Radiant Barrier Performance Estimation for the State of California

By
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Summary

This report presents a brief study of radiant barrier performance based on ceiling heat fluxes and attic temperatures for four major cities within the State of California. The cities were selected because of their locations and climates. They are Fresno, Los Angeles, Sacramento, and San Diego. The location of these cities is shown in Figure 1.

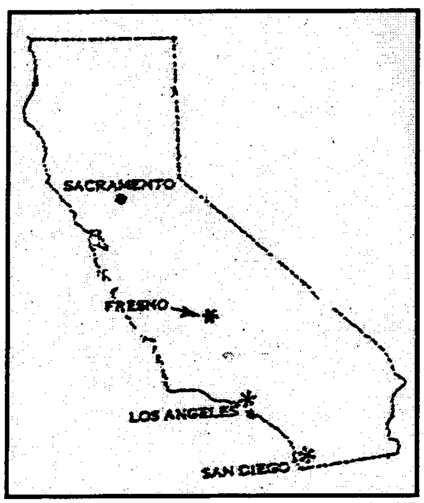

Figure 1. Location of the Cities Considered in This Study

A transient heat and mass transfer model, developed by Medina et al. (1998a, 1998b), was used to run the simulations. The model was driven by TMY2 summer weather data from stations in the selected cities. A ceiling insulated with fiberglass blankets with thermal resistance of R-19 was assumed in a fully vented attic (1 CFM/ft^2). According to the simulations, radiant barriers would prove very effective in every city. The reduction in ceiling heat flux (over a period of days) in the above cities varied from 39.7% for Fresno to 97.7% for Los Angeles.

Description of the Model Used to Produce Simulations

The model that was used for the simulations was developed following the processes described by ASHRAE (1997). These required that heat balances be set up for outside and inside surfaces, for the air zone, and that these be coupled to the wall conduction process. Once these processes were described they were solved simultaneously using an iterative solution. The attic model is described in detail in Medina et al. (1998a)—Paper is included in the Appendix. A brief description follows.

The attic used in the development of the model is shown in Figure 2. It was a five-sided symmetrical attic composed of two pitched roof sections, two vertical gable-end sections, and one horizontal ceiling frame.

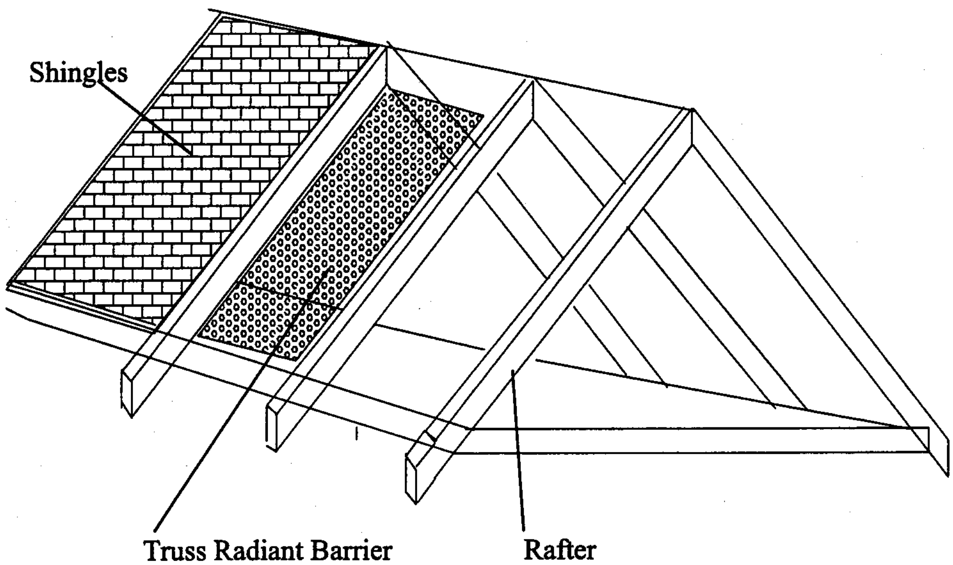

Figure 2. Attic Geometry Showing the Selected Radiant Barrier Configuration

For any surface, the heat balance equation was (Nomenclature is found at the end of this document):

$$Q_{conducted\ (to\ /\ from)} + Heat\ Stored + Q_{convected\ (to\ /\ from)} + Q_{radiated\ (net)} + Q_{latent\ (cond\ /\ evap)} = 0 \tag{1}$$

Using response factor notation, for an attic exterior surface, Equation (1) was expressed as (on a rate basis):

$$\sum_{j=0,i=1}^{N,S} Y_{i,j}(Tsi_{i,n\Delta-j} - Tr) - \sum_{j=0,i=1}^{N,S} X_{i,j}(Tso_{i,n\Delta-j} - Tr) + CR_i q''_{o\ (i,n\Delta-1)} + ho_i(T_{amb} - Tso_{i,n\Delta}) + hro_i(T_{sky\ /\ surr} - Tso_{i,n\Delta}) + \alpha q''_{sol,i} = 0 \tag{2}$$

and for an attic interior surface as,

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

$$+ \sum_{k=1,i=1}^{s,s} hri_{i,k}(Tsi_{i,n\Delta} - Tsi_{k,n\Delta}) + q''_{latent,i} = 0 \tag{3}$$

The convection coefficients ho_i and hi_i were estimated using published correlations based on Nusselt numbers (ASHRAE, 1997). In equation form:

$$\bar{h} = \frac{\overline{Nu}\,k}{L} \tag{4}$$

This approach combined the natural and forced convection Nusselt numbers (Churchill, 1977 and Chen et al., 1986) using:

$$\overline{Nu}^{\,n} = \overline{Nu}_F^{\,n} \pm \overline{Nu}_N^{\,n} \tag{5}$$

Also, different expressions of Nusselt number were formulated depending on heat flow direction and surface orientation. The indoor radiation coefficients were estimated by:

$$hri_{i,k} = G_{i,k}\sigma(T_i^2 + T_k^2)(T_i + T_k) \tag{6}$$

where

$$G_{i,j} = \frac{\varepsilon_i}{1-\varepsilon_i}\psi_{i,k} \tag{7}$$

and where previous values of temperatures were used. For the net radiation on outer attic surfaces to the sky and surroundings, the coefficient was formulated as:

$$hro_i = \varepsilon_{i,out}\sigma(T_{i,out}^2 + T_{sky/surr}^2)(T_{i,out} + T_{sky/surr}) \tag{8}$$

The total solar radiation incident on an inclined surface was estimated by,

$$q''_{sol} = I_d + R_b I_b \tag{9}$$

where,

$$R_b = \frac{\cos(\theta)}{\cos(\theta_z)} \tag{10}$$

$$\cos(\theta) = \sin(\delta)\sin(\phi)\cos(\beta) - \sin(\delta)\cos(\phi)\sin(\beta)\sin(\gamma) + \cos(\delta)\cos(\phi)\cos(\beta)\cos(\omega) + \cos(\delta)\sin(\phi)\sin(\beta)\cos(\gamma)\cos(\omega) + \cos(\delta)\sin(\beta)\sin(\gamma)\sin(\omega) \tag{11}$$

and

$$\cos(\theta_Z) = \sin(\delta)\sin(\phi) + \cos(\delta)\cos(\phi)\cos(\omega) \tag{12}$$

T_{sky} was calculated as follows after Martin and Berdahl (1984):

$$T_{sky} = T_{ambient}\,[\varepsilon_o + (1+\varepsilon_o)C]^{1/4} \tag{13}$$

where

$$\varepsilon_o = 0.711 + 0.56\left(\frac{T_{dp}}{100}\right) + 0.73\left(\frac{T_{dp}}{100}\right)^2 + 0.13\ \cos[2\ \ \frac{t}{24}] \tag{14}$$

and

$$C = n\varepsilon_c\Gamma \tag{15}$$

where n was the fraction of the sky hemisphere covered by clouds, ε_c was the hemispherical cloud emissivity, and Γ a factor depending on the cloud base temperature.

Latent effects were incorporated in a steady-state moisture balance (Burch et al., 1984; Cleary, 1985; and Wilkes, 1989), written as:

$$\sum_{surface\,i}^{S} A_i Perm_i P_{atm}\left(\frac{w_{attic\,air}}{0.622+\omega_{attic\,air}}\right) - P_{o,i} + \sum_{surface\,i}^{S} A_i h_{w,i}(w_{attic\,air} - w_{w,i}) + \dot{Q}_{air}\rho_{air}(w_{attic\,air} - w_o) = 0 \tag{16}$$

In Equation (16), the first term represented the rate of moisture transfer by diffusion through the attic components. The second term represented the moisture loss/gain by adsorption/desorption of water vapor at wood surfaces, and the last term was the moisture transfer by exchange of attic air with the outdoor air. This expression was solved iteratively for w_{attic} air. In Equation (16) the mass transfer coefficient, $h_{w,i}$ was calculated using the Chilton-Colburn analogy between heat and mass transfer

(ASHRAE, 1989), the mass diffusivity term found in the Chilton-Colburn analogy was estimated using Sherwood's (1952) relation. The wood humidity ratio was estimated using a relation by Cleary (1985). Once the attic air humidity ratio, the mass transfer coefficient, and the wood humidity ratio had been calculated, the latent load was obtained using

$$q''_{latent} = h_{w,i}(w_{atticair} - w_{w,i})h_{fg} \tag{18}$$

where h_{fg} was the latent heat of vaporization of water.

