing exit signs. Two typical scenarios are analyzed; an existing fixture having two 7-watt lamps and one having two 15-watt lamps.

Common Assumptions

- 8,760 hours per year operation.

Existing Fixture with Two 7 Watt Lamps

Demand Savings

1 Fixtures x (14 – 2) watts per fixture = .012 kW

Energy Use Savings

.012 kW x 8,760 hrs/yr = 105 kWh

Annual Cost Savings

.012 kW x $7.00/kW x 12 months =$ 1.01
105 kWh x $0.045/kWh =$ 4.73
Sales Tax at 6.5% =$ 0.37

Total =$ 6.11

Cost

1 Conversion Kits @ $45 each =$ 45.00
1 Installations @ $20 each =$ 20.00

Totals =$ 65.00

Simple Payback = 10.6 Yrs

<u>Existing fixture with Two 15 watt lamps</u>

Demand Savings

1 Fixtures x (30 – 2) watts per fixture = .028 kW

Energy Use Savings

.028 kW x 8,760 hrs/yr = 245 kWh

Annual Cost Savings

.028 kW x $7.00/kW x 12 months =$ 2.35
245 kWh x $0.045/kWh =$ 11.03
Sales Tax at 6.5% =$ 0.87

Total =$ 14.25

Initial Cost

1 Conversion Kits @ $45 each =$ 45.00
1 Installations @ $20 each =$ 20.00

Totals =$ 65.00

Simple Payback = 4.6 Yrs

Energy Efficient Motors Opportunities

Heating, ventilating units and pumping systems are sold with energy efficient motors. Energy efficient motors greater than 1 HP are required by the Energy Policy Act of 1992 (Appendix E). Most systems can be ordered with premium efficient motors for an incremental cost, depending on the size of the motor. Premium efficient motors also qualify for rebates from most utilities.

Premium efficient motors can also be retrofit on existing heating, ventilating and pumping systems having either older standard efficient or newer energy efficient motors. Paybacks are dependent on operating hours.

The economics of purchasing premium efficient motors is highly dependent on operating hours. Two examples are provided to illustrate paybacks:

- Replacing an older standard efficiency motor with a premium efficient motor
- Purchasing an optional premium efficient motor

Both scenarios assume that the motor will operate 2,500 hrs/yr (i.e. about 7 hr/day)

<u>Common Assumptions</u>

Motor Size = 2 HP
Standard Efficiency Rating = 80.7%
High Efficiency Rating = 84.0%
Premium Efficiency Rating = 86.5%
Incremental Cost (premium vs high) = $65.00
Labor Cost = None

No labor costs are assumed since the motor needs to be replaced.

Replace 2 HP Standard Efficiency Motor with Premium Efficiency Motor

Energy Savings

kW = 2 HP x .746 kW/HP x (1/80.7% - 1/86.5%) = .12 kW
kWh = .12 kW x 2500 hrs/yr = 300 kWh

Cost Save

kW = .12 kW x $7/kW x 12 mo/yr = $10.00
kWh = 300 kWh x $0.045/kWh = $13.50
Sales Tax = $ 1.50

Total Save = $25.00

Simple Payback

$65 Cost/$25.00 Save = 2.6 yrs

Order optional 2 HP Premium Efficient Motor as opposed to High Efficient Motor

Energy Savings

kW = 2 HP x .746 kW/HP x (1/84.0% - 1/86.5%) = .05 kW
kWh = .05 kW x 2500 hrs/yr = 125 kWh

Cost Save

kW = .05 kW x $7.00/kW x 12 mo/yr = $ 4.20
kWh = 125 kWh x $0.045/kWh = $ 5.60
Sales Tax = $ 0.65

Total Save = $10.45

Simple Payback

$65 Cost/$10.45 save = 6.2 yrs

Energy Efficient Heating System Opportunities

Larger greenhouses often use a combination of heating systems including unit heaters and boilers to provide space heating. Standard efficiencies of boilers is about 80%

Other types of heating systems are available to provide space and ventilation air heating that have higher efficiencies, but with higher first costs. This analysis illustrates one potential option for greenhouses that use hot water boilers

High Efficiency condensing Hot Water Boiler System

High efficiency condensing boilers for space and ventilation air heating have efficiencies up to 95%. These boilers also have high turndown or fully modulating burners that increase overall efficiency during the spring fall months when heating loads are light. The following illustrates the potential savings for a greenhouse consisting of four gutter connected units having a annual heating load of about 2,000 MMBTU.

