Work Paper PGECOAGR101
Greenhouse Thermal Curtains
Revision 0

Pacific Gas & Electric Company

Customer Energy Efficiency Department

Greenhouse Thermal Curtains

Measure Code A10

February 5, 2008

At a Glance Summary: Single Layer Thermal Curtains

Applicable Measure Codes:	A10
Measure Description:	Thermal curtains decrease heat losses in greenhouses (conduction, convection, and radiation losses). Thermal curtains are installed inside the greenhouse and are typically installed horizontally near the greenhouse gutter line. It is assumed that the thermal curtains are deployed during nighttime hours, and open during daytime hours.
Energy Impact Common Units:	Therms per Square feet
Base Case Description:	Source: PG&E Greenhouse Baseline Study, 2005. **Roof:** double-inflated polyethylene <u>with</u> IR inhibiting film. **Wall:** single layer polycarbonate **Thermal Curtains**: None **Heat setpoint:** 55F
Base Case Energy Consumption:	Source: PG&E Calculations. 0.374 therms per year
Measure Energy Consumption:	Source: PG&E Calculations. 0.153 therms per year
Energy Savings (Base Case – Measure)	Source: PG&E Calculations 0.221 therms per year
Costs Common Units:	$ per sq. ft
Base Case Equipment Cost ($/unit):	Source: PG&E Calculations. $0
Measure Equipment Cost ($/unit):	Source: PG&E Calculations and manufacturer's data. $1.50
Measure Incremental Cost ($/unit):	Source: PG&E Calculations and manufacturer's data. $1.50
Effective Useful Life (years):	Source: DEER. 5 years
Program Type:	Assume Express Efficiency Rebates
Net-to-Gross Ratios:	Source: DEER. 0.96
Important Comments:	Energy consumption and savings are based upon weighted average for climate zones 1, 2, 3, 4, 5, 11,12, and 13. Results are extremely sensitive to temperature setpoints for heating. For example, changing the temperature setpoint from 55F to 80F increases gas usage by an average of more than 200%. Due to the enormous variability in conditions needed for various crops, no attempt was made to capture the variability with additional tiers. This analysis uses a 55F set point.[1]

At a Glance Summary: Double Layer Thermal Curtains

Applicable Measure Codes:	For future program enhancement for 2009-2011 program planning
Measure Description:	Double layer thermal curtains decrease heat losses in greenhouses similarly to single-layer thermal curtains. The advantage is increased savings and finer control over daytime light levels.
Energy Impact Common Units:	Therms per Square feet
Base Case Description:	Source: PG&E Greenhouse Baseline Study, 2005. **Roof:** double-inflated polyethylene with IR inhibiting film. **Wall:** single layer polycarbonate **Thermal Curtains**: None **Heat setpoint:** 55F
Base Case Energy Consumption:	Source: PG&E Calculations. 0.374 therms per year
Measure Energy Consumption:	Source: PG&E Calculations. 0.093 therms per year
Energy Savings (Base Case – Measure)	Source: PG&E Calculations 0.281 therms per year
Costs Common Units:	$ per sq. ft
Base Case Equipment Cost ($/unit):	Source: PG&E Calculations. $0
Measure Equipment Cost ($/unit):	Source: PG&E Calculations and manufacturer's data.[2] $2.60
Measure Incremental Cost ($/unit):	Source: PG&E Calculations and manufacturer's data. $2.60
Effective Useful Life (years):	Source: DEER. 5 years
Program Type:	Assume Express Efficiency Rebates
Net-to-Gross Ratios:	Source: DEER. 0.96
Important Comments:	Weighted average for climate zones 1, 2, 3, 4,5, 11,12, and 13

Measure Code	DEER RunID	Measure Description	Building Type	Building Vintage	Climate Zone	Peak Electric Demand Reduction (kW/unit)	Annual Electric Savings (kWh/unit)	Annual Gas Savings (therms/unit)	Base Case Cost ($/unit)	Measure Cost ($/unit)	Measure Incremental Cost ($/unit)	Effective Useful Life (years)
D03-980[1]	CFRM00AVHtCtn	Single-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z01	0	0.064	0.336	$0	$1.50	$1.50	5
		Double-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z01	0	0.080	0.424	$0	$2.60	$2.60	5
D03-980	CFRM00AVHtCtn	Single-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z02	0	0.046	0.249	$0	$1.50	$1.50	5
		Double-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z02	0	0.064	0.341	$0	$2.60	$2.60	5
D03-980	CFRM00AVHtCtn	Single-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z03	0	0.044	0.225	$0	$1.50	$1.50	5
		Double-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z03	0	0.056	0.281	$0	$2.60	$2.60	5
D03-980	CFRM00AVHtCtn	Single-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z04	0	0.042	0.216	$0	$1.50	$1.50	5
		Double-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z04	0	0.056	0.280	$0	$2.60	$2.60	5
D03-980	CFRM00AVHtCtn	Single-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z05	0	0.037	0.184	$0	$1.50	$1.50	5
		Double-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z05	0	0.046	0.229	$0	$2.60	$2.60	5
D03-980	CFRM00AVHtCtn	Single-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z11	0	0.039	0.266	$0	$1.50	$1.50	5
		Double-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z11	0	0.049	0.350	$0	$2.60	$2.60	5
D03-980	CFRM00AVHtCtn	Single-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z12	0	0.043	0.265	$0	$1.50	$1.50	5

[1] This is the DEER Measure ID

Measure Code	DEER RunID	Measure Description	Building Type	Building Vintage	Climate Zone	Peak Electric Demand Reduction (kW/unit)	Annual Electric Savings (kWh/unit)	Annual Gas Savings (therms/unit)	Base Case Cost ($/unit)	Measure Cost ($/unit)	Measure Incremental Cost ($/unit)	Effective Useful Life (years)
		Double-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z12	0	0.051	0.348	$0	$2.60	$2.60	5
D03-980	CFRM00AVHtCtn	Single-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z13	0	0.029	0.191	$0	$1.50	$1.50	5
		Double-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Z13	0	0.035	0.251	$0	$2.60	$2.60	5
D03-980	CFRM00AVHtCtn	Single-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Weighted avg	0	0.042	0.221	$0	$1.50	$1.50	5
		Double-Layer Greenhouse Heat Curtain with Infrared Film (55F setpoint)	AGR	AV	Weighted avg	0	0.054	0.281	$0	$2.60	$2.60	5

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Work Paper Approvals

Ed Mah | Date
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Document Revision History

Revision #	Date	Description	Author (Company)
Revision 0	**02/05/08**	**Greenhouse Thermal Curtains PGECOAGR101 R0.doc**	**Marjorie Stein, Green Building Studio**
Revision 1			

Table of Contents

List of Tables

List of Figures

Section 1. General Measure & Baseline Data

1.1 Measure Description & Background: Heat Curtains

Catalog Description –

Only installations of interior curtains for heat retention in existing gas-heated greenhouses qualify. The rebate applies to new and retrofit curtain system installations in existing greenhouses for specific agricultural end-use. Product must be designed by the manufacturer to be a heat curtain, and the installation must have the ability to automatically or manually move the curtain into place. Curtain must be located such that the gas heat source provides hot air to conditioned space bounded by the curtain. Curtain material must have an Energy Savings rating of >40%, and must have a warranty/product life of 5 years. Include a manufacturer's specification sheet documenting type of curtain. Rebate amount is for square foot of curtain material.

Program Restrictions and Guidelines: Heat Curtains

Terms and Conditions Only installations of interior curtains for heat retention in existing gas-heated greenhouses qualify. The rebate applies to new and retrofit curtain system installations in existing greenhouses for specific agricultural end-use. Product must be designed by the manufacturer to be a heat curtain, and the installation must have the ability to automatically or manually move the curtain into place. Curtain must be located such that the gas heat source provides hot air to conditioned space bounded by the curtain. Curtain material must have an Energy Savings rating of > 40%, and must have a warranty/product life of 5 years. Include a manufacturer's specification sheet documenting type of curtain. Rebate amount is for square foot of curtain material.[3]

Market Applicability This measure is applicable to agricultural or commercial greenhouses involved in the production of nursery products, horticultural specialties, or ornamental products.

Technical Description: Single-Layer Heat Curtains

Typically, greenhouse thermal curtains are designed to be placed horizontally above the growing zone within a greenhouse. Energy is saved in three ways: they trap an insulating air film; the volume of space requiring heating is reduced; and heat curtains with aluminized strips reflect rising heat back into the growing zone.

A vendor participating in the PG&E Greenhouse Baseline study explained that there are two basic types of thermal curtain installations: flat, and slope-flat-slope. The flat is under the gutter level and operates in a horizontal plane. The slope-flat-slope (or tent) installation is used with some greenhouses that have other equipment to avoid, or for growers who want to minimize the air trapped above the curtain (or maximize the area below). Their product is warranted for five years underneath any type of glazing, and they claim an actual replacement interval of every 7-12 years depending on use, installation quality, etc.

According to Bartok[4], there are many different materials used as thermal curtains. Porous materials allow condensation to drain, but are not as effective as nonporous materials in reducing energy use. However, nonporous curtains could cause the track system to fail if they become too heavy from collected moisture. Aluminized curtains save about 10% more energy than non-aluminized curtains. The aluminized curtains are typically a 55% woven white polyester film and double for use as shading. Bartok also refers to research conducted in large greenhouses with parallel bays and compares the effectiveness of reflective curtains facing both directions. The results indicate that outward-facing reflective surface retained heat slightly better than an inward-facing system.

Table 1. Specifications for Ludvig Svensson, Thermal Curtains[5]

Specifications for Ludvig Svensson, Thermal Curtains (Aluminum/Polyester Strips)		
Type	Energy saving	Diffuse Light transmission
Calculated, based upon PG&E's minimum energy savings requirements	40%	84%
XLS 10 Firebreak	45%	78%
XLS 13 Firebreak	49%	65%
XLS 14 Firebreak	52%	53%
XLS 15 Firebreak	57%	43%
XLS 16 Firebreak	62%	34%
XLS 17 Firebreak	67%	24%
XLS 18 Firebreak	72%	17%

Table 1 presents the specifications for thermal curtains from a large manufacturer. This analysis will assume the heat curtain has an energy savings factor of 40%, based upon PG&E's minimal requirement for qualifying products, with a calculated diffuse light transmission of 84%. The figure below illustrates the calculations for arriving at the diffuse light transmission of a 40% energy savings factor heat curtain.

