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A REVIEW OF INTERIOR RADIATION CONTROL COATING RESEARCH

An Interior Radiation Control Coating (IRCC) is a low-emittance paint or coating applied to building materials to reduce the thermal transmission across the space. Emittance or emissivity refers to the percent of radiant heat that a hot object emits or radiates. Building materials like wood and masonry typically have a very high thermal emittance and can have upwards of 80% radiant heat transmission. Due to the low-emissive properties of the coating, a building product's thermal emissivity can be reduced down to 25% or less.

While similar in function, an IRCC is notably different from a sheet radiant barrier. A sheet radiant barrier is a separate building component with a low emissive surface (0.10 or less) added to the building assembly, while an IRCC is a coating applied to an existing building component to lower that component's emissivity. To qualify (under the ASTM definition) as an IRCC, the coating must be able to reduce the emissivity to 0.25 or less.

IRCC technology has been proven by numerous laboratory and field experiments to significantly reduce the radiant heat transfer across vented spaces between roofs and ceilings of buildings. The exact reduction in radiant heat transfer can be partly explained by the equation below, which represents the net transfer of heat by radiation between two surfaces (e.g., the roofing materials, and the top surface of the ceiling insulation). Basically, the IRCC works by altering the emittance value ε of at least one of the surfaces in the assembly. Note that this equation is oversimplified in many ways, but it presents a snapshot of the physics involved when an IRCC is installed in the space.

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

In this equation, ε represents the surface emissivity. The term σ is called the Stefan-Boltzmann constant and it has a value of 0.1714 Btu/hr $\cdot ft^{2} \cdot {}^{o}R^{4}$, and T is the temperature of the surface in ^{o}R (degrees Rankine). A degree Rankine is equal to the temperature in o F plus 459.69. For simplicity, this equation assumes that the areas of the top surface (e.g., the roof) and the bottom surface (e.g., the insulation) are equal and that all the radiant heat that is emitted by the roof arrives at the insulation.

The two most common materials used for roof decks in residential buildings are plywood and oriented strand board (OSB). The average emissivities of plywood and OSB are 0.91 and 0.93, respectively (Infrared Services, Inc., 2010). The average emissivity of attic insulation, including fiberglass and cellulose, is 0.85 (ASHRAE, 2009). Therefore, assuming a deck temperature of 130 ^{o}F and a top-of-insulation temperature of 110 ^{o}F, which are not uncommon values in most parts of the U.S. during the summertime; and assuming the deck to be OSB and the insulation fiberglass, this equation gives the rate of radiant heat transfer as 21.4 Btu/hr ft^2. A typical value for an IRCC is about 0.23 (Yarbrough, 2006), so depending on exactly how the IRCC is applied, the total radiant heat transfer rate can be reduced by as much as 72.4%.

Roof Emissivity	Ceiling Insulation Emissivity	Representative Case	Radiant Heat Transfer Rate (Btu/hr ft²)	Percent Reduction with Respect to Base Case
0.93	0.85	Base Case(1) (Standard Attic)	21.4	-
0.29(2)	0.85	IRCC applied to roof decking	7.38	65.5 %
0.23	0.85	IRCC applied to roof decking and rafters/trusses	5.92	72.4 %

(1) *The base case is comprised of standard OSB decking and plywood rafters/trusses, with no radiant barrier or Interior Radiation Control Coating of any kind.*
(2) *Based on the weighted emissivity of a typical IRCC (0.23 emissivity) and of typical wood rafters (0.87 emissivity) for ratios of 90.6% for IRCC and 9.4% for wood rafters.*

The results summarized in this document, both experimental and computorial, are given in as ceiling heat flux reductions and space cooling load reductions as percentages to simplify comparisons between buildings with and without IRCCs. The effectiveness (i.e., the “thermal performance”) of IRCCs is often an indication of the percent reductions that IRCCs produce.

