De-rating Recommendations

Derived from Past Research

for Reflective Aluminium Foil Insulations As a Result of Dust Accumulation

Aim of this Paper

The paper summarises research studies on the effect of dust on the thermal performance of reflective aluminium foil surfaces in residential attics. It also presents material to support a case for minimal de-rating of effective emissivity, if any, of reflective aluminium foil surfaces installed horizontally and NO de-rating of reflective aluminium foil insulation surfaces elsewhere.

Conclusions and Recommendations

- **Reflective foil insulation should only be de-rated for upward facing surfaces and then only when dust is present in the surrounding environment with access to the surface.**

- **Reflective foil insulation in roof spaces in warm to hot climates should be installed to maximize its effect as a radiant barrier by sealing the roof space.**

- **There is no evidence to support de-rating of upward facing reflective foil insulation in Australia to the full extent - that is to 0.9 effective emissivity. The maximum de-rating for a very dusty environment achieved in the laboratory, and not likely in suburban Australia, is an effective emissivity generally in the range of 0.7 to 0.8, depending on the dust particles.**

- **The matching downward facing reflective surface, not de-rated, should be installed with an air gap below it to ensure maximum thermal performance of BOTH upward and downward facing surfaces.**

- **Published R Values and energy rating systems should be reviewed to eliminate current de-rating prejudice in their treatment of reflective foil insulation surfaces (upwards and downward facing surfaces) in light of research findings.**

Reflectivity / Emissivity Usage

In some reports, written for general public readership, on the performance of reflective cavities, *reflectivity* and *emissivity* are used interchangeably. This is incorrect. Reflectivity is a term used to describe the reflection of solar radiation from reflective surfaces. Emissivity is a term used to describe the ability of a surface to emit electromagnetic radiation. Infrared *Hemispherical emissivity* for each surface of a cavity is used to calculate the resistance to heat transfer across reflective cavities.

Both reflectivity and emissivity from surfaces can be affected by dust deposits. Downward facing aluminium foil surfaces cannot accumulate dust and therefore maintain their full emissivity properties.

Change in R Values as a result of Dust on Reflective Foil Insulation

Changes in effective emissivity of one or more sides of installed reflective foil insulation, changes the R Value of the product or the system in service. Published R Values for specific reflective air cavities facing upwards AND downward surfaces, should be reviewed to determine the correct R Values are used. NOTE: Some trade or regulatory organizations do NOT publish R Values for reflective aluminium foil insulations since they are so dependent on the dimensions and shape of adjacent air cavities.

Factors influencing dust on reflective foil insulation

* Location - potential dust sources in the environment.

A dusty environment for residences includes adjacent unsealed roads, yards without foliage or paving, adjacent industry or other activity which produces dust.

* Period of installation of reflective foil.

If dust is able to enter the attic space at an estimated rate, which needs to be determined, (say 7% per annum [Lotz]), then there is a linear increase in emissivity as the dust loading increases UP TO 1 mg/cm2, additionally dust loadings cause the emissivity measurements to level out at an emissivity, presumed to be the emissivity of the dust. This maximum level was shown generally to be, between 0.7 and 0.8 depending on the type of dust particles. (Cook et al, pp.677-678).

* Type of roof - porous or sealed

Overlapping roof materials tend to be porous at the overlap. It is also common for roofs to be ventilated at soffits, gables or ridges. These all permit various level of entry of dust if it is present in the surrounding area.

* Type of installation - installed at attic floor, or rafters, walls, floors, etc

Generally installation in attics is either horizontal layer above the ceiling, or attached to the rafters following the roof line. In some USA research publications these are referred to as:

HRB - horizontal radiant barrier

TRB - truss (rafter) draped radiant barrier

NatHERS and other house energy rating programs

For residential buildings, NatHERS or other energy rating software, need to include a small routine to determine if any de-rating of reflective foil insulation is required in determining rating level. The rater should ‘ask’, for upward facing reflective foil the following questions, the answers to which determine the de-rating factor, if any:

1. Is this an upward facing reflective foil surface installed horizontally above the ceiling? If NO then NO de-rating. If YES then continue.