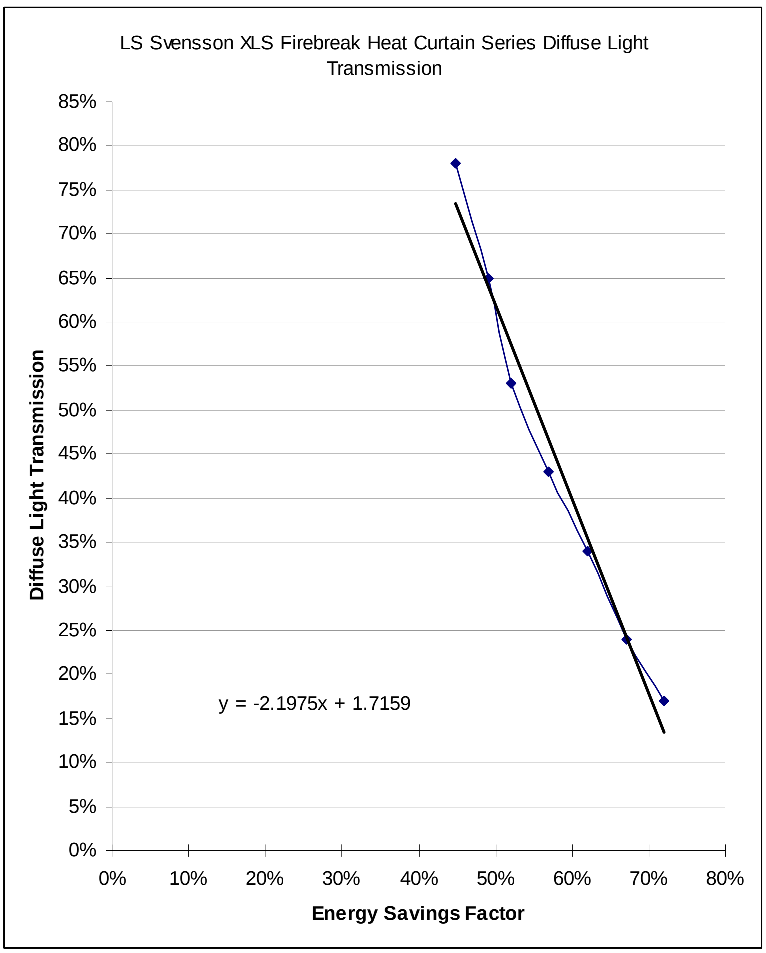


Figure 1. Graph of Ludvig Svensson XLS Firebreak Energy Curtains. Diffuse Light Transmission vs Energy Savings Factor.

Figure 2. Photograph of Ludvig Svensson XLS Firebreak Energy Curtain.

Technical Description: Double-Layer Heat Curtains

Double-layer heat curtains serve the same purpose as single-layer heat curtains; however, as the name implies, this system is composed of two independent curtains. The advantage to growers, in addition to additional energy savings (on the heating side), is the ability to exercise finer control over light levels. The analysis assumes the double-layer heat curtain system consists of a white acrylic layer of 55% woven plus a heat curtain with a 40% energy savings factor. The primary benefit of the 40% energy savings factor heat curtain is radiant heat retention. The primary benefit of the acrylic layer is an added air film to trap heat. This analysis assumes a 12-inch air gap between the two layers of heat curtain. Without an air gap the added benefit of the two layers is greatly reduced. Conductance (u-value) of the 40% energy savings factor heat curtain is 1-0.40 = 0.60. R-value is 1/0.60 = 1.67. R-value of air-film between two layers of heat curtains is approximately 2.5. Total R-value is 4.17. U-value of 0.240 is used as a multiplier on the roof glazing conductance to model heat retention during the night.

Table 2. Thermal Resistance (R-value) of air gaps.[6]

air gap (inches)	0.5	0.75	1.5	3.5	**12**	18
R-value	1.6	1.7	1.8	2.0	**2.5**	3.0

1.2 DEER Differences Analysis: Heat Curtains

The DEER Measure ID D03-981 Greenhouse Heat Curtain[7] is based upon a prototypical 4,000 square foot greenhouse facility with average characteristics for SoCalGas customer participants for Express Efficiency heat curtain measures during PY 2001. This is per section 4.2 of the DEER Update Study Final Report. The results for this measure are sensitive to weather and extremely sensitive to temperature setpoints. The estimated savings from the DEER study is 0.39 therms/square foot.

The incremental cost cited by DEER ($0.49) is much lower than that cited by vendors in the 2005 Greenhouse Baseline Study conducted by PG&E ($1.50 for single-layer).

The useful life of 5 years is approximately what vendors also cite.

DEER does not analyze double-layer heat curtains.

1.3 Codes & Standards Requirements Analysis: Heat Curtains

Greenhouses and the heat curtains measures are not governed by either state or federal codes and standards.
Title 20: These measures do not fall under Title 20 of the California Energy Regulations.
Title 24: These measures do not fall under Title 24 of the California Energy Regulations.
Federal Standards: These measures do not fall under Federal DOE or EPA Energy Regulations.

1.4 EM&V, Market Potential, and Other Studies

M&V Group to Provide appropriate report(s)
Based upon the PG&E Greenhouse Baseline Study (pages 26-27), the use of heat curtains is not standard practice for greenhouses within PG&E's service territory. The study interviewed 22 greenhouse owners. A frequent comment from greenhouse owners regarding thermal curtains is that they would love to use them, but price is a limiting factor. Some reported taking advantage of past PG&E incentives to purchase thermal curtains, stating that they would not have made the purchase without incentives. Seven of the 21 greenhouse owners participating in the study reported using no thermal curtains at all. Ten of the facilities use them on some portion of their greenhouses (one facility uses thermal curtains on less than one percent of the space and complained of the mechanism never functioning satisfactorily). The remaining four use thermal curtains on most or all of their greenhouses. In all cases the thermal curtains serve as a shade-cloth as well. Other comments regarding thermal curtains are:

- would love to have but never seem to have enough $ for investments in energy improvements
- too expensive
- don't feel it's needed
- too expensive, 15 yrs ago PG&E offered incentives but didn't think it was enough, would be nice to have energy curtains
- too expensive
- expensive, thinks >$1/sq ft but not sure how much more. Used PG&E rebate on last purchase
- used in about 15% of houses, wishes he could use more but is expensive
- used in about 40% of houses, would use more but cost is factor
- older houses not set up for it

Table 3. Use of Thermal Curtains

Bin	Never Use	Rarely Use	Sometimes Use	Typically Use
TOTAL	7	1	9	4

Fourteen of the greenhouses have some thermal curtains installed. In one case the mechanism doesn't work properly. In four additional cases, only the newer houses have them installed and the old houses are not set up for the mechanism to be installed. Because only three of the owners use thermal curtains in 100% of the houses it appears that the use of thermal curtains is not a standard practice. In all cases the use of the thermal curtains doubled as shade cloth.

In general, the vendors and consultants indicated that shade cloths used independently from thermal curtains were not that common and are not as good as thermal curtains. However, the thermal curtains that double as shade cloths are fairly common, according to two of the vendor/consultants. Two more indicate that these systems used to be more common than they are now. One other indicated that he thought foliage growers sometimes used them. These mixtures of answers seem consistent with the greenhouse owners as well. Generally it seems that thermal curtains are not a standard baseline in

California greenhouses and their installation is heavily dependent upon incentives to offset the initial expense.

Another vendor commented that if there is an incentive, more growers tend to invest in thermal curtains. He went on to estimate that California greenhouse growers who may invest in energy curtains without the rebate available when planning new construction break down as:

- Approximately 50% of the glass house growers
- 25% of the rigid plastic growers
- 5-10% of the poly house growers.

He speculated the possible reasons for low numbers of poly house growers installing thermal curtains probably had to do with the fact that these structures are more energy efficient in most cases, and also they tend to be the low-cost options and thermal curtains are expensive. Additional comments from the vendors are on the following table:

Table 4. Use of Thermal Curtains, per vendors

How Common are Thermal Curtains
sometimes used--especially among foliage growers
very common. Uses LS aluminized products with 55% shade. Cost $1.25-$1.30/sq ft mostly just applied to ceiling at gutter height.
Very common to use aluminized energy curtains for both shade & heat retention. Typical open at dawn, close at 10am in summer to cut heat (mfg claims 50% of btus), open later afternoon, close at sunset. Cost $1.50-$2.00/sq ft
all else being equal, good curtains are best investment, save 30-40% on heat and allow more control over when crops mature by controlling sunlight
fairly common with dual function shade cloth. Estimates cost at $1.55/sf for complete system.
same as shade cloths
Not very common, need complicated pulleys and controls. Very expensive.
too expensive

Delta Therms Assumption (ΔT): Source: PG&E Calculations.
Baseline therms usage: 0.374 therms/square foot.
Single-Layer heat curtains: 0.153 therms/square foot.
Double-Layer heat curtains: 0.093 therms/square foot.

Net-to-Gross Assumption: *0.96. Source: DEER value, assumes Express Efficiency Rebates program.*

In-service factor/first year installation rate: *From the PG&E Greenhouse Baseline Study (page 26).*[8]
"A frequent comment from greenhouse owners regarding thermal curtains is that they would love to use them, but price is a limiting factor. Some reported taking advantage of past PG&E incentives to purchase thermal curtains, stating that they would not have made the purchase without incentives. Seven of the 21 (33%) greenhouse owners participating in the study reported using no thermal curtains at all. Ten of the facilities (46.7%) use them on some portion of their greenhouses (one facility uses thermal curtains on less than one percent of the space and complained of the mechanism never functioning satisfactorily). The remaining four (19%) use thermal curtains on most or all of their greenhouses."

Hours of Operation: *From the PG&E Greenhouse Baseline Study (page 50*[9]*).*
The interviews with the greenhouse owners revealed that while many crops are seasonal in nature, the greenhouses rarely sit idle. Crops are usually rotated through the nursery during the entire year. Based upon this finding, the baseline schedule of operations will be assumed to be 24-hours per day, 7 days per week.

Effective Useful Life: *5 years. Source: DEER.*

1.5 Base Cases for Savings Estimates: Existing & Above Code

The base case for the single-layer heat curtains measure is no heat curtain.

The base case for the double-layer heat curtains measure is no heat curtain.

No state or federal codes apply to either of these measures.

1.6 Base Cases & Measure Effective Useful Lives

Based upon DEER data an effective useful life of five years is assumed for both single-layer and double-layer heat curtains. DEER source 2004-05, Version 2.01 -- Measure ID D03-0980.

1.7 Net-to-Gross Ratios for Different Program Strategies

The Net-to-Gross (NTG) ratios are estimated based on whole energy efficiency program approaches and strategies. They are summarized in the CPUC Energy Efficiency Policy Manual and on the DEER web site. This section should discuss the possible program strategies applicable to the measure and indicate the NTG ratio for each from approved sources. If there are new EM&V studies with more recent NTG estimates, they may be cited here.

Table 1 below summarizes all applicable Net-to-Gross ratios for programs that may be used by this measure.

Table 5 Net-to-Gross Ratios

Program Approach	NTG
Name of Program	

Section 2. Calculation Methods

2.1 Electric Energy Savings Estimation Methodologies

A computer simulation model has been developed using eQUEST™ and Quickee™. These programs are Windows™ applications that act as interfaces to the DOE 2.2 hourly energy simulation engine. DOE-2.2 was developed by the U.S. Department of Energy and J.J. Hirsch and Associates, specifically for evaluating the energy performance of commercial and residential buildings, and has been widely reviewed and validated in the public domain. DOE-2.2 calculates hour-by-hour building energy consumption over an entire year (8760 hours) using weather data for the location under consideration. eQUEST is a graphical user interface to DOE-2.2 developed by J.J. Hirsch and Associates and others. Quickee is a free utility, which allows a user to use Microsoft Excel to control the input and output of parametric DOE-2 runs.

Input to the program consists of a detailed description of the building being analyzed, including glazing specifications, cooling and heating systems, hourly scheduling of equipment, and thermostat settings.

The baseline greenhouse building consists of the following features:

Roofs: Double-inflated poly[10] without IR film (U-value 0.70, Visible Transmittance 0.78, and Shading Coefficient 0.85). Or single-layer polycarbonate (U-value 1.14, Visible Transmittance 0.83, Shading Coefficient 0.85.

Walls: Single layer polycarbonate: U-value 1.14, R-Value 0.91, Visible Transmittance 0.90, Shading Coefficient 1.00.

Floors: Uninsulated bare soil

Thermostats: Temperature sensors are assumed to be located at crop level (approximately four feet above the floor) near the middle of each greenhouse range. Baseline heaters are assumed to be located overhead. The location of the heating systems causes stratification, with the air above the gutter level 7 to 10º F hotter than at the thermostat level, per John Hoogenboom, a greenhouse consultant [11]. Since the eQUEST computer model cannot account for thermal stratification of air, the thermostat schedules are modified to account for stratification effects by adding a temperature offset. This strategy has been borrowed from the one utilized by Marlin Addison, an eQUEST expert, and Hoogenboom.[12] An assumed space temperature offset of 7.5º F is recommended without heat curtains and 4º F with heat curtains.

