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Evaluation of Ceiling Heat Fluxes in Residential Buildings with Attic Radiant Barriers in Prevalent Climates Across the United States

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ABSTRACT

This paper illustrates how climate affects the performance of attic radiant barriers. The 48 contiguous United States were subdivided into nine predominant climatic regions and a transient heat and mass transfer computer model was used to evaluate the performance of radiant barriers, based on ceiling heat transfer reductions. The simulations were driven by TMY2 weather data from stations within the climatic regions. Results based on integrated hourly ceiling heat fluxes over a 3-month period showed that radiant barriers were most effective in the Tropical Savanna climate (i.e., southern tip of the State of Florida) and least effective in the Mediterranean climate (i.e., the State of California and western regions of the States of Nevada and Arizona). Summer-integrated percent reduction in ceiling heat transfer, based on an insulation level of 3.5 m^2K/W (R-19), ranged from 36.8 percent to 2.3 percent. Peak-hour percent reductions in ceiling heat flux ranged from almost 100 percent in the Marine West Coast climate (i.e., the states of Oregon, Washington, the western region of Idaho, and the northwest part of Nevada) to 23 percent in the Desert climate (i.e., large portions of the states of Arizona, Nevada, Utah, New Mexico, and western Texas).

INTRODUCTION

Studies have shown that about 70 to 90 percent of summer ceiling heat gains normally occur through radiation from solar-heated roof surfaces (Bourne et al., 1990). Radiant barriers are used to decrease the infrared radiation from the attic deck to the top of the insulation on the attic floor. The barriers are basically thin aluminum sheets that have at least one low-emissivity surface of less than 0.05. Aluminum is normally used because it is inexpensive and once exposed to the elements its surface becomes covered with a layer of transparent oxide that helps in maintaining its emissivity value unchanged for long periods. Radiant barriers are considered opaque, and by Kirchoff's law, their emissivity and absorptivity are equal because the surfaces are diffuse and the incident radiation is independent of angle. This means that by facing the reflective side of the radiant barrier to the attic air space only 5% of the incident infrared radiation would be absorbed and emitted and the remaining 95% would be reflected. Radiant barriers are installed in three configurations: horizontally over the ceiling frame (Horizontal Radiant Barrier - HRB), stapled against the trusses (rafters) of the attic (Truss Radiant Barrier - TRB), or attached directly to the plywood deck (Draped Radiant Barrier - DRB). The performance of the barrier is very similar in all three installation methods.

The major topographic features that influence the climate of the contiguous 48 states of the United States are the Sierra Nevada-Cascade ranges and the Rocky Mountains in the west from the Canadian to the Mexican border, and the Appalachian Mountains in the east. Important bodies of water include the Gulf of Mexico, the Great Lakes, and the Atlantic and Pacific Oceans. The climates of the states are classified as Continental, where the essential control is the land; Marine, where the control is the ocean; and Mountain, where altitude is the key control. An extreme development of the continental climate is the desert climate.

Midsummer temperatures are highest over the southwestern desert and inland close to the Gulf Coast, where afternoon readings of more than 38 °C (100 °F) are not uncommon. In the midsection of the country afternoon temperatures range from about 35 °C (95 °F) north of the Gulf of Mexico to about 27 °C (81 °F) near the Canadian border. Sea breezes and oceanic effects result in more moderate temperatures along the Pacific and Atlantic coasts. Mountain peaks in the west are generally the coolest locations in summer; on the East Coast, mountain locations are also cooler than the surrounding piedmont areas, but not as high, so not as cool as the Rocky Mountains.

In winter, the coastal areas are usually warmer than inland regions; as a consequence, the Pacific Coast, the Gulf Coast, and Florida experience the shortest and mildest winters, with average temperatures ranging from about 3.3 °C (38 °F) in the state of Washington to 10 °C (50°F) in southern California, and 15 °C (59 °F) to 20 °C (68 °F) along the Gulf Coast and in Florida. Along the Atlantic Coast, north of the Carolinas, the moderating effect of the Atlantic Ocean is less pronounced. Away from the eastern and western coasts, in the mountains, monthly temperatures vary directly with latitude. Average winter temperatures range from about -15 °C (5 °F) in the northern plains to about 10 °C (50 °F) to 15 °C (59 °F) near the Gulf coast.

In the middle third of the country, the average frost-free period decreases northward. Along the Gulf of Mexico the average frost-free period is 330 days and less than 90 days at the Canadian border. In the northern part of the Great Lakes region the average frost-free period is less than 60 days. In the eastern third, the frost-free period ranges from more than 330 days in southern Florida to less than 90 days in Maine. Mountainous areas generally experience a shorter frost-free period than surrounding piedmont areas. In the West, the Southwestern Desert, and the Pacific Coast have frost-free periods of more than 300 days at low elevations, but in mountainous regions, the period can be less than 30 days.

