"Radiant Barriers – Why Contractors and Homeowners Need to Understand this Option for Heat Load Reduction"

Mario A. Medina, Ph.D., P.E.
Civil, Environmental &Architectural Engineering
The University of Kansas

Presented at the Southeast Louisiana Coalition of the Air Conditioning Industry

New Orleans, LA
October 2, 2014

Introduction

"Preventing the sun's radiation from entering through the roof can make a significant contribution to comfort and reduction in cooling bills/needs."

From: Sustainable Building Sourcebook

Chapter: Energy

Definition

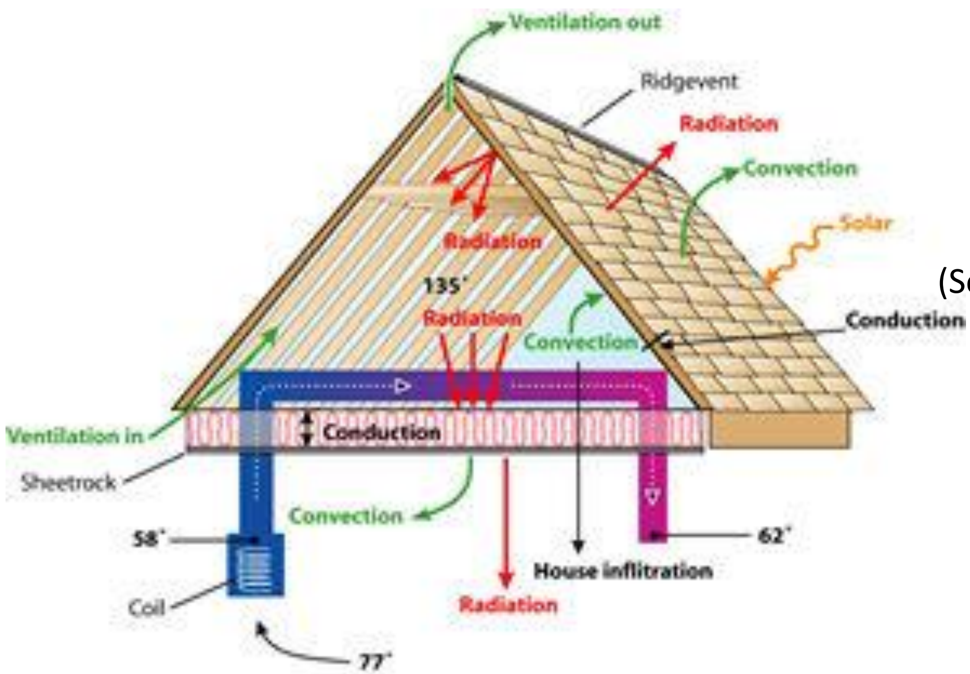
- Radiant barrier are aluminum foil laminates or aluminized synthetic film sheets.

- The foil is typically laminated to either paper, oriented strand board (OSB), or plywood; or aluminum is vacuum-deposited over polymer sheets or boards (e.g., foam board).

- The laminates of films have at least one low emittance surface of 0.1 or less (ASTM Standard C1313, 2010).

Definition

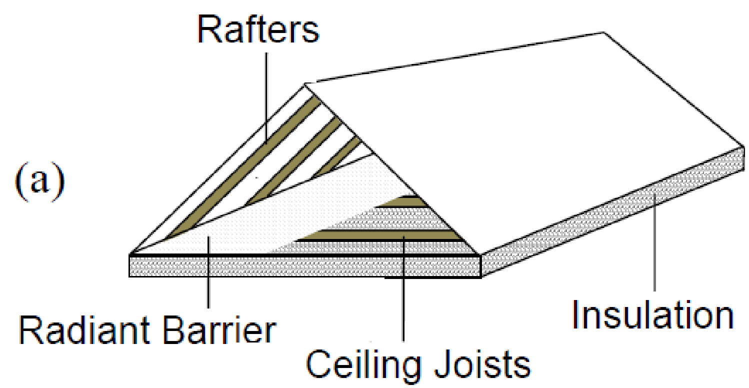
- Radiant barriers reduce the transfer of heat energy <u>radiated</u> from “hotter” surfaces to “colder” surfaces (e.g., the deck of an attic to the attic floor).



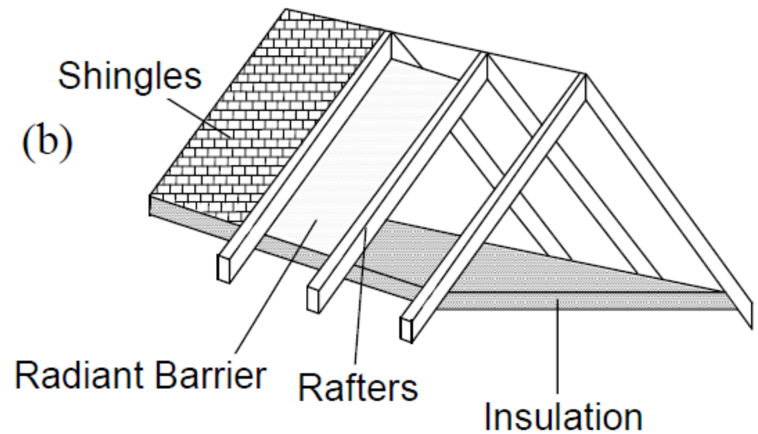
(Source: Florida Solar Energy Center)

- Among the benefits of installing radiant barriers are energy savings, $ savings, and comfort.

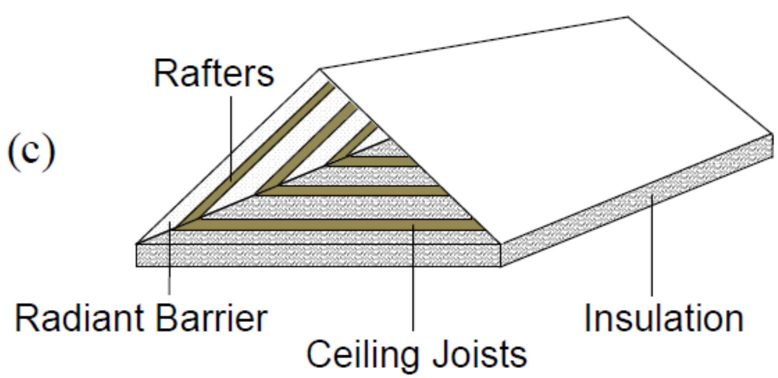
Radiant Barrier Installations



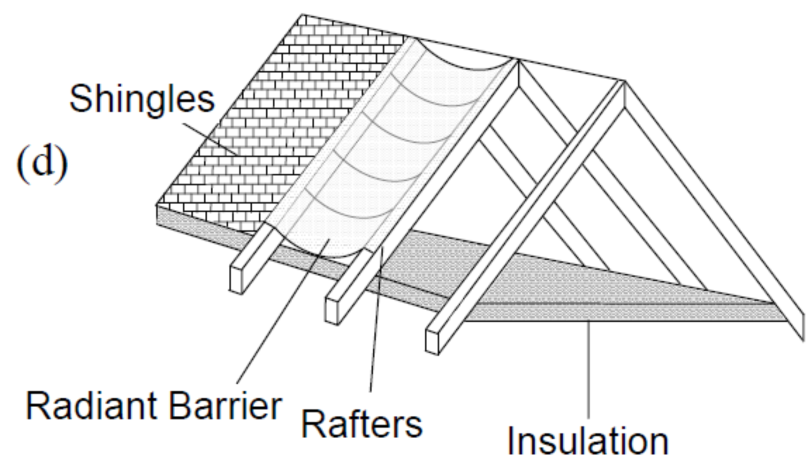
Horizontal Radiant Barrier



Truss Radiant Barrier



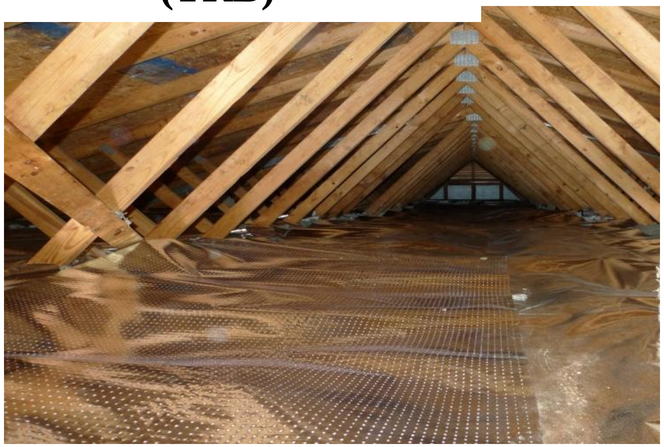
Deck Applied Radiant Barrier



Draped Radiant Barrier

Radiant Barrier Installations

"Truss Radiant Barrier"
(TRB)



Horizontal Radiant Barrier

Truss Radiant Barrier

Deck Applied Radiant Barrier

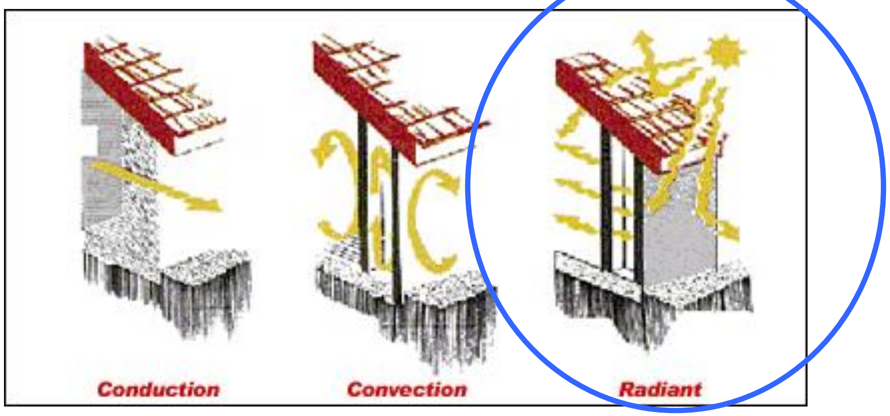
Draped Radiant Barrier

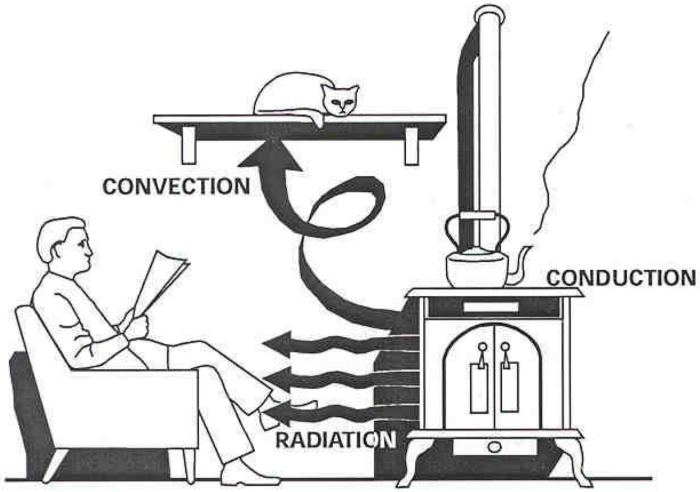
Radiant Barriers

*Source: **"Radiant Barriers: Performance Revealed"***
September/October 2000 Issue, Home Energy Magazine

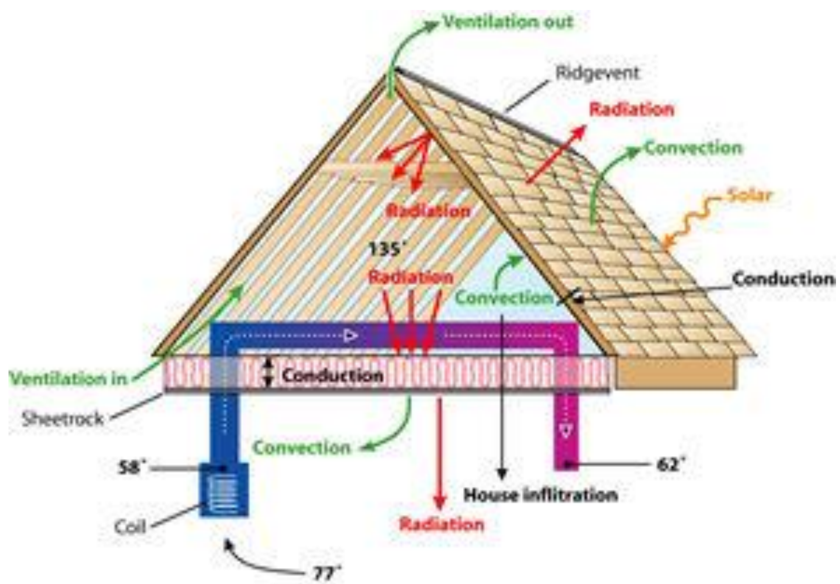
Radiant Barriers

- Modes of Heat Transfer

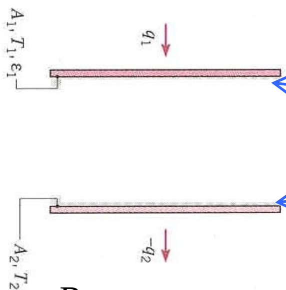




(Source: Btubusters)