Validity of the Model

The model was validated by comparing its predictions to data obtained from monitoring two well-calibrated test houses. One house was used as a control house and the other as the experimental house. The thermal performance of both houses prior to any retrofit was nearly identical. Ceiling heat flows and space-cooling loads differed by less than 3 percent. The experiments and the validations are presented in detail in Medina (1992). Only a brief description is provided here. Figure 3 depicts a comparison between model predictions and experimental data for the case where no radiant barriers were installed. The heavy solid line represents the data while the lighter solid line represents the model predictions. The difference between both sets of lines is less than 5%, which makes the model predictions acceptable and accurate.

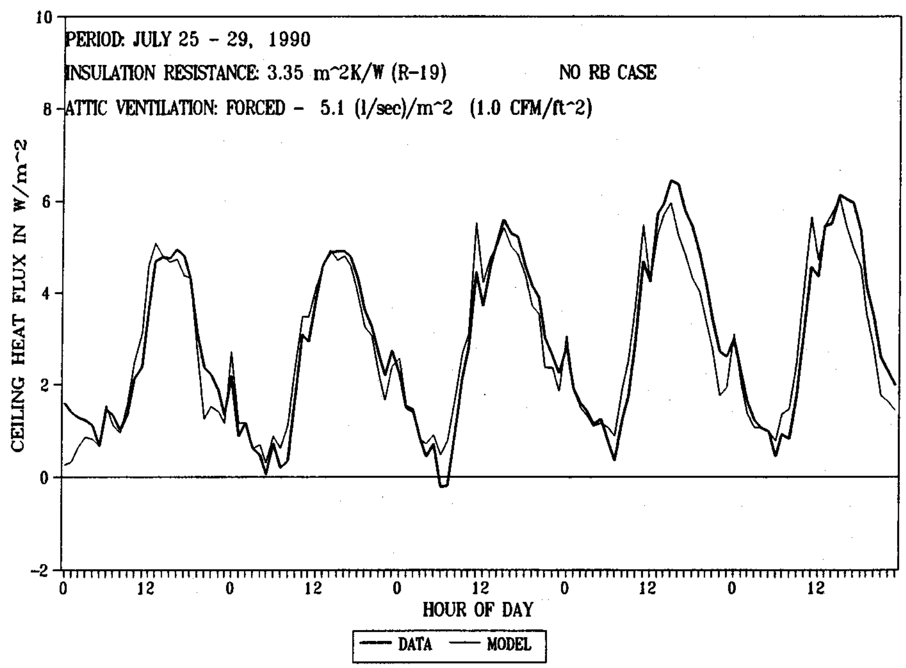

Figure 3. Model Validation: Ceiling Heat Fluxes (No Radiant Barrier Case, insulation resistance: R-19; with attic airflow rate: 1.0 CFM/ft²)

On the other hand, Figure 4 depicts a comparison between model predictions and experimental data for the case where a truss radiant barrier (Figure 2) was installed. Similar to the previous figure, the heavy solid line represents the data while the lighter solid line represents the model predictions. The difference between both sets of lines is also less than 5%, which makes the model predictions for the radiant barrier case acceptable and accurate.

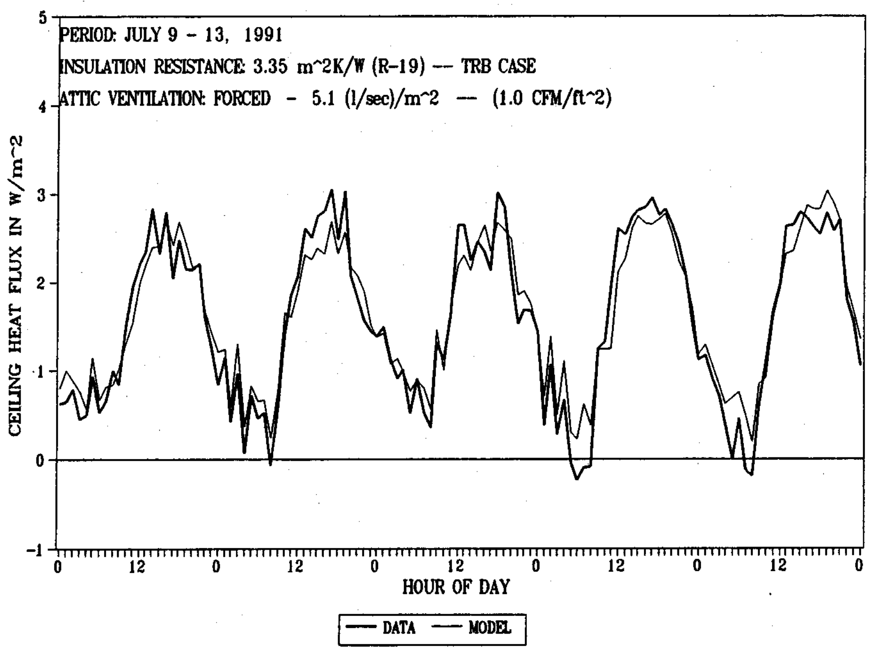

Figure 4. Model Validation: Ceiling Heat Fluxes (Radiant Barrier Case, insulation resistance: R-19; with attic airflow rate: 1.0 CFM/ft^2)

Results and Discussion

The influence of climate on the performance of attic radiant barriers in the four cities within the State of California was evaluated using the heat and mass transfer model. It was driven by the TMY2 weather data from the stations. A truss radiant barrier configuration (Figure 2) was assumed with a ceiling insulation thermal resistance of R-19. The outputs of the model were the ceiling heat flux for radiant barrier case and no radiant barrier case and attic temperatures. For the no radiant barrier case only the R-19 insulation was present at the top of the ceiling frame. For the radiant barrier case, the radiant barrier was stapled to the rafters of the attic. Sample profiles of ceiling heat fluxes the for selected cities are provided. The profiles serve as a useful analytical tool that helps in understanding how the radiant barrier performs in the various climates. The profile time spans from July 25 to July 27.

Radiant Barrier Performance for Fresno, CA

Fresno's weather is generally mild with dry and warm summers. Climatic information for Fresno is given in Table 1.

Table 1. Temperature Summary for the City of Fresno, CA (Sperling's Best Places, 2003)

Fresno, California

Lat / long: 36 20N 119 57W Station notes: Naval air station Lemoore

Altitude: 238 feet

Choose new city Quickview Temperature Precipitation Miscellaneous

Climate Quickview	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High temperature (avg.) degrees F	78	55	63	68	76	86	93	98	97	91	81	66	55
Low temperature (avg.) degrees F	48	36	40	42	45	52	58	62	62	57	49	40	36
Days warmer than 90 deg. degrees F	111	0	0	Tr	3	11	20	28	27	17	6	0	0
Days colder than 10 deg. degrees F	0	0	0	0	0	0	0	0	0	0	0	0	0
More temperature info													
Precipitation (avg.) inches	7.4	1.4	1.4	1.4	0.6	0.2	0.1	Tr	Tr	0.3	0.3	0.8	1
Snow (avg.) inches	Tr	Tr	Tr	0	0	0	0	0	0	0	0	0	Tr
Days with some precip.	43	7	7	7	4	2	1	Tr	Tr	1	2	5	7
More precipitation info													
Days with thunderstorms	2	Tr	Tr	1	Tr	Tr	Tr	Tr	Tr	1	Tr	Tr	Tr
Humidity (4 pm) % relative	38	63	54	44	32	25	23	23	26	28	32	49	64
Windspeed (avg.) knots	7	5	7	7	8	8	8	7	6	6	6	7	5

The following graphs depict how a radiant barrier would perform in a house located in this climate. In Figure 5a, the solid line represents the ceiling heat transfer from the attic in Btu in one hour per square feet of ceiling area. The dashed line represents the same heat transfer rate when a radiant barrier is in place.

The data indicate that over a summer season the radiant barrier would block approximately 40% of the heat from entering the conditioned space. The instantaneous reduction at peak times (demand reduction) would be approximately 36%.

Figures 5b and 5c contain histories of those variables that drive the model. These variables were ambient air temperature, solar irradiation, and wind speed. The ambient air temperature for the simulated period had an amplitude of approximately 37 degrees, from the low 60's to the upper 90's and low 100's. The average ambient air temperature for this period was 81.4 °F. The solar irradiation peaked at 315 Btu/ft^2 while the wind speed averaged 7.65 mph (6.65 knots) with low-end values of approximately 4 mph (3.5 knots) during the morning hours and high-end values of approximately 12 mph (10.4 knots).

