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

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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: <u>Sustainable Building Sourcebook</u> Chapter: Energy

Definition

- •Radiant barrier are aluminum <u>foil</u> laminates or aluminized synthetic <u>film</u> 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 <u>low emittance</u> 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).



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

Radiant Barrier Installations



Radiant Barrier Installations

"Truss Radiant Barrier" (TRB)



Horizontal Radiant Barrier



Truss Radiant Barrier



Deck Applied Radiant Barrier



Draped Radiant Barrier



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





~92% reduction in radiation heat transfer

- 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

• Experiments: Test Houses















• Experimental Results: Calibration (No RB Case)

Ceiling Heat Flux



Indoor Air Temperature

• Experimental Results: Calibration (RB Case)



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



• Experimental Results: Installation Comparisons

Horizontal Configuration vs. Truss Configuration?



Slight Advantage for the Horizontal Configuration 15

Experimental Results: Shingle Temperatures
 Horizontal Configuration
 Vs. No RB Case
 Vs. No RB Case



Experimental Results: Effects of Daily Solar Radiation



• Experimental Results: Effects of Attic Ventilation



• Experimental Results: Effects of Attic Insulation Level



Verification of Model/Experiments











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: Outdoor Air Temperature



• Parametric Analyses: Mean Hourly Relative Humidity



• Parametric Analyses: Mean Hourly Global (H) Radiation



• Parametric Analyses: Latitude



• Parametric Analyses: Altitude



• Parametric Analyses: Roof Solar Absorptivity



• Parametric Analyses: Radiant Barrier Emissivity



• Parametric Analyses: Attic Airflow Rate



• Parametric Analyses: Roof Slope



Radiant Barrier Performance Ceiling Heat Flow

		EXPERIME	NTAL RESULT	'S HIGHLIGH	ITING (CEILING	HEAT	FLOW I	REDUCT	TIONS F	RODU	CED BY	THE RA	DIANT	BARRIE	RS AN	D INTER	RIOR R/	ADIATION CONTRO	L COATIN	IGS DURIN	G THE	CO	OLIN	IG SE	ASO	١		
Season	Reference	Nominal Insulation	Testing	Method					Ceiling	Heat Flow	w Reduct	tions Ove	er Test Pe	eriod (%)					City, St	CDD	Climatic	v	/entil	lation		Occu	pied	Comments	Average
		Level R-Value	Protocol		-				45.40		Sum	mer	05.00		45 40	50 54	55 50				Zone		.						
					-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				ven	iτs	FV	NV	N	Ŷ		
	Joy (1958)	R-7.5	-	HRB												50			N	I/A		S	S	Х		Х		Flat Roof	
	Katipamula & O'Neal (1986)	R-11	Laboratory	HRB											46				N	I/A		-	-	-	-	Х		Flat Roof	41%
	Yarbrough (2010)	R-13	Controlled											41					N	I/A		-	-	-	-	Х		Pitched Roof	
	Joy (1958)	R-7.5		HRB							28								N	I/A		S	S	X		Х		Pitched Roof	
	Swami and Fairey (1986)	R-19	Laboratory Controlled	IRCC								32							Ν	I/A		-	-	-		x		Flat Roof	32%
	Ashley et al. (1994)			HRB/TRB														60	Kingsville, TX	3,404	2	G	G		х		х	Attic fully wrapped	
	Medina (2000a)	R-11	Side-by-Side	TRB										42					College Station, TX	2,938	2	S	G	х		х			45%
	Hall (1988a)			TRB								34							Chattanooga, TN	1,608	4	S	G		х	х			
	Fairey (1985)			TRB										43					Cape Canaveral, FL	3,300	2	S	S	х		х		5 ACH, 1 AS f/down	
	Fairey (1985)			TRB										43					Cape Canaveral, FL	3,300	2	S	s	х		х		5 ACH, 2 AS	
60	Hall (1986)			HRB										40					Chattanooga, TN	1,608	4	s	G		х	х			
2.	Fairey (1990)			TRB									39						Cape Canaveral, FL	3,300	2	-	-		х	х			
÷=	Parker and Sherwin (1998)			TRB									36						Cocoa Beach, FL	3,300	2	S	R		х	х		Vent area = 1:150	
ğ	Levins et al. (1986)			HRB									35						Karns, TN	1,301	4	S	G		х	х			
N.	Medina (2000a)			TRB								34							College Station, TX	2,938	2	S	G	х		х			
0	Levins et al. (1986)			TRB								30							Karns, TN	1,301	4	S	G		х	х			
	Hall (1988a)	R-19	Side-by-Side	TRB								30							Chattanooga, TN	1,608	4	S	G		х	Х			30%
	Medina et al. (1992a)			HRB								30							College Station, TX	2,938	2	S	G	х		Х			
	Parker and Sherwin (1998)			TRB							26								Cocoa Beach, FL	3,300	2	S	R		х	Х		Vent area = 1:300	
	Hall (1986)			TRB						23									Chattanooga, TN	1,608	4	S	G		х	Х			
	McQuiston et al. (1984)			HRB						20									Stillwater, OK	1,881	3	-	-	х		-	-	Curved Roof	
	Ober & Volckhausen (1988)			DRB						20									Orlando, FL	3,428	2	S	G		х	Х			
	Fairey (1985)			TRB					19										Cape Canaveral, FL	3,300	2	-	-			Х		Unvented Attics	
	Fairey <mark>(</mark> 1985)			HRB					18										Cape Canaveral, FL	3,300	2	-	-			Х		Unvented Attics	
	Hall (1986)			DRB					16										Chattanooga, TN	1,608	4	S	G		х	х			
	Medina (2000a)	B 22	olde hu olde	TRB							25								College Station, TX	2938	2	S	G		х	х			229/
	Hall (1988a)	ĸ-30	Side-by-Side	TRB						20									Chattanooga, TN	1608	4	S	G		х	х			23%