Costs Estimates

- One condensing hot water boilers, 92% Efficiency,
  1 MMBTU Input =$ 13,000
- Cost of Standard efficiency boiler, 1 MMBTU Input and
  Standard high/low off burner =$ 5,500

Note that it is assumed that installation costs and pumping costs would be about the same for both a standard efficiency and a condensing boiler.

Energy Use

Standard Efficiency Unit with Seasonal Efficiency of 70%

2000 MMBTU/.7 eff = 2,857 MCF

Condensing Boiler at 90% Seasonal Efficiency

2000 MMBTU/.9 eff = 2,222 MCF

Energy Savings = 635 MCF

Cost Savings

635 MVF x $6.00/MCF =$ 3,810

Simple Paybacks

$7,500 Cost Difference/$3,810 = 2 Yrs

Appendix A

Heating and Ventilation Systems

Heating Systems

Typical heating systems for greenhouse structures are unit heaters with propeller or blower fans. Blower fans are preferred on units ducted under the tables. Controls provide one (100%) or two (50%) stage gas and temperature control. Multistage control contributes to greater seasonal efficiency during the spring/fall months when heating loads are reduced.

Total heating capacity required is dependent on the size of the greenhouse and insulation value of the coverings at design winter temperatures. Design winter temperatures in Minnesota range from –16 F in the southern part of the State to –21 F in the northern part of the State.

Table A – 1 illustrates typical thermal and seasonal efficiencies of gas fired unit heaters from one manufacturer, Modine Company.

Table A – 1, Typical Unit Heating Systems & Efficiencies

Heat System Type	Thermal Eff (%)	Seasonal Eff (%)
Atmospherically Vented	80	65
Power Vented	80	78
Direct Vented	82	80

Descriptions include:

Atmospherically Vented – Combustion air is drawn from inside the greenhouse. Atmospherically vented systems allow warm air to vent out when the unit is off.

Power Vented – Combustion air is metered through the heater unit by separate fans. When the unit is off, warm air venting is cut off. Seasonal efficiency is increased. Exhausts can be installed through the side walls.

Direct Vented – Combustion air is taken from the outside and vented to the outside. Unit designs allow some heat recovery from the flue gases. When the unit is off, warm air venting is cut off and seasonal efficiency is increased.

Table A – 2 provides information on typical list prices for unit heater having different capacities and efficiencies.

Table A – 2, Typical List Prices & Capacities of Unit Heaters

	BTUH Input	BTUH Output	List Price ($)
Atmospherically Vented Heaters			
	350,000	280,000	$1,780
	300,000	240,000	$1,580
	250,000	200,000	$1,350
	200,000	160,000	$1,210
	175,000	140,000	$1,140
	145,000	116,000	$1,055
Power Vented Heaters			
	350,000	280,000	$2,350
	300,000	240,000	$2,090
	250,000	200,000	$1,755
	200,000	160,000	$1,590
	175,000	140,000	$1,485
	145,000	116,000	$1,330
Direct Vented Heaters			
	340,000	275,400	$3,970
	280,000	229,600	$3,590
	225,000	184,500	$3,280
	150,000	123,000	$2,640

Notes:
1 - List Prices for Quantity 1 - 2
2 - Include Sales Tax & Estimated Shipping
3 - Direct Vented_Units include Vent Kit
4 - Single Stage Gas Control and Thermostat

Note that the unit heaters efficiencies and costs are for either natural gas or propane fuels. Oil fired units are available, but the initial costs are about 225% higher. Efficiencies of oil fired units would be about the same as gas fired.

Exhaust & Ventilation Fans

Horizontal Circulation Fans

Horizontal circulation fans are required to distribute heated air and minimize thermal stratification. Moving air over the plants also minimizes condensation and distributes fresh air. The latter replenishes carbon dioxide (CO2).

