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UNIFIED FACILITIES CRITERIA (UFC)

DESIGN: ARCTIC AND SUBARCTIC CONSTRUCTION - BUILDINGS

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DESIGN: ARCTIC AND SUBARCTIC CONSTRUCTION - BUILDINGS

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes TM 5-852-9, dated 25 March 1988. The format of this UFC does not conform to UFC 1-300-01; however, the format will be adjusted to conform at the next revision. The body of this UFC is the previous TM 5-852-9, dated 25 March 1988.

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Support Agency (AFCESA) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request (CCR). The form is also accessible from the Internet sites listed below.

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- Unified Facilities Criteria (UFC) Index http://65.204.17.188//report/doc_ufc.html.
- USACE TECHINFO Internet site http://www.hnd.usace.army.mil/techinfo/index.htm.
- NAVFAC Engineering Innovation and Criteria Office Internet site http://criteria.navfac.navy.mil.
- Construction Criteria Base (CCB) system maintained by the National Institute of Building Sciences at Internet site http://www.nibs.org/ccb.

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ARMY TM 5-852-9
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TECHNICAL MANUAL

ARCTIC AND SUBARCTIC CONSTRUCTION BUILDINGS

DEPARTMENTS OF THE ARMY AND THE AIR FORCE
MARCH 1988

REPRODUCTION AUTHORIZATION/RESTRICTIONS

TECHNICAL MANUAL
TM 5-852-9
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HEADQUARTERS
DEPARTMENTS OF THE ARMY
AND THE AIR FORCE
WASHINGTON, DC, *25 March 1988*

ARCTIC AND SUBARCTIC CONSTRUCTION: BUILDINGS

*This manual supersedes TM 5-852-9/AFM 88-19, Chapter 9, dated 23 July 1971.

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CHAPTER 1

GENERAL

1-1. Purpose. The purpose of this manual is to provide criteria and guidance for the design of buildings in arctic and subarctic regions. This manual supplements TM 5-852-1/AFR 88-19, Volume 1.

1-2. Scope. This manual presents specialized design criteria for existing environmental conditions. These criteria pertain to the building proper and to interior utilities. Other manuals which pertain to arctic and subarctic construction are:

TM 5-852-1/AFR 88-19, Volume 1, Arctic and Subarctic Construction: General Provisions.

TM 5-852-2/AFR 88-19, Volume 2, Arctic and Subarctic Construction: Site Selection and Development.

TM 5-852-4/AFM 88-19, chapter 4, Arctic and Subarctic Construction: Foundations for Structures.

TM 5-852-5IAFR 88-19, Volume 5, Arctic and Subarctic Construction: Utilities.

1-3. Conceptual planning considerations. The facility's basic functional needs must be provided, while total costs are minimized. Particular attention must be given to the harsh environmental stresses, the material availability, the transportation methods to the site, the amount and skill of the available labor force, the relatively short construction season, and conditions under which material will be stored and the facility erected. Constraints that personnel and logistics problems pose to operation and maintenance of remote facilities must be considered. Three primary criteria should be observed: the system must be reliable; easy access for routine and emergency operation and maintenance must be provided; and the system must be as simple as possible. Under harsh environmental conditions, especially in emergency situations, complexity often dooms a system to failure.

a. Morale. Personnel morale, an important but difficult to define factor, must be carefully considered during design. During the long winter, with little daylight and little contrast between land, sea and sky, the monotony can have a negative influence on personnel conduct and efficiency. Comfortable living quarters need to incorporate the creative use of warm, inviting colors and textures. Spatial requirements in excess of those used in the contiguous United States are sometimes necessary. At remote sites, the station becomes the total environment for personnel for sustained periods. Therefore, it may be appropriate to provide individual rooms for the permanent staff, plus single, double or multiple occupancy rooms for visitors. Additional personnel may be required for summer maintenance and emergency winter help. Rooms must be available for those persons. Additional recreational space usable for games, reading, and hobbies is required to counteract the effects of excessive confinement. Many larger remote sites contain a gymnasium and bowling alley, plus separate lounges for officers, noncommissioned officers, and enlisted personnel. Of equal importance to morale are proper temperature control and soundproofing. When personnel are essentially confined to quarters because of the environment, proper temperature for both living and sleeping areas is a major psychological influence. Soundproofing to provide quiet areas will also have a major psychological impact.

b. Multiple-building concept. Originally construction at remote sites usually consisted of many single-function structures, often connected by enclosed passageways. Such facilities occupy large acreages. There are large roof and exterior wall surfaces to maintain which lose heat to the exterior. Thus, large capacity heating systems are required. If there is a central plant, extensive distribution systems are needed. Some enclosed passageways require heat and maintenance but provide limited benefits. Advantageously, however, many small, single-function buildings do not require mechanical ventilation and can be placed on simple, standard foundations which tolerate more foundation movement. Such buildings can minimize fire losses and be constructed more easily on uneven terrain. Standard designs can frequently be site adapted. The multiple-building concept provides adaptability for rearrangement, expansion, or an addition of functions. In cold weather there are psychological advantages in being able to get away from living and working areas by walking in the covered passageways. The multiple-building concept is shown in figure 1-1.

c. Composite building concept. Combining functions into a single composite building should be considered, especially for remote areas and small installations. Since a composite building has a greater volume-to-surface-area ratio, initial construction costs are usually lower, heating is less expensive, and maintenance requirements are reduced. Central heating reduces one fire hazard, but the possible loss of

Figure 1-1. Tin City Air Force Station, Alaska, prior to 1968 (note the multiple buildings connected by long covered walkways).

the entire facility by fire, and the number of potential fire sources, dictate higher fire protection requirements and additional safety measures. A composite structure generally contains fewer roof and wall penetrations than do separate buildings, thus reducing the maintenance associated with snow infiltration, leaks, and vent icing. Utility systems often cost less initially, are less likely to freeze or be damaged by differential settlement, and are easier to operate and maintain. The multistory vertical construction achievable with composite buildings can reduce risks for two high cost, high problem areas: roofs and foundations. Since individual site requirements mandate different combinations of functions and needs, a standard design is usually not available for the composite building, necessitating a greater design effort. High noise and hazard areas should be isolated from offices and quarters. Generators should be as far from residential areas as possible, and exhausted on the downwind side of the facility. Downwind direction may vary with the weather and time of year, but is especially critical during the winter storms when the exhaust could infiltrate the building. Exhaust location, therefore, should be planned with the winter storm season in mind. Composite structures make rearrangement of existing functional areas, expansion of functions, or addition of new functions difficult. Two separate but connected buildings should be considered to allow residential areas to be isolated from power generation and equipment maintenance areas to reduce noise and petroleum odor impacts on personnel and to provide shelter in case of fire in one structure. All support and utility systems should be redundant to assure mission accomplishment and safety. A composite building is shown in figure 1-2.

d. Building operation during replacement. Space shortage and/or operational need may result in a requirement that facilities and buildings being replaced remain in operation during construction. As the replacement structure is frequently adjacent to existing facilities, the Contractor's activities and scope of operations are restricted by this requirement. Detailed planning, scheduling, and coordinating become very important.

Figure 1-2. Tin City Air Force Station Composite Building.

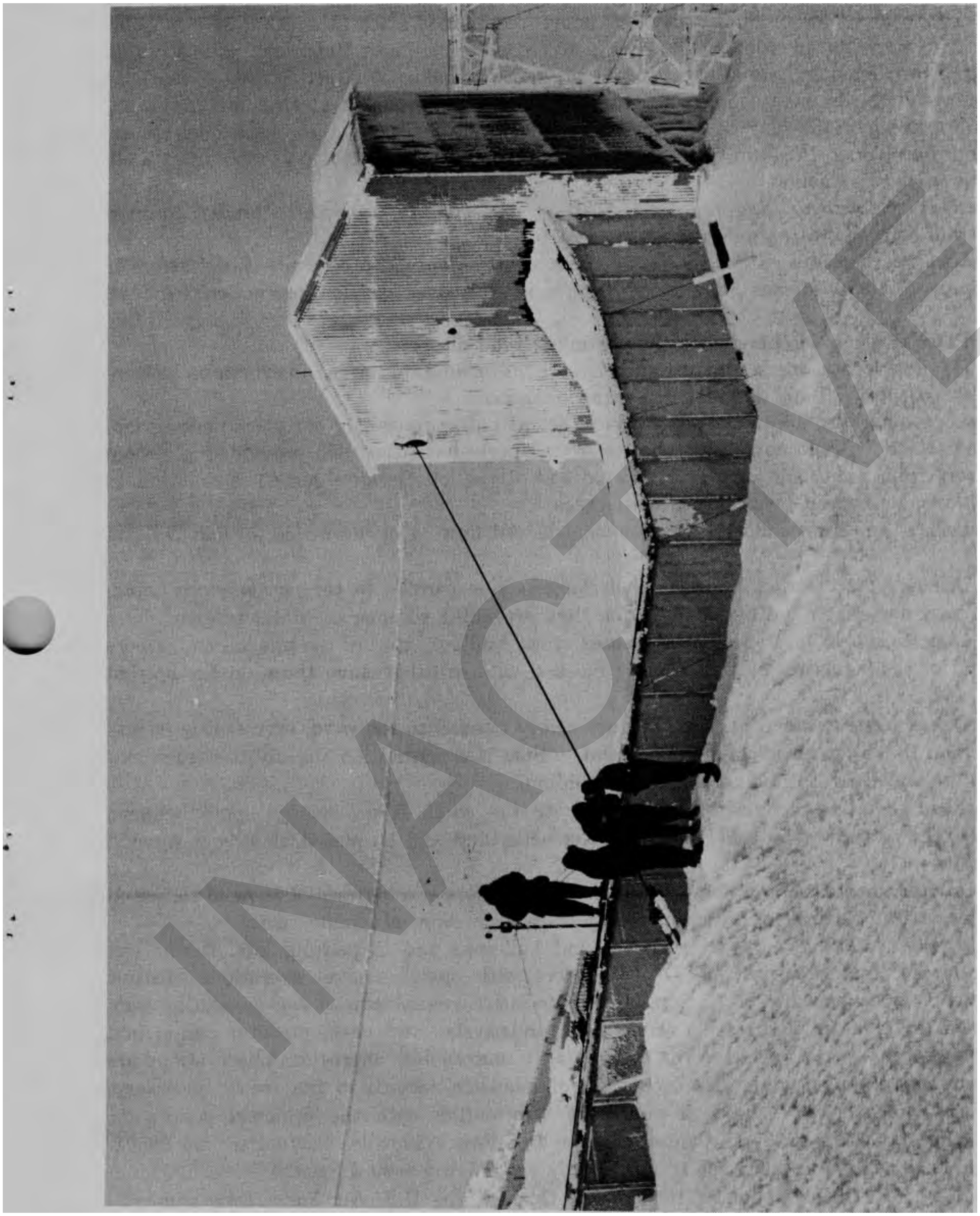
1-4. Environmental factors and considerations. Climatic, hydrologic, topographic, and geographic factors influence overall site selection (see TM 5-852-2/AFR 88-19, Vol. 2) and are also important considerations in establishing the configuration of individual structures. Since the environment desired within buildings is usually drastically different from ambient arctic and subarctic conditions, severe stresses are placed on building components. Rapid deterioration and costly maintenance are inevitable unless these stresses are carefully considered when selecting construction materials. Personnel must also be considered when designing for the environment. Poor visibility caused by whiteouts, fog or darkness, coupled with high winds and cold temperatures make it essential to minimize personnel confrontations with the environment. Additional space may be necessary to house functions that can be accomplished outdoors in temperate zones. Enclosed walkways, as shown in figure 1-3, may be necessary if structures are spread out.

a. *Climatic conditions.* Because of the range and severity of arctic and subarctic conditions, knowledge of *individual site* conditions is particularly important to develop effective methods and procedures for facility design, construction, operation, and maintenance. Temperatures at the Tin City Air Force site in Alaska, for example, range from - 44 to + 71 ° F, with a design wind speed of 110 miles per hour (mph) and design ground snow load of 97 pounds per square foot (psf). Some important climatic factors and ways those factors need to be considered are given in table 1-1.

TABLE 1-1. INFORMATION ON CLIMATE.

Climatic Factors	Areas of Consideration
Temperature	
Mean	General guideline development
Maximum	Material selection and performance
Minimum	Heating system design
Seasonal Variation	Construction planning
Relative Humidity	
Seasonal variation	Condensation control
Wind	
Peak gust	Structure placement & orientation
Prevailing	Structural design ventilation
Seasonal variation	Snow drifting potential
Rain	
Total	Siding materials
Maximum	Roof drainage
Seasonal variation	Roof maintenance season
Snow and Ice	
Snow accumulation	Roof design
Ice accretion	Powerline loads
Drift potential	Building orientation
Seismic Probability	
	Structural design
Daylight/Darkness	
	Lighting design

(1) *Problems caused by snow drifting.* Placing utility distribution systems in or below walkways facilitates repair. Walkways, unfortunately, tend to box in a camp and aggravate snow drifting problems. Blowing snow is an important consideration because large drifts may rapidly develop on and around structures, and construction materials left on the surface can be buried by a single storm. Dry



windblown snow can enter small cracks in doorways, windows, or louvers intended for ventilation. Generator intakes are occasionally blocked, and warm exhaust stacks and vent pipes coated with ice. Large snowdrifts can accumulate on low roofs and in other areas of "aerodynamic shade." In permafrost areas, snow infiltration in ventilated foundations can be a serious problem. Material and equipment must not be stored adjacent to or under buildings elevated above permafrost since that can result in snow drifts which allow soil warming in winter. Observing site conditions gives important indicators of potential snow drifting problems, and aerial photographs are quite valuable. Weather records should also be consulted to determine the intensity, direction, variability, and frequency of storms and prevailing winds. At one site, prevailing winds may be responsible for most drifting; at another, occasional storms may generate the most problems. It is not uncommon for snowdrifts to cover doorways (see figure 1-4). Winter site visits can be very valuable.

(2) *Solutions to snow drifting problems.* Drifting patterns are difficult to predict but the following guidelines will help minimize problems:

(a) Use trees, shrubs, snow fences or other obstructions to precipitate snow before it reaches the site proper. Where storms may come from any direction, provide protection from all quadrants.