By means of temperature and precipitation regimes the three main climates are subdivided into nine climatic regions, four that are located east of the 100° W meridian and five located west of it. The Tropical Savanna (TS), Humid Subtropical (HS), Humid Continental Warm Summer (HCWS), and the Humid Continental Cool Summer (HCCS) climates are found east of the 100°W meridian; the Western High Areas (WHA), Desert (D), Mediterranean (M), Steppe (S), and Marine West Coast (MWC) climates are found to the west of it. The climate subdivision map is shown in Figure 1. The subdivision of the continental US into these climatic regions was important in this study because it is believed that ambient air temperature and humidity play first order effect on the performance of radiant barriers.

The Tropical Savanna climate, which affects residents in the southern tip of the State of Florida (23,000 mi^2), is a hot climate with hot and humid summers and with one distinct dry season (winter). The average monthly summer temperature and relative humidity are around 28 °C (82 °F) and 77%, respectively. The Humid Subtropical climate is a warm, temperate, and rainy climate with no distinct dry season. This climate is found along the east coast from Rhode Island and Pennsylvania to central Florida and then west to the 100th parallel, in the State of Texas, and connecting to the northeast through Arkansas, Kentucky and West Virginia. Average summer temperature and relative humidity for this region are 29 °C (84 °F) and 68%, respectively. Twenty-one states and the District of Columbia, for a total area of 750,400 mi^2 (24.1 % of the mainland area) are affected, in varying degrees, by this climate alone. The Humid Continental Warm Summer region is mainly a cold climate, though summers are warm and humid. This climate affects largely the Midwest states, an area of 640,000 mi^2 (20.5% of land), which includes 17 states east of the Rockies to the eastern part of Pennsylvania and south of Lakes Michigan and Erie and as north as the border between the Dakotas. The Humid Continental Cool Summer region and Western High Areas are similar climates. They are characterized by cold climates with cool summers and humid winters. The HCCS covers the area east and west, along the same latitude, of the Great Lakes from North Dakota to Maine. This climate affects an area of 350,200 mi^2 (11.2 % of land). The WHA climate affects five states, but mainly Colorado and Wyoming, from the southern part of Montana to the northern part of New Mexico and as west as Utah. It covers an area of 187,000 mi^2 (6%). The Steppe climate is a mid-latitude cold and dry region in which there is usually a winter drought. Its summers are cold and dry. The region comprises eight states located from the Canadian border from Idaho to the Dakotas and as south as the northern regions of the states of Nebraska, Utah, and Nevada for a total land area of 286,000 mi^2 (9.2%). In the Desert climate precipitation is meager year round and temperatures are high. The months of April through July are very dry. This climate is found in 473,300 mi^2 (15.2%) of land. A classic Mediterranean climate has three times as much rain in the wettest month of winter as in the driest month of summer. It has cool and pleasant summers. This climate is found in most of the state of California, except the northern region, and the western part of Nevada and the southwest part of Arizona. This climate comprises an area of 197,000 mi^2 (6.3%). The Marine West Coast is a warm, temperate, rainy climate. Most of the precipitation occurs in the winter, and there is little during the summer months. The states of Oregon, Washington, the western region of Idaho, and the northwest part of Nevada are affected by this climate, which covers an area of 216,800 mi^2 (6.9%).

Table 1 provides summer weather data for the nine climates. These are the summer mean monthly values of temperature, relative humidity, and wind speed. It also includes area covered.

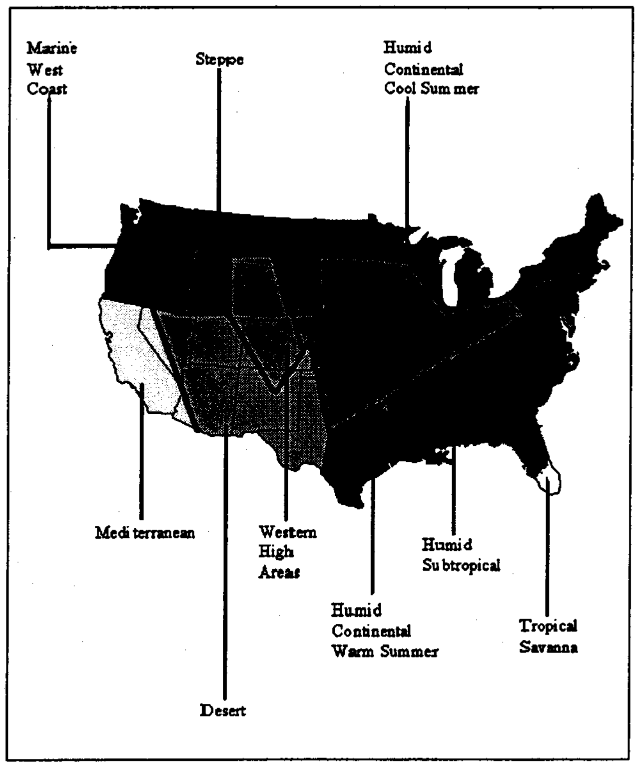

Figure 1. Climatic Regions of the Continental United States

Table 1. Summer Weather Data for the Nine Climates Found in the Continental United States