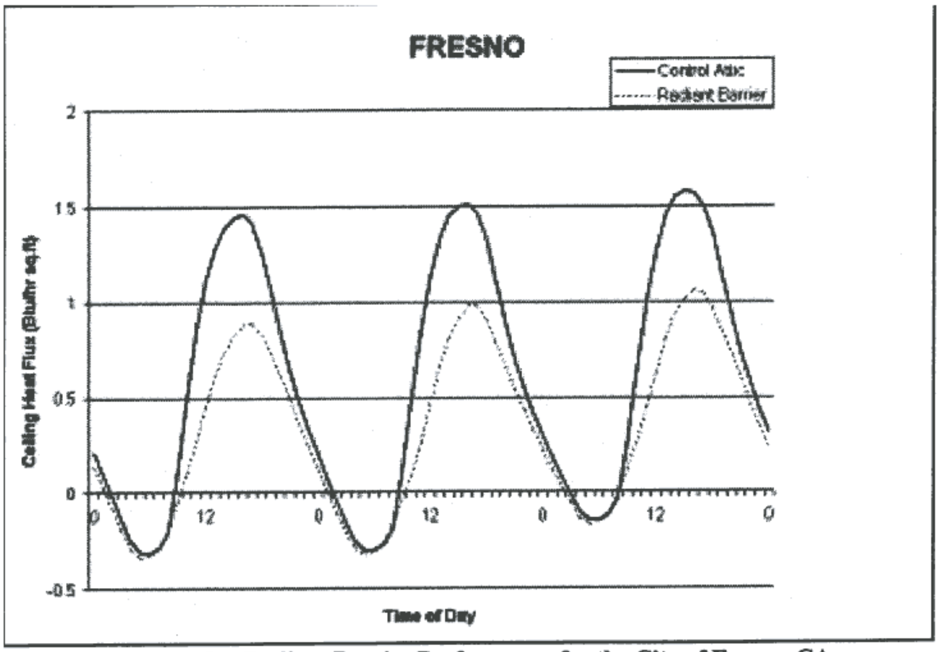

Figure 5a. Radiant Barrier Performance for the City of Fresno, CA

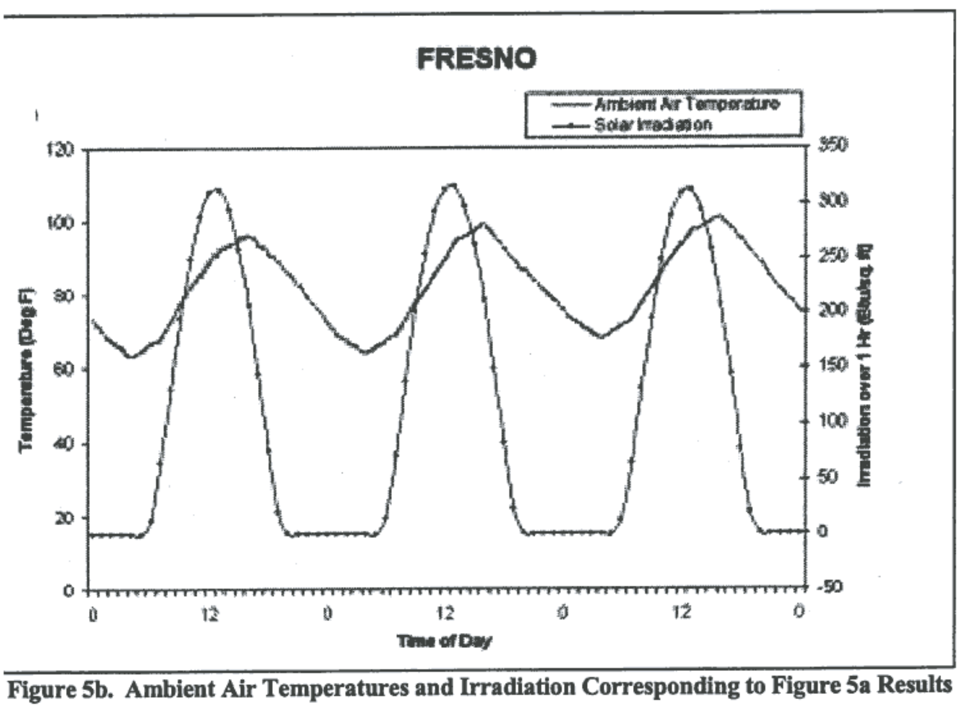

Figure 5b. Ambient Air Temperatures and Irradiation Corresponding to Figure 5a Results

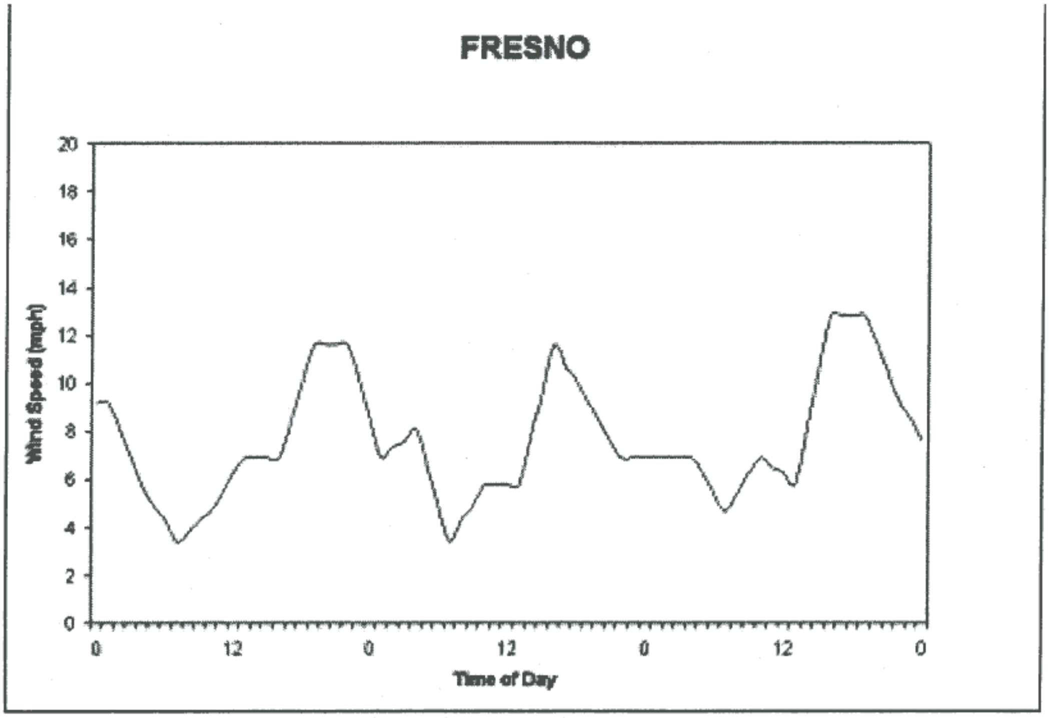

Figure 5c. Wind Speed Corresponding to Figure 5a Results

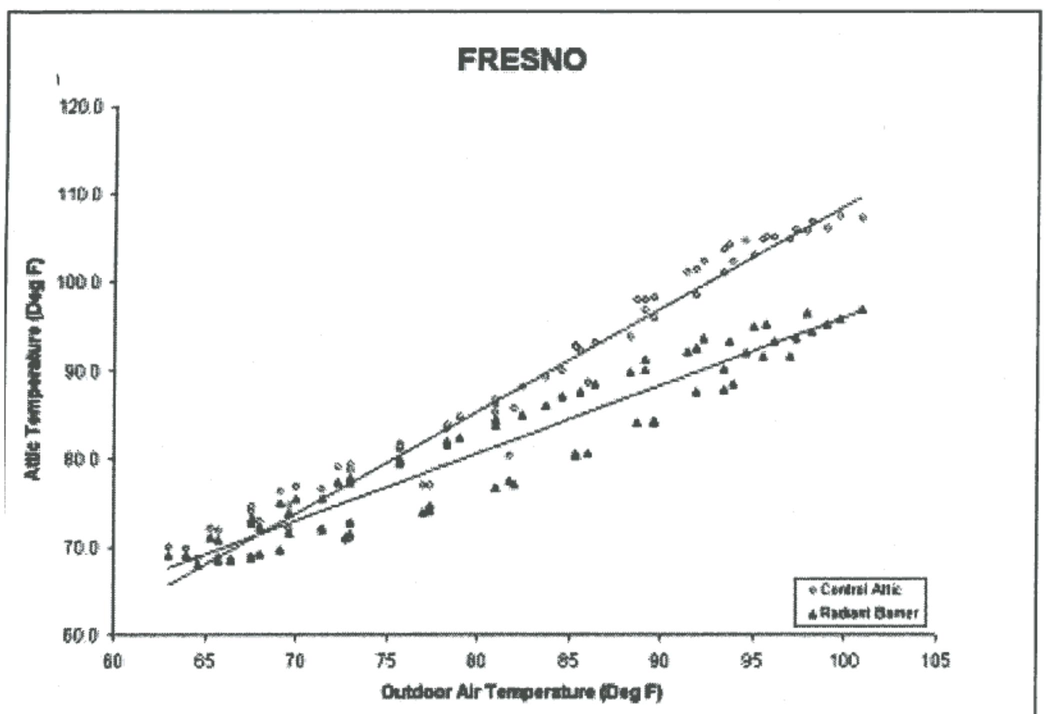

Figure 6. Predicted Attic Temperatures for a House Located in Fresno, CA

Figure 6 represents how the attic temperature would change as a function of outdoor air temperature. The data clearly show that the installation of a radiant barrier would significantly reduce the attic temperature. For the Fresno case, the attic temperature would be reduced an average of 6.5 °F over the entire period of solar activity. The maximum reduction, however, would be approximately 10.6 °F at peak times.