Heating: The baseline heating system in California greenhouses consists of overhead gas-fired unit heaters with an 80% heating efficiency.

Cooling: For coastal areas, the baseline cooling system is passive natural ventilation with ridge & vent design (upper vents sized at 20% of floor area, lower vents same size). For inland valley areas the baseline cooling system is fan and pad. This evaporative cooling system is assumed to be 80% efficient.

Fans and Airflow: For the non-coastal areas, exhaust fans are simulated to provide 60 air changes per hour of ventilation whenever the greenhouse temperature exceeds 75 F. Based upon Energy Conservation for Commercial Greenhouses, it is assumed that the target rate is eight CFM/square foot, and the fans are assumed to deliver 20,000 cfm per hp. For coastal locations, no exhaust fans are assumed in the baseline model—only passive natural ventilation.
Horizontal airflow fans are used to mix the air and reduce mold and mildew growth when the greenhouse is being ventilated. The model assumes HAF fans with a capacity of 0.25 cfm, based upon recommendations from Energy Conservation for Commercial Greenhouses for greenhouses.

Lighting: No supplemental lighting has been assumed in the analysis.

Infiltration: A rate of 1.1 air changes per hour is assumed in the model. Energy Conservation for Commercial Greenhouses cites an average of 0.75 – 1.5 air changes per hour for new Construction glass, fiberglass, polycarbonate, or acrylic sheets:

Orientation: According to Energy Conservation for Commercial Greenhouses[13], locations above 40°N latitude should have the ridge of multi-span greenhouses running north to south, and the ridge of single bay greenhouses running east to west. All houses below 40°N should have the ridges running north to south to optimize the light.

Schedule: 24 hours per day, 7 days per week.

Utility Rates: Assumes PG&E's AG-5 rate for electricity and GNR-1 rate for gas.

Single Heat Curtain System: Assumes a heat curtain with a 40% energy savings factor. Conductance (u-value) is 1-0.40 = 0.60. U-value of 0.60 is used as a multiplier on the roof glazing conductance to model heat retention during the night.

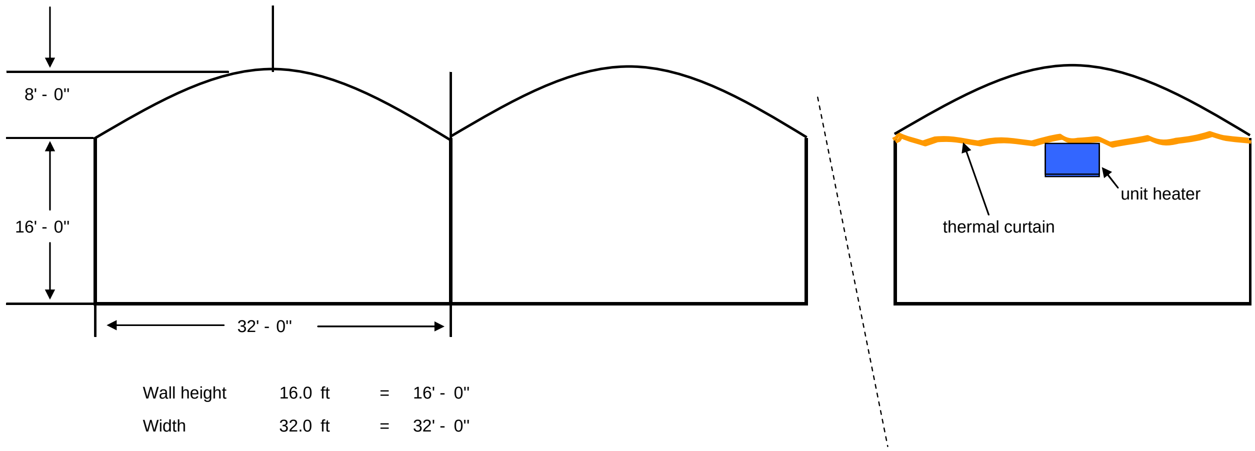
Double Heat Curtain System: Assumes white acrylic layer, 55% woven plus a heat curtain with a 40% energy savings factor. Primary benefit of the 40% energy savings factor heat curtain is radiant heat retention. The primary benefit of the acrylic layer is an added air film to trap heat. This analysis assumes a 12-inch air gap between the two layers of heat curtain. Without an air gap the added benefit of the two layers is greatly reduced. Conductance (u-value) of the 40% energy savings factor heat curtain is 1-0.40 = 0.60. R-value is 1/0.60 = 1.67. R-value of air-film between two layers of heat curtains is approximately 2.5. Total R-value is 4.17. U-value of 0.240 is used as a multiplier on the roof glazing conductance to model heat retention during the night.

Δ*Watts/unit: Heat curtain measures have no demand savings.*

Annual Electric Savings:

Energy Savings [kWh/Unit] =	*Single-layer Heat Curtain: 0.042 kWh/square foot*
	Double-layer Heat Curtain: 0.054 kWh/square foot

Greenhouse Structure



Wall height	16.0	ft	=	16' - 0"
Width	32.0	ft	=	32' - 0"
Roof length	17.9	ft	=	17' - 11"
Attic height	8.0	ft	=	8' - 0"

Description

Design	gutter connected bays with hoop roofs
Roof Material	double inflated PE with IR film
Wall Material	single layer polycarbonate
Floor	uninsulated bare soil
Thermal Curtain Position	truss to truss at gutter height
Thermal Curtain Operation	deployed when temperature falls below 65F

Surface Area and Volume Calculations

Dimensions		
Number of Bays		14
Width (each bay)	ft	32
Wall Height (each bay)	ft	16
Length	ft	256
Roof Pitch, rise to run (**x** in 12)		6.0
Peak Height (gutter to peak)	ft	8.0
Roof Width (gutter to peak)	ft	17.9
Surface Area		
Side Walls	ft^2	8,192
End Wall (without gable)	ft^2	14,336
Total Wall (below gutter)	ft^2	22,528
End Gable	ft^2	3,584
Roof	ft^2	128,225
Floor	ft^2	114,688
Interior Volume		
Total	ft^3	2,293,760
Gable (above gutter)	ft^3	458,752
Main (below gutter)	ft^3	1,835,008

2.2. Demand Reduction Estimation Methodologies

There is no anticipated demand reduction associated with this measure.

2.3. Gas Energy Savings Estimation Methodologies

See section 2.1 for the methodology.

Annual Gas Savings:
Baseline therms usage: 0.374 therms/square foot.
Single-Layer heat curtains: 0.153 therms/square foot.
Double-Layer heat curtains: 0.093 therms/square foot.

Section 3. Load Shapes

Load Shapes are an important part of the life-cycle cost analysis of any energy efficiency program portfolio. The net benefits associated with a measure are based on the amount of energy saved and the avoided cost per unit of energy saved. For electricity, the avoided cost varies hourly over an entire year. Thus, the net benefits calculation for a measure requires both the total annual energy savings (kWh) of the measure and the distribution of that savings over the year. The distribution of savings over the year is represented by the measure's load shape. The measure's load shape indicates what fraction of annual energy savings occurs in each time period of the year. An hourly load shape indicates what fraction of annual savings occurs for each hour of the year. A Time-of-Use (TOU) load shape indicates what fraction occurs within five or six broad time-of-use periods, typically defined by a specific utility rate tariff. Formally, a load shape is a set of fractions summing to unity, one fraction for each hour or for each TOU period. Multiplying the measure load shape with the hourly avoided cost stream determines the average avoided cost per kWh for use in the life cycle cost analysis that determines a measure's Total Resource Cost (TRC) benefit.

3.1 Base Cases Load Shapes

The base case load shape would be expected to follow a typical *(residential or non-residential) (end use name)* end use load shape.

3.2 Measure Load Shapes

For purposes of the net benefits estimates in the E3 calculator, what is required is the load shape that ideally represents the *difference* between the base equipment and the installed energy efficiency measure. This *difference* load profile is what is called the Measure Load Shape and would be the preferred load shape for use in the net benefits calculations.

The measure load shape for this measure is determined by the E3 calculator based on the applicable *(residential or non-residential)* market sector and the *(end-use name)* end-use.

Section 4. Base Case & Measure Costs

4.1 Base Case(s) Costs

There is no cost associated with the base case since the base case is no heat curtain.

4.2 Measure Costs

The single-layer heat curtain measure cost is $1.50 per square foot. This includes materials and full installation costs. The source of the cost is previous studies and manufacturer's data (taken from the PG&E Greenhouse Baseline Study):

Table 6. Measure Costs: Single-Layer Heat Curtains

Life (years)	Installed Cost per sq. ft.	Source	Date	Notes
5	$1.50	*Greenhouse Thermal Curtains and Infrared Films Workpaper for PY2006-2008* prepared for Southern California Gas Co. by Energy and Environmental Analysis, Inc. (B-REP-06-599-17B)	September 2006	
10	$1.51	John Hoogenbom	Nov. 2003	
	$1.10 to $3.35	Scott Sanford, *Reducing Natural Gas / Propane use for Greenhouse Space Heating*	2001	Cost depends on size of greenhouse, blanket material, and type of track / drive system used.
	$1.00-$3.00	John W. Bartok, *Energy Conservation for Commercial Greenhouses*	2001	lower price is for larger areas of 20,000 sq ft or more
5-12	$1.10-$1.40	Kurt Parbst, Ludvig Svensson	Nov. 2005	For large installations > 1 acre.

The double-layer heat curtain measure cost is $2.60 per square foot. This includes materials and full installation costs. The source of the cost is manufacturer's data: Per Peter Fryn of System USA Inc. indicated that a tented, double system would cost $2.60 and a double flat system would cost $2.10 installed

4.3 Incremental & Full Measure Costs

In the case of heat curtains, because the baseline is no heat curtains (and therefore no cost), the incremental costs are identical to the full measure costs.

Index

Naming Convention for Workpaper Codes.

End Use	Code	Number variations
Refrigeration	REF	
Agriculture	AGR	
Appliances (not food Service)	APP	Gas 10X Electric 20X
Food Service	FST	Gas 10X Electric 20X
Domestic Hot Water	DHW	
HVAC (including HVAC water heat)	HVC	
Computers	COM	
Process Loads (not HVAC or DHW	PRO	
Building Shell	BLD	
Lighting	LTG	
Pumping	PUM	

Appendix

This appendix is a copy of January 11, 2008 memo to PG&E, which outlines the results of analysis for several different tiers, the bases for the weighted averages, and other details.

Hello Charlene,

TO:	Charlene Spoor, PG&E Sr. Program Engineer	**FROM:**	Marjorie Stein
CC:	Kathy Burney, PG&E Chris Li , PG&E RAS Program Engineer Charlie Middleton, P.E., PG&E Senior Chemical Engineer John Blessent, PG&E Sr. Program Engineer	**PAGES:**	17
PHONE:	415-973-0747	**DATE:**	January 11, 2008
RE:	Greenhouse Deemed Savings Analysis: Initial Results		

This memo summarizes the initial results of greenhouse modeling for PG&E's Deemed Savings Program. The purpose of this memo is to help PG&E make decisions regarding the number of tiers to offer for the Deemed Savings Program for Heat Curtains and IR Film for Greenhouses.

