Architectural Coatings: Study of Thermal Conductivity

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Abstract

Typical architectural coatings, either in free-standing or composite applications, have a wide range of thermal conductivity. The insulating effects of these coatings on aluminum and steel buildings are extremely pertinent to energy savings. Present coatings systems such as asphalt with aluminum, acrylics, polyvinyl chlorides (PVCs) and other isotropic polymers are reviewed; the thermal conductivity, cost, and environmental effects of these systems are presented. Compared to conventional roofing and coating materials, new cool-buildings materials/coatings (1) are environmentally preferable, non-solvent based and more energy-efficient, providing/maintaining cooler buildings in cold climates/seasons; (2) provide significantly lower costs, both in materials and labor-installation; (3) are easier to install/apply; (4) are lighter weight; (5) provide longer weatherability; and (6) are simpler/easier to repair.

1. Introduction

Consumers and coatings manufacturers are faced with the problem of metal buildings that have roofs and wall with very few insulative and protective properties. These metal buildings, found throughout the United States, are owned by businesses that in many cases have low maintenance budgets for cooling and heating costs. Furthermore, conventional roofing and coating materials are costly and labor intensive when installed, and are usually solvent-based products that are deleterious to the environment.

Today's materials and technology exist to provide newer coatings and roofing materials that can provide 30% of more greater insulating properties while protecting the metal from deterioration, and are cost effective, lightweight, and easy to install. Additional benefits are greater weatherability and repairability than are found in conventional roofing and coating materials. The approaches to solving the cooling problems of cool buildings are many faceted, not only in the understanding of material attributes such as thermal conductivity but also how they interact in whole cool building systems.

More importantly, for these systems to come to fruition, political and marketing problems must be resolved. Specifically, the contractors and building owners must have compelling reasons for using the newer type roof coatings. One route to the marketplace is for government agencies and professional groups such as architects and engineers to specify the cool-building products, making it easier for manufacturers to provide research and development of cool-building materials.

Metal roofing, cement, single-ply roofing and composition roofing often defeat attempts to conserve energy because of their high specific heat, high thermal conductivity or poor solar reflectance. These materials are essential for structural purposes, as well as for waterproofing. Installing insulations behind these materials helps reduce heat gains within a structure, but these systems are fighting a thermogradient in which the materials of the construction have gained enough heat to become a radiant body. There are low-cost external radiant barrier coatings available that reflect up to 60° of solar heat and provide external insulation which prevent the uptake of heat by the basic materials of the construction (metal, concrete, etc.). If the materials of construction do not acquire heat during the solar cycle because of an external barrier, a thermal gradient will not be established beneath the roof surface, and air conditioning systems could be substantially relieved.

Compared to conventional roofing and coating materials, new cool-buildings materials/coatings (1) are environmentally preferable, non-solvent based and more energy-efficient, providing / maintaining cooler buildings in warm climates / seasons, and warmer buildings in cold climates / seasons; (2) provide significantly lower costs, both in materials and labor installation; (3) are easier to install / apply; (4) are lighter weight; (5) provide longer weatherability; and (6) are simpler / easier to repair.

2. Thermal Conductivity of Materials

Materials used that are of low thermal conductivity are varied. Some are of organic chemical base polymers while other are strictly inorganic. The plastic or polymeric materials are normally isotropic or amorphous materials having low crystallinity in their structure. Crystalline materials provide routes for heat to travel through the protective coating, decreasing the insulative properties of the coating (Biscerano 1993).

Crystalline polymers should normally be avoided not only because of higher thermal conductivity. In general, isotropic polymers have much lower thermal conductivity than metals, although metal have molecules immersed in a sea of electrons, thus providing a medium for heat to travel. Table 1 provides some comparisons of polymers and metal thermal conductivity.

Table 1: Thermal Conductivities (Perry & Chilton, 1973)

Material	**Thermal Conductivity (BTU/sq.ft.(hr.)°F/ft.)**
Acrylics	0.12
Epoxies	0.10
Nylon G	0.10 - 0.14
Polyesters	0.12
Silicones	0.01
Polyvinyl Chloride	0.07
Aluminum	1540

The structural differences of metals and polymers are reflected in the thermal conductivities, resulting in wide variations. In organic polymers, electrons are localized in inner atomic orbitals, lone pairs and bonding orbitals (sigma and pi) and do not move freely through the material as do the free electrons of metals (Bicerano, 1993).