Climate	Summer Monthly Dry Bulb Air Temperature °C (°F)	Summer Monthly Relative Humidity (%)	Summer Monthly Wind Speed km/h (mi/h)	Area Covered km² (mi²)	Percent Area Covered (%)
Humid Subtropical	29 (84)	68	13.7 (8.5)	1,939,636 (750,430)	24.03
Humid Continental Warm Summer	25 (77)	70	14.1 (8.8)	1,655,112 (640,350)	20.50
Desert	28 (83)	47	13.0 (8.1)	1,223,467 (473,350)	15.16
Humid Continental Cool Summer	21 (70)	67	14.0 (8.7)	905,291 (350,250)	11.21
Steppe	17 (62)	43	12.7 (7.9)	739,043 (285,930)	9.15
Marine West Coast	15 (59)	80	13.3 (8.3)	560,259 (216,760)	6.94
Mediterranean	17 (63)	74	16.1 (10.0)	508,837 (196,865)	6.30
Western High Areas	20 (68)	50	13.7 (8.5)	481,581 (186,320)	5..97
Tropical Savanna	28 (83)	77	12.9 (8.0)	59,484 (23,014)	0.74
TOTAL				8,072,711 (3,123,269)	100.00

Radiant Barrier Performance

A measure of the performance of an attic radiant barrier is the percentage reduction in ceiling heat transfer that it produces. Once the ceiling heat fluxes were obtained from running the computer model, the percentage reductions were found using Equation 1.

$$Percent\ Reduction = \frac{\int_{Evaluation\ Period} q''_{no\ RB}\, dt - \int_{Evaluation\ Period} q''_{RB}\, dt}{\int_{Evaluation\ Period} q''_{no\ RB}\, dt} x100 \qquad \text{Eq. 1}$$

where

q''_{RB} = Ceiling heat flux when a radiant barrier is present in the attic, W/m^2 ($Btu/h{\cdot}ft^2$)

q''_{noRB} = Ceiling heat flux when there is no radiant barrier present in the attic, W/m^2 ($Btu/h{\cdot}ft^2$)

Description of Computational Model

A transient heat and mass transfer computer model for an attic structure was used in this study. The attic used in the development of the model was composed of two equal-length pitched roof sections, two vertical gable-ends sections, and one horizontal ceiling frame. The model was based on the first law of thermodynamics and it allowed instantaneous sensible and latent cooling and heating loads to be calculated based on energy balance equations written for each enclosing surface and for attic air layers. A full description of the model is found in Medina et al. (1998a) and its verification against experimental data is found in Medina et al. (1998b).

The known parameters input to the program included attic dimensions, radiation constants (outer surface absorptivities, outer and inner surface emissivities), percent surface covered by wood, permeance of attic components and wood moisture content, longitude, latitude and time zone of the location. The hourly data included day, hour, outdoor air temperature, global horizontal solar radiation, wind speed, relative humidity, dew point and cloud cover. A set of linear equations was developed, which set up a matrix of the form

$$\mathbf{MT} = \mathbf{P} \qquad \text{Eq. 2}$$

Matrix **M** contained information about the conduction transfer functions, convection and radiation coefficients, and attic air stratification. Matrix **P** contained information about previous values of heat fluxes at each surface and historical values of all surface temperatures, indoor air temperature, outdoor air temperature, solar radiation at each surface, sky temperature, convection and radiation coefficients, conduction transfer functions and the common ratios. The matrix **T** was solved for surface and attic air temperatures. The computer model was driven using TMY2 weather data of fifteen stations within the climatic regions. A ceiling insulation with a thermal resistance of 3.35 $m^2{\cdot}K/W$ (R-19) was assumed. The output of the model was hourly ceiling heat fluxes for both the radiant-barrier case and the no-radiant-barrier case.

RESULTS AND DISCUSSION

Sample profiles of ceiling heat fluxes for selected stations in the climatic regions are presented, which describe the performance of the radiant barriers. The profiles serve as a useful analytical tool that helps one understand how radiant barriers work in the various climates. Although the performance of the attic radiant barriers was evaluated continuously during the entire summer months (June through August), for clarity reasons full three-months profiles are not shown. The profile time frame spans seven typical summer days (July 25 to July 31).

