Simulation Prediction of Transient Heat Transfer in a Residential Space Using Radiant Barrier Insulations and Coating

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Energy conservation, management, and production will always be an important concern to the residential user and power utility especially in areas experiencing extreme climates burdening utilities and consumers during their high demand seasons. As a result, energy efficient products are continually developed and designed to ease this burden. Along with the products comes the need for a means of evaluating these innovations other than costly trial and error of actual home installations. The solution, as in many other areas, is computer simulation which allows validating of product claims and previewing their impact before purchase. Such a computer model has been developed which is able to predict temperatures in a residential room space and wall structures to within ± 2 F of actual temperatures measured. To accomplish this simulation, the one dimensional heat transfer occurring in a residential room space was modeled by applying the fundamental radiation, conduction, convection, and thermal storage heat transfer mechanisms at forty-five nodes selected throughout the various layers of the walls and ceiling and in the interior air space.

$$q''_{cond} = k\frac{dT}{dx} \qquad q''_{conv} = h(T_f - T_s)$$

$$q''_{rad} = \sigma\varepsilon(T_{\text{surr}}^4 - T_s^4) \qquad q''_{stored} = c_p t_m \rho \frac{\delta T}{\delta r}$$

q'' = heat flux
k = conduction coeff.
$\frac{dT}{dx}$ = temperature gradient
h = convection coeff.
T_f = fluid temperature
T_s = surface temperature
T_{surr} = surrounding temperature
σ = Stefan-Boltzmann const.
ε = surface emissivity
c_p = thermal capacitance
t_m = material thickness
ρ = material density
$\frac{\delta T}{\delta r}$ = temperature change rate

Additionally, a complex “view factor” analysis is included which accounts for the significant radiation exchange among surfaces which see other surfaces. This results in a system of forty-five non-linear equations which must be solved simultaneously.

The model consists of numerous subroutine models which provide over one hundred continually updated parameters and coefficients used in the equations. The system is run on the Cray Y-MP 2/216 at UNLV and uses a resident IMSL subroutine NEQNF to solve the non-linear system. Simulations using 30-second time steps are made for an 11 hour test period representing the daylight hours of a typical day in a hot desert climate where solar insulation typically reached 225 $BTU/hr/ft^2$ at peak sun. [A 30-second time step is required to guarantee convergence of all 45 equations to a relative error less than .0001 ($\approx$ .5F).] CPU time for a run is 27 seconds requiring 1.8 billion instructions. Estimated run time on 386 speed PCs exceeded several hours. Simulations of this complexity are relatively new and have been made possible only by the advent of higher speed supercomputers.

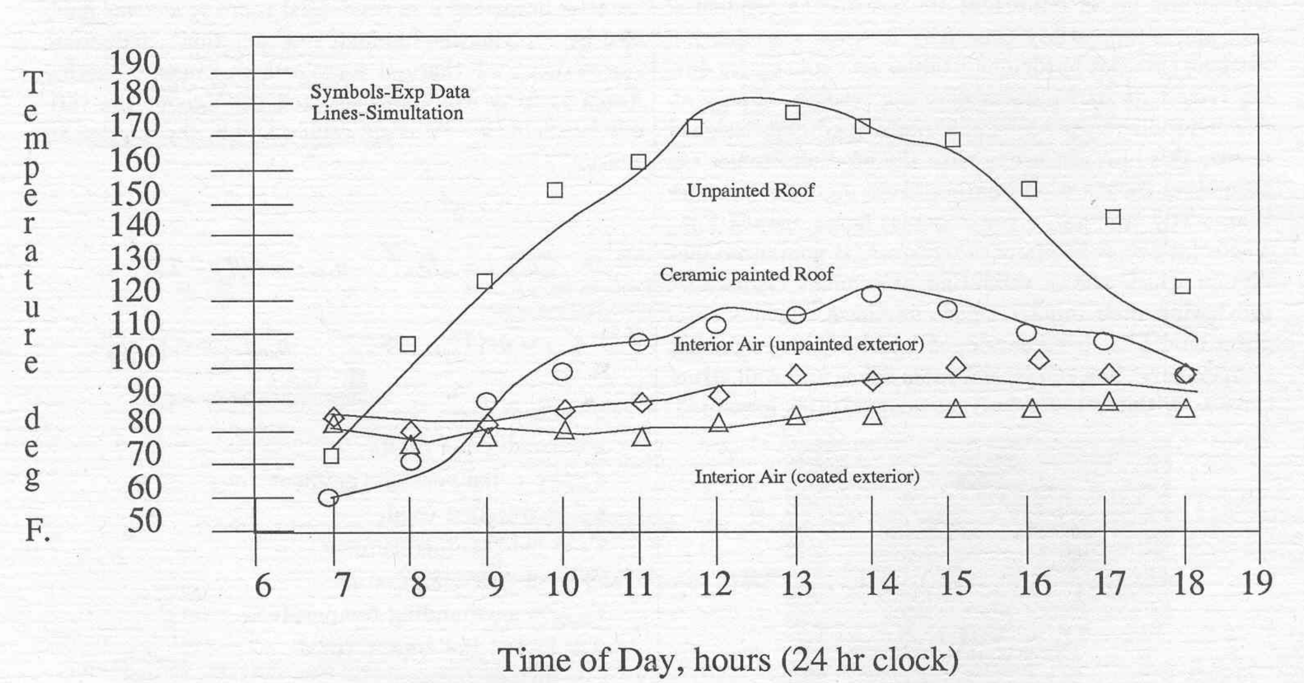

Figure 1. Prediction Comparison to Measure Data for Selected Nodes and Conditions

Figure 1 shows a simulation prediction compared with actual measurements taken in a home where an innovative radiant barrier insulation has been installed and which has an exterior coating of highly reflective ceramic paint.[1] The simulation shows a higher degree of accuracy in predicting actual responses which is attributed to the comprehensive inclusion of terms that to date were generally ignored because of limitations in computational capabilities. From a technical standpoint, the figure shows the significant impact a reflective coating has on the thermal load of a residential space when combined with radiant barrier insulation on an unairconditioned room.

This demonstrates not only the merits of innovative products but also the usefulness of a model capable of accurately quantifying these merits. A detailed paper has been published on this effort and has been accepted with an invitation to present at the Second International Conference on Refrigeration and Air-conditioning, Amman, Jordan and tentatively (abstract accepted) at the Cairo Third International Conference on Renewable Energy Sources to be held December 1992 in Cairo, Egypt.

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[1] "Ceramicoat", Energy Efficient Roof Systems, Inc., Ft. Lauderdale, FL.