The bifurcation in temperatures observed in Figure 6 (Fresno) for the radiant barrier case (▲) and again in Figure 10 (Sacramento) also for the radiant barrier case (▲) at the mid section of the range of ambient air temperatures of the scales is explained as follows: Although radiant barriers reduce the attic air temperatures when compared to attics with no radiant barriers, during a daily cycle of ambient air temperatures an attic with radiant barrier will have (in general) two distinctive attic air temperatures for the same ambient air temperature, one will be a "morning" temperature and the other an "afternoon" temperature. Just as efficiently as the barriers block heat from entering the attic, they also prevent heat from leaving the attic across the roof. The "afternoon" attic air temperature is higher because by this time of day, some heat would have managed to make it into the attic either across the gable ends or with the ventilating air. This heat is in a sense trapped from leaving the attic through the roof and thus creates a higher temperature than the "morning" temperature, but in general less than the control attic. This trend also occurs in cases where the attic is located in places that are windier and more humid, such as in Los Angeles and San Diego (Figures 8 and 12). These two facts, which translate into attic temperatures being more stirred and moister, make the bifurcation not seem as pronounced as the case where the wind is calmer and drier although there still are differences in temperatures correlated to when they are recorded, morning or afternoon.

Radiant Barrier Performance for Los Angeles, CA

Los Angeles is noted for its moderate weather. Los Angeles climate is categorized as *Mediterranean.* This climate type is characterized by pronounced seasonal changes in rainfall, with low to non-precipitation summers and rainy winters, but relatively modest transitions in temperature. In the summer season, the eastern Pacific high-pressure area, a semi-permanent feature of the general hemispheric circulation pattern, dominates the weather over much of southern California. Warm and very dry air descending from this Pacific high caps cool, ocean-modified air under a strong inversion, producing a *marine layer.* This marine layer is the prominent weather feature for the Los Angeles Basin for much of the year, especially from late spring through early fall. Daily variations in the strength of the Pacific high result in variations in the depth and coverage of the marine layer, which typically thickens and advances inland during the night and early morning hours, before retreating to the sea or "burning off" to hazy sunshine around midday. Surface pollutants trapped under the marine inversion result in smog, the infamous LA mixture of smoke and fog. Because of the dominance of the stable marine layer, significant precipitation is rare between May and October. Any rain that does occur at this time of year is usually the result of isolated thunderstorms associated with subtropical moisture. Winds are generally moderate, with frequent afternoon sea breezes of 12 to 17 miles per hour. (National Weather Service Forecast Office, Los Angeles/Oxnard CA). Climatic information for Los Angeles is given in Table 2.

Table 2. Temperature Summary for the City of Los Angeles, CA (Sperling's Best Places, 2003)

Los Angeles, California

Lat/long: 33 56N 118 23W   Station notes: Airport
Altitude: 100 feet

Choose new city   Quickview   Temperature   Precipitation   Miscellaneous

Climate Quickview	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High temperature (avg.) degrees F	70	65	66	65	67	69	72	75	76	76	74	71	66
Low temperature (avg.) degrees F	55	47	49	50	53	56	59	63	64	63	59	52	48
Days warmer than 90 deg. degrees F	5	0	Tr	Tr	Tr	Tr	Tr	Tr	Tr	1	1	1	Tr
Days colder than 10 deg. degrees F	0	0	0	0	0	0	0	0	0	0	0	0	0
More temperature info													
Precipitation (avg.) inches	11.3	2.6	2.3	1.8	0.8	0.1	Tr	Tr	0.1	0.2	0.3	1.5	1.5
Snow (avg.) inches	Tr	Tr	0	0	0	0	0	0	0	0	0	0	0
Days with some precip.	34	6	5	6	3	1	Tr	Tr	Tr	1	2	4	5
More precipitation info													
Days with thunderstorms	1	Tr	Tr	1	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr
Humidity (4 pm) % relative	64	60	62	64	64	66	67	67	68	67	66	61	60
Windspeed (avg.) knots	8	8	8	9	9	9	9	8	8	8	8	8	5

Figure 7a shows how ceiling heat fluxes can be reduced in this climate when radiant barriers are installed. Again, Figures 7b and 7c contain histories of those variables relevant to the simulation.

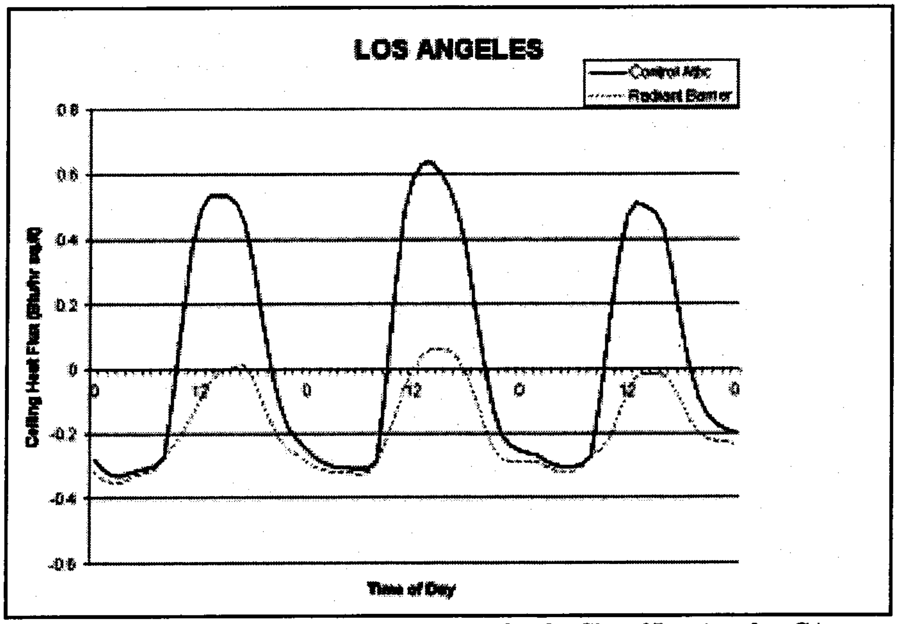

Figure 7a. Radiant Barrier Performance for the City of Los Angeles, CA

Under this type of climate a radiant barrier can be expected to block about 98% of the total ceiling heat load with demand reductions (instantaneous heat transfer) being reduced to almost 100%. Note that the simulations were performed using the hottest weather of the year. For this case, the ambient air temperature had a narrow swing of approximately 9 degrees, from the mid 60's to mid 70's.

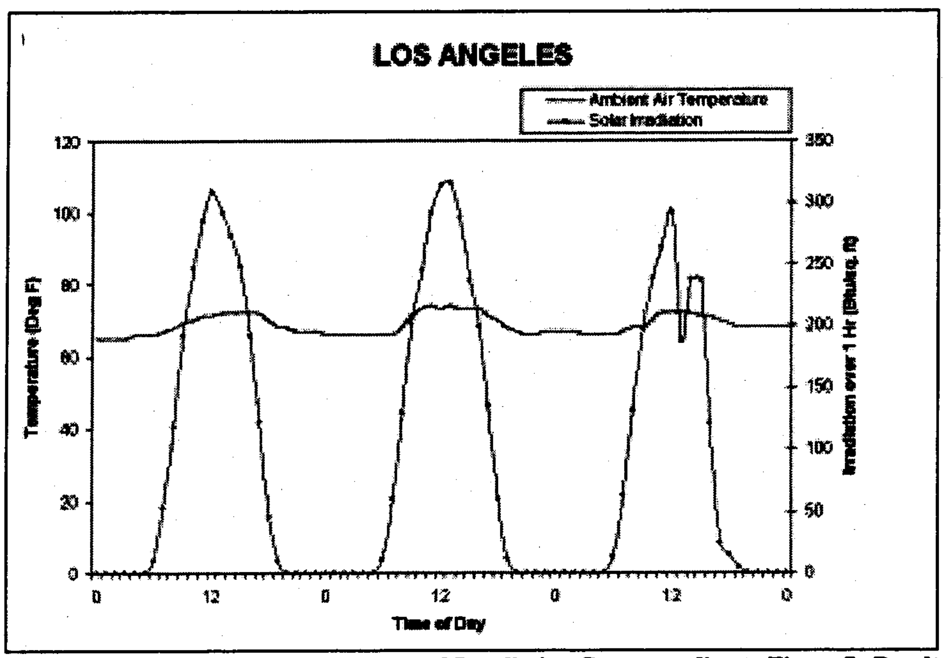

Figure 7b. Ambient Air Temperatures and Irradiation Corresponding to Figure 7a Results

