ECONOMIC EVALUATION OF INSULATION/RADIANT BARRIER SYSTEMS FOR THE STATE OF TEXAS

Mario A. Medina, Ph.D.
Assistant Professor
Mechanical Engineering
Texas A&M University-Kingsville

W. Dan Turner, Ph.D.
Associate Dean
College of Engineering
Texas A&M University

Dennis L. O'Neal, Ph.D.
Associate Professor
Mechanical Engineering
Texas A&M University

ABSTRACT

This paper presents simulated performance of insulation/radiant barrier systems under different Texas climates. A transient heat and mass transfer model which predicts thermal performance of residential attics (Medina, 1992)[1] was coupled with an "economic" subroutine. Simple payback periods were estimated which were based on current insulation and radiant barrier (RB) prices (materials and installation), and current and forecast electric rates. It was found that when the analyses were based solely on reductions of ceiling heat loads during the summer time, a combination of R-11 with RB was more effective than upgrading the insulation level to R-19. Similarly, adding a radiant barrier to an existing insulation level of R-19 proved more effective than upgrading to R-30. When heat gains to the cold air traveling inside A/C ducts (which are usually installed in attic spaces) were considered, all insulation/radiant barrier combinations showed faster payback periods than insulation upgrades. During the winter time, insulation upgrades proved to be more effective than insulation/radiant barrier combinations. The simple payback analyses presented herein include both summer and winter simulations.

INTRODUCTION

Cooling and heating loads from and to the attic spaces represent between 15 and 25 percent of the entire space cooling and heating loads in residences. Radiant barriers (thin aluminum sheets) used in combination with the existing attic insulation have proven to substantially reduce the heat transfer rate across the ceiling when compared to attic insulation with no radiant barriers (Medina et al. 1992)[2]. For the technology to be accepted and implemented, and as the utilities explore the incorporation of RBs in their "good sense" programs, the economics associated with their implementation need to be further explored. This is one of the objectives of this paper.

Model Development

The model used for the evaluation of the thermal performance of insulation/radiant barrier systems was a transient heat and mass transfer model developed by Medina (1992)[1]. The model accounted for transient conduction, convection, and radiation and incorporated moisture and air transport across the attic as well as environmental variables such as solar loads on outer attic surfaces and sky temperatures. The model also accounted for attic air stratification, as well as forced and natural attic ventilation patterns. The model was driven by hourly weather data which included: month, day, time, outdoor air temperature, horizontal sun and sky radiation, wind speed and direction, relative humidity (or dew point), and cloud cover data. The output of the model were ceiling heat fluxes. The model predictions were compared to experimental data gathered throughout a three year experimental effort of side-by-side tests of attics retrofit with radiant barriers. The model predicted ceiling heat flows within 10 percent for most cases. An "economic" subroutine was coupled to the model which estimated simple payback periods based on current insulation and radiant barrier (RB) prices (materials and installation), and current and forecast electric rates.

The model was compared to experimental data collected during a three year period (Figures 1 through 5). For example, Figure 1 depicts ceiling heat flux results from tests corresponding to July 25 through July 29, 1990. (Note: $1 W/m^2 = 0.3171$ $Btu/hr\text{-}ft^2$).

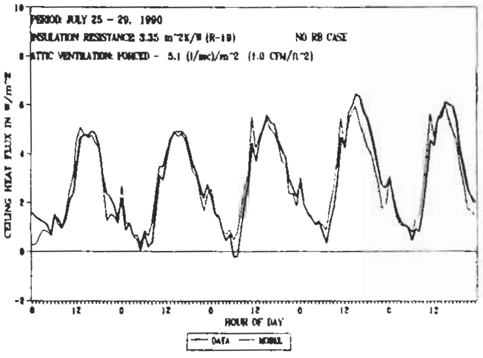

Figure 1. Model Results: ceiling heat fluxes (base case, insulation level: R-19; with attic airflow rate: 1.0 CFM/ft^2)

In all figures the heavy solid line corresponds to the data while the solid line corresponds to the model predictions. As shown in the graphs, the predictions were in good agreement with the data during both the peak and off-peak times. The cumulative difference between data and predictions was less than 10 percent for summer simulations and less than 12 percent for winter simulations. In all comparisons presented herein, the attic insulation had a nominal value of R-19. Figure 2 shows the retrofit case (installing a Horizontal Radiant Barrier -- HRB-- to one of the test houses) corresponding to Figure 1. Figure 3 shows a comparison between model results and experimental data from tests which were carried out during the week of July 8 through July 14, 1991. The radiant barrier was installed in the Truss Radiant Barriers (TRB) configuration.

