insulation having a thermal conductivity of 0.27 at 75 F mean temperature.

Vapor barriers are not required on exterior insulation of ducts used for heating alone, but vapor barriers must be provided where ducts are used for cooling alone, or cooling and heating alternately.

Insulation for Cooling Ducts

Ducts for summer air conditioning are insulated with the same materials as for heating ducts. Generally ducts in any unconditioned space should be insulated and provided with a vapor barrier for condensation prevention and for economic reasons. In addition to affording significant operating cost reductions, duct insulation may reduce heat gain enough to reduce cooling equipment size. The insulation must be faced with a vapor barrier, and the surface temperature must be kept above the dew point of the surrounding air. Joints and laps in the vapor barrier must be thoroughly sealed, using vapor barrier compound, impermeable tape or strips of vapor barrier material and vapor barrier adhesive, to prevent entry of water vapor.

The approximate U values given for heating ducts may also be used for estimating the reduction in heat gain (using the appropriate temperature difference and the thickness of duct insulation to be used). A method with equations for calculating surface temperatures and its application in preventing condensation is shown in an earlier section; the Economic Thickness. Summer dew-point temperatures commonly occurring in the various parts of the United States are: Northern climate zone, high sixties; Central climate zone, mid-seventies; Gulf Coast areas, high seventies. It can be shown that for condensation prevention alone at least one inch of insulation should be used in Gulf Coast areas for duct temperatures of 60 F, and some insulation is advisable in the other zones, depending on design conditions.

Application of Duct Insulation

Duct insulation may be used on the exterior or interior of ducts; interior application as a lining is chosen when sound absorption is desired. Attachment to duct surfaces may be made with an adhesive for temporary support and followed by permanent mechanical support, such as pre-attached pins or clips for impaling; encircling bands, wires, strapping, or tapes going around the outer circumference of the insulation. To satisfy some building codes, the materials, particularly facings, must be noncombustible or have a limited flame spread value. Local authorities having jurisdiction should be consulted.

REFRIGERATED ROOMS OR BUILDINGS

Low temperature rooms can be insulated with a variety of insulations and an even greater variety of methods. The engineer, architect, owner, or contractor should select the most suitable method for their specific use. The purpose of this section is to present accepted practice in the field and to describe the insulations in common use together with the generally accepted application methods. It is recommended that the manufacturers' instructions and specifications be followed for specific directions concerning the use of the insulations, adhesives, and finishes.

GENERAL PRINCIPLES

The following design principles are basic to most low temperature space installations involving any of the accepted insulations commercially available. A detailed guide to good practice in design, construction, operation and maintenance of cold-storage facilities, along with a brief summation of necessary research is given in Reference 23.

Envelope Construction

It is important that the space to be insulated be surrounded wherever possible by a complete envelope of insulation; that is, the structure of the refrigerated space is completely isolated from a higher temperature space by layers of insulation. Where the insulation is penetrated by structural supports, hanger rods, electrical conduits, etc., it is important that these are sufficiently insulated and vapor sealed on the warm side to prevent entry and migration of water.

Venting or Heating Floors

For storage temperatures of approximately 25 F and higher, the areas beneath the floors present no different problems than in nonrefrigerated buildings. However, if a freezer space is contemplated on or below grade, consideration should be given to the possibility that freezing of the ground may cause heaving of the floor, columns, and wall footings. The risk is considerable with storage temperatures below 15 F.

Another limiting factor is the size of the room. Where the distance between two freezer walls adjacent to normal temperature or heated areas is no more than 15 ft, venting or heating of the floor is not usually necessary if the floor is adequately insulated. In all cases positive drainage is essential and must be provided by the use of gravel or cinder fill, and drain tile.