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

		EXPERIME	NTAL RESULT	'S HIGHLIG	HTING	CEILING	i HEAT	FLOW	REDUCT	FIONS P	RODU	CED BY	THE RA	DIANT	BARRI	ERS AN	D INTER	RIOR RA	ADIATION CONTRO	L COATIN	IGS DURIN	G TH	IE HE	ATIN	IG SE	ASON	۷		
Socon	Poforonco	Nominal Insulation	Testing	Mathad					Ceiling	Heat Flov	v Reduct	ions Ove	er Test Pe	riod (%)					City St	HDD	Climatic		Venti	ilation	n	Occu	pied	Commonte	Avorago
Season	Reference	Level	Protocol	wethou							Wi	nter							City, St	HUU	Zone							comments	Average
		R-Value			-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				Ve	ents	FV	NV	Ν	Y		
	Levins and Karnitz (1988)			HRB					19										Karns, TN	3,993	4	S	G		Х	X			
	Hall (1988)		Olda hu Olda	HRB					17										Chattanooga, TN	3,427	4	S	G		х	х			1.29/
	Levins and Karnitz (1988)	K-11	Side-by-Side	TRB			8												Karns, TN	3,993	4	S	G		х	х			1370
	Hall (1988)			TRB			6												Chattanooga, TN	3,427	4	S	G		х	х			
	Levins and Karnitz (1987b)			TRB								30							Karns, TN	3,993	4	S	G		х	Х			
	Fairey (1990)			TRB						24									Cape Canaveral, FL	677	2	-	-		х	х			
	Medina et al. (1992b)			HRB					17										College Station, TX	1,616	2	-	-	-	-	х		Non-vented Attics	
60	Hall (1986)			HRB					15										Chattanooga, TN	3,427	4	S	G		х	х			
2.	Medina et al. (1992b)			TRB					15										College Station, TX	1,616	2	-	-	-	-	х		Non-vented Attics	
-	Medina et al. (1992b)	B 10	Cida hu Cida	HRB				14											College Station, TX	1,616	2	S	G	х		х			1.294
g	McQuiston et al. (1984)	1-13	Side-by-side	HRB				10											Stillwater, OK	3,989	3	-	-	х		-	-	Curved Roof	12/0
₽ ₽	Medina et al. (1992b)			TRB			9												College Station, TX	1,616	2	S	G	х		х			
	Hall (1988a)			HRB			5												Chattanooga, TN	3,427	4	S	G		Х	X			
	Hall (1986)			TRB			8												Chattanooga, TN	3,427	4	S	G		х	X			
	Hall (1986)			DRB		4													Chattanooga, TN	3,427	4	S	G		х	X			
	Hall (1988a)			TRB	-5														Chattanooga, TN	3,427	4	S	G		х	х			
	Hall (1988a)			HRB					15										Chattanooga, TN	3,427	4	S	G		Х	Х			
	Levins and Karnitz (1988)	B 30	Olda hu Olda	HRB				10											Karns, TN	3,993	4	S	G		х	х			0%
	Hall (1988a)	K-30	Side-by-Side	TRB			6												Chattanooga, TN	3,427	4	S	G		х	х			9%
	Levins and Karnitz (1988)			TRB		4													Karns, TN	3,993	4	S	G		Х	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