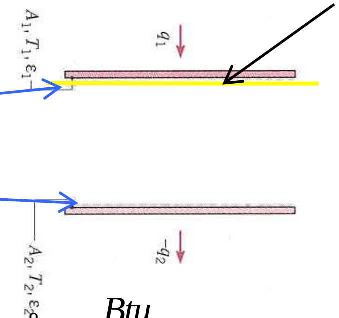


Radiant Barriers



$$q_{1-2} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

Radiant Barrier



$$q_{1-2} = \frac{0.1714\times10^{-8}\,\frac{Btu}{hr\cdot ft^2\cdot {}^oR^4}[(120+460)^4-(90+460)^4]\,{}^oR^4}{\frac{1}{0.7}+\frac{1}{0.8}-1}$$

$$q_{1-2} = \frac{0.1714\times10^{-8}\,\frac{Btu}{hr\cdot ft^2\cdot {}^oR^4}[(120+460)^4-(90+460)^4]\,{}^oR^4}{\frac{1}{0.05}+\frac{1}{0.8}-1}$$

$$q_{1-2} = 22.1\frac{Btu}{hr\cdot ft^2}$$

$$q_{1-2} = 1.84\frac{Btu}{hr\cdot ft^2}$$

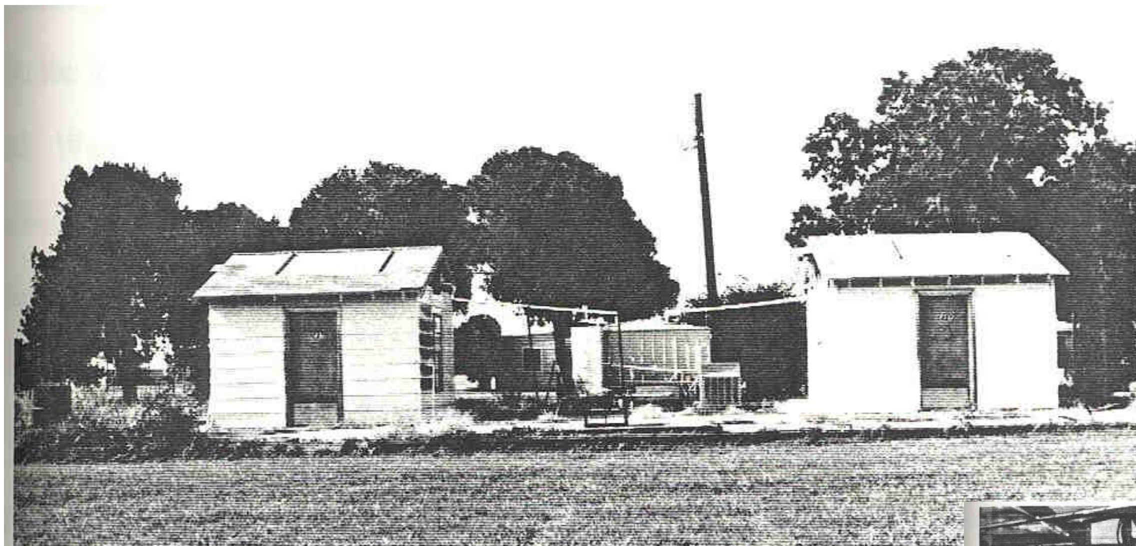
~92% reduction in radiation heat transfer

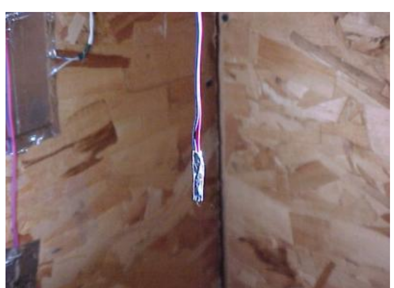
Radiant Barriers

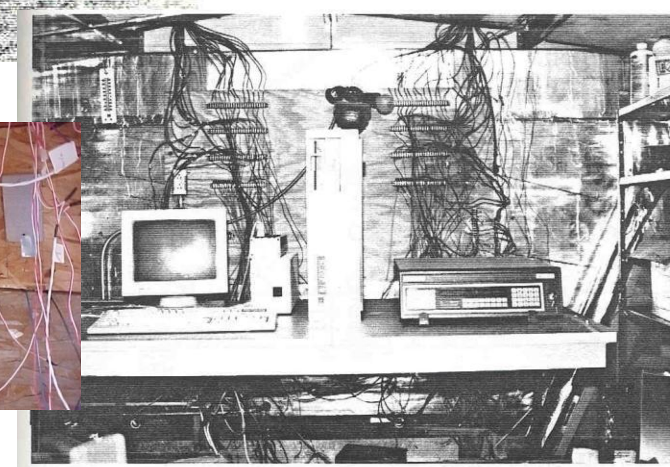
- In the studies, the performance of radiant barriers was assessed via:
  - **Experiments**
    - Side by side monitoring of pre- and post-retrofit data.
  - **Modeling**
    - Mathematical representation of thermal sciences that describe the processes that take place.
    - Implemented using computer programming (e.g., FORTRAN).
  - **Model/Experiment Validation**

Radiant Barriers

- Experiments: Test Houses



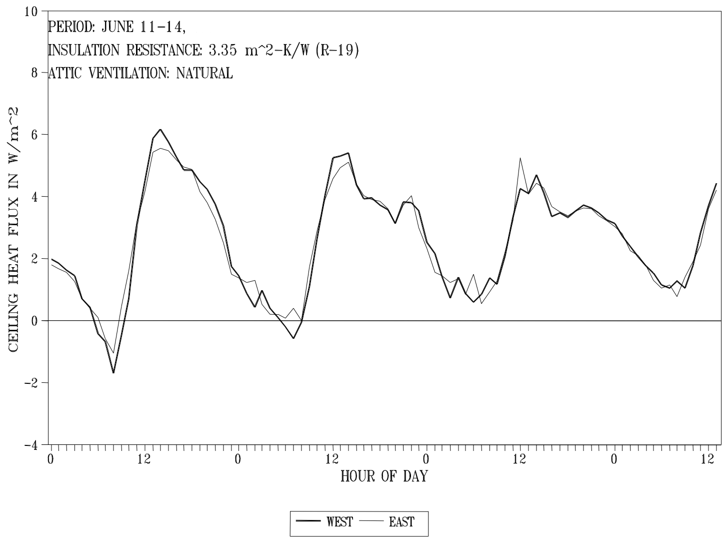




Radiant Barriers

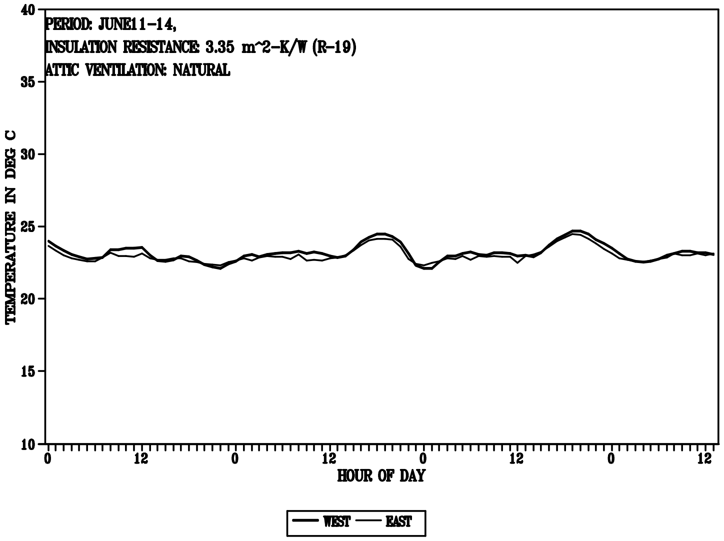
- Experimental Results: Calibration (No RB Case)

Ceiling Heat Flux



< 3 %

Indoor Air Temperature

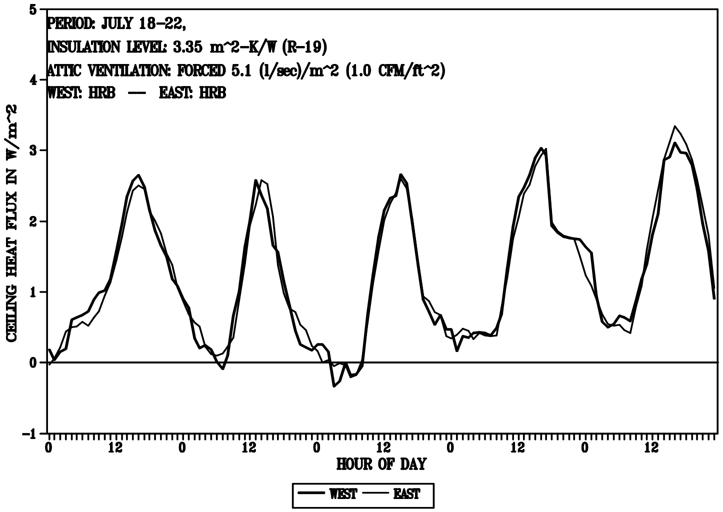


< 0.3 ºF

Radiant Barriers

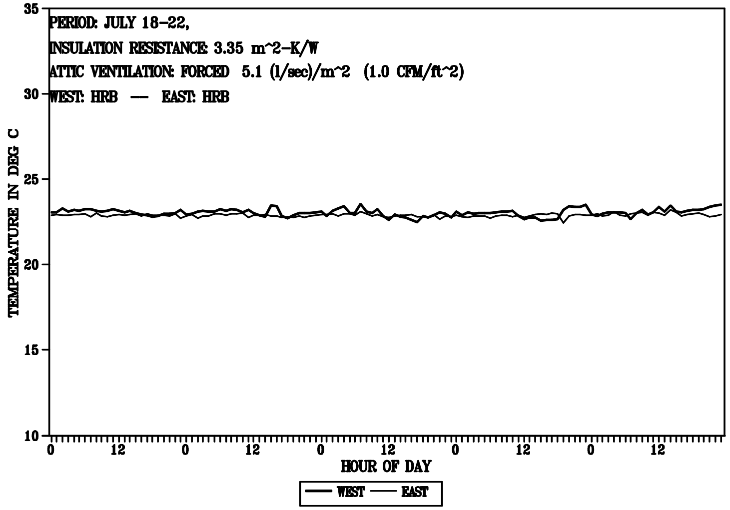
- Experimental Results: Calibration (RB Case)