Horizontal circulation fan capacity (cfm) is typically sized at 25% of the greenhouse volume. Multiples ceiling hung fans are typically used. Single and variable speed fans can be used to match airflow with requirements. Variable speed fans controls (i.e. 20% to 100%) of capacity are available. Typical sizes and power requirements are:

- 12” Fan – 1/10 HP, 115V, .45/.9 A, 2,600 cfm
- 20” Fan – 1/3 HP, 115V, 1.8/3.5A, 6,000 cfm
- 24” Fan – ½ HP, 115V, 2.0/4.0A, 8,500 cfm

Exhaust Fans

Exhaust fans provide two functions:

Provide continuous flow of fresh air to greenhouses to mitigate humidity and condensation and replenish CO2. They are typically sized at 2 cubic feet per minute (cfm) per square foot of floor area.

Larger exhaust fans provide temperature control of greenhouse areas in the spring, summer and fall months. Exhaust fans are typically sized to provide about 8 F temperature drop. Because of the capacities required, many greenhouses have two exhaust fans. Total fan cfm for the structure is about 25% of the volume. Typical single and two speed exhaust fans sizes and power is:

- 24”, ½ HP, 115V, 6,400 cfm
- 36”, ½ HP, 115V, 11,000 cfm
- 36”, ½ HP, 115V, 7,900/11,900 cfm
- 42”, ¾ HP, 115V, 16,400 cfm
- 42”, ¾ HP, 230V, 16,400/10,840 cfm
- 48”, 1 HP, 115V, 22,730 cfm
- 48”, 1 HP, 230V, 15,000/22,700 cfm

Note that many fan models can be retrofit with variable speed controls.

Continuous Exhaust Fans

Continuous exhaust fans operate for extended periods of time to replenish fresh air within the greenhouse.

- 12”, 1/3 HP, 115V, 2.8/2.3A, 1,050/1,550 cfm
- 16”, 1/3 HP, 115V, 1.8 - 3.5A, 3,085 cfm
- 20”, 1/3 HP, 115V, 2.8/2.3A, 2,590/3,540 cfm
- 20”, 1/3 HP, 115V, 3.5 - 1.8A, 3,530 cfm
- 20”, ½ HP, 115V, 4.0 - 2.0A, 4,960 cfm

Inflation Blowers

Inflation blowers are small mounted fans on the inside that maintain an air space between outer coverings. The units can be installed to use inside or outside air, although outside air is recommended in cold climates. Typical capacities and power requirements are:

- 1/100 HP, 115V, .5 A, 60 cfm
- 1/20 HP, 115V, 1.5 A, 148 cfm

Appendix B

Greenhouse Cover Materials

Cover Materials

Many transparent and translucent materials are used for greenhouse coverings including:

- Glass
  - High transmissivity of light, durable, long life
  - Costly, heavy, difficult for small owners to install
- Polyethylene (Single and Double Layer)
  - Low cost, easy to install
  - Short life
- Polycarbonate (Single, Double and Triple Layer)
  - Extended life, hail proof, flexible, better insulation values
  - High cost, prone to UV light discoloring
- Acrylic
  - Good transmissivity of light, good UV resistance
  - High cost
- Selected Combinations of coverings (e.g. polyethylene over single pane glass)

Each has slightly different characteristics of insulation values, visible and infrared light transmittance, life expectancy and cost as indicated below.

Double Ply Polyethylene is a most common greenhouse covering used in Minnesota.

Table B – 1 provides typical greenhouse coverings used in Minnesota and associated solar transmission, insulation values and costs per square foot. Actual values vary by manufacturer.

Table B – 1, Selected Greenhouse Covering Materials

Material	Life (Years)	U Value	R Value	Transmittance		Cost Sq Ft ($)
				Solar % Visible Light	IR Thermal (%)	
Single Pane Glass	>20	0.91	1.1	90	<3	
Single Ply Polyethylene	4	1.10	0.91	87	50	$0.09
Double Ply Polyethylene	4	0.70	1.43	78	50	$0.18
Single Wall Polycarbonate	20	1.10	0.91	90	<3	$1.30
Twin Wall Polycarbonate	20	0.60	1.67	83	<23	$2.10
IRAC Inner, Poly Outer	4	0.50	2	76.5		$0.20

Covering materials are of similar thickness and thus have similar heat conduction characteristics. As indicated in table B – 1, the single cover materials have U values between .9 and 1.1 BTU/Sq Ft Hr F and double wall covering materials between .6 and .7 BTU/Sq Ft Hr F. Note that all two-ply coverings have an air space between layers.