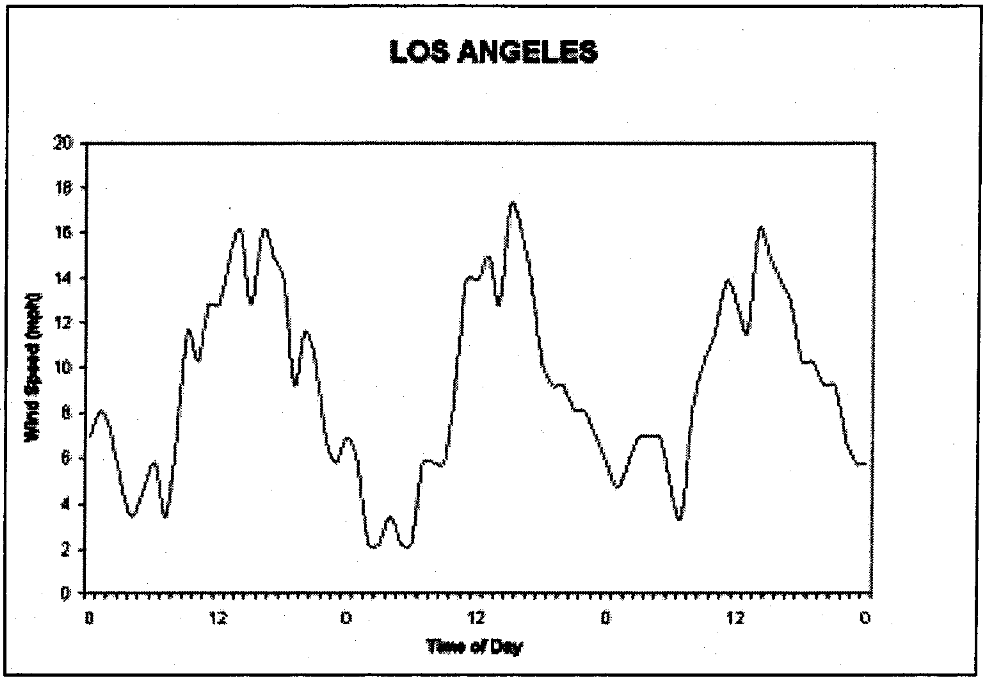

Figure 7c. Wind Speed Corresponding to Figure 7a Results

The lower air temperatures could be the result of higher winds experienced in this area of the state.

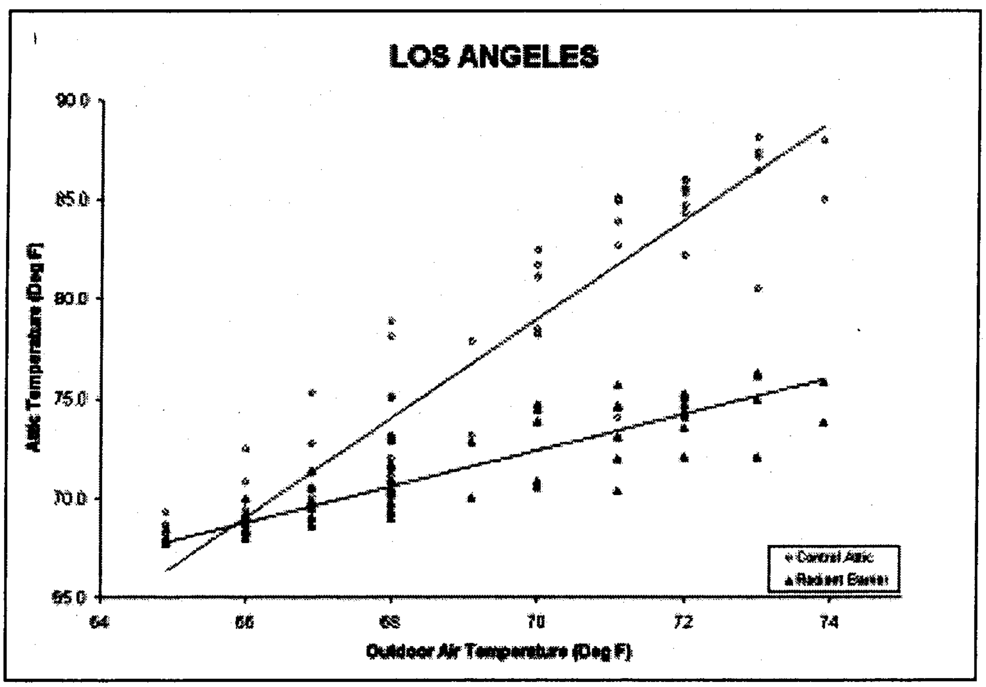

Figure 8. Predicted Attic Temperatures for a House Located in Los Angeles, CA

The wind speed averaged 9.1 mph (7.9 knots) with low-end values of approximately 2 mph (1.74 knots) during the morning hours and high-end values of approximately 17 mph (14.8 knots).

For the Los Angeles case, the attic temperature would be reduced an average of 7.4 °F over the entire period of solar activity. The maximum reduction, however, would be approximately 11.8 °F at peak times.

Radiant Barrier Performance for Sacramento, CA

Sacramento's weather is mild most of the year. The coldest months are January and February, with average temperatures ranging from 40 - 60 °F and about 3 in of rain each month. In March and April, the temperatures are in the mid 60's during the day and about 45 °F at night. An inch or two of rain are usually expected during these months. By July, temperatures climb into the low 90's with several days topping 100 °F. Nights in the summer reach a low in the high 50's. Little rain falls between June through September. By October, temperatures are back to the 50 - 80 °F range. Climatic information for Sacramento is given in Table 3.

Table 3. Temperature Summary for the City of Sacramento, CA (Sperling's Best Places, 2003)

Sacramento, California

Lat / long: 38 31N 121 30W   Station notes: Airport

Altitude: 18 feet

Choose new city   **Quickview**   Temperature   Precipitation   Miscellaneous

Climate Quickview	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High temperature (avg.) degrees F	73	53	60	64	71	80	87	93	91	87	78	63	53
Low temperature (avg.) degrees F	48	38	41	43	46	50	55	58	58	56	50	43	38
Days warmer than 90 deg. degrees F	73	0	0	0	Tr	5	12	22	19	12	2	0	0
Days colder than 10 deg. degrees F	0	0	0	0	0	0	0	0	0	0	0	0	0
More temperature info													
Precipitation (avg.) inches	17.3	3.6	2.8	2.4	1.3	0.4	0.1	Tr	0.1	0.3	1	2.4	2.8
Snow (avg.) inches	Tr	Tr	Tr	Tr	Tr	0	0	0	0	0	0	0	Tr
Days with some precip.	58	10	8	9	5	3	1	Tr	Tr	2	3	7	9
More precipitation info													
Days with thunderstorms	2	Tr	Tr	1	1	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr
Humidity (4 pm) % relative	45	70	59	51	43	36	31	28	29	31	39	57	70
Windspeed (avg.) knots	9	8	8	9	9	10	11	9	9	9	9	8	8

In Sacramento, radiant barriers could be expected to block approximately 50% of the total heat flux into the living space during the summer season and approximately 40% during peak times of the day. This is shown in Figure 9a. Figures 9b and 9c contain histories of those variables relevant to the simulation. For this case, the ambient air temperature had the largest swing, which was approximately 50 degrees, from about 50 to 100. The average temperature for this period was 73.4 °F. The solar peak load was approximately 310 Btu/ft^2 integrated over a one-hour period and the average wind speed was about 6.85 mph (5.95 knots), with a maximum wind speed occurring on the last day of the simulations of about 13.9 mph (12.1 knots).