Ceiling Heat Flux



< 3 %

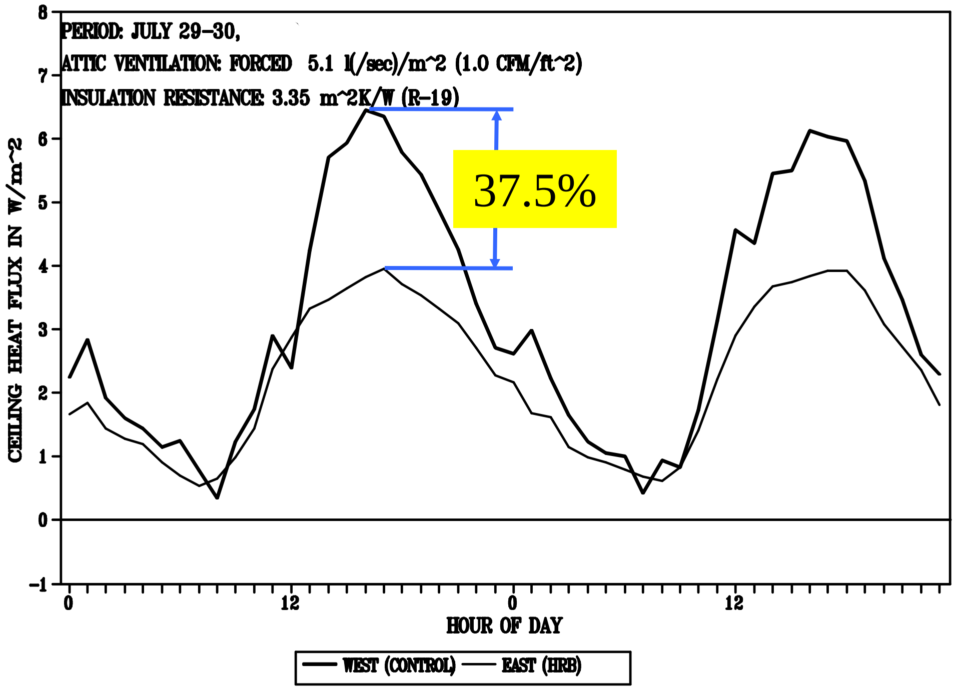
Indoor Air Temperature



< 0.3 ºF

Radiant Barriers

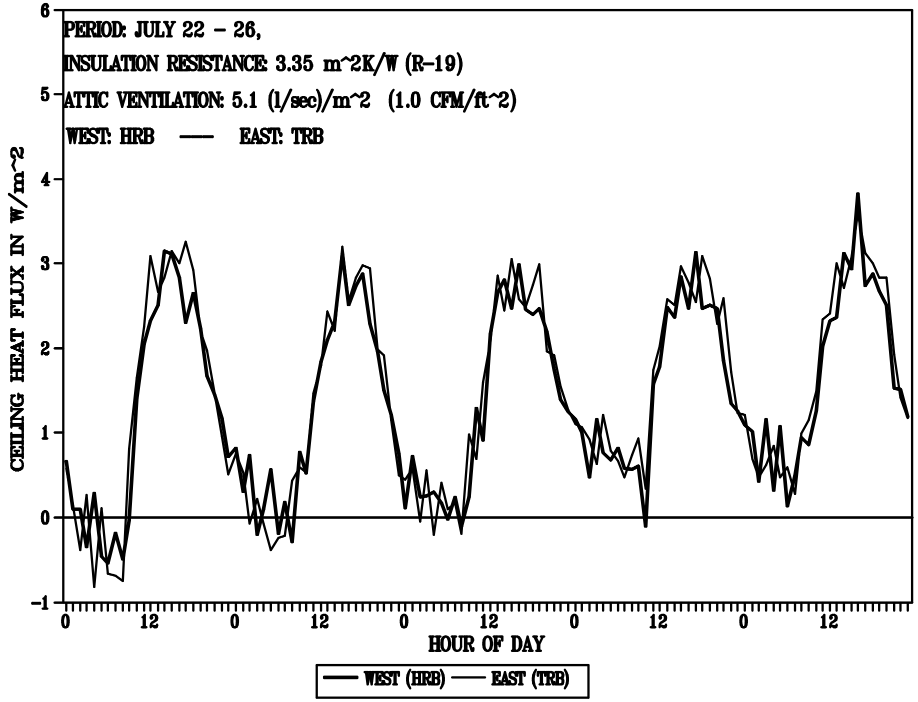
- Experimental Results: Effect of Radiant Barriers
  (~28% Daily Heat Flow Reduction)



Radiant Barriers

- Experimental Results: Installation Comparisons

Horizontal Configuration vs. Truss Configuration?



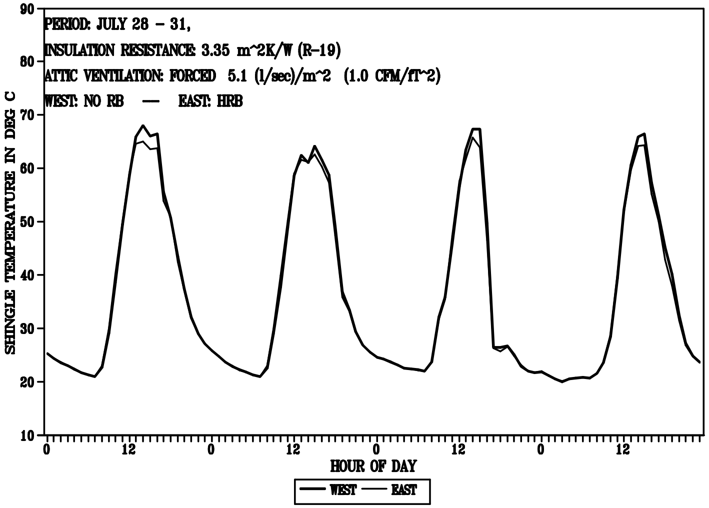
~ 5 %

Slight Advantage for the Horizontal Configuration

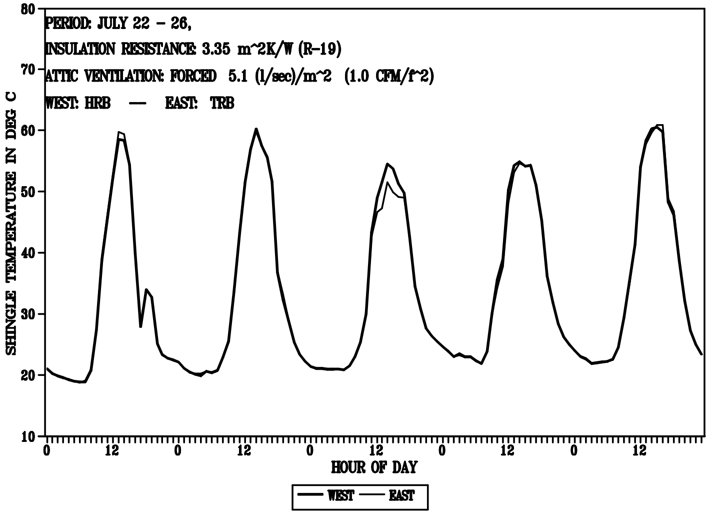
Radiant Barriers

- Experimental Results: Shingle Temperatures

Horizontal Configuration vs. No RB Case



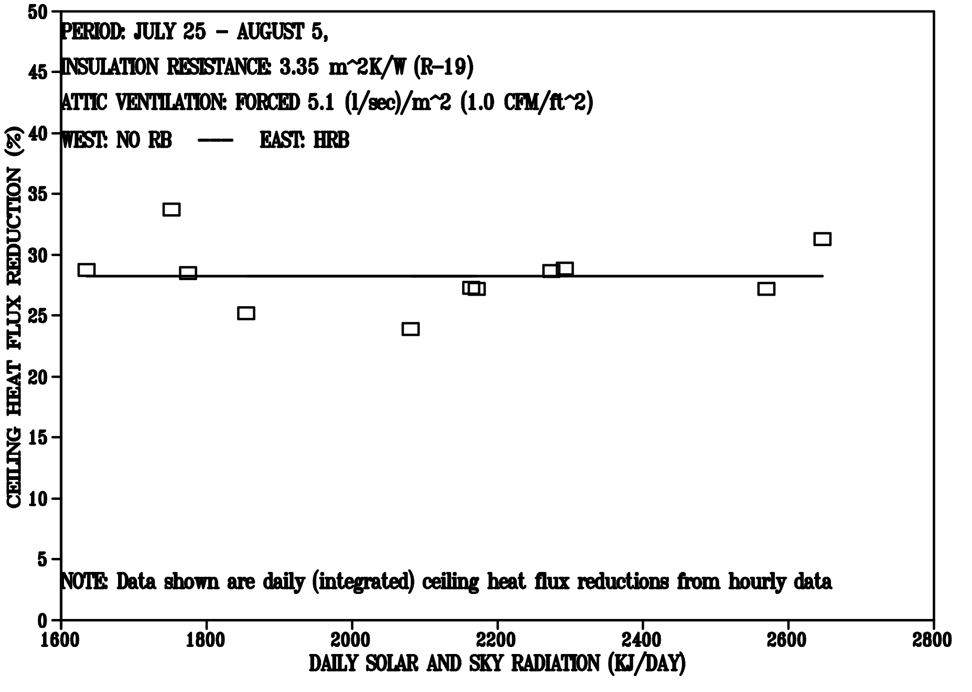
Truss Configuration vs. No RB Case



No difference in shingle temperature

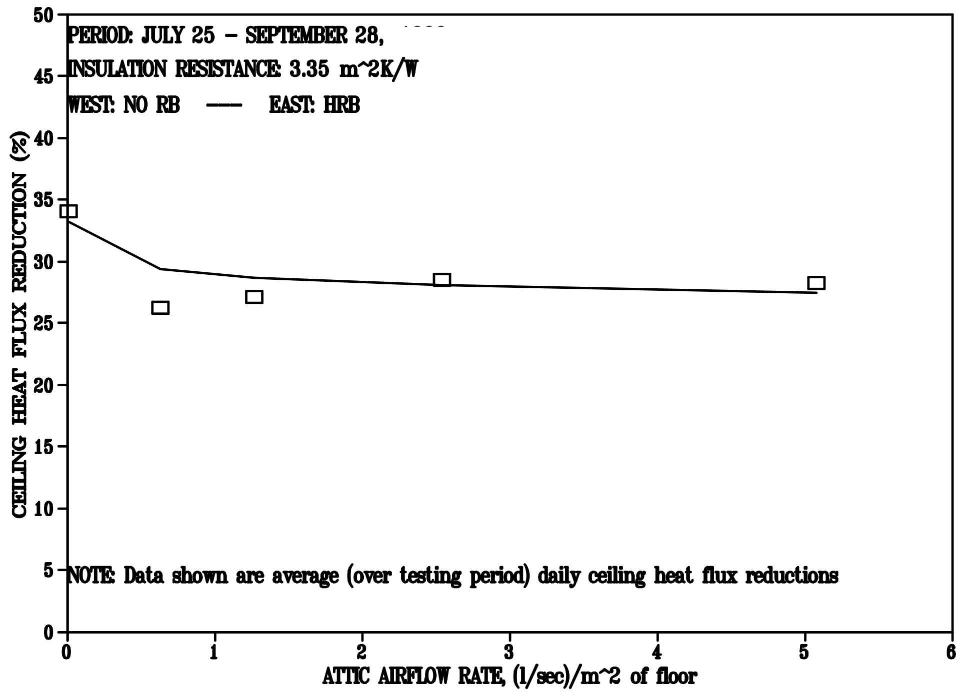
Radiant Barriers

- Experimental Results: Effects of Daily Solar Radiation



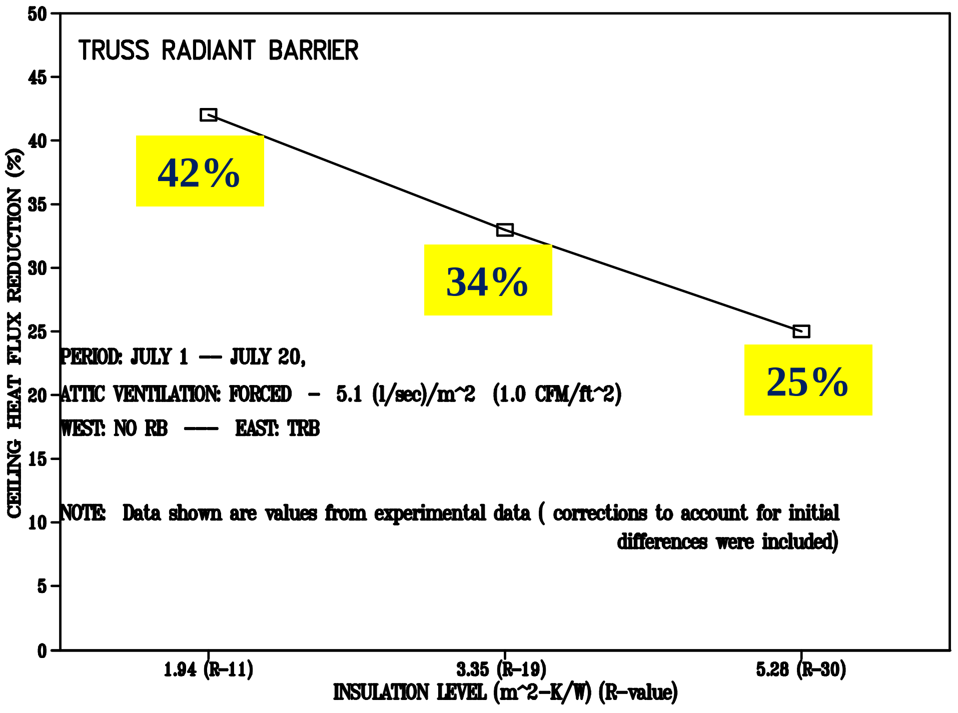
Radiant Barriers

- Experimental Results: Effects of Attic Ventilation



Radiant Barriers

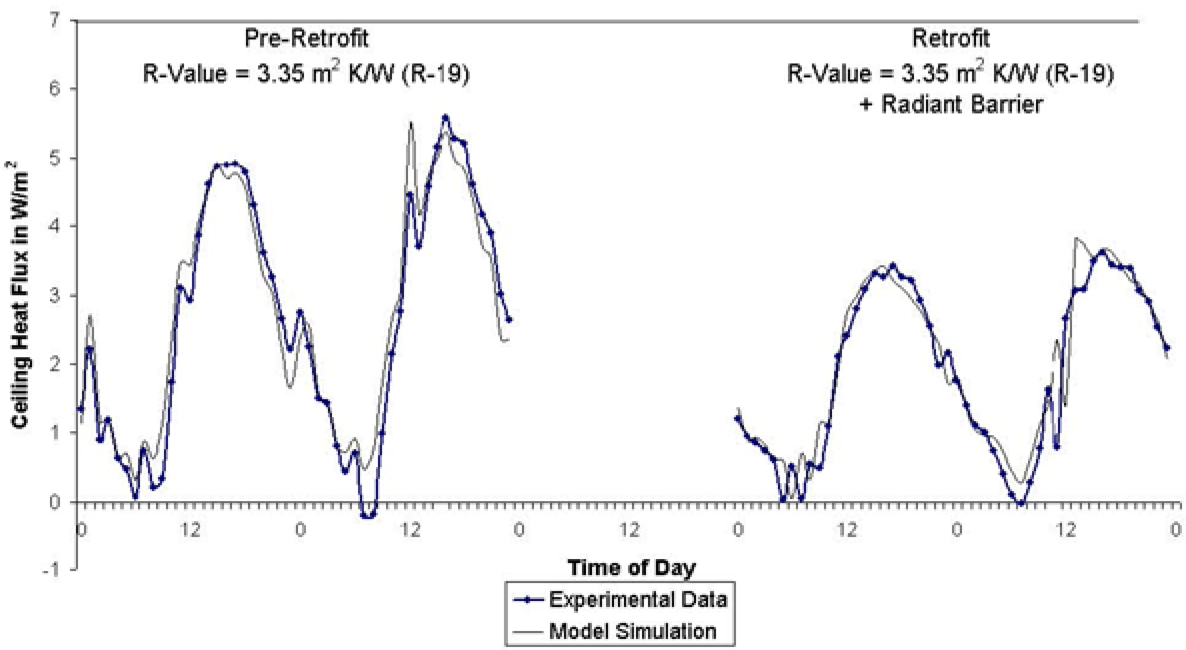
- Experimental Results: Effects of Attic Insulation Level