			EX	PERIMENT	AL RESULT	S HIGH	LIGHTI	NG SPA	CE COC	LING L	OAD RE	EDUCTIO	ONS PF	ODUCED BY THE R	ADIANT B	ARRIERS									
Season	Reference	Nominal Insulation Level	Testing Protocol	Method	Ceiling Area			Spac	ce Load R	eduction	n (%)			City, St	CDD	Climatic Zone	,	Ventil	ation		Occu	pied	Inclu Ducts At	ides in the tic	Average
		R-Value				-5	0 - 4	5 - 9	10 - 14	15 - 19	20 - 24	25 - 29	30				Ve	nts	FV	NV	Ν	Y	Y	Ν	
	Levins and Karnitz (1987a)		otala hu otala	HRB	1,200					16				Karns, TN	1,301	4	S	G		х	X			Х	1 40/
	Levins and Karnitz (1987a)	K-11	Side-by-Side	TRB	1,200				11					Karns, TN	1,301	4	S	G		X	X			х	1470
	Parker and Sherwin (2002)		Pre-and-Post	TRB	2,440							27		Orlando, FL	3,428	2	-	-	-	-		х		Х	
60	Levins et al. (1986)	P 10	Side-by-Side	HRB	1,200						21			Karns, TN	1,301	4	S	G		х	X			Х	20%
	Parker and Sherwin (2002)	K-19	Pre-and-Post	TRB	2,200						20			Largo, FL	3,718	2	-	-	-	-		X	Х		2076
÷	Levins et al. (1986)		Side-by-Side	TRB	1,200				13					Karns, TN	1,301	4	S	G		X	X			Х	
g	Parker and Sherwin (2002)		Pre-and-Post	TRB	1,520					16				Tarpon Springs, FL	3,414	2	-	-	-	-		х			
ĸ	Davis and Tiller (2009)		Side-by-Side	TRB	3,205				14					Charlotte, NC	1,681	3	S	R		х	X		х		
\mathbf{U}	Parker and Sherwin (2002)	P 20	Pre-and-Post	TRB	1,840			5						Apopka, FL	3,428	2	S	Ρ	Х	х		X	Х		60/
	Levins and Karnitz (1987a)	N-50	Side-by-Side	HRB	1,200		2							Karns, TN	1,301	4	S	G		Х	X			х	070
	Parker and Sherwin (2002)		Pre-and-Post	TRB	2,140		0							Orlando, FL	3,428	2	Ρ	Ρ	Х			Х	Part	ially	
	Levins and Karnitz (1987a)		Side-by-Side	TRB	1,200	-1								Karns, TN	1,301	4	S	G		x	X			х	

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

Space Heating Load

			EX	PERIMENT	TAL RESULT	'S HIGH	LIGHTI	NG SPA	ACE HEA	ATING L	OAD R	EDUCTIO	DNS PR	RODUCED BY THE R	ADIANT B	ARRIERS									
Season	Reference	Nominal Insulation Level	Testing Protocol	Method	Ceiling Area			Spa	ice Load I Hei	Reductio	n (%)			City, St	HDD	Climatic Zone		Ventil	ation	I	Occu	pied	Inclu Ducts At	des in the tic	Average
		R-Value				-5	0 - 4	5 - 9	10 - 14	15 - 19	20 - 24	25 - 29	30				Ve	nts	FV	NV	Ν	Y	Y	Ν	
b0	Marcine -5 0-4 5-9 10-14 15-19 20-24 25-29 30 Vents FV NV N Y Y N Mode Levins and Karnitz (1987b) Levins and Karnitz (1987b) R-11 Side-by-Side HRB 1,200 0 9 Image: Constraint of the state of th																								
Ē	Begin Sand Karnitz (1987b) R-11 Side-by-Side HRB 1,200 9 Karns, TN 3,993 4 5 G X																								
ť.	Levins et al. (1986)			HRB	1,200				10					Karns, TN	3,993	4	S	G		X	х			Х	40/
g	Levins et al. (1986)	K-19	Side-by-Side	TRB	1,200	-3								Karns, TN	3,993	4	S	G		X	х			х	4%
Ψ	Levins and Karnitz (1987b)	B 20	ot de las ot de	HRB	1,200		4							Karns, TN	3,993	4	S	G		X	х			х	49/
	Levins and Karnitz (1987b)	K-3U	Side-by-Side	TRB	1,200		4							Karns, TN	3,993	4	S	G		X	Х			Х	470
Legend: C FV= Force	DD = Cooling Degree Days d Ventilation, NV= Natura	s, HDD = Heati al Ventilation,	ing Degree Day , S = Soffit Ver	ys, HRB = Ho nt, G = Gable	orizontal Rad e Vent, R = R	liant Ba Ridge Ve	rrier, Tf nt, P =	RB = Tru: Power F	ss Radia ⁻ an, AC⊦	nt Barri I = Air C	er, DARE hanges p	8 = Deck- ber Hour	Applied , AS = A	d Radiant Barrier, DR luminized Side, f/ =	B = Draped Facing, N/J	Radiant Ba A = Not App	rrier, olicat	, IRCC ple, (-	= Int) = N	erior: ot Sp	Radia ecifie	tion C d	control	Coatir	ng,