Tropical Savanna, Humid Subtropical, and Desert Climates

Results from these three climates were lumped together because similarities in radiant barrier performance under these climates were exhibited. Table 2 shows relevant summer means data of ambient air temperature, ambient air relative humidity, hourly global horizontal solar radiation, and sky cloud cover fraction for three cities, each representing a climate. As depicted in Figures 2, 3, and 4 the key similarity is that under these climates that heat transfer is mostly always into the conditioned space. That is, attic temperatures are generally always higher than the temperatures in the conditioned space.

Table 2. Summer Weather Data for Miami, San Antonio, and Tucson

Station	Mean Temp. °C (°F)	Mean Relative Humidity (%)	Mean Hourly Global Horizontal Solar Radiation W/m^2 (Btu/hr-ft^2)	Mean Sky Cloud Cover Fraction
Miami, FL	28 (82)	74	478 (152)	0.57
San Antonio, TX	27 (81)	66	533 (169)	0.49
Tucson, AZ	29 (84)	37	536 (170)	0.40

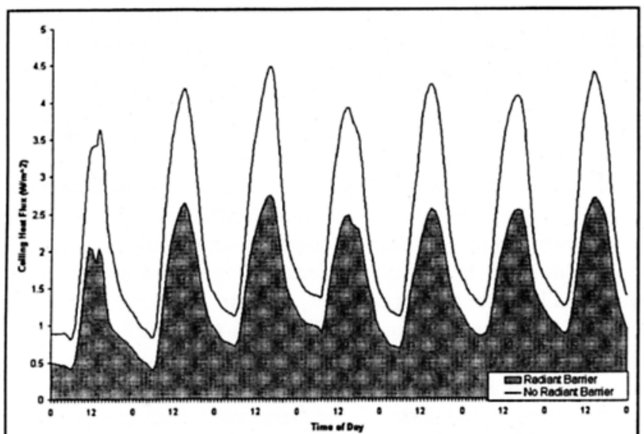

Figure 2. Ceiling Heat Flux Profile for Tropical Savanna Climate, Miami, FL, July 25-31

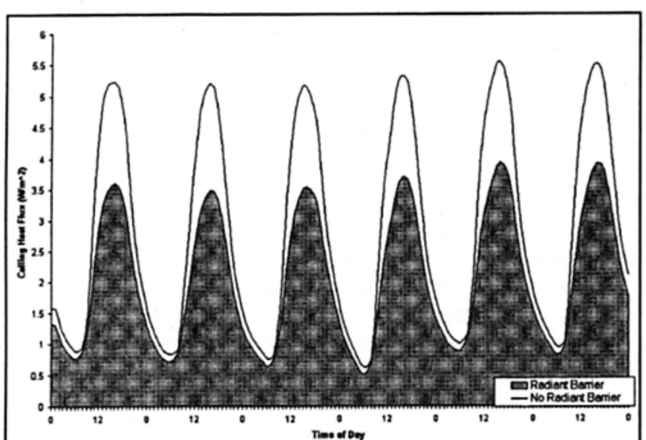

Figure 3. Ceiling Heat Flux Profile for Humid Subtropical Climate, San Antonio, TX, July 25-31

Radiant barrier performance profiles prove the usefulness of the technology in these climates as they help to reduce the ceiling heat gains, which increase during periods of high solar activity. During these periods radiant barriers, because of their low emissivity and absorptivity, decrease the infrared radiation from the attic deck to the top of the insulation on the attic floor. In the afternoons the interior surfaces of the attic deck reach between 54 °C (129 °F) and 60 °C (140 °F). Ventilation air also helps in reducing attic air temperatures by enhancing the convective component from the attic floor to the attic air.