Table of Contents

Recommendations for Heat Curtain and IR Film for Greenhouse Tiers

The following table summarizes our recommendations for PG&E's Deemed Savings program for Greenhouse Heat Curtains and IR Film. The tiers include six baselines with annual natural gas savings shown relative to the appropriate baseline. For example, "Double-inflated polyethylene no IR film" at 55F has an annual natural gas usage of 0.47 therm per square foot; adding a single-layer heat curtain to this baseline results in an annual gas savings of 0.29 therms per square foot; while the use of a double-layer heat curtain saves 0.39 therms per square foot, relative to the "No Heat Curtain" baseline.

		Use	Savings		
Roof Material	Interior Temp Setpoint (F)	No Heat Curtain (baseline)	Single Layer Heat Curtain	Double-Layer Heat Curtain	IR Film
Polycarbonate single layer	55	0.71	0.40	0.55	N/A
	80	3.42	0.86	1.53	N/A
Double-inflated polyethylene no IR film	55	0.47	0.29	0.39	0.13
	80	2.62	0.75	1.25	0.49
Double-inflated polyethylene with IR Film	55	0.34	0.22	0.28	N/A
	80	2.14	0.66	1.03	N/A

Table 7. Summary of Recommended Tiers, Annual Natural Gas Use and Savings (Therms/Square Foot)

Because greenhouse measures are very sensitive to heating temperature setpoints, it is recommended that, at a minimum, PG&E tier the incentives by temperature setpoints (80F for orchids and 55F for all other crops.). We also recommend differentiating single-layer baseline roofs versus double-layer baseline roofs. We do not recommend PG&E tier the incentives by climate zones because the overwhelming majority of greenhouse square footage is in climate zone 3 (nearly 48%--see Figure 9) and the results are more sensitive to interior temperature setpoints and roof material than they are to climate zones.

The analysis indicates that while the natural gas savings are sensitive to weather, the results are more sensitive to baseline roof materials. For example, in Table 8 there is a 19% difference in the annual natural gas savings between the coastal versus inland location when adding a single-layer heat curtain to a double-inflated polyethylene roof with IR film. However; the difference in natural gas savings between adding a single-layer heat curtain to a double-inflated polyethylene roof with IR film versus a single-layer polycarbonate roof, both in a coastal location, is 84%. The results are also displayed in Figure 3.

	Double-Inflated Polyethylene with IR Film	Double-Inflated Polyethylene without IR Film	Single-Layer Polycarbonate	% Difference
Coastal weighted average (55F)	0.21	0.29	0.39	84%
Inland (weighted average (55F)	0.25	0.32	0.45	75%
% Difference	19%	11%	13%	

Table 8. Annual Natural gas savings (therms per square foot) with addition of Single-layer Heat Curtain. Location versus Roof material.

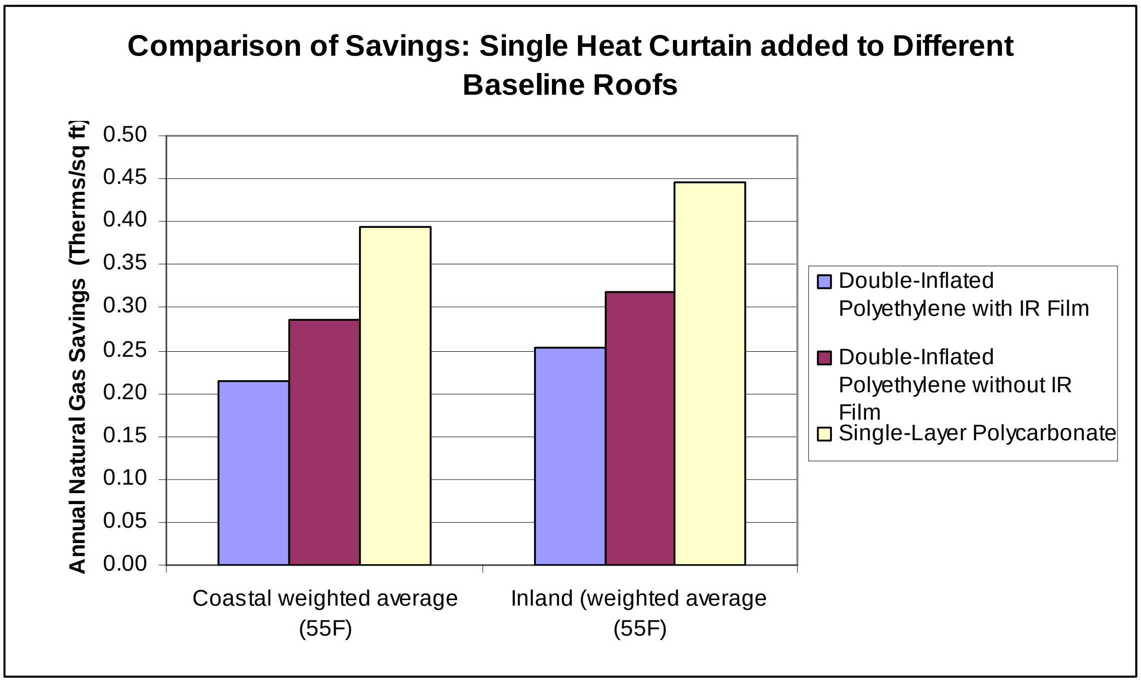


Figure 3. Comparison of Gas Savings for Single-Layer Heat Curtains added to Various Roof Baselines.

If PG&E wishes to tier the deemed savings by location, we propose, for the sake of simplicity, aggregating the climate zones into two categories: coastal (climate zones 1, 2, 3, 4 and 5) and inland (climate zones 11, 12, and 13). See the appendix for details.

Climate Zones	Category
1, 2, 3, 4, and 5	Coastal
11 12, and 13	Inland

Table 9. Proposed Grouping of Greenhouses by Climate Zones for the Deemed Savings Program.

While there is a significant difference in savings with applying heat curtains between double-inflated roofs with and without IR film (see Figure 3), it is recommended that PG&E not adopt a separate tier for these two cases. This recommendation is based upon the findings of the Greeenhouse Baseline Study that the majority of greenhouse roofs consist of double-inflated polyethylene with IR film (see Figure 4 in the appendix). While this study was based upon a small sample size (22 greenhouse facilities), the findings are backed up by anecdotal information from the vendors. Additionally, polyethylene roofs have a very short life-span (3-5 years) compared to polycarbonate or acrylic (10-20+ years). By using the improved double-polyethylene with IR film baseline for heat curtains incentives, PG&E could avoid incenting a more generous amount for a roof which may be replaced within a few years.

Table 10 outlines how the savings realized with the addition of IR inhibiting film to double-inflated polyethylene is much more sensitive to the greenhouse temperature setpoint than the location. For example, with a 55F setpoint, there is only a 14% difference in the annual natural gas savings between the coastal versus the inland greenhouse. However; there is a difference of 276% in savings between a 55F versus a 80F temperature setpoint for a coastal greenhouse.

	55F Setpoint	80F Setpoint	% Difference
Coastal weighted average (55F)	0.13	0.49	276%
Inland (weighted average (55F)	0.15	0.45	203%
% Difference	14%	8%	

Table 10. Annual Natural gas savings (per square foot) with IR Film. Location versus Temperature Setpoint

The following table summarizes the two proposed tiers for greenhouse deemed savings incentives for IR inhibiting film: 55F setpoint and 80F setpoint.

Baseline Location	Baseline Temperature Setpoint	Baseline Roof Material	Measure
Weighted Average of All Locations	55F for all other Crops	Double-inflated polyethylene	IR inhibiting film
	80F for Orchids		

Table 11. Proposed Tiers for the Greenhouse Deemed Savings Program: IR Inhibiting Film.

Baseline Location	Baseline Temperature Setpoint	Baseline Roof Material	Measure
Weighted Average of All Locations	55F for all other Crops	Double-inflated polyethylene w/ IR inhibiting film	Single Layer Heat Curtain
			2nd Layer Heat Curtain added to existing Heat Curtain
		Single layer polycarbonate	Single Layer Heat Curtain
			2nd Layer Heat Curtain added to existing Heat Curtain
	80F for Orchids	Double-inflated polyethylene with IR inhibiting film	Single Layer Heat Curtain
			2nd Layer Heat Curtain added to existing Heat Curtain
		Single layer polycarbonate	Single Layer Heat Curtain
			2nd Layer Heat Curtain added to existing Heat Curtain

Table 12. Proposed Tiers for the Greenhouse Deemed Savings Program: Heat Curtains.

Table 13 summarizes the modeling scenarios investigated for this initial analysis. As can be seen, analysis was carried out for the double-inflated polyethylene roofs both with and without IR inhibiting film for baselines. Additionally, as discussed, analysis was carried out for assuming a 30% production increase with the use of double heat curtains. This production increase is based upon a conversation with Andy Matsui of Matsui Nursery.

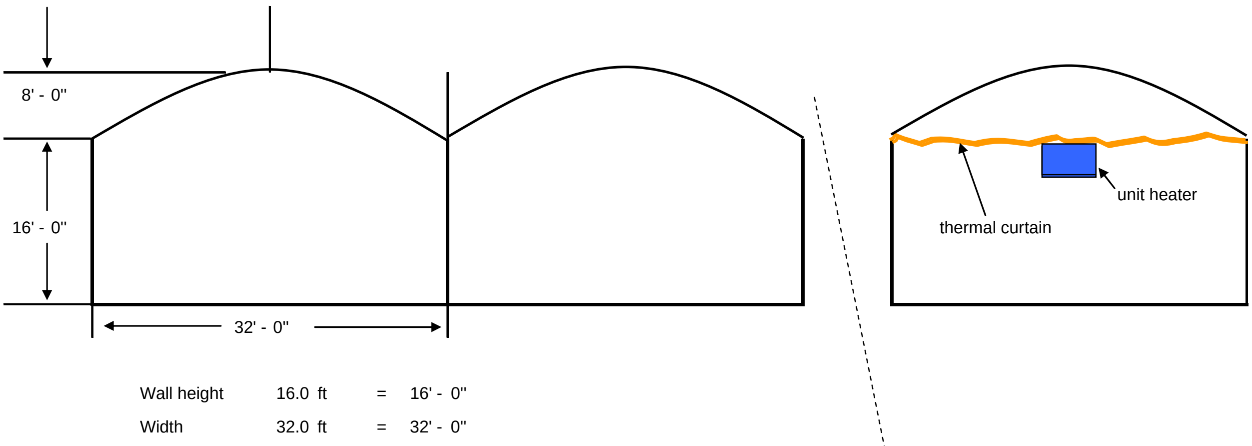
Climate Zone	Roof Material	Interior Temp Setpoint (F)[2]	Modeling Scenarios				
			No Heat Curtain	Single Layer Heat Curtain	Single layer Heat Curtain added to Existing Heat Curtain	Double heat curtains + 30% production increase	IR Film
California Coastal Climate	Polycarbonate single layer	55	**X** (baseline)	**X**	**X**	**X**	N/A
		80	**X** (baseline)	**X**	**X**	**X**	N/A
	Double-inflated polyethylene	55	**X** (baseline)	**X**	**X**	**X**	**X**
		80	**X** (baseline)	**X**	**X**	**X**	**X**
	Double-inflated polyethylene with IR Film	55	**X** (baseline)	**X**	**X**	**X**	N/A
		80	**X** (baseline)	**X**	**X**	**X**	N/A
California Inland Climate	Polycarbonate single layer	55	**X** (baseline)	**X**	**X**	**X**	N/A
		80	**X** (baseline)	**X**	**X**	**X**	N/A
	Double-inflated polyethylene	55	**X** (baseline)	**X**	**X**	**X**	**X**
		80	**X** (baseline)	**X**	**X**	**X**	**X**
	Double-inflated polyethylene with IR Film	55	**X** (baseline)	**X**	**X**	**X**	N/A
		80	**X** (baseline)	**X**	**X**	**X**	N/A

Table 13. Greenhouse Deemed Savings Modeling Matrix

[2] The recommended heating setpoint is 55F for Gerbera, a common floral crop. Orchid crops are kept at approximately 80F.