Space Cooling and Space Heating Load



Attic Temperature Reductions

			E)	KPERIMEN	TAL RE	SULTS H	HIGHLIG	HTING	ATTIC	AIR TEI	MPERA	TURE RI	EDUCT	IONS PR	ODUCE	D BY T	HE RADIANT I	ARRIERS DURING	THE COOI	LING SEASO	DN							
Season	Reference	Nominal Insulation Level	Testing Protocol	Method						Tempe	rature Re Sum	ductions	i (Deg F)					City, St	CDD	Climatic Zone		Venti	ilation	n	Осси	ıpied	Comments	Average
		R-Value			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				Ve	nts	FV	NV	N	Y		
	Hall (1988a)			700						10								Chattanooga, TN	1,608	4	S	G		Х	Х			0.5
	Levins and Karnitz (1987a)	K-11	Side-by-Side	IRB					7									Karns, TN	1,301	4	S	G		х	х			91
Parker and Sherwin (1998) Side-by-Side Side-by-Side																												
	Parker and Sherwin (1998) Side-by-Side Pre-and Post- Side-by-Side Parker and Sherwin (2002) Pre-and Post- Parker and Sherwin (2002) Pre-and Post- Side-by-Side Side-by-Side No N																											
	Hall (1988a) R-11 Bide-by-Side TRB Image: Control (1) and (445													
60	Hall (1988a) Re.11 Side-by-Side TRB Image: Constraint of the state of														14 F													
C	Hall (1988a)	K-19	Side-by-Side							10								Chattanooga, TN	1,608	4	s	G		х	х			
÷=	Reference Level R-Value Pricod Pricod Method Evel R-Value Pricod Method																											
Q	R-Value R-Value R-Value 0 0 - 2 3 - 4 5 - 6 7 - 8 9 - 10 11 - 12 13 - 10 17 - 18 19 - 20 2 - 2																											
Q	Levins and Karnitz (1986)		Side-by-Side	пкр		0												Karns, TN	1,301	4	S	G		Х	Х			41
0	Davis and Tiller (2009)		Side-by-Side													23		Charlotte, NC	1,681	3	S	R		Х				
	Parker and Sherwin (2002)		Pre-and Post-													22		Tarpon Springs, FL	3,414	2	-	-	-	-		х		
	Parker and Sherwin (2002)	B 00	Pre-and Post-	700							11							Apopka, FL	3,428	2	s	Р	х	х		х		44.5
	Hall (1988a)	R-30	Side-by-Side	TRB						10								Chattanooga, TN	1,608	4	S	G		х	х			11 F
	Levins and Karnitz (1987a)		Side-by-Side						7									Karns, TN	1,301	4	S	G		х	х			
	Parker and Sherwin (2002)		Pre-and Post-				3											Orlando, FL	3,428	2	Р	Ρ	Х			Х		
legend: (DD = Cooling Degree Day	s, HDD = He	ating Degree	Days, HRB	= Horiz	ontal R	adiant I	Barrier,	TRB = T	russ R	adiant I	Barrier,	DARB	= Deck-A	pplied	Radian	t Barrier, DRB	= Draped Radiant B	arrier, IR	CC = Interio	r Rad	liatio	on Co	ontrol	Coat	ing, F	/= Forced Ventilation	on,