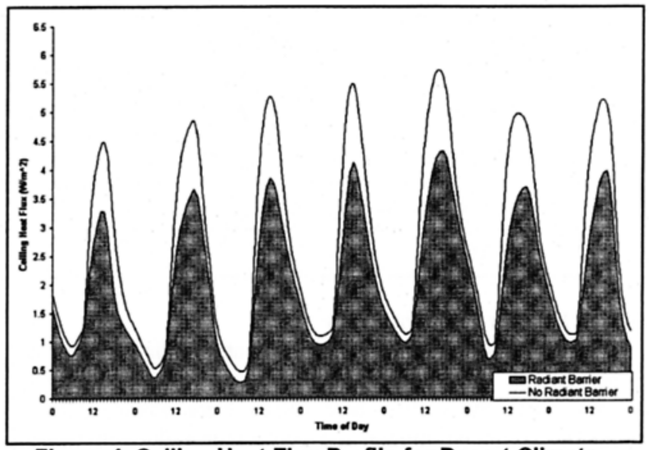

Figure 4. Ceiling Heat Flux Profile for Desert Climate, Tucson, AZ, July 25-31

The profiles show that in the Tropical Savanna climate radiant barriers are useful throughout the entire 24 hours of the day. In the Humid Subtropical and in the Desert climates radiant barriers are mainly useful during the hours of 10 AM through 6 PM, but still help somewhat in decreasing the heat transfer rate during nights and early mornings. That is, best possible performance is achieved during the periods of high solar radiation. The largest heat flux reduction during the on-peak hour is produced in the Tropical Savanna climate; 42 percent compared to 31 percent and 24 percent in the Humid Subtropical and Desert climates, respectively. The overall 3-month integrated ceiling reductions in heat transfer in the three climates were 36.8, 34.3, and 23.0 percent for the Tropical Savanna, Humid Subtropical, and Desert climates, respectively. From observing the weather data of Table 2 these results are not obvious because mean air temperatures are almost identical and mean hourly global horizontal solar radiation and cloud cover fraction are least and highest, respectively, in the Tropical Savanna climate. The reason for these results is the higher relative humidity of the Tropical Savanna climate. This means that higher solar loads alone do not drive the performance of radiant barriers, but instead a combination of solar load, which drives the ambient air temperatures, and humidity. In humid climates an evaporation process, of deposited moisture, takes place in the attic surfaces. The evaporation produces a cooling effect in the attic surfaces, which seems to be greater in the attic fitted with radiant barriers, thus producing the largest difference in ceiling heat fluxes between control and retrofit cases. In the Tropical Savanna climate this process continues until the late hours of the day. This translates to largest observed ceiling heat transfer reductions in this climate.

Humid Continental Warm Summer, Humid Continental Cool Summer, Western High Areas, and Steppe Climates

In these climates, heat transfer across the ceiling travels in both directions, to and from the conditioned space, as a result of ambient air temperature, which drop below the indoor air temperature of 24 °C (75 °C). This is evident from the summer mean air temperatures shown in Table 3.

Table 3. Summer Weather Data for Minneapolis, Topeka, Boulder, and Helena

Station	Mean Temp. °C (°F)	Mean Relative Humidity (%)	Mean Hourly Global Horizontal Solar Radiation W/m^2 (Btu/hr-ft^2)	Mean Sky Cloud Cover Fraction
Minneapolis, MN	21 (70)	68	489 (155)	0.52
Topeka, KS	23.3 (74)	67	511 (162)	0.45
Boulder, CO	20.5 (69)	49	501 (159)	0.50
Helena, MT	18 (65)	48	523 (166)	0.47

The performance profiles of Figures 5 through 8 show that radiant barriers are effective in reducing heat transfer across the ceiling during the daytime hours, when the solar loads are high, but are not effective during the night and early morning hours. The profiles further indicate that outdoor temperature falls below the indoor temperature of 24 °C (75°F) for approximately half of the day. Cool nights and mornings are characteristic of these climates likely due to enhanced sky radiation, which is further enhanced by atmospheric dryness.

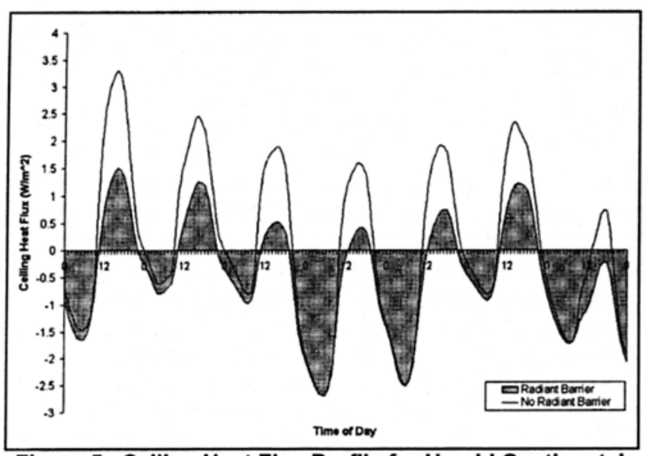

Figure 5. Ceiling Heat Flux Profile for Humid Continental Cool Summer Climate, Minneapolis, MN, July 25-31

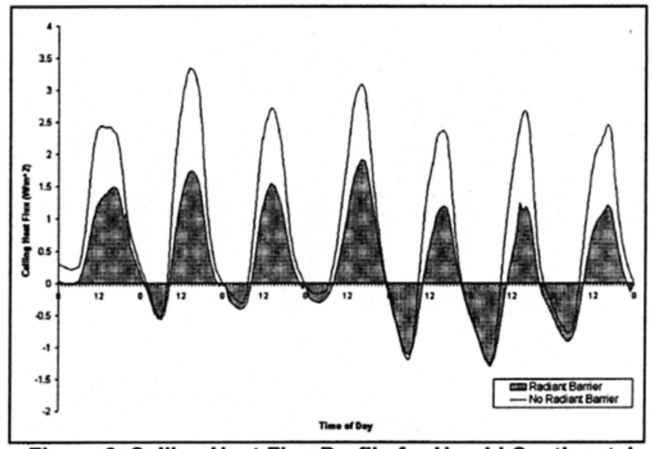

Figure 6. Ceiling Heat Flux Profile for Humid Continental Warm Summer Climate, Topeka, KS, July 25-31