Radiant Barriers

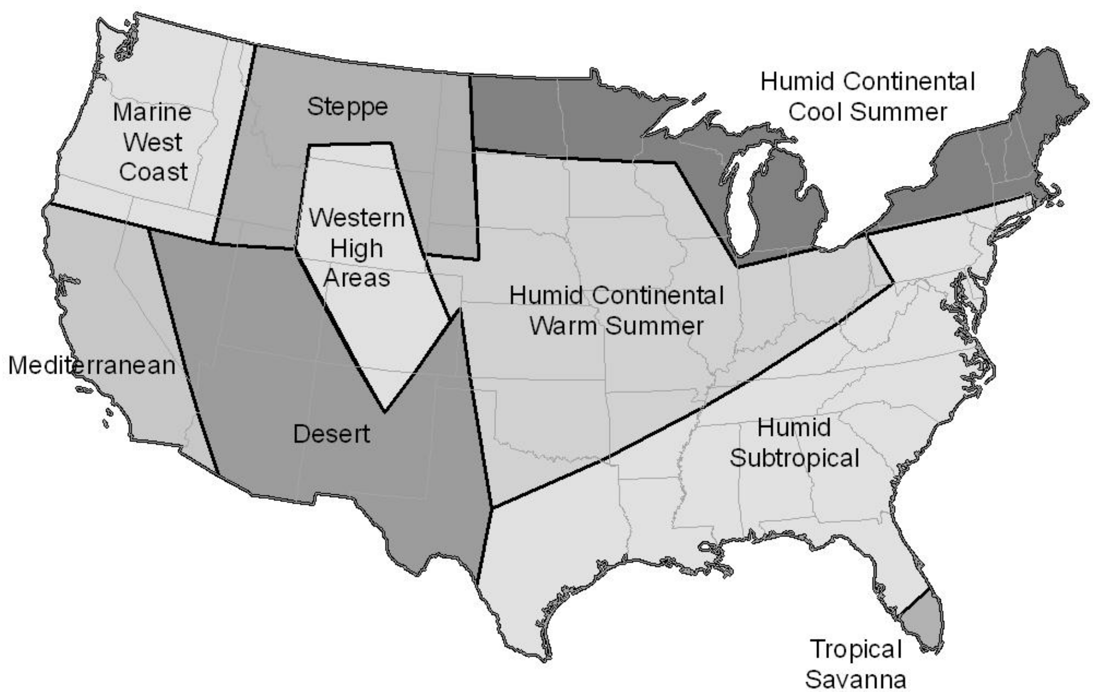
- Verification of Model/Experiments

No Radiant Barrier Configuration | Horizontal Configuration



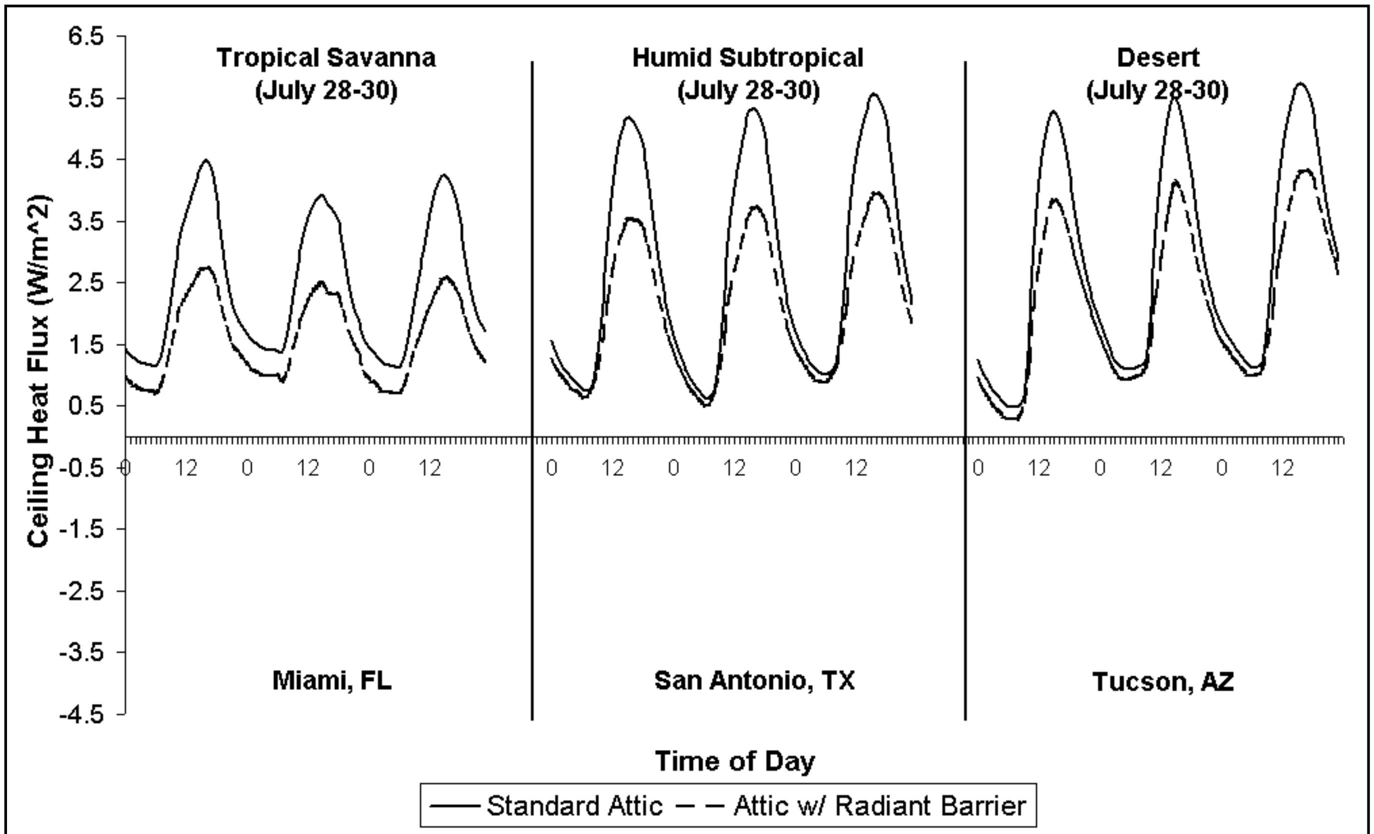
Radiant Barriers

- Computer Simulations: Climate Influence



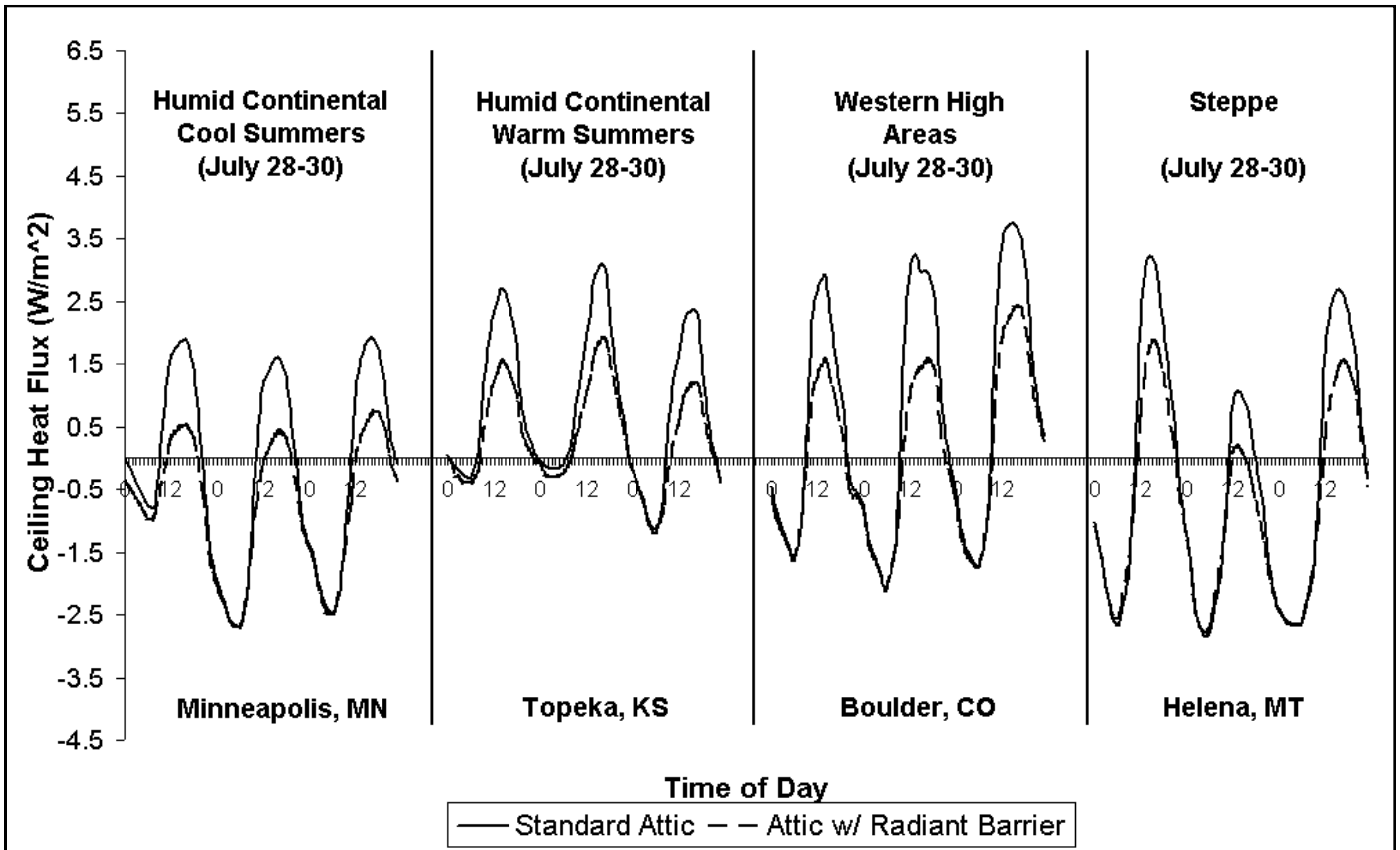
Radiant Barriers

- Computer Simulations: Climate Influence



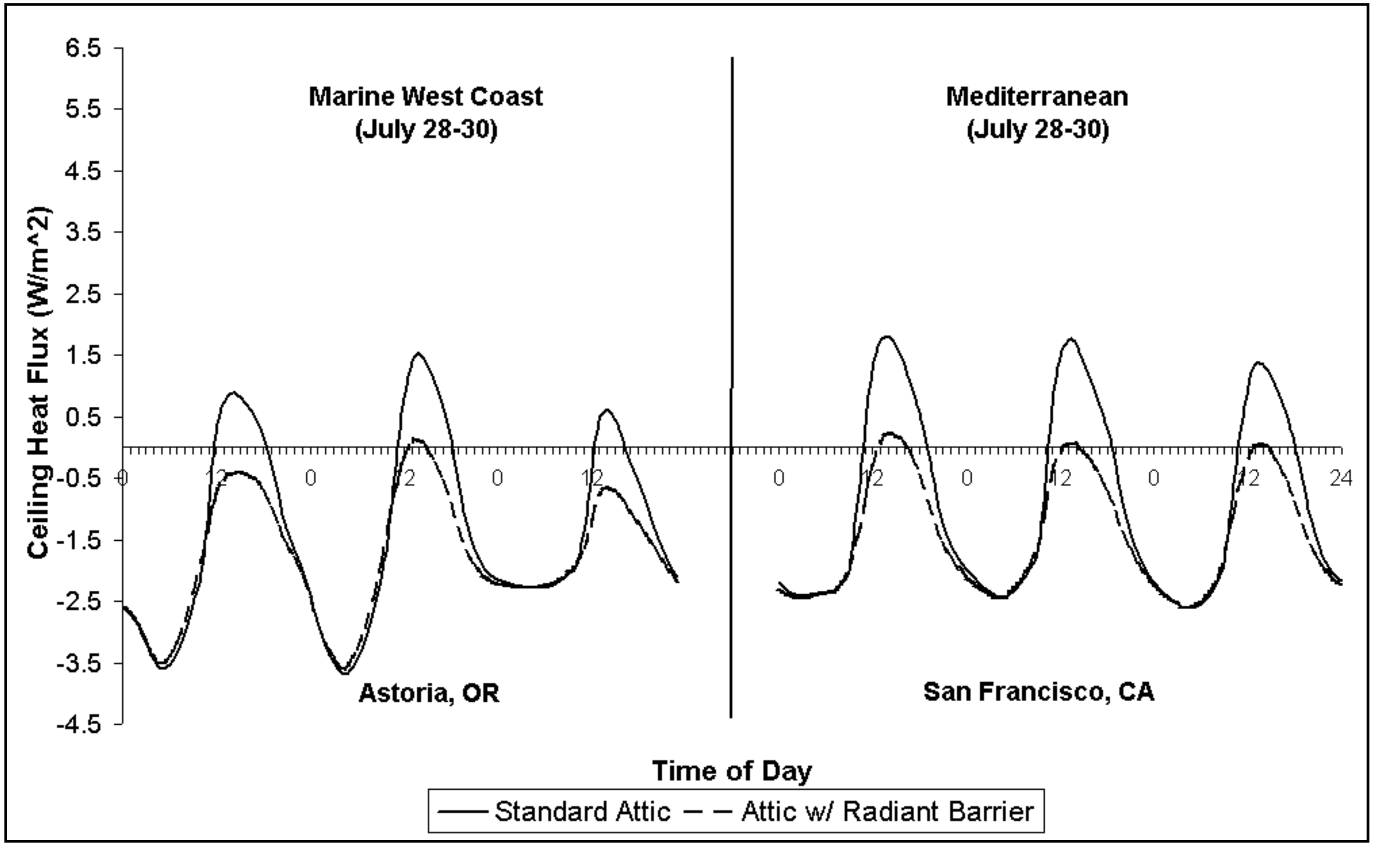
Radiant Barriers

- Computer Simulations: Climate Influence



Radiant Barriers

- Computer Simulations: Climate Influence



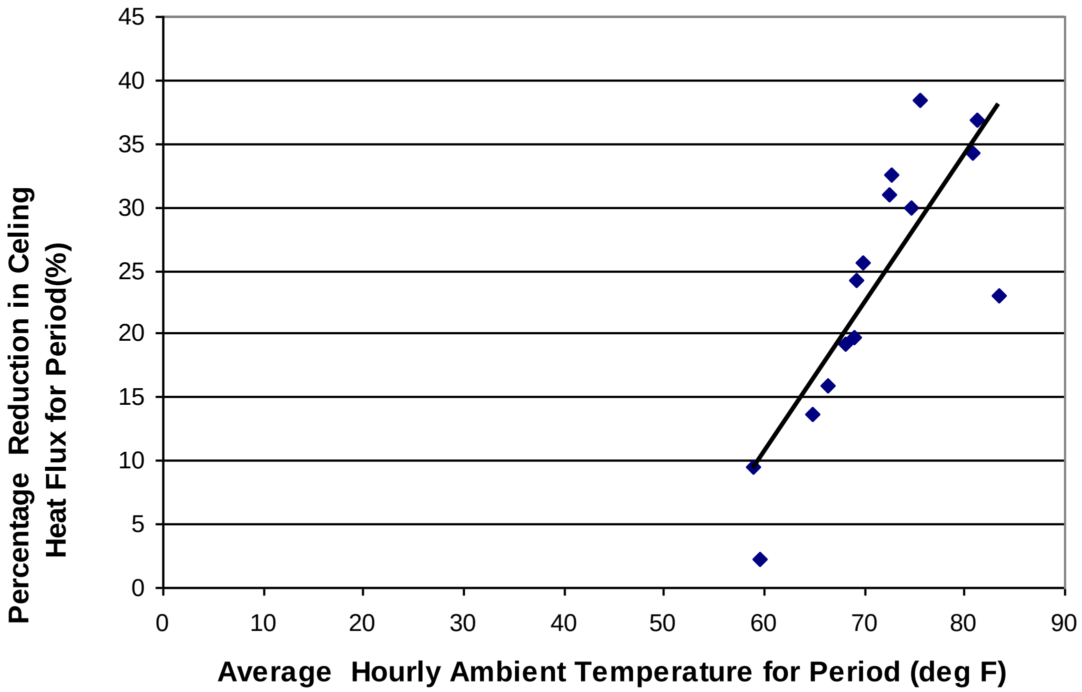
Radiant Barriers

