“RESNET, Home Raters, and Reflective Insulation Manufacturers: How All Can Work Together”

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RESNET
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Outline

- Introduction to Radiant Barriers (RBs) and Interior Radiation Control Coatings (IRCCs)
- Reflective Insulation Manufacturers' Association – International (RIMA-I)
- RESNET and RB and IRCCs
- RIMA-I Available Information Related to RBs and IRCCs
- Technical and Scientific Information
- Performance Data – Reduced Energy Consumption in Homes with Installed RBs and IRCCs

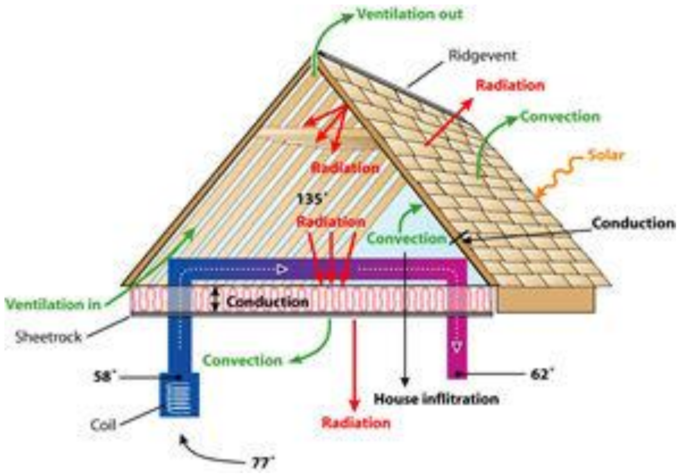
Radiant Barriers and Interior Radiation Control Coatings

- Radiant Barriers (RBs) and Interior Radiation Control Coatings (IRCCs) function by reducing heat transfer by *radiation*.
- The thermal performance or the reduction of radiant heat transfer is proportional to the surface *emittance* of the RB and IRCC surface material and follows:

$$\dot{q}_{12} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\varepsilon_1}{A_1\varepsilon_1} + \frac{1}{A_1F_{12}} + \frac{1-\varepsilon_2}{A_2\varepsilon_2}}$$

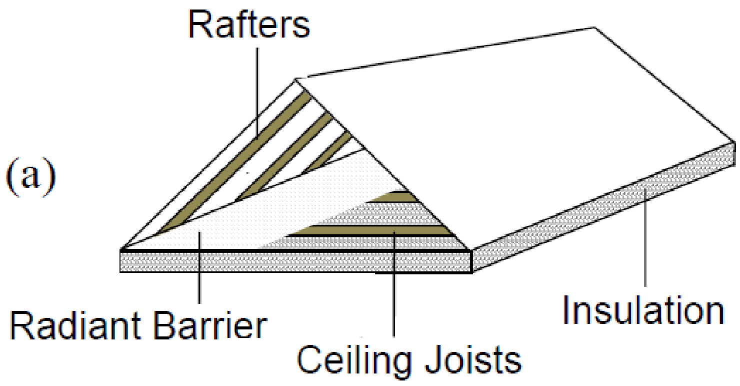
- Common building materials, such as wood, masonry, and fiberglass insulation have average surface emittances of approximately 0.85; *products defined as **radiant barriers** have surface emittances less than or equal to 0.1 and products defined as **interior radiation control coatings** convert surface emittances to 0.25 or less.*

*Source: **"Radiant Barriers: Performance Revealed"***
September/October 2000 Issue, Home Energy Magazine
By Mario A. Medina

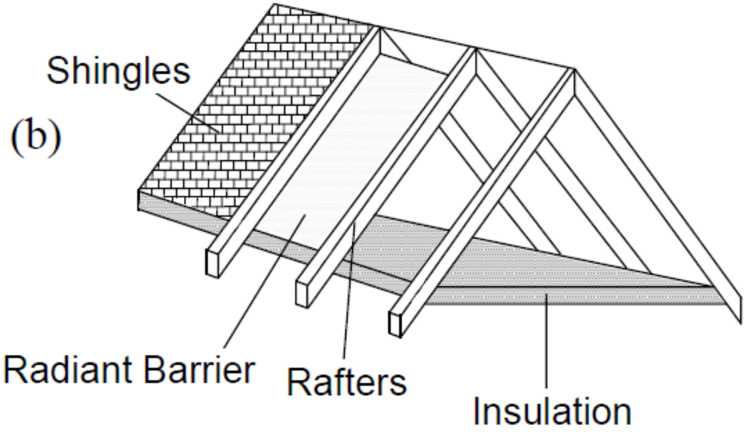


(Source: Florida Solar Energy Center)

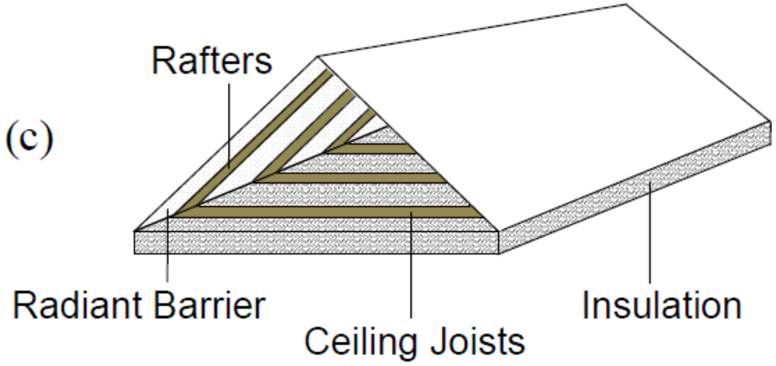
RB and IRCC Installations



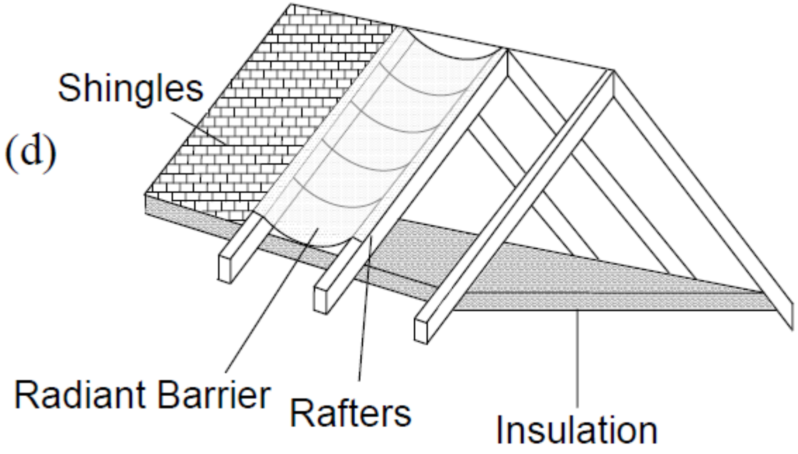
Horizontal Radiant Barrier



Truss Radiant Barrier



Deck Applied Radiant Barrier
Interior Radiation Control Coating



Draped Radiant Barrier

RB and IRCC Installations

“Truss Radiant Barrier”
(TRB)

“Horizontal Radiant Barrier”
(HRB)

“Deck Applied Radiant Barrier”
(DARB)

“Interior Radiation Control Coating”
(IRCC)

RB and IRCC Installations

“Radiant Barrier Below Roof Tile”

About RIMA-I

The Reflective Insulation Manufacturers Association International is a non-profit association that represents manufacturers and distributors of reflective insulation, radiant barriers and interior radiation control coating materials (IRCCs).

RIMA-I's activities are guided by an active board of industry members who participate on national and regional levels of building code organizations and governmental agencies. The association went international in 2008 when more than 1/3 of the membership were outside North America.

I-RIM Conference

International Reflective Insulation Manufacturers Conference

Saving Energy Today for a Better World Tomorrow

Because of the growing interest and need for reflective research around the world, RIMA-I recently launched the International Reflective Insulation Manufacturers Conference which is held bi-annually alternating between North America and overseas.

For example, the last two events were held in 2010 in Barcelona, Spain and in Fort Lauderdale, Florida in May 1-2, 2012.

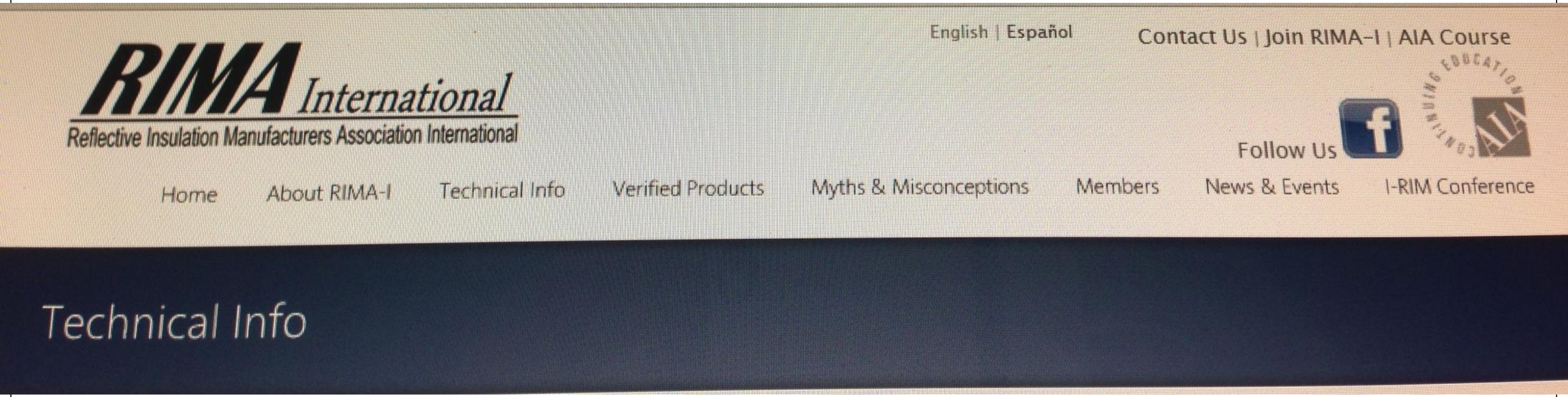
RESNET and RBs and IRCCs

- About RBs Chapter 4 (Insulation) of the RESNET Accredited Rater Training course states:
  - *Radiant Barriers*
    - *Aluminum material bonded to Kraft paper.*
    - *Normally applied to the underside of the roof decking*
    - *Will drop attic temperature 20 to 30 F*
    - *Has to have air against the side with the barrier (attic) → RB/IRCC should face the attic space.*
- About RBs and IRCCs Chapter 8 (Cooling) of the RESNET Accredited Rater Training course states:
    - *Mentions paper faced radiant barrier*
    - *Refers to the one stapled to the rafters*
    - *Mentions IRCCs*
    - *Drops the attic temperature 20 to 30 F*
    - *Poor emitters*
    - *"You can expect up to 10 % energy savings depending on the climate and insulation level"*
    - *"We can expect more saving from using RBs than from improving attic ventilation"*

RESNET and RBs and IRCCs

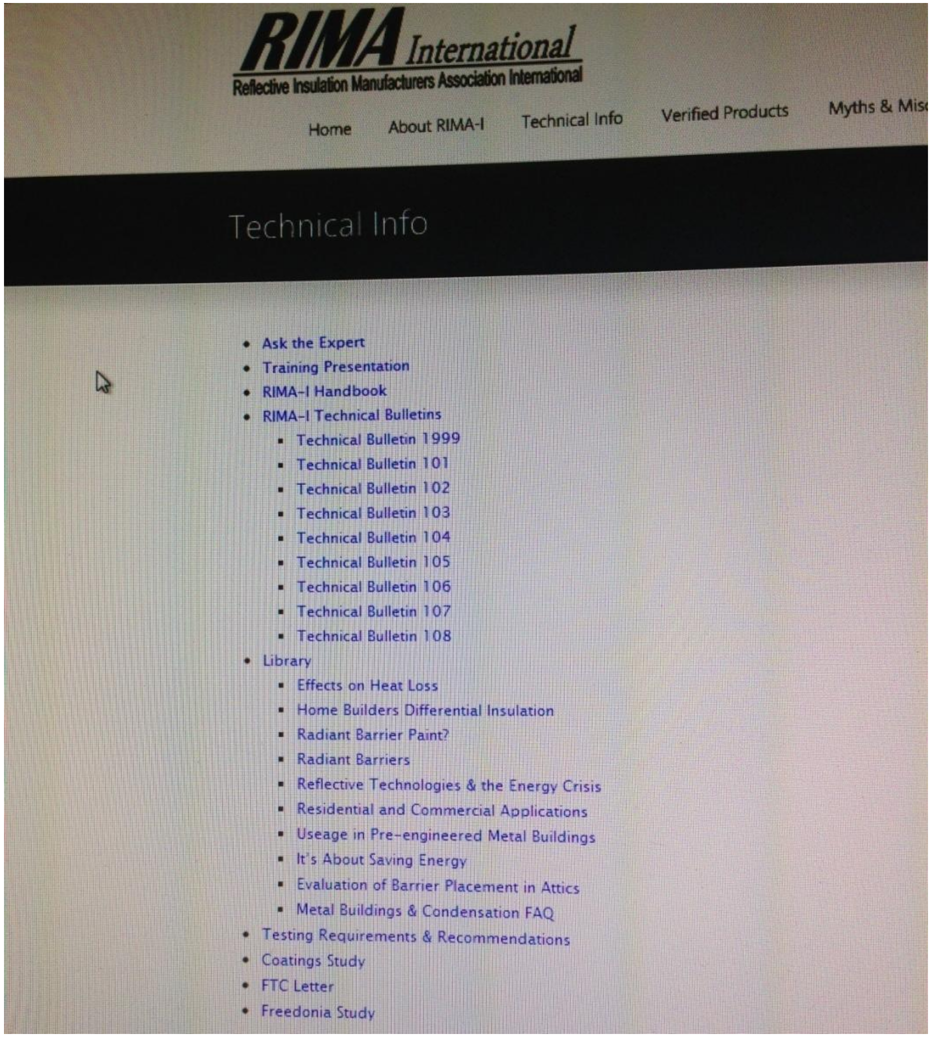
- About RBs Section 115R Plans Specs and Gathering Data for RemRate of the RESNET Accredited Rater Training course states:
  - *“Check to see if radiant barriers are installed…”*

RIMA-I Information Available About RBs and IRCCs



From RIMA – International 's Website
http://www.rimainternational.org/

RIMA-I Information Available About RBs and IRCCs



Technical Info

- Ask the Expert
- Training Presentation
- RIMA-I Handbook
- RIMA-I Technical Bulletins
  - Technical Bulletin 1999
  - Technical Bulletin 101
  - Technical Bulletin 102
  - Technical Bulletin 103
  - Technical Bulletin 104
  - Technical Bulletin 105
  - Technical Bulletin 106
  - Technical Bulletin 107
  - Technical Bulletin 108
- Library
  - Effects on Heat Loss
  - Home Builders Differential Insulation
  - Radiant Barrier Paint?
  - Radiant Barriers
  - Reflective Technologies & the Energy Crisis
  - Residential and Commercial Applications
  - Useage in Pre-engineered Metal Buildings
  - It's About Saving Energy
  - Evaluation of Barrier Placement in Attics
  - Metal Buildings & Condensation FAQ
- Testing Requirements & Recommendations
- Coatings Study
- FTC Letter
- Freedonia Study

Technical and Scientific Information

- Radiant barriers function by reducing heat transfer by radiation.

- The thermal performance or the reduction of radiant heat transfer is directly proportional to the surface emittance of the radiant barrier material.

- Emittance measurements of all materials range between zero (0), no radiant heat transfer, and one (1) that of a “blackbody” surface or complete radiant heat transfer.

- Common building materials, such as wood, masonry, and fiberglass insulation have surface emittances of approximately 0.85 and therefore have high radiant heat transfer rates.

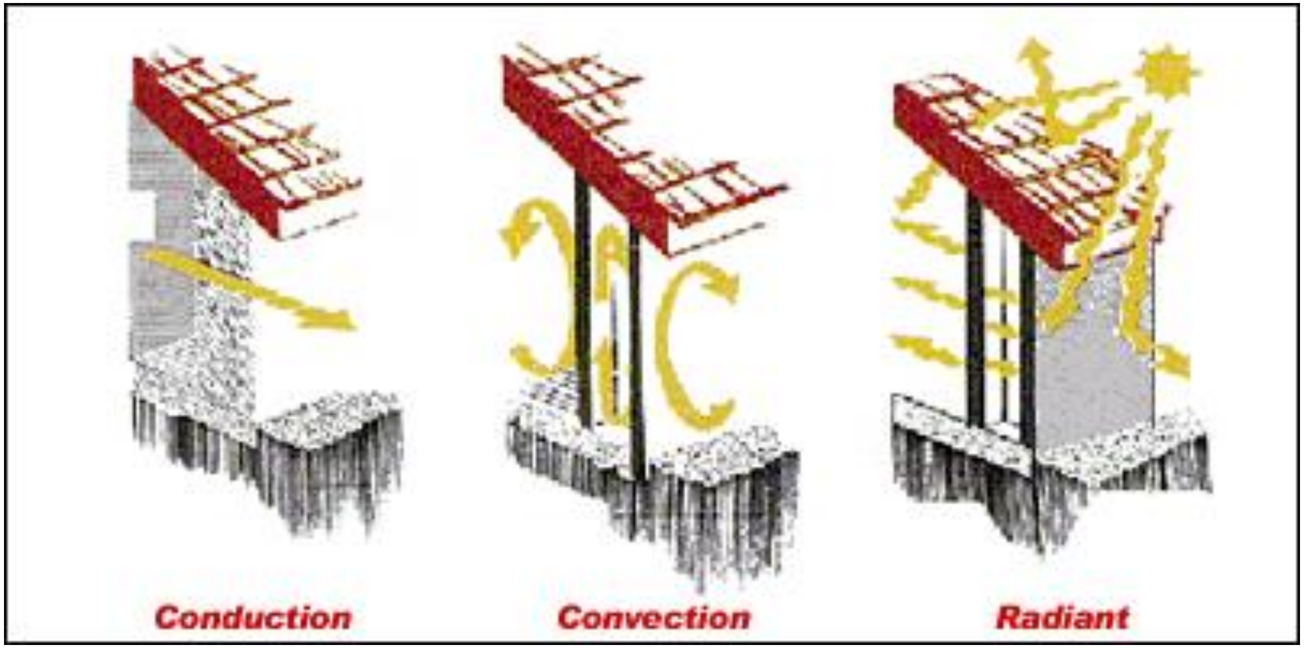
- *Products defined as radiant barriers have surface emittances less than or equal to 0.1 or low radiant heat transfer rates and products defined as* ***interior radiation control coatings*** *convert surface emittances to 0.25 or less.*

How They Work

RBs and IRCCs work by reducing radiation heat transfer *across air spaces*.

Example: in residential attic applications, this radiation heat transfer is the one between the roof deck and/or end gables and the attic floor. This is the heat energy that is controlled (e.g. blocked) by the radiant barriers.

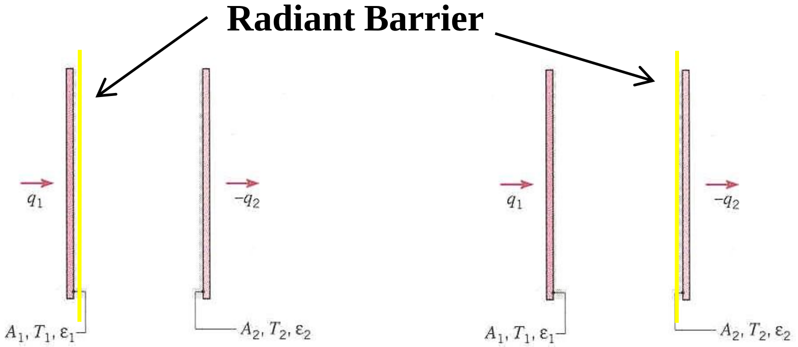
Modes of Heat Transfer



Source: Energy Savers of America
http://www.btubusters.com/typesofheat.gif

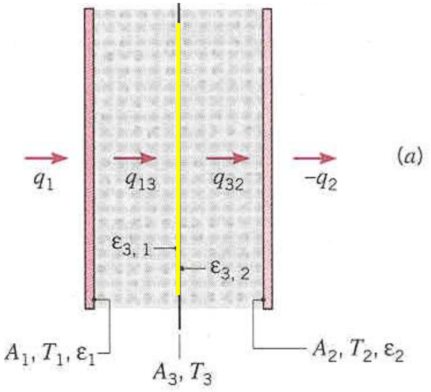
Radiant Barriers and IRCCs

Heat Transfer Schematic


Radiant Barrier

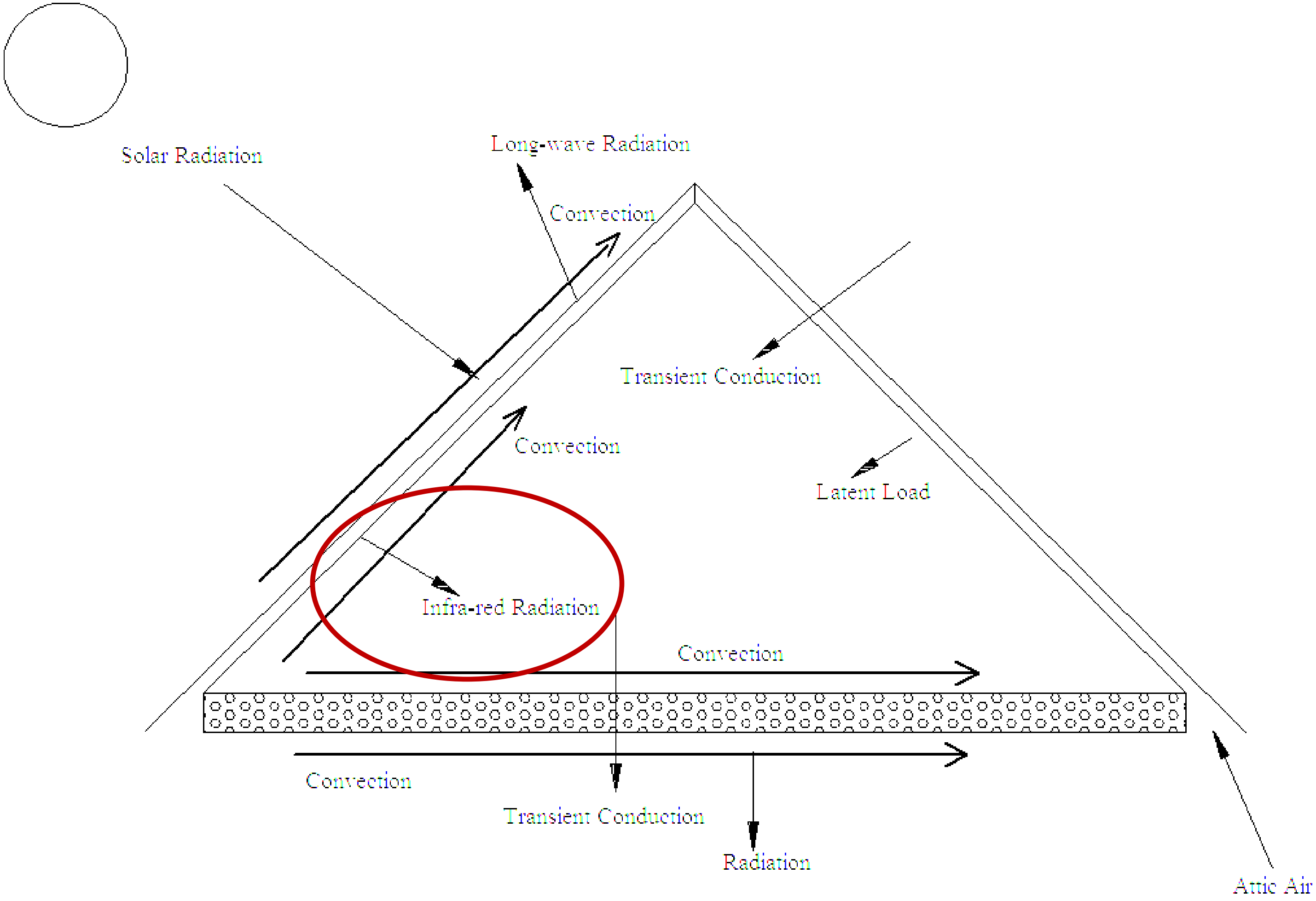
$$\dot{q}''_{1\rightarrow 2} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1}$$

Radiant Barrier

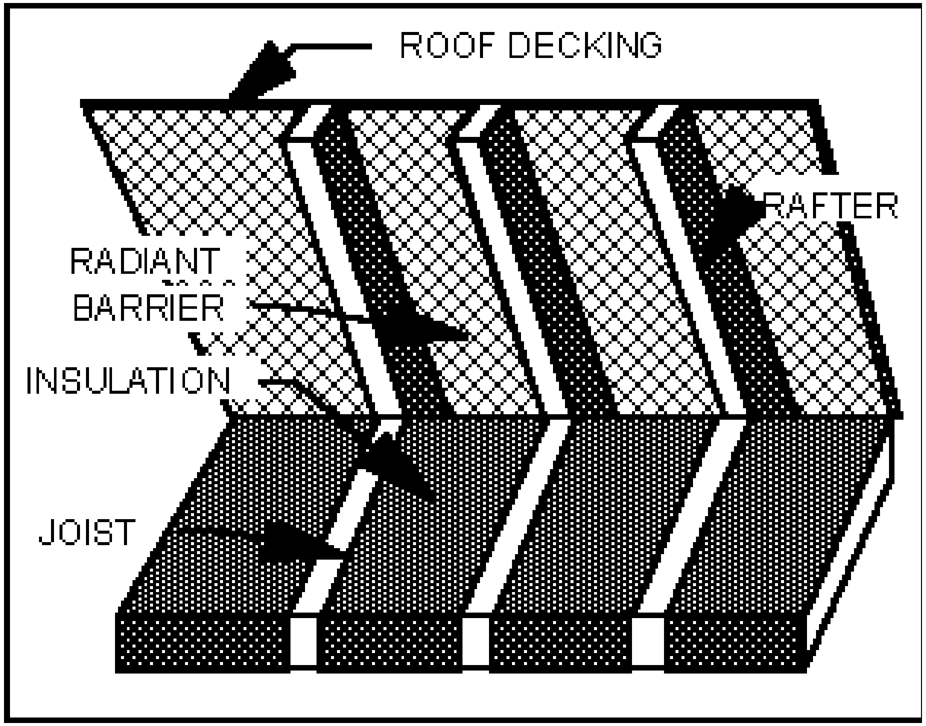


$$\dot{q}''_{1\rightarrow 2} = \frac{\sigma(T_1^4 - T_2^4)}{\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right) + \left(\frac{1}{\epsilon_{3,1}} + \frac{1}{\epsilon_{3,2}} - 1\right)}$$