Although the summer mean air temperatures in these climates are approximately 7 °C (13 °F) lower than the temperatures of the previous three climates, while the solar loads are comparable, the peak-hour heat flux reductions are higher in the four climates of this section. The peak-hour ceiling heat flux reductions are 54, 46, 44, and 36 percent for the Humid Continental Cool Summer, Humid Continental Warm Summer, Western High Areas, and Steppe climates, respectively. However, the overall 3-month integrated percent reductions for the same climates are 25.7, 30, 19.7, and 13.7, respectively, which are much lower than their equivalent values for the previous three climates. The reason for these lower integrated values, particularly in the Western High Areas and the Steppe climates, is the zero contribution of the radiant barriers during nights and early morning hours.

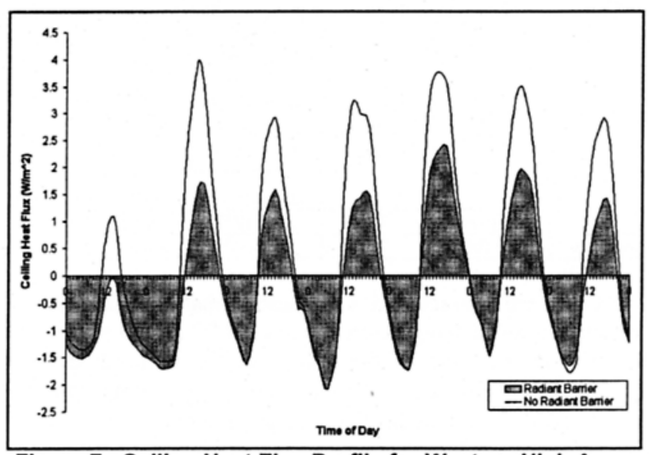

Figure 7. Ceiling Heat Flux Profile for Western High Areas Climate, Boulder, CO, July 25-31

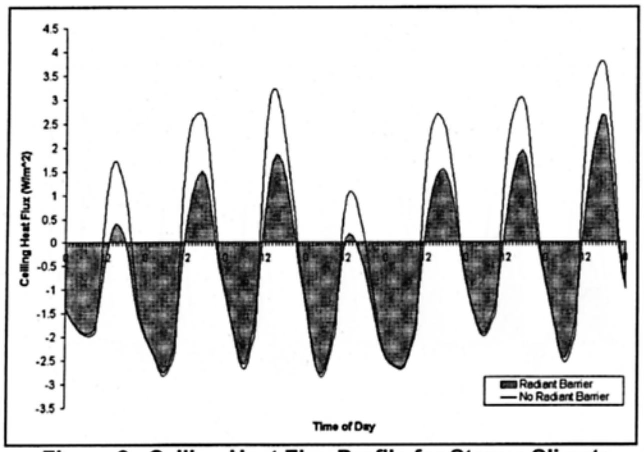

Figure 8. Ceiling Heat Flux Profile for Steppe Climate, Helena, MT, July 25-31

Marine West Coast and Mediterranean Climate

Table 4 shows the mean summer weather data for Marine West Coast and for the Mediterranean climates.

Figures 9 and 10 show that on a typical afternoon the hourly percentage reduction in ceiling heat flux for the Marine West Coast climate is about 100 percent and approximately 97 percent for the Mediterranean climate. The radiant barriers block nearly all heat transfer into the conditioned space. The heat loss from the residences across the ceilings is practically the same in both the retrofit and control cases in both the Marine West Coast and Mediterranean climates. This means that if space heating were required during the nighttime and early mornings in these climate, having radiant barriers installed would not translate into more costs due to space heating.