(b) Place major roads parallel to the prevailing wind direction.

(c) Do not locate roads directly upwind or downwind of large obstructions. Where possible, maintain 100-foot upwind and 200-foot downwind clearances.

(d) Locate parking lots alongside roads to act as buffer zones. Do not place parking lots among buildings. Expect additional snow accumulation around parked vehicles, and provide ample room for snow storage away from roads and on the downwind end of the lot. Because curbed islands hinder snow removal operations, they are not suitable in most cases.

(e) Parking aprons should be placed alongside, not upwind or downwind, of hangars and garages.

(f) Orient surface structures with their longest side parallel to the *winter storm wind.* Winter storm winds may come from a different direction than prevailing summer or winter winds.

(g) Doors are best located along the sides of the building, toward the upwind end. Doors on the downwind end of the structure may be rapidly blocked with drifting snow: those on the upwind face are difficult to seal.

(h) Orient large garage doors so they are nearly parallel to the wind, even if this results in a building orientation that is perpendicular to the wind. Adjust this orientation slightly to assure that the doors are not in the lee of the upwind corner of the building.

(i) Place structures in rows perpendicular to the wind. Allow enough space between buildings to permit effective snow removal. Each row of structures should be placed directly downwind from the preceding row.

(j) Provide snow dumping areas to eliminate large piles or windrows of snow in the camp area. Piles and windrows are obstructions which increase future snow removal requirements.

(k) Avoid decorative earthen berms around buildings and in parking lots. Berms can cause additional snow accumulation problems and interfere with snow removal operations, disrupt building access for maintenance and fire protection, and create moisture problems at the foundation wall.

(3) *Sources of climatic information.* Due to the relatively brief developmental period and sparse population, long-term climatological records are primarily unavailable. Short-term observations are often incomplete and may be misleading. Extrapolation of available records is frequently necessary. Governmental agencies are generally the best source of information with the principal source for worldwide data the National Climatic Data Center, Federal Building, Asheville, North Carolina 28801. Much of the information available at Asheville is supplied by the Environmental Science Administration (ESA). DOD agencies should request climatic information through the U.S. Air Force Environmental Technical Application Center (ETAC), Building 159, Navy Yard Annex, Washington, DC 20333. TM 5-785/AFM 88-29 contains information obtained at military sites.

1-5. Cost Factors. Many cost factors must be evaluated to provide a cost effective design.

a. Labor. Skilled labor is usually in short supply locally, so costs are high. Minimizing skills needed and scheduling work to occupy each worker's time fully will reduce total work time. Providing housing

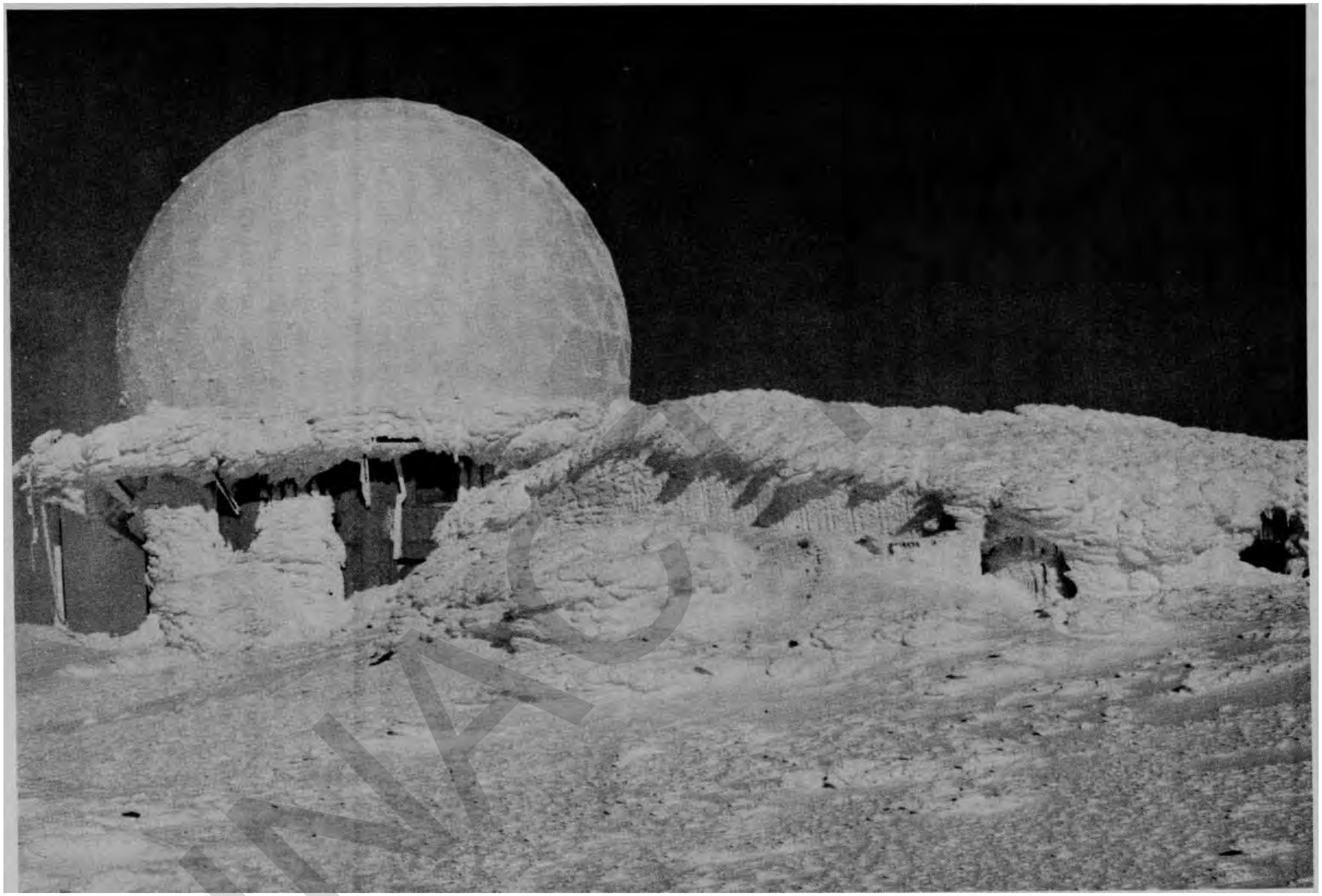


Figure 1-4. Cape Newenham Air Force Station, Alaska, in winter (note the entrances that are unusable because of snow accumulations).

and meals increases costs in remote areas, therefore, optimum use of work time assumes an even greater importance. Summer months of almost continuous daylight contrast to winter months of almost complete darkness. That variation in daylight and darkness becomes more extreme as one goes farther north. Consequently, long summer work hours are appropriate to take advantage of the daylight and minimize idle time.

b. Materials. Generally, maximum factory prefabrication is most economical. Such savings can be lost, however, because of higher handling and shipping costs. Possible damage and breakage en route could influence a decision to utilize onsite construction. In many areas, common construction materials are unavailable. Sand, gravel, cement, or water for concrete may have to be transported long distances. Suitable timber products, especially piling, may not be locally available, as timber quality and size in the arctic is usually less than that of other areas. Transporting costs for large or heavy construction equipment can become a major portion of the construction cost in remote areas. Eliminating the need for such equipment, or combining separate buildings to utilize special equipment more fully, will reduce overall cost. Delays in shipping equipment can result in prolonged construction time, expensive emergency air freight costs, or unsatisfactory job site improvisation. In coastal areas, prefabricated construction should be considered more seriously as the materials or buildings can be shipped or barged and unloaded on a beach near or adjacent to the site. A short construction season sometimes dictates prefabricated construction. During the design stage, it must be kept in mind that damage to, or loss of, an important building component can postpone the completion date until after the next shipping season. This is especially true if prefabricated components cannot be airlifted to the site or duplicated onsite. If such problems occur, project construction costs may be increased and the facility completion jeopardized, particularly if existing buildings were disposed of in the interim.

c. Maintenance. Since it is desirable to reduce high maintenance costs, the designer must consider whether a high initial cost will be outweighed by decreased maintenance costs, resulting in a lower total cost. Maintenance costs are high due to high local wages, scarce skilled local labor, necessity for providing room and board at remote locations, difficulties, costs, and risks in shipping materials and equipment, decreased efficiency of men and machines due to environmental conditions, and the length and cost of communications and re-supply channels.

1-6. Scheduling. Work scheduling must utilize the least expensive transportation methods. During ice-free periods, the most economical means is usually by water, on rivers and northern seas. Materials will not arrive until ice breakup at the site, however, unless icebreakers or ice-strengthened vessels are available. Planning to utilize full barge loads will reduce costs, since barge charges are fixed by the rental cost of the barge and towing vehicle. Scheduling all work at a particular site under one contract can cut transportation costs. During the winter, transportation over frozen land, rivers, lakes, and marshes where there are no roads or rivers may be more economical than air transportation. Because of short construction seasons, outside work must be accomplished quickly. Scheduling work so that the structure can be closed in during mild weather, with interior work done during severe weather, will expedite completion, reduce costs, and eliminate many problems. The types of material and construction method used will be impacted by the length of the construction season. For example, cold weather may limit concrete work, while prefabricated-type construction could still proceed. Because of the short construction season and soil conditions, the first year is often used to establish a camp, clear the site, move required materials into the area, construct foundations, and do whatever prefabrication is possible; the second season is then used for actual building construction. For additional information on seasonal work scheduling, see TM 5-852-4/AFM 88-19, chapter 4. The optimum time for shipping construction materials and supplies coincides with the optimum time for construction. This factor may require expensive air delivery of construction materials used early in the project, or a longer completion time when cost is the most important consideration.

CHAPTER 2

ARCHITECTURAL

2-1. General. Buildings should be designed and constructed in accordance with standard practice except that special attention should be given to features listed herein and in TM 5-852-1/AFR 88-19, Volume 1. Special designs and construction techniques are required primarily because of prolonged and extreme cold, permafrost, snow and wind combinations, transportation, equipment, and maintenance problems. Designers must provide a functional building while considering all factors required to provide an environment which will meet the total needs of the occupants and contribute to high morale. In addition to the facility's intended function, consideration must be given to general data discussed in chapter 1. Factors affecting morale and psychological acceptance must be considered. Inside, proper use of materials, fixtures, colors, textures, component arrangement, space, form and style, temperature and noise control are of key importance. Outside, vegetation and landscaping will contribute toward the goal: a total environment which positively affects personnel stationed at the facility.

2-2. Types of construction. Three general types of building construction may be used in arctic and subarctic regions: concrete, metal, and wood. All have advantages and disadvantages. Transportation methods and costs, necessary labor to construct, existing site conditions, material availability, length of construction season, feasible use of prefabricated items, temperature affects on materials, material fire resistance, stability, durability, plasticity, etc., all must be considered when evaluating the type of construction best suited to a particular function and location. All construction shall comply with fire protection criteria established for Army and Air Force projects. The Uniform Building Code (UBC) and National Fire Protection Association (NFPA) codes shall be followed to the extent authorized by the current criteria. Special attention shall be paid to the NFPA 101. Type of construction shall be specified as required in the above referenced fire protection manuals. Selection processes are discussed later in this technical manual.

a. *Concrete.* Concrete's fire resistant quality is especially important because low temperatures, high winds, and possible water or chemical shortages make fires extremely dangerous. Concrete has a high thermal conductivity compared with insulative materials, therefore thermal breaks must be provided, and thermal bridges avoided. A concrete slab supporting an exterior masonry wall is one example of a thermal bridge often seen in poorly designed buildings. Even with insulation on the wall's inside surface, heat flows through the slab to the wall, is distributed laterally and dissipated to the outdoors. This process effectively bypasses the insulation. Exterior insulation used with no exposed concrete provides a solution to this problem. Other types of thermal breaks are possible, but successful use is difficult. Concrete is durable in arctic climatic conditions because of its inert nature after curing. Surface cracks and air-path porosity will allow moisture to enter the concrete, however, and freezing results in surface spalling. Air entraining admixtures help prevent such surface spalling and provide a more durable finish. All concrete, whether used indoors or out, should be air entrained to protect it from frost damage during construction. Specifications must include adequate cold weather curing, placing, and handling procedures. (See American Concrete Institute ACI 306.) Quality control is difficult to maintain in the field because of inconsistent batching and limited raw material availability. Local aggregates, if available, may require testing with consistent time requirements. The costs of shipping cement, aggregate, reinforcing steel, form materials, and production equipment for cast-in-place concrete, versus shipping costs and equipment to assemble prefabricated concrete members, plus the basic costs of the materials or members themselves and onsite labor, must all be considered when evaluating the use of concrete for construction.

(1) *Prefabricated concrete items.* Factory prefabricated items such as wall, roof, partition and floor panels, columns, and beams should be considered especially for sites where sand, gravel, and water may not be available or would require excessive hauling or processing. The possibility of damage in transit, the suitability of the manufacturer's and site delivery dates, handling capability at the site, and construction time must all be evaluated. Generally, because prefabricated concrete items are bulky and heavy, the only economical transportation is by water. Occasionally, the components are subjected to the severest stresses in transit rather than during or after erection. Differential settlement often occurs with foundations placed on permafrost, however, and can cause problems with precast concrete wall panels. This potential problem should be considered in the design process. Prefabricated concrete buildings have been successfully utilized for major construction projects in arctic and subarctic regions. Where

repetitive patterns can be used, precast concrete panels should be considered for walls and roofs because they have proven more economical than cast-in-place concrete, even at remote sites. Use of a prefabricated system generally reduces construction time. Particular attention should be given to caulking the joints and connections of prefabricated items. Caulking is discussed more fully under TM 5-805-6, and in paragraph 2-6 in this chapter.

