



BUILDING ENVELOPE
GREENHOUSE HEAT CURTAIN
SWBE001-02

C O N T E N T S

Measure Name	2
Statewide Measure ID.....	2
Technology Summary	2
Measure Case Description	2
Base Case Description.....	3
Code Requirements	3
Normalizing Unit	3
Program Requirements Program Requirements.....	3
Program Exclusions.....	4
Data Collection Requirements	4
Use Category.....	4
Electric Savings (kWh).....	5
Peak Electric Demand Reduction (kW)	5
Gas Savings (Therms)	5
Life Cycle.....	8
Base Case Material Cost (\$/unit)	9
Measure Case Material Cost (\$/unit).....	9
Base Case Labor Cost (\$/unit)	10
Measure Labor Cost (\$/unit).....	10
Net-to-Gross (NTG)	10
Gross Savings Installation Adjustment (GSIA)	11
Non-Energy Benefits	11
DEER Differences Analysis.....	11
Revision History	12

MEASURE NAME

Greenhouse Heat Curtain

STATEWIDE MEASURE ID

SWBE001-02

TECHNOLOGY SUMMARY

Thermal curtains decrease conduction, convection, and radiation heat losses in greenhouses. Thermal curtains are installed inside the greenhouse and are designed to be placed horizontally above the growing zone within a greenhouse. In addition to retaining heat, thermal curtains are commonly used for shading.

There are two basic types of thermal curtain installations: flat, and slope-flat-slope.¹ The flat is under the gutter level and operates on 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).

Thermal curtains are made of several different materials that impact the heat retention properties.² Porous materials allow condensation to drain but are not as effective as nonporous materials for reducing energy use. However, nonporous curtains could cause the track system to fail if they become too heavy from collected moisture. The aluminized curtains typically consist of a 55% woven white polyester film.

Thermal curtains save energy by 1) trapping an insulating air film; 2) reducing the volume of space requiring heating, and/or 3) reflecting rising heat back into the growing zone (with aluminized strips). Research results indicate that outward-facing reflective surface retain heat slightly better than an inward-facing system.³ Aluminized curtains save about 10% more energy than non-aluminized curtains.

MEASURE CASE DESCRIPTION

This measure case is defined as the installation of a single-layer heat curtain in a greenhouse area in which a heat curtain was not present, or where heat curtains were present but nonfunctional. It is assumed that the thermal curtains are deployed during nighttime hours, and open during daytime hours.

Measure Case Specification

Statewide Measure Offering ID	Measure Offering Description
SWBE001A	Greenhouse heat curtain, installed in double layer polyethylene with IR greenhouse

¹ Green Building Studio. 2005. *Greenhouse Baseline Study Final Report*. Prepared for Pacific Gas and Electric Company.

² Bartok, J. 2001. *Energy Conservation for Commercial Greenhouses*. Natural Resource, Agriculture, and Engineering Service (NRAES). Ithaca, NY: Natural Resource, Agriculture, and Engineering Service.

³ Bartok, J. 2001. *Energy Conservation for Commercial Greenhouses*. Natural Resource, Agriculture, and Engineering Service (NRAES). Ithaca, NY: Natural Resource, Agriculture, and Engineering Service.

SWBE001B	Greenhouse heat curtain, installed in polycarbonate single layer greenhouse
----------	---

BASE CASE DESCRIPTION

The base case for this measure is defined as greenhouse area without any heat curtains, or a greenhouse area with nonfunctional heat curtains.

Base Case Specification

Statewide Measure Offering ID	Measure Offering Description
SWBE001A	Hoop house greenhouse with double layer polyethylene covering with IR film
SWBE001B	Ridge and furrow greenhouse with polycarbonate single layer covering

CODE REQUIREMENTS

Greenhouses and the heat curtains measures are not governed by state or federal codes and standards.

