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Monitored Performance Enhancement of a Radiant Barrier Automobile Window Shade

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ABSTRACT

The Florida Solar Energy Center (FSEC) has monitored several automobiles in order to investigate how hot interior temperatures in parked cars might be reduced through the use of improved technology car shades. We observed interior temperatures in un-shaded stationary automobiles in Cape Canaveral, Florida to commonly reach 150°F and dashboard temperatures to rise to nearly 200°F. We found the addition of a conventional cardboard car shade behind the automobile windshield on sunny days to reduce the interior air temperatures by an average of 15°F. Dashboard temperatures were reduced by 40°F.

We found radiant barrier system (RBS) car shades to offer further improvements over conventional cardboard shades. RBS car shades are similar to conventional ones, but have a low emissivity foil backing laminated to the **interior** facing surface of the shade. When using an RBS car shade, automobile interior air temperatures are reduced an average of 3 - 5°F over conventional shades; the steering wheel and dashboard temperatures are reduced by a further 6 - 11°F. Although a seemingly a modest reduction, this improvement represents approximately an 8% reduction in heat transfer to the car interior during sunny conditions over the use of conventional car shades.

1. INTRODUCTION

Use of cardboard car shades to reduce the interior temperatures inside parked automobiles have become popular in Florida and other hot regions in the United States. Sealed automobiles commonly encounter interior temperature conditions that are exceedingly uncomfortable to their passengers (1).

In experiments at the Florida Solar Energy Center (FSEC) we monitored interior air temperatures on clear days inside un-shaded automobiles of 150° F. We observed dashboard and steering wheel temperatures of nearly 200° F. Strategies to reduce these temperatures are important because they promise to reduce passenger discomfort, increase the longevity of interior automobile components, and reduce initial automobile air conditioning loads (2). Simulation analysis of automobile thermal performance have shown solar radiation through windows to dominate the heat build-up during parked conditions (3).

Such high temperatures exacerbate initial automobile air conditioning loads increasing the capacity requirements for car air conditioning equipment. Treatment of this problem is important in light of recent concerns with depletion of the earth's ozone layer which is adversely affected by release of chloro- fluorocarbons (CFC5). Automobile air conditioning systems have been widely implicated in the release of CFCs to the atmosphere.

We decided to see if the effectiveness of conventional cardboard car shades could be increased through the use of a low- emissivity surface facing the **interior** of the car. Radiant barrier systems (RBS) successfully reduce the heat transfer in houses from hot roof decking to ceilings (4). We expected that the same physical principals should work equally well for car shades. We conducted an initial experiment to explore the concept.

2. INITIAL EXPERIMENT

We obtained two conventional cardboard car shades and used graphics adhesive to laminate aluminum foil to the interior surface of one of the cardboard car shades. This became the prototype RBS car shade for use in the experiments. We left the other shade in original condition.

On June 1st, 1988 we conducted an experiment at FSEC using an off-white Volvo sedan. At 8:40 A.M. EST we oriented the car south. Two shielded thermocouples were installed inside to monitor interior temperatures. One probe was taped to the car dashboard in the shadow of the car shade; the other recorded the air temperature at passenger breathing level around the steering wheel. We then placed the foil faced radiant barrier car shade in the front window. From 9:00 A.M. to 5:00 P.M. we took manual measurements of the thermocouples every half hour. The car was left sealed and only opened briefly every hour to switch the car shade from the conventional type to the radiant barrier and vice versa.

We made a total of 15 observations, eight with the RBS shade and seven with the conventional shade. The resulting profile of the car air and dashboard temperatures is depicted in Figure 1. The times when the RBS shade was installed are clearly distinguishable in the temperature data, particularly for the car dashboard. Table 1 summarizes the recorded experiment. The uncertainty estimates for the temperature differences were evaluated at a 95% confidence limit. Both temperature differences were significant, even with a very small number of observations.