(2) *Concrete masonry units.* Characteristics of concrete masonry units (CMU) with added reinforcement are similar to those of concrete construction. Disadvantages of concrete block construction are the relatively high costs of shipping, breakage, labor, and longer construction time. Therefore, these units are not generally used in remote areas. The inherent multiple horizontal joints tend to collect and hold moisture, especially at extremely wet sites. Most types of concrete blocks have to be sealed and painted or covered with another material for weatherproofing. The covering must breathe sufficiently to allow internal moisture to escape. Trapped moisture causes increased deterioration. Over the life of a building, maintenance can become costly. Concrete block construction is more practical when the source of supply is near the building site. Thermal breaks are also required in concrete masonry unit construction [see paragraph 2-2c,(4)], but concrete masonry units are inherently thermal bridging. The concrete web between the indoor and outdoor surfaces conducts heat past the holes which may contain either air or insulation. Even special blocks designed to incorporate maximum insulation and minimize the cross section of concrete between the inside and outside are usually not suitable for arctic or subarctic construction. Metal masonry ties between blocks and another masonry layer represent another type of thermal bridge, even when insulation is present. An exterior insulation layer can avoid problems with breaking thermal bridges across walls with masonry. Differential settlement which often occurs with foundations on permafrost can cause problems with CMU walls and this factor should be considered in the design process.

b. Metal. Metal buildings constructed of rigid steel frames or columns and beams with metal siding and roofing may be composed of standard steel products or components prefabricated at the factory and assembled at the construction site. The basic advantages of prefabricated metal buildings include lower cost of manufacturer's stock items (constructed with revisions to meet the arctic wind and snow loads), and erection speed. Stock sizes can be factory-modified to space members or fasteners closer to meet greater wind and snow loading design criteria. If only air transportation is available to remote sites, consideration must be given to the size and weight of members. Many prefabricated buildings require only standard equipment for erection. A positive thermal break (such as cellular plastic or wood isolators installed in compliance with local fire codes, as illustrated in figures 2-1 and 2-2) is required in heated buildings to prevent cold conduction through the structural members. If conduction is present, frost, and ultimately, dripping water, can form on the interior walls. A continuous, sealed vapor retarder is necessary on the warm side of exterior walls in all heated buildings to minimize condensation within the wall insulation.

(1) Metal frame, siding, and roofing. Metal frames may be erected rapidly at the site; however, to obtain a given fire rating additional fire-resistant treatment may be required. Covering the surfaces with noncombustible, heat-resistant materials may be necessary. Fastening the siding and roofing to the framing, whether by screws, bolts, or welding, will cause through-metal-conduction problems. Through-metal conduction, and resulting condensation and ultimate frost buildup inside of buildings where such accumulation would create problems, must be prevented or minimized. Minor frost buildup caused by through-metal conduction may be tolerated in subarctic areas, however, for such structures as automotive maintenance shops, heated auto storage buildings, etc. Thermal-break insulation for components is available from most manufacturers but careful selection must be made to assure suitability for arctic construction. Figures 2-1 and 2-2, following page, show how wood or cellular plastic, when installed in compliance with local fire codes, can be used to prevent through-metal conduction. Voids in thermal walls and roofs should either be filled with insulation to curtail the chimney effect, or adequate draft stops should be provided. Metal roofing fastened directly to the steel frame is apt to leak in time as thermal movements stress the fasteners. The newer standing seam metal systems, which are supported on clips with a sliding feature, have improved long-term performance.

(2) Insulated arctic metal panels. The advantage of using these panels is rapid field installation. Panels may be used in lieu of separately installed metal sheets, insulation, a vapor retarder, and the interior finish. There are also disadvantages, however: the possibility of damage during

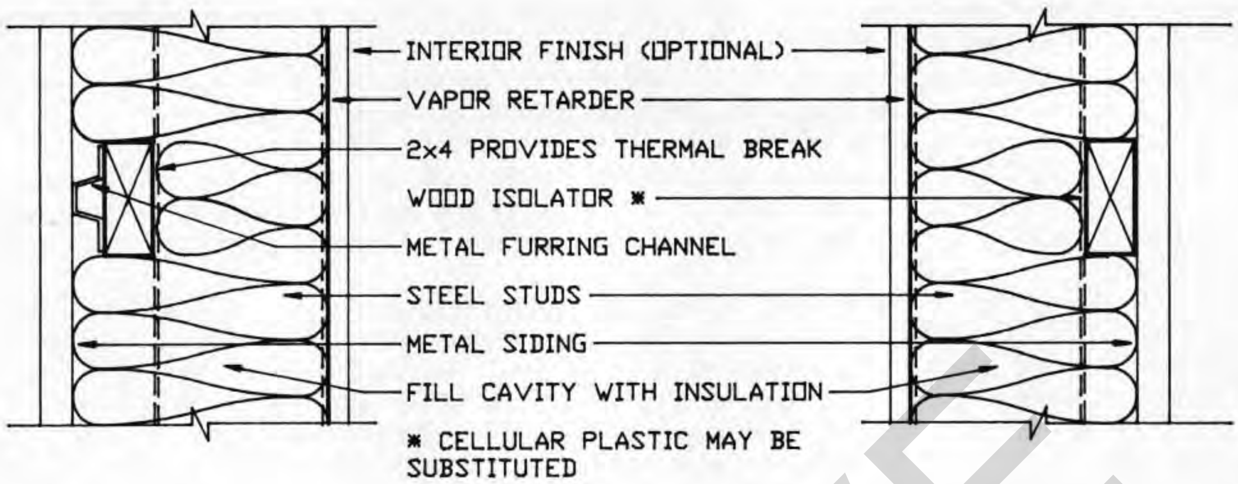


Figure 2-1. Thermal isolator for metal siding.

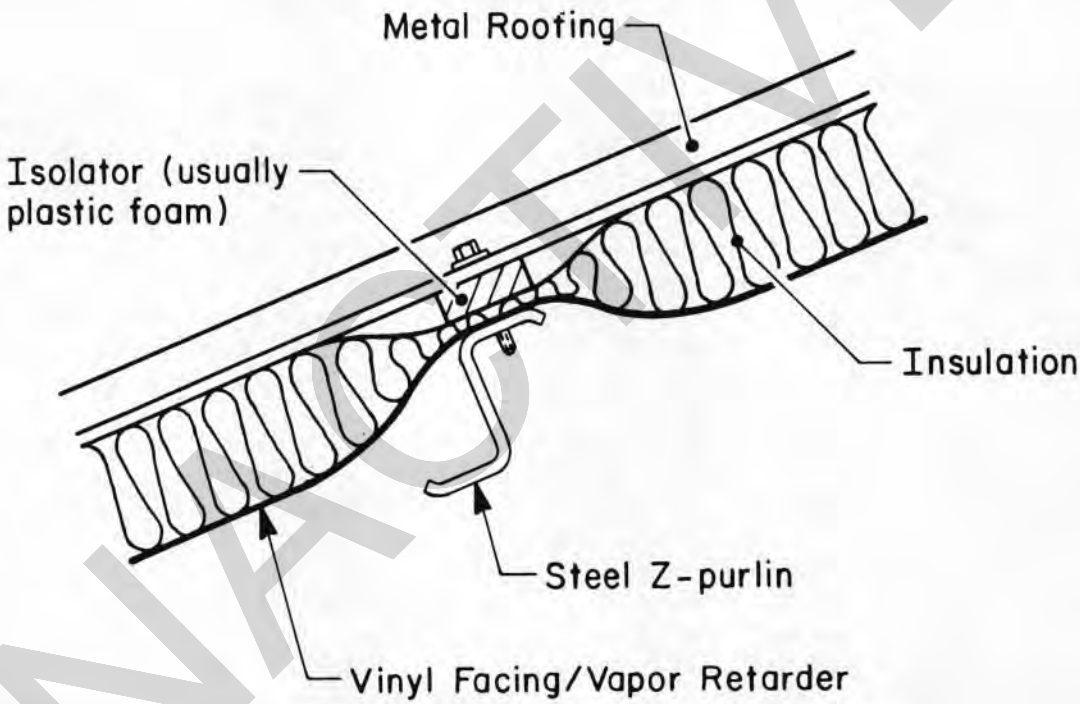


Figure 2-2. Thermal isolator for metal roofing.

transportation and installation; slow replacement of damaged items; penetration in either or both skins; unsuitable storage; and improper joint sealing between panels. In specifying a panel, the adhesive bond between the exterior metal skin and the plastic insulation must be determined sufficient to prevent delamination over the life of the building.

c. Wood framing and siding. Wood frame construction is commonly used in family housing units and in relatively low cost semi-permanent and temporary structures. Wood studs may also be used for interior partitions in other types of construction, provided that the fire codes are met. Metal studs are more commonly used in other building types because wood may require fire retardant treatment.

(1) Construction. Wood construction requires fewer technically skilled workers than other types of building materials, and allows extremely wide design flexibility to adapt to special requirements for arctic construction. Wood components may be fabricated at factories or in the field. Proper fasteners, such as screw or ring nails, should be selected to minimize nail popping.

(2) Fire resistance. One major problem with using wood framing and siding for building construction in remote arctic and subarctic regions is wood's susceptibility to fire. Heavy timber

construction, laminated wood beams, and arches can burn for several hours without collapsing, however. Wood frame structures are frequently finished with 5/8-inch fire rated Type X gypsum board to provide 1-hour fire-rated construction. Fire-retardant treatments which increase wood's fire resistance should be used on wooden structural members and wood finishes exposed to the interior. Nails, screws, and other fasteners must be compatible with the chemical used in fire-retardant treatments. Intumescent foaming paint may also be used for fire protection, particularly to modify old structures or where other methods are impractical. Non-combustible metal studs are an acceptable and common alternative to wood studs. A thermal break must be incorporated when metal studs are used in a thermal insulating wall, however (see figure 2-1).

(3) Frost buildups. Fewer frost buildup problems are encountered in wood frame construction because wood has a lower thermal conductivity than other construction materials. Metal, masonry, and concrete conduct cold much more readily which may result in problems such as below freezing temperatures on warmer interior surfaces, at the connections, and at places of contact between the interior and exterior surfaces. This, in turn, may lead to condensation and resulting discoloration, frost buildup, or water damage. While wood use may solve these problems, care should be taken to avoid shrinkage and air leakage problems more prevalent when wood is used.

(4) Other applications. Because of its insulating characteristics, wood members are used for furring strips on concrete construction, and as spacers, sash and window frames to minimize cold penetration.

2-3. Roofing.

a. Bituminous membranes. Bituminous built-up membranes have been widely used in cold regions. Many have performed well but others have been problematic. Most problems can be eliminated by providing the membrane with a 1/4 in./ft minimum slope to drain, by ensuring that the membrane and the insulation below it are properly attached to the deck (mechanical fasteners are required for steel decks), and by using Type IV glass felts for the reinforcing plies (if organic or asbestos felts get wet they become very weak and may split). Bituminous membrane external durability and fire resistance can be greatly improved by embedding aggregate in its flood coat. Alternative surfaces, such as mineral-surfaced cap sheets, have a very poor record in cold regions as they are prone to blistering. Two Cold Regions Research and Engineering Laboratory (CRREL) papers, "Roofs in Cold Regions" and "Lessons Learned from Examination of Membrane Roofs in Alaska," overview the subject.

b. Elastomeric Roofing—Liquid and Sheet Applied.

(1) Liquid applied. Liquid applied elastomeric roofing materials have been used infrequently in the subarctic. Elastomeric roofing consists primarily of a liquid neoprene water proofer with a coating such as chlorosulfonated polyethylene polymer to protect it from ultraviolet rays, sometimes referred to as neoprene-hypalon system. The hypalon finish coating can be furnished in all colors and grays shading from white to black. Elastomeric roofing has been used most successfully over concrete decks; use over lightweight concrete decks is not recommended. Some installations over plywood decks have been successful. The success of elastomeric roofing is strongly dependent upon a clean deck surface initially, properly taped joints in the roof deck, and proper temperature application. The roofing should be applied in accordance with manufacturer's instructions. In some applications, however, sheet neoprene may be a more suitable choice to cover deck joints than the more commonly used glass fabric fiber tape because of its greater resiliency.

(2) Single membrane sheet. The membrane can be loose laid, fully adhered to the deck surface with contact adhesive, or partially adhered at spots or along strips using a variety of mechanical fasteners. Loose laid membrane must be covered with a ballast (concrete pavers or stone aggregate) to prevent wind uplift and to protect against ultraviolet (uv) rays (for uv sensitive materials). Ethylene Propylene Diene Monomers (EPDM) and neoprene are resistant to ultraviolet rays. The advantages of these types of membranes are their elasticity. They can expand and contract or stretch easily, diminishing the stress at joints, penetrations and the roof perimeter. The material are produced in wide rolls, thus decreasing and often eliminating the seams, and making installation fast and simple. Reinforced polyvinyl chloride (PVC) systems have also performed well in cold regions. When adhering any membrane to the deck surface, special attention should be paid to adhesive and the mechanical attachment used, or the combination of the two, because of wind uplift and the elastic properties of the membrane. Pavers cast from air entrained 3,500 pound per square inch (psi) concrete may be used on the entire roof, with double thickness pavers around the perimeter where wind uplift forces are greatest. If stone aggregate is used, compensate for wind uplift with extra stone or pavers around the perimeter.