In extreme cases when freezer rooms have to be located where the ground water level may approach the subfloor slab, enough heat should be provided beneath the floor insulation to balance that flowing up into the cold room when the ground temperature is between 25 and 33 F. This can be done by making the subfloor a form of panel heating. A noncorroding pipe or tubing in the concrete carrying heated oil or water is one way to meet such conditions. Other methods include electric strip heaters and air channels beneath the slab carrying heated air.[24,25]

Venting Air Spaces Above Ceilings and in Walls

Unventilated air spaces above ceilings or in stud walls generally lead to trouble due to trapped moisture and should be vented whenever possible to the outside. Air spaces, normally on the warm side of the vapor seal, tend to have such high humidity that water may collect on any surface having a lower temperature than that of the dew-point temperature of the air space. This can destroy the necessary strength characteristics of the structure in the case of wood, or it can cause staining, dripping, or frosting. This may eventually lower the efficiency of the insulation and usually detracts from the appearance of the room. If by venting to the outside, especially in ceilings, drier air is circulated through the air space, the condensation or frosting problem will be minimized. Also, venting with warm dry air tends to warm the surfaces it contacts and therefore helps keep these surfaces above the dew-point temperature of the air.

Vapor Barrier Treatments

Vapor barriers are necessary to varying degrees with all insulations. In coolers, water vapor migrating through the walls is less critical than in freezers but still can be damaging if the dew-point temperature occurs within the insulation, allowing moisture to collect therein and impair the efficiency of the insulation.

In freezers vapor treatment is necessary because condensation will not only tend to destroy the insulation, but if it freezes may create forces that will cause the insulation to heave or buckle from its supporting surface.

Vapor barriers for the warm side of cold rooms may be surface coatings applied hot or cold, with or without reinforcing membranes, and sheet materials such as metal foils and laminates having a maximum permeance of 0.1 perms. Supervision and inspection must be provided during application of vapor barriers to insure that adequate sealing is obtained. Lapping or sealing joints in sheet vapor barriers must be carefully done to maintain the effectiveness of the vapor barrier envelope. All penetrations through the vapor barrier due to piping, conduits, ducts, and doors must be thoroughly flashed or caulked with a vapor barrier compound to prevent water vapor leakage.

The junctures of walls, ceilings, and floors require special attention to make sure that the vapor barriers are not broken through movement of the structure during expansion or contraction. At such critical locations, vapor barrier coatings should be reinforced with a strong compatible membrane. Both sheet barriers and membrane-reinforced coating barriers should be provided with a loop at floor and ceiling junctures which will permit structural movement without breaking of barrier. Where adjacent cold rooms operate at different temperatures, a vapor barrier must be provided on the warmer side of the common wall, floor, or ceiling.

Installations where reversible water vapor flow may be encountered must be specially treated to prevent moisture accumulation within insulation. The usual treatment is vapor barriers on both sides of insulation.

Interior Finish Treatments

It has been shown from test data that, in almost every case where an interior finish acts as a vapor barrier, serious difficulties have occurred. From the standpoint of best results for vapor transmission it would be preferable to have no interior finish. However, where other considerations, such as sanitary regulations, prevention of mechanical damage, and physical appearance are important, an interior finish is required.

The interior finish may or may not require mounting independent of the insulation. The interior finish should have a significantly higher permeance than that of the vapor barrier, adhesive, or insulation. The ratio of the interior finish perm-value to the vapor barrier perm-value has not been clearly established.

TYPES AND GENERAL INSTALLATION TECHNIQUE

Insulation used for low temperature rooms is generally one of the following four types: (1) rigid, (2) loose fill, (3) flexible, or (4) reflective.

Rigid Insulation

Rigid insulation is widely used for low temperature rooms. Basic installation principles are:

a. Rigid type insulations are generally applied in two or more layers.

b. All joints are butted as tightly as possible. In addition, all joints are staggered in relation to each other in the layer being applied, between adjacent layers, at the wall to wall juncture, wall to ceiling juncture, and wall to floor juncture.

c. Rigid insulation requires a fairly level surface to start with and unless the wall is exceptionally smooth, the insulation application is preceded by a back plastering operating.

d. The vapor barrier treatment may not be as important as with the other types of insulation. For instance, some manufacturers' specifications require no vapor barriers in cooler construction.