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

							TABL	E 6. SIMU	LATED RE	SULTS HIG	SHLIGHTI	NG SPACE	COOLING	LOAD RE	DUCTIONS	PRODUCED BY THE RADIAN	T BARRIE	RS								
Season	Reference	Insulation	Model	Method	Ceiling	Cooling	Cooling Load			:	Space Load F	Reduction (9	6)			Location (CDD)		Ven	tilation		Includes D	ucts in the	Duct Insulation	Duct Le	eage Rate	Mean
Scuson	hererenee	R (m2K/W)	Model	method	Area	(kWh)	w/RB (kWb)				Co	oling				[Zone]										(Median)
							(KWII)	-5	0-4	5-9	10 - 14	15 - 19	20 - 24	25 - 29	30->		V	ents	FV	NV	Y	N		Supply	Return	
						4.308	3.576					17				Knoxville, TN (1.450) [4]										
						9,877	8,734				12					Las Vegas, NV (3,168) [3]										
	DEG, 2000/EPRI, 1991	R-11 (1.94)	AtticSim	HRB	1,540	13,277	11,870				11					Miami, FL (2,893) [1]	s	R		x		х	N/A	N/A	N/A	16%
						2,140	1,817					15				Minneapolis, MN (699) [6]										(15%)
						1,055	791							25		Portland, OR (398) [4]										
						3,634	3,283				10					Knoxville, TN (1,450) [4]										
						8,968	8,441			6						Las Vegas, NV (3,168) [3]										
	DEG, 2000/EPRI, 1991	R-19 (3.35)	AtticSim	HRB	1,540	12,515	11,928			5						Miami, FL (2,893) [1]	s	R		x		х	N/A	N/A	N/A	9%
						1,934	1,758			9						Minneapolis, MN (699) [6]										(370)
						879	762				13					Portland, OR (398) [4]										
						3,400	3,165			7						Knoxville, TN (1,450) [4]										
						8,529	8,206		4							Las Vegas, NV (3,168) [3]										
	DEG, 2000/EPRI, 1991	R-30 (5.28)	AtticSim	HRB	1,540	12,104	11,694		3							Miami, FL (2,893) [1]	s	R		x		х	N/A	N/A	N/A	6%
						1,817	1,700			6						Minneapolis, MN (699) [6]										(0/0)
						733	674			8						Portland, OR (398) [4]										
						5,627	4,543					19				Knoxville, TN (1,450) [4]										
						12,778	11,020				14					Las Vegas, NV (3,168) [3]										
	DEG, 2000	R-11 (1.94)	Micropas	TRB	1,540	15,328	13,277				13					Miami, FL (2,893) [1]	-	-		x		х	N/A	N/A	N/A	20%
						-	-									Minneapolis, MN (699) [6]										(1770)
-						1,172	762								35	Portland, OR (398) [4]										
2						5,012	4,308				14					Knoxville, TN (1,450) [4]										
. 						11,694	10,610			9						Las Vegas, NV (3,168) [3]										4500
0	DEG, 2000	R-19 (3.35)	Micropas	TRB	1,540	14,185	12,896			9						Miami, FL (2,893) [1]	-	-		x		х	N/A	N/A	N/A	15%
ŏ						2,227	1,876					16				Minneapolis, MN (699) [6]										(1470)
Ŭ						938	703							25		Portland, OR (398) [4]										
_						4,572	4,132				10					Knoxville, TN (1,450) [4]										
						10,903	10,229			6						Las Vegas, NV (3,168) [3]										
	DEG, 2000	R-30 (5.28)	Micropas	TRB	1,540	13,365	12,544			6						Miami, FL (2,893) [1]	-	-		x		х	N/A	N/A	N/A	8%
						2,022	1,817				10					Minneapolis, MN (699) [6]										(0,0)
						-										Portland, OR (398) [4]										
						6,444	5,108						21			Knoxville, TN (1,450) [4]										
						14,561	12,423					15				Las Vegas, NV (3,168) [3]								"normal"	"normal"	
	DEG, 2000	R-11 (1.94)	Micropas	TRB	1,540	17,330	14,805					15				Miami, FL (2,893) [1]	-	-		x	x		-	(180 CFM	(180 CFM	(18%)
						-										Minneapolis, MN (699) [6]								per sq. ft.	per sq. ft.)	(10/0)
						1,356	864								36	Portland, OR (398) [4]										
						5,740	4,875					15				Knoxville, TN (1,450) [4]										
						13,709	12,268				11					Las Vegas, NV (3,168) [3]								"normal"	"normal"	
	DEG, 2000	R-19 (3.35)	Micropas	TRB	1,540	16,034	14,373				10					Miami, FL (2,893) [1]	-	-		x	x		-	(180 CFM	(180 CFM	16%
						2,552	2,130					17				Minneapolis, MN (699) [6]								per sq. ft.	per sq. ft.)	(1570)
						1,087	789							27		Portland, OR (398) [4]										
						5,242	4,673				11					Knoxville, TN (1,450) [4]										
						12,804	11,856			7						Las Vegas, NV (3,168) [3]			1					"normal"	"normal"	
	DEG, 2000	R-30 (5.28)	Micropas	TRB	1,540	15,108	14,001			7						Miami, FL (2,893) [1]	-	-	1	x	x		•	(180 CFM	(180 CFM	9%
						2,318	2,039				12					Minneapolis, MN (699) [6]			1					per sq. ft.	per sq. ft.)	(374)
						-	-									Portland, OR (398) [4]										
Legend: (-) = Not Specified, FV	= Forced Ve	ntilation, NV	= Natural \	Ventilatio	n, S = Soffit	Vent, G = G	able Vent	, R = Ridg	e Vent, P	= Power Fa	an														