Simulation Model Baseline

Greenhouse Structure



Wall height	16.0	ft	=	16' - 0"
Width	32.0	ft	=	32' - 0"
Roof length	17.9	ft	=	17' - 11"
Attic height	8.0	ft	=	8' - 0"

Description

Design	gutter connected bays with hoop roofs
Roof Material	double inflated PE with IR film
Wall Material	single layer polycarbonate
Floor	uninsulated bare soil
Thermal Curtain Position	truss to truss at gutter height
Thermal Curtain Operation	deployed when temperature falls below 65F

Surface Area and Volume Calculations

Dimensions		
Number of Bays		14
Width (each bay)	ft	32
Wall Height (each bay)	ft	16
Length	ft	256
Roof Pitch, rise to run (**x** in 12)		6.0
Peak Height (gutter to peak)	ft	8.0
Roof Width (gutter to peak)	ft	17.9
Surface Area		
Side Walls	ft^2	8,192
End Wall (without gable)	ft^2	14,336
Total Wall (below gutter)	ft^2	22,528
End Gable	ft^2	3,584
Roof	ft^2	128,225
Floor	ft^2	114,688
Interior Volume		
Total	ft^3	2,293,760
Gable (above gutter)	ft^3	458,752
Main (below gutter)	ft^3	1,835,008

The baseline greenhouse building consists of the following features:

Roofs: Double-inflated poly[3] without IR film (U-value 0.70, Visible Transmittance 0.78, and Shading Coefficient 0.85[4]).

Double-inflated poly with IR film (U-value 0.50, Visible Transmittance 0.78, and Shading Coefficient 0.85).

Single-layer polycarbonate (U-value 1.14, Visible Transmittance 0.83, Shading Coefficient 0.85.

Walls: Single layer polycarbonate: U-value 1.14, R-Value 0.91, Visible Transmittance 0.90, Shading Coefficient 1.00.

Floors: uninsulated bare soil

Thermostats: Temperature sensors are assumed to be located at crop level (approximately four feet above the floor) near the middle of each greenhouse range. Baseline heaters are assumed to be located overhead. The location of the heating systems causes stratification, with the air above the gutter level 7 to 10º F hotter than at the thermostat level, per Hoogeboom. Since the eQUEST computer model cannot account for thermal stratification of air, the thermostat schedules are modified to account for stratification effects by adding a temperature offset. This strategy has been borrowed from the one utilized by Marlin Addison, an eQUEST expert, and John Hoogenboom, a greenhouse consultant. An assumed space temperature offset of 7.5º F is recommended without heat curtains and 4º F with heat curtains.

Heating: The baseline heating system in California greenhouses consists of overhead gas-fired unit heaters with an 80% heating efficiency. .

Cooling: For coastal areas, the baseline cooling system is passive natural ventilation with ridge & vent design (upper vents sized at 20% of floor area, lower vents same size). For inland valley areas the baseline cooling system is fan and pad. This evaporative cooling system is assumed to be 80% efficient.

Fans and Airflow: For the non-coastal areas, exhaust fans are simulated to provide 60 air changes per hour of ventilation whenever the greenhouse temperature exceeds 75 F. Based upon Energy Conservation for Commercial Greenhouses, it is assumed that the target rate is eight CFM/square foot, and the fans are assumed to deliver 20,000 cfm per hp. For coastal locations, no exhaust fans are assumed in the baseline model—only passive natural ventilation.
Horizontal airflow fans are used to mix the air and reduce mold and mildew growth when the greenhouse is being ventilated. The model assumes HAF fans with a capacity of 0.25 cfm, based upon recommendations from Energy Conservation for Commercial Greenhouses for greenhouses.

Lighting: No supplemental lighting has been assumed in the analysis.

Infiltration: A rate of 0.75 air changes per hour is assumed in the model. Energy Conservation for Commercial Greenhouses cites an average of 0.5 – 1.0 air changes per hour for greenhouse construction:

Orientation: According to Energy Conservation for Commercial Greenhouses, locations above 40°N latitude should have the ridge of multi-span greenhouses running north to south, and the ridge of single bay

[3] Peter Fryn of System USA inc. is a major vendor to greenhouse owners. His experience is that the baseline roof material for coastal greenhouses is single-layer Dynaglas (Polycarbonate) and not double-inflated polyethylene. Our 2005 baseline study for PG&E found that of the 22 greenhouse facilities in coastal locations interviewed for the study, the largest number (7) had double-polyethylene roofs, 5 had glass roofs, and 3 had single polycarbonate roofs. The remaining roof types were distributed among other materials.

[4] Our original greenhouse baseline study for PG&E published in 2005 used a shading coefficient for double-inflated polyethylene film of 0.28—this is a reasonable proxy when taking into account the energy absorption of plants. We have subsequently revised our methodology to separate out the energy absorption of plants and utilize a shading coefficient value of 0.85 (Source: Aldrich, Robert A. and Bartok, John W., Jr. 1994. *Greenhouse Engineering*. NRAES-33. Ithaca, NY: Natural Resource, Agriculture, and Engineering Service.)

greenhouses running east to west. All houses below 40°N should have the ridges running north to south to optimize the light..

Schedule: 24 hours per day, 7 days per week.

Utility Rates: Assumes PG&E'sAG-5 rate for electricity and GNR-1 rate for gas.

Single Heat Curtain System: Assumes a heat curtain with a 40% energy savings factor. Conductance (u-value) is 1-0.40 = 0.60. U-value of 0.60 is used as a multiplier on the roof glazing conductance to model heat retention during the night.

Double Heat Curtain System: Assumes white acrylic layer, 55% woven plus a heat curtain with a 40% energy savings factor. Primary benefit of the 40% energy savings factor heat curtain is radiant heat retention. The primary benefit of the acrylic layer is an added air film, which trap heat. This analysis assumes a 12-inch air gap between the two layers of heat curtain. Without an air gap the added benefit of the two layers is greatly reduced. Conductance (u-value) of the 40% energy savings factor heat curtain is 1-0.40 = 0.60. R-value is 1/0.60 = 1.67. The R-value of air-film between two layers of heat curtains is approximately 2.5. Total R-value is 4.17. U-value of 0.240 is used as a multiplier on the roof glazing conductance to model heat retention during the night.

air gap (inches)	0.5	0.75	1.5	3.5	**12**	18
R-value	1.6	1.7	1.8	2.0	**2.5**	3.0

Table 14. Thermal Resistance (R-value) of air gaps.[5]

Specifications for Ludvig Svensson, Thermal Curtains (Aluminum/Polyester Strips)		
Type	Energy saving	Diffuse Light transmission
Calculated	40%	84%
XLS 10 Firebreak	45%	78%
XLS 13 Firebreak	49%	65%
XLS 14 Firebreak	52%	53%
XLS 15 Firebreak	57%	43%
XLS 16 Firebreak	62%	34%
XLS 17 Firebreak	67%	24%
XLS 18 Firebreak	72%	17%

Table 15. Specifications for Ludvig Svensson, Thermal Curtains[6]

Table 1 presents the specifications for thermal curtains from a large manufacturer. This analysis will assume the heat curtain has an energy savings factor of 40%, based upon PG&E's minimal requirement for qualifying products, with a calculated diffuse light transmission of 84%. Figure 5 (in the appendix) illustrates the calculations for arriving at the diffuse light transmission of a 40% energy savings factor heat curtain.

[5] Based upon ASHRAE Fundamentals (page 25.4. Mean Temp of 50F, Temp difference of 10F, upward direction of heat flow. Effective emittance of air space is assumed to be 0.2, based upon one side of air gap having thermal curtain with foil strips. According to ASHRAE, moderate extrapolation for air spaces greater than 3.5 inches are permissible. See the appendix for calculations.

[6] See manufacturers' website for further information: (http://www.ludvigsvensson.com/)

Results

The following table presents the annual natural gas usage and savings, based upon weighted averages of the coastal climate zones (climate zones 1, 2, 3, 4 and 5) ; the weighted averages of the inland climate zones (climate zones 11, 12, and 13); and the weighted average of all zones together. Refer to the appendix for data on square footage of greenhouses by county and climate zone. Because less than one percent of California greenhouse space is in climate zone 16, this region has been ignored. As can be seen, while the gas usage is significantly different between the inland and the coastal greenhouses, the savings are comparable. Refer to Table 21 in the appendix for annual electricity use savings for climate zones 3 and 12. The electricity savings is from the fan energy consumed by the heaters. There is no peak demand savings. All savings in the following table are relative to the shaded row in that group. For example the savings for alternative 5 "Alt 4 + 2nd layer heat curtain" are relative to alternative 3 and are equal to 1.04 therms/sf for coastal zones and 0.98 therms/sf for inland zones.

		Coastal Climate Zones Usage					**Coastal zones, weighted averages**		**Inland Climate Zones Usage**			**Inland zones, weighted averages**		**All zones, weighted averages**	
		cz 01	cz 02	cz 03	cz 04	cz 05			cz 11	cz 12	cz 13				
	% of total greenhouse area (grouped by coastal vs inland)	1.1%	1.3%	53.9%	28.3%	15.3%	**100%**		2.8%	74.3%	22.9%	**100%**		N/A	
	% of total greenhouse area (all zones)	1.0%	1.2%	47.7%	25.1%	13.6%	**88%**		0.3%	8.3%	2.8%	**12%**		**100%**	
Alt	Description	**Use**	**Use**	**Use**	**Use**	**Use**	**Use**	**Saving**	**Use**	**Use**	**Use**	**Use**	**Saving**	**Use**	**Saving**
0	Double Inflated Poly w/ IR, 55F	0.59	0.44	0.34	0.32	0.24	0.32	N/A	0.54	0.49	0.32	0.45	N/A	0.34	N/A
1	Alt 0 + Single Heat Curtain	0.25	0.18	0.12	0.11	0.05	0.11	0.21	0.27	0.22	0.12	0.20	0.25	0.12	0.22
2	Alt 1 + 2nd layer heat curtain	0.15	0.08	0.06	0.04	0.01	0.05	0.27	0.17	0.12	0.05	0.11	0.35	0.05	0.28
2b	Alt 2 + 30% production increase	0.1	0.06	0.04	0.03	0.007	0.03	0.29	0.12	0.09	0.04	0.08	0.37	0.04	0.30
3	Double Inflated Poly w/ IR, 80F	2.71	2.05	2.28	1.92	2.02	2.14	N/A	2.15	2.3	1.59	2.13	N/A	2.14	N/A
4	Alt 3 + Single Heat Curtain	2.05	1.36	1.74	1.26	0.9	1.47	0.67	1.71	1.59	1.17	1.50	0.64	1.48	0.66
5	Alt 4 + 2nd layer heat curtain	1.68	1	1.36	0.93	0.48	1.10	1.04	1.39	1.22	0.9	1.15	0.98	1.11	1.03
5b	Alt 5 + 30% production increase	1.18	0.7	0.95	0.65	0.34	0.77	1.37	0.97	0.86	0.63	0.81	1.32	0.77	1.36
6	Double Inflated Poly no IR, 55F	0.78	0.59	0.47	0.46	0.35	0.45	N/A	0.7	0.65	0.43	0.60	N/A	0.47	N/A
7	Alt 6 + Single Heat Curtain	0.35	0.26	0.18	0.17	0.1	0.17	0.29	0.36	0.31	0.19	0.28	0.32	0.18	0.29
8	Alt 7 + 2nd layer heat curtain	0.2	0.13	0.09	0.07	0.02	0.08	0.38	0.22	0.17	0.09	0.15	0.45	0.08	0.39
8b	Alt 8 + 30% production increase	0.14	0.09	0.06	0.05	0.01	0.05	0.40	0.16	0.12	0.06	0.11	0.49	0.06	0.41
9	Alt 6 with IR film	0.59	0.44	0.34	0.32	0.24	0.32	0.13	0.54	0.49	0.32	0.45	0.15	0.34	0.13
10	Double Inflated Poly no IR,80F	3.24	2.5	2.74	2.49	2.48	2.63	N/A	2.57	2.78	1.95	2.58	N/A	2.62	N/A
11	Alt 10 + Single Heat Curtain	2.44	1.69	2.12	1.55	1.63	1.88	0.75	2.06	1.96	1.47	1.85	0.73	1.88	0.75
12	Alt 11 + 2nd Layer Heat curtain	1.97	1.22	1.65	1.15	0.74	1.37	1.26	1.66	1.49	1.13	1.41	1.17	1.37	1.25
12b	Alt 12 + 30% production	1.38	0.85	1.16	0.8	0.52	0.96	1.67	1.16	1.05	0.79	0.99	1.59	0.96	1.66