The interior temperature while the RBS was in place averaged 6.8° F. cooler than when the conventional shade was installed; the dashboard temperature averaged 14.3° cooler. Thus, the initial assessment of the radiant barrier car shade concept showed good promise for improving automobile comfort.

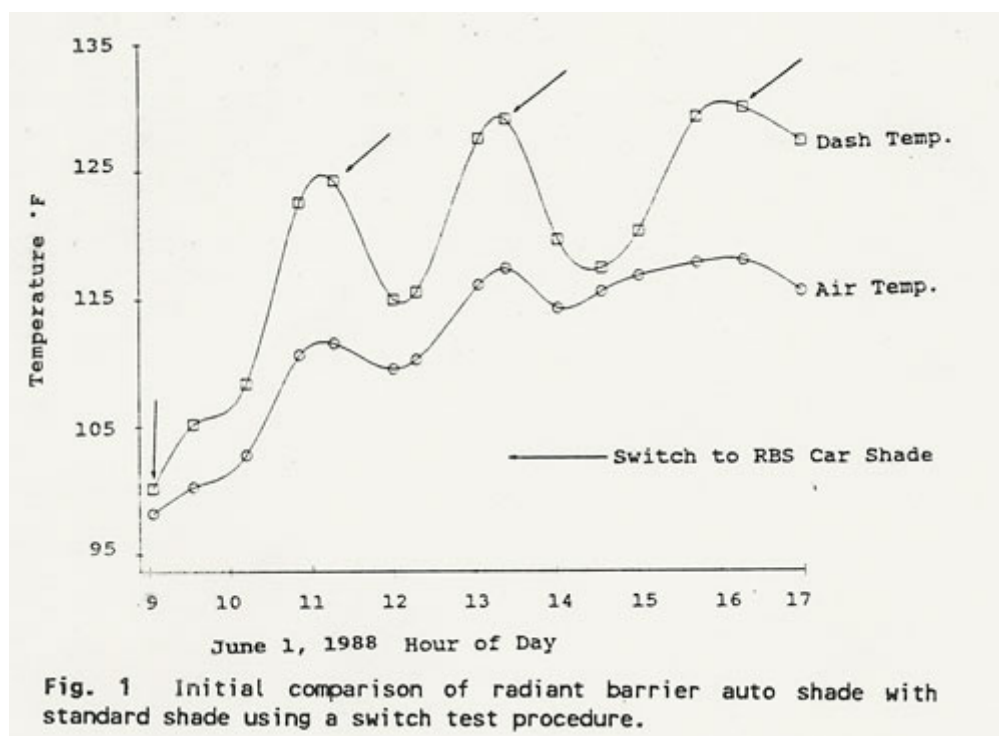


Fig. 1 Initial comparison of radiant barrier auto shade with standard shade using a switch test procedure.

Table 1
RADIANT BARRIER CAR SHADE EXPERIMENT

June 1, 1988

Case	Mean (°F)	Std Devn (°F)
Std Shade Air	115.2	3.0
RBS Shade Air	108.4	7.2
Difference	6.8	±5.5
Std Shade Dash	127.0	2.7
RBS Shade Dash	112.7	7.2
Difference	14.3	±5.4

3. POTENTIAL IMPROVEMENTS TO THE CONCEPT

Two problems were noted with the concept in the initial experiment:

1. The interior foil face became hot to the touch after long periods. We planned to monitor the car shade interior surface temperatures to determine the severity of this drawback.
2. Due to the crude technique used to adhere the foil to the car shade, the foil tended to de-laminate from the cardboard backing under high levels of insolation. We solved this problem by the use of contact cement to adhere the foil surface.

A number of suggestions were suggested to improve the concept. The most significant of these concerned the optical characteristics of the exterior facing surface. The white exterior facing surface on the standard cardboard shade had a significant amount of dark-colored printing with an overall solar absorptance of approximately 0.40. The heat absorbed by this exterior color is readily transferred to the inward foil-facing side of the shade. The low emissive foil in turn retains the heat leading to excessively high temperatures.