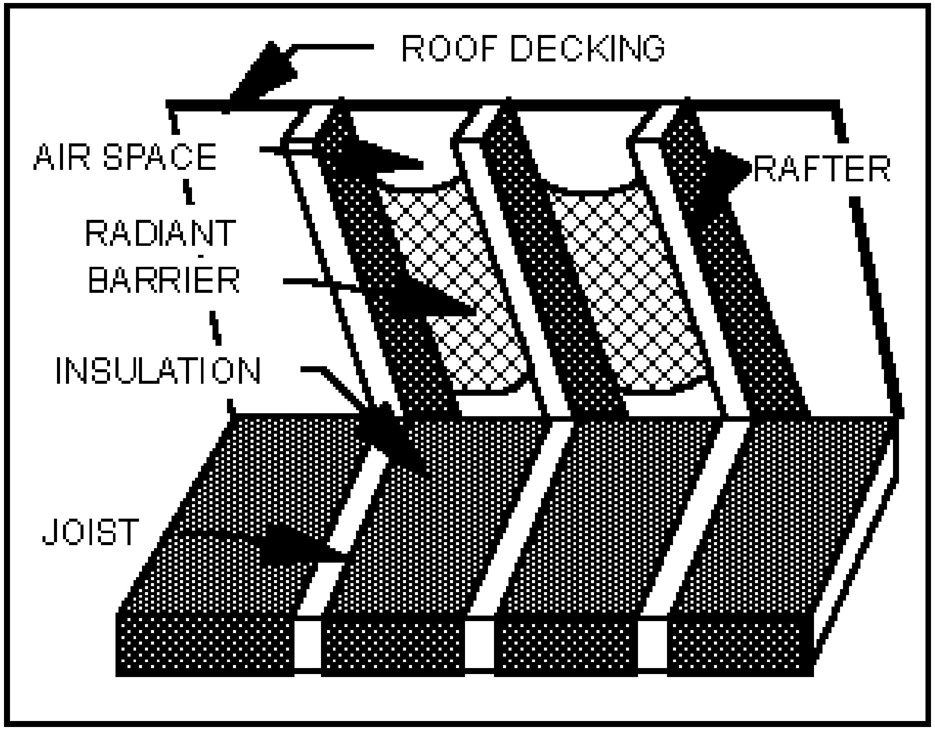
Attic Heat Transfer Schematic



Installation Configurations



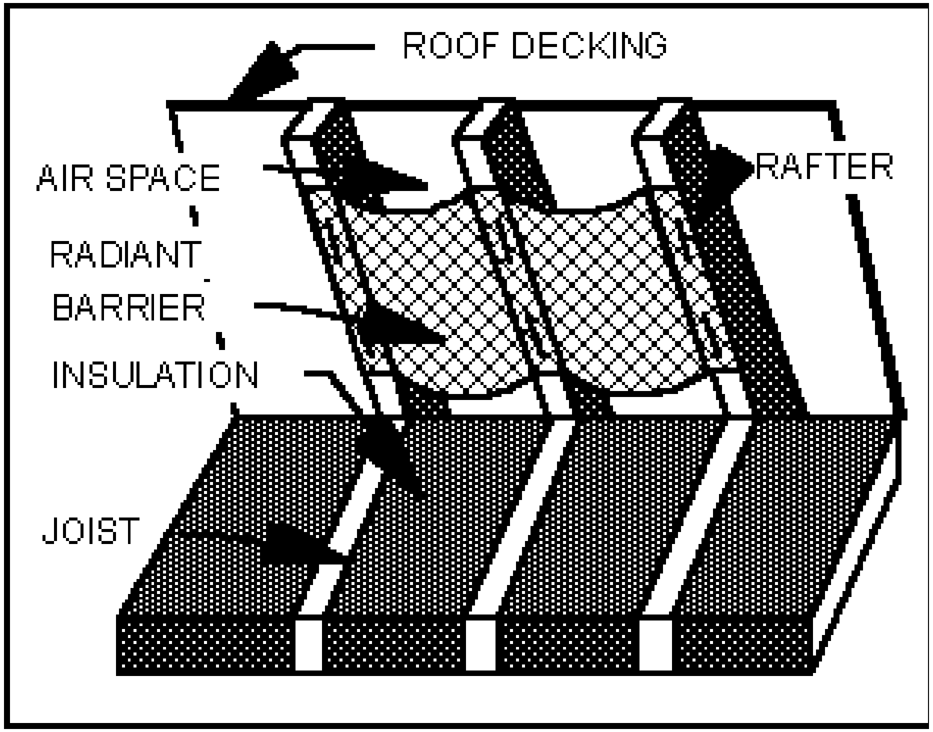
Deck Applied RB (IRCC)



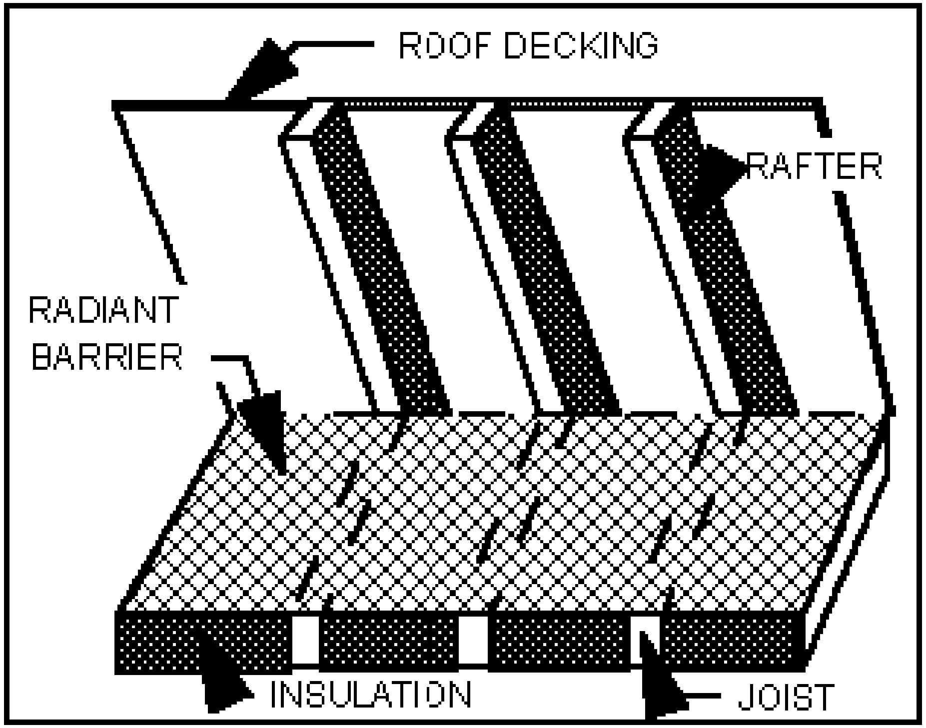
Draped RB

Source: Alternative Heating Info.com

Installation Configurations



Truss Radiant Barrier
TRB



Horizontal Radiant Barrier
HRB

Source: Alternative Heating Info.com

How Is Their Performance Assessed

Experiments

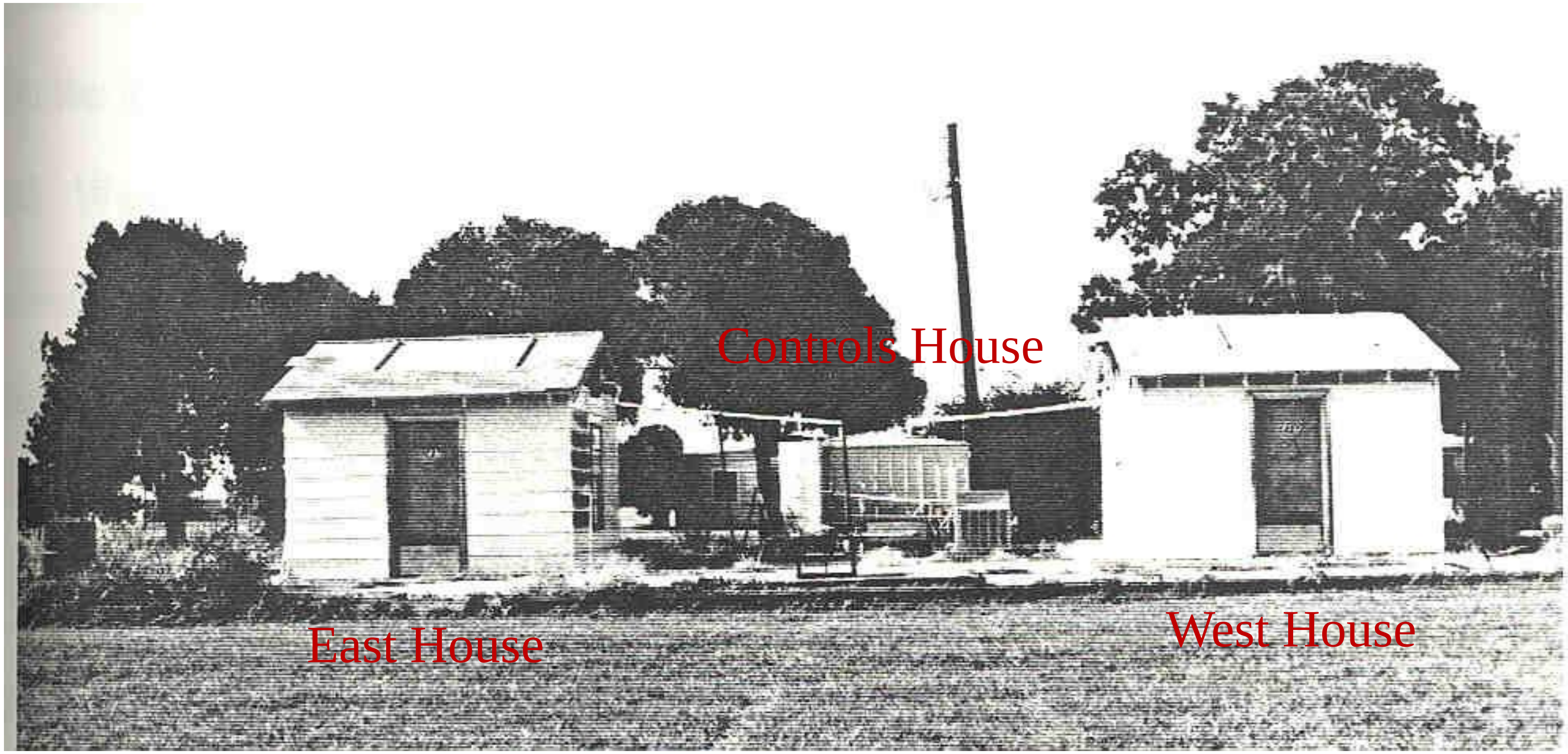
Side by side monitoring of pre- and post-retrofit data.

Modeling

Mathematical combination of thermal science theories that describe the heat and mass processes that take place in attic systems. Usually implemented with computers.

Model/Experiment Verification (Validation)

Experiments: Test Houses



Houses were 12 ft by 12 ft with 8 ft ceilings.

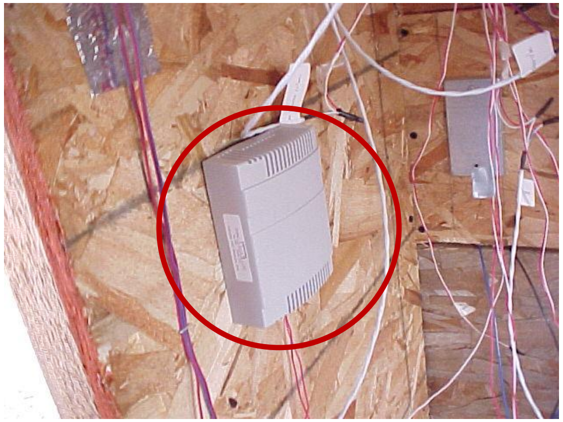
The houses were located in Central Texas. Climate is humid subtropical.

Houses thermal responses were identical prior to the retrofits.

Experiments: Sample Sensors

Heat Flux Meter

Thermocouple



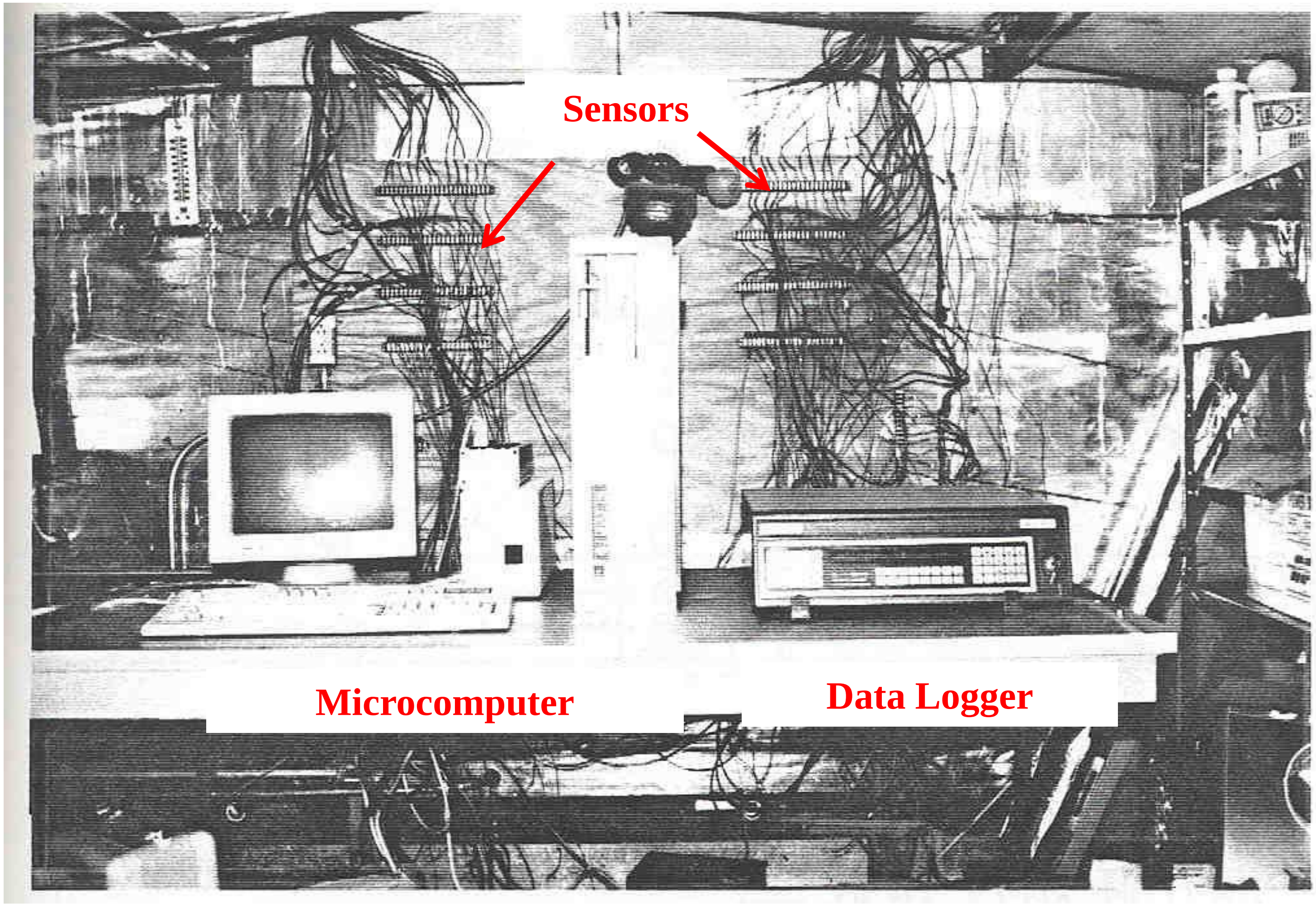
Relative Humidity Transducer

Pyranometer

Turbine Mass Flow Meter

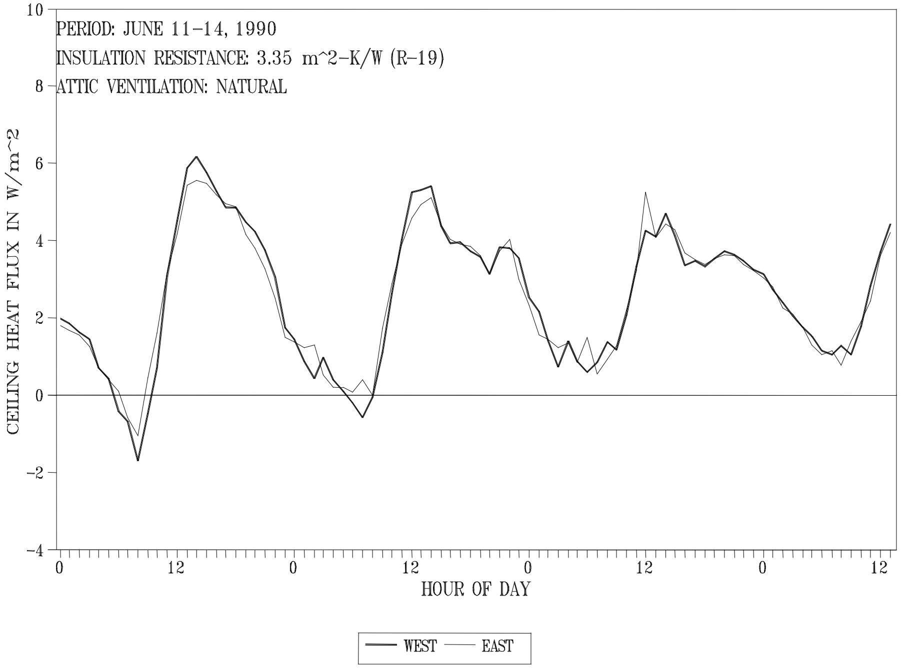
Anemometer

Experiments: Monitoring Equipment

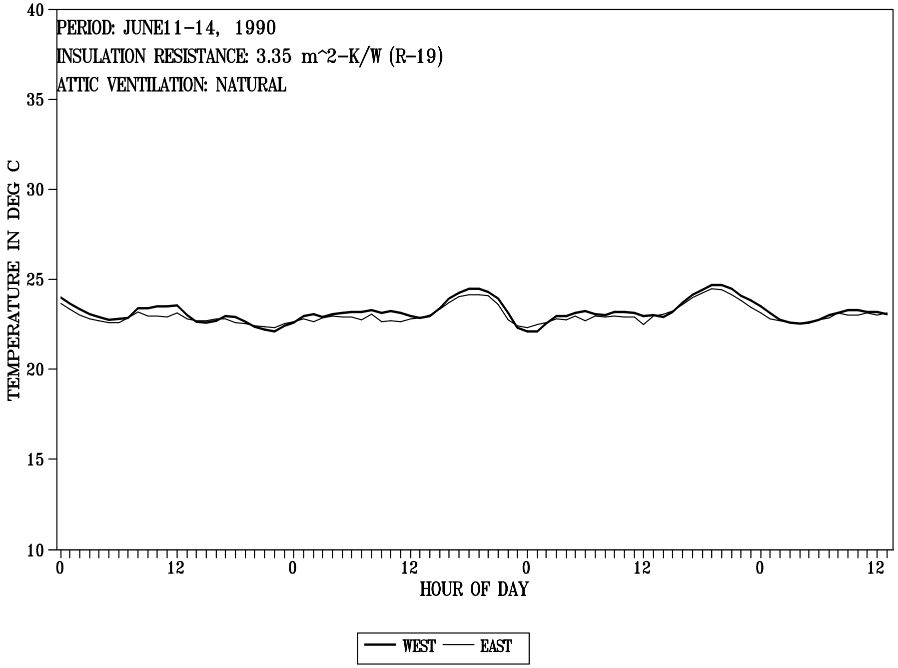


Experimental Results: Calibration (No RB)

Ceiling Heat Flux

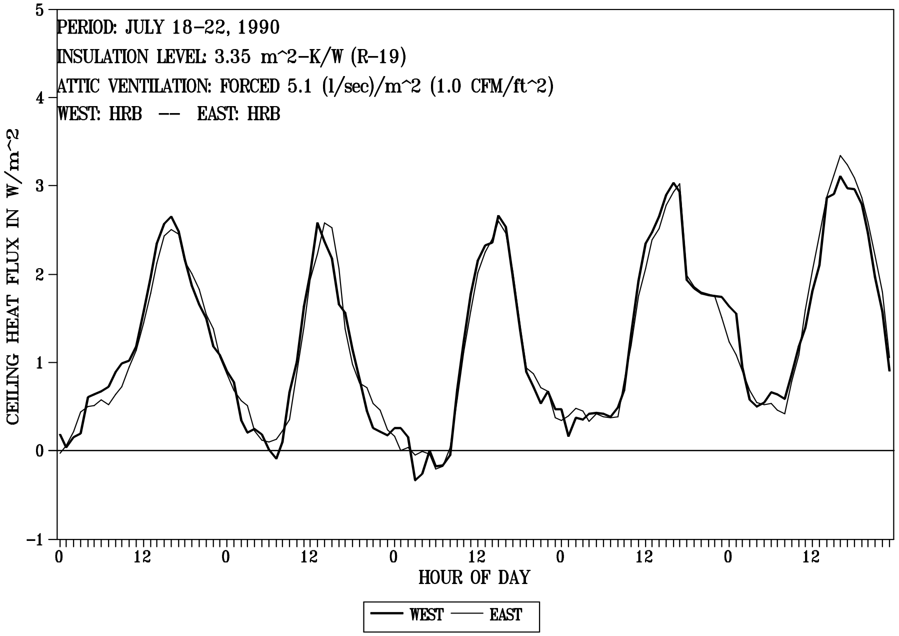


Indoor Air Temperature

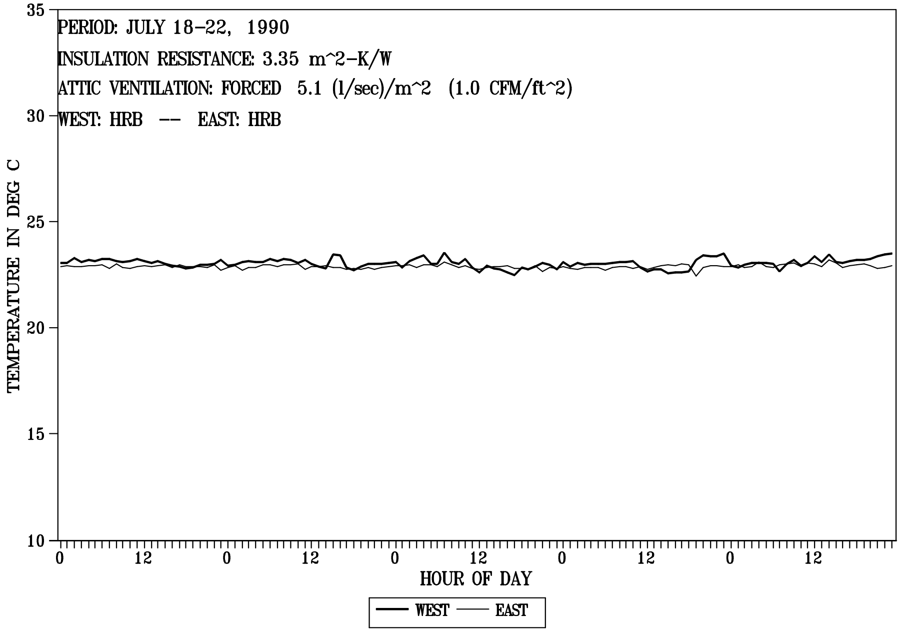


Experimental Results: Calibration (RB)

Ceiling Heat Flux

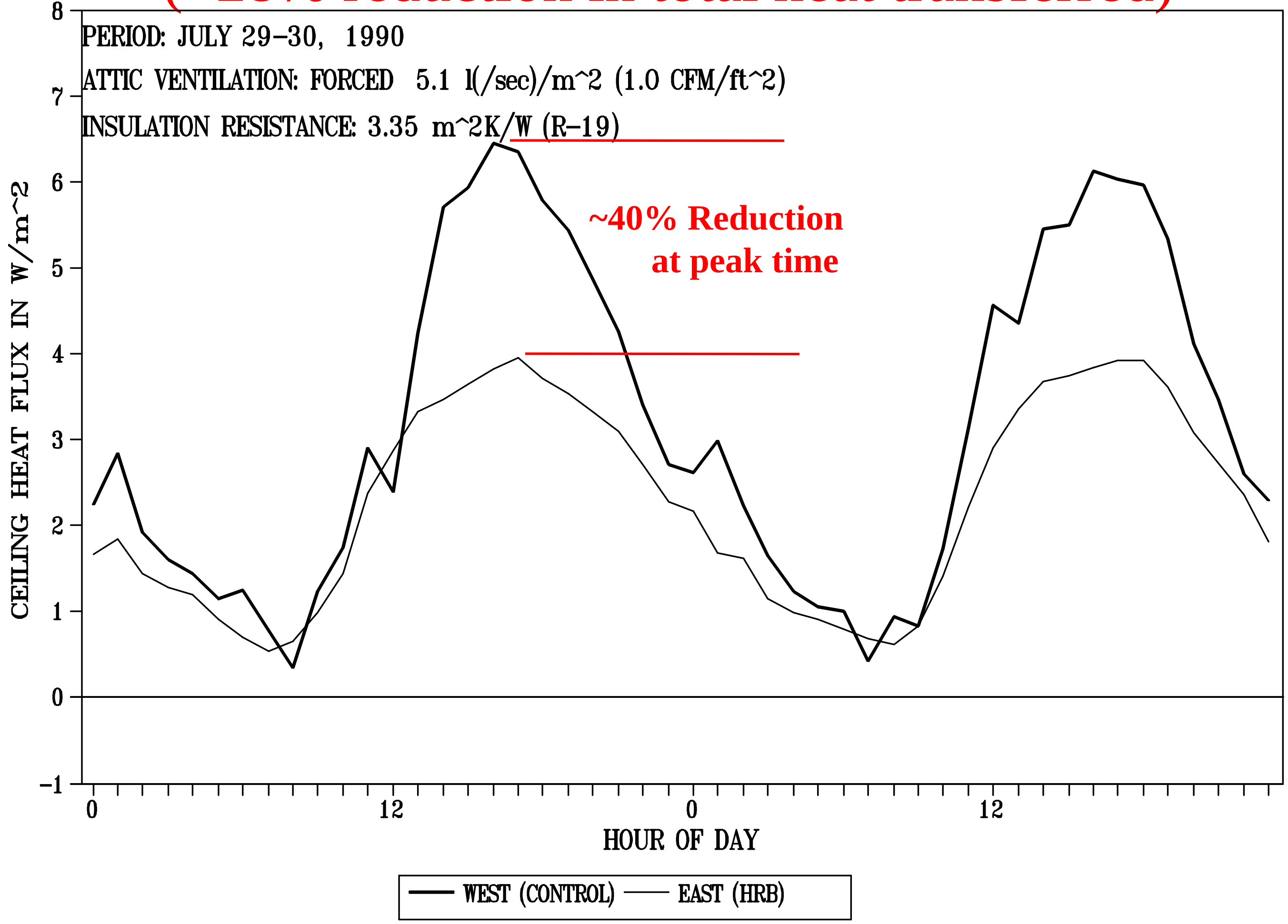


Indoor Air Temperature



Experimental Results Attic w/Radiant Barrier vs. Control Attic

(~28% reduction in total heat transferred)