2. Is the air cavity, facing the reflective foil sealed from dust? If YES then NO de-rating and the remaining questions are irrelevant. If the air cavity is NOT sealed, then continue

3. Are the surrounding roads sealed? If YES - no de-rating - unless factors 5 or 6 exist.

4. Is there landscaping, such as trees, bushes, lawns, and paving surrounding the house? If YES then NO de-rating - unless factors 5 or 6 exist.
5. Is there an adjacent industrial area which produces dust? If YES then some de-rating, less if intervening landscaping
6. Is the location an area prone to dust storms? If YES then some de-rating, depending on landscaping and exposure
7. When was the insulation installed? Any de-rating should be pro-rated according to date installed.
8. Is there a second layer of foil protected from dust by the first layer? If YES then NO de-rating of the second and any consequent layers.

Suggested De-rating levels:

Comment It is unrealistic to de-rate reflective foil insulation to 0.7 or 0.8 because these figures are not justified in the field. They have never been observed in the field, only in laboratory tests where foil is coated with a thick layer of dust. In these cases the readings taken are the emissivity of the dust itself and depend on the type of dust particles.

The following recommendations are made for horizontally installed reflective foil insulation:

0.03 effective emissivity - no dust

0.1 effective emissivity reached after 5 years (or 0.1/5 pa de-rating) of slight dust cover in constantly light dusty environment.

0.4 effective emissivity reached after 5 years (or 0.4/5 pa de-rating) of moderate dust cover in constantly dusty environment

Rate of dust production

Lotz stated this to be about 7% of total area per annum for light dusting (but results were for only one house).
USA Dept of Energy states, “reflective foil will lose half its effectiveness through dust in 1 to 10 years” !
Many others showed negligible changes over years (see statements elsewhere)

Other Factors

* The reflectivity and emissivity of foil cannot be judged by its appearance.
* The reflectivity and emissivity of foil can be temporarily affected by water/condensation but this has been shown to reverse when the moisture dries.

Installation recommendations for Reflective Foil Insulation in Attics

Manufacturers should recommend the installation of reflective foil insulation in such a way as to minimise dust accumulation on the upward facing surface. ASTM C727 states, in Section 7 Installation Guidelines*

1. The insulation materials shall be handled in accordance with manufacturer's instructions and should be kept free of extraneous materials. The materials should be kept dry and should not be in contact with the ground or other sources of water.

2. Manufacturer's instructions and local buildings code shall be followed to ensure proper installation. The thermal performance of reflective insulation is based on the maintenance of a totally enclosed air space adjacent to the low emittance surface.

3. The thermal performance of a reflective insulation depends upon adherence to manufacturer's spacing recommendations. When instructions for insulating undersize and oversize cavities is not provided the manufacturer shall be consulted.

4. The thermal performance of a reflective insulation may be reduced by a corrosive environment. Reflective insulations should not be installed in environments that are corrosive to the low emittance surface.

5. The thermal performance of a reflective insulation may be adversely affected by materials such as dust, oil or paint on the surfaces. These materials shall be removed during installation taking care not to damage the insulation.

Manufacturers warranty:

A suggested manufacturer's warranty statement is: *'Manufacturer's product warranty of performance is voided if reflective foil insulation is installed in a dusty location.'*

More Research

Research into thermal performance of reflective foil RBM insulations and RFL fluctuates. Much of the research has been carried out to date in the USA, where the climate is different and metal roofing is rare, so the need for some bulk insulation in winter is necessary. This is not the case in warm temperate to hot portions of Australia which can be served with reflective foil insulation alone. In order to obtain better de-rating factors, R Values, and general details of the thermal performance of reflective foil insulation installed in specific situations, a large scale public funded research project is required. Portions of this project, such as those related to dust issues, need to span several years. Data from this project can be made available to the public and could be incorporated into regulations, ratings software etc, when completed.