Applicable State and Federal Codes and Standards

Code	Applicable Code Reference	Effective Date
CA Appliance Efficiency Regulations – Title 20	None.	n/a
CA Building Energy Efficiency Standards – Title 24	None.	n/a
Federal Standards	None.	n/a

NORMALIZING UNIT

Square feet of building floor area (Area-ft²-BA)

PROGRAM REQUIREMENTS PROGRAM REQUIREMENTS

Measure Implementation Eligibility

All combinations of measure application type, delivery type, and sector that are established for this measure are specified below. Measure application type is a categorization based on the circumstances and timing of the measure installation; each measure application type is distinguished by its baseline determination, cost basis, eligibility, and documentation requirements. Delivery type is the broad categorization of the delivery channel through which the market intervention strategy (financial incentives or other services) is targeted. This table also designates the broad market sector(s) that are applicable for this measure.

Note that some of the implementation combinations below may not be allowed for some measure offerings by all program administrators.

Implementation Eligibility

Measure Application Type	Delivery Type	Sector
Add-on equipment	DnDeemed	Ag
Add-on equipment	DnDeemDI	Ag
New Construction	DnDeemed	Ag

Eligible Products

Eligible products must meet the following requirements:

- Must be a single-layer interior curtain installed for heat retention
- Must be installed in a gas-heated greenhouse facility
- The facility must be a greenhouse with the primary purpose of agricultural use.
- The heat curtain must be a new curtain installed where none previously existed or a new curtain that is replacing an existing curtain that is no longer functional.
- The heat curtain must be installed above the conditioned area where the gas heat source provides hot air to plant and seed species.
- The heat curtain must have a natural gas savings rating that meets or exceeds 40%.
- The heat curtain must have a warranty/product life of five years.
- The installation must allow the curtain to be automatically or manually moved into place.

Eligible Building Types and Vintages

This measure is applicable for agricultural or commercial greenhouse of any vintage for the primary purpose of the production of nursery products, horticultural specialties, or ornamental products.

Eligible Climate Zones

This measure is applicable in all California climate zones.

PROGRAM EXCLUSIONS

The square footage of the new heat curtain cannot exceed the square footage of the greenhouse floor. Additionally, any overhang and overlap of curtain material cannot be included in the square footage calculation.

DATA COLLECTION REQUIREMENTS

Data collection requirements are to be determined.

USE CATEGORY

Building envelope (BldgEnv)

ELECTRIC SAVINGS (kWh)

Not applicable.

PEAK ELECTRIC DEMAND REDUCTION (KW)

Not applicable.

GAS SAVINGS (THERMS)

The gas unit energy savings (UES) of greenhouse heat curtain were modeled in Virtual Grower Version 3.1. Virtual Grower is a software developed by the USDA to help greenhouse growers simulate and determine heating costs to figure out where greenhouse heat savings can be achieved.⁴

Base Case Inputs and Assumptions

The following base case inputs were used in the Energy Simulation modeling. First the greenhouse size and construction are described, then the heating system type, control, and efficiency are detailed below.

Heating System/Schedule

Heater Type	Parameter	Parameter	Source
Unit Heater	Schedule Type	Constant Temperature	Engineering Judgement based on: BASE ENERGY 2021. <i>Baseline Study of Infrared Films and Heat Curtains for Agriculture Greenhouses</i> . Prepared for Southern California Gas (SCG) Company.
	Set Temperature	65 °F	
	Heater Efficiency	78 %	
	Heater Age	3-5 years	
	Ventilation	Separated Combustion	
	Delivery Method	Forced Air, Above Bench	
Boiler with Radiant Floor Heating	Schedule Type	Constant Temperature	Engineering Judgement based on: BASE ENERGY 2021. <i>Baseline Study of Infrared Films and Heat Curtains for Agriculture Greenhouses</i> . Prepared for Southern California Gas (SCG) Company.
	Set Temperature	65 °F	
	Heater Efficiency	78 %	
	Heater Age	3-5 years	
	Ventilation	Separated Combustion	
	Delivery Method	Insulated radiant floor	