Two well-established and widely accepted methods for evaluating the performance of IRCCs are laboratory tests and computer simulations. Laboratory tests have the advantage that several parameters, such as roof temperature and wind speed, can be controlled, which allows first order parameters, such as ceiling heat fluxes, to be isolated and studied. Although laboratory tests are well received and are essential in the study of IRCCs, one of the short comings is that conditions are not entirely reproduced in a laboratory setting. As a result, most laboratory experiments are carried out under steady-state conditions, which are not representative of the conditions in which buildings operate. Another way to evaluate the thermal performance of IRCCs is computer simulation using mathematical models. These mathematical models can approximate and take into account other variables, like outdoor (weather-like) conditions, not entirely reproduced in a laboratory setting.

SIMULATED RESULTS HIGHLIGHTING CEILING HEAT FLOW REDUCTIONS PRODUCED BY 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 (%) 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 -	City, St	CDD	Climatic Zone	Ventilation: Vents		FV	NV	Occupied: N	Y	Comments	Average
	Medina (2010)														45				Minneapolis, MN	699	6	S	G	X		X			
	Medina (2010)												37						Washington, DC	1,243	4	S	G	X		X			
	Medina (2010)											34							Denver, CO	696	5	S	G	X		X			
	Medina (2010)											33							Charlotte, NC	1,681	3	S	G	X		X			
	Medina (2010)											32							Atlanta, GA	1,810	3	S	G	X		X			
	Medina (2010)											31							Louisville, KY	1,443	4	S	G	X		X			
	Medina (2010)											30							Kansas City, MO	1,676	4	S	G	X		X			
Cooling	Medina (2010)	R-19	Side-by-Side	IRCC (E = 0.19)							26								Sacramento, CA	1,248	3	S	G	X		X			25%
	Medina (2010)										25								Riverside, CA	1,863	3	S	G	X		X			
	Medina (2010)									24									Miami, FL	4,361	1	S	G	X		X			
	Medina (2010)									22									Salt Lake City, UT	1,066	5	S	G	X		X			
	Medina (2010)									22									San Antonio, TX	3,038	2	S	G	X		X			
	Medina (2010)							7											Phoenix, AZ	4,189	2	S	G	X		X			
	Medina (2010)							5											Las Vegas, NV	3,214	3	S	G	X		X			
	Medina (2010)						2												San Francisco, CA	142	3	S	G	X		X			

Legend: CDD = Cooling Degree Days, HDD = Heating Degree Days, 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, N/A = Not Applicable, (-) = Not Specified

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(CONTINUED) SIMULATED RESULTS HIGHLIGHTING SPACE COOLING LOAD REDUCTIONS PRODUCED BY THE INTERIOR RADIATION CONTROL COATINGS																												
Season	Reference	Nominal Insulation Level R-Value	Model	Method	Ceiling Area	Cooling Load Base (kWh)	Cooling Load w/RB (kWh)	Space Load Reduction (%)								City, St	CDD	Climatic Zone	Ventilation				Includes Ducts in the Attic		Duct Insulation Level	Duct Leakage Rate		Average
								Cooling																				
								-5	0 - 4	5 - 9	10 - 14	15 - 19	20 - 24	25 - 29	30->				Vents		FV	NV	Y	N		Supply	Return	
Cooling	Enercomp (2008)	R-11	Micropas	IRCC (E = 0.20)	1,500	101	69								32	CA Climatic Zone 1	-	3	-	-		1/300	X		R-4.2	Duct Leakage Factor = 0.89		14%
						3,931	3,457				12					CA Climatic Zone 2	-	3										
						697	563					19				CA Climatic Zone 3	-	3										
						2,555	2,195				14					CA Climatic Zone 4	-	3										
						820	648						21			CA Climatic Zone 5	-	3										
						1,099	905					18				CA Climatic Zone 6	-	3										
						1,849	1,543					17				CA Climatic Zone 7	-	3										
						3,953	3,430				13					CA Climatic Zone 8	-	3										
						5,483	4,854				11					CA Climatic Zone 9	-	3										
						7,382	6,623				10					CA Climatic Zone 10	-	4										
						7,691	7,008			9						CA Climatic Zone 11	-	3										
						5,962	5,410			9						CA Climatic Zone 12	-	3										
						10,790	9,842			9						CA Climatic Zone 13	-	3										
						9,086	8,355			8						CA Climatic Zone 14	-	4										
						19,593	18,312			7						CA Climatic Zone 15	-	5										
						2,530	2,202				13					CA Climatic Zone 16	-	2										