						T	ABLE 6 (CC	NTINUED) SIMULA	TED RESU	ILTS HIGH	IGHTING	SPACE CO	DOLING LO	AD REDU	CTIONS PRODUCED BY THE R	ADIANT I	BARRIERS								
Season	Reference	Insulation Level	Model	Method	Ceiling Area	Cooling Load Base	Cooling Load w/RB				Space Load F	Reduction (9	5)			Location (CDD) [Zone]		Ven	tilation		Includes [A	Ducts in the ttic	Duct Insulation Level	Duct Leke	eage Rate	Mean (Median
		K (M2K/W)				(KWN)	(kWh)	-5	0 - 4	5 - 9	10 - 14	15 - 19	20 - 24	25 - 29	30->		Ve	ents	FV	NV	Y	N		Supply	Return	
						5,957	5,395			9													R-4			
	Kim and Unberl (2007)	D 40 (0 05)	501	700	1 100	5,647	5,198			8	-					Houston					~		R-6		1.00%	8%
	Killi and Haberi (2007)	K-19 (5.55)	COL	IND	1,100	5 423	5,105			7	-					[2]	-			^	^		R-10	- 10%	10%	(7%)
						5,370	5,012			7													R-12	1 1		
						5 315	5.054			5													P-4			<u> </u>
						5,212	4,963			5	-					Houston							R-6	1 1		
	Kim and Haberl (2007)	R-19 (3.35)	EnergyGauge	TRB	1,100	5,154	4,913			5						3,440	s	R		x	x		R-8	10%	10%	5%
						5,117	4,881			5						[2]							R-10	1		(5%)
						5,091	4,858			5													R-12]		
						5,350	4,924			8						Houston								5%		
	Kim and Haberl (2007)	R-19 (3.35)	ESL	TRB	1,100	5,980	5,503			8						3,440	-	-		x	x		R-6	15%	10%	(8%)
60						6,353	5,847			8						[2]								20%		(214)
Ē						4,871	4,634			5						Houston								5%		594
:=	Kim and Haberl (2007)	R-19 (3.35)	EnergyGauge	TRB	1,100	5,602	5,341			5						3,440	S	R		x	x		R-6	15%	10%	(5%)
l o						6,039	5,766			5						[2]								20%		
18						4,979	4,694			5						Houston									5%	11%
	Kim and Haberl (2007)	R-19 (3.35)	ESL	TRB	1,100	6,599	5,855				11					3,440	-	-		x	x		R-6	10%	15%	(11%)
						8,141	6,761					17				[2]									20%	
						5,013	4,811		4							Houston									5%	5%
	Kim and Haberl (2007)	R-19 (3.35)	EnergyGauge	TRB	1,100	5,399	5,113			5						3,440	S	R		×	x		R-6	10%	15%	- (5%)
						5,576	5,261			6						[2]									20%	
		R-10 (1.76)				5,900	5,343			9						University										
	Kim and Haberl (2007)	R-15 (2.64)	ESL	TRB	1.100	5,729	5,245			8						3.440	-			x	x		R-6	10%	10%	8%
		R-25 (4.41)			-,	5,568	5,152			7						[2]										(8%)
		R-30 (5.28)				5,524	5,126			7																
		R-10 (1.76)				5,446	5,119			6						Houston										
	Kim and Haberl (2007)	R-15 (2.64)	EnergyGauge	TRB	1,100	5,291	5,016			5						3,440	-	-		×	x		R-6	10%	10%	5%
		R-25 (4.41)				5,115	4,900		4							[2]										(5%)
		R-30 (5.28)				5,057	4,860		4	L	L												1			