Still other theories of heat transfer in insulators such as isotropic amorphous polymers state that acoustic sound waves called phonons, or "particles" of sound , are transmitted by atomic vibrations, and relate these vibrations to thermal conductivity, velocity of sound and heat capacity (Saeki, Tsubokawa, & Wamaguchi 1990).

Also types of motion such as stretching, bending, wagging, scissoring of molecular bonds of organic polymer structures caused by the absorption of energy in the infrared region have an effect on heat movement and transfer of heat into polymers.

3. Methods of Reducing Thermal Conductivity

a. Absorption of shortwave radiation. Daniels (1993) notes in his study in Hawaii that the shortwave versus downward heat conduction is in watts/square meters. These included a built-up-roof (BUR) with a white acrylic latex coating and other white coatings that had least shortwave absorption (ultraviolet visible wave) and least downward heat conduction correlation of R=0.89. Longwave absorption coefficients plotted against downward heat conduction was less conclusive, with a correlation coefficient of R=0.70.

Daniels (1993, p.24) noted surprise that aluminum coating did poorly and explains this low performance due to low emiision coefficients at long wavelengths. It could also be because aluminum pigment has a high thermal conductivity.

Daniels notes that white ethylene propylene diene monomer (EPDM) did twice as well in heat-flow reduction as white polyvinyl chloride (PVC) and white chlorosulfonated polyethylene (CSPE) or Hypalon. The researchers do not know the reason. It is possible that this is due to the chromophores such as chlorine and other pi bonding in the PVC and CSPR that do not exist in the EPDM. The chromophores have the ability of absorb short wavelengths and excite the molecule electronically. This electronic energy is stored in the polymer system and degrades into lower forms of energy, mainly mechanical and heat, thus changing the character of the polymeric system.

Colors other than white, such as green and red, can be effective, and certain colors can reflect long wavelengths of the infrared spectrum (Berdahl, 1994).

b. Structural methods of reducing thermal conductivity.

Other materials that will aid in the lowering of thermal conductivity are filler that are porous or contain air space. These materials are available in many forms such as polystyrene foam. These materials are inexpensive and reduce the weight of the material.

Smooth texture is important in reflectance of infrared waves, and there are numerous methods of providing smooth surfaces, one being a coating that easily levels; fillers that enhance the surface of the coating, such as large molecular idols, also provide these smooth characteristics.

4. Costs

The consumer and manufacturer are faced always with the cost of coating systems that have the desirable characteristics of low thermal conductivity, greater reflectance and lower absorbance for the best molecular structure for weatherability at a low cost. One approach to the solution of this problem is to focus on the plastic wastes that plague the country in the form of landfills. There, major sources of plastics are available at little cost -- polyvinylbutyral, polyesters and polyvinyl chloride, to name a few. These can be used as a filler part of a composite or be depolymerized, used in a new polymer system either as homopolymer or copolymer. Some of the various polymerization systems available would be free radical cationic or anionic types.

5. Composite Engineering

In nature, living creatures reproduce organs such as teeth and bones that are designed of many materials and shapes to insure their survival. Coatings scientists and engineers must use the same techniques to have low thermal conductivity, reduce shortwave absorbance and enhance longwave reflectance, to create a system that is durable.

In addition, the coatings must be smooth for increased longwave reflectance, durable, waterproof, easy to install and at a low cost. To do this requires a multiple component system that provides all of these attributes, because no single material has all these characteristics.

Included in the list of protection must be ultraviolet absorbers, free radical quenchers, bacteriocides, fungicides and various fillers, monomers, plasticizers and a vehicle solvent, preferably water. All of these components would be mutually compatible.

References: Paul Berdahl, Jozef Bicerano, Anders Daniels, Halim Hamid, Robert Perry, Cecil Chilton.

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