⁴ USDA Agricultural Research Service, 2021. [Virtual Grower 3 Model : USDA ARS](#)

Base Case Structure Size and Materials

Greenhouse Type	Parameter	Parameter	Source
Ridge and Furrow	Number of Spans	1	Engineering Judgement based on: KEMA, Inc. 2010. <i>PG&E Agricultural and Food Processing Program; Greenhouse Heat Curtain and Infrared Film Measures</i> . Prepared for the California Public Utility Commission (CPUC) Energy Division.
	Length	200 ft	
	Width	48 ft	
	Sidewall Height	14 ft	
	Roof Height	20 ft	
	Roof Shape	Triangular multi	
	Peaks per span	2	
	Roof Material	Corrugated Polycarbonate	
	Roof Material U-Value	1.2	
	Air Exchange Rate	1.1	
Hoop House	Number of Spans	1	Navigant 2013. <i>Market Characterization Report For 2010-2012 Statewide Agricultural Energy Efficiency Potential and Market Characterization Study</i> . Prepared for the California Public Utility Commission (CPUC) Energy Division.
	Length	200 ft	
	Width	48 ft	
	Sidewall Height	12 ft	
	Roof Height	17 ft	
	Roof Shape	Arch multi	
	Peaks per span	2	
	Roof Material	Double Polyethylene with IR	
	Roof Material U-Value	0.5	
	Air Exchange Rate	1.1	

Measure Case Inputs and Assumptions

The following measure case inputs were used in the Energy Simulation modeling. The same inputs were used as the base case except for the installation of the heat curtain and the subsequent U value increase and air infiltration decrease from the curtain. The same heating system and schedule was used in the measure case as in the base case.

Heating System/Schedule

Heater Type	Parameter	Parameter	Source
Unit Heater	Schedule Type	Constant Temperature	Engineering Judgement based on: BASE ENERGY 2021. <i>Baseline Study of Infrared Films and Heat Curtains for Agriculture Greenhouses</i> . Prepared for Southern California Gas (SCG) Company.
	Set Temperature	65 °F	
	Heater Efficiency	78 %	
	Heater Age	3-5 years	
	Ventilation	Separated Combustion	
	Delivery Method	Forced Air	
Boiler with Radiant Floor Heating	Schedule Type	Constant Temperature	Engineering Judgement based on: BASE ENERGY 2021. <i>Baseline Study of Infrared Films and Heat Curtains for Agriculture Greenhouses</i> . Prepared for Southern California Gas (SCG) Company.
	Set Temperature	65 °F	
	Heater Efficiency	78 %	
	Heater Age	3-5 years	
	Ventilation	Separated Combustion	
	Delivery Method	Insulated radiant floor	

Measure Case Structure Size and Materials

Greenhouse Type	Parameter	Parameter	Source
Ridge and Furrow	Number of Spans	1	Engineering Judgement based on: KEMA, Inc. 2010. <i>PG&E Agricultural and Food Processing Program; Greenhouse Heat Curtain and Infrared Film Measures</i> . Prepared for the California Public Utility Commission (CPUC) Energy Division.
	Length	200 ft	
	Width	48 ft	
	Sidewall Height	14 ft	
	Roof Height	20 ft	
	Roof Shape	Triangular multi	
	Peaks per span	2	
	Roof Material	Corrugated Polycarbonate	
	Roof Material U-Value	0.45	
	Air Exchange Rate	0.4	
Hoop House	Number of Spans	1	Navigant 2013. <i>Market Characterization Report For 2010-2012 Statewide Agricultural Energy Efficiency Potential and Market Characterization Study</i> . Prepared for the California Public Utility Commission (CPUC) Energy Division.
	Length	200 ft	
	Width	48 ft	
	Sidewall Height	12 ft	
	Roof Height	17 ft	
	Roof Shape	Arch multi	
	Peaks per span	2	
	Roof Material	Double Polyethylene with IR	
	Roof Material U-Value	0.36	
	Air Exchange Rate	0.4	