- Computer Simulations: Climate Influence

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

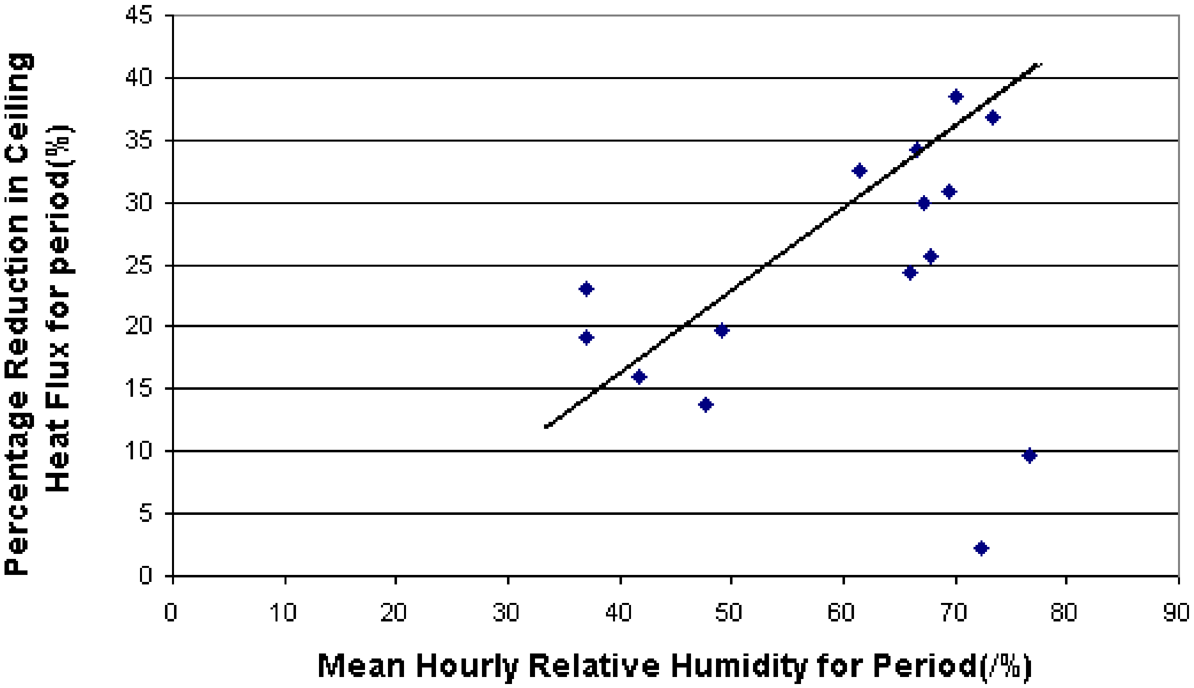
Radiant Barriers

- Parametric Analyses: Outdoor Air Temperature



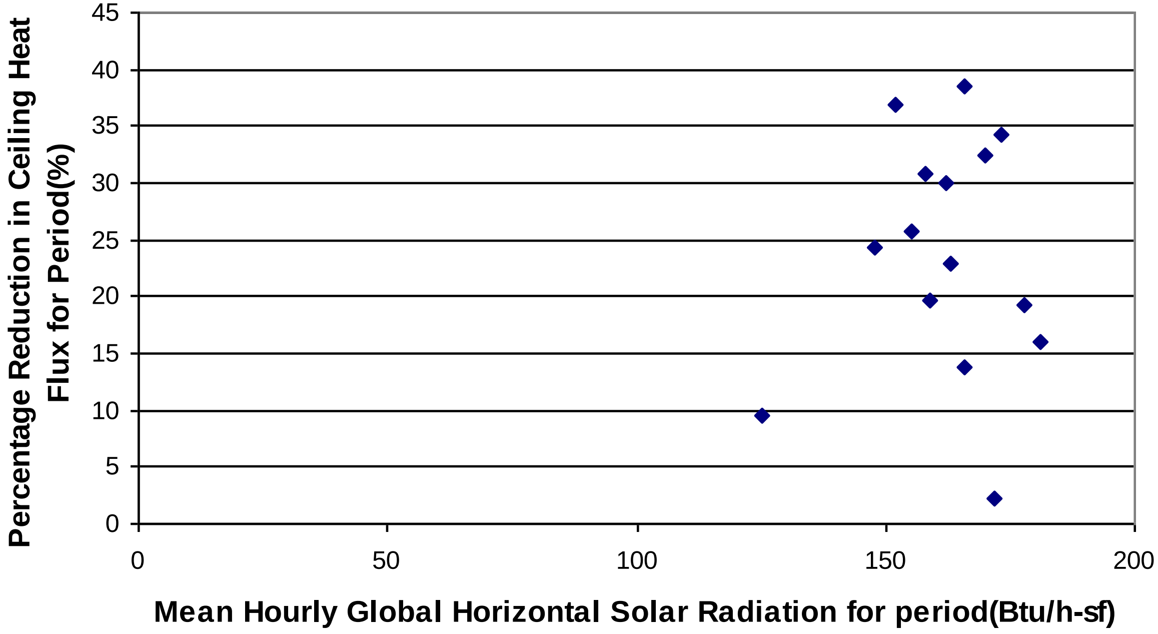
Radiant Barriers

- Parametric Analyses: Mean Hourly Relative Humidity



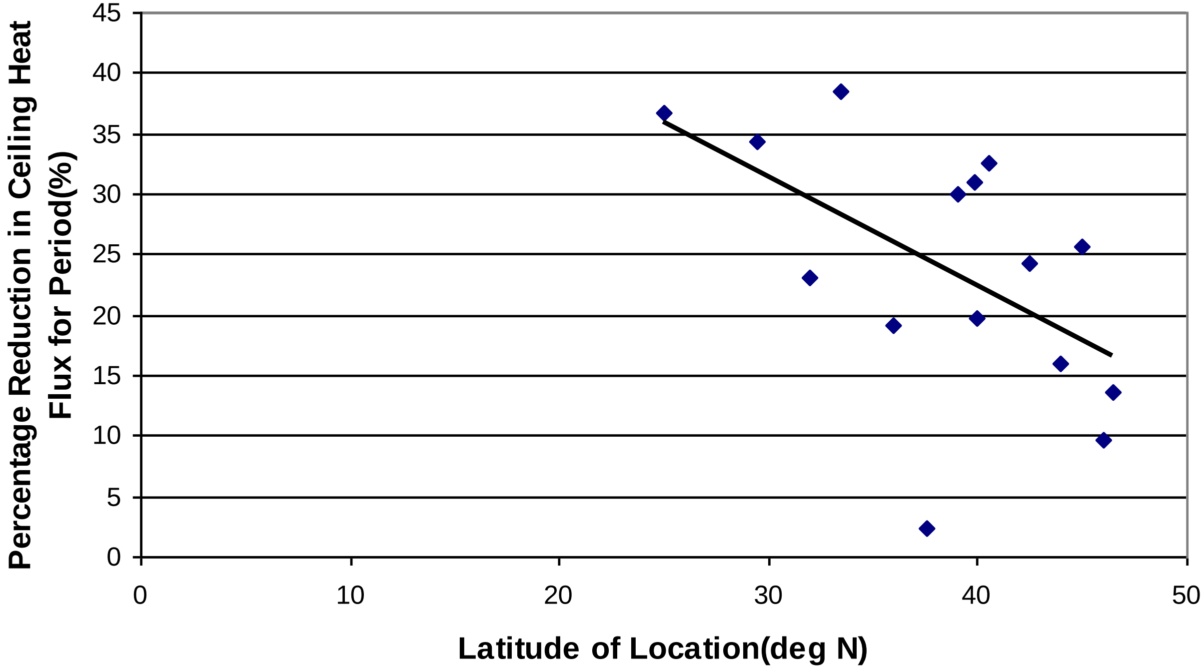
Radiant Barriers

- Parametric Analyses: Mean Hourly Global (H) Radiation



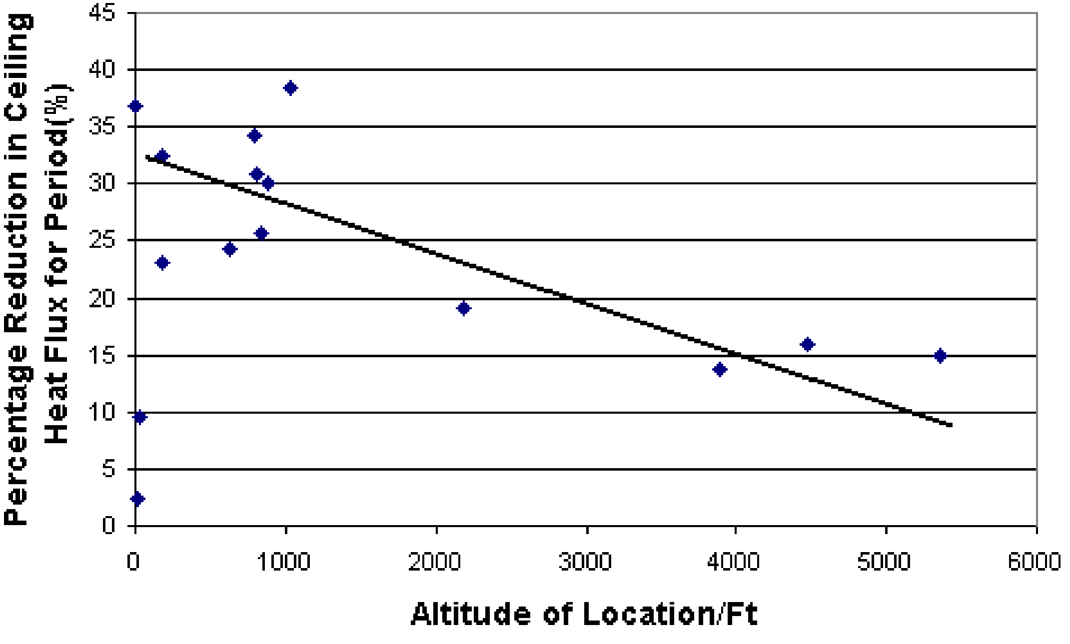
Radiant Barriers

- Parametric Analyses: Latitude



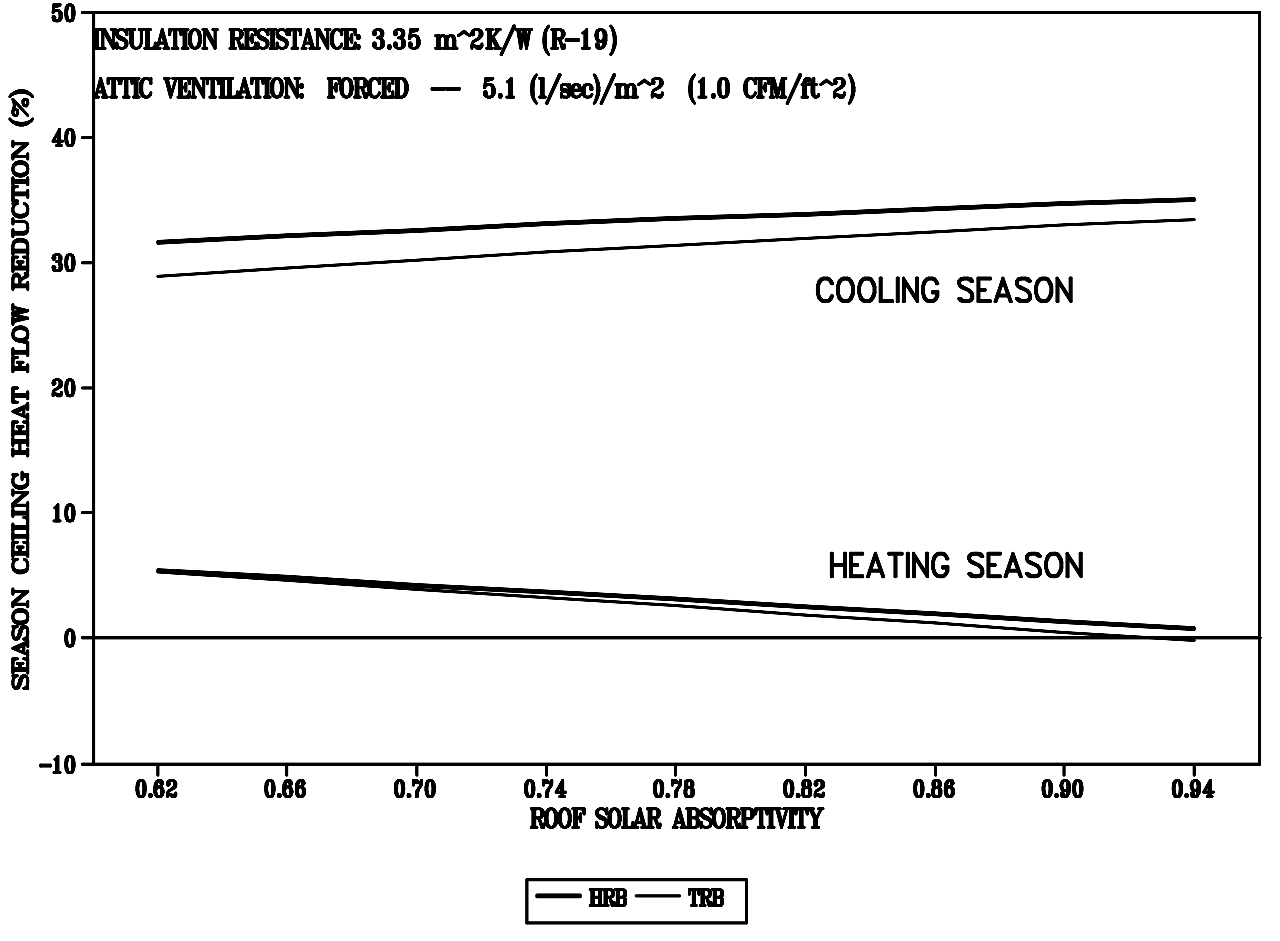
Radiant Barriers