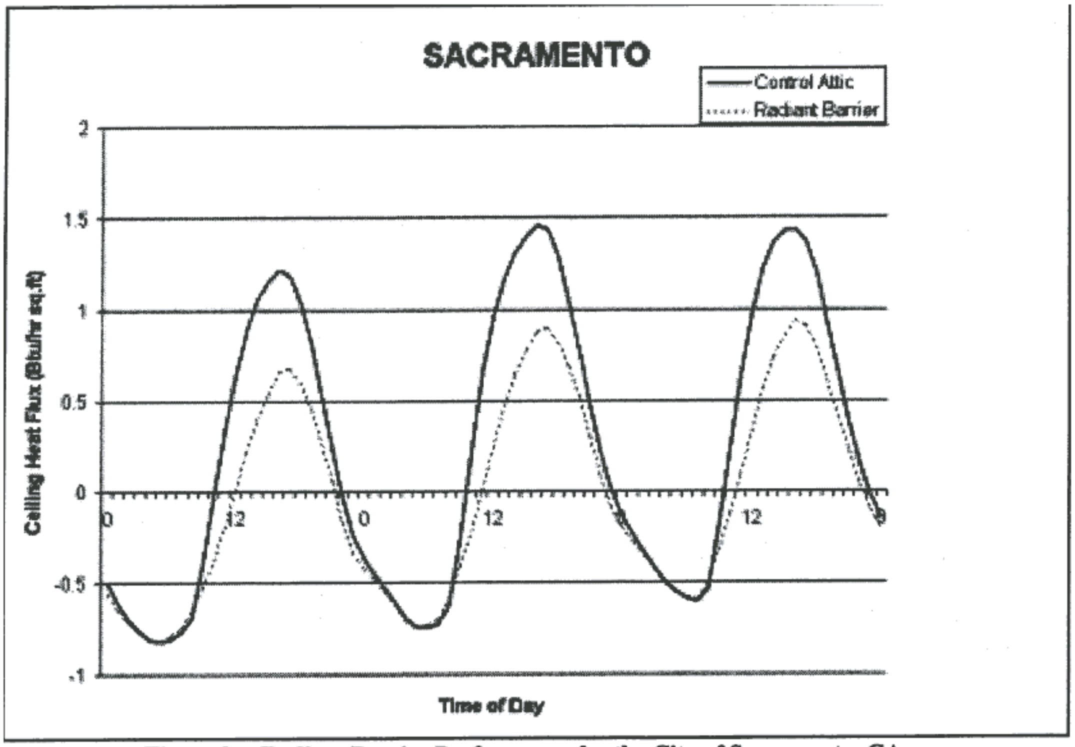

Figure 9a. Radiant Barrier Performance for the City of Sacramento, CA

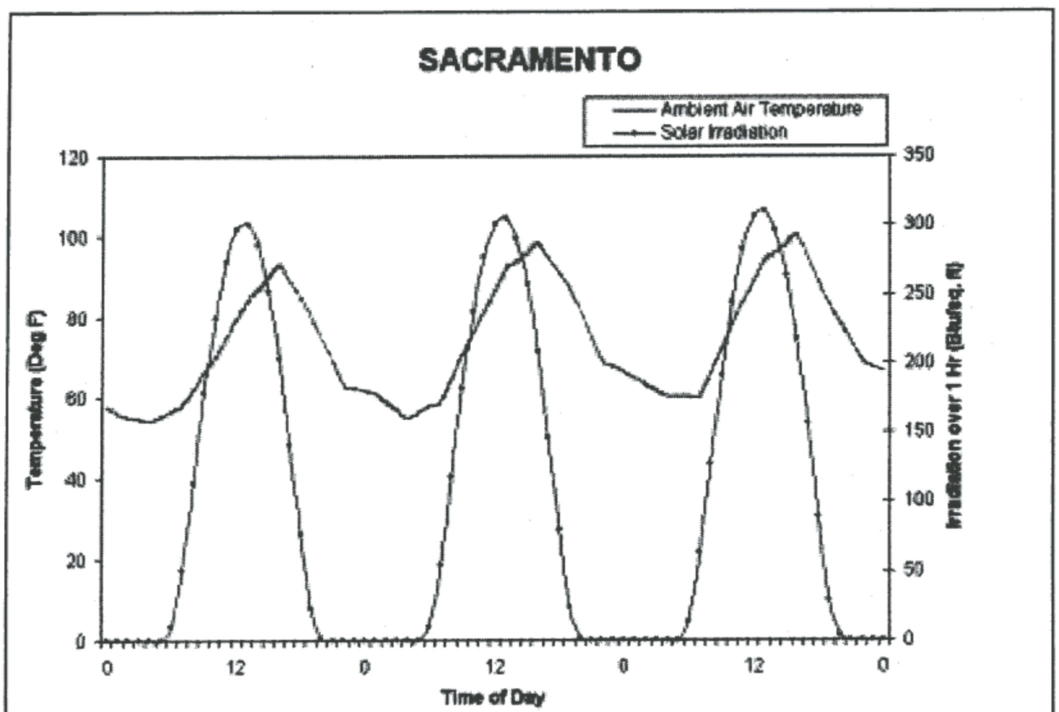

Figure 9b. Ambient Air Temperatures and Irradiation Corresponding to Figure 9a Results

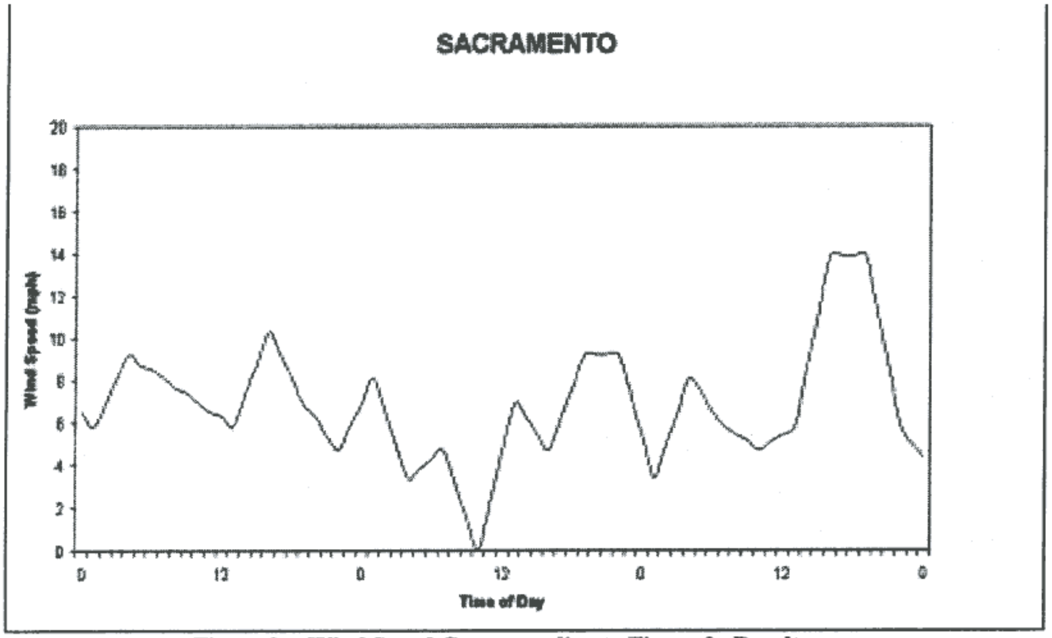

Figure 9c. Wind Speed Corresponding to Figure 9a Results

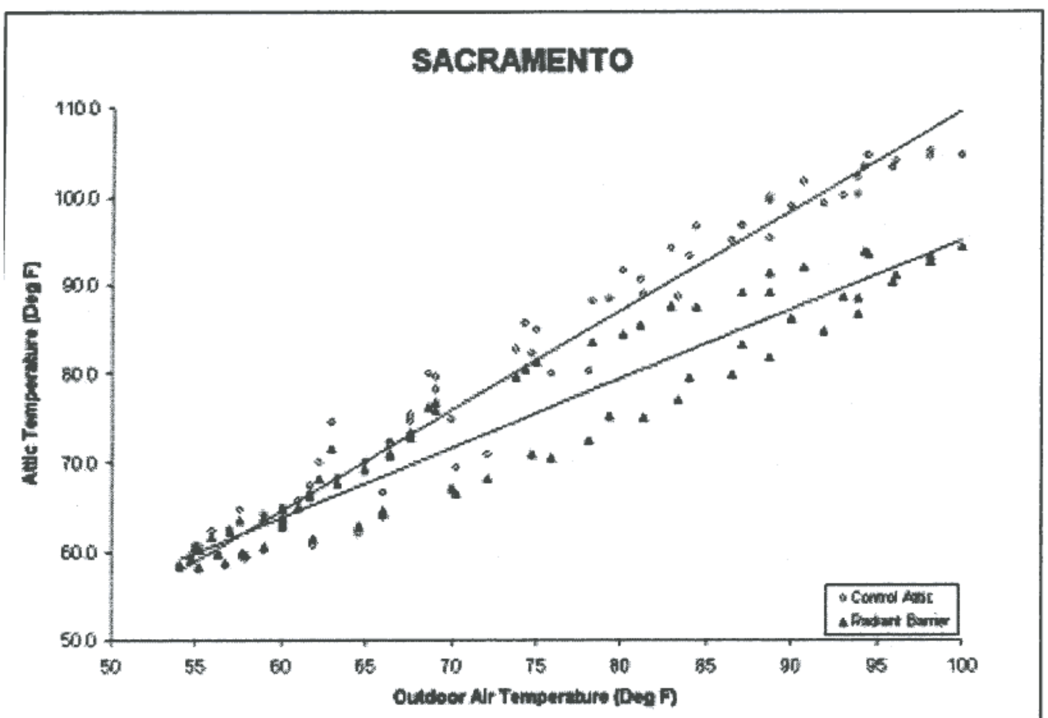

Figure 10. Predicted Attic Temperatures for a House Located in Sacramento, CA

Figure 10 depicts how the attic temperature would be reduced as a function of outdoor air temperature if a radiant barrier were installed. For the Sacramento case, the attic temperature would be reduced an average of 8.1 °F over the entire period of solar activity. The maximum reduction, however, would be approximately 10.8 °F at peak times.