Performance of reflective foil due to dust – Statements & research results
(in chronological order)

1940 Professor Wilkes, MIT, "Aluminium foil [has been] exposed in a *vertical* position since 1929 to the dust and fumes in the Heat Measurement Laboratory, MIT. Samples of this foil have been removed from time to time and the emissivity determined. Over a period of 10 years no appreciable change was found." (ASHRAE J. Jan 1940. Also Wilkes, et al ASHVE vol.46, 1940)

1950 Gordon B Wilkes, MIT, . "Before the installing of reflective insulation, the question of permanence naturally arises. Aluminium foil has been in use since 1930 and one can be assured that when it is employed under proper conditions, protected from the outside atmosphere, it will last as long as the average house without any serious change in emissivity. If dust should collect in sufficient quantity to obscure the aluminium surface, the emissivity of that surface would be much increased. This would not happen in a vertical or inclined wall, but the top layer of foil in an attic ceiling might be affected in this way. The lower surface of the top layer would still be effective as well as the succeeding layers below." ("Heat Insulation" John Wiley & Sons, 1950)

1961. Lund, C F "Heat Transfer through Mineral Wool Insulation in Combination with Reflective Surfaces" ASHRAE J. vol.3, no.3, 47-54, 98, 100, 102, 104. (Lund found dust accumulations increased the emittance of aluminium foils installed in residences.)

Yarbrough (1983) quotes "Lund measured emissivity of aluminium foils installed in four residences. Foil emissivity was measured annually for three years starting with a value of 0.022. The results after three years they were 0.207 [6.1%pa], 0.341[10.6%pa], and 0.432 [13.7%pa]." A fourth was discarded as other insulation was added. Lund attributed this deterioration to dust. The details of installation are not known. (Yarbrough, 1983, p.20)

1964. Lotz "It was found that when the foil was in contact with the ceiling, the normal accumulation of dust rendered it virtually ineffective within less than a year. If, however, an air space is provided between the under surface of the foil and the upper surface of the ceiling, the accumulated dust has much less effect on the insulating performance of the foil." p.iv

"The very low rate at which dust accumulated in the Meyers Park house can be explained by the fact that in this house special care was taken by the owner to seal all fortuitous openings in the roof space. For example, all roof overhangs were lined." p.3

"... Even if special precautions are taken to retard it by sealing the eave openings, as was done in one house investigated, dust still accumulates at a rate of about 7% per year which is sufficient after one year to reduce the insulating efficiency of reflective metal foils in direct contact with ceilings by about 58 per cent." p.7

"This is not surprising since, as already indicated, the convection plus conduction component is very small in comparison with the heat exchanged by radiation. As a matter of interest this further substantiates the findings reported elsewhere that the ventilation of attic spaces does relatively little to improve indoor thermal conditions in buildings, since it has little effect on the heat exchanged by radiation." p.7

"When the reflective foil insulation is applied in such a manner that other surfaces face air spaces, the effect of dust on its upper surface is relatively small. In this connection it might be more economical to use a paper-backed foil-side down, a procedure common in Australia, since it would eliminate the relatively ineffective upper layer of foil and thus reduce the cost appreciably. Although the maximum heat gain may be more than double as a result of dust accumulation, the net heat gain will still be relatively small and less than 30 per cent of the heat gained through a similar un-insulated ceiling." p.7

1965 Keith G Martin, Senior Research Scientist, CSIRO, November 1965 "With metal roofing's, thermal barriers must be used to reduce peak indoor temperatures. This may be achieved most economically by a horizontal air space of 4 inches which has the upper boundary provided by a material of low emissivity to heat such as aluminum foil, preferably as two layers laminated to a paper reinforcement. As the upward facing surface will collect dust, the effect of this surface is usually neglected in calculations.