Unit Energy Savings Calculation

The unit energy savings (UES) of the greenhouse infrared film run in Virtual Grower Version 3.1 with inputs described above. Virtual Grower reports energy outputs as Heating load for a greenhouse building. To determine the heating consumption of a particular HVAC system in a building, the heating load of a greenhouse must be divided by the heating system efficiency of the HVAC system. The heating efficiency of the system is reported by virtual grower, depending on the configuration of the heating system. Once the baseline and measure case consumption is determined, the savings can be determined by taking the difference between the base and measure case consumption.

Heating System Efficiencies

Heater Type	Parameter	Parameter
Unit Heater	HVAC System Efficiency	45%
Boiler with Radiant Floor Heating	HVAC System Efficiency	73%

Sample Calculation

A sample calculation for the post processing of the Virtual Grower data follows:

$$UEC_{year} = \frac{Heating_{Load}}{Sys_{Eff} \times BTU_{Therm}}$$

$$UEC_{year} = \text{Annual unit energy consumption (therms/sqft/year)}$$

$$Heating_{Load} = \text{Heating load of the Greenhouse (Btu/sqft/yr)}$$

$$Sys_{Eff} = \text{HVAC System Efficiency (\%)}$$

$$BTU_{Therm} = 100,000 \text{ Btu/Therm}$$

$$UES_{year} = UEC_{year,baseline} - UEC_{year,measure}$$

$$UES_{year} = \text{Annual unit energy savings (therms/year)}$$

$$UEC_{year,baseline} = \text{Annual unit energy consumption for baseline case (therms/year)}$$

$$UEC_{year,measure} = \text{Annual unit energy consumption for measure case (therms/year)}$$

LIFE CYCLE

Effective useful life (EUL) is an estimate of the median number of years that a measure installed through a program is still in place and operable. Remaining useful life (RUL) is an estimate of the median number of years that a technology or piece of equipment replaced or altered by an energy efficiency program would have remained in service and operational had the program intervention not caused the replacement or alteration. The RUL is only applicable to the first baseline period for a retrofit measure with an applicable code baseline.

As per Resolution E-4807, the California Public Utilities Commission (CPUC) defined the EUL of a retrofit add-on (REA) measure as the minimum of the EUL of the measure itself and the RUL of the host equipment.⁵ The RUL of the host equipment (which is a greenhouse for this particular measure) is

⁵ California Public Utilities Commission (CPUC). 2016. *Resolution E-4807*. December 16. Page 13.

calculated as one-third of the EUL of a greenhouse. The EUL of a greenhouse is not available and thus is assigned the maximum allowable EUL of 20 years, as permitted by Version 2 of the Energy Efficiency Policy Manual. The methodology to calculate the RUL of the host equipment conforms with Version 5 of the Energy Efficiency Policy Manual, which recommends “one-third of the effective useful life in DEER as the remaining useful life until further study results are available to establish more accurate values.” This approach provides a reasonable RUL estimate without the requiring any a priori knowledge about the age of the equipment being replaced.⁶

The EUL and RUL specified for a greenhouse heat curtain are specified below. The EUL value adopted for this measure is the EUL of the heat curtain measure. The RUL is based upon the EUL of the host equipment, a cool roof. The EUL for a cool roof was adopted for the 2005 version of the Database for Energy Efficient Resources and was developed by the Lawrence Berkeley National Laboratory (LBNL).