In freezer construction, the use of a vapor barrier adhesive for the first layer is specified as sufficient protection. This varies with the various brands; manufacturers' literature should be consulted for exact recommendations.

e. In ceiling construction where the insulation is applied from below, the first layer is usually fastened mechanically.

f. Any additional layers are usually attached to the preceding layer with treated wood or plastic skewers driven at an acute angle. This is in addition to the specified adhesive.

g. All wood used in the refrigerated area, including skewers, bucks, sheathing, furring, etc., should be of pressure treated wood that will resist the rotting action of the moist conditions.

The following procedures normally apply to the application of rigid insulation to various building components.

a. Walls. The first layer can be applied to masonry walls with adhesive alone and any succeeding layer with adhesive and skewers. Horizontal wood supports are necessary in the first layer when using certain insulations or adhesives or on excessively high walls.

Walls made entirely of insulation can be erected with rigid insulation. Although one layer can be used, usually the wall is made up of two or more layers. The wall can either be built up against a temporary framework which is later removed or the wall can be erected block by block as in laying brick.

b. Ceilings. Ceilings can be classified into three general types: overdeck, underdeck, and suspended.

Overdeck ceilings are those for which insulation is applied from above, directly to the top surface of what normally is the roof deck. The first layer is applied with adhesive, or mechanical fastening, or both. Additional layers are applied with adhesive and, generally, treated wood skewers. The built-up roof system is then applied directly over the insulation.

Underdeck ceilings are similar to the overdeck except that insulation is applied from beneath directly to the underside of the roof deck. In this case the first layer of insulation must be fastened mechanically in addition to being held by an adhesive. Additional layers are applied from beneath with adhesive and treated wood skewers.

Suspended ceilings have many variations but all basically are suspended from a higher ceiling with wires or rods. The insulation is applied from above quite similarly to that described for overdeck ceiling. The hanging rods or wires must be insulated sufficiently to prevent condensation on the rods or wires, and be vapor sealed to prevent entry of water into the insulation.

One type of suspended ceiling is the T-iron ceiling. In this construction the T-irons with the web on top are suspended from the ceiling or span the room. The first layer is generally routed out to fit snugly around the T-irons between which the insulation is placed. The second and any succeeding layers are applied from above or below with adhesive and skewers. Finally, the top surface is covered with hot asphalt or a Portland cement grout and vapor sealed.

c. Floors. Because of the moist conditions that generally exist below floors of refrigerated rooms, it has become a general rule to apply a vapor seal of some kind over the subslab before application of the insulation.

With concrete floors, the first layer is applied in hot asphalt mopped onto the subslab. Additional layers are bonded with adhesive and may be held with skewers until the wearing floor is poured. In some cases, the second layer may be put in dry.

Most insulations also require a water seal between the insulation and the top slab. This is used generally to prevent water from seeping into the insulation, either from cracks that are always present in a floor of any size or from the wet concrete during the pour of the wearing slab. A coating material is also needed over some insulations to prevent a bond between the slab and the insulation.

In coolers the floor insulation can sometimes be omitted altogether or at the most, consists of a ribbon of insulation around the perimeter of the room extending under the slab or down the foundation as best suited to the plant or area conditions.

d. Miscellaneous. Columns or beams penetrating the insulation are insulated with pieces of rigid insulation, fabricated so as to completely fill any voids. Round columns can be insulated with lagging bonded in place. Rectangular shapes of insulation are usually held by skewers and adhesive. One rule of thumb is to insulate all projections with a minimum of one-half the insulation thickness specified for the walls and to insulate along the column or beam a distance equal to four times the specified wall thickness.

Curbs and bumper rails are generally provided and are located around the perimeter of the refrigerated room. Bumper rails can be anywhere from a few feet high to the full height of floor to ceiling. They not only provide the wall protection from mechani-