Use of flat white paint with light colored lettering could easily achieve an absorptance of 0.30 or less and minimize interior foil surface temperatures. Accordingly, we painted our prototype RBS car shade flat white to decrease exterior solar absorptance.

Initially, we believed that a reflective foil covering on the exterior car shade surface coupled with a foil low emissivity interior covering might result in improved performance. The solar absorptance of foil is fairly low, often in the range 0.15 - 0.10. To test this concept, we assembled a third car shade with reflective foil cemented to both sides.

4. DETAILED SIDE-BY-SIDE MONITORING

After proving that the basic concept, we pursued more detailed experiments to validate our initial findings. We monitored two automobiles at FSEC over a period of five weeks. We used identical automobiles to minimize differences that were likely to exist from one model to the next. This seemed especially important in due to the likely dependence of interior thermal loads on car color and window layout. The test automobiles were two nearly identical 1987 Toyota Tercels with a metallic green exterior color and gray interiors belonging to FSEC employees.

Ten copper-constantan thermocouples recorded the following measurements on each car:

1. Interior air temperature
2. Dashboard temperature -
3. Steering wheel temperature
4. Car shade interior surface temperature
5. Car hood surface temperature

The thermocouples were installed according to procedures established at FSEC to insure accurate air and surface temperature measurements (5). Nonetheless, each day the thermocouples were checked within the Passive Cooling Laboratory (PCL) to insure that readings were consistent. Average disagreement between probes was less than 0.1°F. We made a final check on July 1st, 1988 in which a car was instrumented with two probes at each location. Disagreement between temperatures taken averaged less than 0.2°F.

We assembled three car shades for the experiments. One was left in its original condition; another was altered into a prototype for the RBS car shade. The last car shade had foil faced backing installed on both interior and exterior surfaces. We collected the monitored data on a FLUKE 2280 data logger which was also used to collect meteorological data on site (ambient temperature, insolation, wind speed, relative humidity). The following experiments were planned for full day periods:

- A. No car shade
- B. Conventional car shade
- C. RBS Car shade
- D. Reflective RBS Car Shade

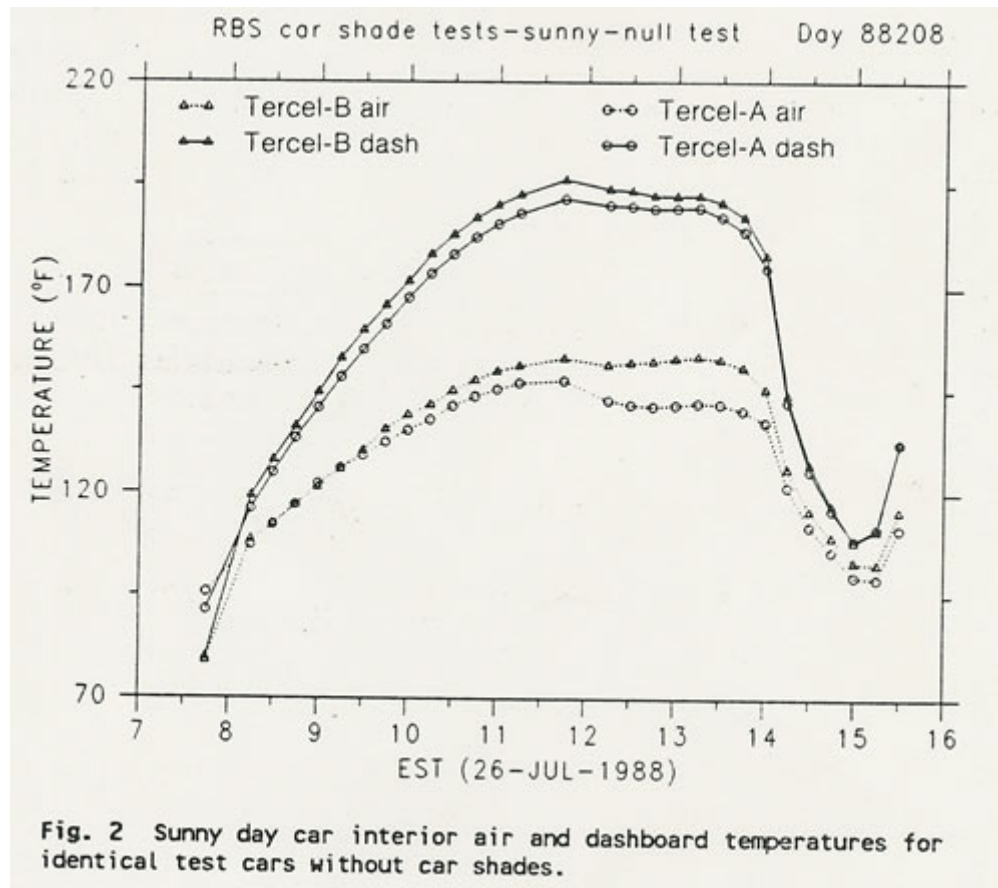
We also planned several other experiments to determine the effect of window venting on car thermal response. We planned that each car would be alternately given a different part of the four car shade treatments over four days. We encountered number of problems during the monitoring process. Clear or partly cloudy conditions were preferred although not always present and several experiments were inconclusive due to weather conditions. The cars themselves were not always available since one the Tercels is used in an FSEC car pool. This resulted in