Effective Useful Life and Remaining Useful Life

Parameter	Value	Source
EUL (yrs) – heat curtain ^a	5.0	California Public Utilities Commission (CPUC), Energy Division. 2003. Energy Efficiency Policy Manual v 2.0. Page 18, Table 4.1.
EUL (yrs) - bldg. cool roof	15.0	California Public Utilities Commission (CPUC), Energy Division. 2008. “EUL_Summary_10-1-08.xls.”
RUL (yrs) – bldg. cool roof	5.0	

BASE CASE MATERIAL COST (\$/UNIT)

Because the base case is defined as no heat curtain, the base cast material cost is equal to \$0.

MEASURE CASE MATERIAL COST (\$/UNIT)

The measure case material cost for this measure was derived from the *2010-2012 WO017 Ex Ante Measure Cost Study* conducted by Itron, Inc. (See “Heat curtain installed in greenhouse that has roofs with IR film and bare wall” in Appendix F.) As shown below, the cost analysis includes data from 2013 to 2019 and assumes an annual inflation rate.

Cost data from the SoCalGas commercial rebate program (2017 to 2020) indicate cost range from \$0.21 to \$3.16 per square foot of heat curtain ignoring the highest cost installation of \$8.61 on a very small greenhouse. The average cost of all projects in SoCalGas rebate program excluding the outlier was \$0.76. These results aligned with the WO017 study results.

⁶ KEMA, Inc. 2008. "Summary of EUL-RUL Analysis for the April 2008 Update to DEER." Memorandum submitted to Itron, Inc.

Measure Case Material and Installation Cost Inputs for a Single-Layer Greenhouse Heat Curtain

Year	Equipment Material Cost (\$/unit)	Labor Cost (\$/unit)	Misc. Cost (\$/unit)	Inflation Rate	Inflation Adder per IMC	Source
2013	\$ 0.46	\$ 0.17	\$ 0.03	3%	\$ 0.02	Itron, Inc. 2014. <i>2010-2012 WO017 Ex Ante Measure Cost Study Final Report</i> . Prepared for the California Public Utilities Commission. Appendix F.
2014	\$ 0.47	\$ 0.18	\$ 0.03	3%	\$ 0.02	
2015	\$ 0.49	\$ 0.18	\$ 0.03	3%	\$ 0.02	
2016	\$ 0.50	\$ 0.19	\$ 0.03	3%	\$ 0.02	
2017	\$ 0.52	\$ 0.19	\$ 0.03	3%	\$ 0.02	
2018	\$ 0.53	\$ 0.20	\$ 0.03	3%	\$ 0.02	
2019	\$ 0.55	\$ 0.20	\$ 0.04	3%	\$ 0.02	
2020	\$ 0.57	\$ 0.21	\$ 0.04	3%	\$ 0.03	
2021	\$ 0.59	\$ 0.21	\$ 0.04	3%	\$ 0.03	

BASE CASE LABOR COST (\$/UNIT)

Because the base case is defined as no heat curtain, the base case labor cost is equal to \$0.

MEASURE LABOR COST (\$/UNIT)

See Measure Case Material Cost.

The measure case labor cost for this measure was derived from the *2010-2012 WO017 Ex Ante Measure Cost Study* conducted by Itron, Inc. (See “Heat curtain installed in greenhouse that has roofs with IR film and bare wall” in Appendix F.)

NET-TO-GROSS (NTG)

The net-to-gross (NTG) ratio represents the portion of gross impacts that are determined to be directly attributed to a specific program intervention. These NTG values are based upon the average of all NTG ratios for all evaluated 2006 – 2008 commercial, industrial, and agriculture programs, as documented in the 2011 DEER Update Study conducted by Itron, Inc. These sector average NTGs (“default NTGs”) are applicable to all energy efficiency measures that have been offered through commercial, industrial, and agriculture sector programs for more than two years and for which impact evaluation results are not available.

The NTG for the greenhouse heat curtain measure is based upon evaluation results of the PG&E Agriculture and Food Processing Program published by KEMA, Inc. in 2010 and is specific to downstream delivery type.