IR anti-condensate (IRAC) films offer characteristics that address a number of issues of associated with greenhouse coverings. These include:

- Eliminate condensation drops from the film and allow lighter to reach the plants. Condensate spreads over the film and drains off the sides.
- Provides diffuses light within the greenhouse that penetrates to all plant surfaces. Solar transmittance is slightly lower than two-ply clear polyethylene.
- Reduces radiation losses during clear nighttime hours. Additives to the film reduce radiation at night. Reductions claimed by one manufacturer are up to 30%. The resultant effect on a two-ply application would be a U value of .5 BTU/Sq Ft Hr F.

IRAC film costs are slightly higher than polyethylene (i.e. about $0.02/Sq Ft more). Thus a two ply covering of I film on the inside layer and clear polyethylene on the outside layer would cost about $0.20/Sq Ft.

Studies have shown that while additional benefits are available, IR films do not provide the heat loss reductions available from thermal blankets. Thermal blankets can serve a dual purpose in that they provide shading during the summer months. Shading is more of an issue in southern states than in Minnesota. Costs of thermal blankets are high (Appendix D).

Cost of Clamping Systems

Material costs indicated include only material. Additional costs for material clamping systems for the baseline structure size is estimated at:

Double Ply Films	=$ 750
Twin Wall Polycarbonate	=$ 2,750
Single Wall Polycarbonate	=$ 2,750

Appendix C

Insulation Materials

Insulation Applications in Greenhouses

Insulation can be added to many areas within and exterior to greenhouse structures. Common areas include:

- Lower Walls – Lower areas on exterior walls. On structures with non-concrete or brick walls, the insulation would be clamped to structure support members.
- Upper Walls – Upper wall areas on sides (e.g. North and East) that will minimize loss of solar gain and light during the winter months.
- Footings – Exterior or interior areas on poured concrete or brick wall footings along post foundations. The insulation would be installed below and above grade.

Insulation has also been used to provide side supports when used in conjunction with ceiling mounted thermal blankets. Insulation can be incorporated into the design and construction of new greenhouses or retrofit on existing structures.

Two types include polyurethane and polystyrene 4' x 8' sheets. Both have been used in the home and commercial building construction. Polystyrene is a more rigid material and durable material. Thicker panels will provide additional support and have increased life expectancy. Costs and insulation values are described below.

Type	R Value (Sq Ft Hr F/BTU)	Cost per 4' x 8' ($)
Polystyrene (4' x 8' x 1")	5.0	$9.50 to $10.00
Polystyrene (4' x 8' x 1.5")	7.5	$13.50 to $14.00
Polystyrene (4' x 8' x 2.0")	10.0	$15.00 to $15.50

A simple clamping system is estimated to cost about $7.50 per panel. Installation costs are not included. It is assumed that owners and operators would install the insulation panels during the heating season, mid October through March, and remove the panels during the spring, summer and fall months.

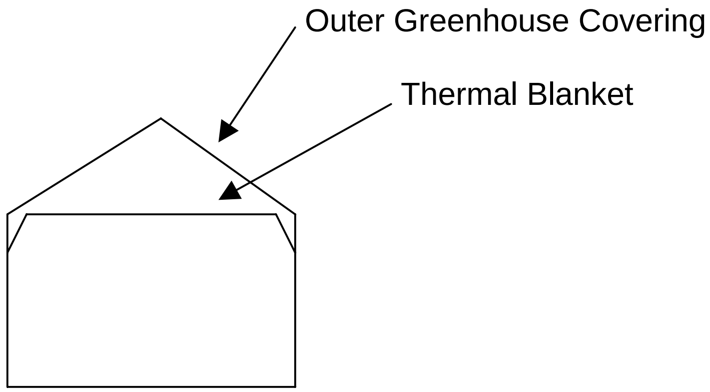
Polystyrene is readily available from most lumber and home building stores.

Appendix D

Thermal Blankets

Description

Thermal blankets are used as an internal cover for plants and creates a “envelop” within the greenhouse structure much like a home with an attic.



Thermal blankets reduce energy use in three ways:

Reduce heated air space – Reduce the amount of greenhouse volume that requires heating.

Provides additional insulation value – The additional insulation values of the blanket material provide thermal resistance. The amount is dependent on the material and is difficult to predict because of the characteristic of the material.