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

(CONTINUED) SIMULATED RESULTS HIGHLIGHTING SPACE HEATING LOAD REDUCTIONS PRODUCED BY THE INTERIOR RADIATION CONTROL COATINGS																												
Season	Reference	Nominal Insulation Level R-Value	Model	Method	Ceiling Area	Heating Load Base (MMBtu)	Heating Load w/RB (MMBtu)	Space Load Reduction (%)								City, St	HDD	Climatic Zone	Ventilation				Includes Ducts in the Attic		Duct Insulation Level	Duct Leakage Rate		Average
								Heating																				
								-5	0 - 4	5 - 9	10 - 14	15 - 19	20 - 24	25 - 29	30->				Vents		FV	NV	Y	N		Supply	Return	
Heating	Enercomp (2008)	R-11	Micropas	IRCC (E = 0.20)	1,500	3.84	3.74		3							CA Climatic Zone 1	-	3	-	-		1/300	X		R-4.2	Duct Leakage Factor = 0.89		4%
						2.99	2.89		3							CA Climatic Zone 2	-	3										
						2.19	2.13		3							CA Climatic Zone 3	-	3										
						2.25	2.18		3							CA Climatic Zone 4	-	3										
						2.22	2.15		3							CA Climatic Zone 5	-	3										
						1.04	1.00		4							CA Climatic Zone 6	-	3										
						0.92	0.87			5						CA Climatic Zone 7	-	3										
						1.07	1.02			5						CA Climatic Zone 8	-	3										
						1.08	1.04		4							CA Climatic Zone 9	-	3										
						1.45	1.38		4							CA Climatic Zone 10	-	4										
						2.88	2.80		3							CA Climatic Zone 11	-	3										
						2.70	2.63		3							CA Climatic Zone 12	-	3										
						2.13	2.07		3							CA Climatic Zone 13	-	3										
						2.95	2.84		4							CA Climatic Zone 14	-	4										
						0.75	0.71			5						CA Climatic Zone 15	-	5										
						6.29	6.15		2							CA Climatic Zone 16	-	2										

Legend: CDD = Cooling Degree Days, HDD = Heating Degree Days, 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, N/A = Not Applicable, (-) = Not Specified

EXPERIMENTAL RESULTS HIGHLIGHTING CEILING HEAT FLOW REDUCTIONS PRODUCED BY THE 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	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					
Cooling	Swami and Fairey (1986)	R-19	Laboratory Controlled	IRCC								32							N/A			Flat Roof	32%

Legend: CDD = Cooling Degree Days, HDD = Heating Degree Days, IRCC = Interior Radiation Control Coating, N/A = Not Applicable, (-) = Not Specified

Data from laboratory controlled experiments indicate that IRCCs reduce the summer ceiling heat flows by as much as 32% in an attic with R-19 ceiling insulation. Simulated data indicate that IRCCs would reduce the summer heat flows across the ceiling by an average of 25% in attics with R-19 ceiling insulation. Simulated results predict that IRCCs installed in attics of residential buildings would reduce the space cooling load by an average of 14% and the space heating load by an average of 4%, in both cases for attics with an insulation level of R-11, where the air handling ducts are placed in the attic.

Depending on your exact application, IRCCs can contribute to the overall thermal performance of a building, but many variables need to be considered, like the exact emittance of the coating, the level of existing insulation (R-value), and the climate in which the IRCC is installed, to name a few. For more information on the research described above, or on Interior Radiation Control Coatings (IRCCs) in general, please contact us.

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