"Where aluminum foil has been used as a thermal barrier it also acts as both a vapour barrier to prevent moist air reaching the cold roofing, and as a sarking to catch any drips of condensation." (Building Science Forum, paper 1965)

1973 St Regis ACI. p22 "Reflective Insulation and the Control of Thermal Environments." "Upward facing foil surfaces will have their reflectivity impaired by dust which settles over a period of time. If presence of dust is expected then all upward facing foil surfaces should be considered to be non-reflective when performing calculations." (no supporting research cited)

"Air spaces, wherever possible, should be bounded on the ***upper*** side by foil by incorporating spacing battens, etc. at the design stage." p.22.

"Vertical and downward facing foil surfaces are not affected by dust."

198? US Dept Commerce - letter circular 535 "Thin layers of dust readily visible to the eye do not cause very serious lowering of the reflective power. The appearance of the surface is not a reliable guide as to its reflectivity for radiant heat, and foil which appears dark or discoloured may have lost little in insulating value if the surface film is thin" (quoted on web - not viewed in full)

1983. Yarbrough, D "Assessment of Reflective Insulations for Residential and Commercial Applications". Statement which indicates the effect of increase in emissivity:
"E values are related to $\underline{e}$ by Equation (4) and the subscript "0" signifies values obtained with reflective surface assigned the value e=0.03. The results show, for example, that in the case of downward heat flow (k=5) where radiative transfer dominates, an increase of $\underline{e}$ from 0.03 to 0.10 results in a 26% decrease in R-value [US R Value] for a two foil assembly." p.17

"A need exists to establish if aging affects the thermal performance of reflective insulations. A laboratory study of accelerated aging due to surface reactions in typical chemical environments should be undertaken. Means by which foil emittance can be maintained or improved should be sought." p.31

1988 Florida Solar Energy Center (FSEC) is conducting a field test in which each attic of 11 homes was retrofitted with an HRB. Multiple small boxes containing RB were placed in each of these attics. The boxes are being retrieved on a logarithmic time schedule. After emissivities are measured, RB samples are studied with a microscope to determine the percentage area covered by dust, and samples are then carefully weighed to determine the weight of dust accumulation. Average emissivities were also measured. Results after 6 months showed HRB emissivities mostly between 0.05 and 0.10, with 2 samples showing higher emissivities (0.14 and 0.16). (Fairey, et al 1988, as reported by Levins et al, 1990, p.8.)

1988 Hall, James "Even with significant dust accumulation on RBT, the RB's performance or reduction in ceiling heat flux may not degrade nearly as much as would be expected from the significant increases in RB emissivity caused by the small amount of dust" p.179.

1989 Yarbrough et al "Testing done by Yarbrough at Tennessee Technological University in 1987 showed that small amounts of dust cause significant increases in RB emissivity. Yarbrough measured the emissivities of 46 RB samples containing various, known amounts of 'Tennessee crawl space' dust. FSEC developed the following curve for the emissivity as a function of dust loading; Emissivity = 0.02 + 0.829 [1 - exp(-0.688 * dust)] where "dust" is the dust loading in milligrams per square centimeter. (Levins et al p.10)

1989 Cook, J C, Yarbrough, D W and Wilkes, K E "The presence of dust on aluminium foil increases the measured value of the emittance." Emittance increases rapidly as dust concentration increases from 0 to 1mg/cm2. Maximum emittance values from 0.674 to 0.849 were obtained for heavily dusted foil depending on the type of dust.

"A correlation between surface area covered and emittance was obtained for foils taken from residential attics. The correlation did not give good results in two cases involving a large fraction of large particles with large average shape factors, but did give a good correlation for five samples." P.680.

"Foils taken from attics [of houses in Chicago area] after about 4 years had emittances from 0.066 to 0.423 with an average of 0.239." The foil surface contamination included dust, fly ash, pollen and fibers [and insect parts]. p.680

Figures 2 and 3 (page.678) show graphs for measured emittances for dust loadings for "attic" dust and "Arizona test" dust respectively. Both figures range from 0 to 10 mg/cm2 dust loadings, both level out at about 1mg/cm2, "attic dust" reaching about 0.7 emissivity and "Arizona test" dust reaching 0.8 emissivity, as measured by a emissometer to 3 digit output.