- Parametric Analyses: Altitude



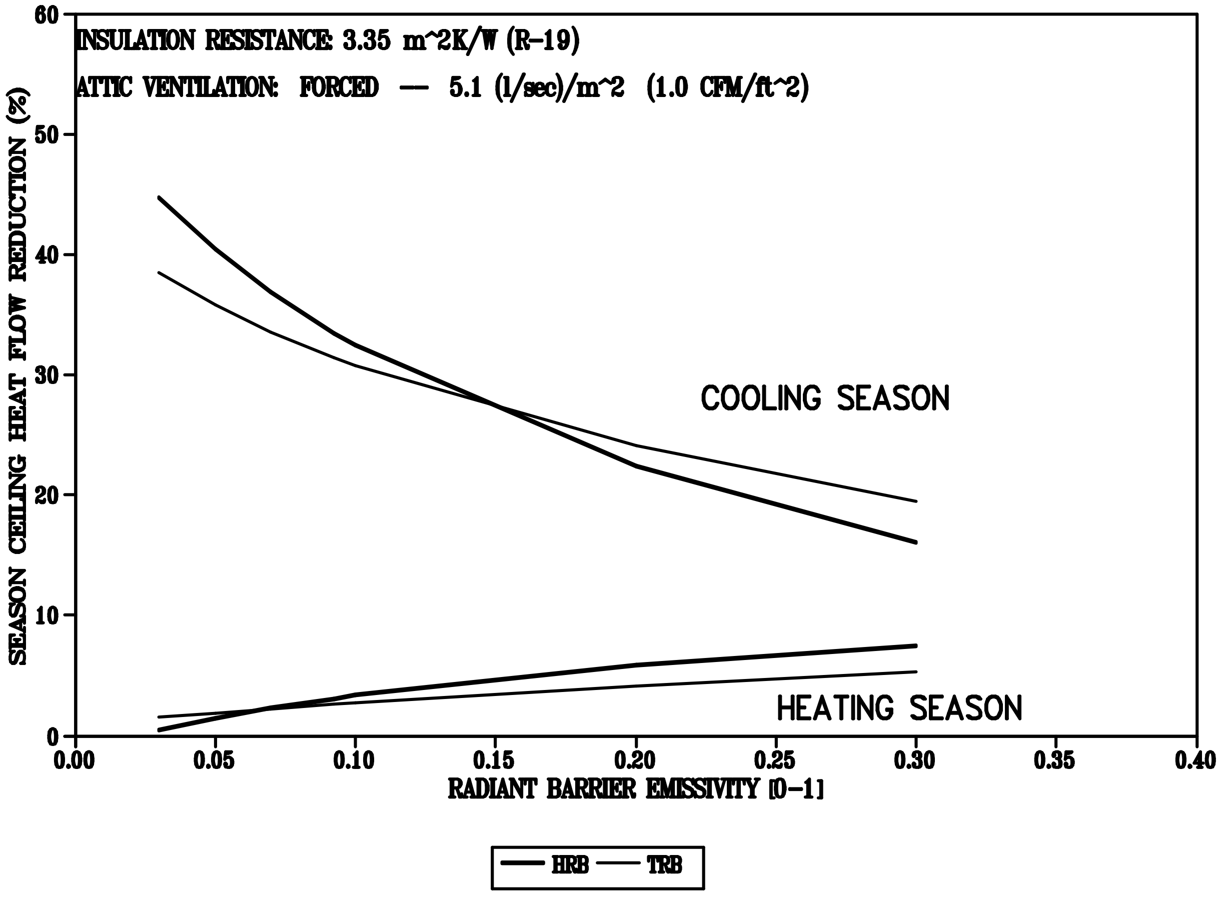
Radiant Barriers

- Parametric Analyses: Roof Solar Absorptivity



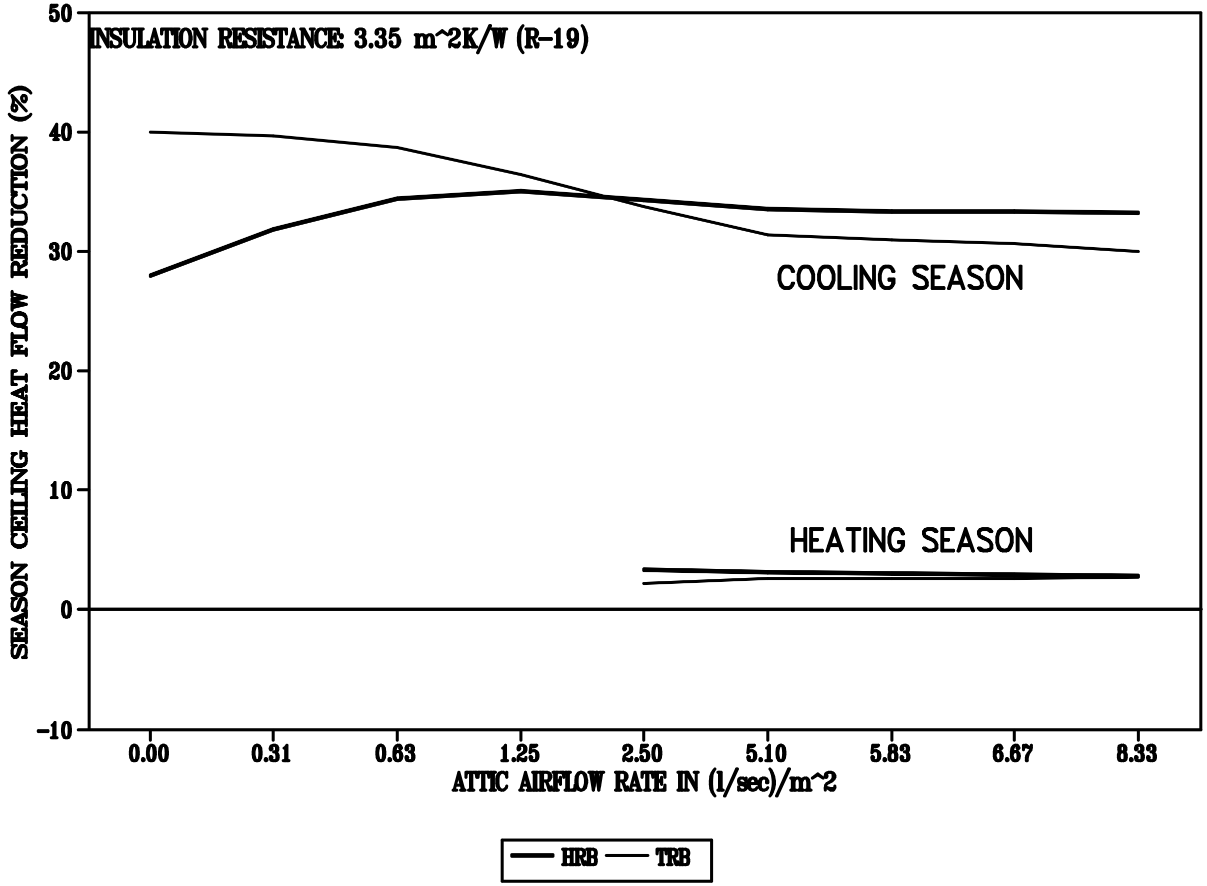
Radiant Barriers

- Parametric Analyses: Radiant Barrier Emissivity



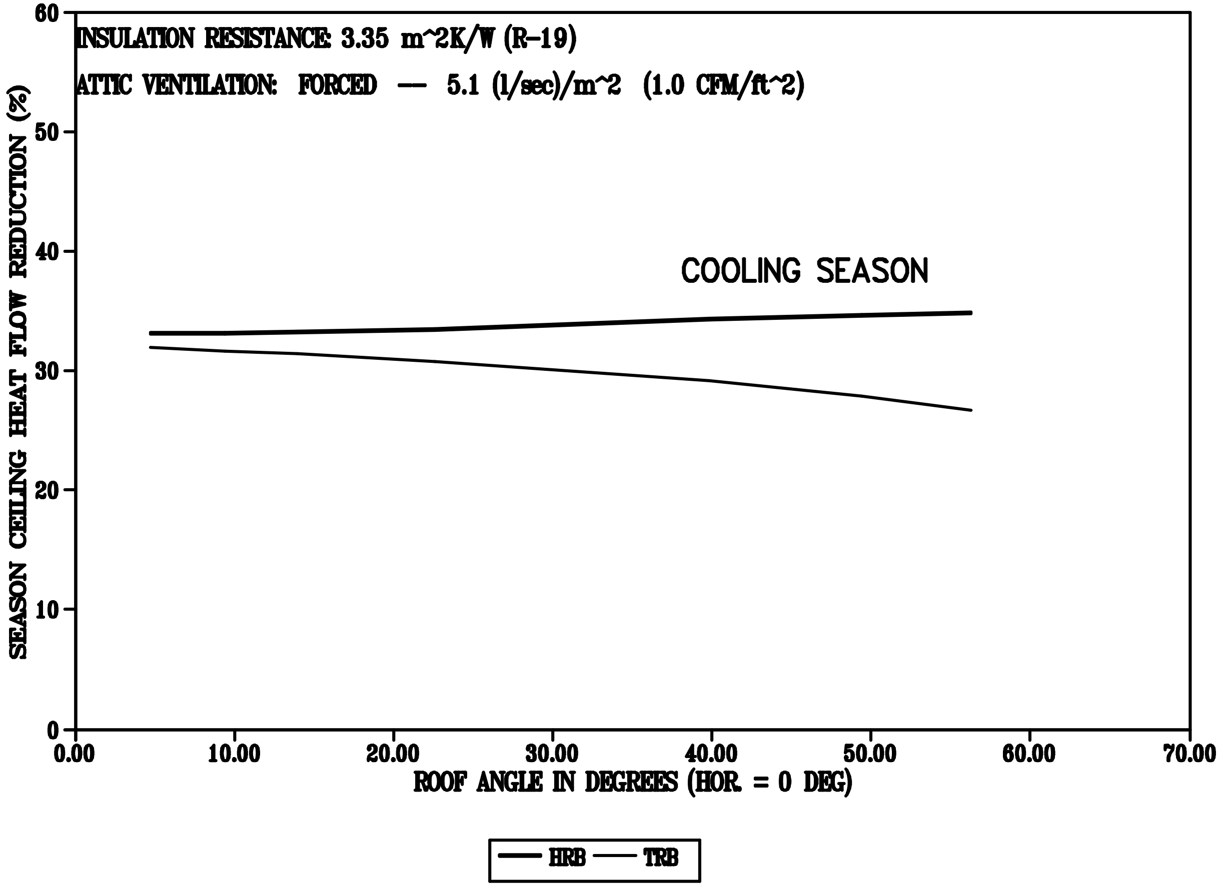
Radiant Barriers

- Parametric Analyses: Attic Airflow Rate



Radiant Barriers

- Parametric Analyses: Roof Slope



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

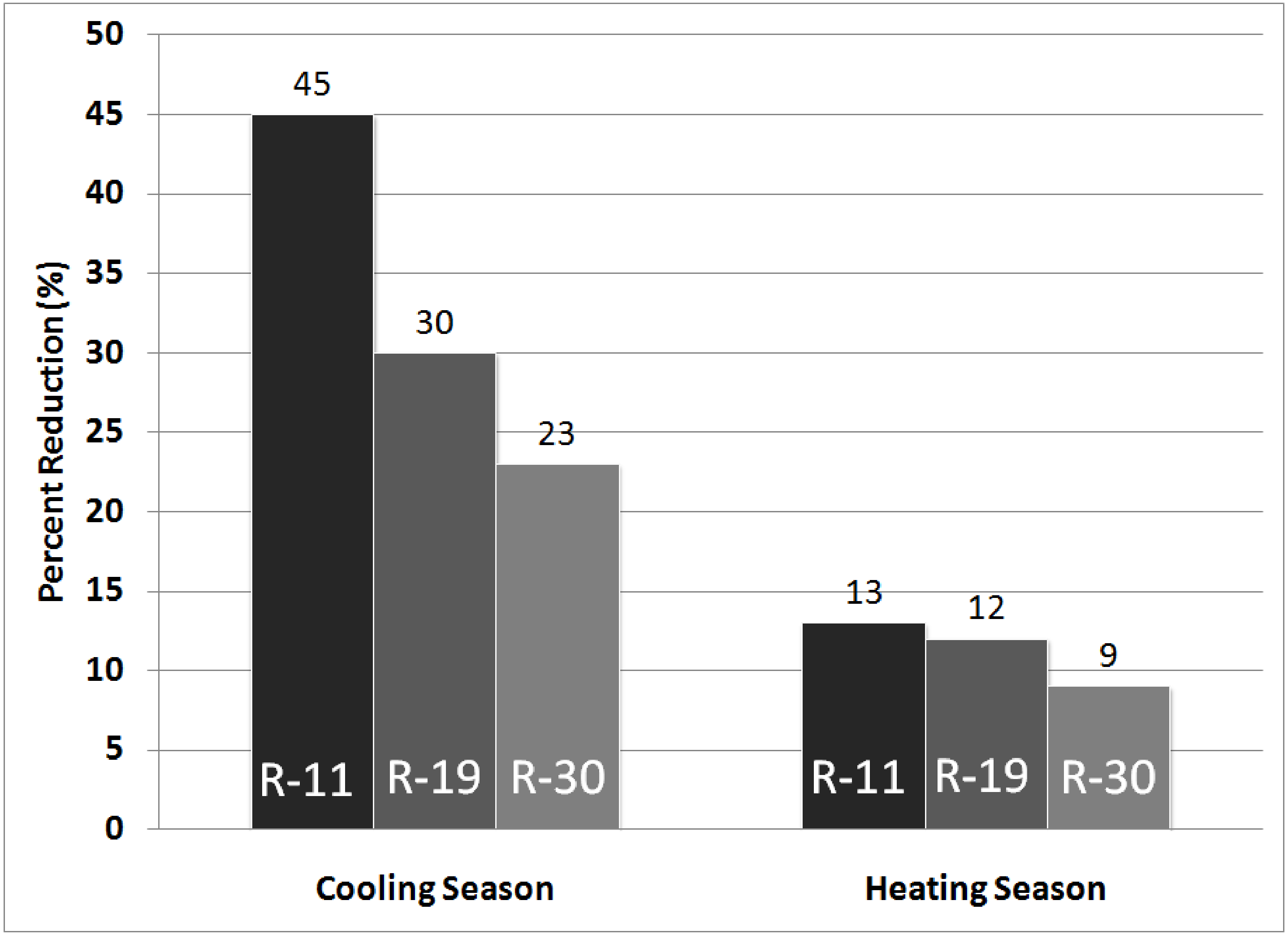
Ceiling Heat Flow

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 (%) Winter													City, St	HDD	Climatic Zone	Ventilation				Occupied		Comments	Average