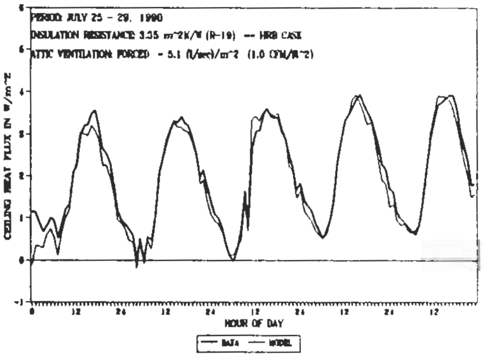

Figure 2. Model Results: ceiling heat fluxes (HRB case, insulation level: R-19; with attic airflow rate: 1.0 CFM/ft^2)

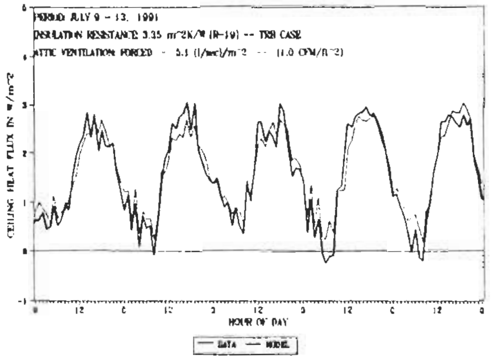

Figure 3. Model Results: ceiling heat fluxes (TRB case, insulation level: R-19; with attic airflow rate: 1.0 CFM/ft^2)

Figures 4 and 5 show comparisons of ceiling heat fluxes from data gathered during the winter of 1990-91. The data are from January 1 through January 6, 1991.

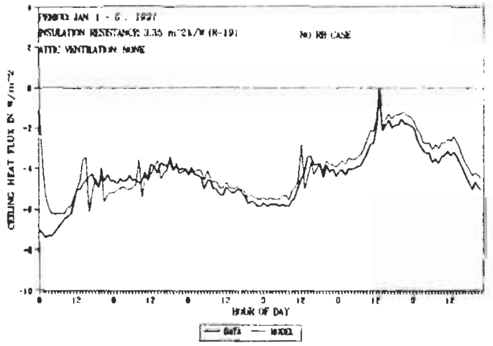

Figure 4. Model Results: ceiling heat fluxes during the heating season (base case, insulation level: R-19; with attic airflow rate: 0 CFM/ft^2)

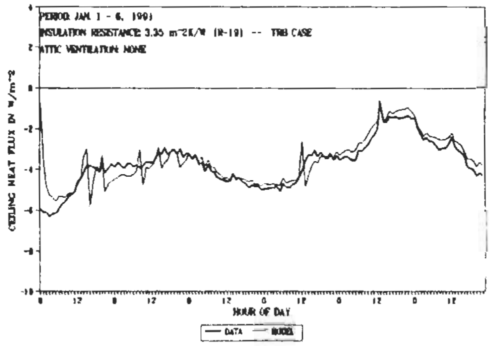

Figure 5. Model Results: ceiling heat fluxes during the heating season (TRB case, insulation level: R-19; with attic airflow rate: 0 CFM/ft^2)

As depicted in these figures, the model also predicted reasonably well during the heating seasons. Figure 5 shows the radiant barrier case for the same period as Figure 4.

The radiant barrier emissivity used in the simulations was estimated using the following relation:

$$\varepsilon_{RB} = \varepsilon_{aluminum} \, \%A_{aluminum} + \varepsilon_{perforation} \, \%A_{perforation}$$

$$\varepsilon_{RB} = 0.05\ (0.95) + 0.90\ (0.05) = 0.0925 \qquad \text{Equation (1)}$$

Only a few figures are presented to demonstrate the accuracy of the model; however, the model predicted well in many situations. In addition, it captured the moisture processes, it was sensitive to attic airflow variations, it predicted reasonably well when different values of insulation were used (unless the actual thickness of the insulation was not known), and it produced accurate results in the post-retrofit (radiant barrier case) when either the horizontal or truss radiant barriers were used. All predictions depicted in this section for the summer season were within 10 percent when compared to the data (based on the duration of the tests) and 12 percent for the winter season. However, the model usually predicted within five percent. This degree of accuracy provided reliable estimates of savings produced by the radiant barriers for seasonal or year-long simulations under a variety of situations for different weather conditions and geographic locations.