PERIOD: JULY 29–30, 1990

ATTIC VENTILATION: FORCED 5.1 l(/sec)/m^2 (1.0 CFM/ft^2)

INSULATION RESISTANCE: 3.35 m^2K/W (R-19)

~40% Reduction at peak time

Radiant Barrier Performance

$$\% \, Reduction = \frac{\int_{Test\,Period} q_{Control}\,dt - \int_{Test\,Period} q_{Retrofit}\,dt}{\int_{Test\,Period} q_{Control}\,dt} \, x \, 100$$

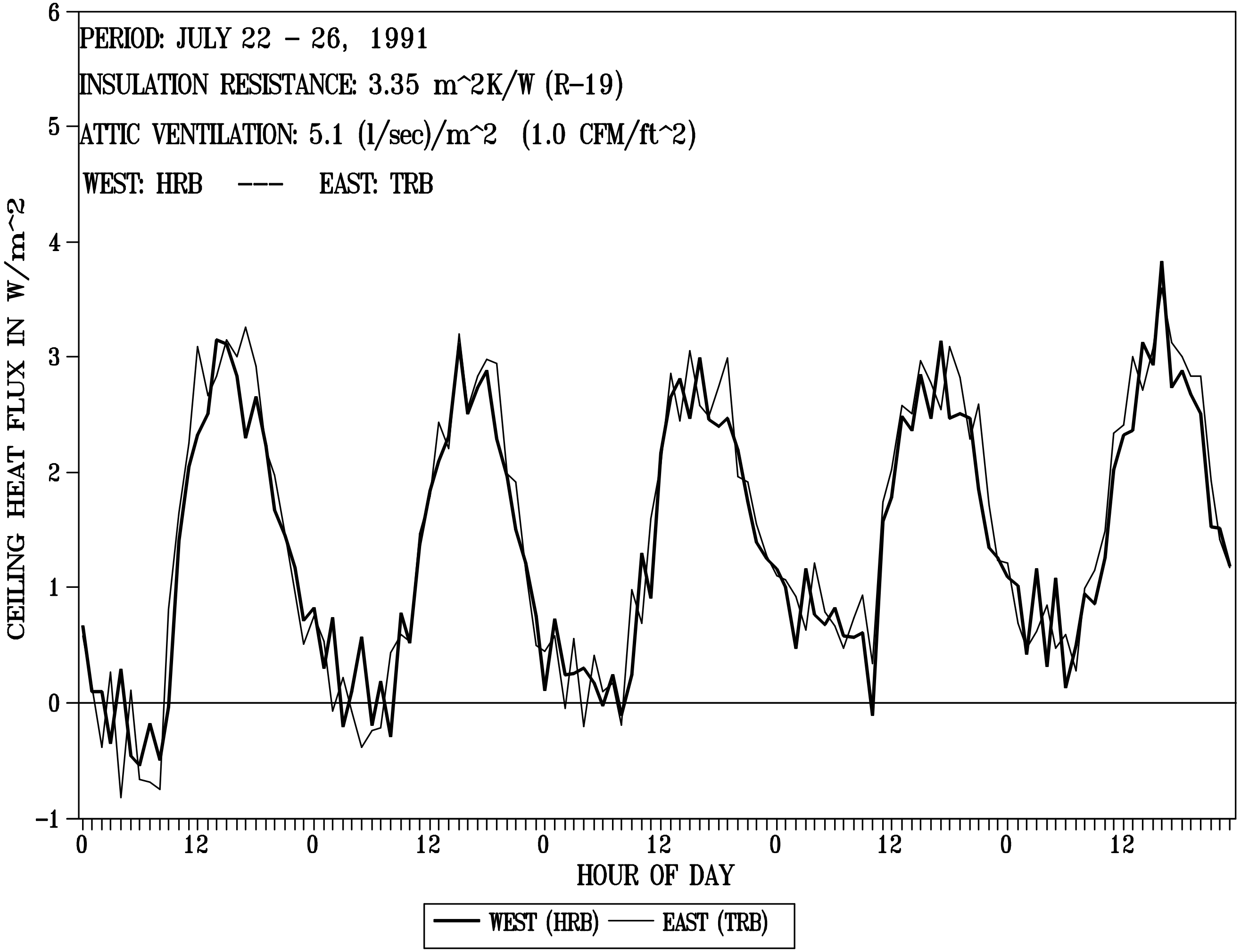
$q_{Control}$: Ceiling heat flux from the control attic [Btu/hr-ft^2, W/m^2]

$q_{Retrofit}$: Ceiling heat flux from the retrofit attic [Btu/hr-ft^2, W/m^2]

Test Period: Testing period used in the integration

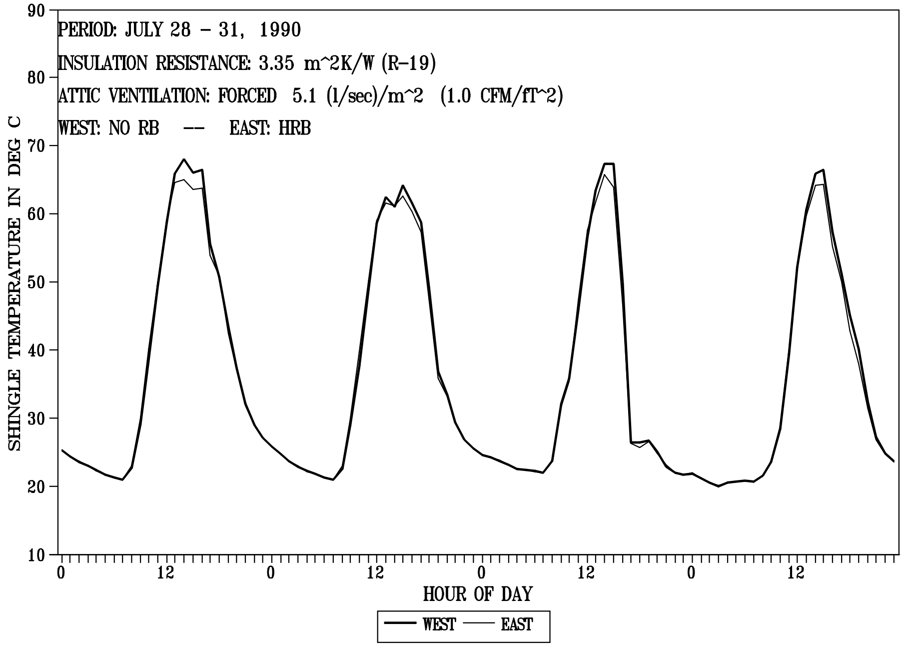
Experimental Results
Installation Comparisons

(HRB performs slightly better ~ 5%)

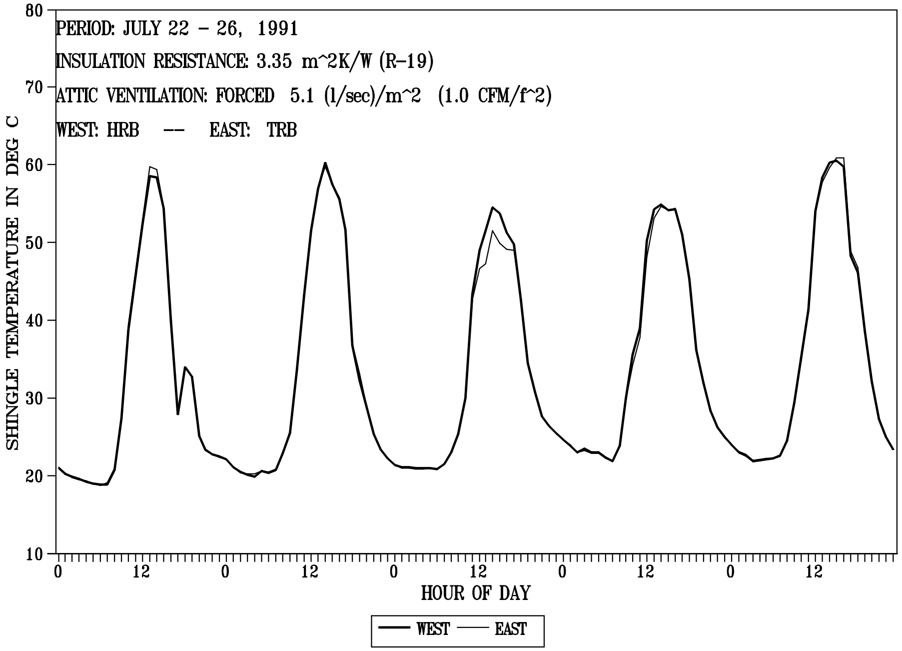


Experimental Results
Roof Shingle Temperatures

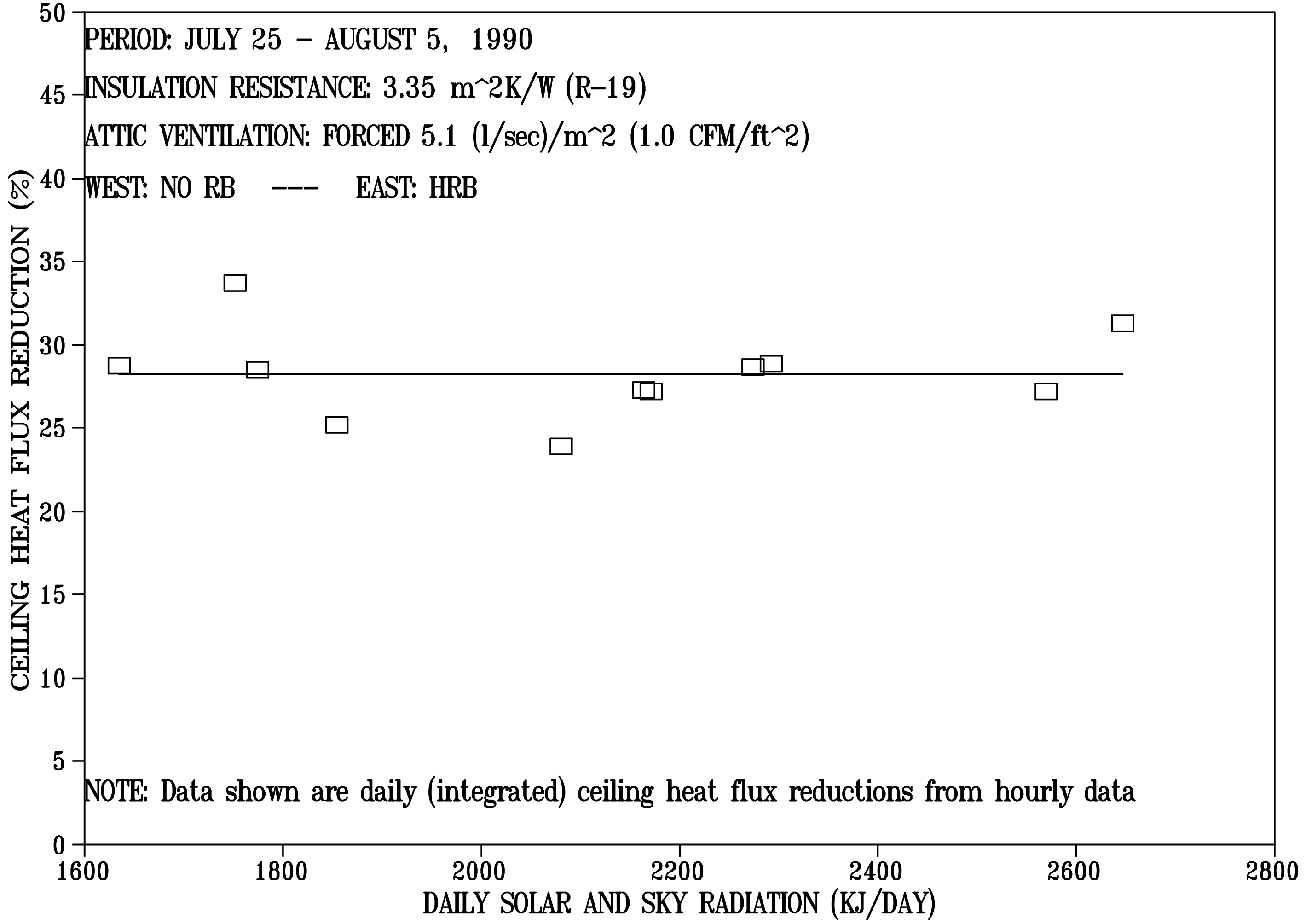
HRB vs No RB



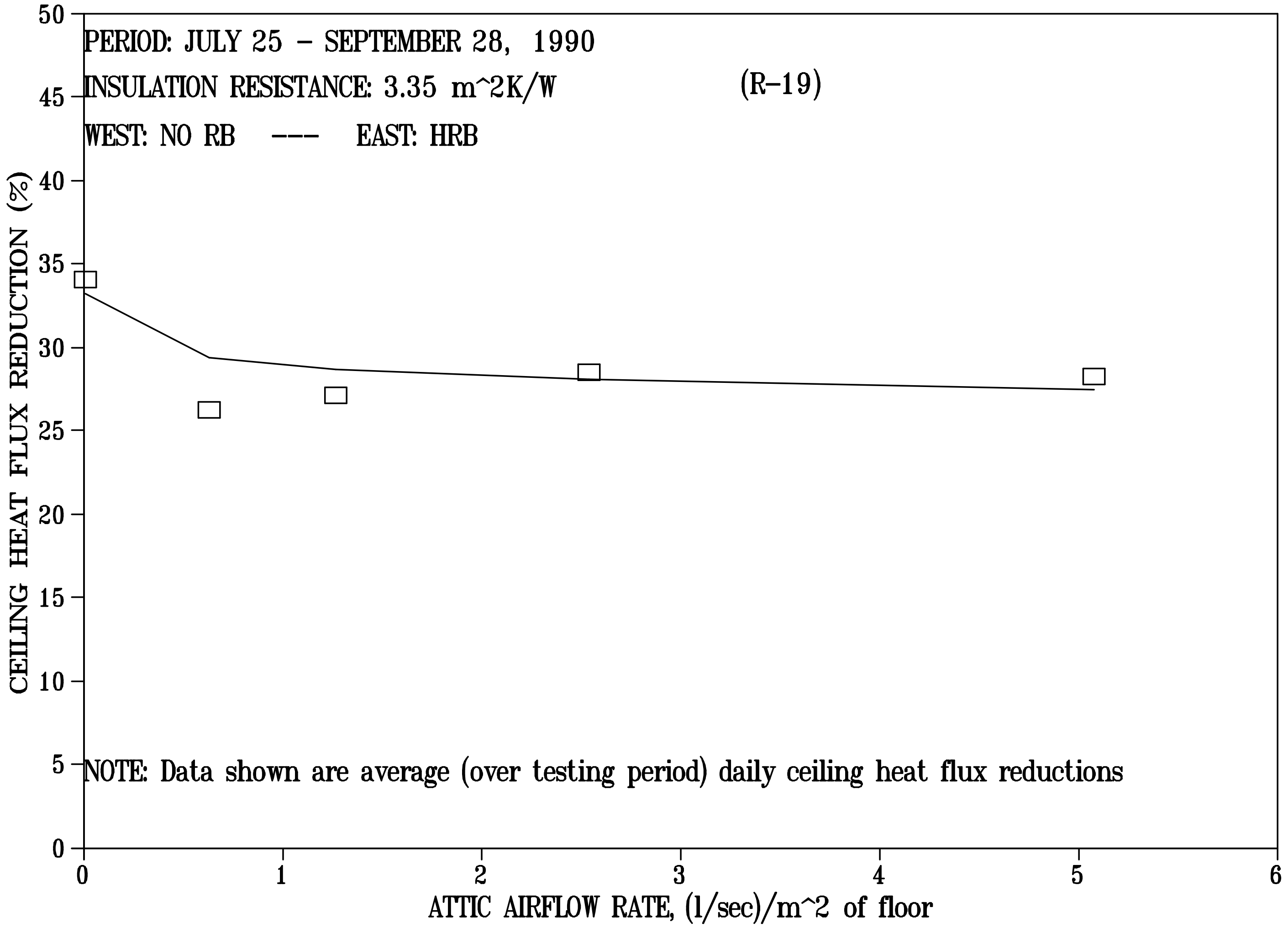
HRB vs TRB



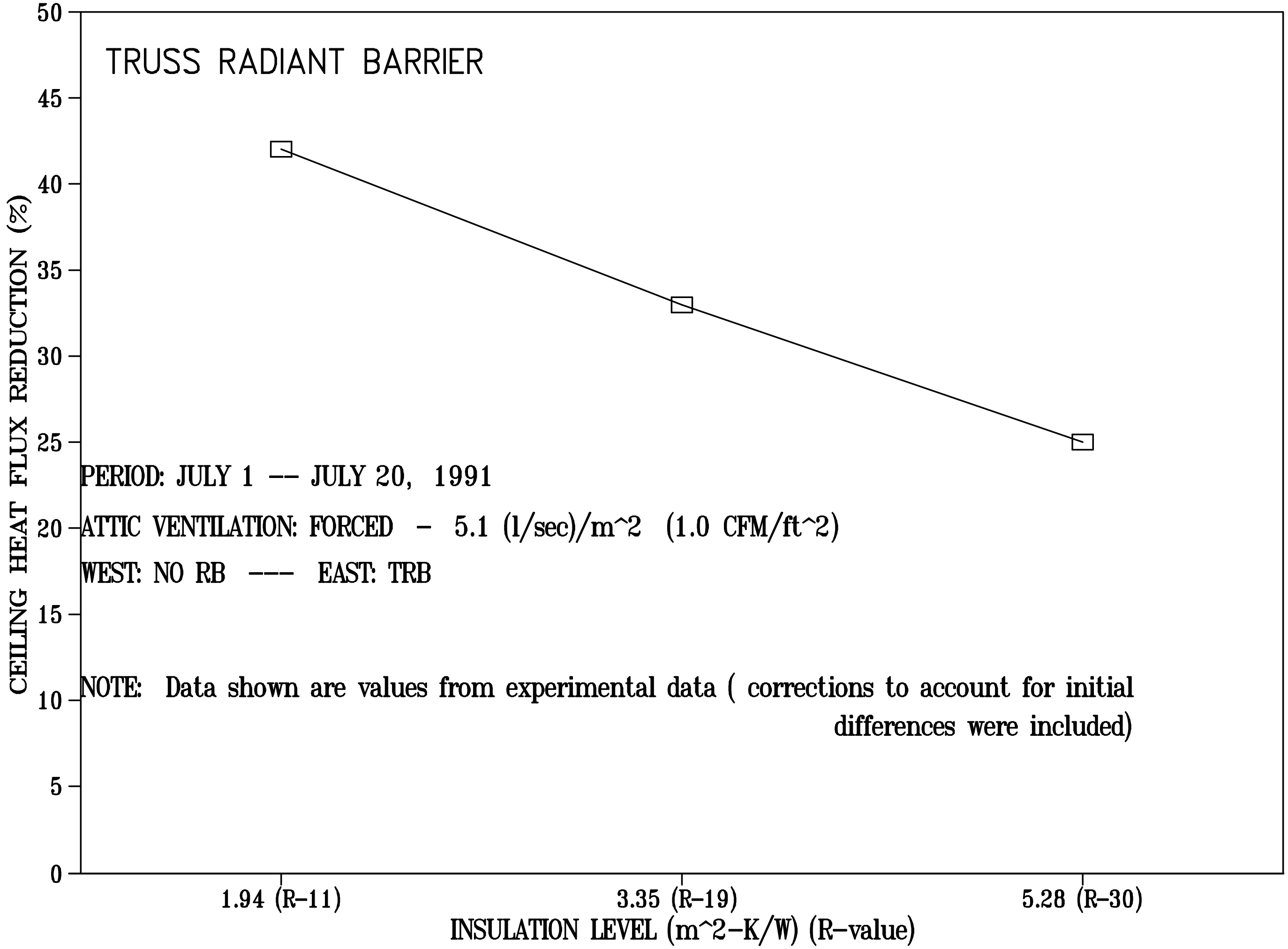
Experimental Results
Effects of Daily Solar Radiation



Experimental Results
Effects of Attic Ventilation



Experimental Results
Effects of Attic Insulation Level



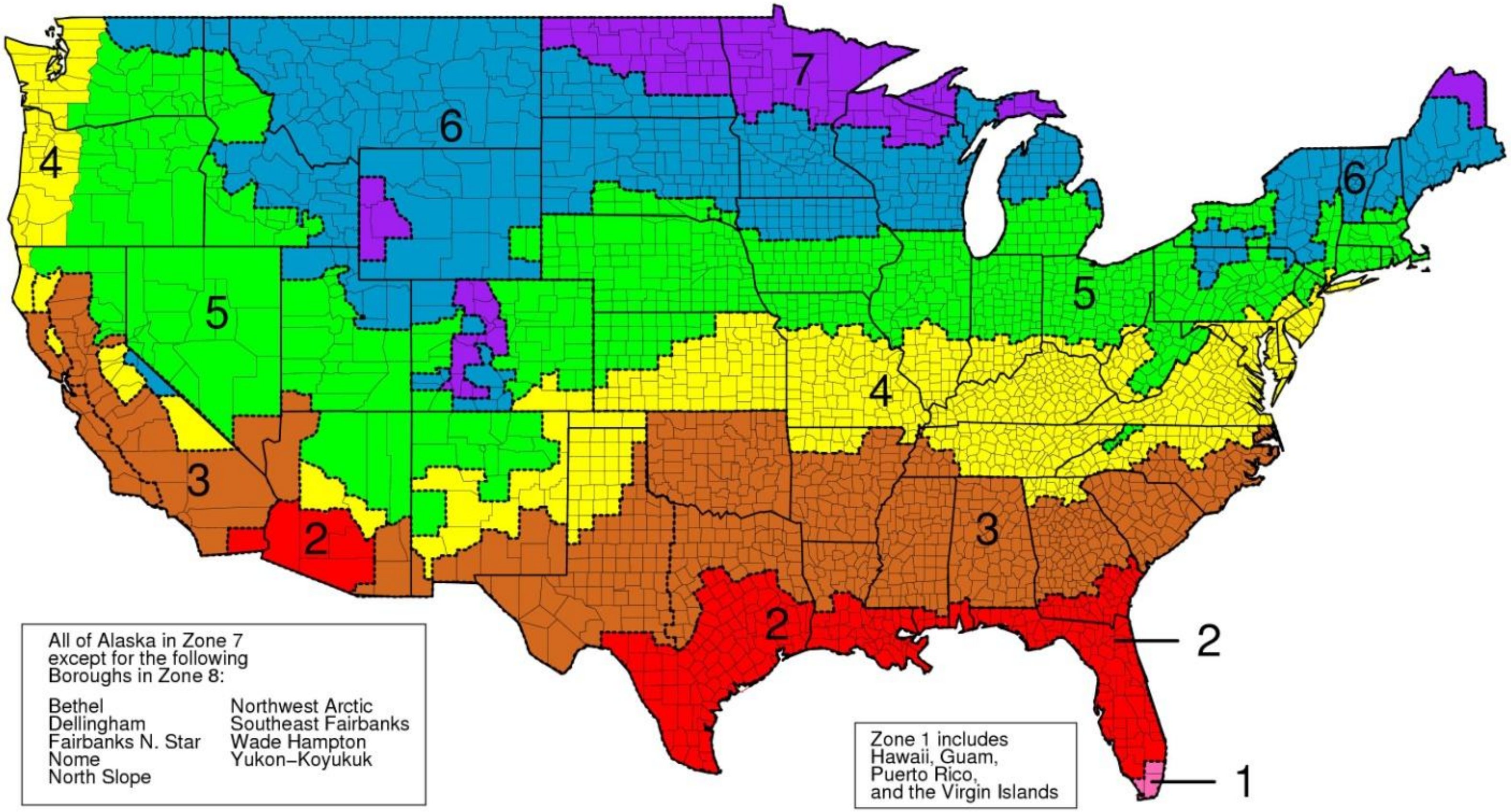
PERIOD: JULY 1 -- JULY 20, 1991

ATTIC VENTILATION: FORCED - 5.1 (l/sec)/m^2 (1.0 CFM/ft^2)

WEST: NO RB --- EAST: TRB

NOTE: Data shown are values from experimental data (corrections to account for initial differences were included)

Radiant Barrier Performance



U.S. Climate Zone Map (ASHRAE Standard 169-2006, 2006)