an experimental availability averaging two times a week. This was, by far, the greatest handicap to completion of the experiments.

4.1 Null Test: Static Soak Conditions

The null test consisted of monitoring both cars under full sun or 'static soak' conditions without any car shades or ventilation. This experiment, carried out on July 26th, 1988 is depicted in Figure 2. The monitored results show the severity of the problem: interior air temperatures reached over 150°F and dashboard temperatures rose to nearly 200°F. These values are similar to a previous study of ten car models which showed interior air temperatures of 142°F to 158°F in static tests in Phoenix, Arizona (6). Such high temperatures contribute directly to passenger discomfort, initial automobile air conditioner loads and the need for large air conditioners to abate them.

The test also showed that the Tercel-A had a tendency to maintain lower internal temperatures than its twin. The systematic bias was 4.9°F for the interior temperature and 3.1°F for the dash temperature. We attribute some of this difference to the somewhat darker color of interior upholstery in Tercel-B. To correct for this potential problem we switched the experimental treatment from one car to another during the tests.



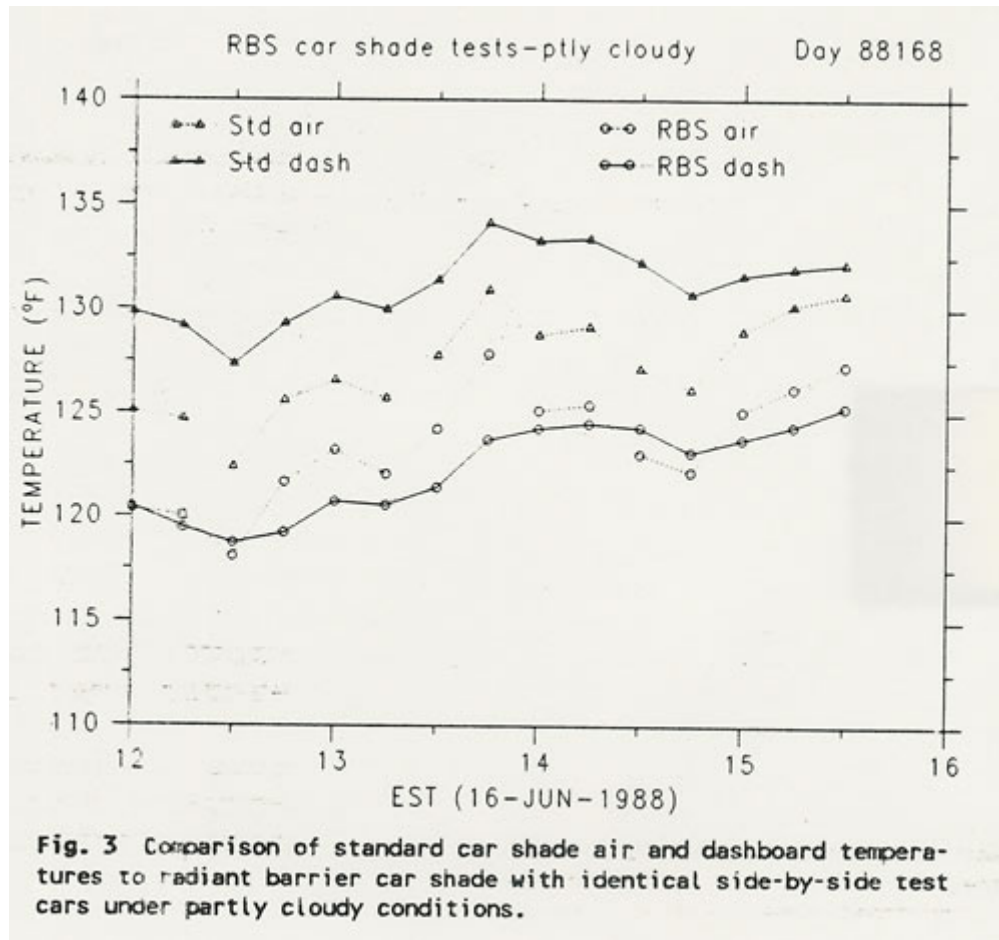
4.2 RBS versus non-RBS Car Shade

The major objective of the study was to identify systematic differences between a conventional car shade and an RBS car shade. The most successful experiments were performed on June 16th and 17th and are shown in Figures 3 and 4. June 16th was typical of summertime conditions in Florida; it was partly cloudy with temperatures in the mid-80s in the afternoon. With the conventional car shade the interior temperature reached a maximum of 130°F at 1:45 P.M. At that time the temperature rose to 127°F in the car with the RBS car shade. Over the monitoring period, the car with the RBS car shade remained 3.0°F cooler inside than the car with the conventional car shade. The differences between the dashboard temperatures were significantly greater, averaging 7.6°F.

The tests on the following day were made under clear sky conditions. We switched the RBS car shade to Tercel-A in order to correct for differences between the individual automobiles. With the cars facing south (as they did in all the experiments) the cars heated rapidly in the morning hours. This results from the large solar input through the east-facing driver's side windows. Again the RBS car shade showed superior performance compared to the conventional shade, with interior air temperatures averaging 3.9°F cooler with the improved shade. Given

the high levels of insolation, the differences in the dashboard temperature were even greater than the previous day, averaging 8.8°F. Steering wheel temperature reductions averaged 6.6°F over the two days. Since drivers must grasp the steering wheel upon entering the parked automobile, this temperature reduction should provide improved comfort.

One concern expressed in the initial experiments was the higher surface temperatures on the RBS car shade that resulted from the low-emissive foil surface. The data show that the interior car shade surfaces are raised substantially by the presence of the radiant barrier. The average increase was 22.1°F over the two days with a maximum temperature on the radiant barrier surface of 165°F at 11:00 A.M. on June 17th. The temperature at the same time was 142°F on the interior of the conventional shade. Key results of the two day tests are summarized in Table 2.