					-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 (%) Cooling								City, St	CDD	Climatic Zone	Ventilation				Occupied		Includes Ducts in the Attic		Average
						-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

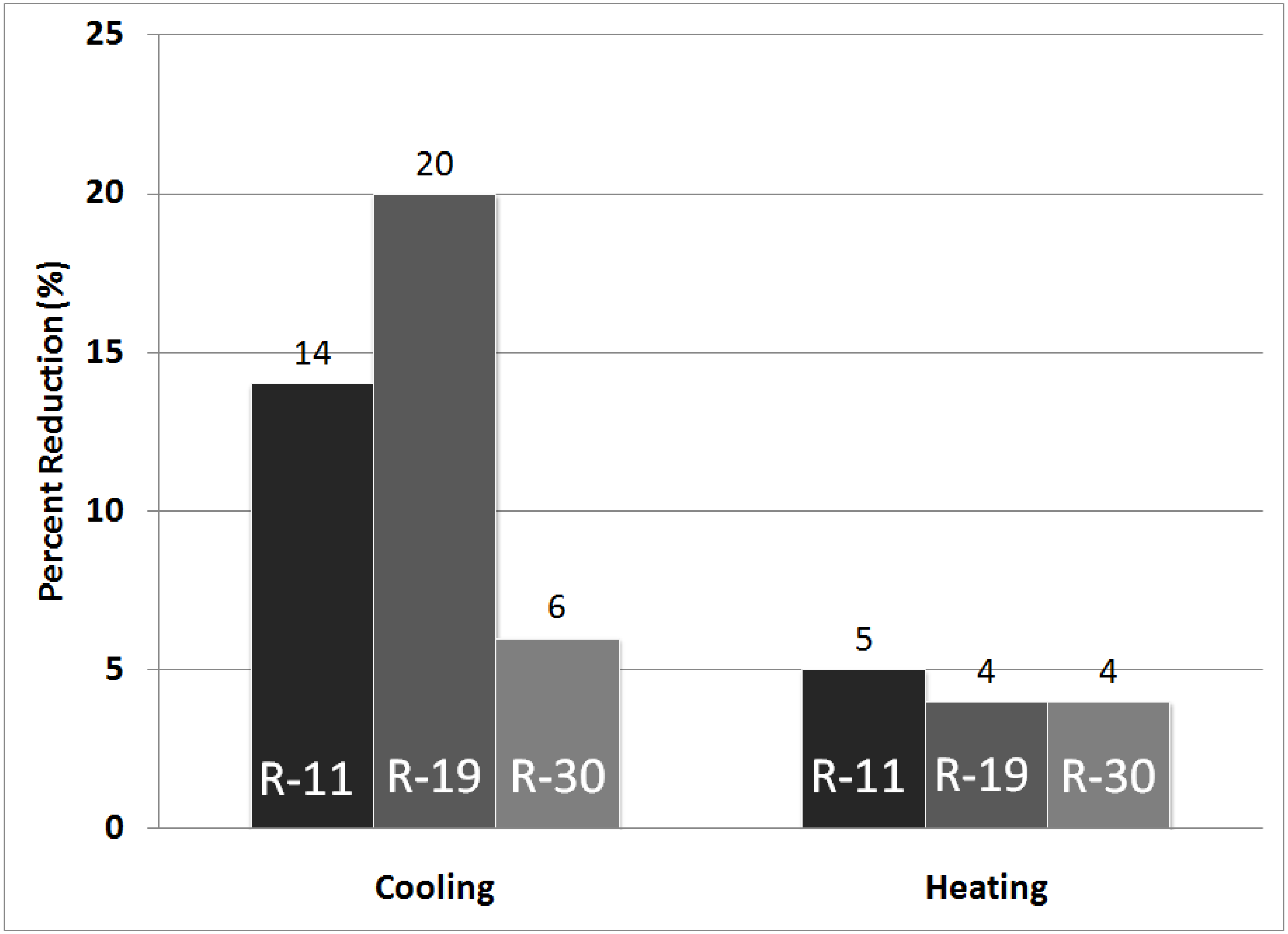
Space Heating Load

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) 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	City, St	CDD	Climatic Zone	Ventilation Vents		FV	NV	Occupied N	Y	Comments	Average
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