Radiant Barrier Performance

Ceiling Heat Flow

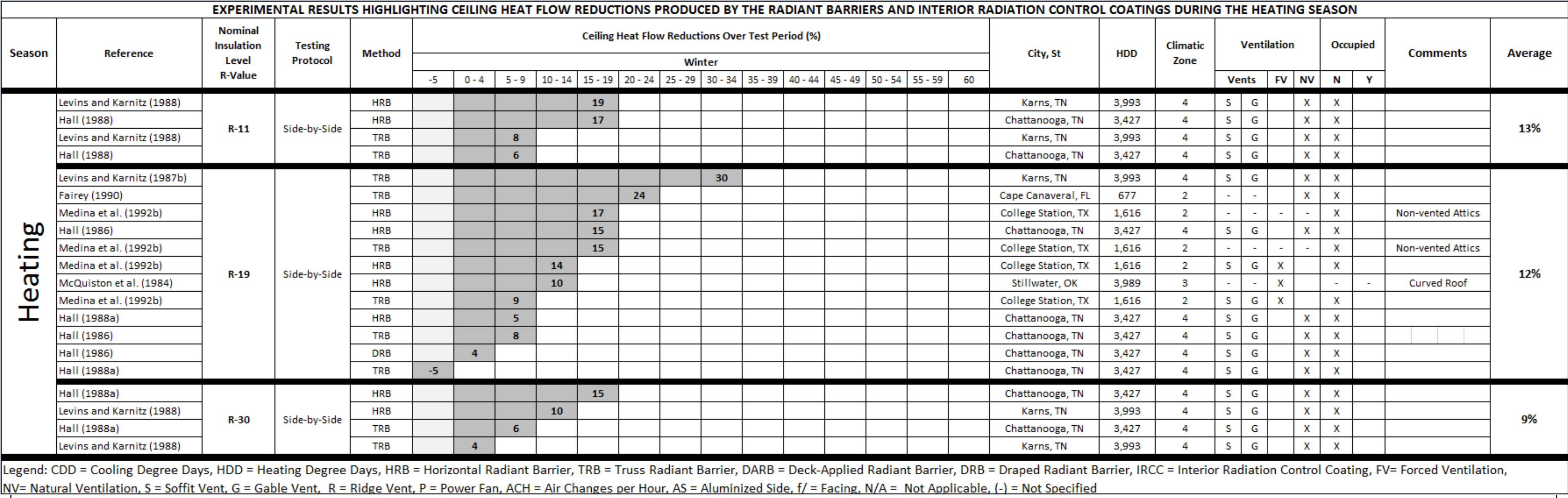
EXPERIMENTAL RESULTS HIGHLIGHTING CEILING HEAT FLOW REDUCTIONS PRODUCED BY THE RADIANT BARRIERS AND INTERIOR RADIATION CONTROL COATINGS DURING THE COOLING SEASON

Season	Reference	Nominal Insulation Level R-Value	Testing Protocol	Method	Ceiling Heat Flow Reductions Over Test Period (%)														City, St	CDD	Climatic Zone	Ventilation				Occupied		Comments	Average
					Summer																								
					-5	0 - 4	5 - 9	10 - 14	15 - 19	20 - 24	25 - 29	30 - 34	35 - 39	40 - 44	45 - 49	50 - 54	55 - 59	60				Vents		FV	NV	N	Y		
Cooling	Joy (1958)	R-7.5	Laboratory Controlled	HRB												**50**			N/A			S	S	X		X		Flat Roof	**41%**
	Katipamula & O'Neal (1986)	R-11		HRB											**46**				N/A			-	-	-	-	X		Flat Roof	
	Yarbrough (2010)	R-13												**41**					N/A			-	-	-	-	X		Pitched Roof	
	Joy (1958)	R-7.5		HRB							**28**								N/A			S	S	X		X		Pitched Roof	
	Swami and Fairey (1986)	R-19	Laboratory Controlled	IRCC								**32**							N/A			-	-	-		X		Flat Roof	**32%**
	Ashley et al. (1994)	**R-11**	Side-by-Side	HRB/TRB														**60**	Kingsville, TX	3,404	2	G	G		X		X	Attic fully wrapped	**45%**
	Medina (2000a)			TRB										**42**					College Station, TX	2,938	2	S	G	X		X			
	Hall (1988a)			TRB								**34**							Chattanooga, TN	1,608	4	S	G		X	X			
	Fairey (1985)	**R-19**	Side-by-Side	TRB										**43**					Cape Canaveral, FL	3,300	2	S	S	X		X		5 ACH, 1 AS f/down	**30%**
	Fairey (1985)			TRB										**43**					Cape Canaveral, FL	3,300	2	S	S	X		X		5 ACH, 2 AS	
	Hall (1986)			HRB										**40**					Chattanooga, TN	1,608	4	S	G		X	X			
	Fairey (1990)			TRB									**39**						Cape Canaveral, FL	3,300	2	-	-		X	X			
	Parker and Sherwin (1998)			TRB									**36**						Cocoa Beach, FL	3,300	2	S	R		X	X		Vent area = 1:150	
	Levins et al. (1986)			HRB									**35**						Karns, TN	1,301	4	S	G		X	X			
	Medina (2000a)			TRB								**34**							College Station, TX	2,938	2	S	G	X		X			
	Levins et al. (1986)			TRB								**30**							Karns, TN	1,301	4	S	G		X	X			
	Hall (1988a)			TRB								**30**							Chattanooga, TN	1,608	4	S	G		X	X			
	Medina et al. (1992a)			HRB								**30**							College Station, TX	2,938	2	S	G	X		X			
	Parker and Sherwin (1998)			TRB							**26**								Cocoa Beach, FL	3,300	2	S	R		X	X		Vent area = 1:300	
	Hall (1986)			TRB						**23**									Chattanooga, TN	1,608	4	S	G		X	X			
	McQuiston et al. (1984)			HRB						**20**									Stillwater, OK	1,881	3	-	-	X		-	-	Curved Roof	
	Ober & Volckhausen (1988)			DRB						**20**									Orlando, FL	3,428	2	S	G		X	X			
	Fairey (1985)			TRB					**19**										Cape Canaveral, FL	3,300	2	-	-			X		Unvented Attics	
	Fairey (1985)			HRB					**18**										Cape Canaveral, FL	3,300	2	-	-			X		Unvented Attics	
	Hall (1986)			DRB					**16**										Chattanooga, TN	1,608	4	S	G		X	X			
	Medina (2000a)	**R-30**	Side-by-Side	TRB							**25**								College Station, TX	2938	2	S	G		X	X			**23%**
	Hall (1988a)			TRB						**20**									Chattanooga, TN	1608	4	S	G		X	X			

Legend: CDD = Cooling Degree Days, HDD = Heating Degree Days, HRB = Horizontal Radiant Barrier, TRB = Truss Radiant Barrier, DARB = Deck-Applied Radiant Barrier, DRB = Draped Radiant Barrier, IRCC = Interior Radiation Control Coating, FV= Forced Ventilation, NV= Natural Ventilation, S = Soffit Vent, G = Gable Vent, R = Ridge Vent, P = Power Fan, ACH = Air Changes per Hour, AS = Aluminized Side, f/ = Facing, N/A = Not Applicable, (-) = Not Specified

Radiant Barrier Performance

Ceiling Heat Flow



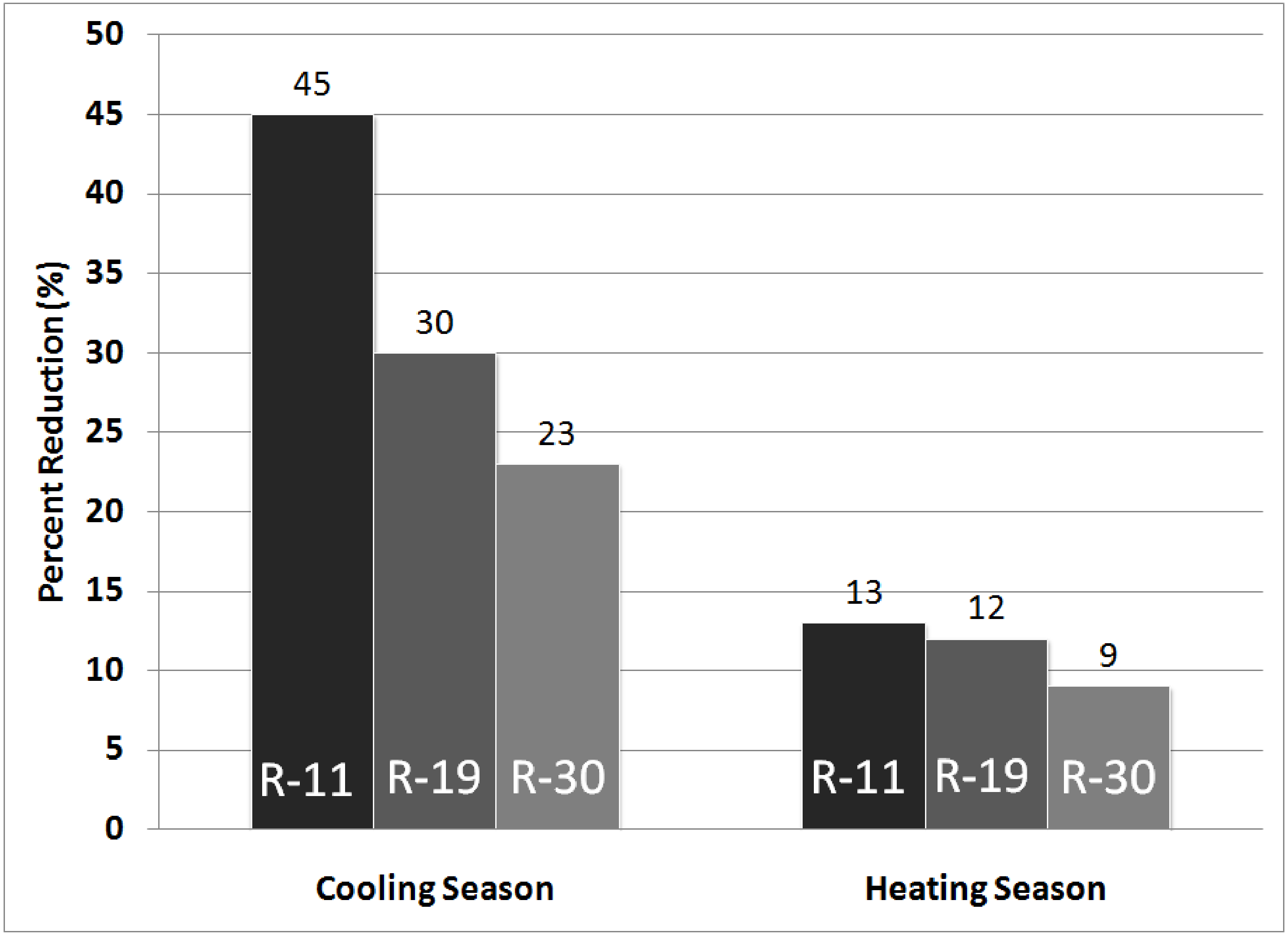
EXPERIMENTAL RESULTS HIGHLIGHTING CEILING HEAT FLOW REDUCTIONS PRODUCED BY THE RADIANT BARRIERS AND INTERIOR RADIATION CONTROL COATINGS DURING THE HEATING SEASON

Season	Reference	Nominal Insulation Level R-Value	Testing Protocol	Method	Ceiling Heat Flow Reductions Over Test Period (%)														City, St	HDD	Climatic Zone	Ventilation				Occupied		Comments	Average
					Winter																								
					-5	0 - 4	5 - 9	10 - 14	15 - 19	20 - 24	25 - 29	30 - 34	35 - 39	40 - 44	45 - 49	50 - 54	55 - 59	60				Vents		FV	NV	N	Y		
Heating	Levins and Karnitz (1988)	R-11	Side-by-Side	HRB					19										Karns, TN	3,993	4	S	G		X	X			13%
	Hall (1988)			HRB					17										Chattanooga, TN	3,427	4	S	G		X	X			
	Levins and Karnitz (1988)			TRB			8												Karns, TN	3,993	4	S	G		X	X			
	Hall (1988)			TRB			6												Chattanooga, TN	3,427	4	S	G		X	X			
	Levins and Karnitz (1987b)	R-19	Side-by-Side	TRB								30							Karns, TN	3,993	4	S	G		X	X			12%
	Fairey (1990)			TRB						24									Cape Canaveral, FL	677	2	-	-		X	X			
	Medina et al. (1992b)			HRB					17										College Station, TX	1,616	2	-	-	-	-	X		Non-vented Attics	
	Hall (1986)			HRB					15										Chattanooga, TN	3,427	4	S	G		X	X			
	Medina et al. (1992b)			TRB					15										College Station, TX	1,616	2	-	-	-	-	X		Non-vented Attics	
	Medina et al. (1992b)			HRB				14											College Station, TX	1,616	2	S	G	X		X			
	McQuiston et al. (1984)			HRB				10											Stillwater, OK	3,989	3	-	-	X		-	-	Curved Roof	
	Medina et al. (1992b)			TRB			9												College Station, TX	1,616	2	S	G	X		X			
	Hall (1988a)			HRB			5												Chattanooga, TN	3,427	4	S	G		X	X			
	Hall (1986)			TRB			8												Chattanooga, TN	3,427	4	S	G		X	X			
	Hall (1986)			DRB		4													Chattanooga, TN	3,427	4	S	G		X	X			
	Hall (1988a)			TRB	-5														Chattanooga, TN	3,427	4	S	G		X	X			
	Hall (1988a)	R-30	Side-by-Side	HRB					15										Chattanooga, TN	3,427	4	S	G		X	X			9%
	Levins and Karnitz (1988)			HRB				10											Karns, TN	3,993	4	S	G		X	X			
	Hall (1988a)			TRB			6												Chattanooga, TN	3,427	4	S	G		X	X			
	Levins and Karnitz (1988)			TRB		4													Karns, TN	3,993	4	S	G		X	X			

Legend: CDD = Cooling Degree Days, HDD = Heating Degree Days, HRB = Horizontal Radiant Barrier, TRB = Truss Radiant Barrier, DARB = Deck-Applied Radiant Barrier, DRB = Draped Radiant Barrier, IRCC = Interior Radiation Control Coating, FV= Forced Ventilation, NV= Natural Ventilation, S = Soffit Vent, G = Gable Vent, R = Ridge Vent, P = Power Fan, ACH = Air Changes per Hour, AS = Aluminized Side, f/ = Facing, N/A = Not Applicable, (-) = Not Specified

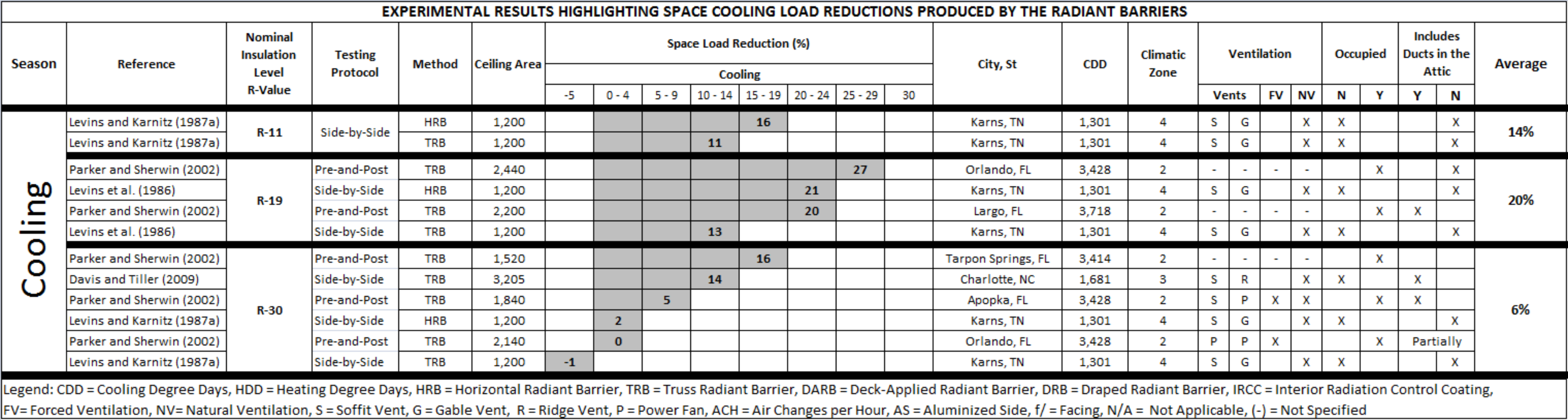
Radiant Barrier Performance

Ceiling Heat Flow



Radiant Barrier Performance

Space Cooling Load



EXPERIMENTAL RESULTS HIGHLIGHTING SPACE COOLING LOAD REDUCTIONS PRODUCED BY THE RADIANT BARRIERS

Season	Reference	Nominal Insulation Level R-Value	Testing Protocol	Method	Ceiling Area	Space Load Reduction (%)								City, St	CDD	Climatic Zone	Ventilation				Occupied		Includes Ducts in the Attic		Average
						Cooling																			
						-5	0 - 4	5 - 9	10 - 14	15 - 19	20 - 24	25 - 29	30				Vents		FV	NV	N	Y	Y	N	
Cooling	Levins and Karnitz (1987a)	R-11	Side-by-Side	HRB	1,200		▨	▨	▨	16				Karns, TN	1,301	4	S	G		X	X			X	14%
	Levins and Karnitz (1987a)			TRB	1,200		▨	▨	11					Karns, TN	1,301	4	S	G		X	X			X	
	Parker and Sherwin (2002)	R-19	Pre-and-Post	TRB	2,440		▨	▨	▨	▨	▨	27		Orlando, FL	3,428	2	-	-	-	-		X		X	20%
	Levins et al. (1986)		Side-by-Side	HRB	1,200		▨	▨	▨	▨	21			Karns, TN	1,301	4	S	G		X	X			X	
	Parker and Sherwin (2002)		Pre-and-Post	TRB	2,200		▨	▨	▨	▨	20			Largo, FL	3,718	2	-	-	-	-		X	X		
	Levins et al. (1986)		Side-by-Side	TRB	1,200		▨	▨	13					Karns, TN	1,301	4	S	G		X	X			X	
	Parker and Sherwin (2002)	R-30	Pre-and-Post	TRB	1,520		▨	▨	▨	16				Tarpon Springs, FL	3,414	2	-	-	-	-		X			6%
	Davis and Tiller (2009)		Side-by-Side	TRB	3,205		▨	▨	14					Charlotte, NC	1,681	3	S	R		X	X		X		
	Parker and Sherwin (2002)		Pre-and-Post	TRB	1,840		▨	5						Apopka, FL	3,428	2	S	P	X	X		X	X		
	Levins and Karnitz (1987a)		Side-by-Side	HRB	1,200		2							Karns, TN	1,301	4	S	G		X	X			X	
	Parker and Sherwin (2002)		Pre-and-Post	TRB	2,140		0							Orlando, FL	3,428	2	P	P	X			X	Partially		
	Levins and Karnitz (1987a)		Side-by-Side	TRB	1,200	-1								Karns, TN	1,301	4	S	G		X	X			X	

Legend: CDD = Cooling Degree Days, HDD = Heating Degree Days, HRB = Horizontal Radiant Barrier, TRB = Truss Radiant Barrier, DARB = Deck-Applied Radiant Barrier, DRB = Draped Radiant Barrier, IRCC = Interior Radiation Control Coating, FV= Forced Ventilation, NV= Natural Ventilation, S = Soffit Vent, G = Gable Vent, R = Ridge Vent, P = Power Fan, ACH = Air Changes per Hour, AS = Aluminized Side, f/ = Facing, N/A = Not Applicable, (-) = Not Specified

Radiant Barrier Performance

Space Heating Load

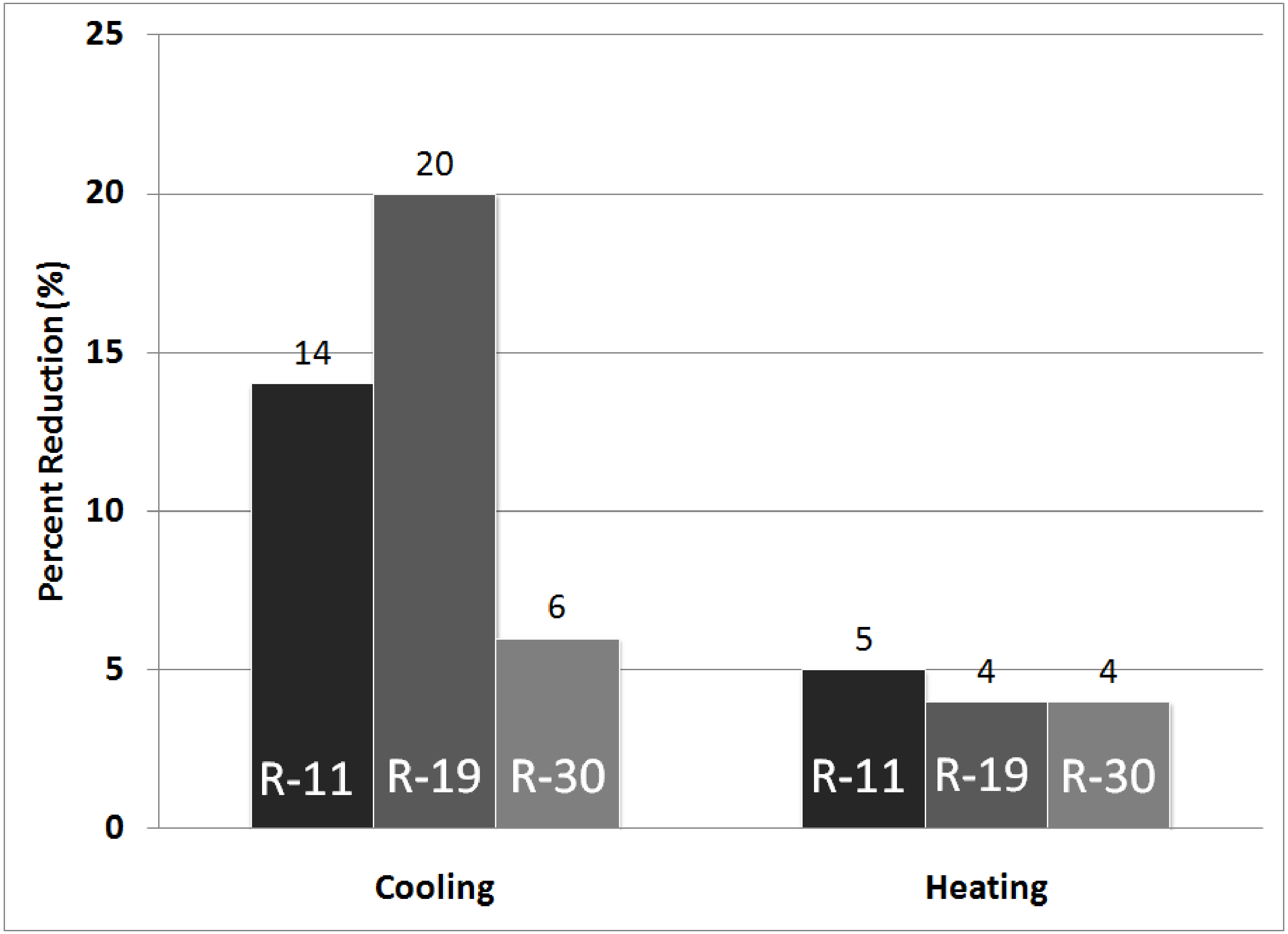
EXPERIMENTAL RESULTS HIGHLIGHTING SPACE HEATING LOAD REDUCTIONS PRODUCED BY THE RADIANT BARRIERS

Season	Reference	Nominal Insulation Level R-Value	Testing Protocol	Method	Ceiling Area	Space Load Reduction (%)								City, St	HDD	Climatic Zone	Ventilation				Occupied		Includes Ducts in the Attic		Average
						Heating																			
						-5	0 - 4	5 - 9	10 - 14	15 - 19	20 - 24	25 - 29	30				Vents		FV	NV	N	Y	Y	N	
Heating	Levins and Karnitz (1987b)	**R-11**	Side-by-Side	HRB	1,200			**9**						Karns, TN	3,993	4	S	G		X	X			X	**5%**
	Levins and Karnitz (1987b)			TRB	1,200		**0**							Karns, TN	3,993	4	S	G		X	X			X	
	Levins et al. (1986)	**R-19**	Side-by-Side	HRB	1,200				**10**					Karns, TN	3,993	4	S	G		X	X			X	**4%**
	Levins et al. (1986)			TRB	1,200	**-3**								Karns, TN	3,993	4	S	G		X	X			X	
	Levins and Karnitz (1987b)	**R-30**	Side-by-Side	HRB	1,200		**4**							Karns, TN	3,993	4	S	G		X	X			X	**4%**
	Levins and Karnitz (1987b)			TRB	1,200		**4**							Karns, TN	3,993	4	S	G		X	X			X	

Legend: CDD = Cooling Degree Days, HDD = Heating Degree Days, HRB = Horizontal Radiant Barrier, TRB = Truss Radiant Barrier, DARB = Deck-Applied Radiant Barrier, DRB = Draped Radiant Barrier, IRCC = Interior Radiation Control Coating, FV= Forced Ventilation, NV= Natural Ventilation, S = Soffit Vent, G = Gable Vent, R = Ridge Vent, P = Power Fan, ACH = Air Changes per Hour, AS = Aluminized Side, f/ = Facing, N/A = Not Applicable, (-) = Not Specified