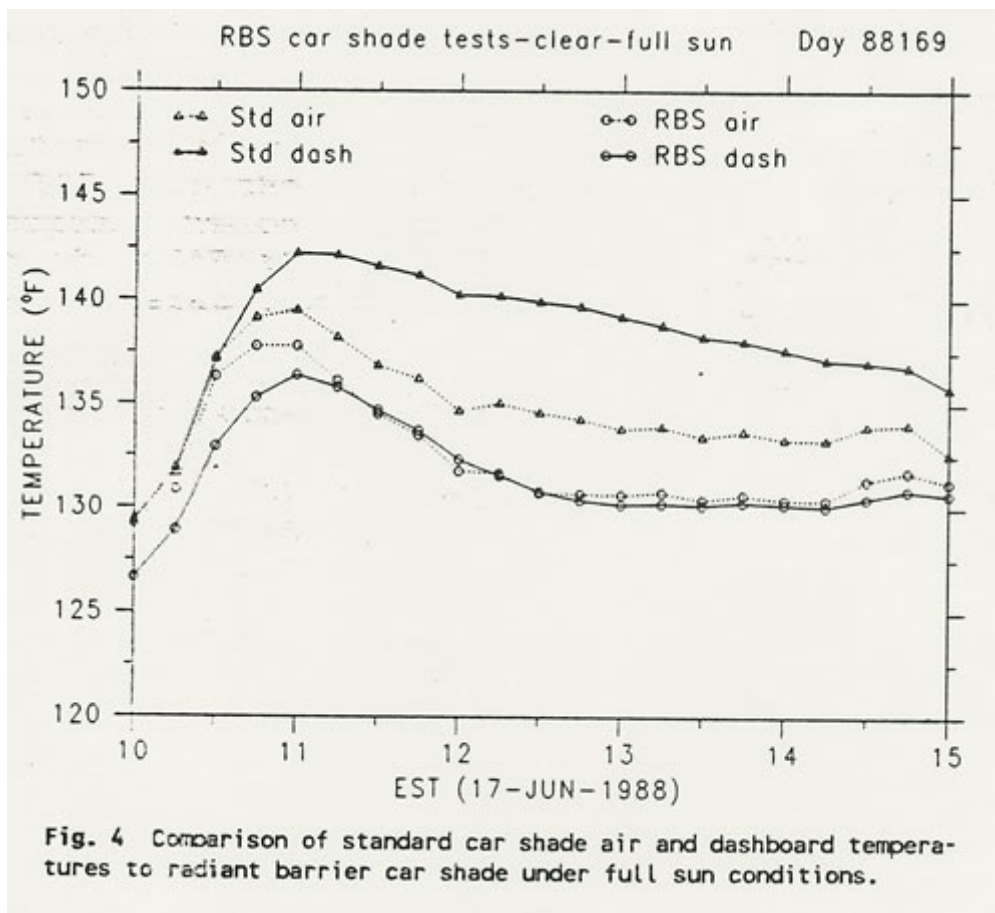