Pavers may also be used for walkways on stone covered roofs. Ballast design must be site specific, using the proper design wind load.

c. Protected membrane roofs. Applying the roof membrane directly on the roof deck or underlayment and covering it with insulation protects the membrane from the temperature differentials. This "upside-down" method has proven very successful in cold regions, even when installed using built-up and/or single sheet membrane roofing. The insulation used must have a low moisture absorption co-efficient to preclude loss of insulation values. Extruded polystyrene board conforming to ASTM C 578 has been extremely satisfactory, and is the only insulation approved for this application. Insulation should be installed using a minimum of two layers with all joints staggered. To prevent silt and debris from accumulating on the membrane surface and possibly clogging the roof drains, install filter fabric on top of the insulation before placing the ballast. Filter fabric also helps to unify and stabilize the ballast's holddown capability. See the preceding paragraph for further ballast information. The insulation's bottom surface should be grooved or the bottom edges beveled with a 1/2-to 3/4-inch chamfer to facilitate water drainage. Insulation and ballast should be installed over the roof drains and the filter fabric (see figure 2-3). Roof drain strainers may be eliminated and replaced by a piece of hardware cloth or expanded metal capable of supporting the load above the drain. Key the bottom of the first layer of insulation to fit the drain and hardware cloth, enabling insulation and ballast to be laid in an even plane across the roof surface. Pavers directly above the drains should be marked to facilitate drain inspection and maintenance. Use of the proper thickness of insulation for local thermal requirements should maintain the surface temperature of the roof membrane well above freezing, thereby keeping the roof drains open. Due to the high smoke developed rating of polystyrene insulation, a fire shield of 1-hour-fire-resistive material is required for non-fire rated decks such as wood and steel. An underlayment of rigid perlite board on top of the deck before the roofing membrane is installed is recommended. Parapet walls framed with metal or sheathed with plywood and covered with a layer of perlite board maintain the fire shield integrity.

d. Metal roofing. Metal roofing has been used extensively in arctic regions. To minimize warming of metal roofing, which can result in alternate thawing and freezing of the covering snow and glaciation, design should incorporate a cold attic or well insulated roof system with ample ventilation. Heat from the building, and to some extent solar radiation and heating on the bare metal areas, causes roof glaciation and ice dams at eaves. Although nothing is known to completely prevent glaciation, calking laps and fasteners with polysulfide, silicone, or polyurethane sealant will preclude water entry into cracks and joints. Roofing with concealed fasteners and raised joints (or standing seams) should be designed to keep the joints above the draining surface. The seams should be sealed by embedding in sealant or using a gasket liner to inhibit water entrance from glaciation or ice damming. Building entrances under eaves should be protected by canopies or some similar means to prevent property damage or injury from falling ice and sliding snow. Roof overhangs should be kept at a minimum to reduce ice damming at eaves, but must be at least 6 inches wide to ensure dry exterior walls. For metal roofs, minimum slopes should be 1 inch per foot with 1 1/2 inches per foot preferred, while suggested slopes are 4 to 5 inches per foot.

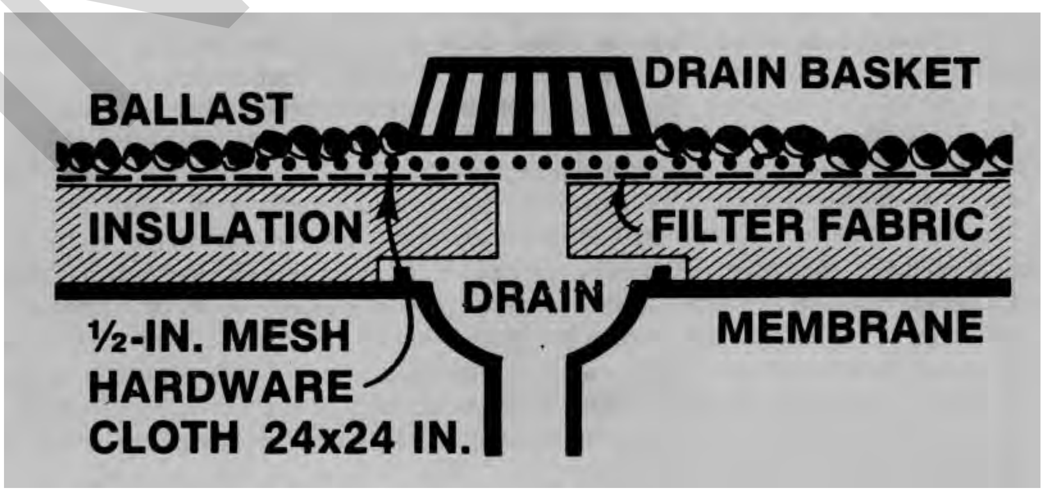


Figure 2-3. Protected membrane roof drain.

e. Temporary roofing. Where it can be predetermined that a complete permanent roof cannot be applied because of weather conditions, temporary roofing should be applied directly to the roof deck. The temporary roofing should not be incorporated in the final roof design.

2-4. Roof slope.

a. Dead-level roofs. Dead-level roofs are not permitted. Water does not drain off of a level roof when the roof drain is surrounded by ice or snow. Also, deflection in mid-span often creates a point lower than the drain. All membrane roofs tend to have inherent shallow ponds that do not drain well without adequate slope.

b. Sloped or pitched roofs. As a result of a report by the Alaska Roofing Board, sloped roofs from 1 on 12 to 4 on 12 have been adopted since 1957. Plate roofs should not be used in cold regions because snow or ice accumulation in valleys causes leaks and other problems. A slope which will provide positive drainage and prevent ponding should be used. A steep pitch on large roof areas produces a high attic which may not be desirable. A slope of 1/4 inch per foot is the minimum recommended for built-up and elastomeric roofing. For protected membrane roofs, the design roof slope should be 1/4 inch per foot to minimize ponding, prevent creep of membrane and pavers, and limit parapet height. The maximum slope for built-up roofs is 3 on 12. The minimum slope for metal roofs is 1 on 12. Regardless of degree of slope, crickets, fill, or similar means should provide positive drainage to roof drains in all directions. Basic roof slopes should be built into the structural roof framing system whenever possible. Tapered insulation has been used selectively to produce adequate drainage on rehabilitation and new projects.

c. Roof drains and gutters. Gutters on eaves and exterior downspouts should not be used on buildings in arctic and subarctic regions because of snow and ice accumulation. In subarctic areas, interior roof drains are normally used on buildings having large roof areas [see paragraph 4-6b,(2)]. Whenever feasible, overflow scuppers should be used through the parapet walls. The bottom of the scupper should not be lower than the roof drain. Scuppers should not be located above doorways. If scuppers cannot be provided, overflow drains should be located up-slope from roof drains and connected to a separate drain leader. Overflow drains, however, are not as effective as scuppers and should be used only where scuppers cannot be provided (example: roof area isolated from an exterior parapet wall).

2-5. Exterior painting.

a. General. Because of the extreme temperature variations in arctic and subarctic regions, paints should be flexible enough to contract and expand with the substrate. TM 5-618/NAVFAC MO 110/AFM 85-3, and the "Steel Structures Painting Manual," published by the Steel Structures Painting Council, are good references. Whenever possible avoid the need for exterior painting by using materials that do not require painting in the field such as natural, pre-finished, or integrally colored materials. Latex base paints perform better on exterior wood than oil base paints because they breathe and thereby allow passage of vapor through the paint which may avoid blistering.

b. Ambient temperature. Exterior paint is usually applied when the structure is nearing completion, often late in the construction season. At this time of year, the night temperatures frequently fall to 40° F and below. Such low temperatures do not allow proper curing, and the result will often be poor adhesion, poor strength, permanent tackiness, or excessive wrinkling. This problem should be considered when planning the construction schedule; for example, the exterior painting could be performed the summer following construction. Paint may be cured during unfavorable weather or temperatures by providing properly heated and vented enclosures where proper curing temperature is maintained.

c. Areas for special consideration. Major paint damage occurs where glaciation forms on exterior wall surfaces from defective eave flashing, around exhaust louvers, and where water vapor leaks from within the buildings. Wall glaciation, which results from melted snow on the roof through defective eave flashing and moisture condensed around exhaust louvers, will cause removal of paint film and unsightly discoloration. The paint film will break and blister on exterior wall surfaces where there is poor water vapor exfiltration control. Moisture penetrates the paint film, prying it loose from the substrate. Designers should consider these problems during design to eliminate the causes of glaciation, or provide finishes that do not require painting, such as glazed structural units, clay tile, stucco, stone, mineral-surfaced colored non-asbestos panels, metal siding with factory finish, CMU, or concrete. Water can get behind and freeze, then dislodge finishes such as tile, stone, etc. This problem should be addressed in the design. Exhaust louvers and fans should be located away from fire escapes, entrances, landings, etc., to prevent glaciation on these areas.

2-6. Caulking. Caulking compounds normally used in temperate regions do not perform satisfactorily in arctic or subarctic areas. The extreme variation between low and high summer and winter temperatures causes common caulking compounds to become brittle and lose their cohesion and adhesion. Caulking materials which can maintain flexibility with permanent cohesion and adhesion at - 60° F should be used to caulk or seal joints of precast concrete panels and metal roofing, around window and door frames, and in similar areas. Some sealants which meet these criteria are: butyl, polybutene, and polyisobutylene based sealants; single compound polysulfides, polyurethanes and silicones; and two-component polysulfide and polyurethane based sealants. For additional information on caulking materials and practices, see TM 5-805-6.

2-7. Exterior doors.

a. *Exterior personnel doors.* Exterior personnel doors are normally free from frost buildup unless there is high humidity within the building. Vestibules or arctic entrances should be provided in particularly high-humidity buildings and windy areas. Typical high-humidity areas are laundry and dry cleaning plants, restaurants, dormitories, swimming pools, kitchen areas in mess halls, etc. Because of high winds and extreme cold, doors located on the prevailing windward side of the building should have special protection (windscreen or baffle) in addition to arctic entrances which are discussed in paragraph 2-10a, this chapter. Wind screens, baffles, or heavy bumper stops mounted on steel posts should be provided to protect the doors and hinges from damage and to prevent injury. For energy conservation reasons, arctic entrances are advised at all major personnel doors. For exterior use, metal doors and frames are sturdier, will look better longer, are better insulated, and will retain their shape better than wooden doors and frames. Both doors and frames must be insulated and weatherstripped, and should have an integral thermal break. Seams in doors should be sealed (continuously welded and ground smooth). Many metal doors have the outside skin directly attached to the inside. This type of door is unacceptable because the inside surface efficiently collects heat, which the metal edge then conducts to the outside surface which dissipates it efficiently. When wooden doors are used, they should be solid-core wood stave to provide maximum insulation and warpage resistance. In the arctic, temperatures may range from an inside door surface of 60°F to an outside door surface of 60°F. Exclusive use of insulated metal doors and frames is highly recommended.

(1) *Weather-stripping.* The entire perimeter of all exterior doors should be weather-stripped with adjustable cold weather neoprene or butyl rubber in extruded aluminum holders. This type of weather-stripping retains its flexibility at - 60°F. Spring-type or interlocking metal weather-stripping should not be used because they lack durability, particularly because snow or ice clogging can result in mechanical damage. Metal weather-stripping should not be used because it will form a through-metal connection between interior and exterior and ice up quickly.

(2) *Thresholds.* Thresholds should be hardwood or metal with integral thermal breaks to minimize cold penetration. Set the threshold in sealant.

(3) *Locks.* On doors with weather-stripping, cylinder locks or latches should be installed with center line of lock or latch 5 inches from edge of door. Personnel will be able to avoid skinned knuckles, and operate knobs easily while wearing mittens and gloves if this 5-inch distance is maintained. Mortise locks or latches should have lever handles to provide more clearance for hands.

b. Overhead doors. On shop and warehouse buildings where large doors are required, sectional overhead doors should be used. Standard steel sectional doors consisting of sections fabricated from steel panels with a foamed-in-place polyurethane core are available from several manufacturers. The outside and inside panels must be separated by a thermal break. Positive seals, sometimes achieved with cam action hardware and seals of PVC, neoprene, or butyl rubber, must be provided at head, jambs, and sill, and also between sections. Steel panels may be galvanized, with the exterior panel having a factory finish, usually baked-on acrylic, and the interior either factory primed and field painted or factory finished. Individual sections and the entire door assembly must be capable of withstanding design wind loads. Nominal thickness of panels should be a minimum 1 1/2 inches. Panels may contain thermal glazing provided thermal breaks are used in the framing. Doors may be operated manually or electrically, depending on their location and function. When electric operators are used, an automatic safety edge that will stop or reverse the door's downward motion when the bottom edge strikes an object is an important safety feature. Wooden overhead doors are not recommended. Metal rollup doors should not be used in exterior walls. Floors should not be sloped to the door as the melted snow will freeze at the doorsill and affect the door operation.

2-8. Windows.

a. During the 3 months in mid-winter when the sun is at its lowest angle and shining for only a few hours each day, little natural illumination is available through windows. In contrast, there is too much sunlight during the summer. The need for windows should be weighed carefully because there is a lot of unwanted sunlight in summer and cold infiltration in winter. As a rule, window area should not exceed 10 percent of the floor area served by the window(s) in a given room or area. Another factor which must be considered is that continuous daylight during summer months necessitates use of opaque window shades for some functions. If passive solar heating is being considered because of the high heating degree days, however, more windows on the sun exposed side are allowed to achieve this design. The number of operable windows should be held to a minimum to reduce cold infiltration and heat loss. AFR 88-15 requires operable windows in sleeping rooms for use as emergency and secondary exits. Operable window area shall be in conformance with NFPA 80 and 101, and U.B.C. Low air infiltration rate and frames that provide a thermal barrier are essential for window design in cold climates. Windows that do not have these inherent qualities frost up and freeze. The result is an ice buildup which melts and drips, transmits cold air, allows heat to escape, and is most unsatisfactory. Aluminum windows with an integral thermal break and metal clad wood windows (aluminum cladding with baked-on factory finish) are good design choices. Both require minimum maintenance, painting, etc. Vinyl clad wood windows should be specified with caution since some vinyl cladding becomes brittle when subjected to low temperatures. The composite "U" value of approximately 0.54 for units fabricated from both types of materials is satisfactory. The American Architectural Manufacturer's Association's Voluntary Specification for Aluminum Prime Windows, AAMA 101, and the National Woodwork Manufacturer's Association's Industry Standards for Wood Windows, I.S. 2-80, both require the air infiltration rate not to exceed 0.5 cubic feet per minute (cfm) per foot of crack of all operable sash when tested in accordance with American Society of Testing Materials, ASTM E 283. In the arctic, the tested air leakage rate should not exceed 0.15 cfm per lineal foot of crack for a pressure difference of 0.3 in. of H_20 across the window. In the subarctic, the same test should not exceed 0.25 cfm per lineal foot of crack. The gap between the window unit and the rough opening should be thoroughly sealed so that air leakage around the unit won't negate the benefits of a low leakage window.

b. Adding a weather-stripped storm sash to existing windows can improve the U-value of the window system. However, most will not significantly improve the air leakage characteristics of existing windows. When occupants neglect to close storm windows during cold weather, they nullify the benefits of storm sashes. Avoid using windows with double prime sashes, either sliding or double hung, in cold-dry arctic and subarctic regions, because occupants are likely to leave one set of sashes open and nullify the potential benefits of the window design. In wet, windy areas, however, such double sash windows are suitable because they can provide ventilation without allowing water to enter. The occupant simply opens an outer sash such that air encounters a closed inner sash behind it and is diverted sideways to an open inner sash behind a closed outer sash. Modern window units glazed with insulated glass and equipped with effective weather-stripping have been used very satisfactorily on many buildings in the arctic and subarctic to reduce heat loss, condensation, and frost buildup. Triple or double insulating glass, with a single pane piggyback unit in a removable weather-stripped frame attached to the interior face of the sash, should be used in areas that have heating degree days exceeding 10,000, and/or when economically justified. Insect and/or bird screens in removable aluminum frames should be provided. Window units that can be cleaned from inside the building are highly recommended.

c. Windows should be designed to avoid condensation and frost problems. Table 2-1 indicates the indoor relative humidities which will cause condensation or frost at various outdoor temperatures for double, triple and quadruple glazed windows, with or without interior curtains or blinds. For example, table 2-1 indicates that a double pane glass can function to almost minus 20 degrees F but when it is covered with a curtain, frost will form at zero degrees F and condensation may be expected at about 15 degrees F. Outdoor wind speeds that are less than the assumed 15 miles per hour will permit higher indoor relative humidities than those shown.