Reduce radiant heat loss – Radiant heat loss reduction is the largest benefit. Warm plant surfaces radiate energy. The net energy exchange is the rate of emission of the surface (emissivity), temperature and surface area. A thermal blanket blocks and thus reduces the radiation. The reduction is dependent on the blanket material and its emissivity. A good material is one that has low emissivity (i.e. high reflectivity) on the surface facing the outer cover and is highly reflective on the inner surface facing the plants. Since heat loss is a direct function of emissivity, heat loss is minimized by blanket materials having aluminized surfaces with low emissivity values.

Since thermal blankets also serve to shade crops, the material tends to be porous (e.g. woven materials). Porous blankets allow moisture to drain and allow some heat to escape. Non-porous materials, such as polyethylene trap water and condensation and block out light (i.e. depends on material) that reduces heat retention during daylight hours. Aluminized material provides a compromise between the two extremes; reflecting sunlight during the day and reducing heat loss at night.

Radiant Heat Loss

Radiant heat loss can be calculated by the following methodology suggested in ASHRAE.

Q = Ceiling Area x Fci x Const x (Tc**4 – Tp**4)

Where

Fci = [1/fci + (1/Ec – 1) + Ac/Ap x (1/Ep – 1)]
Q = Radiant heat loss (BTU/Sq Ft Hr)
Ac = Area of ceiling (Sq Ft)
Ap = Plant Area (Sq Ft)
Ec =Emissivity of ceiling material
Ep = Emissivity of plant material
fci = Angle factor (ceiling to plant) and dependent of greenhouse geometry, but between 0 and 1.
Const = Stephan-Boltzman constant (.0.1714 x 10**-8 BTU/Hr Sq Ft R**4)
Tc = Surface temperature of ceiling (Degrees R)
Tp = Surface temperature of plant (Degrees R)

As indicated, the calculation is dependent on temperatures and emissivity values that are difficult to determine and vary by plant type, greenhouse covering and outdoor temperatures.

Published information on heat loss savings for greenhouse’s having thermal blankets have been determined by installing thermal blankets, measuring or recording energy use over a period of time or season and adjusting the overall U value of the greenhouse covering thermal blanket combination.

Installation

Installation on a new structure is the most optimal since the blanket and drive system can be installed on overhead structural supports before other components such as fans and lights are attached.

Retrofit on Existing Structures

Thermal blankets can be retrofit on existing greenhouse structures. The main issue is that existing equipment and systems mounted on the ceiling supports (e.g., lighting fixtures, piping, fans, heaters) may have to be re-moved and re-mounted.

Insulation Values

Insulation values published in Greenhouse Engineering publications provide net insulation values for selected combinations of thermal blankets material and single glass glazing. These are summarized in Table D – 1.

Table D – 1, Insulation Values of Selected Greenhouse Single Pane Glass Covering/Thermal Blanket Combinations

Blanket Description	Net U Value BTU/Sq Ft Hr F	Net R Value Sq Ft Hr F/BTU
Single Glass Glazing	1.1	0.91
Aluminized Polyethylene Tubes	0.54	1.85
White-White Spun Bonded Polyolefin Film	0.51	1.96
Heavy Weight Grey White Spun Bonded Film	0.43	2.33
Light Weight Grey White Spun Bonded Film	0.56	1.79
Clear Polyethylene Film	0.45	2.22
Black Polyethylene Film	0.48	2.08
Aluminum Foil-clear Vinyl Film Laminate	0.4	2.50
Aluminum Foil - Black Vinyl Film	0.63	1.59
Aluminum Fabric	0.39	2.56

Heat losses vary from approximately 34% to 54%.

One manufacturer of thermal blanket material publishes energy saving potential for their product (e.g. L.S. Svenson). Published energy saving data ranges from 47% to 72% for the XLS10 to XLS18 material, which is aluminum foil with clear vinyl film laminate. Different energy savings are functions of the percentage blanket area covered by the aluminum foil.

The baseline building used for comparison in this analysis has a covering of 2 ply polyethylene (i.e. U = .69). A comparative range of net U values from R=2.44 (40% save) to R=3.57 (60% save) are used in the analysis presented in this report.

Cost estimates for a thermal blanket installed in a new greenhouse structure 30’ wide x 96’ long are:

Material	$ 8,250
Installation Estimate	$ 6,500

This single quote is based on an aluminum material with 55% shade factor and 64% energy savings and does not include a fire retardant material. This would cost an additional $1,150. Material costs include blanket material (i.e. estimated at about $1,000 of the material cost) and the transport system and controls.