RESULTS

Case Scenario

The main assumption was the existence of a 2000 ft^2 house located at the specific regions within the State. The house then underwent the RB retrofits. The roofs had dark shingles with absorptivity of 0.85. The attic ridge line ran east-west and the ventilation rate was 0.35 CFM/ft^2. Different insulation levels were used. The radiant barrier was installed in the TRB configuration. An A/C unit with a seasonal energy efficiency ratio (SEER) of 9.0 was assumed to provide cooling during the summer and heating strip elements provided heating during the winter time. The summer included the months of May through September, and the winter months were December through February. No cooling or heating was assumed in the remaining 4 months.

Radiant barrier simulations were run for five Texas climates. The simulations were driven by weather tapes from Typical Meteorological Year (TMY) data from the National Oceanic and Atmospheric Administration (NOAA). Because the weather patterns in several cities (i.e., Austin, Houston, San Antonio, and Brownsville) were similar, the State was subdivided into three major regions: a South-Central Texas (SCT) region which covered the area from Killen, and Bryan-College Station, to the border with Mexico from Del Rio to Brownsville. The South-West Texas (SWT) region included El Paso and vicinity; and the North Texas (NT) region included the areas from Lubbock to the panhandle to the border with New Mexico and Oklahoma.

It was found that irrespective of the location within the State, an upgrade of insulation from R-11 to R-19 always produced an integrated ceiling heat load reduction of 38 percent during the summer. If the upgrade was from R-11 to R-30, the reduction was 55 percent. If the upgrade was from R-19 to R-30, the reduction was 28 percent. This is shown in Figure 6.

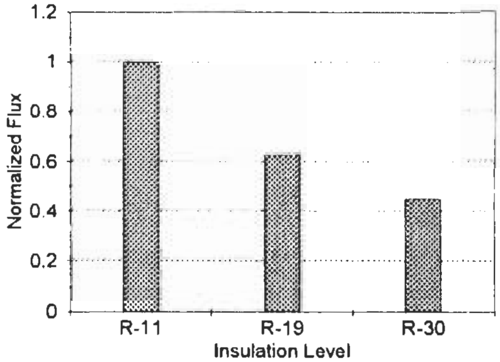

Figure 6. Normalized Ceiling Heat Fluxes

When radiant barriers were used in combination with existing insulation, reductions were observed which differed depending on which part of the State the house was located. For example, adding a radiant barrier to an existing insulation level of R-11 reduced the ceiling heat load by approximately 42 percent in the SCT region. In the SWT region the reductions approached 51 percent which increased to 61 percent in the NT region (Figure 7). If the level of insulation was R-19 and a radiant barrier was added, the reductions were around 33 percent for SCT, 41 percent for SWT and 50 for NT. For R-30 insulation the reductions were 31, 40, and 49 percent for the SCT, SWT and NT regions, respectively.

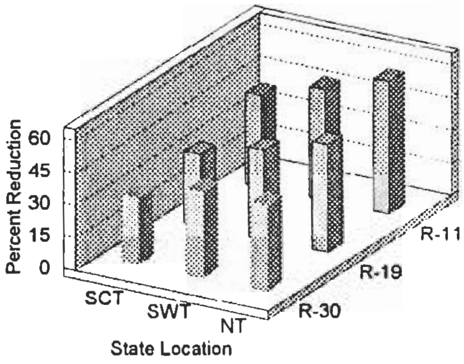

Figure 7. Percent Ceiling Heat Flux Reductions (when radiant barriers are added to existing insulation at different locations).

Therefore, when Figures 6 and 7 were combined, it was found that based solely on reductions of ceiling heat loads during the summer time, a combination of R-11 with RB was more effective than upgrading to R-19; similarly, and a combination of R-19 with RB was more effective than upgrading to R-30.