2-9. Condensation, vapor retarder, insulation, and ventilation. Ventilation or provisions for vapor escape should be incorporated in the design of enclosed buildings. Two possible designs are: roofing applied on the roof sheathing of a gable roof with a vapor retarder installed on the ceiling; or roofing on top of decking with a vapor retarder on the bottom of joists. With these designs the enclosed areas must be vented or be able to breathe into the outside atmosphere. If this precaution is not taken, condensation will form on the underside of sheathing or decking (wood, metal or concrete) during cold weather. As the temperature of the roof deck becomes warmer, the enclosed air will expand and vapor will be ingested by the decking and roofing membrane. If a large volume of moisture or condensation accumulates in the trapped enclosed areas, water will leak from the ceiling. There can be similar problems in walls. Moisture

Table 2-1. Temperatures and Relative Humidities at Which
Moisture Condenses on Window Glass
Relative Humidity

No. of Glass Panes:	Double		Triple		Quadruple	
Window Cover?	Yes	No	Yes	No	Yes	No
Outdoor Temperature (Fahrenheit)						
60	82	88	87	90	87	95
40	53	68	62	77	70	82
20	33	51	46	66	55	75
0	20	38	32	55	42	62
- 20	*	29	24	46	32	55
- 40	*	21	16	38	24	50
- 60	*	*	*	31	rg	42

Underline indicates *Frost* on window glass.
* Less than 15% relative humidity.
Note: These numbers are developed from basic data in the ASHRAE Handbook of Fundamentals, using the following assumptions: an indoor temperature of 70°F, a 0.5-in. air space between panes, and a 15 mph outdoor wind speed.

can become trapped in the insulated cavity between the vapor retarder and the exterior surface material. In wood sheathed and sided walls, there tend to be sufficient joints to provide vapor relief. Corrugated and/or fluted metal panels should have preformed filler strips in the interior flute voids. These strips should be mechanically fastened near the top and bottom of the wall, and fit tight enough to prevent chimney action but provide vapor relief. Walls finished with concrete products also require venting. In precast or cast-in-place items, near the top and bottom of the insulated cavity, small holes (3/8-inch diameter) should be built into the panels at 32 inches center-to-center maximum. Concrete block should have weep holes built into the wall near the top and bottom of the insulated portion, at 32 inches center-to-center. All holes should be covered with insect screen on the interior face of the wall prior to placing the insulation and finishing the interior. Vents should be provided on the top and bottom of wood frame arctic type insulated metal panels with vapor sealed joints on the metal finish of the inner surface.

a. *Condensation.* Condensation control in arctic and subarctic areas requires: a complete and continuous vapor retarder on the warm side of the exterior enclosure of the building; insulation to maintain the interior surfaces and the vapor retarder at warmer than dew point temperature; a vapor permeable exterior surface of the building enclosure (for a roof, this may require ventilation). Satisfactory building envelope design requires that all three factors—vapor retarder, insulation and vapor dissipation—be properly balanced. Inadequate condensation control can: damage wall and ceiling finishes; permit ice and frost buildup in walls and under roofs; leach fire retardants from wood and insulation. Condensation causes are: design deficiencies and poor installation of vapor retarder; incomplete sealing of the joints or damage to the vapor retarder; and failure to operate the heating and ventilating systems in accordance with design, allowing high humidity by inadequate ventilation or excess humidification. The latter problem is discussed in chapter 7. Condensation may form on through-metal and concrete members (particularly in structural steel or concrete frame buildings) because of thermal conductance near exterior walls. Conductance can be controlled by installing thermal breaks, insulation, and vapor retarder around the members and inward along the surfaces of interior walls, floors and ceilings. Leaks of moist air from ducts into cold attics can cause severe frost buildup and subsequent melting. Design must provide thermal breaks in large metal ducts through the roof such as exhaust ducts or vent hoods which can produce a huge volume of water from condensation. That water could migrate into the roof structure and cause leakage. Means and details must be provided to minimize this process or to divert the water to prevent damage to the structure or equipment in the building. Large metal ducts should be insulated with vapor retarder on the warm sides. Other items such as electrical outlet boxes installed on exterior walls should be placed on the warm side of the insulation and vapor retarder, or the vapor retarder should be carefully sealed at the box. In high wind areas, a special hood should be designed for exhaust and intake louvers to prevent condensation accumulation and keep snow from drifting through the louvers (see figures 2-4 and 2-5).

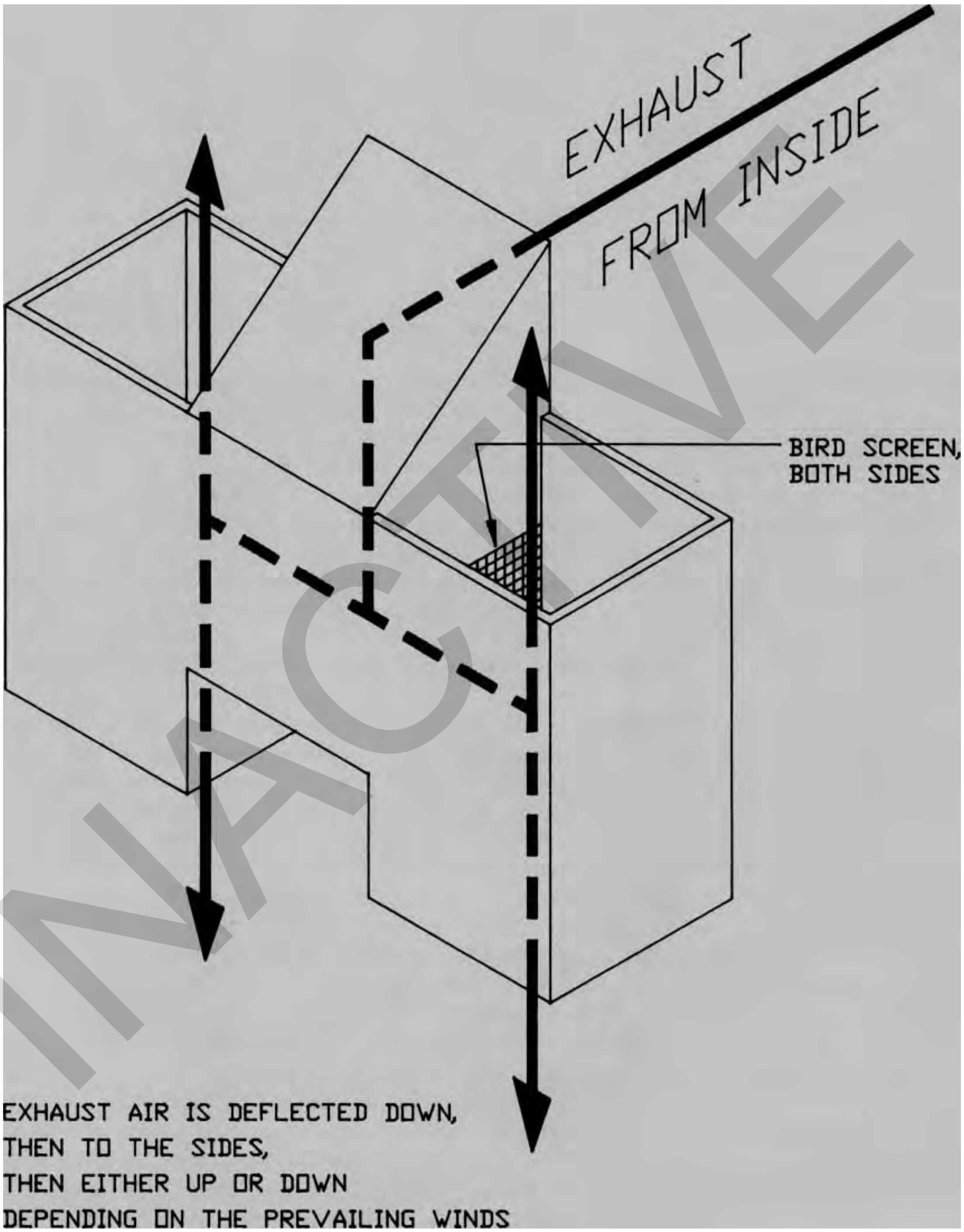


Figure 2-4. Exhaust hood.

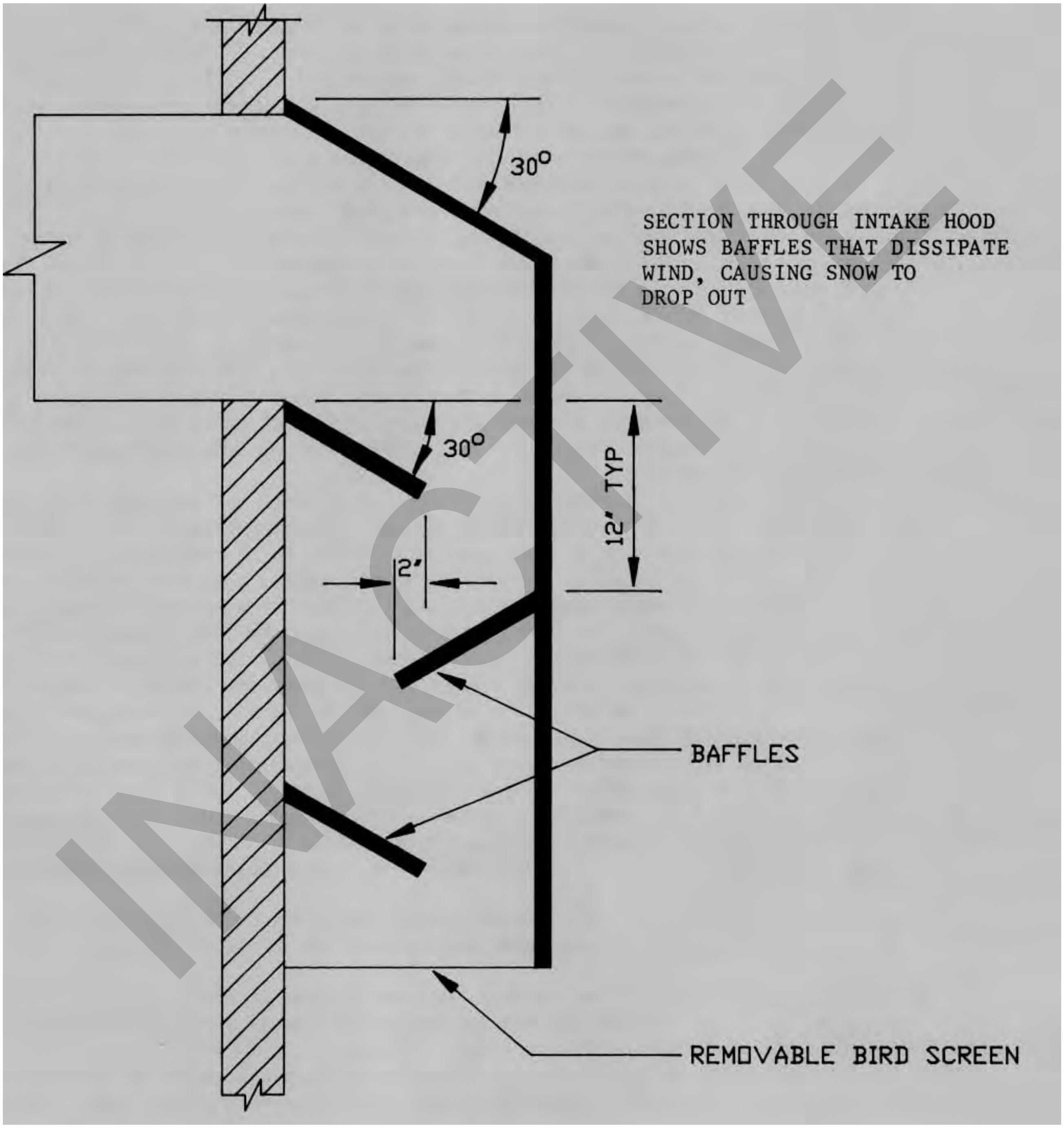


Figure 2-5. Intake hood.