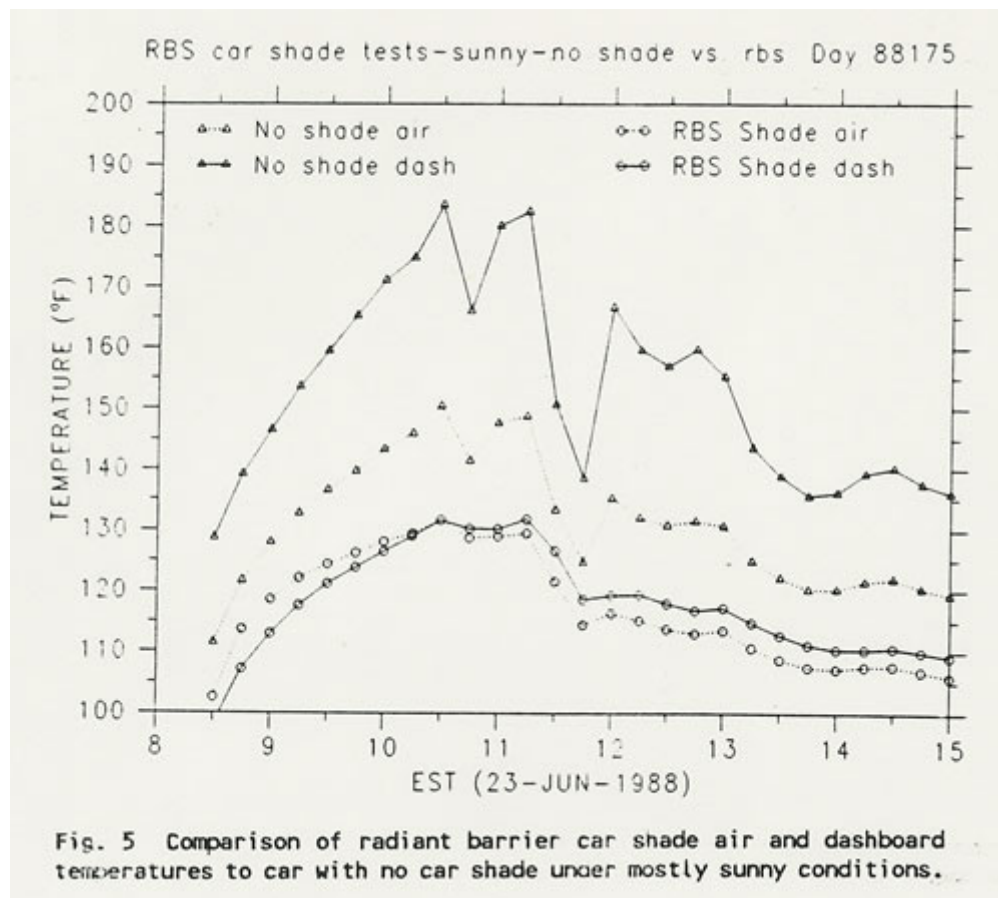


