Table 5 .... Normal Insulation Thickness Used in Mobile Equipment

Equipment	Insulation Thickness
Passenger Service and Mobile Homes	Up to 3 in. (for comfort)
Freight, Perishable, non-frozen	Up to 6 in. (above 32 F)
Freight, Perishable, frozen	Up to 10 in. (down to 0 F)
Freight, Perishable, liquids	Up to 8 in. (minus 70 F to plus 400 F)

water vapor in the atmosphere is transferred to the insulation space by infiltration through cracks in the outer shell. These cracks occur at joints or seams and penetrations of refrigeration piping and attachments. The water accumulates at a high rate when mobile equipment is in motion. The water usually causes deterioration of thermal characteristics and structural members.

Another problem is the formation of voids or uninsulated areas. These areas are caused by the settling with vibration of either improper insulation or proper insulation poorly installed.

A third problem is the low resistance heat flow path through metal. These low resistance heat flow paths are commonly called *short circuits*. In this section *short circuits* are considered as heat flow paths having a resistance of one-third, or less, of the total resistance of the fully insulated section.

STRUCTURE

Passenger Service, Mobile Homes and Non-frozen Perishable Freight Types

Any treatment of heat flow must start with the structure to be insulated. Almost any structure can be insulated suitably for all three types. Structural details given in the next section, Frozen Perishable Freight, can be applied when the features can be worked into the design at little or no extra cost.

Mobile homes and passenger service aircraft, buses, and trains usually have double windows for comfort and to prevent condensation. Mobile homes usually have heating ducts in the floor between certain floor joists. Only the upper part of the joist space is used for the duct, while insulation is placed between the duct and the outer sub-floor.

Frozen Perishable Freight

A temperature of 0 F or lower is quite common for hauling frozen perishable freight. For mobile equipment designed to haul frozen foods, commonly called *reefers*, the structure becomes quite important. A continuously welded outer shell has been demonstrated to be quite satisfactory for preventing troubles caused by water accumulation.[27] Although many consider a welded outer shell too costly, there are several advantages for this type structure, which are mentioned in the section Water and Water Vapor Exclusion.

Thermal short circuits have caused deterioration and spoilage of frozen foods in transit. Metal short circuits should be avoided by the proper use of wood, wood products, or plastics.

No structure is insulated properly when short circuits cause *hot spots* on the inner surface of the structure.

The inside liner of walls and roof for *reefers* must be impervious to water penetration to allow for washdown. This same inside liner of walls and roof for trucks, truck trailers and railway refrigerator cars must be permeable to water vapor; so any moisture entering through leaks from the outside will be allowed to pass through the insulation and the liner to the refrigeration coil. For example, plywood is permeable to water vapor and impervious to liquid water. The water vapor permeable liner should not allow air movement from insulation space to the interior. Ships holds (usually for more than one service) are built with a water vapor barrier in the liner.

Floors for all mobile equipment must be built with greater structural strengths than walls or roof. The framing members are often floor joists running lengthwise of the unit extending halfway through the thickness of the floor with additional wood members running crosswise of the unit and extending to the sub-floor underneath. There are no short circuits in this type of construction. The floor wearing surface is usually an extruded metal floor or metal sheets welded at joints. Cleaning operations often include washdown with a hose. Therefore, a water-tight pan is needed as an integral part of the floor to contain the washdown water until the water can drain out or is otherwise removed. This pan is formed by a sheet metal guard (baseboard effect) applied to the wall at the floor level and extending up the wall 6 to 18 in. and sealed to the metal floor. Until a better method is demonstrated, recommended practice is to seal the floor insulation from the wall cavity with a water vapor barrier.

Wood members can absorb moisture from condensate or water trapped from other sources. Unless naturally decay-resistant species are used, the wood should be properly treated with a preservative to make it decay resistant.

The pay load (volume) to gross weight ratio is always important in mobile equipment. For greater pay-load the thickness for insulated walls (roof and floor) must be kept to some satisfactory minimum. Some lading, such as frozen foods, need protection against spoilage by cold air circulation around the load. Ribs or an inner flue section provide space for circulating air between the load and inner wall surface (roof and floor).

Perishable Liquids

For hauling liquids that must be maintained within a given range of temperatures, metal tanks are often mounted on a heavy metal bolster similar to those for tanks for hauling non-perishable liquids. Good practice is to build the necessary strength into wood bolsters as well as at other points thus avoiding the metal short circuits. It is recommended that all metal short circuits be avoided by the proper use of low conductance materials. There has been reluctance to use anything except metal for tank connections (piping, etc.) to handle liquids. However, short circuits in tank connections cause heated areas. When design includes metal spacers between the tank and the outer shell, the short circuit has been satisfactorily avoided by the use of a breaker strip of insulation placed between the spacer and the outer shell.

WATER AND WATER VAPOR EXCLUSION

Fundamentals of water vapor flow are the same for all types of insulated units whether mobile or stationary. However the methods for water exclusion in mobile equipment, are highly specialized. The one factor which makes unpredictable the performance of insulated reefers is that of air and water leakage through openings in the exterior shell at seams, service outlets, refrigeration lines, etc. Many vapor barriers and sealants that are quite satisfactory for stationary units will tear, crack at the seams or otherwise fail from the racking of mobile equipment.

When the outer shell is impermeable, as in a welded ship's hull, or when a sheet membrane vapor barrier envelope is sealed according to the best known practice, virtually all insulation problems having to do with refrigerated *reefers* are solved. When there is no sheet membrane vapor barrier envelope near the outer shell, trouble develops from water accumulation.