Metal hoods with plywood lining and baffles should be provided to prevent frost accumulation from restricting air flow through the intake hood. During the winter, a slight positive pressure normally occurs in a heated building; therefore, mechanical pipe chases for plumbing in buildings should be sealed to prevent the condensation, in cold attics and on the undersides of cold roofs, that is caused by moisture rising to these areas. To prevent condensation, vent pipes, ducts, rain leaders, and chimneys should be insulated where sections go through the cold attic. All joints in walls and roof should be sealed to prevent snow, wind, and condensation infiltration, particularly if a negative pressure could develop in the building.

b. Vapor retarder. The vapor retarder should be installed on the warm side of the insulation. Vapor retarder materials are normally required to have a permeance not to exceed 0.5. To obtain a continuous vapor retarder, care must be exercised to assure that all joints, corners, and penetrations are completely sealed with properly specified mastic or sealants. Well detailed designs and careful supervision during construction must be provided to obtain maximum retarder continuity between walls and roof. The design should strive to provide a 100 percent vapor retarder. The degree of success is a function of both the material used in construction of the basic structure, and the skill, diligence, and supervision of the workmen applying the vapor retarder. Therefore, design provisions should always be made to assure that the insulation behind the vapor retarder can breathe, that is, rid itself of moisture before excess trapped moisture can develop which would lead to deterioration. There is an economic balance point where the cost of attaining 100 percent vapor retarder has to be weighed against the potential damage aspect from nonattainment. The vapor retarder should consist of a not less than 1/2-ounce copper sheet, or 2 to 3-mil-thick aluminum foil adhered to heavy kraft paper with glass fiber reinforcing spaced not more than 1/4 inch in each direction, or 4 to 8 mil polyethylene sheet. Polyethylene sheet does not meet the flame spread and smoke development rating listed previously. It may be used, however, if covered by properly designed gypsum wallboard or a fire resistant material. The polyethylene material is considerably less expensive and easier to install than the other vapor retarders, resulting in fewer and better sealed joints and providing a more effective end product.

c. Insulation. Insulation should be provided in walls, ceilings or roofs, and elevated floors to provide the required heat transmission "U" value difference between the interior and exterior surfaces (see paragraph 4-8). Three general types of insulating systems currently being used are: rigid board which is normally used on top of roof decks, in refrigeration plants, and as perimeter insulation at foundation walls; batts or blankets between furring or framing members in walls and ceilings; and insulated panels in sandwich construction. For information on insulation for roof decking see TM 5-805-3 and TM 5-805-14. For typical installation of vapor retarder and insulation see figures 2-6 and 2-7. All exterior foundation walls shall have properly designed (2-inch minimum) perimeter insulation board extending from the top of the footing to the bottom of floor slab. At doors, a preformed joint filler should be used between slab(s) and wall. Depending upon the wall construction, the insulation may be on the exterior or interior face of the wall. If used on the exterior, it shall be protected with metal or other durable finish materials and shall be extruded polystyrene conforming to ASTM C-578, Type IV which has a low moisture coefficient. Type I is acceptable on interior surfaces in areas where the fill does not retain moisture and the water table does not rise up to the insulation level. All insulation shall meet flame spread and smoke development rating requirements, or shall be covered on the interior by properly designed gypsum wallboard, or a fire resistant material.

(1) Spaces between wall framings and door and window frames should be fully and carefully filled with insulation. This not only provides continuous insulation, but minimizes cold air penetration and infiltration.

(2) Blanket-type insulation should be fastened down near the eave vents to prevent it from curling back or being lifted which can block the air flow and reduce the insulation value in these areas. Wire mesh baffles between rafters are often used to maintain vent space (see figure 2-8).

(3) All interior air spaces in the wall cavity should be filled with insulation or blocked at intervals to minimize the chimney effect of air flow within the cavity. This construction helps reduce moisture condensation and freezing in the cavity. Where the air space is not completely filled, all types of insulation must be adequately supported to assure that settlement does not occur.

d. Ventilation. In addition to an effective vapor retarder and sufficient insulation, a building needs adequate ventilation to eliminate indoor pollution, reduce excessive humidity, and bring in fresh air.

(1) *Attic, roof and under-floor ventilation.* Usually, a small amount of frost or vapor condensation accumulates on the underside of the cold roof even though the ceiling is protected with an

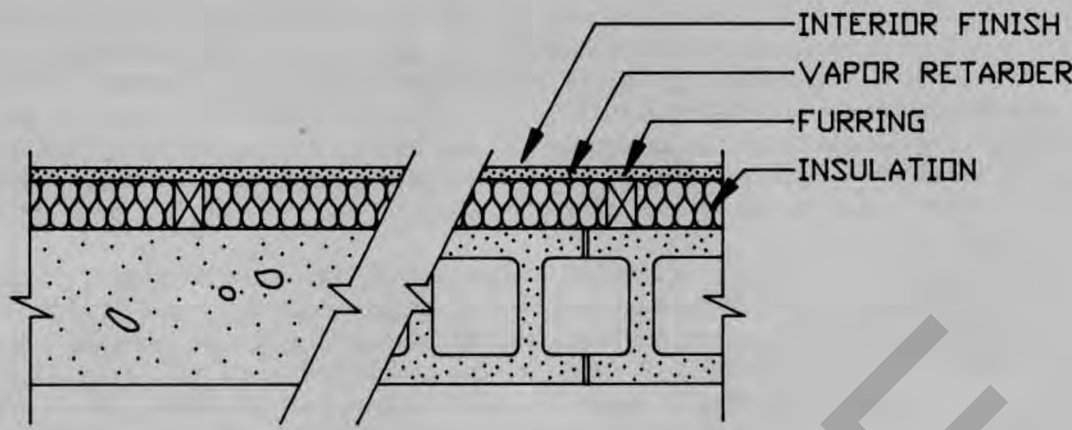


Figure 2-6. Concrete and CMU walls (plan view).

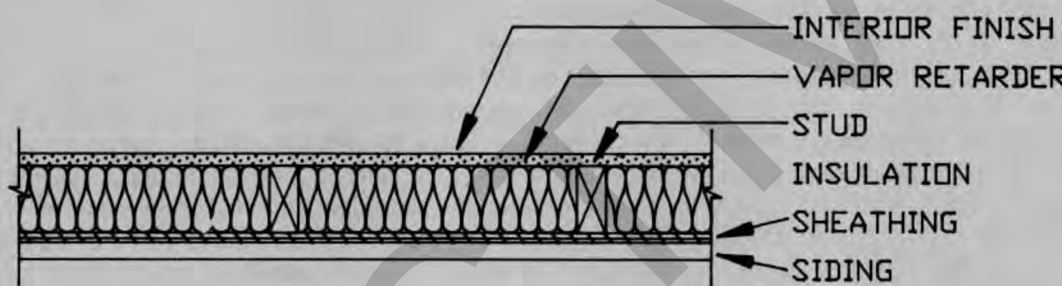


Figure 2-7. Wood frame wall (plan view).

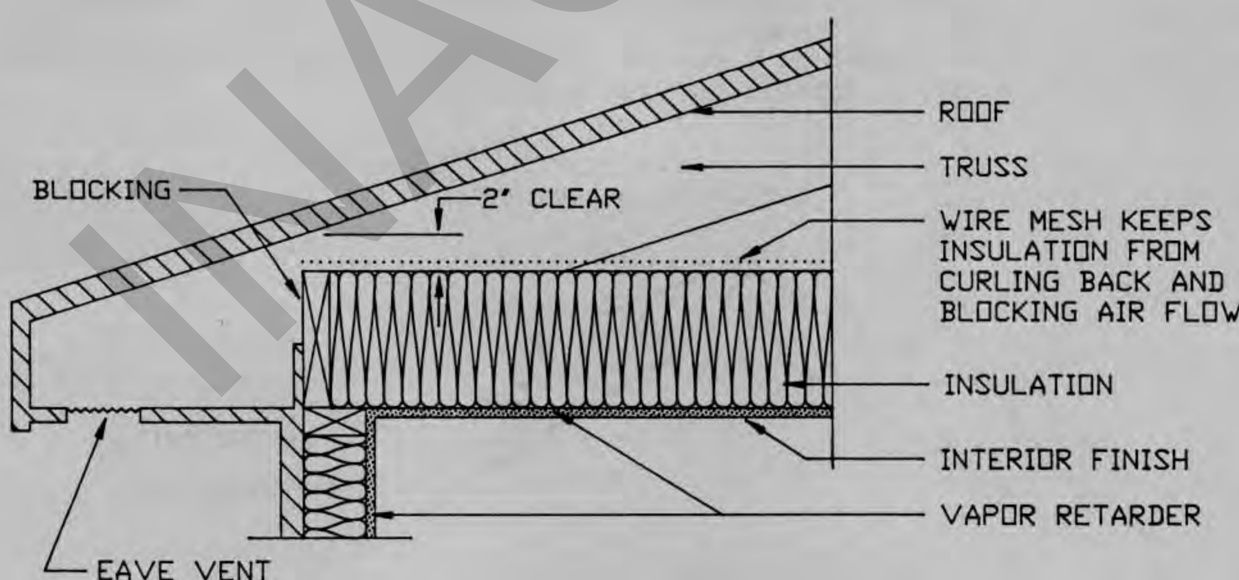


Figure 2-8. Cold attic with insulation on ceiling.

effective vapor retarder. Primarily, this occurs because it is impossible to obtain a 100 percent vapor seal and a continuous small amount of vapor escapes through tiny gaps, cracks, and holes in the insulated ceiling. Eave and ridge vents should be provided for roofs having cold attic spaces (see figures 2-8 and 2-9). Buildings in areas having frequent high winds and powdery drifting snow, however, should have insulation installed directly under the roofing material; in this case, no eave or ridge vents are permitted. Ventilation should be provided between the insulation and the built-up roofing by using ribbon or spot mopped base sheet, ventilation sheet or kerfed plywood with venting provided under the metal flashing at the eaves or parapets. This allows release of vapor laden air and prevents air pressure buildup underneath the roofing.

(2) *Mechanical ventilation for equipment and occupants.* Louvers and/or fans are normally used in connection with mechanical ventilation necessary to protect equipment and occupants in the buildings. Louvers and fans should be protected with specially designed hoods, as previously described, to decrease air velocity and keep snow from filtering into the building. Because heating and ventilation are so important in cold regions, additional spaces for large heating and ventilating ducts and pipes must be considered. These spaces are generally provided above the ceiling of each story or attic, or below the floors. For additional ventilation discussion, see paragraph 4-3.

2-10. Miscellaneous architectural requirements.

a. Arctic entrance. An arctic entrance is a vestibule used to shut out cold air, high wind, or drifting snow after the exterior door closes and before the inside door is opened. Arctic entrances should also be used in high humidity areas, as discussed in paragraph 2-7a. The exterior doors should open inward to preclude blocking by drifting snow and possible damage by high winds. An inswinging door permits burrowing out when blocked, although it violates the fire code for certain occupancies and functions. Each inswinging door requirement must be evaluated separately in terms if risk, alternate exits, and other factors relating to occupant safety. Where drifting snow is not a problem, codes for exit doors should be followed. The floor should be depressed and provided with a grating and pan to allow snow and water removal from footwear. Mats or carpet should be provided at the inside door of the arctic entrance. A canopy should cover the entrance to protect personnel from falling icicles and dripping water. Walkways within 5 feet of exterior building walls should also be protected from falling icicles and water that may freeze, causing a safety hazard. Exterior access ramps for use by the handicapped shall be covered. Otherwise, design for the handicapped shall conform to current criteria.

b. Finish floor elevation. Except for ventilated floors, the floor elevation should be at least 6 inches to 1 foot above the finish grade around the building to eliminate the possibility of water backing up into the building during thaw periods. In extremely flat terrain and where snow drifting is anticipated, the higher elevation may be justified. A stoop should be provided at all exterior doorways other than emergency exits. If a stoop is provided for an outward swinging door, it should be depressed 6 inches below the floor elevation to allow the door to swing above ice and snow.

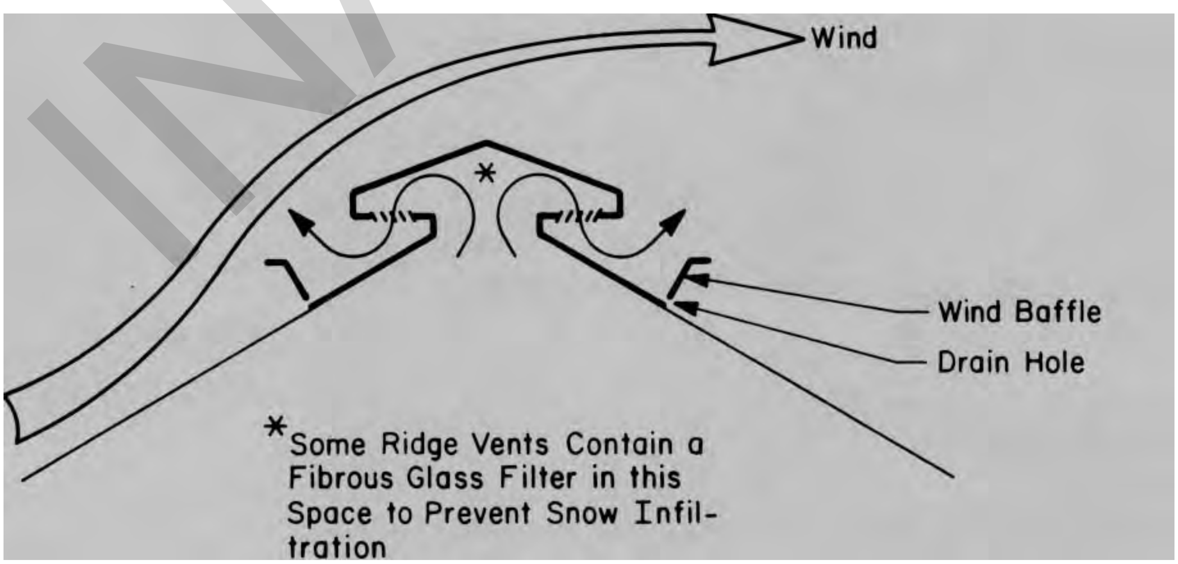


Figure 2-9. Ridge vent.

c. Exterior landings, stairs, and railings. To prevent ice and snow accumulation on horizontal surfaces, open grating type materials should be used for walking surfaces on exterior landings and stairs. Wooden railings or railings provided with rubberized coverings should be considered instead of metal for exterior installation to avoid possible frostbite or bonding of bare skin to metal. Interior or enclosed stairways are preferable. Exterior stairs and landings should be hinged at the building or cantilevered from it to allow for movement from frost heave. If differential heave is anticipated, large landing structures or docks should be isolated from the main structure. Proper foundation treatment may minimize differential movement between warm and cold structures.

CHAPTER 3

STRUCTURAL

3-1. General. This chapter extends the basic structural design criteria to cover items that are unique to arctic and subarctic regions. It extends the criteria provided in TM 5-852-1/AFR 88-19, Volume 1, and other criteria documents.