		Coastal Climate Zones Usage					Coastal zones, weighted averages		Inland Climate Zones Usage			Inland zones, weighted averages		All zones, weighted averages	
		cz 01	cz 02	cz 03	cz 04	cz 05			cz 11	cz 12	cz 13				
% of total greenhouse area (grouped by coastal vs inland)		1.1%	1.3%	53.9%	28.3%	15.3%	**100%**		2.8%	74.3%	22.9%	**100%**		N/A	
% of total greenhouse area (all zones)		1.0%	1.2%	47.7%	25.1%	13.6%	**88%**		0.3%	8.3%	2.8%	**12%**		**100%**	
Alt	Description	**Use**	**Use**	**Use**	**Use**	**Use**	**Use**	**Saving**	**Use**	**Use**	**Use**	**Use**	**Saving**	**Use**	**Saving**
	increase														
13	Alt 10 with IR film	2.71	2.05	2.28	1.92	2.02	2.14	0.49	2.15	2.3	1.59	2.13	0.45	2.14	0.49
30	Single layer polycarbonate, 55F	1.13	0.86	0.71	0.69	0.57	0.69	N/A	0.99	0.94	0.65	0.87	N/A	0.71	N/A
31	Alt 30 + Single Heat Curtain	0.53	0.42	0.31	0.3	0.2	0.29	0.39	0.55	0.48	0.32	0.45	0.43	0.31	0.40
32	Alt 31 + 2nd layer Heat Curtain	0.32	0.23	0.16	0.15	0.06	0.14	0.54	0.34	0.29	0.16	0.26	0.61	0.16	0.55
32b	Alt 32 + 30% production increase	0.23	0.16	0.12	0.1	0.05	0.11	0.58	0.24	0.2	0.12	0.18	0.69	0.11	0.60
33	Single layer polycarbonate, 80F	4.14	3.24	3.54	3.28	3.27	3.42	N/A	3.33	3.65	2.59	3.40	N/A	3.42	N/A
34	Alt 33 + Single Heat Curtain	3.12	2.26	2.82	2.28	2.23	2.57	0.85	2.73	2.66	2.02	2.52	0.88	2.56	0.86
35	Alt 34 + 2nd layer Heat Curtain	2.55	1.55	2.2	1.72	1.05	1.88	1.54	2.19	2.03	1.57	1.93	1.47	1.89	1.53
35b	Alt 35 + 30% production increase	1.78	1.08	1.54	1.2	0.74	1.32	2.11	1.53	1.42	1.1	1.35	2.05	1.32	2.10

Table 16. Annual Natural Gas Usage and Savings (therms per square foot)

Appendix

Baseline Roof Material

While there is a significant difference in savings with applying heat curtains between double-inflated roofs with and without IR film (see Figure 3), it is recommend that PG&E not adopt a separate tier for these two cases. This recommendation is based upon the findings of the Greenhouse Baseline Study that the majority of greenhouse roofs consist of double-inflated polyethylene with IR film (see Figure 4). While this study was based upon a small sample size (22 greenhouse facilities), the findings are backed up by anecdotal information from the vendors. Additionally, polyethylene roofs have a very short life-span (3-5 years) compared to polycarbonate or acrylic (10-20+ years). By using the improved double-polyethylene with IR film baseline for heat curtains incentives, PG&E could avoid incenting a more generous amount for a roof which may be replaced within a few years.

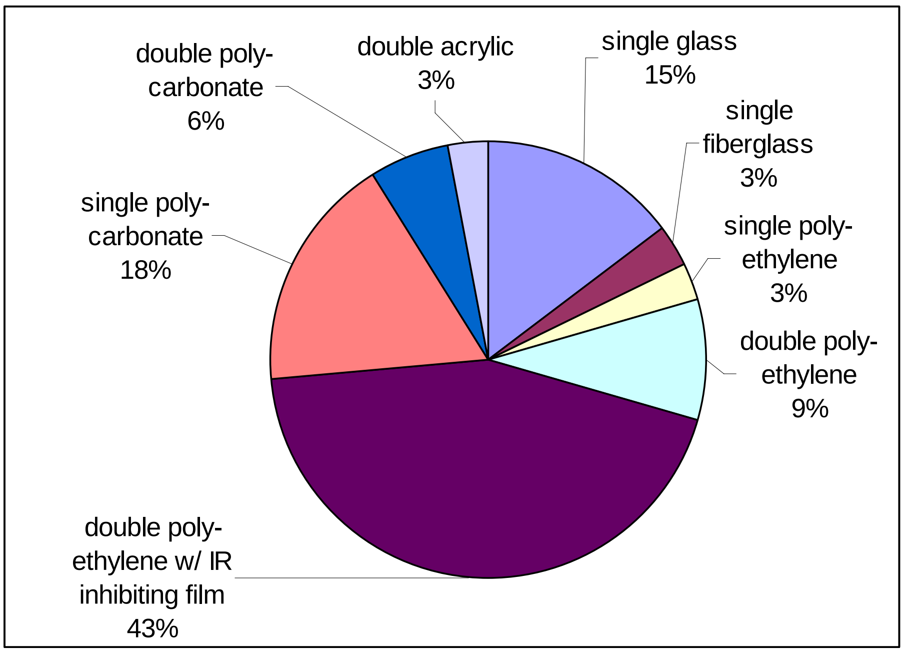


Figure 4. Distribution of Greenhouse Roof Materials (Source: PG&E Greenhouse Baseline Study)

Figure 5 illustrates the calculations for arriving at the diffuse light transmission of a 40% energy savings factor heat curtain.

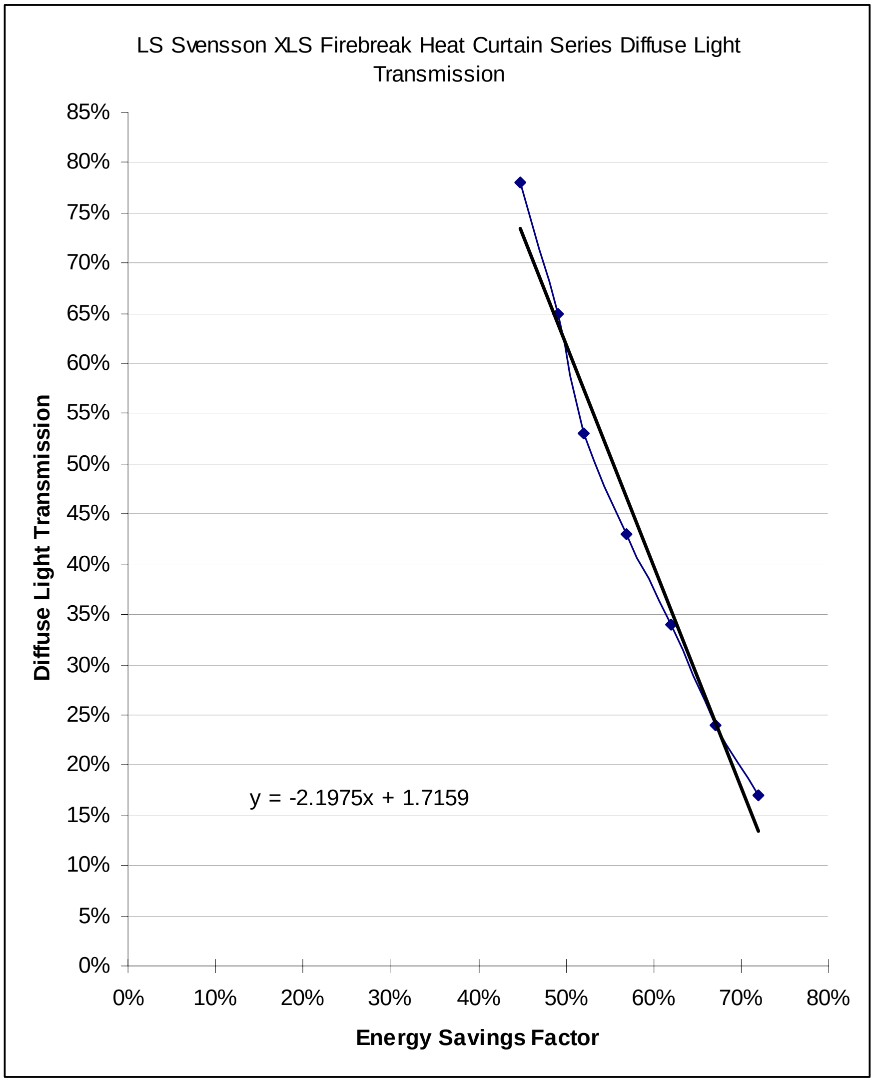


Figure 5. Graph of Ludvig Svensson XLS Firebreak Energy Curtains. Diffuse Light Transmission vs Energy Savings Factor.

Climate Zones

The original Greenhouse Baseline Study conducted for PG&E stratified the data into three different geographic regions: coastal, coastal valley, and inland valley. This aggregation was based upon conversations with PG&E project manager John Blessent and PG&E meteorologist Woody Whitlatch. The geographical segregation was accomplished by mapping the greenhouse locations with the California Energy Commission climate zones (see Figure 10 in the appendix). Refer to Table 17 for the assignment of the geographic regions by climate zone. Because less than one percent of California greenhouse space is in climate zone 16, this region has been ignored.

Climate Zones	Category
2, 4, and 12	Coastal Valley
1, 3, and 5	Coastal
11 and 13	Inland Valley

Table 17. Grouping of Greenhouses by Climate Zones for the PG&E Greenhouse Baseline Study.

If PG&E wishes to tier the greenhouse deemed savings by climate zones, we propose, for the sake of simplicity, further aggregating the climate zones into two categories: into coastal (climate zones 1, 2, 3, 5 and 5) and inland (climate zones 11, 12, and 13).

Climate Zones	Category
1, 2, 3, 4, and 5	Coastal
11 12, and 13	Inland

Table 18. Proposed Grouping of Greenhouses by Climate Zones for the Deemed Savings Program.

Refer to Table 20 for a summary of the square footage of crops grown under cover (by County and climate zones), based upon 2002 Census data.

Results indicate that natural gas usage is higher in climate zone 12, which may seem counter-intuitive. However, climate zone 12 has colder temperatures than climate zone 3, as can be seen in Figure 6 and Table 19. The data presented in Table 19 is from the California Energy Commission weather files for climate zones 3 (Oakland is the reference city) and 12 (Sacramento is the reference city). The results compare the number of heating degree days (HDD) and shows that climate zone 12 is colder than climate zone 3. The weather files used in the analysis have been approved by the California Energy Commission.