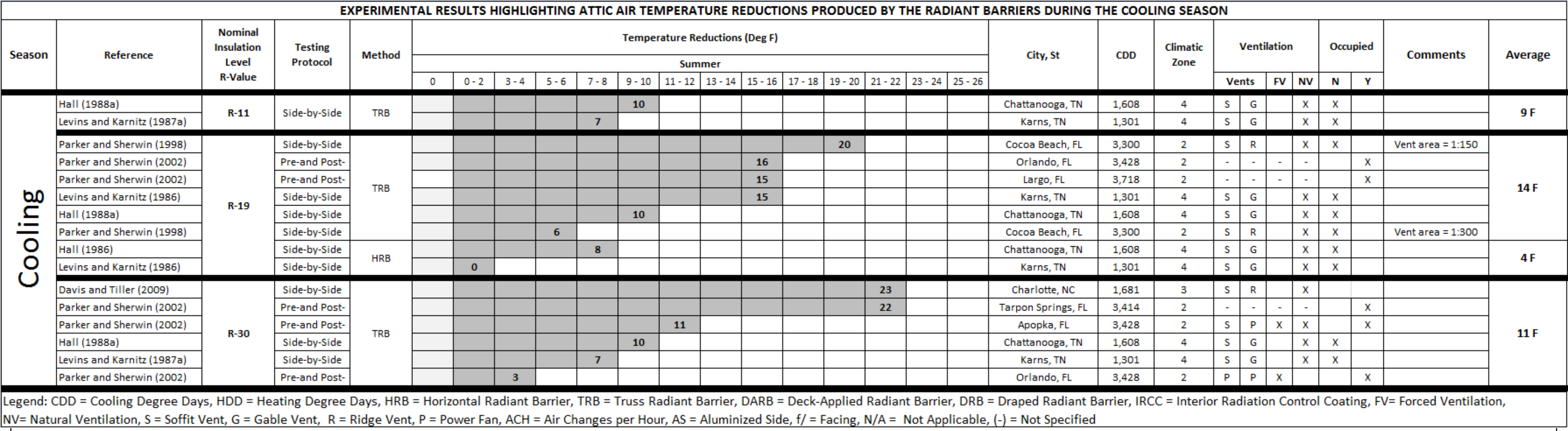
Radiant Barrier Performance

Space Cooling and Space Heating Load



Radiant Barrier Performance

Attic Temperature Reductions

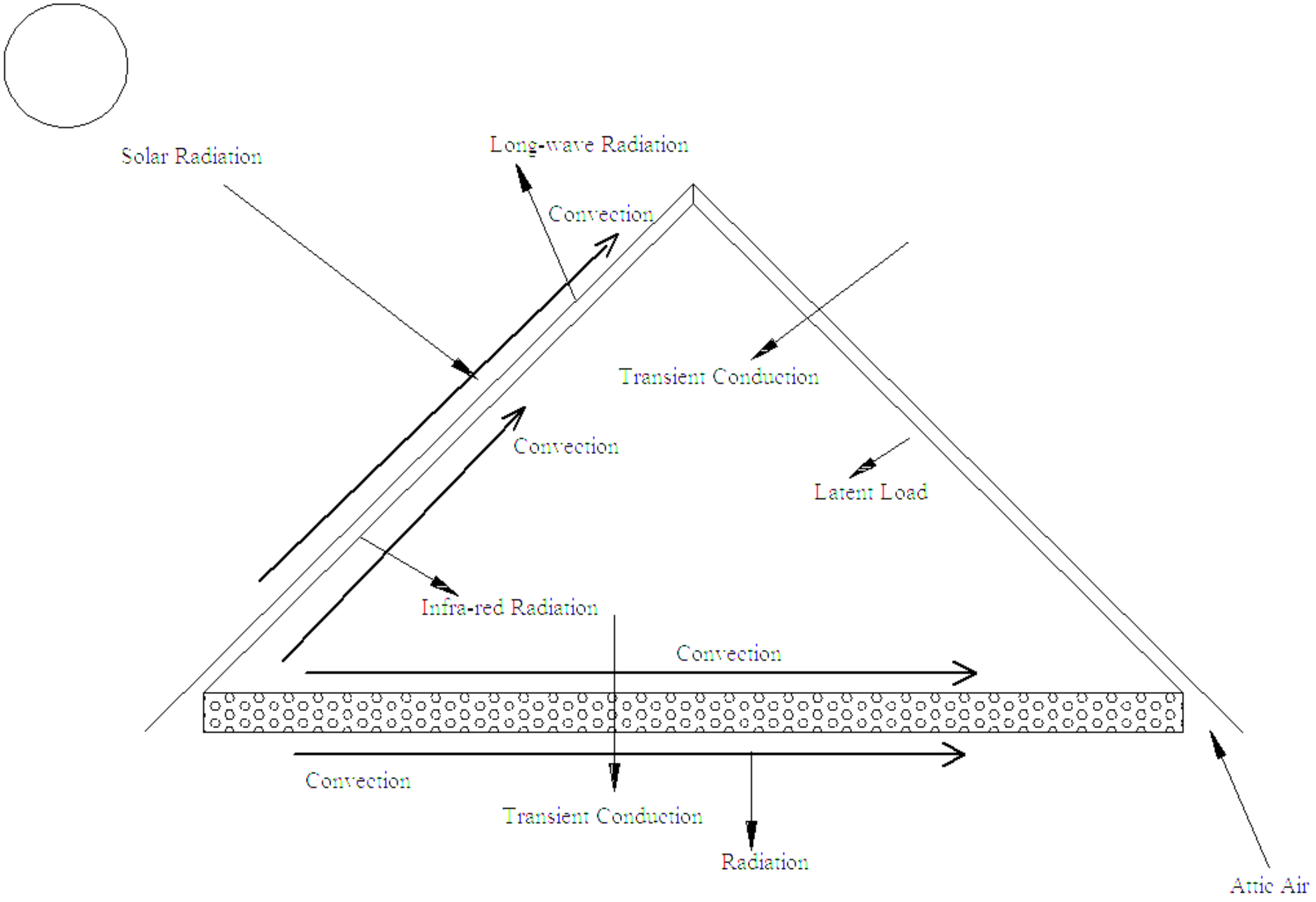


EXPERIMENTAL RESULTS HIGHLIGHTING ATTIC AIR TEMPERATURE REDUCTIONS PRODUCED BY THE RADIANT BARRIERS DURING THE COOLING SEASON

Season	Reference	Nominal Insulation Level R-Value	Testing Protocol	Method	Temperature Reductions (Deg F)														City, St	CDD	Climatic Zone	Ventilation				Occupied		Comments	Average
					Summer																								
					0	0 - 2	3 - 4	5 - 6	7 - 8	9 - 10	11 - 12	13 - 14	15 - 16	17 - 18	19 - 20	21 - 22	23 - 24	25 - 26				Vents		FV	NV	N	Y		
Cooling	Hall (1988a)	**R-11**	Side-by-Side	TRB		▨	▨	▨	▨	**10**									Chattanooga, TN	1,608	4	S	G		X	X			**9 F**
	Levins and Karnitz (1987a)					▨	▨	▨	**7**										Karns, TN	1,301	4	S	G		X	X			
	Parker and Sherwin (1998)	**R-19**	Side-by-Side	TRB		▨	▨	▨	▨	▨	▨	▨	▨	▨	**20**				Cocoa Beach, FL	3,300	2	S	R		X	X		Vent area = 1:150	**14 F**
	Parker and Sherwin (2002)		Pre-and Post-			▨	▨	▨	▨	▨	▨	▨	**16**						Orlando, FL	3,428	2	-	-	-	-		X		
	Parker and Sherwin (2002)		Pre-and Post-			▨	▨	▨	▨	▨	▨	▨	**15**						Largo, FL	3,718	2	-	-	-	-		X		
	Levins and Karnitz (1986)		Side-by-Side			▨	▨	▨	▨	▨	▨	▨	**15**						Karns, TN	1,301	4	S	G		X	X			
	Hall (1988a)		Side-by-Side			▨	▨	▨	▨	**10**									Chattanooga, TN	1,608	4	S	G		X	X			
	Parker and Sherwin (1998)		Side-by-Side			▨	▨	**6**											Cocoa Beach, FL	3,300	2	S	R		X	X		Vent area = 1:300	
	Hall (1986)		Side-by-Side	HRB		▨	▨	▨	**8**										Chattanooga, TN	1,608	4	S	G		X	X			**4 F**
	Levins and Karnitz (1986)		Side-by-Side			**0**													Karns, TN	1,301	4	S	G		X	X			
	Davis and Tiller (2009)	**R-30**	Side-by-Side	TRB		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	**23**			Charlotte, NC	1,681	3	S	R		X				**11 F**
	Parker and Sherwin (2002)		Pre-and Post-			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	**22**			Tarpon Springs, FL	3,414	2	-	-	-	-		X		
	Parker and Sherwin (2002)		Pre-and Post-			▨	▨	▨	▨	▨	**11**								Apopka, FL	3,428	2	S	P	X	X		X		
	Hall (1988a)		Side-by-Side			▨	▨	▨	▨	**10**									Chattanooga, TN	1,608	4	S	G		X	X			
	Levins and Karnitz (1987a)		Side-by-Side			▨	▨	▨	**7**										Karns, TN	1,301	4	S	G		X	X			
	Parker and Sherwin (2002)		Pre-and Post-			▨	**3**												Orlando, FL	3,428	2	P	P	X			X		

Legend: CDD = Cooling Degree Days, HDD = Heating Degree Days, HRB = Horizontal Radiant Barrier, TRB = Truss Radiant Barrier, DARB = Deck-Applied Radiant Barrier, DRB = Draped Radiant Barrier, IRCC = Interior Radiation Control Coating, FV= Forced Ventilation, NV= Natural Ventilation, S = Soffit Vent, G = Gable Vent, R = Ridge Vent, P = Power Fan, ACH = Air Changes per Hour, AS = Aluminized Side, f/ = Facing, N/A = Not Applicable, (-) = Not Specified

Modeling
Based on Energy Balances



Modeling and Its Importance in RemRate

Energy Balance (General)

$$Q_{conducted(to\ /\ from)} + Q_{convected(to\ /\ from)} + Q_{radiated(net)} + Q_{latent(condensation/\ evaporation)} = 0$$

Energy Balance (Heat Transport Processes)

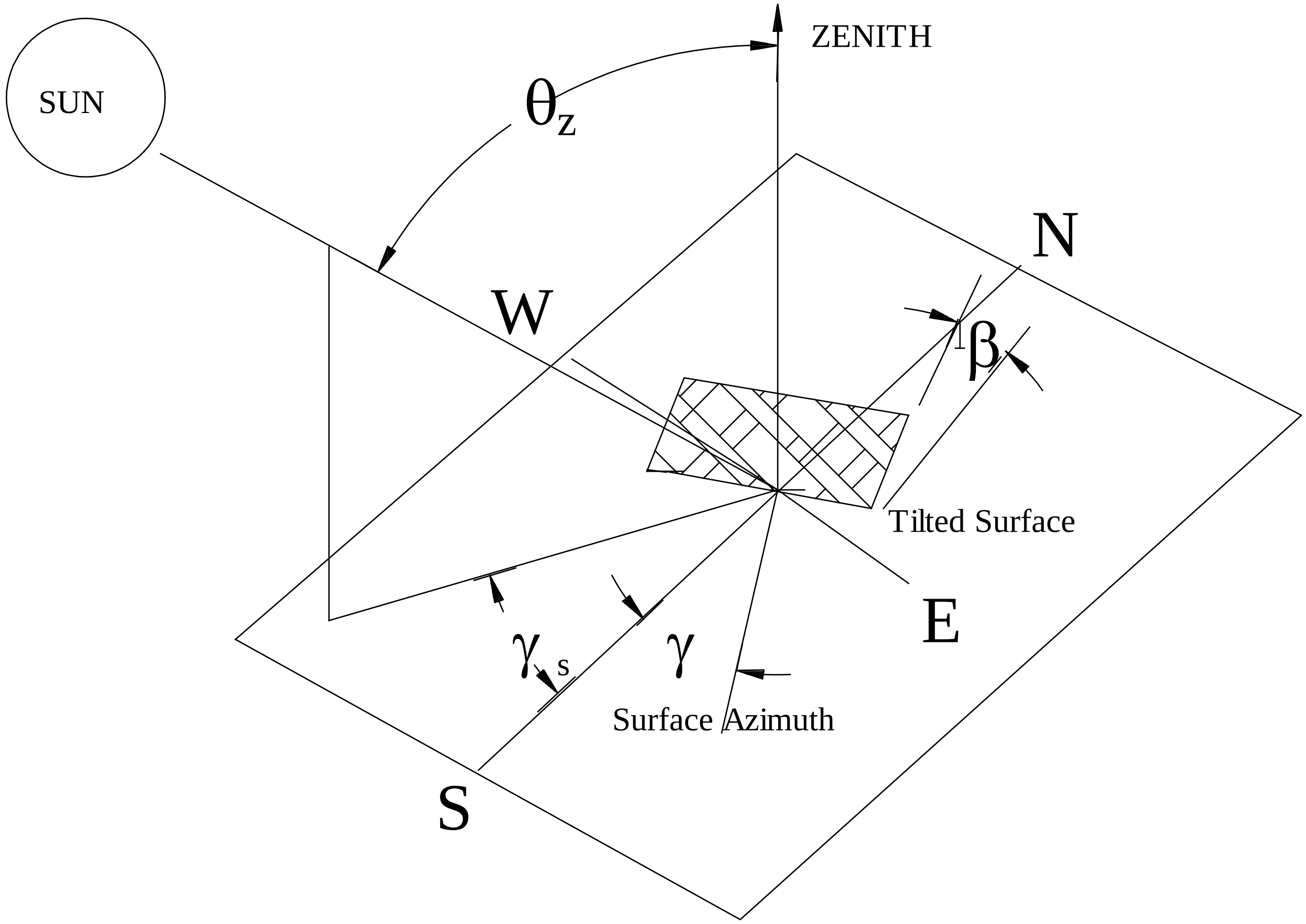
$$\sum_{j=0,i=1}^{N,S} Y_{i,j}(Tsi_{i,n\Delta - j} - Tr) - \sum_{j=0,i=1}^{N,S} X_{i,j}(Tso_{i,n\Delta - j} - Tr)$$
$$+ CR_i q''_{o\ (i,n\Delta - 1)} + ho_i(T_{amb} - Tso_{i,n\Delta})$$
$$+ hro_i(T_{sky\ /\ surr} - Tso_{i,n\Delta}) + \alpha q''_{sol,i} = 0$$

←Outdoor Energy Balance

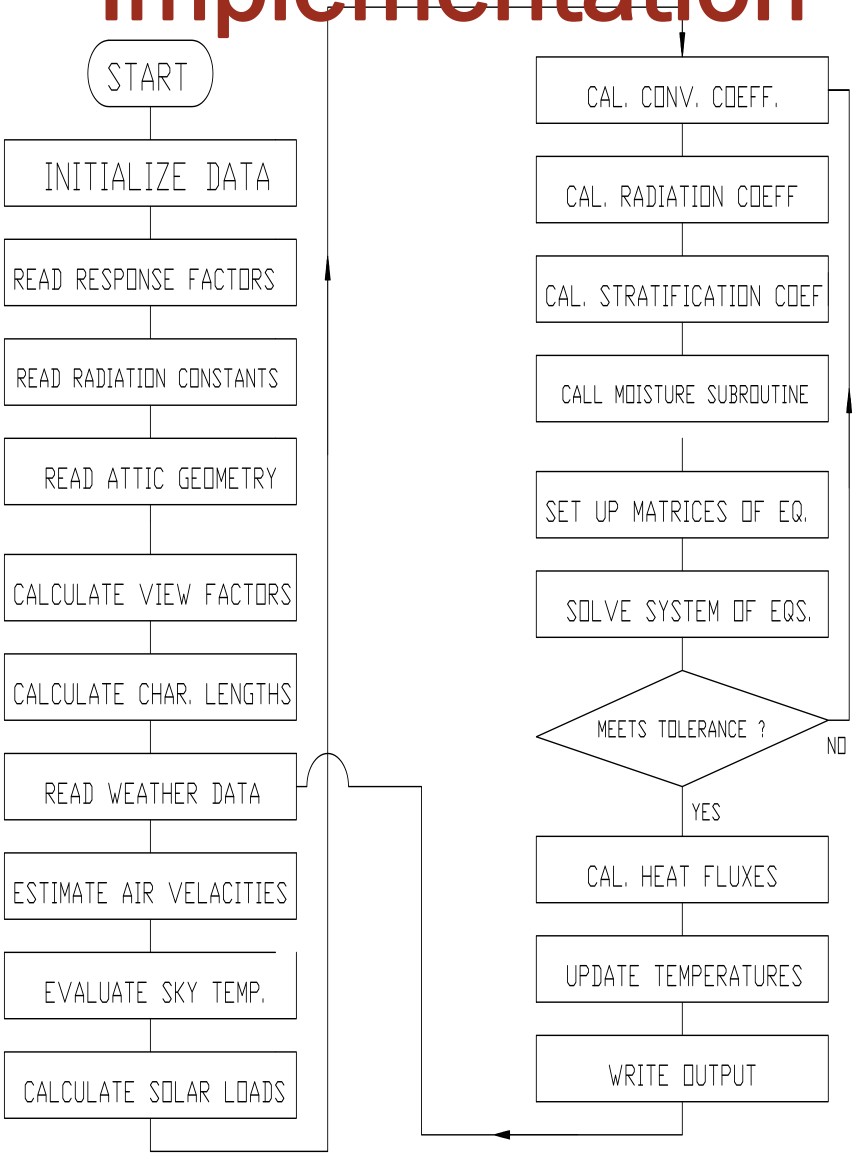
Indoor Energy Balance →

$$\sum_{j=0,i=1}^{N,S} Z_{i,j}(Tsi_{i,n\Delta - j} - Tr) - \sum_{j=0,i=1}^{N,S} Y_{i,j}(Tso_{i,n\Delta - j} - Tr)$$
$$+ CR_i q''_{i\ (i,n\Delta - 1)} + hi_i(Tsi_{i,n\Delta} - T_{atticair,n\Delta})$$
$$+ \sum_{k=1,i=1}^{s,s} hri_{i,k}(Tsi_{i,n\Delta} - Tsi_{k,n\Delta}) + q''_{latent,i} = 0$$

Modeling Solar Radiation



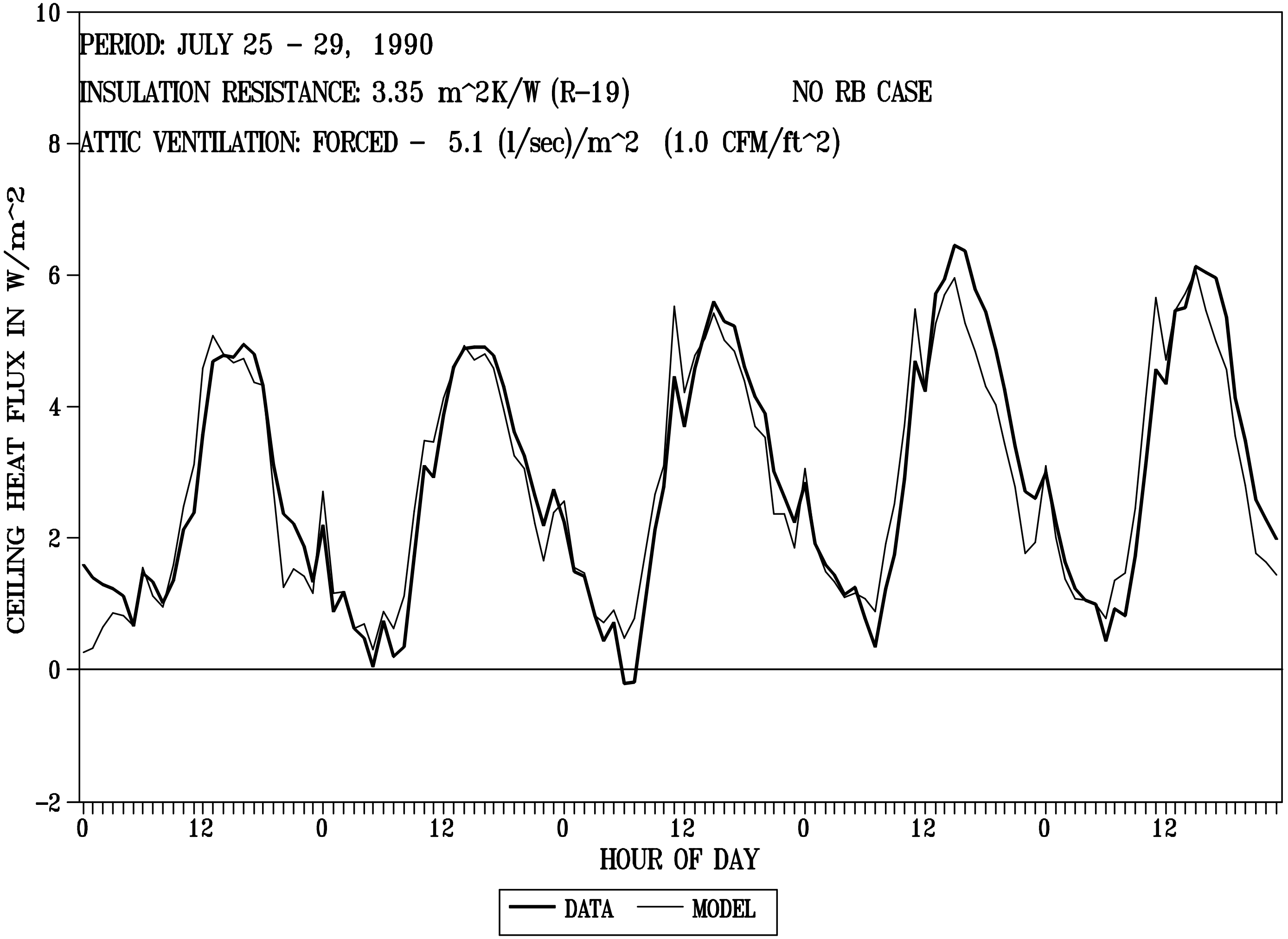
Modeling Implementation



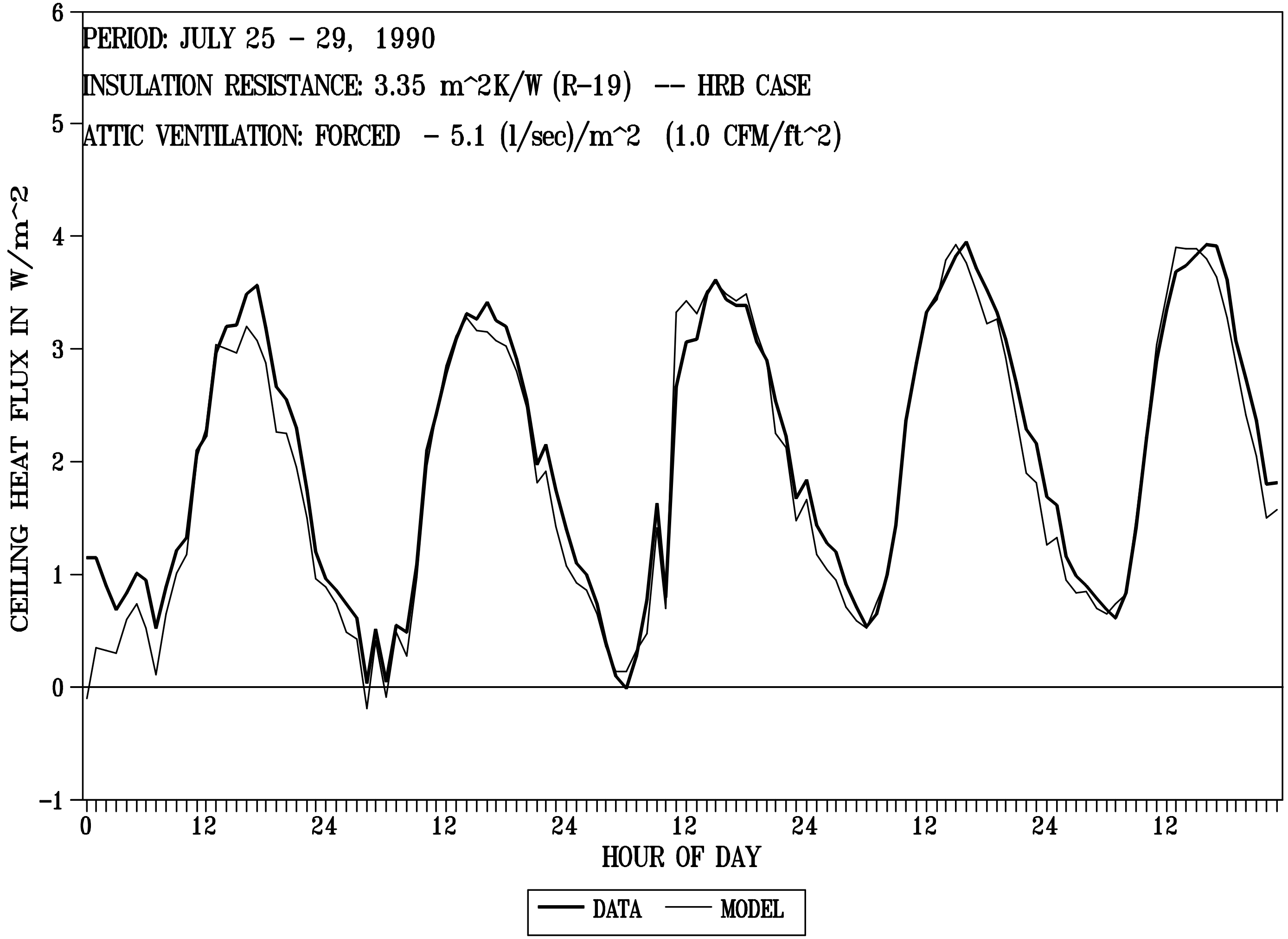
START
INITIALIZE DATA
READ RESPONSE FACTORS
READ RADIATION CONSTANTS
READ ATTIC GEOMETRY
CALCULATE VIEW FACTORS
CALCULATE CHAR. LENGTHS
READ WEATHER DATA
ESTIMATE AIR VELACITIES
EVALUATE SKY TEMP.
CALCULATE SOLAR LOADS

CAL. CONV. COEFF.
CAL. RADIATION COEFF
CAL. STRATIFICATION COEF
CALL MOISTURE SUBROUTINE
SET UP MATRICES OF EQ.
SOLVE SYSTEM OF EQS.
MEETS TOLERANCE ?
NO
YES
CAL. HEAT FLUXES
UPDATE TEMPERATURES
WRITE OUTPUT