3-2. Structural design. Structural design of building construction in arctic and subarctic regions is unique only in that conditions found elsewhere are compounded there. Large, and often indeterminate design loads, wide seasonal temperature variances, short construction seasons, and limited availability of skilled labor, construction materials, and transportation form the basis of design problems. Department of the Navy, NAVFAC DM 9, and Department of the Army, TM 5-349, discuss these problems.

3-3. Special considerations.

a. *Design loads.* Design loads for selected arctic locations are listed in TM 5-809-1/AFM 88-3, chapter 1, and TM 5-809-10/NAVFAC P-355/AFM 88-3, chapter 13, and American National Standards Institute (ANSI) A58.1. Climatological data at remote sites should be obtained from individual sites to determine snow and wind loads. Precipitation varies greatly between sites in the same general area and between areas; consequently, snow depths and densities also vary. Many military installations have building sites at two or more greatly differing elevations, and usually have different snow and wind loads at each location. Roof systems with vertical irregularities are subject to increased snow loadings due to drifts and, in certain roof configurations, snow can slide from high roofs to low roofs. Additional loads due to snow drifting, plus additional loads and impact forces associated with sliding snow, must be considered during structural design of roof systems.

(1) Wind loads and related problems. Metals that extend through building walls from the exterior to interior will contract in the extreme outside cold and expand in the interior heat. If metals are restrained at the wall, this expansion/contraction can result in unusual stress on the buildings. Solar radiation on metal surfaces of one side of a structure, with extreme cold in shadows on the opposite side, has caused buildings to rack or be distorted. These conditions can be minimized or avoided by painting, by providing for expansion and contraction in connections, and by avoiding designs which require continuous metal connections through insulated walls. When used as exterior walls, metal-surfaced sandwich panels with insulation as a fill material can cause problems. When the outer skin is exposed to extreme cold, it will contract, while the inner skin, exposed to room temperature, maintains a constant size. As a result, the panels deflect inward, which could result in outer skin failure, excessive shearing stresses in the insulation, or excessive tensile stresses in the inner skin. Providing adequate skin plate thickness or internal ribs will reduce the deflection.

(2) Ice loads. Solar radiation and heat transferal from within the building melts snow on the roof. As the roof cools with a drop in air temperature or with darkness, this water turns to ice. Repetition of this process results in glaciation. Glaciation occurring on a building eave is frequently referred to as an "ice dam" (see figure 3-1). This concentrated type of loading must be accounted for in the design.

b. Material considerations. Common structural materials can be used in arctic and subarctic regions with few problems. Some special considerations must be remembered, however.

(1) Wood. Low humidity conditions are common in buildings where subfreezing temperatures reduce the amount of moisture in the air which can be taken into heating systems from outside. Frequently, other considerations prevent the addition of moisture as the air is heated. The resultant dry atmosphere draws moisture out of the wood. As a result, wood shrinks, adhesives dry, planks and timbers check and split, fasteners loosen, and warping occurs. The use of kiln-dried lumber or laminated beams will prevent some of these problems.

(2) Steel. At cold temperatures, steel will change from a ductile to a brittle material. This change takes place at a point called the transition temperature, which can vary over 100°F due to differences in composition and grain size. Increases in carbon and phosphorus content will raise the transition temperature. Adding nickel will lower the transition temperature, as will decreasing the grain size by heat treatment. When designing structures subject to impact loadings, consideration should be given to specifying steel that has impact resistance at low temperatures. Building foundation pilings have broken while being driven and reinforcing steel has broken while being bent. Nickel alloy steel

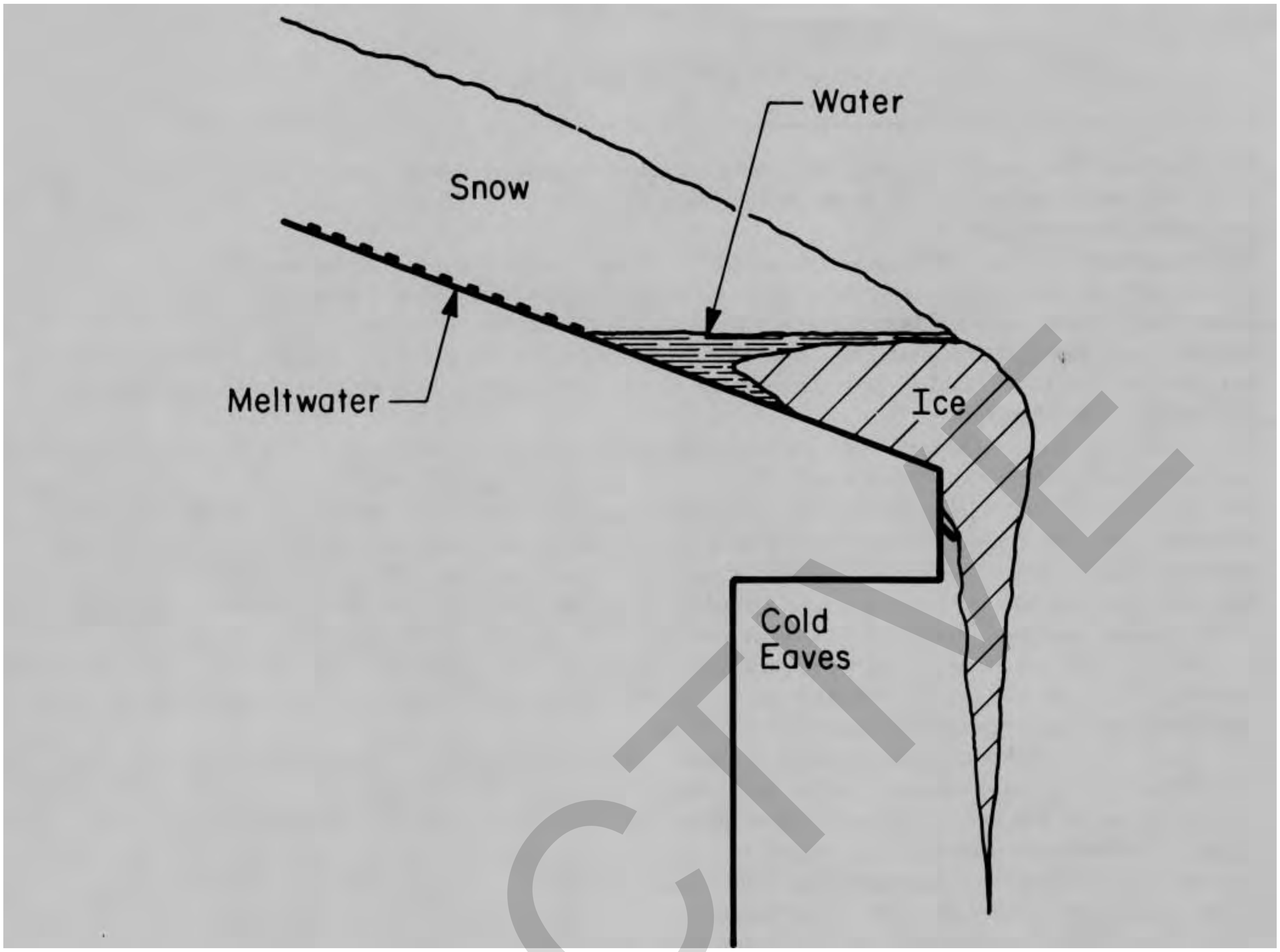


Figure 3-1. Example of an ice dam.

provides needed ductility; however, it may not be economically feasible. Steel conducts heat through walls, causing condensation and ice formation on structural members or melting snow which subsequently forms ice on the exterior surfaces. Where feasible, metals should not extend through exterior walls. Insulation or other materials should be used to interrupt the heat transmission. For example, rails armoring floors against abrasion or other damage from operation of tracked vehicles should be interrupted at entrance doors. This is discussed further in TM 5-852-4/AFM 88-19, chapter 4.

(3) Concrete. Concrete structures are very successful in the arctic when concrete mix is properly designed and cold weather concreting is accomplished in accordance with ACI Standard 306, or when the concrete is placed in warmer weather. The concrete mix should be designed with entrained air to provide durability against freeze-thaw effects. Precast and prestressed concrete techniques, including tilt-up panels, have been used without problems. Most commonly, failure of properly placed concrete has occurred because the concrete has been subjected to water saturation, then allowed to freeze. This can frequently be avoided by diverting the water. The temperature of the concrete, when placed, should not be less than 40°F and special protection should assure it is not subjected to temperatures less than 40°F before final set has occurred.

(4) Epoxy bonding agents. When using epoxy, be sure to check the manufacturer's recommendations. Some epoxy cannot be successfully applied when surfaces are below 50°F.

3-4. Foundations. As in all climates, foundation design is of major importance. The unusual consideration in arctic and subarctic environments is the presence of deep seasonal frost or permafrost. Depending on the characteristics of the soil and its thermal regime, foundation designs may be either passive (maintaining the foundation materials in a frozen state for the entire service life of the structure) or active (thawing and consolidating the foundation material, or replacing it with more suitable material).

In areas where permafrost is stable, the passive approach is generally used. One common passive method is placing the structure on a layer of gravel on top of rigid insulation. This layer of gravel and insulation must be designed to isolate the frozen foundation from the building heat, keeping the ground permanently frozen. Ventilation ducts are often placed in the gravel layer to control the temperature of the frozen ground by maintaining air movement. Another common passive method is placing the structure on piling. The piling either extends into the permanently frozen material, with an insulating layer under the building, or the structure is elevated, permitting free passage of exterior air to dissipate the building heat. Where the permafrost is fragile, special piling called thermal piling is sometimes used. There are several thermal pile designs, all intended to keep the foundation material permanently frozen. In all cases, particular attention must be given to ensuring proper surface and subsurface water drainage away from the structure. Poor drainage and ponding of water can seriously affect the ground thermal regime and cause structural damage from permafrost degradation and frost action. Building foundation design is discussed in TM 5-852-4/AFM 88-19, chapter 4. For structures on spread or continuous wall footings, a soil investigation should be made at the site to determine the possible presence of layers of silty soils that may be susceptible to frost heave during the freeze-thaw cycle. Foundation designs should require removal of frost-susceptible soils under a building which will be affected by freezing, and replacement of those soils with non-frost-susceptible gravelly backfill. Design should consider the thaw bulb which will develop under the building upon completion; therefore all of the frost susceptible materials may not require removal. The contract document should require the contractor to assure these materials do not freeze and cause jacking during construction.

CHAPTER 4

MECHANICAL

4-1. General. Design and operation of mechanical systems in arctic and subarctic regions are basically similar to those systems used in the northern regions of the continental United States; however, extended periods of extremely low temperatures and high wind conditions of the arctic can cause failures in systems that function normally in other areas. Therefore, mechanical system design for arctic regions must utilize arctic-type technical changes and economic considerations. Systems should be as simple as possible to avoid operator confusion. Operation and maintenance considerations are important since expert technical assistance may not be available at isolated arctic sites. Components should be standardized whenever possible to reduce the inventory of repair materials necessary. Material in this chapter should be used to supplement applicable technical manuals.

4-2. Heating.

a. *General.* A satisfactory, reliable, and easy to maintain heating system is extremely important for personnel comfort. Remote locations, severe climatic conditions, and short daylight hours which all tend to confine personnel to the site are primary reasons for maintaining a good physical environment. Cold floors and downdrafts from windows should be minimized by using adequate floor insulation and locating heating units below windows. While constant circulating heat systems will usually provide more uniform room temperatures, it is important that all available information be evaluated before selecting a system. To provide further design guides, various types of heating systems are discussed in detail below. Noted are the advantages or disadvantages of each when used in the arctic environment. Unless otherwise stated herein, heating designs shall be in accordance with TM 5-810-1.

(1) Hot air heating. Hot air heating is one of the simplest and most widely used systems in arctic areas. Major advantages are that it is less expensive to construct, is easily understood, and requires less maintenance. Systems with extensive ductwork, however, are expensive to ship, difficult to install, and can be difficult to balance. When reliable electrical power is available, forced-air heaters with gun type oil or gas fired burners should be utilized as operation is more efficient and less costly. Forced-air heaters must be separated from the rest of the building by a 1-hour fire rated partition. Low-cost ventilating can be provided by bringing dampered outside air into the building through the furnace cold air return. Where large quantities of fresh air are required, however, a split system should be used. Forced-air heating systems can utilize duct mounted humidifiers to increase humidity, and filters to control dust. Blowers in hot air furnaces distribute heat effectively and should be operated continuously for best results. Hot air supply outlets should be located near the floor to induce increased circulation in office and living spaces and in buildings with many open spaces and high ceilings. Fans to move the hot air from the ceiling toward the floor are extremely desirable. Air systems are not generally damaged by freezing if power is lost, and little preventive maintenance is necessary.

(2) Steam and hot water heating. Central steam and hot water heating systems are the most widely used in arctic regions because of the simplicity of heat distribution. Heat storage in steam and water systems can prevent freezing during short power failures; however, a rapid means of emergency drainage is essential. These systems require immediate attention if a problem develops, therefore alarm systems should be installed. The use of thermostat draindown valves developed for solar systems should be investigated. In addition to heating, the steam and hot water systems can provide a practical and economical heat source for various water treatment processes. Steam and hot water can also be used to melt snow for domestic water. Anti-freeze keeps hot water systems from freezeup.

(a) *Steam heating systems.* Steam is used extensively in heat distribution systems and in primary building heating systems. Steam heating can be used for shops, hangars, and garage-type buildings where system noise and wide ranging temperatures are not objectionable. Conversely, steam is undesirable in offices and living spaces because of noise problems and lack of precise control. Steam can be piped long distances where unavoidable pressure losses would be excessive if using a normal hot water system. Adequate condensate and steam line slopes must be provided to avoid freezing damage during outages. Drip legs and receivers also require protection from freezing. Provide automatic condensate drainage with steam traps such as the thermostatic bellows-type. Good water treatment is required to reduce corrosion in the return lines. Maintain control of pH between 6.7 and 7.7 to avoid excessive corrosion. Pure condensate (pH 7), however, can cause rapid pipe deterioration.