"The program predicts that a foil with, 0.239 emittance was 46% as effective as clean foil in reducing ceiling heat when installed on top of nominal R-19 attic insulation.)" p.680

[Further comment by Yarbrough, 2003:
"Whole-house monitoring is not the way to evaluate small changes in energy use. I took the position that emittance was the important property. Then the question is whether or not the emittance changes with contamination. J. Cook and I had a dust chamber that uniformly distributed dust on a surface. The amount was then characterized in terms of weight per unit area. K. Wilkes has a model for calculating ceiling heat flux that includes the radiant barrier emittance as an input variable. Ken's model is in ASTM C 1340. If you accept a model for the rate of dust accumulation and run ASTM C 1340 you can evaluate the heat gains and losses year-by-year. (quite a task)"]

1990 Levins, Karnitz & Hall [dust] This paper has a summary of past research on dust. The 3 objectives of the study were to determine the effects of attic ventilation area ratio, attic ventilation type and dust buildup on radiant barriers. p.xv

"Small pieces of clean RB material (emissivity - 0.035) were placed in boxes in the attic of each of the homes that had HRBs to allow periodic removal of an HRB sample and measurement of its emissivity. Eight months after installation, one box was removed from each attic of the HRB homes. The highest measured HRB emissivity was 0.10, with an average of about 0.07. It is planned to retrieve boxes and to measure emissivities two more times in these retrofitted homes during this test" (p.7-8 - referring to a TVA [Tennessee Valley Authority] study on 30 homes in Kentucky commenced in 1986).

"Two homes in Chattanooga, Tennessee, have had HRBs in their attics for an extended period. An HRB had been installed for over **five years in one house when the emissivity was measured at an average of 0.15.** In the second house the HRB had been installed for about 1.5 years and its emissivity measured at an average of 0.10." p.8.

"The TVA tests in the summer of 1987 using Arizona dust, which is commonly used for testing air filters, to simulate naturally occurring dust accumulation. This dust was sprinkled as evenly as possible on a small RB sample of known weight until an arbitrarily high emissivity (0.43) was reached."

"The dust weight and the area of the RB sample were measured and used to calculate the amount of dust required for each HRB in each TVA two cell to give an HRB emissivity of 0.43. The result was 57 grams of dust for each 48 square feet test cell (or 1.28 mg/cm2)...."p.10.

"Results of the dust tests showed an increase in cooling loads by 2.3% for light dust covering (emissivity 0.125) and 8.4% for the heavy dust loading (emissivity 0.185)." p. xvii.

"However, even with these excessive dust levels, which resulted in very high emissivities, the HRBs provided sizable and statistically significant reductions in the 20% range in ceiling heat flux. An important conclusion from this work is that 'large dust accumulations do not degrade the performance of an HRB. Since amounts of dust used resulted in excessive dust coverings, it may be that dust accumulation on an HRB is not a prohibitive problem.' TVA researchers generally agreed that further testing was needed to confirm or refute these results." p.12-15

[**Note** that this attic space also included fibreglass insulation throughout all tests. The reflective foil insulation was either placed directly on top of the fibreglass on the ceiling or stapled to the roof trusses. Therefore the lower surface of the reflective foil had NO adjacent air space. These results must be viewed in this context].

1990 Levins et al [ventilation results] There was essentially no difference in house cooling load reduction between either ridge/soffit or gable/soffit vent type with a truss radiant barrier, as both reduced cooling loads by about 8% when compared to no radiant barrier conditions. The attic ventilation type testing was done with a ventilation area ratio of 1/150. p xi.