	CZ 03 (Oakland)	CZ 12 (Sacramento)
Average Daily Max Tdb	67.4	73.7
Average Daily Min Tdb	49.2	47.5
Avg. Annual Tdb	57.5	59.5
Annual Max Tdb	91	103
Annual Min Tdb	34	27
HDD (24 hours/65F)	3107	3351

Table 19. Summary of California Energy Commission Climate Zone HDD Calculations

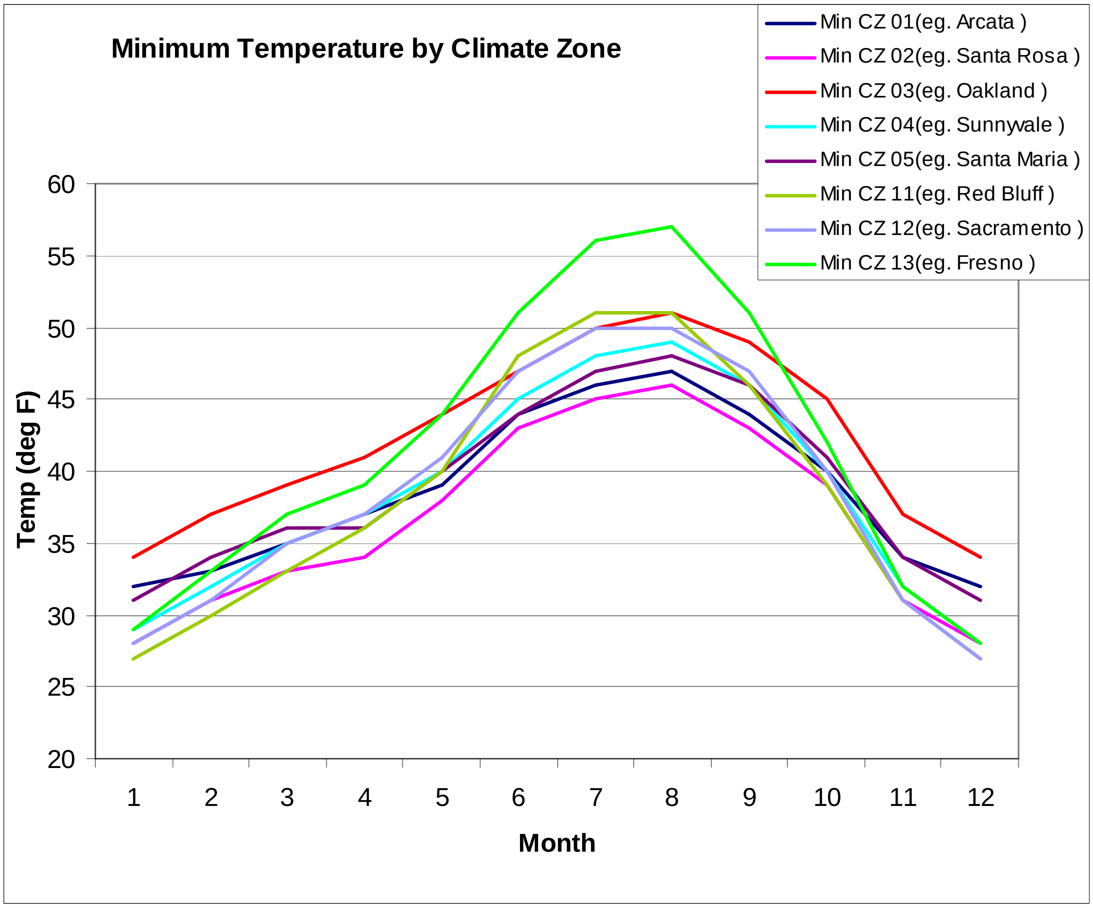


Figure 6. Monthly Minimum Temperatures

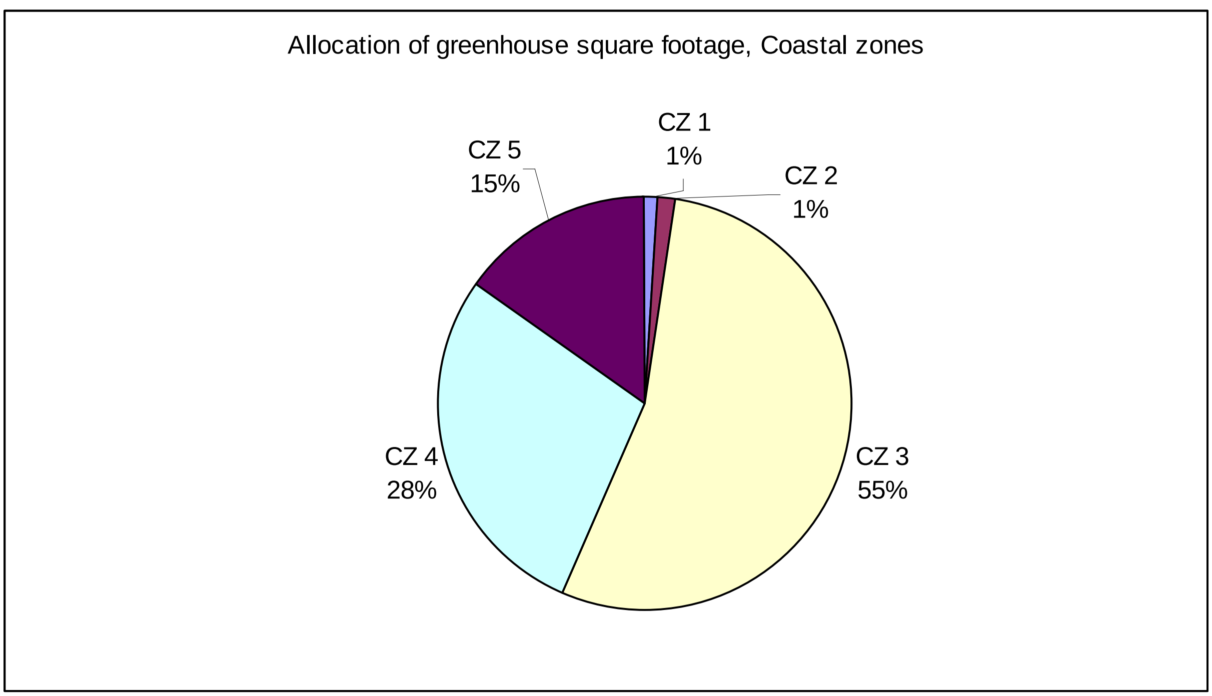


Figure 7. Allocation of greenhouse square footage, coastal climate zones.

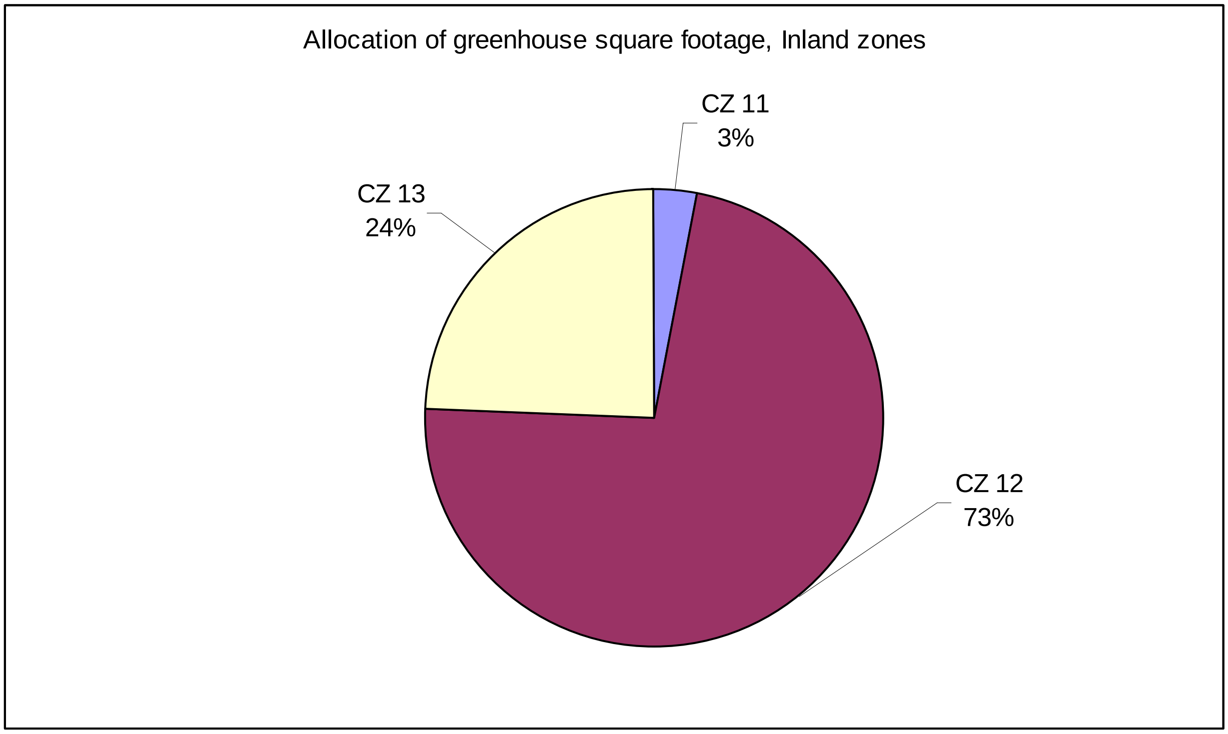


Figure 8. Allocation of greenhouse square footage, inland climate zones.

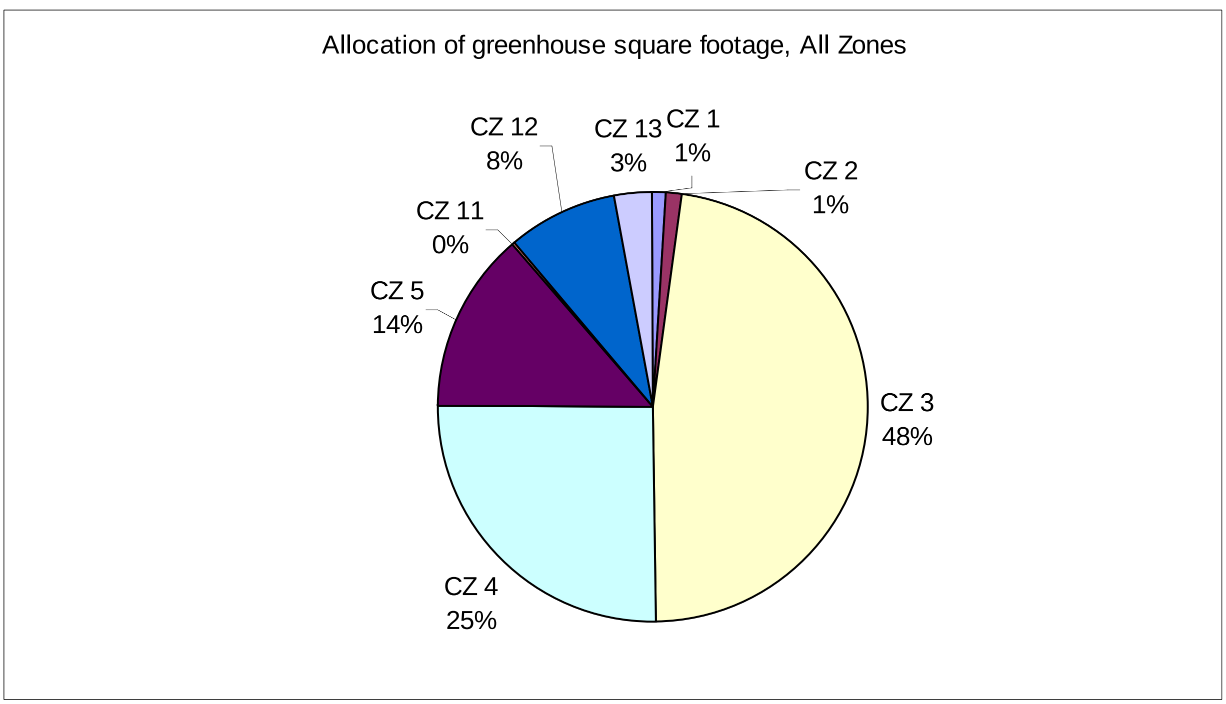


Figure 9. Allocation of greenhouse square footage, all climate zones.

