EXECUTIVE SUMMARY

An assembly of steep-slope attics with shed-type roofs was installed on top of the envelope systems research apparatus (ESRA) at Oak Ridge National Laboratory (ORNL) for field-testing stone-coated metal roofs with shake and S-mission profiles. All roofs were equipped with ridge and soffit vents for ventilating the attic. The ratio of the vent opening area to attic floor area was 1 to 300. The stone-coated metal roofs were either directly nailed to the roof deck or offset-mounted from the deck using battens and counter-battens. The offset mounting provided a ventilation path along the underside of the shake and S-mission roof profiles.

The objective of this project was to document the potential energy savings of stone-coated metal roofs with and without IrBCPs and also the benefits of venting between the underside of the roof cover and the roof deck. The Metal Construction Association (MCA) and its affiliate members are keenly interested in specifying their roofs as cool roof products and want to know the effects of solar reflectance, thermal emittance and underside venting.

Dark-gray and light-gray stone-coated metal shakes with and without infrared-blocking color pigments (IrBCPs), a steel gray polyvinylidene fluoride (PVDF) painted metal shake with IrBCPs, and two stone-coated metal roofs with a S-mission profiles were installed on the attic assemblies by MCA. The facility enabled a direct side-by-side comparison of the effect of IrBCPs, fascia and deck venting, underside thermal emittance roof profile (whether moderately flat or S-mission), and a retrofit application over an existing cedar shake roof. To compare deck and ceiling heat transfer rates, a control assembly with a conventional asphalt shingle roof was set up.

Solar reflectance measures of the stone-coated metal and painted metal roofs exposed at ORNL were collected quarterly. The light-gray shakes had an initial solar reflectance of about 0.25 and an initial thermal emittance of 0.90. The underside of the shakes is bare metal with a thermal emittance of 0.34, which acts as a radiant barrier for the roof structure. After almost 1½ years of exposure, the light-gray shakes showed about a 10% loss in solar reflectance, which is leveling off as the time of exposure approaches 2 years. The dark-gray shake actually showed a slight increase in solar reflectance due to the accumulation of airborne contaminants. Dust tends to lighten a darker color. The painted metal roof with IrBCPs had the highest solar reflectance of the roofs tested, about 0.29. Also, it lost only about 3.5% of its original solar reflectance because of its durable PVDF paint finish.

Stone-coated metal roofs are energy-efficient, offering excellent energy credits as steep-slope cool roof products because of the improved solar reflectance afforded by IrBCPs and the underside venting. The best-performing roofs were the S-mission profile roofs on battens and the light-gray IrBCPs shake roof on battens and counter-battens. The reduction in heat penetrating the ceiling with these prototypes was about 70% of the daily heat penetrating the control shingle roof. Thus, the home air-conditioner would handle only 30% of the load incurred by a home with asphalt shingle roof, resulting in an energy savings cost of about 7¢ per square foot per year. Retrofitting a stone-coated shake roof over an existing cedar shake roof proved to be beneficial and resulted in the best thermally performing roof system, dropping ceiling heat flow by 75% that of an attic with a conventional shingle roof.

The stone-coated metal roofs negate the heating penalty associated with a cool roof in Tennessee's moderate climate.[1] The improved summer performance coupled with the reduced heat losses during the winter as compared to a shingle roof show that offset-mounting stone-coated metal roofs can provide the metal roof industry the opportunity to market stone-coated metal roofs in climates that are

[1] Tennessee has 3662 heating degree days based on 65°F (HDD_{65}) and 1366 cooling degree days based on 65°F (CDD_{65}).

predominated more by heating loads. Typically, the monetary breakeven point for cool roofs occurs where the ratio $(CDD/HDD)_{65}$ is about 0.4; however, underside venting can move this climatic boundary of affordable energy cost savings farther north.

Numerical simulations of the air flow in the inclined air channel formed by stone-coated metal roof systems demonstrated that naturally induced flow can be expected at very low roof slopes and very small temperature differences, well below those experienced in conventional roofing systems. Natural convection flow inside inclined ducts is conduction-dominated if the Rayleigh number (Ra_H)[2] is less than about $1708/\cos(\theta)$. Simulations yielded a bulk airflow rate on the underside of the roofs that was very similar to measures made using tracer gas techniques.

The AtticSim computer tool was validated against the steep-slope attic assembly with direct-nailed asphalt shingles. The model predicted the surface temperature of the shingles, the attic air temperature, and, as a result, the heat flow penetrating the conditioned space. Efforts are continuing to modify the code for predicting the effects of the airflow occurring on the underside of the stone-coated metal roofs. Correlations by McAdams (1954) and Brinkworth (2000) and simple boundary layer theory for a constant solar flux are predicting reasonable heat transfer measures within the inclined air channel. The measures of airflow determined from the tracer gas experiments match well the back-calculated values deduced from the McAdams (1954), Brinkworth (2000) and simple boundary layer theory correlations. We therefore have good representative airflow measures for subtile venting and are in good position to implement an algorithm formulated after the work by Brinkworth (2000) for use in AtticSim to predict the thermal performance of roofs with subtile venting.

---

[2]The height of the air gap is the characteristic length of the Rayleigh number (Ra_H) used here.