Table 4. Summer weather data for Astoria and San Francisco

Station	Mean Temp. °C (°F)	Mean Relative Humidity (%)	Mean Hourly Global Horizontal Solar Radiation W/m^2 ($Btu/hr\text{-}ft^2$)	Mean Sky Cloud Cover Fraction
Astoria, OR	15 (59)	77	394 (125)	0.73
San Francisco, CA	15.5 (60)	73	542 (172)	0.34

Ocean breezes are characteristics of these climates. Thus, as cool ventilation air at temperatures below 24 °C (75°F) enters the attic the temperature of the attic, T_{attic}, is reduced and $|T_{insulation} - T_{attic}|$ is increased. Also, the convected heat transfer between the attic air and the insulation is given by

$$Q_{convection} = h_c A \,|(T_{insulation} - T_{attic})| \qquad \text{Eq. 3}$$

where A represents the surface area exposed to convection. Chen et. al. (1992), proved that h_c is greater for upward heat flow. These two factors tend to bring about an increase in convection heat transfer, Q_{con}, from the top of the insulation to the attic air. Under these circumstances the radiant barriers are unable to prevent heat loss from the conditioned space. Therefore, there is no significant difference between the ceiling heat flux for the radiant barrier case and no radiant barrier case.

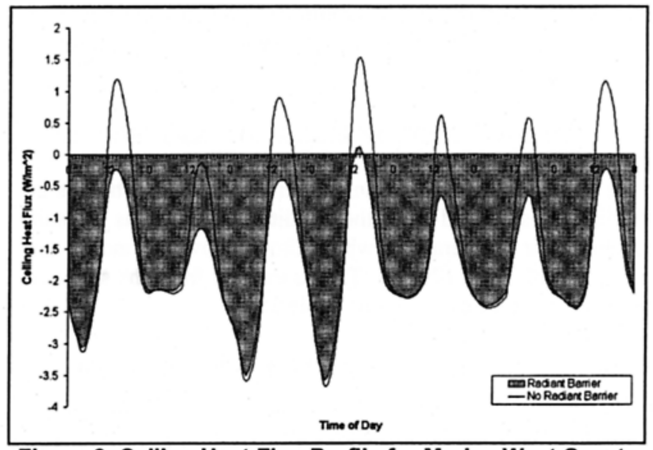

Figure 9. Ceiling Heat Flux Profile for Marine West Coast Climate, Astoria, OR, July 25-31

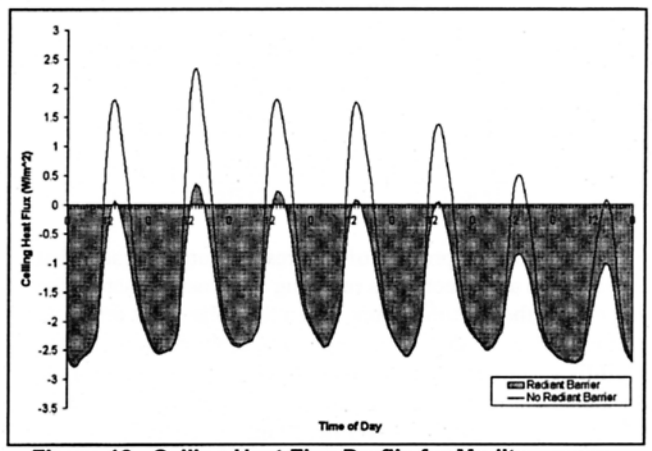

Figure 10. Ceiling Heat Flux Profile for Mediterranean Climate, San Francisco, CA, July 25-31

SUMMARY

A measure of the performance of an attic radiant barrier is the percentage reduction in ceiling heat transfer that it produces. Once the ceiling heat fluxes were obtained by running the model, the percentage reductions in ceiling heat flux were estimated using Equation 1. The analysis was done based on the hourly data during a three-month period from June 1 through August 31 using synthesized TMY2 weather files. Table 5 presents the performance of attic radiant barriers in selected cities representative of the nine climatic regions of the continental United States. It is evident from the values that performance of attic radiant barriers depends on the climate in which the building is located. For the climates considered, the summer integrated percent reduction in ceiling heat flux varied from 2.3% in the Mediterranean climate to 36.8% in the Tropical Savanna climate. The peak-hour heat flux reductions varied from 23% in the Desert climate to about 100 percent in the Marine West climate. The results reveal that attic radiant barriers will prove useful in all the climates.

Table 5. Performance Data of Attic Radiant Barriers in the Continental United States

Climate	Sample Station	Summer Integrated Percent Reduction (%)	Peak-Hour Heat Flux Reduction in Represented Climate (%)
Humid Subtropical	San Antonio, Texas New York- New York Atlanta, Georgia	34.3 32.5 38.5	31
Humid Continental Warm Summer	Topeka, Kansas Indianapolis, Indiana	30.0 30.1	46
Desert	Las Vegas, Nevada Tucson, Arizona	19.2 23.0	23
Humid Continental Cool Summer	Minneapolis, Minnesota Detroit, Michigan	25.7 24.3	54
Steppe	Pocatello, Idaho Helena, Montana	16.0 13.7	36
Marine West Coast	Astoria, Oregon	9.6	~100
Mediterranean	San Francisco, California	2.3	97
Western High Areas	Boulder, Colorado	19.7	44
Tropical Savanna	Miami, Florida	36.8	42

Figure 11 shows the summer integrated average performance of attic radiant barriers across the continental United States.