The reductions (percent reductions) in ceiling heat losses from the conditioned space to the attic during the winter time were numerically the same as the reductions during the summer season. That is, upgrading the insulation level from R-11 to R-19 yielded integrated ceiling heat loss reductions of approximately 38 percent irrespective of the location within the State. Upgrading from R-11 to R-30 yielded reductions of approximately 55 percent and 27 percent when the upgrade was from R-19 to R-30 (see Figure 6). Radiant barriers proved not effective during the winter time. Even though radiant barriers helped reduce the losses from the conditioned space, they blocked solar radiation from entering the conditioned space which assisted the heating systems; this was the reason for their reduced overall impact during the winter season.

When the A/C ducts were taken into account in the overall energy reductions, the analyses favored the insulation/radiant barrier combinations rather than just insulation upgrades. The following analyses accounted for both, ceiling heat flows reductions and reductions in ceiling heat gains to the air traveling inside the A/C ducts which are usually installed in attic spaces. Additional variables (mainly economical) which affected the performance of insulation/radiant barrier retrofits were included. The following analyses are presented in terms of simple payback. These assumed that the cost of installing R-11 insulation was $\$0.45/ft^2$; to install R-19 insulation was $\$0.64/ft^2$; and $\$ 0.90/ft^2$ to install R-30 insulation[1] ; in all cases installation costs included material and labor. Only incremental costs were assumed when upgrading from one insulation level to another. The cost of installing radiant barriers were $\$0.135/ft^2$ for new construction[2] and $\$0.35/ft^2$ for the retrofit/remodeling case[3]. The costs of electricity were those which were currently in effect at various cities located within specific regions.

R-11 as the Base Case

This case scenario assumed that a house started out with R-11 insulation and then retrofits were made to it. The simulations showed that for new constructions located in the SCT region the most economical retrofit (based on the lowest payback period) was achieved when a house was retrofit with a radiant barrier. At current electric rates the payback period was approximately 5 years. This retrofit compared (+/- 2-3 months in payback) to adding insulation to a level of R-19. Increasing the insulation from R-11 to R-30 had an average payback of 8 years. In the SWT and NT region the most economical retrofit was to upgrade from R-11 to R-19 with an average 4-year payback. In these regions, upgrading from R-11 to R-30 had a 7-year payback. In case of existing houses (not new constructions, but retrofits/remodeling/renovations), the insulation upgrades were always more economical than the addition of RBs and insulation/RB combinations; mainly because of the cost to install a radiant barrier.

R-19 as the Base Case

In the SCT region the most economical retrofit in new construction was to add a radiant barrier which yielded an average payback period of a little over 9.5 years. To simply upgrade to R-30 had an average payback period of approximately 16 years. Upgrading to an R-30/RB combination had an approximate payback period of 14.5 years. In the SWT and NT regions it was also more economical to add a radiant barrier with an approximate payback of 7.5 (SWT) and 11.5 (NT) years, respectively. For existing houses, upgrades from R-19 to R-30 were most economical. The payback periods for the SWT and NT regions were 11- and 13-years, respectively.

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[1] From the 1992 MEANS Repair and Remodeling Cost Data, The Robert Snow Means Company.

[2] The KOOL*PLY Company, Austin, TX.

[3] Innovative Insulation Company, Fort Worth, TX.

R-30 as the Base Case

Adding a radiant barrier on a new construction with R-30 had an average payback of 11 years in the SCT region. In the SWT region an added radiant to R-30 in new construction would payback in 8.5 years and it will take 14 years in the NT region. Adding radiant barriers to existing houses has a current payback period of 29 years in the SCT region while a 23 year payback in the SWT and 36 years in the NT area.

CONCLUSION AND RECOMMENDATION

It was concluded that radiant barriers in combination with existing insulation offered the potential to reduce energy consumption (cooling bills). The combinations of RB/insulation were generally more attractive than to simply upgrade to the next insulation level. The payback periods, however, are not immediate. In addition, a radiant barrier installed in the TRB configuration lowered the attic air temperature; thus reducing the heat gain to the cold air inside A/C ducts; this should be further explored by the utility sector since substantial peak demand reductions can be achieved by having colder attics. The radiant barrier combinations were not as effective during the winter seasons.

ACKNOWLEDGMENT

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2. Medina, M.A., O'Neal D.L., and Turner, W.D. 1992 "Effects of Attic Ventilation on the Performance of Radiant Barriers," A.S.M.E. Journal of Solar Energy Engineering, November.