County	Climate Zone(s)	sq ft of greenhouses	% of total
Alameda	12	478,560	0.3%
Butte	11/16	864,063	0.5%
Contra Costa	3/12	3,682,708	2.0%
El Dorado	12/16	77,352	0.0%
Fresno	13/16	1,877,395	1.0%
Humboldt	1	1,514,335	0.8%
Kern	13/14/16	309,354	0.2%
Lake	2	47,396	0.0%
Lassen	16	93,400	0.1%
Madera	13/16	124,400	0.1%
Marin	2/3	60,576	0.0%
Mendocino	1/2/3/16	746,950	0.4%
Monterey	3/4	51,680,374	28.6%
Napa	2	6,050	0.0%
Nevada	11/16	67,280	0.0%
Sacramento	12	2,811,632	1.6%
San Benito	4	29,464	0.0%
San Francisco	3	114,039	0.1%
San Joaquin	12	9,434,276	5.2%
San Luis Obispo	4/5	13,773,982	7.6%
San Mateo	3	17,192,804	9.5%
Santa Barbara	4/5/6	25,918,293	14.3%
Santa Clara	4	14,663,782	8.1%
Santa Cruz	3	25,638,304	14.2%
Shasta	11/16	64,692	0.0%
Siskiyou	16	70,156	0.0%
Solano	3/12	25,828	0.0%
Sonoma	2/3	5,148,121	2.8%
Stanislaus	12	299,478	0.2%
Sutter	11	113,000	0.1%
Tehama	11/16	34,310	0.0%
Trinity	2/11/16	3,046	0.0%
Tulare	13/16	3,591,573	2.0%
Yolo	12	316,948	0.2%

Table 20. Square Footage of Greenhouses by County and Climate Zones.

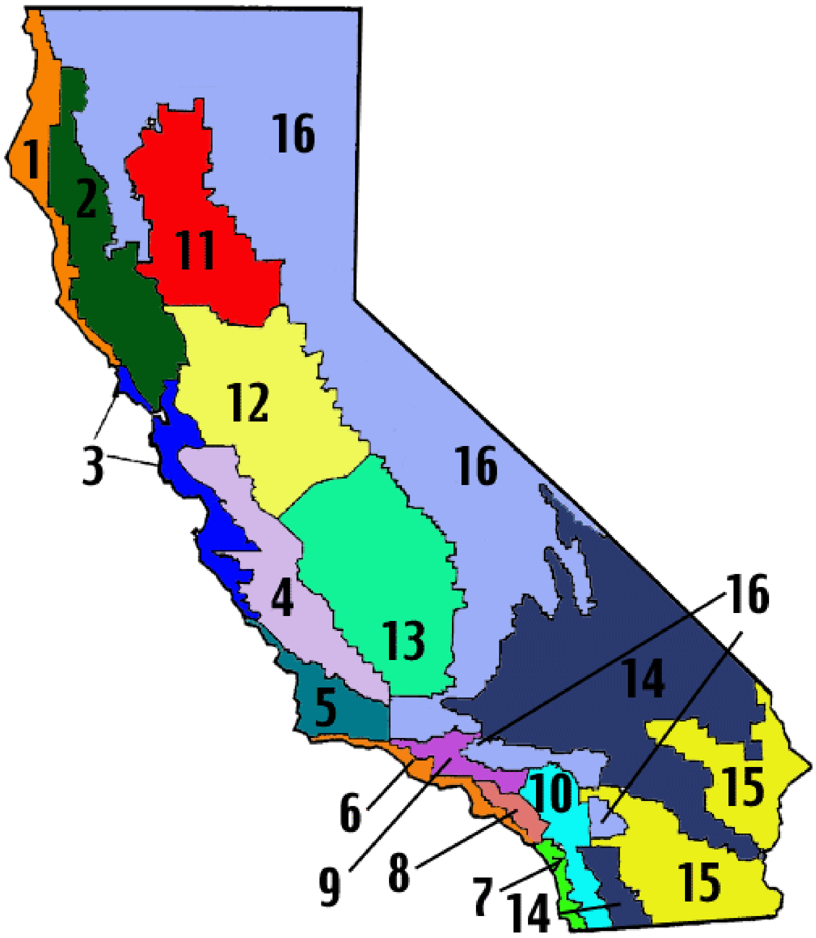


Figure 10. California Climate Zones Map

Electricity Savings

The following table outlines the annual electricity use and annual electricity savings, per square foot, for only climate zones 3 and 12. The electricity savings is from the fan energy consumed by the heaters. There is no peak demand savings.

Alt		Annual Electricity Use (kWh/sq ft)	Annual Electricity Savings (kWh/sq ft
0	Double Inflated Poly with IR Roof, 55F, CZ03 (Coastal) baseline	0.16	N/A
1	Alt 0 + Single-Layer Heat Curtain	0.12	0.04
2	Alt 1 + 2nd layer heat curtain	0.11	0.01
3	Double Poly Roof with IR, 80F, CZ03 (Coastal) baseline	0.50	N/A
4	Alt 3 + Single-Layer Heat Curtain	0.41	0.09
5	Alt 4 + 2nd layer heat curtain	0.34	0.07
6	Double Inflated Poly Roof no IR film, 55F, CZ03 (Coastal) baseline	0.19	N/A
7	Alt 6 + Single-Layer Heat Curtain	0.14	0.05
8	Alt 7 + 2nd layer heat curtain	0.12	0.02
9	Alt 6 with IR film	0.16	0.03
10	Double Inflated Poly Roof no IR Film, 80F, CZ03 (Coastal) baseline	0.58	N/A
11	Alt 10 + Single-Layer Heat Curtain	0.47	0.11
12	Alt 11 + 2nd Layer Heat curtain	0.39	0.08
13	Alt 10 with IR film	0.50	0.08

Alt		Annual Electricity Use (kWh/sq ft)	Annual Electricity Savings (kWh/sq ft
14	BLANK		
15	Double Poly with IR roof, 55F, CZ12 (Inland) baseline	0.51	N/A
16	Alt 15 + Single-Layer Heat Curtain	0.48	0.03
17	Alt 17 + 2nd layer heat curtain	0.49	-0.01
18	Double Poly Roof with IR, 80F, CZ12 (Inland) baseline	0.63	N/A
19	Alt 18 + Single-Layer Heat Curtain	0.53	0.10
20	Alt 19 + 2nd Layer Heat curtain	0.48	0.05
21	Double Inflated Poly Roof no IR film, 55F, CZ12 (Inland) baseline	0.51	N/A
22	Alt 21 + Single-Layer Heat Curtain	0.48	0.03
23	Alt 22 + 2nd Layer Heat curtain	0.48	0.00
24	Alt 21 with IR film	0.51	0.00
25	Double Inflated Poly Roof no IR film, 80F, CZ12 (Inland) baseline	0.70	N/A
26	Alt 25 + Single-Layer Heat Curtain	0.58	0.12
27	Alt 26 + 2nd Layer Heat curtain	0.51	0.07
28	Alt 25 with IR film	0.63	0.07
29	BLANK		
30	Single layer polycarbonate roof, 55F, Coastal (CZ 3) baseline	0.23	N/A
31	Alt 30 + Single Heat Curtain	0.16	0.07
32	Alt 31 + 2nd layer Heat Curtain	0.13	0.03
33	Single layer polycarbonate roof, 80F, Coastal (CZ 3) baseline	0.72	N/A
34	Alt 33 + Single Heat Curtain	0.59	0.13
35	Alt 34 + 2nd layer Heat Curtain	0.48	0.11
36	BLANK		
37	Single layer polycarbonate roof, 55F, Inlandl (CZ 12) baseline	0.52	N/A
38	Alt 37 + Single Heat Curtain	0.46	0.06
39	Alt 38 + 2nd layer Heat Curtain	0.46	0.00
40	Single layer polycarbonate roof, 80F, Inland (CZ 12) baseline	0.82	N/A
41	Alt 40 + Single Heat Curtain	0.67	0.15
42	Alt 41 + 2nd layer Heat Curtain	0.58	0.09

Table 21. Electricity Use and Savings Results

References

[1] The PG&E Greenhouse Baseline Study found that the greatest majority of crop types grown within PG&E service territory greenhouses is cut flowers (47%). This figure is based upon 2002 Census data. According to Bond, T.E. et. al. 1985. Reducing Energy Costs in California Greenhouses. University of California Cooperative Extension. (http://ohric.ucdavis.edu/Newsltr/GreenhouseEnergy.pdf) typical cut flowers can be grown at 55F or less.

[2] Per Peter Fryn of System USA Inc., a tented, double system would cost $2.60 and a double flat system would cost $2.10 installed

[3] Copied from PG&E "Energy Efficiency Rebates For Your Business" brochures. http://www.pge.com/includes/docs/pdfs/catalogs/biz_catalog.pdf

[4] Bartok, John W., Jr. 2001. *Energy Conservation for Commercial Greenhouses*.NRAES-3. Ithaca, NY: Natural Resource, Agriculture, and Engineering Service.

[5] Source of characteristics, the manufacturer's website. (http://www.ludvigsvensson.com/Default.asp?LocationID=1&LanguageID=3)

[6] Based upon ASHRAE Fundamentals (page 25.4. Mean Temp of 50F, Temp difference of 10F, upward direction of heat flow. Effective Emittance of air space is assumed to be 0.2, based upon one side of air gap having thermal curtain with foil strips. According to ASHRAE, moderate extrapolation for air spaces greater than 3.5 inches are permissible.

[7] Southern California Edison. December 2005. *2004-2005 Database for Energy Efficiency Resources (DEER) Update Study Final Report*. Prepared by Itron, Inc., Vancouver, Washington. http://www.energy.ca.gov/deer/

[8] Greenhouse Baseline Study, prepared for PG&E by Green Building Studio, December 2005. This reference is included as Attachment #1.

[9] Greenhouse Baseline Study, prepared for PG&E by Green Building Studio, December 2005. This reference is included as Attachment #1.

[10] Peter Fryn of System USA Inc. is a major vendor to greenhouse owners. His experience is that the baseline roof material for coastal greenhouses is single-layer Dynaglas (Polycarbonate) and not double-inflated polyethylene. Our 2005 baseline study for PG&E found that of the 20 greenhouse facilities in coastal locations interviewed for the study, the largest number (7) had double-polyethylene roofs, 5 had glass roofs, and 3 had single polycarbonate roofs. The remaining roof types were distributed among other materials.

[11] Hoogeboom, John, Hill, John, and Addison, Marlin. 2004. Savings By Design Whole Building Analysis Summary: Gilroy Young Plant Nursery. PG&E Report.

[12] *Ibid*

[13] Bartok, John W., Jr. 2001. *Energy Conservation for Commercial Greenhouses*.NRAES-3. Ithaca, NY: Natural Resource, Agriculture, and Engineering Service.