The water which accumulates is carried through openings in the outer shell in the form of water vapor by three processes; namely, forced convection, free convection, and diffusion. Although water vapor does enter by the processes of free convection and by diffusion the rate by forced convection (*ram effect*) overshadows other factors. Large quantities of airborne water vapor are forced through small openings in the outer shell when the *reefer* is in motion. Investigation[27] has shown that the ram air pressure is 1.21 in. water gage at 50 mph and that a 6 ft length of unsealed seam can permit the entry of 1440 cu ft of air per hour. At conditions of 100 F ambient temperature, 50 percent relative humidity, and a truck trailer temperature of 0 F, the heat gain caused by this amount of infiltration air could be 4600 Btuh, assuming that this leakage air left the vehicle saturated at 0 F. Although these findings show the importance of completely water vapor sealing the outer side, manufacturers of *reefers* for both the railway and trucking industries have not as yet found it practicable to use a welded outer shell. Since it has been shown that the primary need in the construction of refrigerated mobile equipment is water and water vapor exclusion, more consideration should be given to a welded outer shell. Welding the sheet metal outer shell costs more initially, but, when no water accumulates some of the advantages are: less non-revenue weight, quicker cool down, longer equipment life, less heat gain, and less spoilage of product.

Passenger Service and Mobile Homes

The general discussion of water exclusion mainly concerns the transportation of perishable material at some temperature below ambient.

For mobile homes and passenger service the water vapor barrier should be toward the inside near the living quarters, since the water vapor pressure across the wall is greater in winter when the unit is heated than in summer when the unit is cooled.

Mobile homes, in contrast to most residences, are often subjected to extremely high humidities during the coldest winter days. For the colder localities the only satisfactory water vapor exclusion treatment has been a sheet barrier.

Non-Frozen Perishable Freight

For this type of service the load may be refrigerated or may be heated depending on both the type of load and the outdoor weather conditions. It follows then that the water vapor pressure is sometimes greater outside and sometimes greater inside, as when top icing is used, or for heater service during winter months. With reversible water vapor flow both the outer skin and the inner liner usually are given a vapor-barrier treatment.

Most of the treatments discussed in the section on Water Vapor Barriers of this chapter are suitable for this service when properly applied.

Frozen Perishable Freight

Water accumulating in mobile equipment presents additional problems for frozen perishable freight. At temperatures below freezing some of the problems are:

1. For cooling down prior to loading, accumulated water which freezes into ice requires extra cooling and greater time delay to reach the desired temperature.
2. The formation of ice may be destructive to the structure and insulation.
3. Ice offers little resistance to heat flow (the thermal conductivity of ice is about 16 compared to 0.30 Btu per (hr) (sq ft) (F deg/in.) for many insulations.
4. The accumulated water or ice is extra non-revenue weight which may reduce the pay load.

Because of the above and other reasons, vapor barrier materials for each unit of mobile equipment must be carefully chosen. Many of the water vapor barrier materials used in passenger service and non-frozen perishable freight service are unsatisfactory for *reefers*. *Vapor sealing* materials are necessary. A non-permeable sheet vapor barrier is used inside the outer shell and is sealed at joints with a water vapor sealing compound such as neoprene. The sheet vapor barrier must be strong and flexible to withstand the *racking* movements of mobile equipment. Sometimes the non-permeable sheet vapor barriers are sealed to the outer shell but longer life can be expected when the sheet vapor barrier is not thus attached, allowing it some freedom from the racking movements. It is also good practice to seal the joints in the outer shell metal sheets to eliminate rain penetration. The impermeable sheet vapor barrier should be applied by following the recommendations of the manufacturer, using great care to provide a continuous water vapor seal and air-infiltration barrier over the entire warm surface.

Another method for keeping the insulation dry is to completely seal the insulation in plastic bags impervious to vapor. The welded outer shell may also be made practical for overland equipment in which use many of the present problems disappear.

INSULATION

The choice of insulation for mobile equipment is quite important. A critical evaluation of insulation characteristics is necessary for the proper choice. The ordinary factors of economics such as thermal conductivity, thickness of insulation (Table 5), installed cost and cost of refrigeration are of little importance *if* the insulation will not stay in place, *if* the insulation becomes wet or *if* considerable moisture-laden air pumped in by ram pressure infiltrates from the outside.

The economic factors are important in a properly designed unit where due consideration is given to the suggested structural characteristics, a proper continuous vapor barrier, and insulation at a thickness representing a compromise between economics of thermal characteristics (insulation and refrigeration) and economics of load volume to be hauled.

Insulation should be installed so there are no voids. The insulation should be selected and applied to prevent settling due to vibration. The weight of the insulation selected will be a compromise in regard to density and thickness used, and pay load to gross weight ratio. It is advisable to use a convection barrier between layers of thick low density fibrous insulation, which also helps reduce infiltration of moisture-laden air. This convection barrier, being permeable to water vapor, is not to be confused with the vapor barrier. If condensation occurs on the warm side of any unit, it is evidence of improper design whether of insufficient insulation, metal short circuits, water accumulation in the wall, or combinations of these factors with others.

Other characteristics of insulation such as fire resistance, resiliency, moisture absorption, and mold growth are important for mobile equipment use.

ENVIRONMENTAL SPACES

Environmental spaces, as the name implies, are used to provide environments of selected temperature, humidity, pressure and composition. These may be desired singly or in combination, in stabilized degree or in phased fluctuating degree. The designed environment may be required for short or long term tests, for continued or periodical production or manufacture, or for short or long term storage.

The design of the insulation construction, including water vapor barriers and functional protective finish of insulation, is based on the environmental conditions to be encountered.