Table 2
RADIANT BARRIER CAR SHADE EXPERIMENTS
 Side-by-Side Tests: June 16-17, 1988

Case	Mean (°F)	Std Devn (°F)
Std Shade Air	131.0	2.1
RBS Shade Air	127.7	2.4
Difference	3.3	±0.8
Std Shade Dash	135.2	2.9
RBS Shade Dash	127.0	2.1
Difference	8.2	±0.9



The RBS car shade resulted in an average air temperature that was 3.3°F cooler than with the conventional shade. Dashboard temperatures were reduced by an average of 8.2°F. Maximum differences for any given observation were on the order of 5°F for air temperatures and 10°F for dashboard temperatures. Data analysis indicated that although these differences are modest, they are statistically significant at a 95% confidence level. Since the elevation in the automobile interior air temperature over the ambient air temperature is proportional to the level of solar gains over the rate of heat loss, the 3.3°F reduction by the RBS car shade corresponds to approximately an 8% reduction in the rate of heat transfer to the car interior during sunny conditions over that achieved by a standard car shade.

Finally, a test on June 23rd compared the no car shade condition to the use of an RSS car shade. The results are depicted in Figure 5. Average air temperature reduction in the car with the RBS car shade was 13.4°F and the maximum difference was 21.7°F. Dash temperature reductions were greater averaging 44.3°F with a maximum difference of 53.1°F.

The results of the three days of testing confirmed the findings from the initial experiments. RBS car shades perform better than standard car shades and provide substantial reductions in interior temperatures in parked automobiles when compared to no car shade at all.

4.3 Vented Cases

One venting test was designed to determine how sensitive the performance of the RBS car shade is to ventilation. The other test would simply determine how much venting can reduce interior temperatures in unshaded automobiles. We defined car venting strategy as rolling down the driver side car window so it provided a two inch vertical crack length for venting.

We performed first venting test on June 24th. Conditions on this day were cloudy until 11:00 A.M. and then sunny thereafter. Nevertheless, the venting test showed that the RBS car shade resulted in air temperatures that averaged 1.4°F lower than the conventional shade. More importantly, the difference in the dash temperature caused by the RBS shade was still similar in magnitude to the unvented case-- an average temperature depression of 8.2°F. The difference in the steering wheel temperatures averaged 6.0°F during the late afternoon. Thus, the radiant barrier shade still results in considerably lower interior surface temperatures within the car during vented operation although reductions to interior air temperature are less substantial.