Radiant Barrier Performance for San Diego, CA

San Diego's weather is tempered by the Pacific Ocean, which results in relatively cool summers and warm winters. Temperatures below freezing are rare, while hot weather, 90 degrees and above, is more frequent. Winter is considered the rainy season; however, each winter month averages 1.5 inches of rainfall, hardly enough to qualify for monsoons. Climatic data are presented in Table 4 for the City of San Diego.

Table 4. Temperature Summary for the City of San Diego, CA (Sperling's Best Places, 2003)

San Diego, California

Lat / long: 32 44N 117 10W   Station notes: Airport

Altitude: 13 feet

Choose new city   **Quickview**   Temperature   Precipitation   Miscellaneous

Climate Quickview	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High temperature (avg.) degrees F	71	65	66	66	68	69	72	76	77	77	74	71	66
Low temperature (avg.) degrees F	57	48	50	52	55	58	61	65	66	65	60	53	49
Days warmer than 90 deg. degrees F	4	0	0	Tr	Tr	Tr	Tr	Tr	Tr	1	1	Tr	0
Days colder than 10 deg. degrees F	0	0	0	0	0	0	0	0	0	0	0	0	0
More temperature info													
Precipitation (avg.) inches	9.5	1.9	1.4	1.7	0.8	0.2	0.1	Tr	0.1	0.2	0.4	1.2	1.4
Snow (avg.) inches	Tr	Tr	0	0	0	0	0	0	0	0	0	0	Tr
Days with some precip.	40	7	5	7	4	2	1	Tr	1	1	2	5	6
More precipitation info													
Days with thunderstorms	5	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr
Humidity (4 pm) % relative	62	57	56	59	59	63	66	65	66	65	63	60	58
Windspeed (avg.) knots	8	7	8	9	9	8	8	8	8	8	8	8	7

Under San Diego weather, one could expect a radiant barrier to block approximately 73% of the heat from the attic into the living space. The instantaneous reduction during peak times would be approximately 59%. This is shown in Figure 11a. This figure also revealed that under this climate a reduction in ceiling heat flux occurred even at times when there was no solar activity. The stored heat on the attic structures together with heat gained by the process of phase change of the moist air in contact with the attic surfaces (condensation on cold attic surfaces) created a positive heat flux, which entered the house through the ceiling. The radiant barrier did block a major fraction of this flux. Figures 11b and 11c are presented as relevant to the results of Figure 11a. The ambient air temperature swing was about 12 °F (69 – 81 °F) with an average temperature of 73.3 °F. The solar irradiation peaked at 311 Btu/ft^2 and the average wind speed was approximately 8.58 mph (7.46 knots). As for temperature reductions, the attic with a radiant barrier installed would have a lower average attic temperature during the period of solar activity of approximately 5.4 °F. The reduction in temperature at peak times would be approximately 12.2 °F. This is depicted in Figure 12.

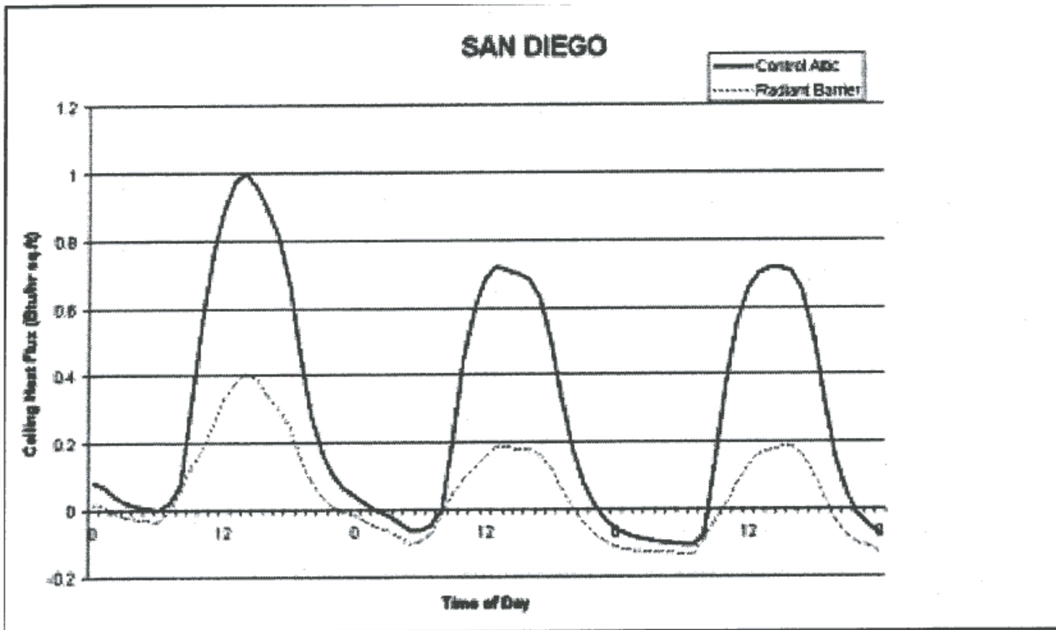

Figure 11a. Radiant Barrier Performance for the City of San Diego, CA

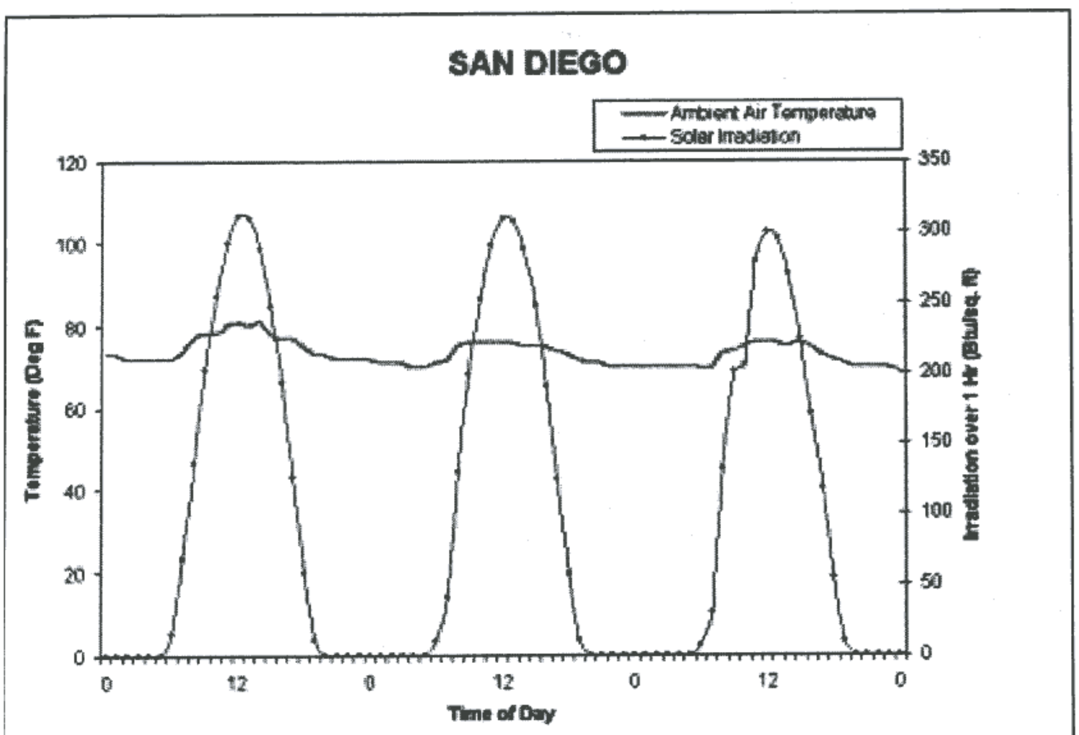

Figure 11b. Ambient Air Temperatures and Irradiation Corresponding to Figure 11a Results