1990 Levins, W P & Herron, D L "Although RBs remained in the attics of five sites for a six-month period, **practically no change in surface emissivities was measured.** Evidently, because of low wind velocities and relatively clean air at Fort Benning, little dust settles on the RB surface." p.596.

1991 DOE Radiant Attic Barrier Fact Sheet "Predictive modeling results, based on testing, suggests that a dusty attic floor application will lose about half of its effectiveness after about one to ten years."

1994 Noboa, H et al "The effect of dust on the emissivity of the radiant barrier was as expected: larger amounts of dust applied to the barrier increased its emissivity so that its emissivity asymptotically approached the emissivity of the dust. The model predicted that the curves of emissivity vs dust loading were different for differing mean dust diameters. The prediction of the model agreed with the experimental testing in the sense that, for equal dust loading measured by weight, dust with smaller mean diameters increased emissivity more than courser dust." p.28-29.

1995. Beal, D & Chandra, S, Florida Solar Energy Center,
"The results returned from the RBS roof confirm RBS's long term performance. The RBS was installed in the summer of 1987, and has performed without any significant change for this period. On some of the RBS surface that was exposed to outside air, such as near the soffit areas, there is noticeable corrosion. Further time will tell if this has a significant effect on the performance of the RBS installation. It should be noted that the installation is within ten miles of the Atlantic Ocean, and within two miles of a large body of brackish water. The salt content of the air in this area is among the highest in the world." p 11. [This research also noted the presence of mould on cement tiles and algae on elastomeric roofing]

2001 ASHRAE Fundamentals "Polluted environments may cause rapid and severe material degradation. However, site inspections show a predominance of well-preserved installations and only a small number of cases in which rapid and severe degradation has occurred." p.25.2

2003 Yarbrough, D [private communication] [Reflective Insulation Manufacturers Association – (RIMA) USA] "took a position against horizontal attic radiant barriers for many years. One or two years ago they reversed their position. The new statement goes along the line that horizontal attic radiant barriers are fine as long as they don't get contaminated. I recall the discussion that some or many attics have minimal ventilation and, as a result, will not have much contamination."

Performance of Reflective Foil Insulation due to Corrosion - Statements

Beal (1995) “On some of the RBS surface that was exposed to outside air, such as near the soffit areas, there is noticeable corrosion. Further time will tell if this has a significant effect on the performance of the RBS installation. It should be noted that the installation is within ten miles of the Atlantic Ocean, and within two miles of a large body of brackish water. The salt content of the air in this area is among the highest in the world.” P.11

Bassett, M. (1983) The paper does illustrate the serious contamination of foils by moulds and corrosion effects in the very humid moist climate which New Zealand has. While condensation lasts it destroys the reflective surface.

Robinson et al (1957 as quoted by Riskowski et al) found reduction of 30% in ability to reduce downward radiation due to stains from water which *were reversible*.

Wilkes, G B et al (1940 – as quoted by Yarbrough 1983 p.20) showed foil exposed to salt spray increased in emissivity to 0.1 after 2 years. Other changes were much less. Other cases (7) in place up to 10 years showed no changes in appearance.

ASHRAE “Hundreds of samples of aluminium foil have been stored in the laboratory for various periods of time up to 10 years with no visible signs of deterioration” ASHRAE J. Jan,. 1940

US Rubber Co. “Aluminium is highly resistant to the effect of corrosion. Aluminium is constantly being used where it is exposed to weather, salt spray and other conditions, which would adversely affect most metals.” US Rubber ‘Serving through Science’

References on Dust on Reflective Foil Surfaces (arranged alphabetically by author)

ASHRAE Fundamentals. (2001) and earlier editions. Atlanta, ASHRAE, 2000.

ASTM C 727-01 "Standard Practice for Installation and Use of Reflective Insulation in Building Constructions". (Full standard - section relating to dust quoted elsewhere)

Bassett, M. (1983) “Age, Corrosion and Dust on Reflective Insulation” BRANZ, November, Judgeford. (Full paper). This paper quotes Lotz’s South African study and then proceeds to demonstrate a more successful arrangement.