We performed a single experiment on August 1st on one of the test cars to determine venting potential for a car without a car shade. We left the single available Tercel sealed until 11:30 A.M. at which time we cracked its driver side window two inches. The automobile had no car shade during the test. The results showed about a 10°F drop in interior air temperature from the venting, although little effect on dashboard or steering wheel temperatures. We conclude that venting potential may be significant, but that further experiments are necessary.

4.4 Specular -Reflective RBS versus RBS Car Shade

A limited series of experiments have attempted to determine the relative benefits of the a specularly reflective car shade with an interior radiant barrier (SRBS) over the conventional RBS car shade. Such a car shade has foil laminated on both the interior and exterior faces. Analysis of the data taken shows that such an exterior reflective source results in little or no performance improvement.

An experiment on a cloudy day, July 14th, showed Tercel- A equipped with the SRBE to perform only slightly better than the conventional RBS car shade. We considered this result insignificant given the tendency of Tercel- A to remain cooler than its twin as observed in the null test. The experiment was terminated at 12:45 P.M. in a heavy rainstorm when lightning struck the PCL and disabled the datalogger.

We completed a more successful experiment on July 27th using two different cars, the Volvo sedan and a Ford Escort. We used a switch procedure to isolate the effect of the SRBS versus the RBS car shade from the differing car types. The Escort began with the SRBS shade, switching to the RBS shade at 11:30 A.M.

The results showed that the SRBS offers no discernable advantage over the RBS shade for interior air or dashboard temperatures. Furthermore, the monitored temperature of the car shade interior surface actually showed the SRBS to be much **hotter** than the RBS shade. We explain this by the fact that the exterior foil face on the SRBS shade exterior is also a low emissive surface. As a result it retains most the heat absorbed from the sun rather than re-emitting it to the glass above it, the coolest surface in view of the absorption plane. On the other hand the flat white exterior face of the RBS car shade is also highly emissive. Although it absorbs more of the incident solar radiation, it readily re-emits much of it back to the car window. In summary, monitored results show that a double foil faced car shade performs no better than a standard RBS car shade. There is a great aesthetic problem as well; such reflective car shades can be nearly blinding to individuals approaching such an automobile.

5. CONCLUSIONS

Monitored interior temperatures in unshaded parked automobiles in a hot climate such as Cape Canaveral, Florida commonly reach 150°F and dashboard temperatures can approach 200°F. The addition of a conventional cardboard car shade behind the automobile windshield on sunny days can reduce the interior air temperatures by an average of 15°F and reduce dashboard temperatures by 40°F.

Radiant barrier system (RBS) car shades offer further improvements over conventional cardboard shades. RBS car shades are similar to conventional ones, but have a low emissivity foil backing laminated to the **interior** facing surface of the shade. When using an RBS car shade, automobile interior air temperatures are reduced an average of 3 - 5° F over conventional shades. Steering wheel and dashboard temperatures are reduced by a further 6 - 11°F. The RBS car shade results in approximately an 8% reduction in overall heat transfer to the car interior during sunny conditions over that taking place with a standard shade.

The benefits of the RBS car shade are relatively unaffected by venting by car windows. Such venting results in less difference in air temperature between a standard and RBS car shade (1.4°F). However, the reductions in the dashboard and steering wheel temperatures are relatively unchanged by venting; an RBS car shade still results in an 8°F reduction in the car dash temperature.

We tested a number of different car shade configurations. Contrary to popular belief, we found that a two-sided foil faced car shade actually performs no better than an RBS car shade with foil only on the interior face. Because of the low emissivity characteristics of the exterior facing surface on such a shade, the shade surface temperatures become significantly hotter than for a shade with foil only on the interior facing surface.

In summary, the improvements from an RBS car shade results in the following advantages:

1. Increased passenger comfort.
2. Less thermal stress on car interior components.
3. Lower initial automobile conditioner loads.

Our monitoring work has provided important side benefits. Most previous studies of automobile thermal performance have used analytical simulation models. These models require a large number of assumptions to predict performance (7, 8, 9). We believe our empirical approach offers benefits to research by providing data which can be used by others to verify simulation methods.

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