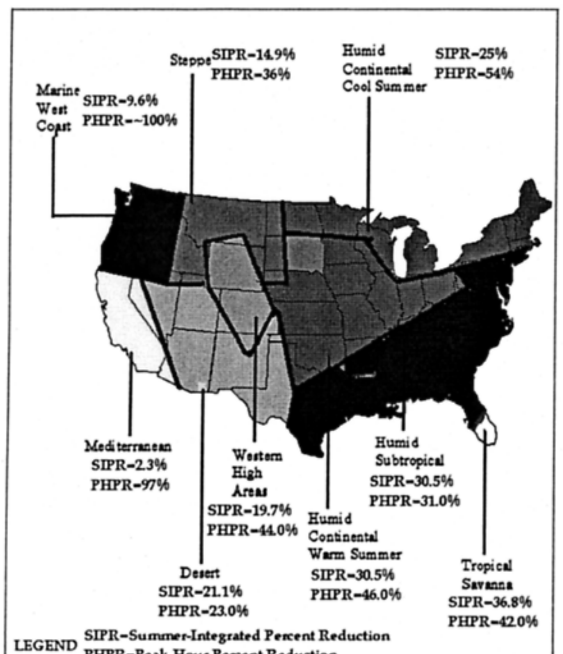

Figure 11. Map Showing Summer-Integrated and Peak-Hour Performance of Attic Radiant Barriers Across the Continental United States

It also depicts the peak-hour ceiling heat flux reductions. Using this map one can roughly estimate the percentage reduction in ceiling heat flux that would be achieved by a radiant barrier in any of the contiguous 48 states.

The importance of the parameters summarized in Tables 2, 3, and 4 is demonstrated in a parallel study (in progress). The preliminary data reveal that the weather parameters with first order effects on the performance of radiant barriers are the ambient air temperature, humidity, and percent of cloud cover. The data also show that solar load has no effect on the performance of radiant barriers.

CONCLUSIONS

The objective of this study was to determine the influence of climate on the performance of attic radiant barriers in the continental United States. To achieve this objective the continental United States was classified into nine climatic regions. The climatic regions were Tropical Savanna, Humid Subtropical, Humid Continental Warm Summer, Humid Continental Cool Summer Steppe, Desert, Western High Areas, Mediterranean, and Marine West Coast. The ceiling insulation was assumed to have a resistance value of 3.35 m^2K/W (R-19). A heat and mass transfer computer model for an attic structure was then used to determine the hourly ceiling heat fluxes when there was no radiant barrier and then when there was a radiant barrier. Fifteen weather stations were selected to represent the nine climatic regions. The analysis was done by integrating continuous hourly heat fluxes for the months of June, July and August. The percentage reduction in ceiling heat flux was then found for this period for each station. The results showed the percentage reduction in ceiling heat flux differed for each climate, which implied that the performance of attic radiant barriers depend on the climate in which the building was located. The lowest summer integrated percent reduction in ceiling heat transfer was 2.3% in the Mediterranean climate and the highest was 36.8% in the Tropical Savanna climate. The performance in the Continental Warm Summer and Humid Subtropical climate were also high. The peak-hour ceiling heat flux reductions ranged between 23 percent for the Desert climate to almost 100 for the Marine West Coast climate. In summary, The results revealed that attic radiant barriers will prove useful in all the above climates. Of course, buildings in some climates would benefit more than others in different climates.

ACKNOWLEDGMENTS

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REFERENCES

Bourne, M.A. and Hoeschele, R. (1990) "Climate Influence on Attic Radiant Barriers and Demand Savings," *American Council for an Energy-Efficient Economy Summer Study on Energy Efficiency in Buildings*, pp. 1.5-1.13.

Chen, H, Larson, T., and Erikson, R.W., (1992) "The Performance of an Attic Radiant Barrier for a Simulated Minnesota Winter," *Proceedings of the Thermal Performance of the Exterior Envelopes of Buildings*, Clearwater, FL.

Medina, M.A., O'Neal, D.L., and Turner, W.D., (1998a) "A Transient Heat and Mass Transfer Model of Residential Attics Used to Simulate Radiant Barrier Retrofits – Part I: Development," *ASME Journal of Solar Energy Engineering*, Vol. 120, No. 1, pp. 32-38.

Medina, M.A., O'Neal, D.L., and Turner, W.D., (1998b) "A Transient Heat and Mass Transfer Model of Residential Attics Used to Simulate Radiant Barrier Retrofits – Part II: Validation and Simulations," *ASME Journal of Solar Energy Engineering*, Vol. 120, No. 1, pp. 39-44.