“The author shows that a much more successful arrangement of **foil draped on battens 25 mm above the ceiling is not affected by dust accumulating on the top surface**” (p.2).

Note: The paper does illustrate the serious contamination of foils by moulds and corrosion effects in the very humid moist climate which New Zealand has. While condensation lasts it impairs the reflective surface.

Beal, David, (1995) “Side by Side Testing of Four Residential Roofing and Attic Ventilation Systems” prepared for the Dept of Energy, by Florida Solar Energy Center, FSEC-CR-822-95. 34pp. (Full paper - a significant study which showed NO effects of dust from 1987 until **1994** for samples in houses. Corrosion only on the very outside of the RBS despite it being located in a high salt content environment)

Conover, David (1992) “Radiant Barrier Update” Home Energy Magazine Online July/Aug,1992. 3pp.

Cook, J C, Yarbrough, D W and Wilkes, K E (1989) "Contamination of Reflective Foils in Horizontal Applications and the Effect on Thermal Performance." ASHRAE Trans., vol.95, part 2, 677-681. (Full paper - Results of tests on reflective foil surfaces with coatings of applied dust, and others collected from the field in Chicago - see statements elsewhere)

Fairey, P et al (1988) “RBS Technology: Task 3 Report. FSEC-CR-88, Florida Solar Energy Center, April 26, 1988 [I do not have this but it is quoted elsewhere by Levins et al]

Fricker, James (1997) “Computational Analysis of Reflective Air Spaces” AIRAH J. Oct. (Paper from web)

Goss, W P and Miller, R G (1989) "Literature Review of Measurement and Predictions of Reflective Building Insulation Systems Performance - 1900-1989.” ASHRAE Trans.,vol.95, part 2, 651-664 (A good summary up to 1989 - includes section on dust and other contaminants including condensation.)

Hall, James (1988) “Performance of Radiant Barriers (RB) with R11, R19 and R30 Cellulose and Rock Wall Insulation” Fifth Annual Symposium on Improving Building Energy Efficiency in Hot and Humid Climates, Sept 13-14, Houston. 174-185. (RB’s significantly reduced heat gain through the ceiling during summer. Winter heat transfer reductions were smaller but still significant. Even with significant dust accumulation on RBT, the RB’s reduction in ceiling heat flux may not degrade nearly as much as would be expected from significant increases in RB emissivity caused by the small amount of dust.)

Levins, W P and Hall, JA (1990) “Measured Effects of Dust on the Performance of Radiant Barriers Installed on Top of Attic Insulation” ORNL., 29pp.

Levins, W P & Herron, D L (1990) "Radiant Barrier Field Tests in Army Family Housing Units at Fort Benning, Georgia" ASHRAE Trans., vol.96, pt.2, 589-597 (Full paper - includes tests of emissivities at intervals over 6 months - no change. This study included summer and winter conditions. It concluded that there were savings in energy loads in <u>BOTH</u> summer and winter and all houses tested had this result.)

Levins, W P, Karnitz, M A and Hall, J A (1990) “Cooling Season Energy Measurements of Dust and Ventilation Effects on Radiant Barriers.” ORNL, 94 pp. (Full paper - this paper has a summary of past research on dust. It focuses on the amount of dust and the effectiveness of the reflective insulation in stopping radiant heat. The results show reflective insulation above the ceiling performed consistently better than truss hung reflective barriers.

However, the presence of dust on the ceiling’s reflective insulation did NOT make the barrier ineffective. In fact the dusty reflective insulation on the ceiling outperformed the clean truss hung barrier in reducing radiant heat.