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

<table-container></table-container>								TABL	E 7. SIMUI	LATED RE	SULTS HIG	HLIGHTIN	IG SPACE	HEATING	LOAD REI	DUCTIONS	PRODUCED BY THE RADIAN	T BARRIEI	RS								
Image111 <t< td=""><td>Season</td><td>Reference</td><td>Insulation</td><td>Model</td><td>Method</td><td>Ceiling</td><td>Heating</td><td>Heating Load</td><td></td><td></td><td>:</td><td>pace Load F</td><td>Reduction (9</td><td>6)</td><td></td><td></td><td>Location (HDD)</td><td></td><td>Vent</td><td>ilation</td><td></td><td>Includes D</td><td>oucts in the</td><td>Duct Insulation</td><td>Duct Lek</td><td>eage Rate</td><td>Mean</td></t<>	Season	Reference	Insulation	Model	Method	Ceiling	Heating	Heating Load			:	pace Load F	Reduction (9	6)			Location (HDD)		Vent	ilation		Includes D	oucts in the	Duct Insulation	Duct Lek	eage Rate	Mean
VIEWV	beabon	hererene	R (m2K/W)	mouer		Area	(MMBtu)	w/RB (MMBtu)				Hea	ating				[Zone]										(Median)
Note: Note: <th< th=""><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th>(initiota)</th><th>-5</th><th>0 - 4</th><th>5-9</th><th>10 - 14</th><th>15 - 19</th><th>20 - 24</th><th>25 - 29</th><th>30-></th><th></th><th>Ve</th><th>ents</th><th>FV</th><th>NV</th><th>Y</th><th>N</th><th></th><th>Supply</th><th>Return</th><th></th></th<>								(initiota)	-5	0 - 4	5-9	10 - 14	15 - 19	20 - 24	25 - 29	30->		Ve	ents	FV	NV	Y	N		Supply	Return	
<td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>34.7</td> <td>33.6</td> <td></td> <td>3</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>Knoxville, TN (3,685) [4]</td> <td></td>							34.7	33.6		3							Knoxville, TN (3,685) [4]										
							20.3	19.1			6						Las Vegas, NV (2,276) [3]	1									
		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%
</td <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>82.9</td> <td>81.3</td> <td></td> <td>2</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>Minneapolis, MN (7882) [6]</td> <td>1</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>(3%)</td>							82.9	81.3		2							Minneapolis, MN (7882) [6]	1									(3%)
Normer Normer <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>45.4</td> <td>44.0</td> <td></td> <td>3</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>Portland, OR (4366) [4]</td> <td></td>							45.4	44.0		3							Portland, OR (4366) [4]										
							29.8	29.3		2							Knoxville, TN (3,685) [4]										
0 0 0 0 0 0 0 0 0							17.0	16.4		3							Las Vegas, NV (2,276) [3]	1									
Image: bit image:		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	(2%)
Image: product of the state of the							73.1	72.4		1							Minneapolis, MN (7882) [6]										(2.0)
A 1 · · · · · · · · · · · · · · · ·							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]										1%
Image: bit is and section in the section integrate is and section integrate. Note: bit is a sectin inteachine. Not: bit is a section integrate. Note: bit		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%)
VICA Image: Probability of the state of the							67.9	67.6		0.4							Minneapolis, MN (7882) [6]	-									
 							36.2	35.9		1							Portland, OR (4366) [4]										
Figure 1: 1: 1: 1: 1: 1: 1: 1: 1: 1: 1: 1: 1:							35.9	33.1			8						Knoxville, TN (3,685) [4]										
							17.9	16.0				11					Las Vegas, NV (2,276) [3]										11%
		DEG, 2000	R-11 (1.94)	Micropas	TRB	1,540	2.3	1.9					17				Miami, FL (155) [1]	-	-		×		×	N/A	N/A	N/A	(10%)
VICUP VICUP <th< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td>-</td><td>-</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Minneapolis, MN (7882) [6]</td><td>-</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></th<>							-	-									Minneapolis, MN (7882) [6]	-									