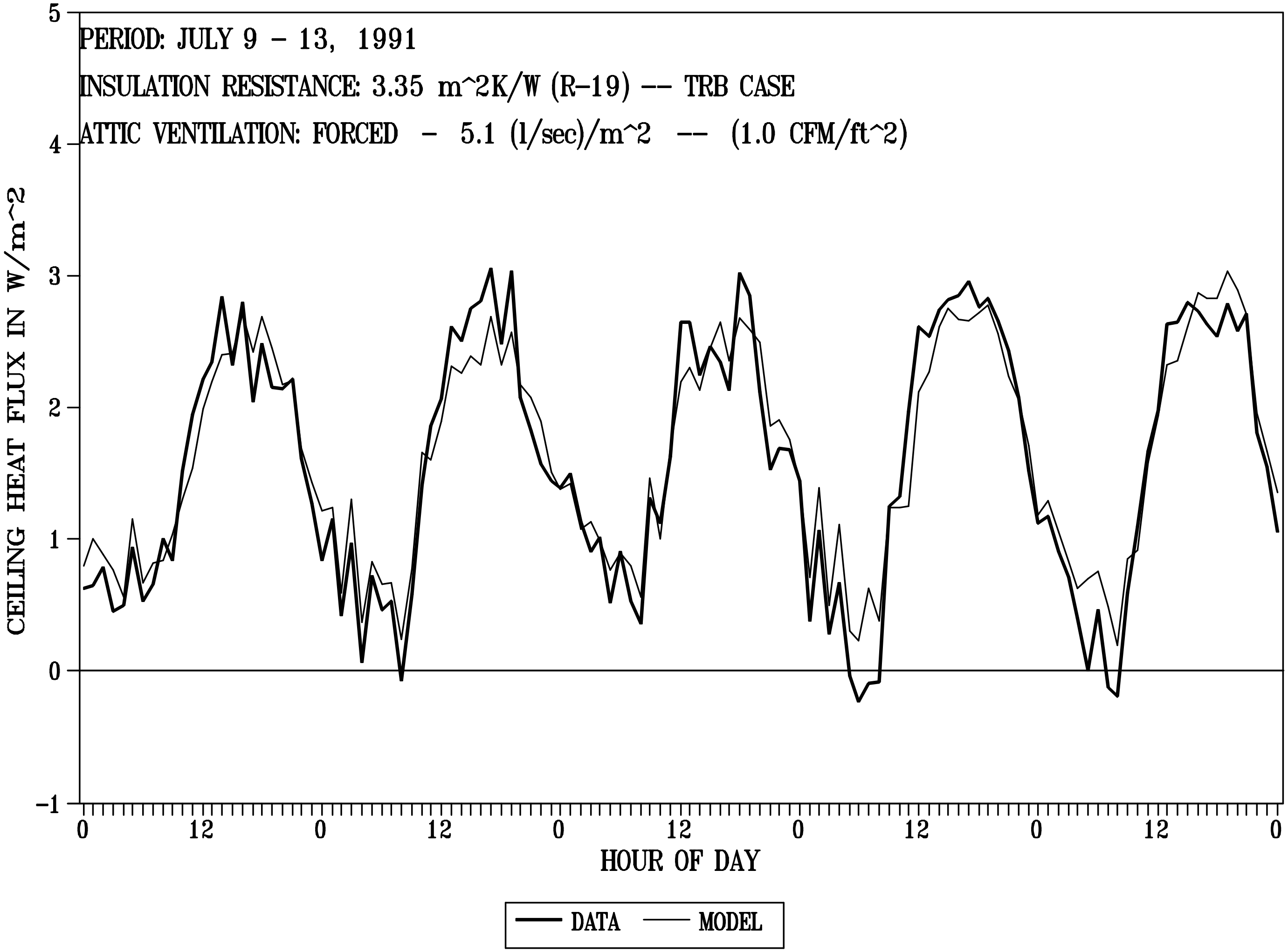
Modeling
Model Verification vs Exp. Data (No RB)



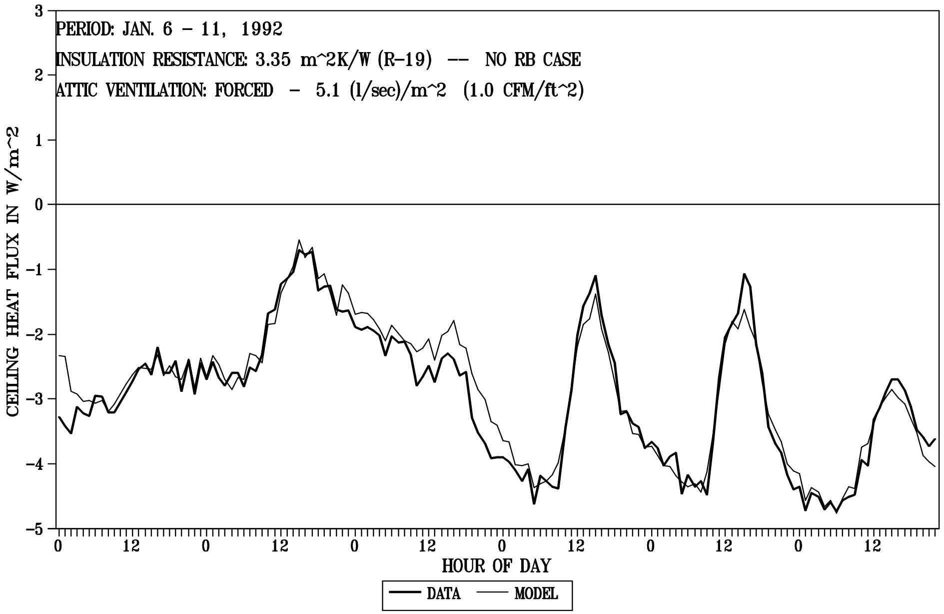
Modeling
Model Verification vs Exp. Data (HRB)

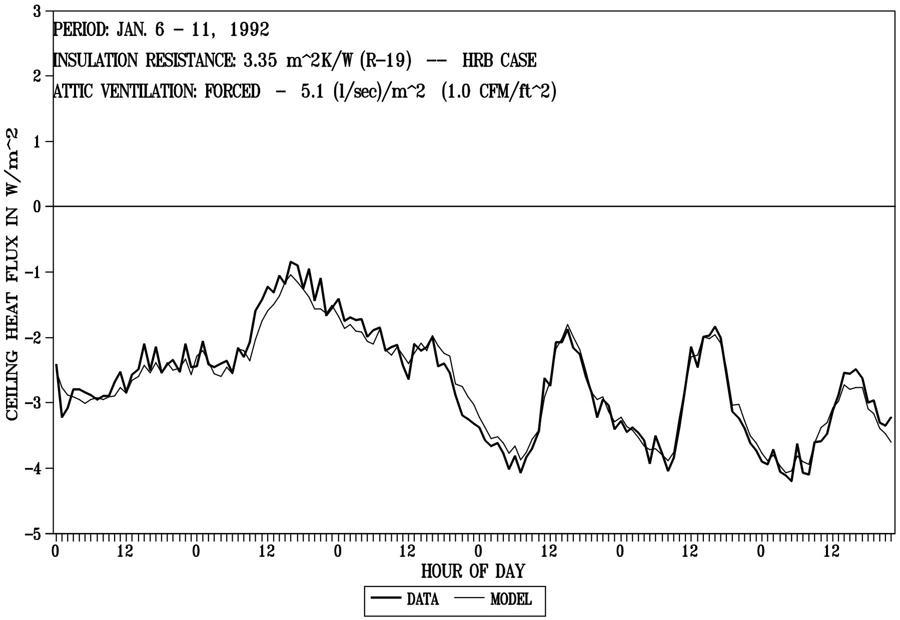


Modeling
Model Verification vs Exp. Data (TRB)

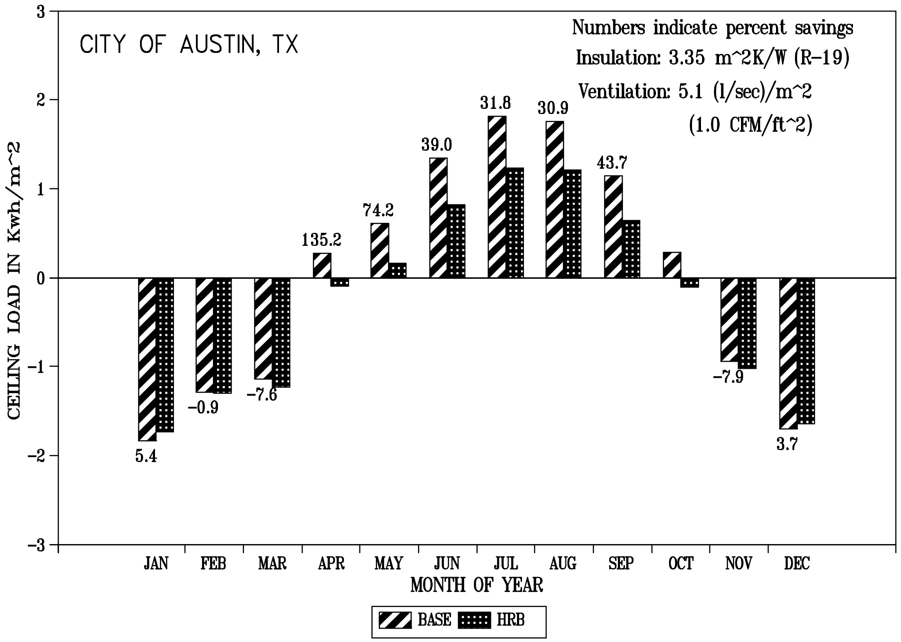


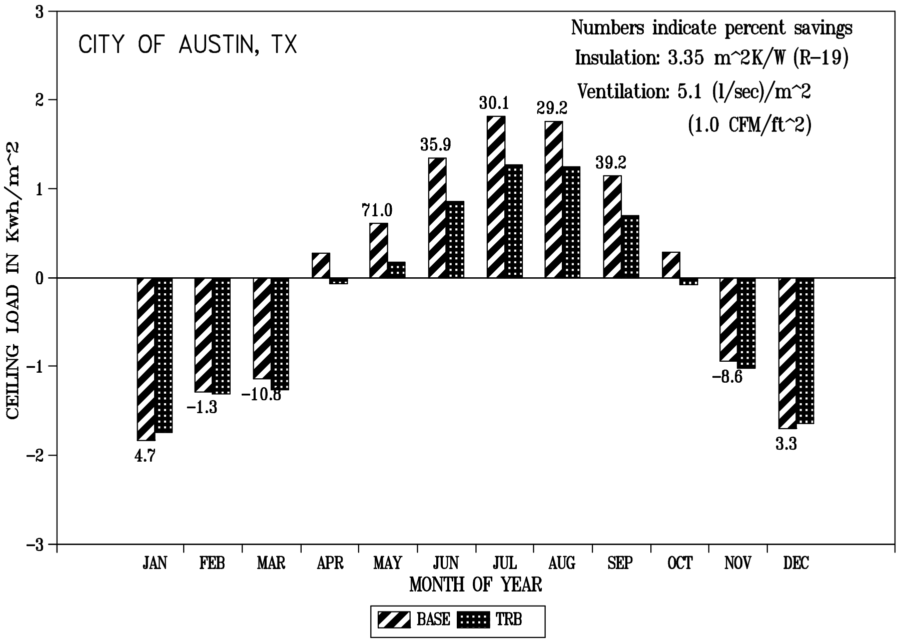
Modeling
Model Verification vs Exp. Data (Winter)



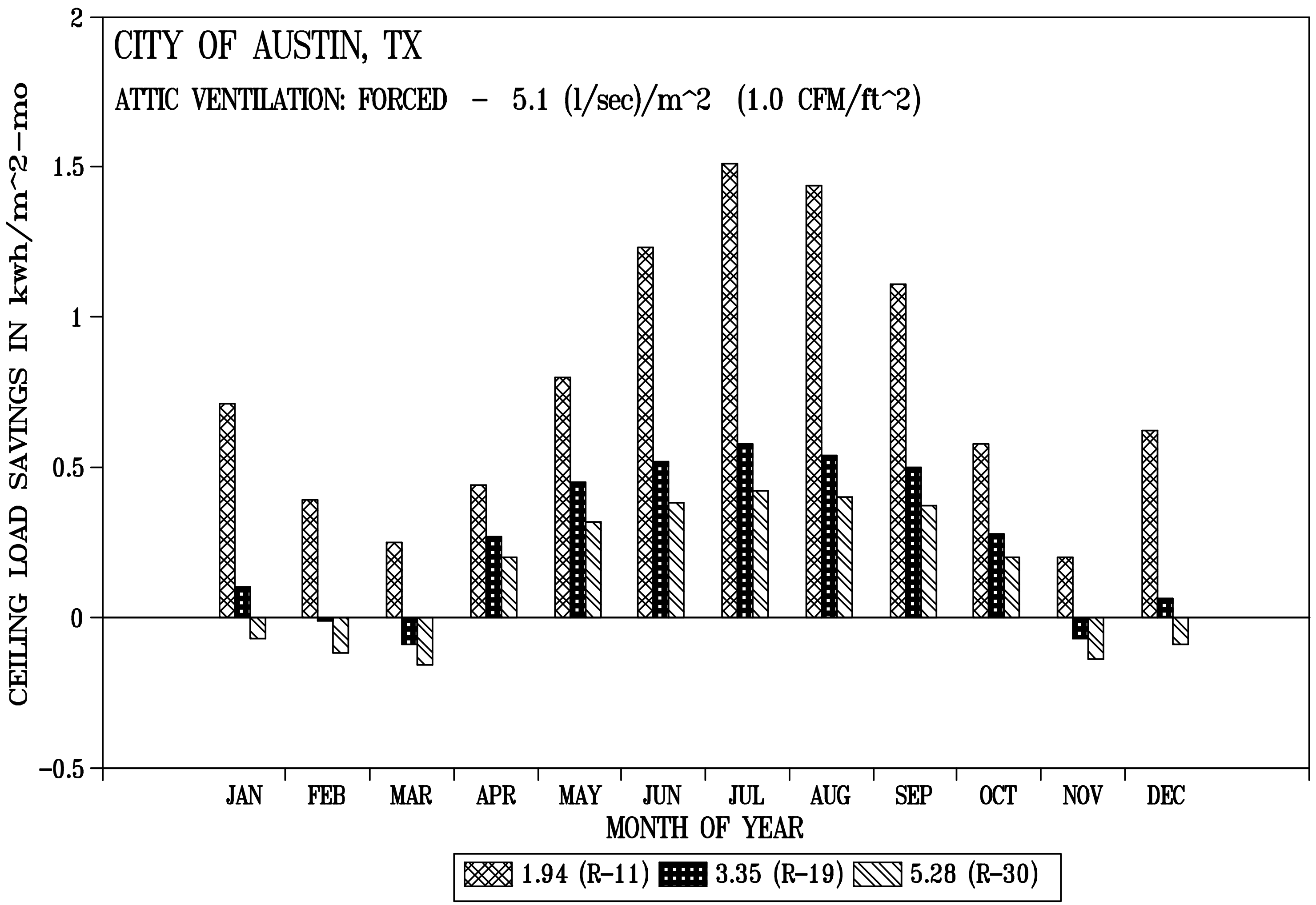


Computer Simulations
Yearly Performance



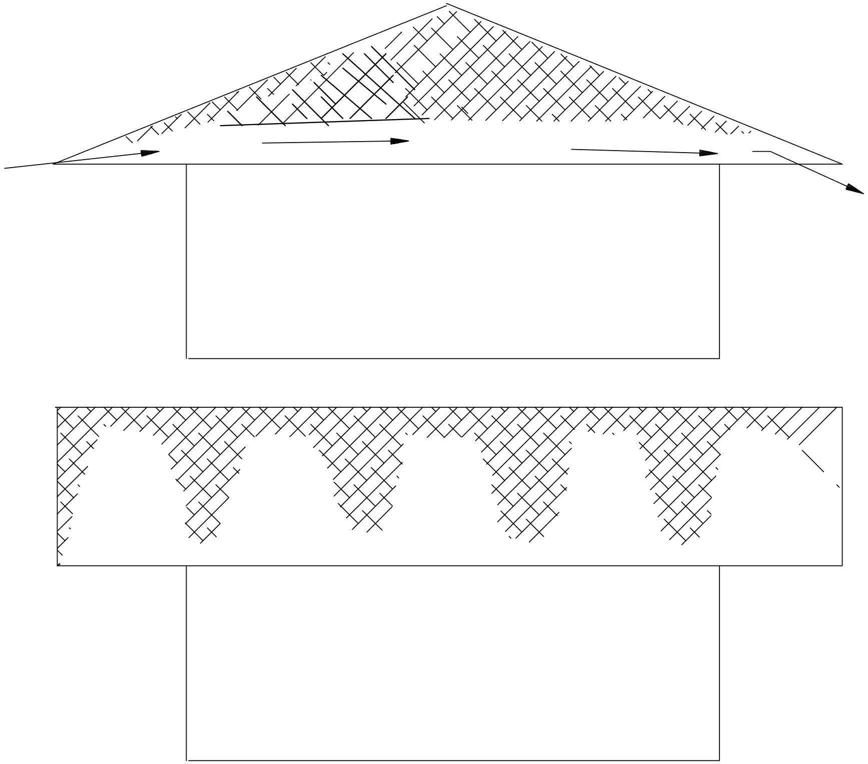


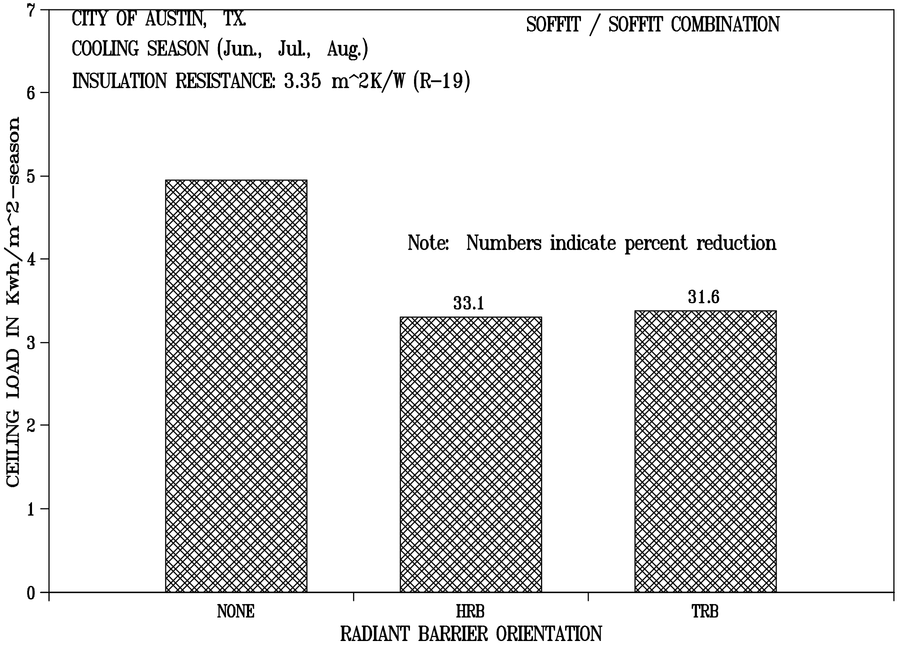
Computer Simulations
Yearly Performance



Computer Simulations
Attic Ventilation Patterns

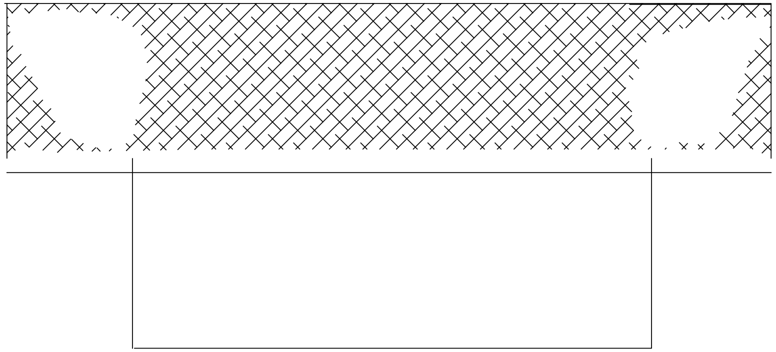
(Soffit/Soffit)



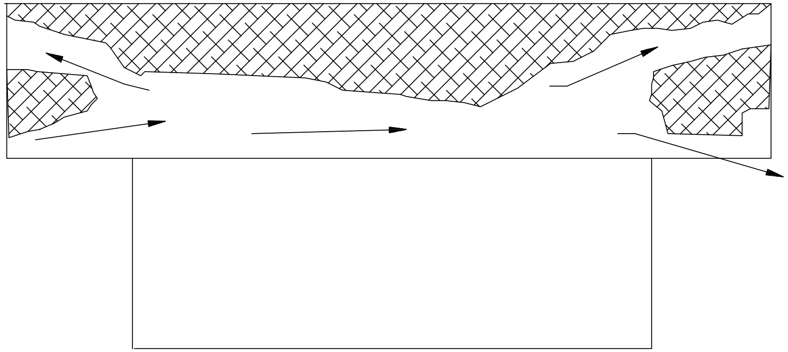


Computer Simulations
Attic Ventilation Patterns

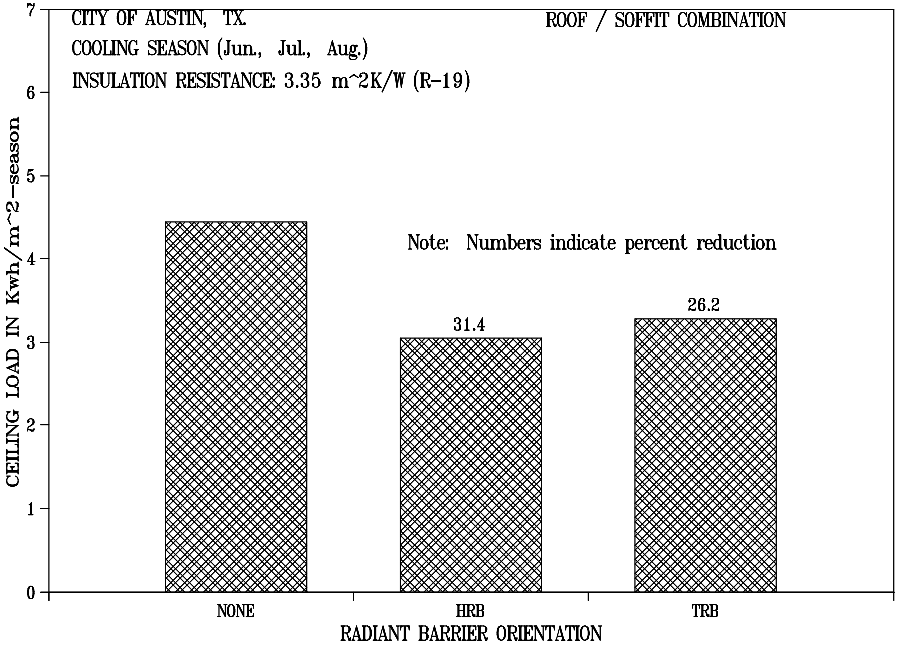
(Roof/Soffit)