Loomis, Ken (1997) “Insulation Versus Radiant Barrier”. U-B-Kool.com

Lotz, F J (1964) “The Effect of Dust on the Efficacy of Reflective Metal Foil used as Roof/Ceiling Insulation.” National Building Research Institute Bulletin 33, Council for Scientific and Industrial Research. Pretoria? (covers tests on samples from 5 houses in Pretoria, of varying ages. It deduced rates of dust accumulation and the effect of this accumulation on the performance of reflective foil. Some tests took no precautions to exclude dust. When precautions were taken the rate of deposit dropped to 75% of original. Heat flow was measured not emissivity.)

Lund, CF and Lander, RM (1961) “Heat transfer through Mineral Wool Insulation in combination with Reflective surfaces” ASHRAE J. Vol.3, No3, 47-54, 98, 100, 102, 104.

Noboa, H et al (1994) "A Model of the Effect of Dust on the Emissivity of Radiant Barriers” ASHRAE Trans., vol. 100, part 2, 23-30. (paper which confirmed that more dust produced higher emissivity. However, it also confirmed that courser dust particles in the dust loading produced a lesser effect than fine dust particles of equal loading. Dust with low mass density increased the radiant barrier emissivity more than high mass density dust for a given loading. There were difficulties in measuring the area covered by the dust. An electron microscope was required. A model was developed and tested. This model requires input for the real distribution of dust, the rate of accumulation, and the density of the dust that settled in the attic - information that is not readily available).

Oak Ridge National Laboratory (2002?) “Present Value Savings for Dusty Radiant Barrier on Attic Floor” web page [evaluations of energy savings in conjunction with other insulation]

Riskowski, G L et al (1989) "Thermal Performance of Typical Light Frame Walls with Reflective Surface Insulations" ASHRAE Trans., vol.95, pt.2, 671-676. (Full paper with some very significant statements about mean temperature and test results, dust summary, calculated R values, consideration of different types of reflective foil).

St Regis ACI (1969) “The Effect of Dust on the Performance of Reflective Insulation” Sydney, Feb. St Regis said they fully discounted the reflective property of the upward facing surface due to dust. However they included statements from others who supported reflective insulation - see under Statements re Performance of Reflective Foil Insulation.

St Regis ACI (1971) “Field Test of Sisalation Aluminium Foil Insulation” Sydney, Jan/Feb.

St Regis ACI (1972) “Insulation in the Tropics” Sydney.

St Regis ACI (1972) “Reflective Insulation; Heat Transfer Coefficients”, Sydney. (paper states “All upward facing surfaces are completely dust covered. Downward facing and vertical foil surfaces are not affected by dust“). **[This statement is found by tests to be untrue - that dust does NOT automatically cover the upward facing surface and even when there is some covering of dust the reflective foil still stops a significant percentage of heat from transferring].**

US Dept. of Energy [DOE] (1991) “Radiant Barrier Attic Fact Sheet” (Full paper from web).

Wilkes, G B et al (1940) “Thermal Test Coefficients of Aluminium Insulation for Buildings” ASHRAE J. Jan 1940, 69-72. A lso Wilkes, G B et al ASHVE vol.46, 1940.

Wong Cheng Chen, Barber, Ernest (1998) "A Method to Measure Dust Production and Deposition Rates for a Ventilated Airspace without Recirculation Systems" ASHRAE Trans 1998, vol. 104, part1, SP-98-26-3 (Abstract - aimed at controlling dust in animal [pigs, cattle] sheds where it contains odours and bacteria. The researcher has published other papers on controlling dust in the environment of animal sheds. The most successful technique was to spray canola oil in the atmosphere.)

Yarbrough, D W (1983) “Assessment of Reflective Insulations for Residential and Commercial Applications.” ORNL, October. (Discusses current issues associated with reflective insulations, including thermal resistance factors and performance. The development of a computational model of reflective insulation assemblies is included in the Appendices. Statements relating to effects of dust are quoted elsewhere in this summary).

Yarbrough, D W et al (1989) “Contamination of Reflective Foils in Horizontal Applications and its Effect on Thermal Performance” ASHRAE Conference, Vancouver, BC, June 25-28, 1989. (Reference only from Levins et al).

The End

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