Appendix E

Energy Efficient Motors

Energy Efficient Motors

The Energy Pact Policy Act of 1992 (EPACT) requires that most general purpose motors manufactured for sale in the United States after 10/24/97 meet minimum efficiency standards. These efficiency standards are known as EPACT or Energy Efficient Motors and apply to all single speed, T Frame, Open Drip Proof and Totally Enclosed Fan Powered general purpose motors between 1 and 200 HP. These types of motors are supplied in heating, cooling and ventilation systems.

Premium Efficient Motors

Motors efficiency levels have increased and now premium efficiency motors are available. Premium efficiency levels were established by NEMA and thus have a "recognized and consistent efficiency standard". They can be ordered as option on new fan systems and pumps or retrofit on existing systems. Table E – 1 illustrates premium efficient motor catalog efficiency and list prices for open drip proof motors.

Many motors used in greenhouse heating and ventilation systems are less than 1 HP. Some manufactures have premium efficient motors in fractional HP sizes from about .5 HP to 1 HP.

Incremental Costs

Average incremental list prices for premium efficient motors from 1 to 5 HP are illustrated in Table E – 1 for two major vendors.

Table E – 1, Energy Efficient & Premium Efficient Motor Efficiency & Average Cost Differences

HP	Energy Efficient (%)	Premium Efficient (%)	Average Cost Difference ($)
1.0	82.5	85.5	35
1.5	84.0	86.5	60
2.0	84.0	86.5	65
3.0	86.5	88.5	80
5.0	87.5	89.5	120
7.5	88.5	91.0	145

Appendix F

Control Systems

Control Systems

Control systems are available to perform a number of control functions for greenhouse operations. Control systems range from simple thermostats and timers to more sophisticated microprocessor control systems that can provide monitoring and control of a number of greenhouse systems. The following outlines three options applicable to the baseline greenhouse structure.

Thermostats

Thermostats are required to control temperatures during both the heating season and during spring/fall months when solar heat gain causes interior temperatures to raise. Typical thermostats used for heating system control are single and dual stage thermostats that can withstand greenhouse environments. Costs range from $100 to $125 plus installation.

Thermostats that control space temperatures as a function of time of day are available. Thermostats having multiple time set points per day are preferable to meet the many types of crops and their growth cycles needs. An environmental enclosure with remote sensing capability is required. Typical costs range from $200 to $250 plus installation time (i.e. estimated at $100).

Timers

Mechanical and digital timers are available to control systems such as lighting and exhaust fans as a function of time of day. Mechanical and digital timers can be purchased for about $125 to $150 and installed by an electrician in about 3 – 4 hours (i.e. estimated at $320).

Microprocessor Control Systems

Control systems are available to perform a number of control functions for greenhouse operations, including:

- Start/Stop of Heating, Cooling and Ventilation Systems (e.g. circulation fans, exhaust fans).
- Space Temperature Control as a Function of Time of Day (e.g. Day, Night, Differentials)
- Multi-Stage Space Temperature Control
- Relative Humidity Control
- Fogging Control
- Thermal Blanket Operation (Energy savings and Shading)
- CO2 Control
- Roof/Siding Ventilation Control
- Lighting Control
- Alarm Monitoring and Reporting

The primarily advantage of microprocessor based controls is the ability to develop more complex control strategies such as controlling the on/off operation of exhaust fans to maintain specified space temperatures.

A number of these control functions can save energy and optimize crop growth by more precise control of environmental conditions within the greenhouse. These types of control systems have been used successfully in commercial buildings over the last 30 – 35 years to control workspace environment and have often provided energy savings ranging from 10% to 20% of total building energy use. The advent of microprocessor based control technology has resulted in systems that can meet the needs of both small and large greenhouse operations at reasonable costs. The following is an example of a basic system and costs.

Basic System Functionality & Costs

- Cooling System Control – 3 Stages
- Heating System Control – 2 Stages
- Space Temperature Control – Multiple Day Settings
- Air Circulation Control
- Sensors and Sensor Cable
- Outputs for Additional Equipment Controls

Note that additional relays are required to control the start/stop operation of equipment such as lights and exhaust fans.

Approximate Costs

Control System	=$ 1,000 to $1,200
Installation (One Day of Electrician Time)	=$ 500 to $700
Additional Control Relays	=$ 200 to $300 each