When wind is perpendicular to the ridge line

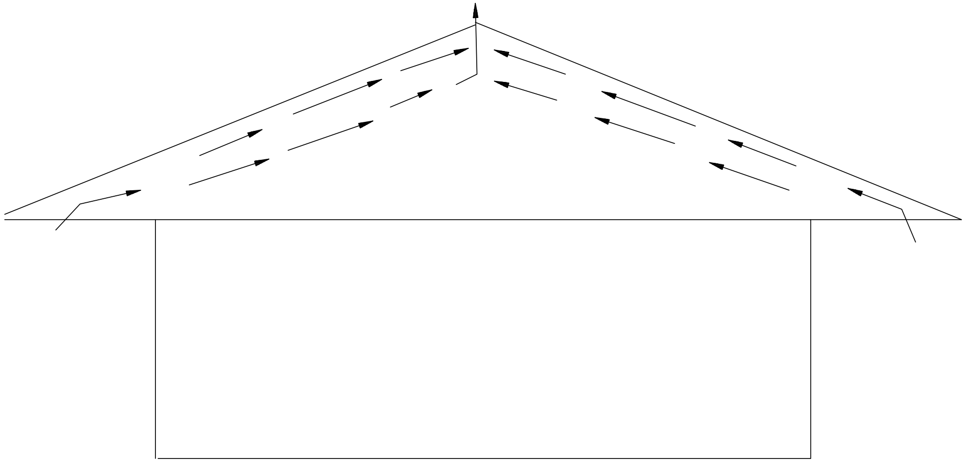


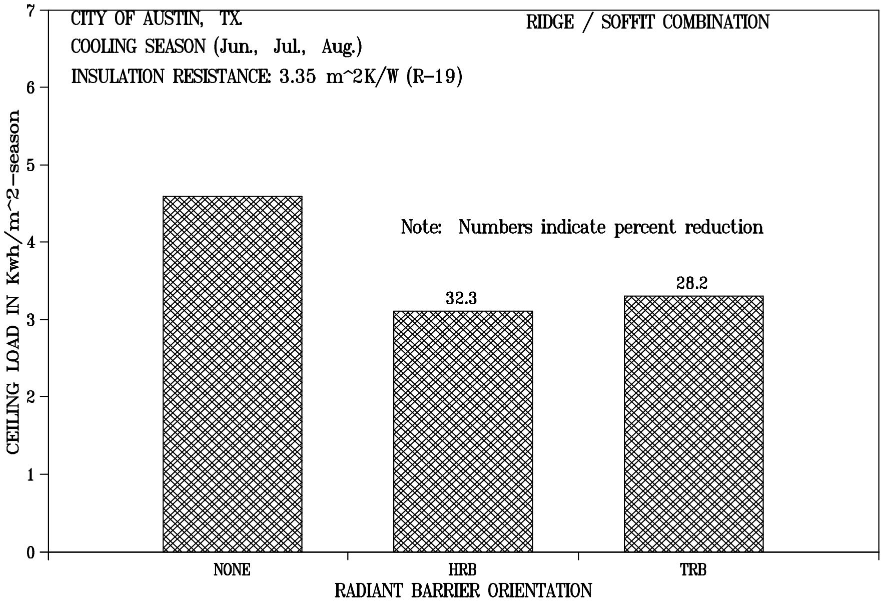
WHen wind is parallel to the ridge line



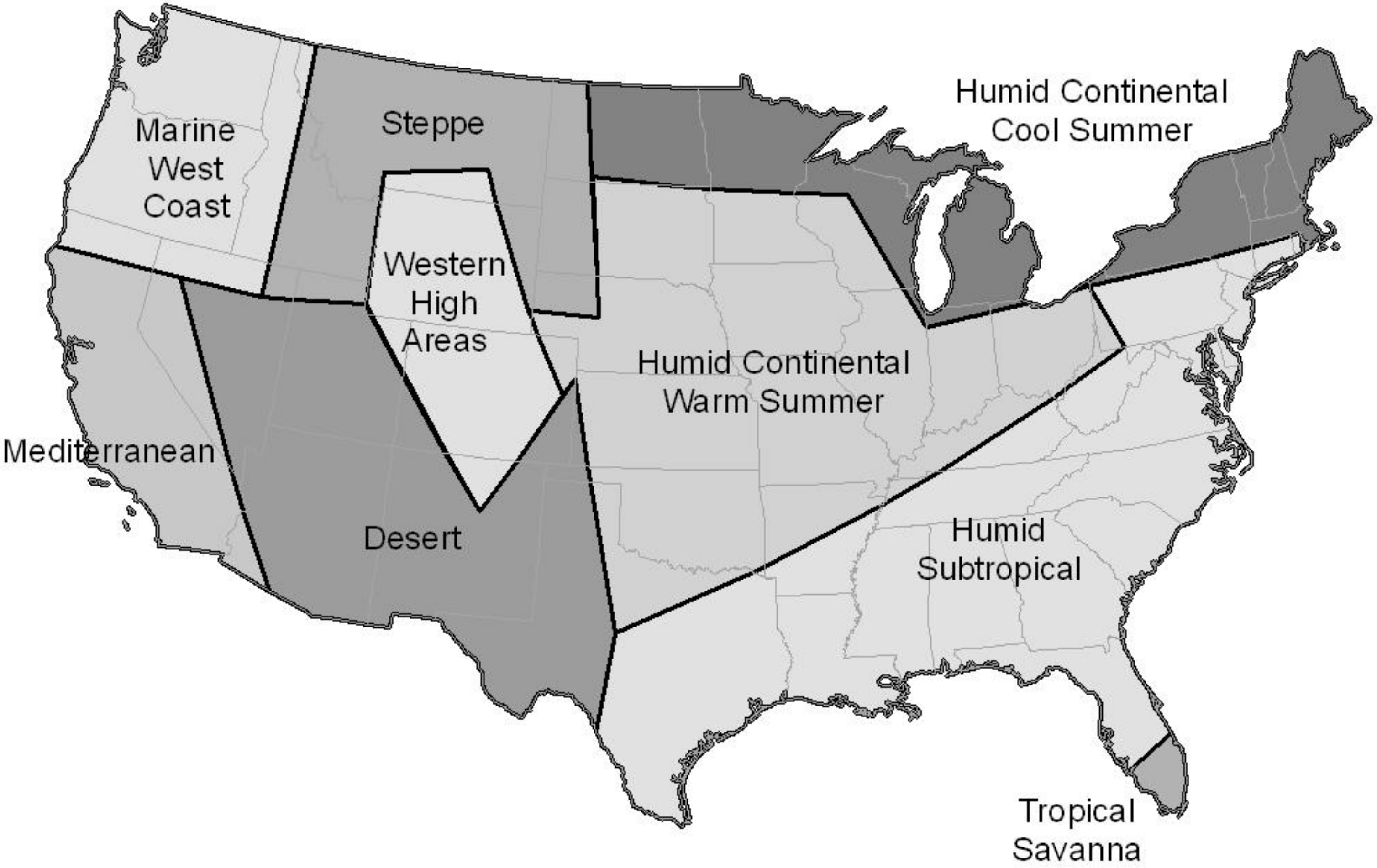
Computer Simulations
Attic Ventilation Patterns

(Soffit/Ridge)

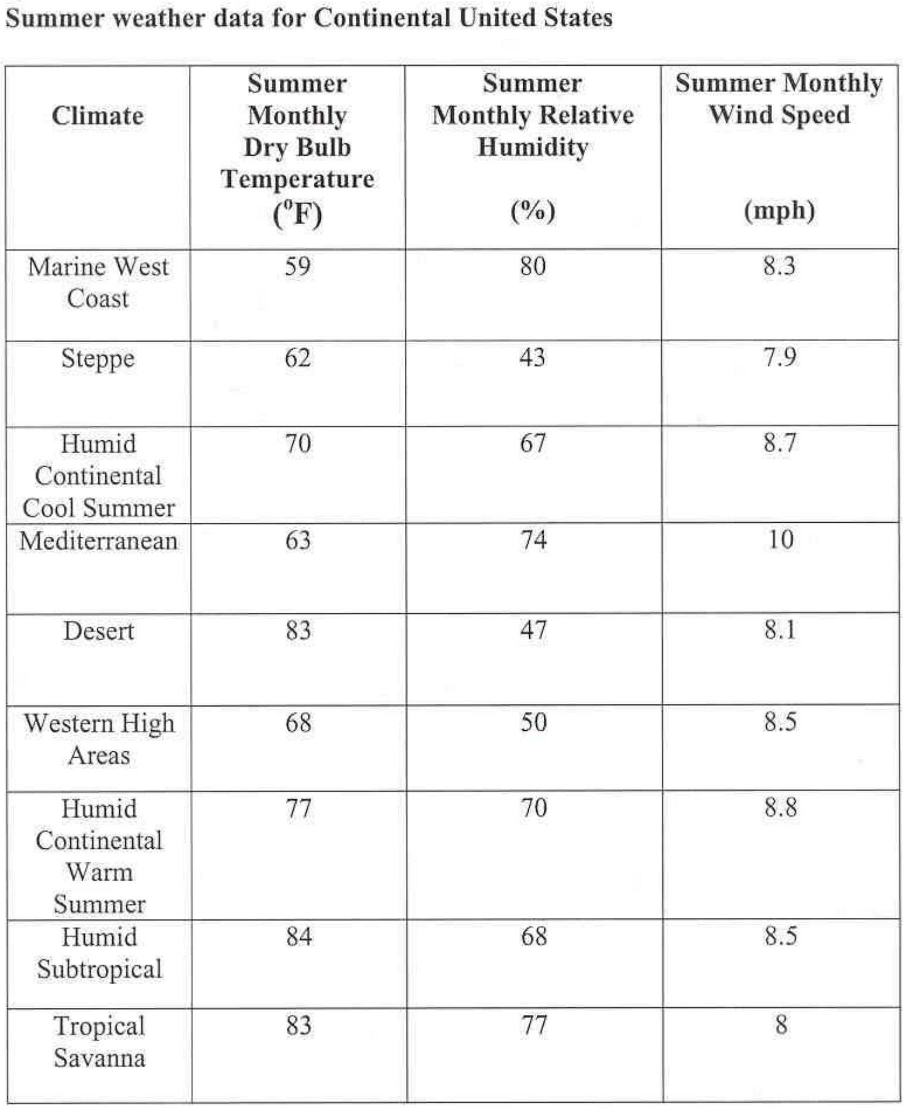




Computer Simulations Climatic Influences



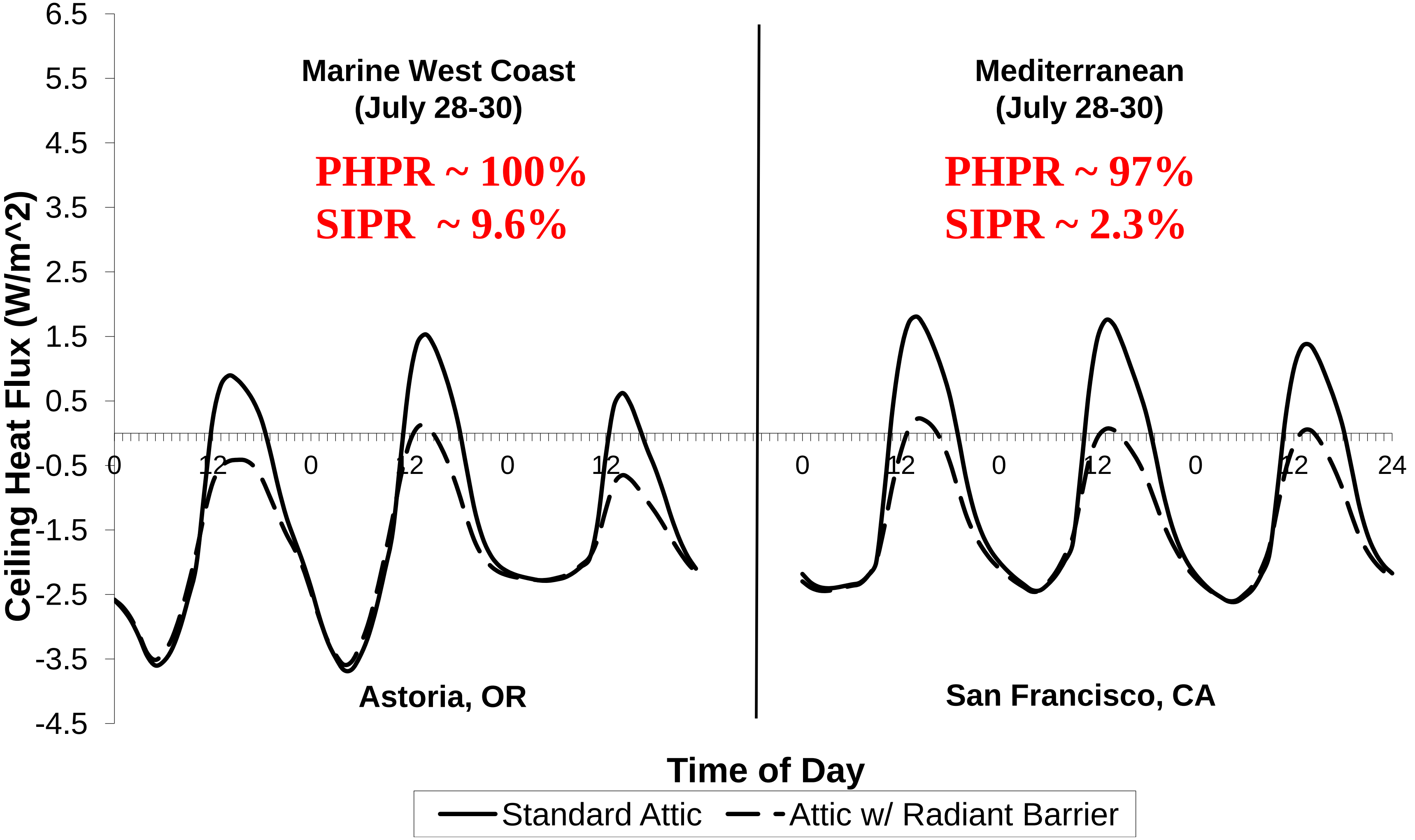
Computer Simulations Climatic Influences



Summer weather data for Continental United States

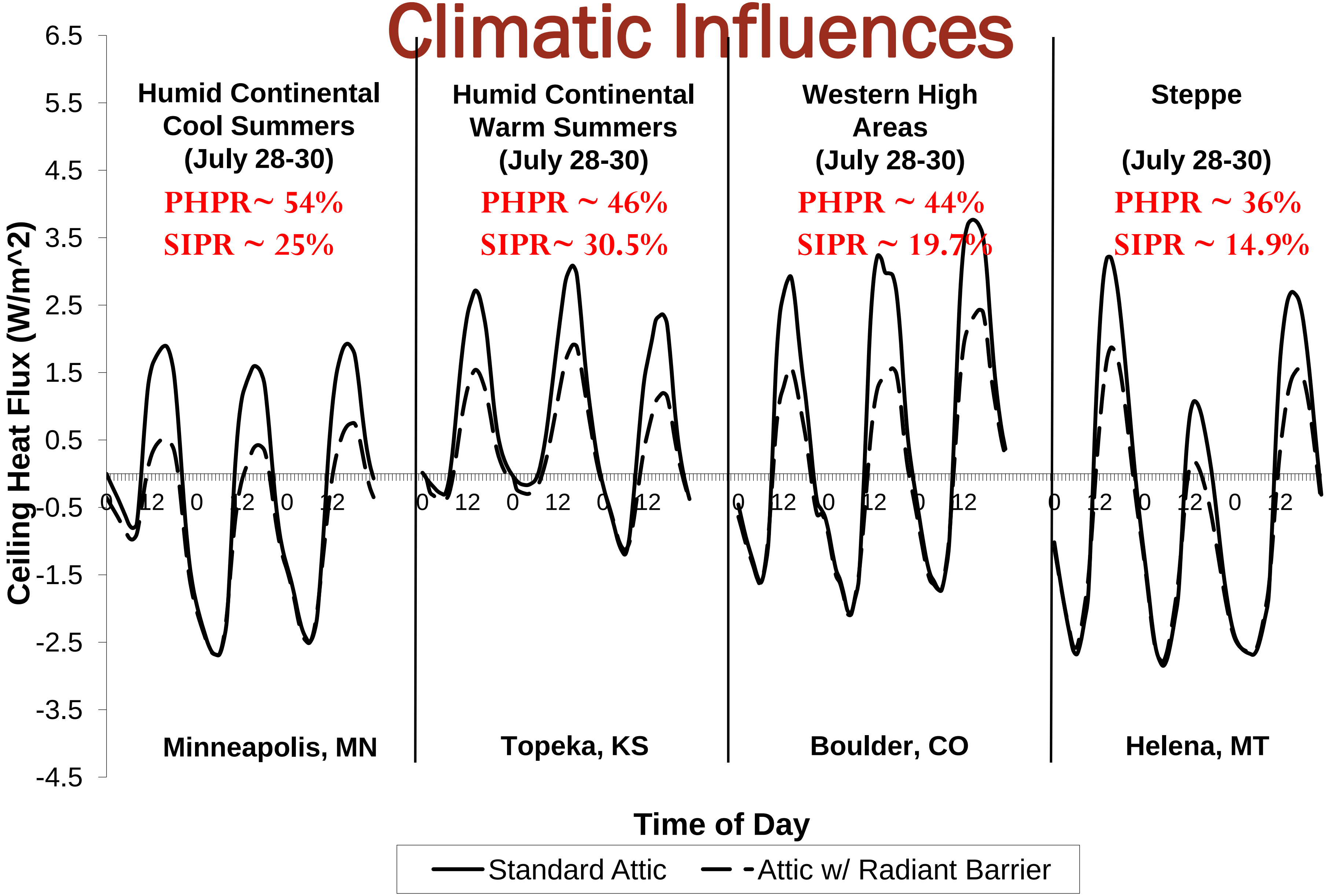
Climate	Summer Monthly Dry Bulb Temperature (^{o}F)	Summer Monthly Relative Humidity (%)	Summer Monthly Wind Speed (mph)
Marine West Coast	59	80	8.3
Steppe	62	43	7.9
Humid Continental Cool Summer	70	67	8.7
Mediterranean	63	74	10
Desert	83	47	8.1
Western High Areas	68	50	8.5
Humid Continental Warm Summer	77	70	8.8
Humid Subtropical	84	68	8.5
Tropical Savanna	83	77	8

Computer Simulations
Climatic Influences



PHPR: Peak Hour Percent Reduction SIPR: Summer Integrated Percent Reduction

Computer Simulations
Climatic Influences



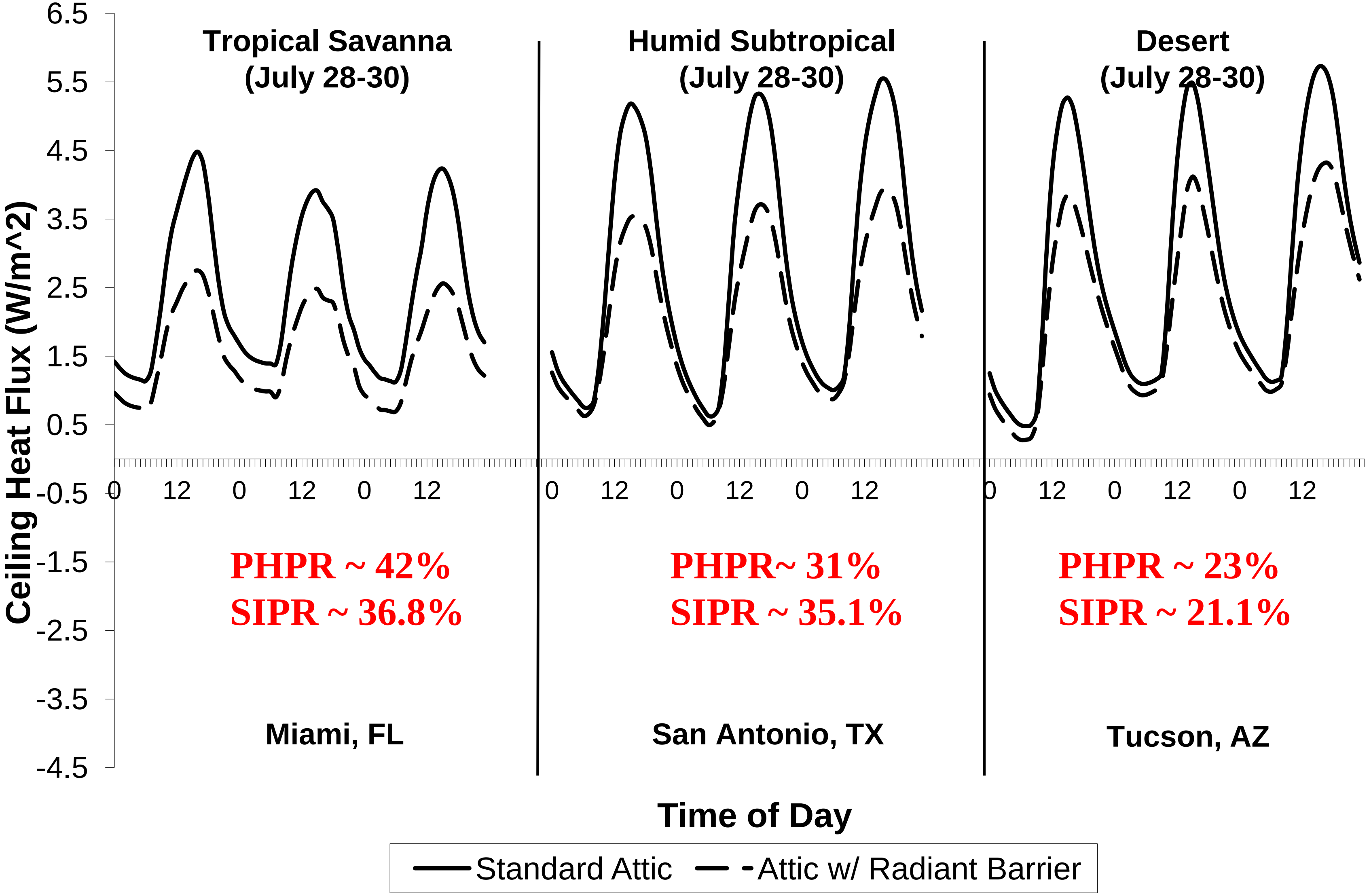
Humid Continental Cool Summers (July 28-30)
PHPR~ 54%
SIPR ~ 25%
Minneapolis, MN