Net-to-Gross Ratios

Delivery Type	NTG ID	NTG Ratio	Source
Downstream	<i>NonRes-sGHS-mHtCrtn-dn</i>	0.63	KEMA, Inc. 2010. <i>2006-2008 Evaluation Report: PG&E Agricultural and Food Processing Program; Greenhouse Heat Curtain and Infrared Film Measures</i> . CALMAC Study ID: CPU0024.01. Page 43. Itron, Inc. 2011. <i>DEER Database 2011 Update Documentation</i> . Prepared for the California Public Utilities Commission. Page 9-4.
Direct Install	<i>Agric-Default>2yrs</i>	0.60	Itron, Inc. 2011. <i>DEER Database 2011 Update Documentation</i> . Prepared for the California Public Utilities Commission. Page 15-4 Table 15-3.

GROSS SAVINGS INSTALLATION ADJUSTMENT (GSIA)

The gross savings installation adjustment (GSIA) rate represents the ratio of the number of verified installations of the measure to the number of claimed installations reported by the utility. This factor varies by end use, sector, technology, application, and delivery method. This GSIA rate is the current “default” rate specified for measures for which an alternative GSIA has not been estimated and approved. This installation rate reflects the fact that customers typically install the curtain rather than store the equipment after purchase.

Gross Savings Installation Adjustment Rates

Parameter	Value	Source
GSIA	1.0	California Public Utilities Commission (CPUC), Energy Division. 2013. <i>Energy Efficiency Policy Manual Version 5</i> . Page 31.

NON-ENERGY BENEFITS

Non-energy benefits for this measure have not been quantified.

DEER DIFFERENCES ANALYSIS

This section provides a summary of DEER-based inputs and methods, and the rationale for inputs and methods that are not DEER-based.

DEER Difference Summary

DEER Item	Comment / Used for Workpaper
Modified DEER methodology	No
Scaled DEER measure	No
DEER Base Case	No
DEER Measure Case	No
DEER Building Types	No
DEER Operating Hours	No
DEER eQUEST Prototypes	No
DEER Version	No

DEER Item	Comment / Used for Workpaper
Reason for Deviation from DEER	Greenhouse DEER measures are expired
DEER Measure IDs Used	N/a
NTG	The NTG of 0.63 is associated with NTG ID: <i>NonRes-sGHS-mHtCrtn-dn</i> The NTG of 0.60 is associated with NTG ID: <i>Agric-Default>2yrs</i>
GSIA	Source: DEER. The GSIA of 1.0 is associated with GSIA ID: <i>Def-GSIA</i>
EUL/RUL	Source: DEER 2005. The value of 5 years is associated with EUL ID: <i>Agr-GHC</i> . RUL ID: <i>BldgEnv-CoolRoof</i>

REVISION HISTORY

Measure Characterization Revision History

Revision Number	Revision Completion Date	Primary Author, Title, Organization	Revision Summary and Rationale for Revision Effective Date and Approved By
01	03/31/2018	Jennifer Holmes, Cal TF Staff	Draft of consolidated text for this statewide measure is based upon Workpaper PGECOAGR101 Revision 3 (August 28, 2012) WPSDGENRAG0003 Revision 0 (January 1, 2019) Consensus reached among Cal TF members.
	06/13/2019	Andres Marquez, SoCalGas Jennifer Holmes Cal TF Staff	Revisions for submittal of version 01.
02	7/30/2021	Anders Danryd, SoCalGas	Revisions to workpaper due to expiration of DEER measures. Savings modeled using Virtual Grower 3 using results of baseline study, added new Delivery types and NC
	9/24/2021	Anders Danryd, SoCalGas	Text edits and clarifications, switched measures A and B to better align with version 1
	10/20/2021	Anders Danryd, SoCalGas	Added sample calculation section describing the calculations to data needed after Virtual Grower modeling
	11/15/2021	Anders Danryd, SoCalGas	Clarifications to text in sample calculation section