VP DEG, 2000 N:9 (3.3) Micropes THB N:A Si I Si I Si I Si S	60						44.5	40.6			9						Portland, OR (4366) [4]										
	Ē						32.8	31.2			5						Knoxville, TN (3,685) [4]	-									
OP 060,000 *19 (33) 0100 / (100) 130 0 0 0000 / (100) 010	□ ; =		0.40(0.05)				16.0	14.8			8	40					Las Vegas, NV (2,276) [3]	-									6%
P Image: biole	g	DEG, 2000	R-19 (3.35)	wicropas	TRB	1,540	2.0	1.8		4		10					Minnespelie MM (7882) [6]		-		×		×	N/A	N/A	N/A	(5%)
$ \ \ \ \ \ \ \ \ \ \ \ \ \ $	<u><u></u></u>						40.5	38.3		4	5						Portland OR (4366) [4]	1									
h = h = h = h = h = h = h = h = h = h							00.5	00.0			-																
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$							30.5	29.6		3	5						KnoxVille, IN (3,685) [4]	-									
A = 0 + 0 + 0 + 0 + 0 + 0 + 0 + 0 + 0 + 0		DEG 2000	B-30 (5.28)	Micronas	TRB	1 540	1.8	18		0							Miami El (155) [1]	· .	-		×		×	N/A	N/A	N/A	3%
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		020,2000		incropus		2,510	71.3	69.6		2							Minneapolis, MN (7882) [6]	1			<u> </u>						(3%)
$ \left[$							-	-									Portland, OR (4366) [4]	1									
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$							43.4	39.3			9						Knoxville TN (3.685) [4]										
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$							21.5	18.8				12					Las Vegas, NV (2,276) [3]	1							"normal"	"normal"	
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		DEG, 2000	R-11 (1.94)	Micropas	TRB	1,540	2.7	2.2					16				Miami, FL (155) [1]	- I	-		x	x		-	(180 CFM	(180 CFM	12%
Image: bit in the state in the sta							-										Minneapolis, MN (7882) [6]	1							per sq. ft.)	per sq. ft.)	(11%)
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$							53.1	47.7				10					Portland, OR (4366) [4]	1									
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$							39.7	37.3			6						Knoxville, TN (3,685) [4]										
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$							19.2	17.9			7						Las Vegas, NV (2,276) [3]	1							"normal"	"normal"	
Image: Problem		DEG, 2000	R-19 (3.35)	-19 (3.35) Micropas		1,540	2.4	2.1				10					Miami, FL (155) [1]	- I	-		x	x		-	(180 CFM	(180 CFM	7%
Increase Increase <th< td=""><td></td><td></td><td></td><td colspan="2"></td><td></td><td>95.3</td><td>90.2</td><td></td><td></td><td>5</td><td></td><td></td><td></td><td></td><td></td><td>Minneapolis, MN (7882) [6]</td><td>]</td><td></td><td></td><td></td><td></td><td></td><td></td><td>per sq. ft.)</td><td>per sq. ft.)</td><td>(770)</td></th<>							95.3	90.2			5						Minneapolis, MN (7882) [6]]							per sq. ft.)	per sq. ft.)	(770)
Ave: Ave: <th< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td>48.4</td><td>45.2</td><td></td><td></td><td>7</td><td></td><td></td><td></td><td></td><td></td><td>Portland, OR (4366) [4]</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></th<>							48.4	45.2			7						Portland, OR (4366) [4]										
DEG, 2000 R-30 (5.28) Micropes TR8 17.5 16.6 5 0 0 Las Vegas, NV (2,276) [3] - A							37.0	35.6		4							Knoxville, TN (3,685) [4]										
DEG, 2000 R-30 (5.28) Micropas TRB 1,540 2.2 2.0 5 Image: Constraint of the state of the stat							17.5	16.6			5						Las Vegas, NV (2,276) [3]]							"normal"	"normal"	
89.7 86.6 3 Mineapolis, MN (7882) [6] - - 0 0 Portland, OR (4366) [4]		DEG, 2000	R-30 (5.28)	Micropas	TRB	1,540	2.2	2.0			5						Miami, FL (155) [1]	-	-		x	x		-	(180 CFM	(180 CFM	4%
Portland, OR (4366) [4]							89.7	86.6		3							Minneapolis, MN (7882) [6]								per sq. ft.)	per sq. ft.)	
							-	-									Portland, OR (4366) [4]										

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 °F, while RBs in the HRB configuration would reduce the attic temperature by an average of 4 °F

THANK YOU