Humid Continental Warm Summers (July 28-30)
PHPR ~ 46%
SIPR~ 30.5%
Topeka, KS

Western High Areas (July 28-30)
PHPR ~ 44%
SIPR ~ 19.7%
Boulder, CO

Steppe
(July 28-30)
PHPR ~ 36%
SIPR ~ 14.9%
Helena, MT

Computer Simulations
Climatic Influences

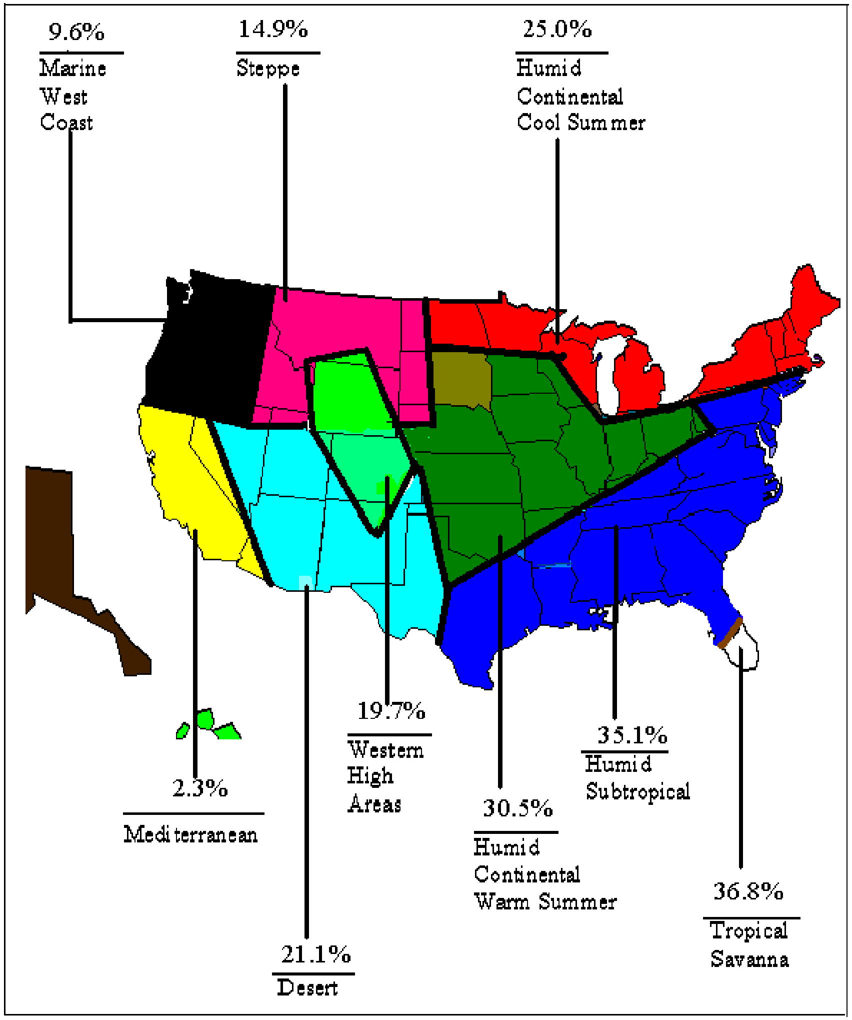


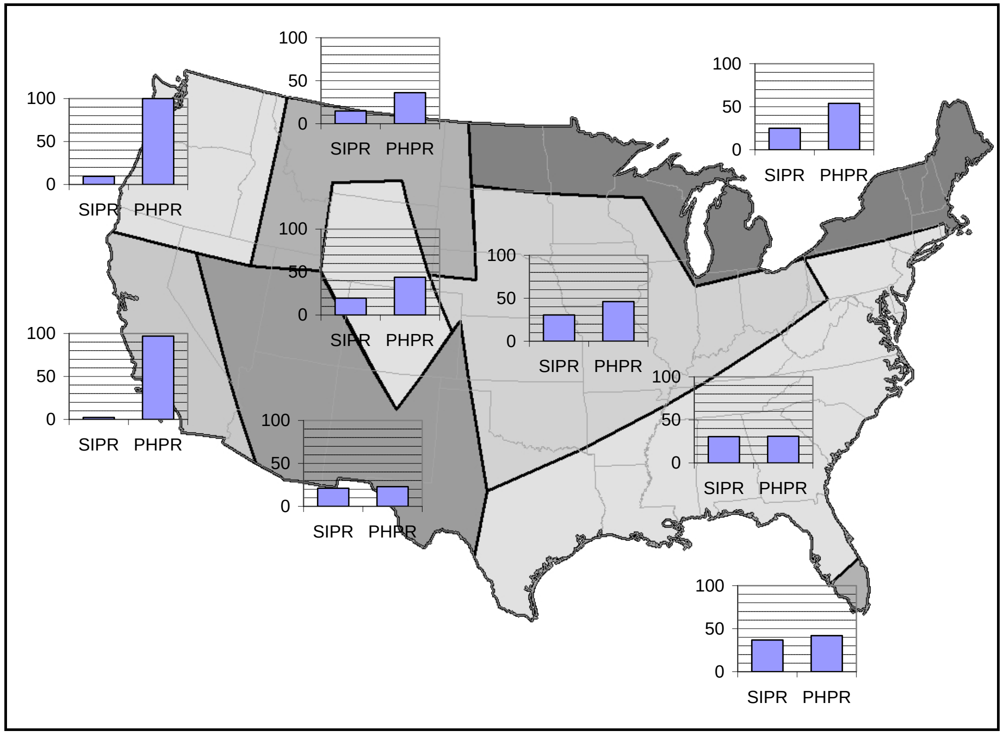
PHPR ~ 42%
SIPR ~ 36.8%

PHPR~ 31%
SIPR ~ 35.1%

PHPR ~ 23%
SIPR ~ 21.1%

Computer Simulations
Climatic Influences

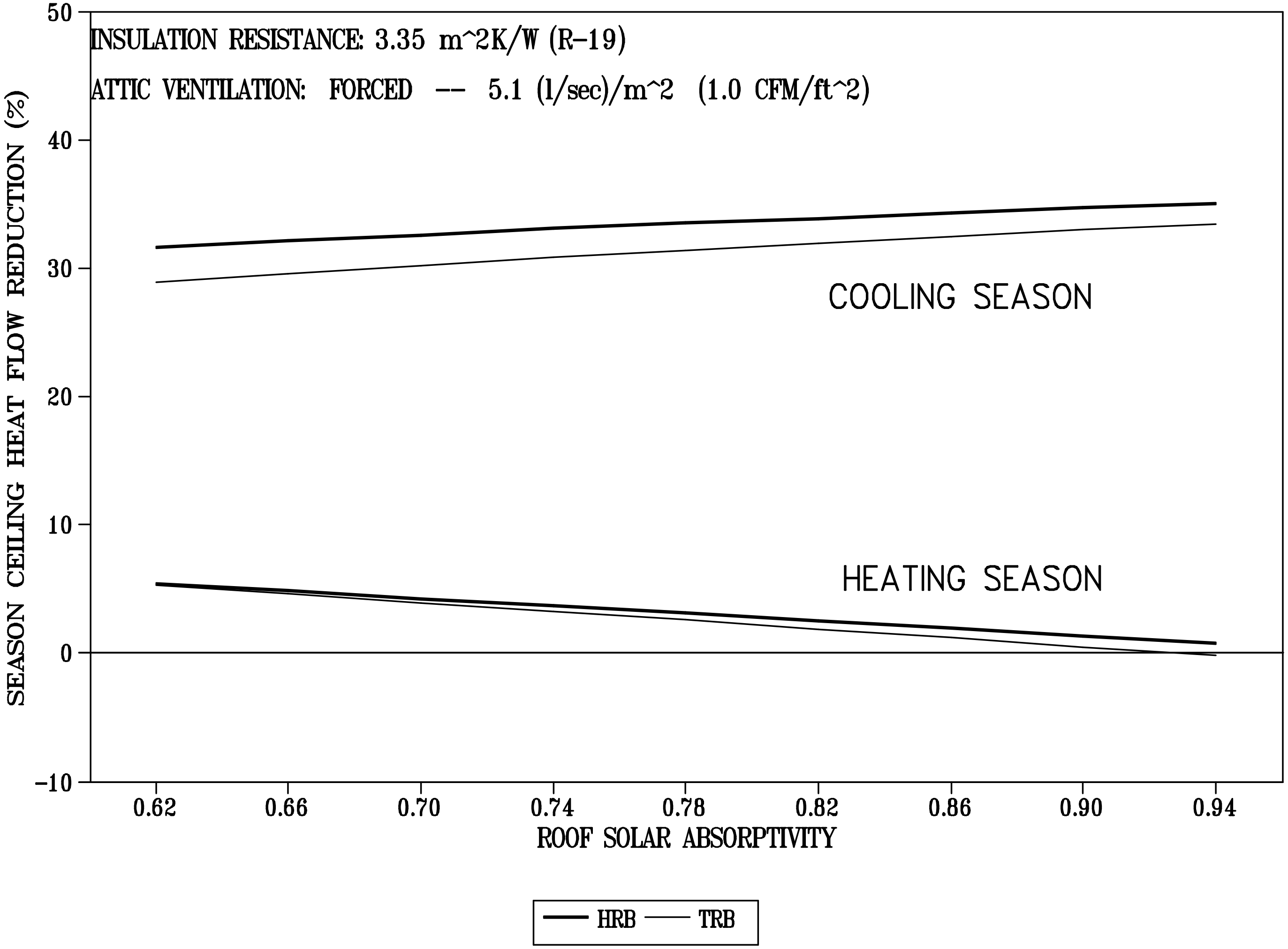




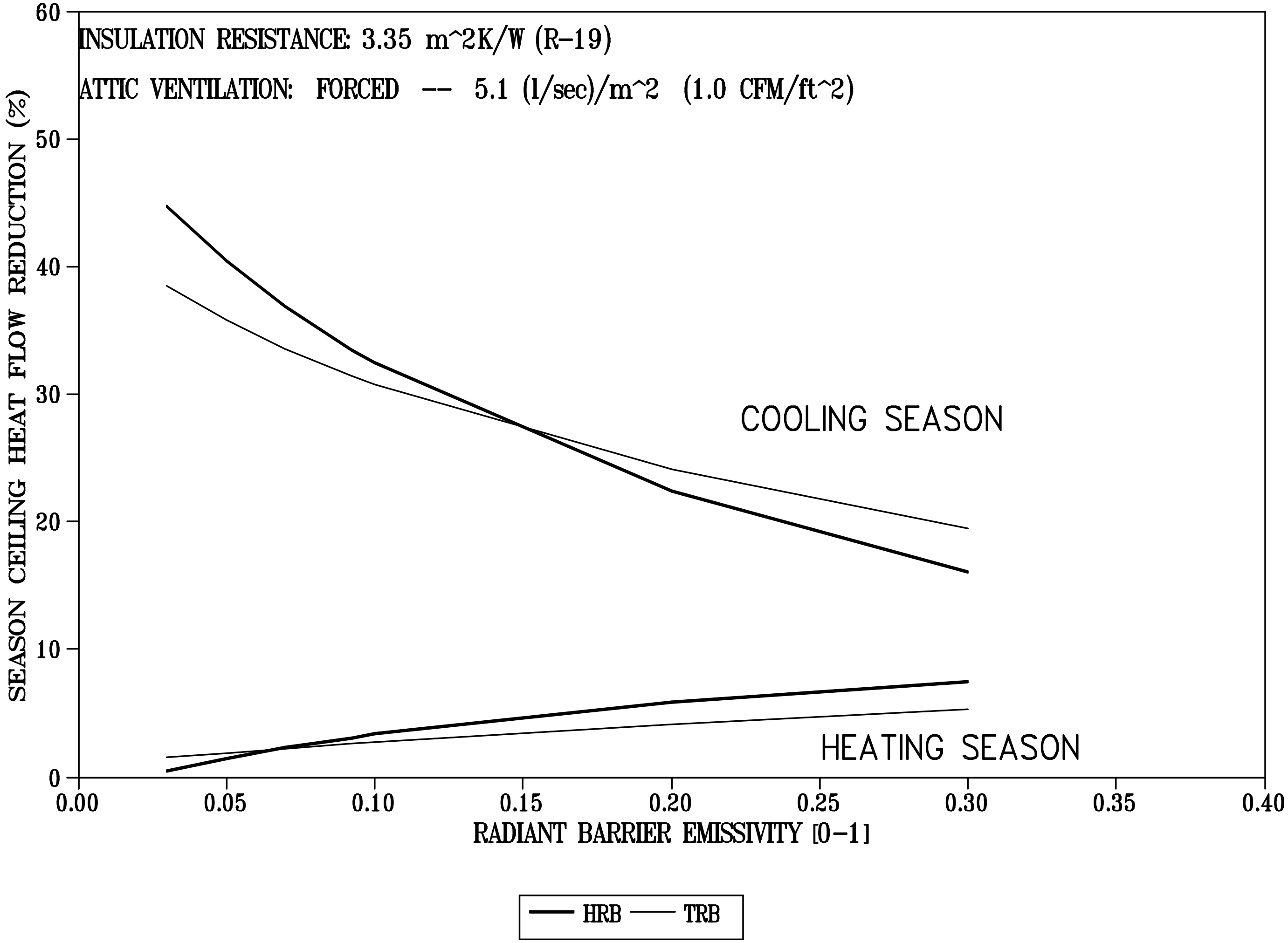
Computer Simulations Climatic Influences

Climate	**Sample Station**	**Sample Summer Integrated Percent Reduction (SIPR) (%)**	**Average**	**Peak-Hour Percent Reduction (PHPR) (%)**
Humid Subtropical	San Antonio, TX New York- NY Atlanta, GA	34.3 32.5 38.5	35.1	31
Humid Continental Warm Summer	Topeka, KS Indianapolis, IN	30.0 30.1	30.5	46
Desert	Las Vegas, NV Tucson, AZ	19.2 23.0	21.1	23
Humid Continental Cool Summer	Minneapolis, MN Detroit, Michigan	25.7 24.3	25.0	54
Steppe	Pocatello, ID Helena, MT	16.0 13.7	14.9	36
Marine West Coast	Astoria, OR	9.6	9.6	~100
Mediterranean	San Francisco, CA	2.3	2.3	97
Western High Areas	Boulder, CO	19.7	19.7	44
Tropical Savanna	Miami, FL	36.8	36.8	42

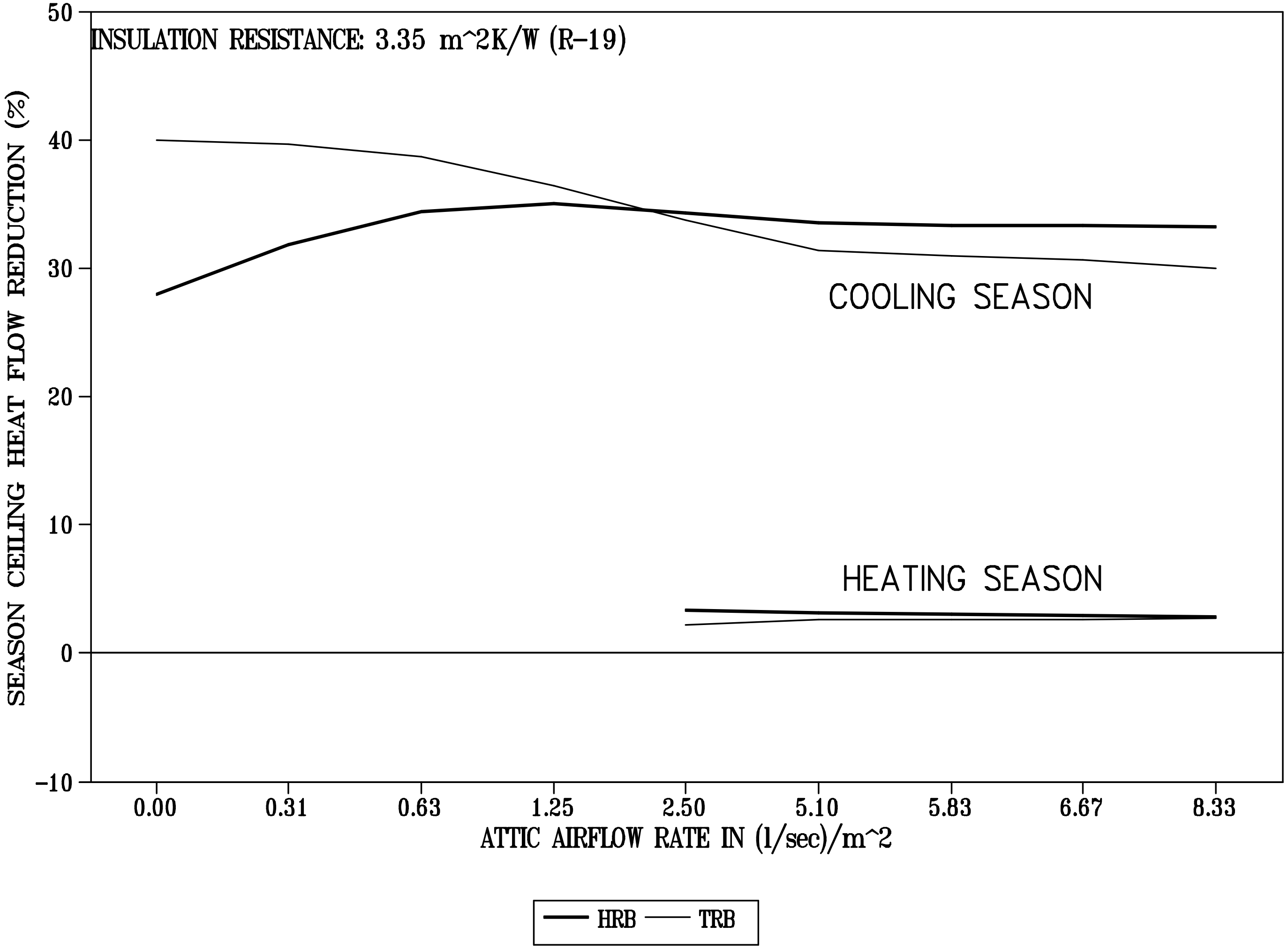
Parametric Analyses
Roof Solar Absorptivity



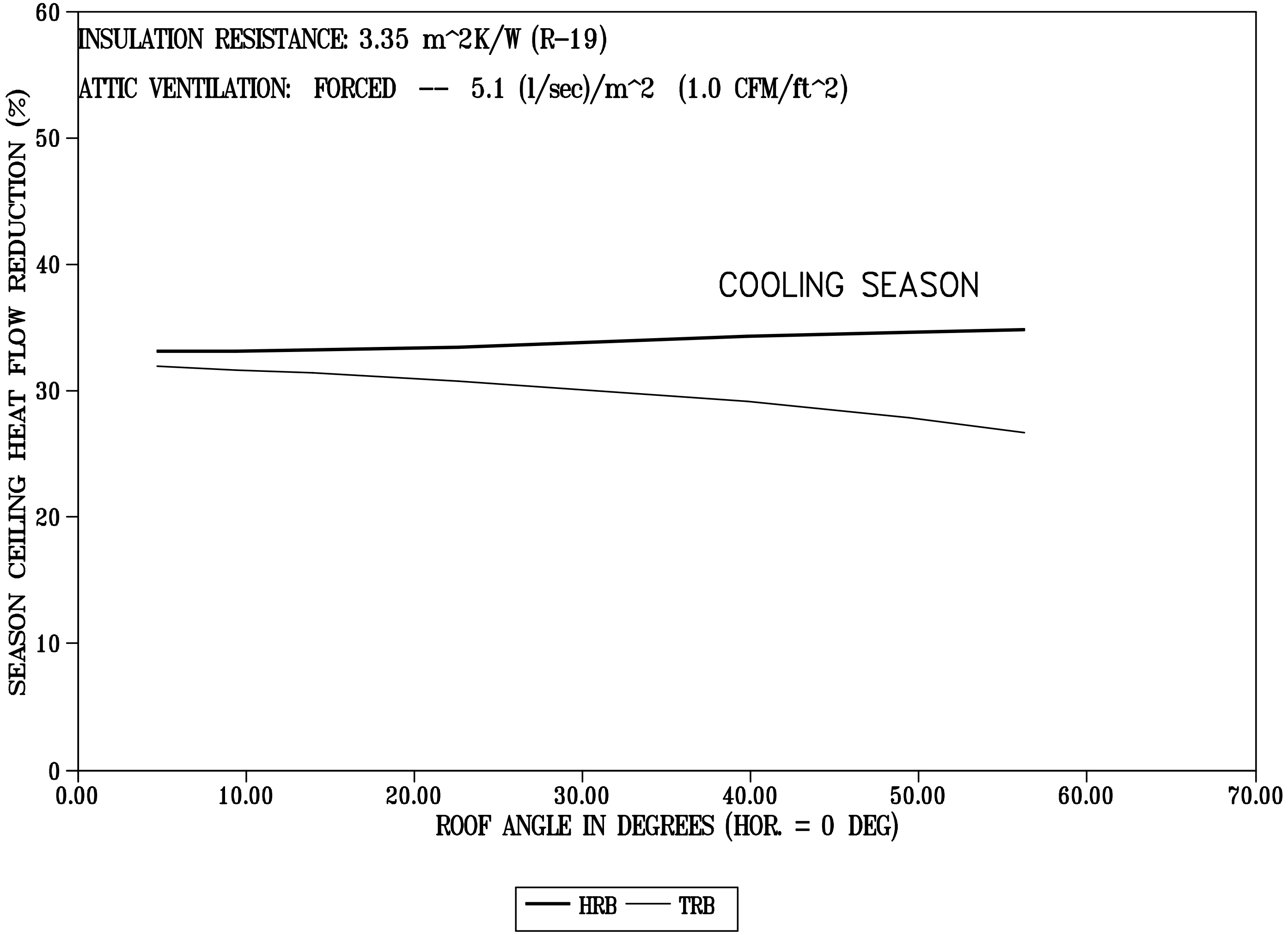
Parametric Analyses
Radiant Barrier Emissivity



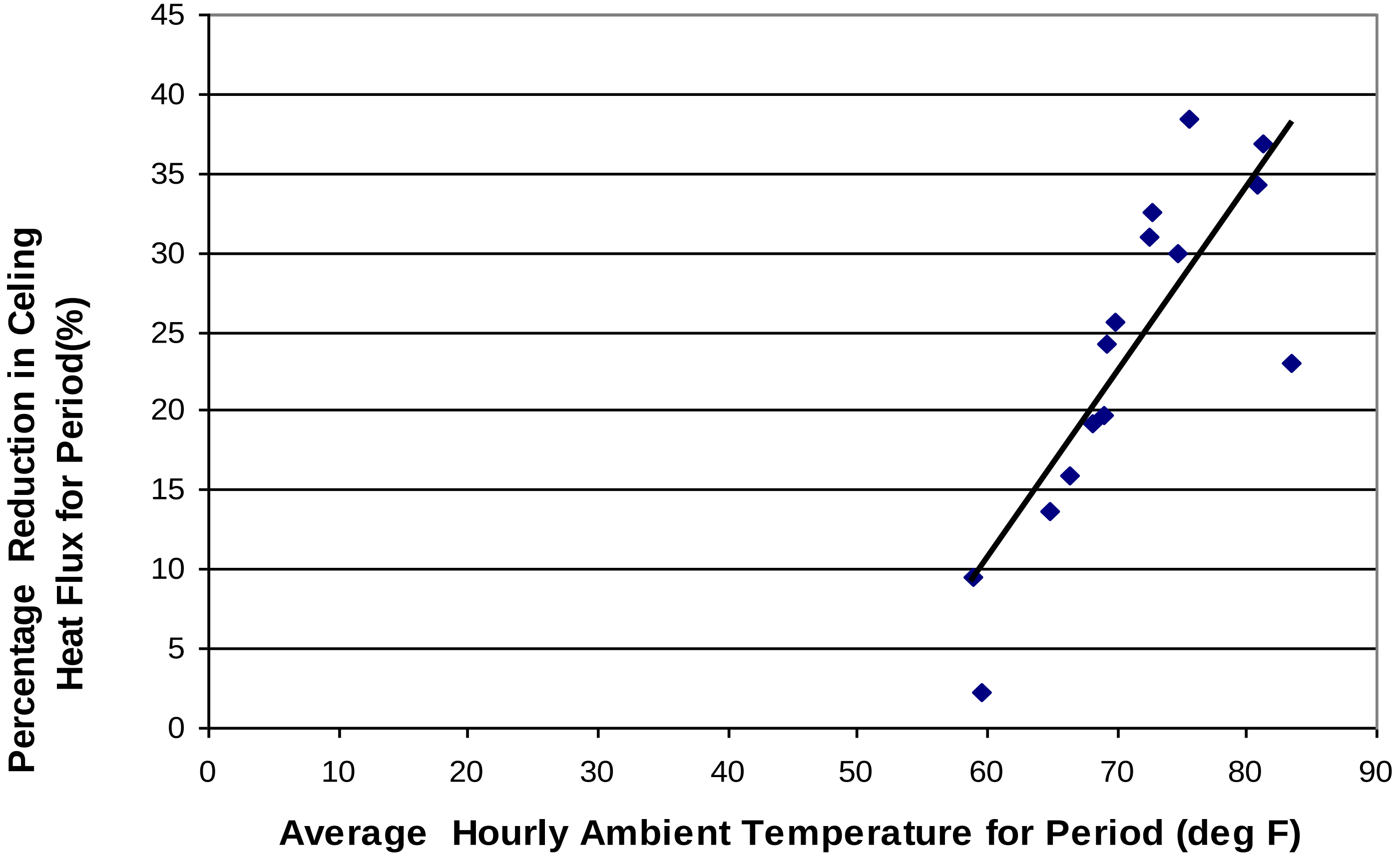
Parametric Analyses
Attic Airflow Rate



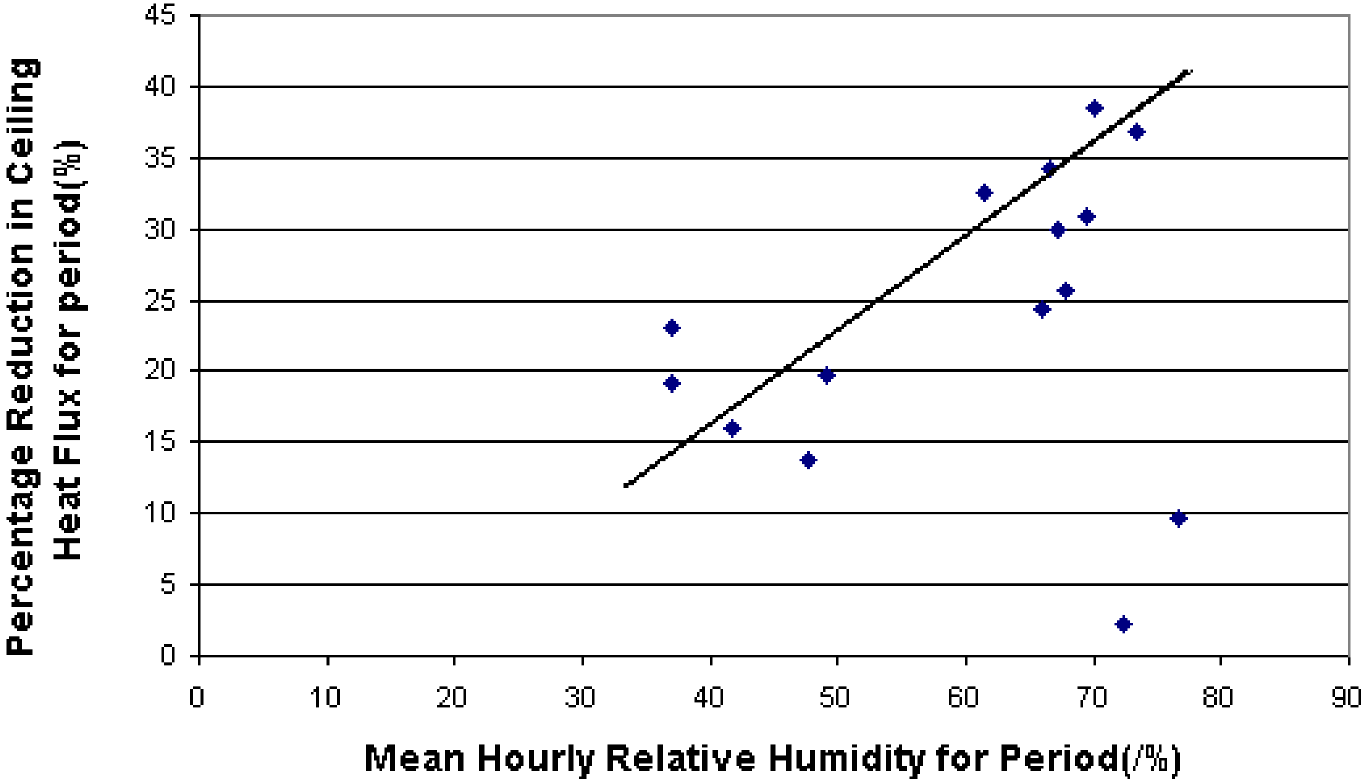
Parametric Analyses
Roof Slope



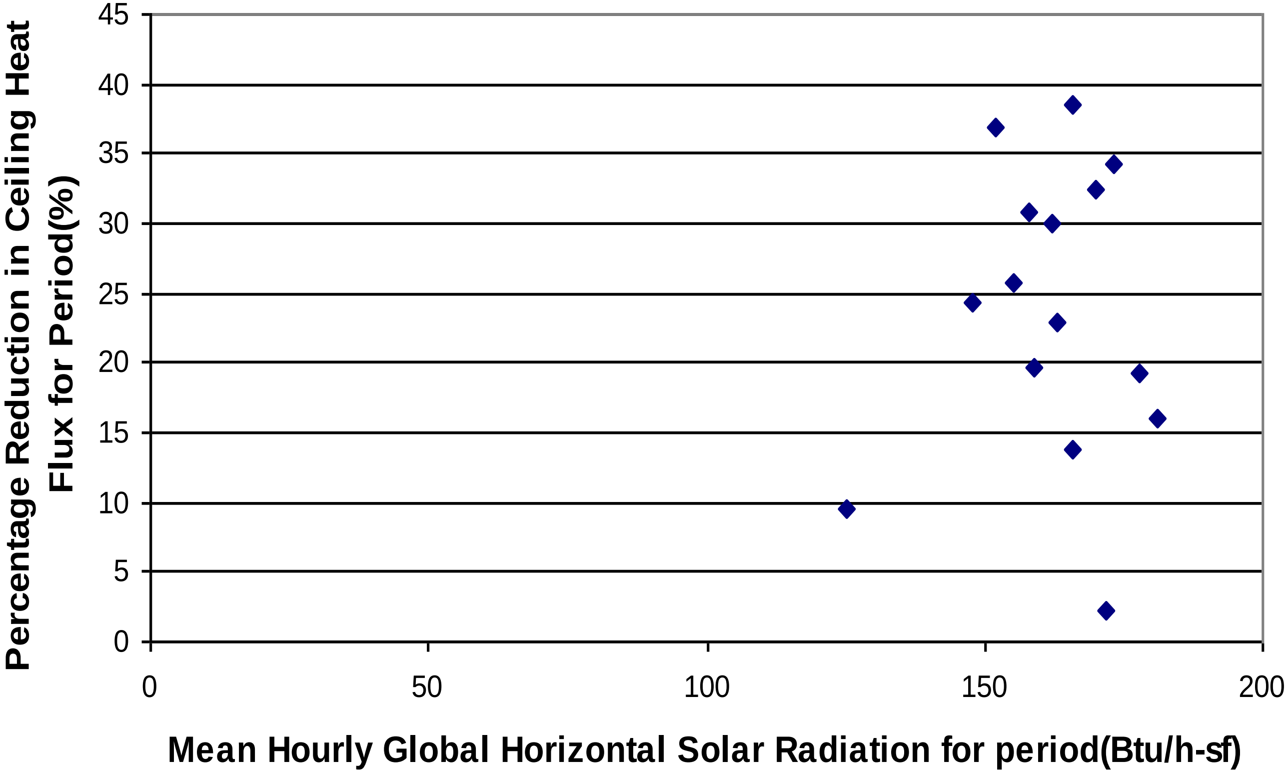
Parametric Analyses
Outdoor Air Temperature



Parametric Analyses
Mean Hourly Relative Humidity



Parametric Analyses
Mean Hourly Global (H) Radiation



Conclusions

- On average, RBs reduce summer ceiling heat flows by approximately 23 to 45% depending on the insulation level. Winter ceiling heat flow reductions are approximately 40% of the summer values for the same insulation levels.

- Space cooling loads are reduced by 6 to 20% and space heating load reductions would be approximately 40% of the space cooling load reductions for the same insulation levels.

- IRCCs with an emittance of 0.25 or less would provide reductions in ceiling heat flows equivalent to 61% of the values produced by RBs.

- DARBs and TRBs would reduce attic temperatures by an average of 13 ^{o}F, while RBs in the HRB configuration would reduce the attic temperature by an average of 4 ^{o}F

Conclusions

- Climate (e.g., temperature and humidity) and radiant barrier emissivity have first order effects on the performance of radiant barriers.

- Attic ventilation flow rate, amount of solar radiation, shingle color, roof pitch have little to no effect on the performance of radiant barriers.

THANK YOU