Radiant Barrier Performance

TABLE 6. SIMULATED RESULTS HIGHLIGHTING SPACE COOLING LOAD REDUCTIONS PRODUCED BY THE RADIANT BARRIERS																										
Season	Reference	Insulation Level R (m2K/W)	Model	Method	Ceiling Area	Cooling Load Base (kWh)	Cooling Load w/RB (kWh)	Space Load Reduction (%)								Location (CDD) [Zone]	Ventilation				Includes Ducts in the Attic		Duct Insulation Level	Duct Lekeage Rate		Mean (Median)
								Cooling																		
								-5	0 - 4	5 - 9	10 - 14	15 - 19	20 - 24	25 - 29	30->		Vents		FV	NV	Y	N		Supply	Return	
Cooling	DEG, 2000/EPRI, 1991	R-11 (1.94)	AtticSim	HRB	1,540	4,308	3,576					17				Knoxville, TN (1,450) [4]	S	R		X		X	N/A	N/A	N/A	16% (15%)
						9,877	8,734				12					Las Vegas, NV (3,168) [3]										
						13,277	11,870				11					Miami, FL (2,893) [1]										
						2,140	1,817					15				Minneapolis, MN (699) [6]										
						1,055	791							25		Portland, OR (398) [4]										
	DEG, 2000/EPRI, 1991	R-19 (3.35)	AtticSim	HRB	1,540	3,634	3,283				10					Knoxville, TN (1,450) [4]	S	R		X		X	N/A	N/A	N/A	9% (9%)
						8,968	8,441			6						Las Vegas, NV (3,168) [3]										
						12,515	11,928			5						Miami, FL (2,893) [1]										
						1,934	1,758			9						Minneapolis, MN (699) [6]										
						879	762				13					Portland, OR (398) [4]										
	DEG, 2000/EPRI, 1991	R-30 (5.28)	AtticSim	HRB	1,540	3,400	3,165			7						Knoxville, TN (1,450) [4]	S	R		X		X	N/A	N/A	N/A	6% (6%)
						8,529	8,206		4							Las Vegas, NV (3,168) [3]										
						12,104	11,694		3							Miami, FL (2,893) [1]										
						1,817	1,700			6						Minneapolis, MN (699) [6]										
						733	674			8						Portland, OR (398) [4]										
	DEG, 2000	R-11 (1.94)	Micropas	TRB	1,540	5,627	4,543					19				Knoxville, TN (1,450) [4]	-	-		X		X	N/A	N/A	N/A	20% (17%)
						12,778	11,020				14					Las Vegas, NV (3,168) [3]										
						15,328	13,277				13					Miami, FL (2,893) [1]										
						-	-									Minneapolis, MN (699) [6]										
						1,172	762								35	Portland, OR (398) [4]										
	DEG, 2000	R-19 (3.35)	Micropas	TRB	1,540	5,012	4,308				14					Knoxville, TN (1,450) [4]	-	-		X		X	N/A	N/A	N/A	15% (14%)
						11,694	10,610			9						Las Vegas, NV (3,168) [3]										
						14,185	12,896			9						Miami, FL (2,893) [1]										
						2,227	1,876					16				Minneapolis, MN (699) [6]										
						938	703							25		Portland, OR (398) [4]										
	DEG, 2000	R-30 (5.28)	Micropas	TRB	1,540	4,572	4,132				10					Knoxville, TN (1,450) [4]	-	-		X		X	N/A	N/A	N/A	8% (8%)
						10,903	10,229			6						Las Vegas, NV (3,168) [3]										
						13,365	12,544			6						Miami, FL (2,893) [1]										
						2,022	1,817				10					Minneapolis, MN (699) [6]										
						-	-									Portland, OR (398) [4]										
	DEG, 2000	R-11 (1.94)	Micropas	TRB	1,540	6,444	5,108						21			Knoxville, TN (1,450) [4]	-	-		X	X		-	"normal" (180 CFM per sq. ft.)	"normal" (180 CFM per sq. ft.)	22% (18%)
						14,561	12,423					15				Las Vegas, NV (3,168) [3]										
						17,330	14,805					15				Miami, FL (2,893) [1]										
						-	-									Minneapolis, MN (699) [6]										
						1,356	864								36	Portland, OR (398) [4]										
	DEG, 2000	R-19 (3.35)	Micropas	TRB	1,540	5,740	4,875					15				Knoxville, TN (1,450) [4]	-	-		X	X		-	"normal" (180 CFM per sq. ft.)	"normal" (180 CFM per sq. ft.)	16% (15%)
						13,709	12,268				11					Las Vegas, NV (3,168) [3]										
						16,034	14,373				10					Miami, FL (2,893) [1]										
						2,552	2,130					17				Minneapolis, MN (699) [6]										
						1,087	789							27		Portland, OR (398) [4]										
	DEG, 2000	R-30 (5.28)	Micropas	TRB	1,540	5,242	4,673				11					Knoxville, TN (1,450) [4]	-	-		X	X		-	"normal" (180 CFM per sq. ft.)	"normal" (180 CFM per sq. ft.)	9% (9%)
						12,804	11,856			7						Las Vegas, NV (3,168) [3]										
						15,108	14,001			7						Miami, FL (2,893) [1]										
						2,318	2,039				12					Minneapolis, MN (699) [6]										
						-	-									Portland, OR (398) [4]										

Legend: (-) = Not Specified, FV= Forced Ventilation, NV= Natural Ventilation, S = Soffit Vent, G = Gable Vent, R = Ridge Vent, P = Power Fan

Radiant Barrier Performance

Season	Reference	Insulation Level R (m2K/W)	Model	Method	Ceiling Area	Cooling Load Base (kWh)	Cooling Load w/RB (kWh)	Space Load Reduction (%) Cooling -5	0 - 4	5 - 9	10 - 14	15 - 19	20 - 24	25 - 29	30->	Location (CDD) [Zone]	Ventilation: Vents		FV	NV	Includes Ducts in the Attic: Y	N	Duct Insulation Level	Duct Lekeage Rate: Supply	Return	Mean (Median)
Cooling	Kim and Haberl (2007)	R-19 (3.35)	ESL	TRB	1,100	5,957	5,395			9						Houston 3,440 [2]	-	-		X	X		R-4	10%	10%	8% (7%)
						5,647	5,198			8													R-6			
						5,505	5,103			7													R-8			
						5,423	5,048			7													R-10			
						5,370	5,012			7													R-12			
	Kim and Haberl (2007)	R-19 (3.35)	EnergyGauge	TRB	1,100	5,315	5,054			5						Houston 3,440 [2]	S	R		X	X		R-4	10%	10%	5% (5%)
						5,212	4,963			5													R-6			
						5,154	4,913			5													R-8			
						5,117	4,881			5													R-10			
						5,091	4,858			5													R-12			
	Kim and Haberl (2007)	R-19 (3.35)	ESL	TRB	1,100	5,350	4,924			8						Houston 3,440 [2]	-	-		X	X		R-6	5%	10%	8% (8%)
						5,980	5,503			8														15%		
						6,353	5,847			8														20%		
	Kim and Haberl (2007)	R-19 (3.35)	EnergyGauge	TRB	1,100	4,871	4,634			5						Houston 3,440 [2]	S	R		X	X		R-6	5%	10%	5% (5%)
						5,602	5,341			5														15%		
						6,039	5,766			5														20%		
	Kim and Haberl (2007)	R-19 (3.35)	ESL	TRB	1,100	4,979	4,694			5						Houston 3,440 [2]	-	-		X	X		R-6	10%	5%	11% (11%)
						6,599	5,855				11														15%	
						8,141	6,761					17													20%	
	Kim and Haberl (2007)	R-19 (3.35)	EnergyGauge	TRB	1,100	5,013	4,811		4							Houston 3,440 [2]	S	R		X	X		R-6	10%	5%	5% (5%)
						5,399	5,113			5															15%	
						5,576	5,261			6															20%	
	Kim and Haberl (2007)	R-10 (1.76)	ESL	TRB	1,100	5,900	5,343			9						Houston 3,440 [2]	-	-		X	X		R-6	10%	10%	8% (8%)
		R-15 (2.64)				5,729	5,245			8																
		R-25 (4.41)				5,568	5,152			7																
		R-30 (5.28)				5,524	5,126			7																
	Kim and Haberl (2007)	R-10 (1.76)	EnergyGauge	TRB	1,100	5,446	5,119			6						Houston 3,440 [2]	-	-		X	X		R-6	10%	10%	5% (5%)
		R-15 (2.64)				5,291	5,016			5																
		R-25 (4.41)				5,115	4,900		4																	
		R-30 (5.28)				5,057	4,860		4																	

TABLE 6 (CONTINUED) SIMULATED RESULTS HIGHLIGHTING SPACE COOLING LOAD REDUCTIONS PRODUCED BY THE RADIANT BARRIERS

Legend: (-) = Not Specified, FV= Forced Ventilation, NV= Natural Ventilation, S = Soffit Vent, G = Gable Vent, R = Ridge Vent, P = Power Fan

Radiant Barrier Performance

TABLE 7. SIMULATED RESULTS HIGHLIGHTING SPACE HEATING LOAD REDUCTIONS PRODUCED BY THE RADIANT BARRIERS

Season	Reference	Insulation Level R (m2K/W)	Model	Method	Ceiling Area	Heating Load Base (MMBtu)	Heating Load w/RB (MMBtu)	Space Load Reduction (%) Heating								Location (HDD) [Zone]	Ventilation				Includes Ducts in the Attic		Duct Insulation Level	Duct Lekeage Rate		Mean (Median)
								-5	0 - 4	5 - 9	10 - 14	15 - 19	20 - 24	25 - 29	30->		Vents		FV	NV	Y	N		Supply	Return	
Heating						34.7	33.6		3							Knoxville, TN (3,685) [4]										
						20.3	19.1			6						Las Vegas, NV (2,276) [3]										
	DEG, 2000/EPRI, 1991	R-11 (1.94)	AtticSim	HRB	1,540	2.0	1.8				10					Miami, FL (155) [1]	S	R		X		X	N/A	N/A	N/A	5% (3%)
						82.9	81.3		2							Minneapolis, MN (7882) [6]										
						45.4	44.0		3							Portland, OR (4366) [4]										
						29.8	29.3		2							Knoxville, TN (3,685) [4]										
						17.0	16.4		3							Las Vegas, NV (2,276) [3]										
	DEG, 2000/EPRI, 1991	R-19 (3.35)	AtticSim	HRB	1,540	1.6	1.5			6						Miami, FL (155) [1]	S	R		X		X	N/A	N/A	N/A	3% (2%)
						73.1	72.4		1							Minneapolis, MN (7882) [6]										
						39.3	38.6		2							Portland, OR (4366) [4]										
						27.4	27.1		1							Knoxville, TN (3,685) [4]										
						15.4	15.0		3							Las Vegas, NV (2,276) [3]										
	DEG, 2000/EPRI, 1991	R-30 (5.28)	AtticSim	HRB	1,540	1.4	1.4		0							Miami, FL (155) [1]	S	R		X		X	N/A	N/A	N/A	1% (1%)
						67.9	67.6		0.4							Minneapolis, MN (7882) [6]										
						36.2	35.9		1							Portland, OR (4366) [4]										
						35.9	33.1			8						Knoxville, TN (3,685) [4]										
						17.9	16.0				11					Las Vegas, NV (2,276) [3]										
	DEG, 2000	R-11 (1.94)	Micropas	TRB	1,540	2.3	1.9					17				Miami, FL (155) [1]	-	-		X		X	N/A	N/A	N/A	11% (10%)
						-	-									Minneapolis, MN (7882) [6]										
						44.5	40.6			9						Portland, OR (4366) [4]										
						32.8	31.2			5						Knoxville, TN (3,685) [4]										
						16.0	14.8			8						Las Vegas, NV (2,276) [3]										
	DEG, 2000	R-19 (3.35)	Micropas	TRB	1,540	2.0	1.8				10					Miami, FL (155) [1]	-	-		X		X	N/A	N/A	N/A	6% (5%)
						75.9	72.9		4							Minneapolis, MN (7882) [6]										
						40.5	38.3			5						Portland, OR (4366) [4]										
						30.5	29.6		3							Knoxville, TN (3,685) [4]										
						14.6	13.9			5						Las Vegas, NV (2,276) [3]										
	DEG, 2000	R-30 (5.28)	Micropas	TRB	1,540	1.8	1.8		0							Miami, FL (155) [1]	-	-		X		X	N/A	N/A	N/A	3% (3%)
						71.3	69.6		2							Minneapolis, MN (7882) [6]										
						-	-									Portland, OR (4366) [4]										
						43.4	39.3			9						Knoxville, TN (3,685) [4]										
						21.5	18.8				12					Las Vegas, NV (2,276) [3]										
	DEG, 2000	R-11 (1.94)	Micropas	TRB	1,540	2.7	2.2					16				Miami, FL (155) [1]	-	-		X	X		-	"normal" (180 CFM per sq. ft.)	"normal" (180 CFM per sq. ft.)	12% (11%)
						-	-									Minneapolis, MN (7882) [6]										
						53.1	47.7				10					Portland, OR (4366) [4]										
						39.7	37.3			6						Knoxville, TN (3,685) [4]										
						19.2	17.9			7						Las Vegas, NV (2,276) [3]										
	DEG, 2000	R-19 (3.35)	Micropas	TRB	1,540	2.4	2.1				10					Miami, FL (155) [1]	-	-		X	X		-	"normal" (180 CFM per sq. ft.)	"normal" (180 CFM per sq. ft.)	7% (7%)
						95.3	90.2			5						Minneapolis, MN (7882) [6]										
						48.4	45.2			7						Portland, OR (4366) [4]										
						37.0	35.6		4							Knoxville, TN (3,685) [4]										
						17.5	16.6			5						Las Vegas, NV (2,276) [3]										
	DEG, 2000	R-30 (5.28)	Micropas	TRB	1,540	2.2	2.0			5						Miami, FL (155) [1]	-	-		X	X		-	"normal" (180 CFM per sq. ft.)	"normal" (180 CFM per sq. ft.)	4% (5%)
						89.7	86.6		3							Minneapolis, MN (7882) [6]										
						-	-									Portland, OR (4366) [4]										

Legend: (-) = Not Specified, FV= Forced Ventilation, NV= Natural Ventilation, S = Soffit Vent, G = Gable Vent, R = Ridge Vent, P = Power Fan

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. When the HVAC ducts were placed in the attics, the reductions increased by about 2% points.

- 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

THANK YOU