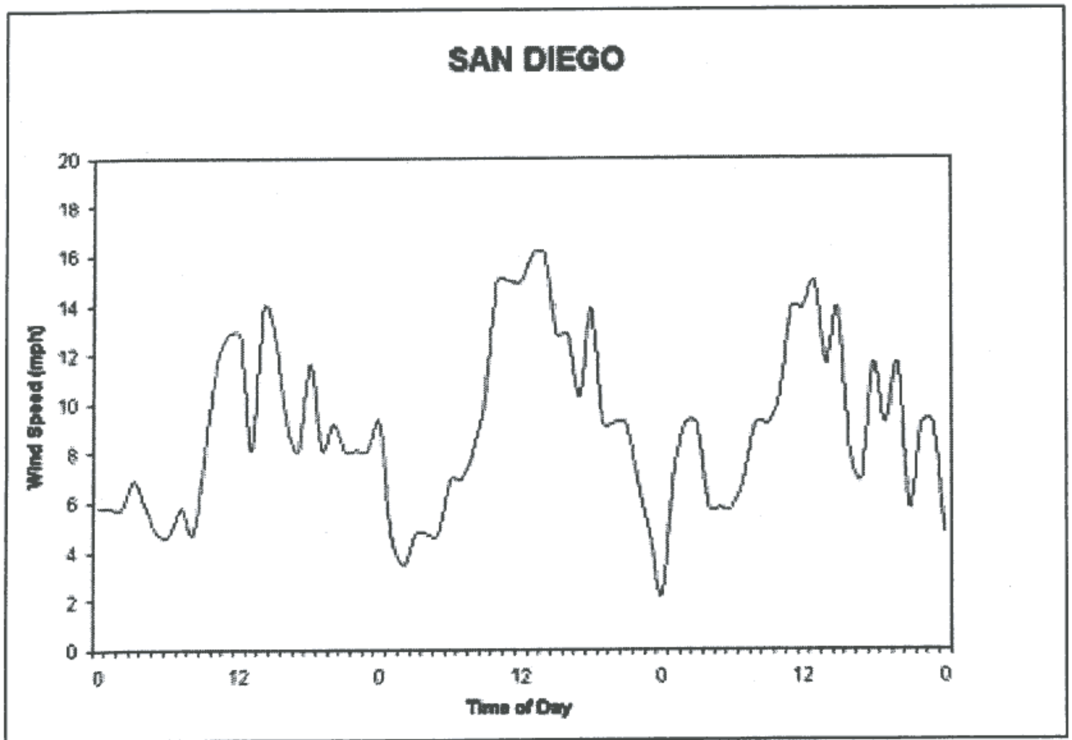

Figure 11c. Wind Speed Corresponding to Figure 11a Results

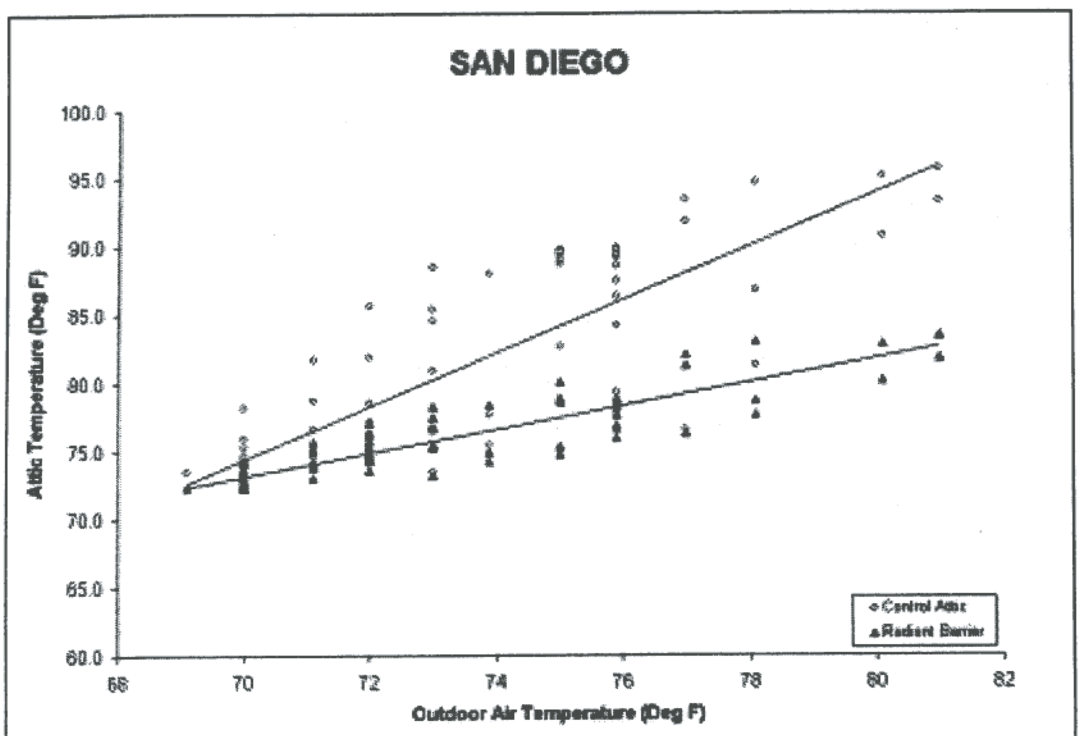

Figure 12. Predicted Attic Temperatures for a House Located in San Diego, CA

Summary

Radiant barriers would prove to be very beneficial in reducing attic heat transfer to the conditioned space in most cities in the State of California. Significant reduction in overall heat transfer, instantaneous heat transfer during peak hours, and in attic temperatures would be produced. Table 5 presents a summary of attic temperature reductions and ceiling heat flux reductions as a result of installing radiant barriers in the selected cities.

Table 5. Summary of Attic Temperature and Ceiling Heat Transfer Reductions Produced by Radiant Barriers.

City	Attic Temperature Reduction (Average over Season) (Deg. F)	Attic Temperature Reduction (Peak Hour) (Deg. F)	Ceiling Heat Transfer Reduction (Average over Season) (Btu/hr Sq.Ft)	Ceiling Heat Transfer Reduction (Peak Hour) (Btu/hr Sq.Ft)
Fresno	6.5	10.6	38.7	35.7
Los Angeles	7.4	11.6	97.7	-10.0
Sacramento	8.1	10.8	50.4	30.6
San Diego	5.4	12.3	72.8	50.4

References

- ASHRAE, 1989, *Handbook of Fundamentals,* American Society of Heating, Refrigeration, and Air Conditioning Engineers, Atlanta, GA.
- ASHRAE, 1997, *Handbook of Fundamentals,* American Society of Heating, Refrigeration, and Air Conditioning Engineers, Atlanta, GA.
- Burch, D.M., Lemay, M.R., Rian, B.J., and Parker, E.J., 1984, "Experimental Validation of an Attic Condensation Model," *ASHRAE Transactions,* Vol. 20, Part 2A, pp. 59-77.
- Chen, T.S., Armaly, B.F., and Ramachandran N., 1986, "Correlations for Laminar Mixed Convection Flows on Vertical, Inclined, and Horizontal Flat Plates," *Journal of Heat Transfer,* Vol. 108, pp. 835-840.
- Churchill, S.W., 1977, "A Comprehensive Correlating Equation for Laminar Assisting, Forced and Free Convection," *AIChE Journal,* Vol. 23, pp. 10-16.
- Cleary, P.G., 1985, "Moisture Control by Attic Ventilation --An In-Situ Study," *ASHRAE Transactions,* Vol. 91, Part 1, pp. 227-239.
- Martin, A., and Berdahl, 1984, "Characteristics of Infrared Sky Radiation in the United States," *Solar Energy,* Vol. 33, pp. 321-336.
- Medina, M.A., 1992, "Development of a Transient Heat and Mass Transfer Model of Residential Attics to Predict Energy Savings Produced by the Use of Radiant Barriers," Ph.D. dissertation, Department of Mechanical Engineering, Texas A&M University, College Station, TX.
- Medina, M.A., O'Neal, D.L., 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, pp. 32-38.
- Medina, M.A., O'Neal, D.L., 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, pp. 39-44.
- Sherwood, T.K., and Pigford, R.L., 1952, *Absorption and Extraction,* McGraw-Hill Book Company, New York.
- Sperling's BestPlaces, 2003 – On-Line at http://www.bestplaces.net/

- Wilkes, K.E., 1989, "Modeling of Residential Attics with Radiant Barriers," Proceedings *of the Fifth Annual Symposium on Improving Building Energy Efficiency in Hot and Humid Climates,* Houston, TX, pp. 161-168.

Nomenclature

Symbol	**Description**
A	= surface area
CR	= common ratio
G	= radiation coefficient
h, hi, ho	= heat transfer coefficient
hf_g	= latent heat of vaporization
hri, hro	= radiation heat transfer coefficients
HRB	= horizontal radiant barrier
I	= irradiation
k	= thermal conductivity
L	= length, characteristic length
n	= cloud cover fraction, index
Nu	= Nusselt number
P	= pressure
Perm	= permeability
Q	= heat flow, volumetric flowrate
q"	= heat flux
T	= temperature
Tr	= reference temperature
TRB	= truss radiant barrier
Tsi	= inside surface temperature
Tso	= outside surface temperature
w	= humidity ratio
X,Y,Z	= response factors

Greek Symbol	**Description**
β	= tilt angle
χ	= radiation matrix
δ	= declination angle
Δ	= time increment
ε	= thermal emissivity
ϕ	= angle, latitude, relative humidity
Γ	= cloud emissivity factor
γ	= surface azimuth angle
θ	= incidence angle
σ	= Stefan-Boltzman constant
ω	= hour angle
ψ	= inverse of χ matrix

Subscript	Description
0,1,2,...	= time denoting index (response factors)
amb	= ambient conditions
b	= beam
cond	= condensation
d	= diffuse
dp	= dew point
evap	= evaporation
F	= forced
i	= denotes surface, index, indoor conditions
j	= denotes time, index
k	= denotes surface
N	= natural
nΔ	= time step
o	= outdoor conditions
sky / surr	= sky and the surroundings

Index	Description
N	= Number of surfaces
S	= Number of time steps