(b) Hot water systems. The same types of hot water systems are used in arctic areas as in temperate climates, however, positive control and system reliability must be provided. As mentioned above, the primary advantages of hot water over steam are uniform temperature control, relatively quiet operation, and much less maintenance because there is no condensate return system. To prevent freezing, antifreeze solutions should be utilized. Hot water or antifreeze systems are very effective in panel heating, which provides even heat distribution over large radiating surfaces. Radiant floor temperatures should not exceed 70°F. However, when outside temperatures are below - 65°F, radiant floor panels may not give off sufficient radiation to heat the building unless the floor temperature is raised above the comfort limits recommended by American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Handbook of Fundamentals. Additional insulation or dual systems may be required to maintain proper floor temperatures in this case. Where insulation is used under the floor heating system, designers need to consider its effect on the thaw bulb. Consideration also needs to be given to: the heat's effect on the floor slabs; effect of shrinking on the designers selection of contraction joint spacing; designing heating loops to contraction joint spacing to minimize crossing of control joints. High density polybutylene tubing is recommended rather than copper or steel because of its greater flexibility and lower corrosiveness. If leaks develop, radiant floor systems are hard to repair because such leaks are difficult to locate. Hot water or antifreeze systems are most widely used in building perimeter heating systems (fin-tube radiators), which are very effective in providing even heat distribution. The hot water or antifreeze system can be set up with temperature reset controls which reset the hot water or antifreeze operating temperature based on the outside air temperature, thus saving energy.

(3) Electric heating systems. Electric heating systems can be utilized in areas where electric power is economically available. The advantages of electrical systems—ease of installation, distribution, control, small space requirements, and low initial cost—make electric heating appealing. The operating costs for electric heating systems are generally higher than for other systems. Where major changes such as increasing the size of wall studs to accommodate the extra insulation are required to make operational costs competitive, the total cost of installing an electrical system may exceed that of other systems. Electric heating may also be limited by the size of the base power plant. Favorably, however, electric heaters can also be used for tempering outside air for ventilation.

(4) Gas heating systems. Both propane and natural gas heating systems can be utilized effectively in arctic climates. When using propane, precautions should be taken to heat and maintain the propane cylinder and regulator at the proper temperature to vaporize the gas. At atmospheric pressure, propane liquefies at a temperature of - 44°F, therefore, tanks must be protected from such cold, non-vaporizing temperatures. Where these tanks are enclosed, a ventilation system is necessary to prevent any hazardous *gas* accumulations. Natural gas can be piped long distances even in arctic climates. Orifices and controls can freeze and become inoperative when gas containing water vapor expands or is subjected to freezing temperatures. In these cases, heaters and water separators must be used. An alcohol can also be entrained into the dried gas to prevent freezing of condensed moisture in the system. The water-alcohol mixture is collected at low drain points in the piping systems, where it is expelled using a blow down connection. Natural gas can also be used effectively for heating outside air for ventilation.

b. Heating problems in cold areas. Problems outlined below may be encountered in mechanical systems because of the arctic environment. The systems must be modified to operate properly.

(1) *Freezing of water and steam systems.* A temperature alarm system should be installed in each remote unoccupied building to alert maintenance personnel when the building's inside temperature approaches freezing.

(a) Heating lines and equipment. Running hot water lines in exterior walls is not recommended. If lines must be placed in exterior walls, however, they must be properly protected. When the boiler, furnace, or heat exchanger ceases to function, localized freezing of water in the system can be delayed if constant circulation is utilized. Other problems can occur. Where automatic room temperature control is not provided, personnel may open windows to provide necessary control and lines may freeze when the room is left unattended. For this reason, individual room thermostat controls should be provided. In garages or hangars, unit heaters installed within 20 feet of doors should be interlocked with those doors, so that the fans on the unit heaters shut off when the doors open. When fans are left running, cold outside air is blown over the coil, and it frequently freezes.

(b) Antifreeze system design problem. The most common antifreeze solutions are made up of approximately 50 percent by volume of ethylene glycol and 50 percent by volume of water. Pumps in

ethylene glycol systems must utilize mechanical seals to prevent leakage. Glycol in its pure state is a corrosive liquid, therefore, rust inhibitors must be added to eliminate corrosive effects. Inhibitors break down and deteriorate at high temperatures, forming a sludge and increasing the solution's corrosiveness. Above 240°F the breakdown can occur very rapidly. To reduce this breakdown, it- is recommended that glycol systems not be operated above 200°F. Consideration should also be given to substituting other commercially available antifreeze solutions which are effective and do not deteriorate at higher temperatures, such as heat transfer oils or antifreeze solutions designed specifically for heating and snow melting systems. These antifreezes, usually ethylene glycol solutions, contain inhibitors such as mercaptobenzothiazole, disodium, or dipotassiumphosphates. When using commercial brands of anti-freeze, always be sure to check additive compatibility. Velocity in heating coils and heating tanks should be kept high enough to prevent extensive sludge buildup. Small diameter but longer heat exchangers or multipath heat exchangers can be specified for this purpose. If possible, use straight tube heat exchangers, with removable heads on each end to facilitate routing sludge from tubes. The straight tube exchanger is recommended, but not mandatory, in lieu of the more common "U" tube exchanger. If properly sized to provide a 4 to 6-fps fluid velocity in the tubes, "U" tube heat exchangers are acceptable. Sludge deposits can be particularly bad in heat exchangers or air heating coils where three-way valves are used to control output because of reduced flow through the tubes under lighter loads. Gylcol solutions should be checked frequently to maintain a pH of at least 6.4. Due to the peculiar manner in which water affects glycol ionization, the pH can be varied over a fairly wide range (about 6.7 to 7.7) by adding small amounts of water. It is also good practice to replace glycol yearly. When replacing the glycol, the system should be completely flushed to remove sludge deposits.

(2) *Shop and hangar heating.* The frequent opening of large doors and the usual high ceilings in such buildings can create many heating problems. Some items to be considered are:

(a) Fast heat recovery is necessary in hangars and shops to maintain good working conditions. The warm building air can be very rapidly displaced when doors are opened, especially when there are strong winds or cold outside air temperatures. Minimum recovery measured 4 feet above the floor should be from 20°F to 50°F in 120 minutes.

(b) When projection type heaters are used in shops, hangars and other large spaces, units with sufficient throw and a low discharge air temperature must be selected. Air throw and projection from the unit should cover the entire floor area. Units selected in this manner will frequently have a larger than required heating capacity so the quantity of water supplied must be specified and controlled. Installation of overhead radiant heaters is economical and they should be considered where gas or cheap electric power is available.

(c) Snow melting systems should be installed under hangar doors and ramps to reduce ice and snow accumulation and keep doors operable. Ramp heating should extend far enough so that vehicle or aircraft wheels make the transition from ice to bare pavement outside the entrance door.

(d) Radiant heating should be considered for hangar and maintenance shop floors in addition to the regular heating system. Heat from floor slabs provides greater comfort for workmen.

(e) Infiltration through windows, louvers, and overhead doors is a major cause of building heat loss in arctic areas. Extreme care in door design and good weather-stripping is required to eliminate excessive losses. In addition, heat loss calculations must include adequate figures to compensate for infiltration. To reduce infiltration, operable windows should be kept to a minimum. Window and door construction methods are covered in chapter 2 in this manual.

(3) *Heating control.* Controls for heating and ventilating systems should generally be automatic. Manual control systems should also be provided to preclude complete shutdown if automatic controls fail. Night temperature setback should be considered wherever practical applications exist. Heating coils must have adequate controls to protect them against freezing. Control systems must be kept simple because expert maintenance is often not available.

(4) *Cooling water and recharge wells.* Cooling water supply and recharge wells should be considered where outside temperatures are too high to cool electronic equipment during summer months. During winter months discharging waste water in recharging wells, rather than on the ground surface, can effectively reduce ice fog and glaciation. The reduction of ice fog is especially important near airfields. The temperature of well water in subarctic regions is usually not over 39°F.

(5) *Fuel oil design problems.*

(a) Fuel oils used in arctic areas should comply with grade DF-A arctic grade as specified under Federal Specification VV-F-800. Fuel oil meeting this specification has a pour point of - 60°F. When

used in areas where such low temperatures prevail, special heating and insulation of fuel lines should be considered. When commercial diesel fuels with a higher pour point are used in arctic and subarctic regions, heating may be required for the system to function properly. Lines may be increased one pipe size; however, greater increases reduce velocities and cause sluggish operation.

(b) It is not advisable to bury exterior fuel oil tanks in permafrost areas because the supply and return connections are extremely vulnerable to breakage when settlement occurs. Aboveground tanks, however, are exposed to cold temperatures and a protective shelter may be required. When installing aboveground tanks which are higher in elevation than the burner unit, a vacuum relief or antisyphon device should be installed on the fuel oil supply line. Dikes or double wall construction are required for all fuel tanks.

(6) *Air elimination.* Eliminating air in a hot water heating system can be a problem in any climate. It becomes more critical in arctic areas because of the need for continuous operation. Therefore, systems should provide for positive air removal and drainage of the piping and equipment.

(7) *Improper piping in hot water heating systems.* An improperly piped system in a temperate zone may perform satisfactorily, but the same system, when exposed to extreme arctic conditions, can cause heating problems. These problems can be minimized by careful design. Positive flows must be maintained in all of these piping systems unless an antifreeze filled system is utilized.

(a) Avoid numerous parallel zones fed from one circulating pump. These zones are difficult to balance and eliminating air from the many circuits is difficult. Flow can easily stop in one of the parallel zones because of poor air elimination. A freeze-up may result, which, when concealed, becomes extremely difficult to correct. If parallel zones must be used, provide accessible balancing control and indicating devices and a manual bypass to allow operation during maintenance.

(b) Risers from direct or reverse return heating circuits serve a specific area and return as directly as possible to the main. Too much radiation should not be connected on one branch take off. Serving several floors with the same take off riser can cause problems similar to those described in (a) above.

(8) *Design considerations for simple effective mechanical systems.*

(a) The designer must ensure adequate space in the mechanical room and around equipment to facilitate maintenance inside during cold weather. Piping connections and space must be arranged to permit removal of coils, tube bundles, and filters. Ready access must be provided to maintain motors, automatic controls, dampers, traps, etc. Inaccessibility is one of the largest problems encountered by maintenance personnel, especially when repairs must be made immediately to reduce system outages: fast repairs require sufficient maintenance space. Systems subject to interior condensation should be provided with drain valves to drain moisture annually.

(b) Sites are frequently in remote areas where experienced personnel and ready sources of spare parts are not available. Simple mechanical systems are required so that they can be understood by inexperienced maintenance personnel.

(c) Specifications for heating and plumbing piping should emphasize the need to keep dirt and gravel out of piping during construction. Inspectors should be alert to assure compliance. After years of operation, military bases in arctic areas are still plagued with stoppages and restrictions from gravel remaining in glycol grid snow melting systems. Gravel and other debris have also caused stoppages in steam heating and plumbing systems many years after they were placed in service.

4-3. Ventilation.

a. General. Ventilation systems, unless stated otherwise herein, shall be in accordance with TM 5-810-1. Requirements for ventilation in arctic areas are basically the same as those in temperate climates. Ventilation quantity should conform to the applicable Army and Air Force criteria, and to the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). Mechanical ventilation is normally required for a portion of most occupied buildings. Quantities of fresh air supplied to the building should be minimized to avoid the cost of heating cold air. General experience has indicated that 5 cubic feet per minute (cfm) of fresh air per person is adequate for arctic ventilation. In heating and electrical plants that generate a large amount of heat, ventilation must be installed. Mechanical rooms containing furnaces must be equipped with a means of supplying sufficient combustion air, as tight construction may make air supply by infiltration impossible.

b. Special considerations for arctic and subarctic regions. In cold regions, many problems result from inadequate or improper ventilation systems design. Some items to consider are:

(1) *Freezing of heating coils in ventilating units.* Whenever flow of the heating medium within the

coil is modulated and coils are subjected to outside air, they become vulnerable to freezing. The following should therefore be considered.

(a) Antifreeze solutions. Circulating an antifreeze solution as the heat exchange medium can avoid freezing and the system can operate down to very low temperatures. Some difficulties, however, can be encountered. When coils carrying antifreeze solution pass below freezing air, the steam-to-antifreeze system heat exchanger can be damaged if the automatic steam control valve or the steam trap serving the heat exchanger fails. Manual bypass valves shall be installed around the control valves and trap assemblies to prevent heat exchanger freeze-ups. It is also possible to freeze up the entire building system from outside air blowing through the ventilating system when the circulating pump fails. This can also happen following a power outage, when the fan automatically resumes operation but the antifreeze solution pump does not. It is good practice to provide a low limit thermostat control in the air discharge from the coil to stop the fan and close the outside air dampers if air temperatures drop to about 35°F.

(b) Steam with face and bypass damper control. Coils using steam as the heating medium can be used to heat outside air. However, some precautions must be taken to avoid freezing the coil. A bypass should be incorporated around the heating coil to regulate downstream air temperatures. The steam supply to the coil must *not* be modulated when air temperature to the coil is below 32°F. So-called nonfreeze or steam distributing coils freeze easily under modulated steam supply. In addition, a vacuum breaker should be used on the steam supply to the coil to permit complete coil drainage when steam is shut off. A low-limit thermostat, set to actuate when any single foot of a 20-foot length of bulb is exposed to the set temperature, should be installed on the downstream side of the coil. This thermostat should shut off the fan and close the outside air damper when air leaving the coil is approaching freezing temperature (40°F.) Figure 4-1 shows a control diagram for a heating and ventilating unit with face and bypass control. Note the many controls required for satisfactory operation. Figure 4-2 shows one method in which steam could be used for preheating to prevent frost closure of filters. Again note the complex system. Condensate will leave the coil more readily if vertical nonfreeze coils are used. Steam traps with adequate capacity for the pressure differentials encountered under operation must be used. Traps should be installed not less than 12 inches, and preferably 18 inches, below the bottom of the coils to provide sufficient static head for condensate drainage. Condensate discharge from traps serving coils handling cold air is drained by gravity. The condensate piping from trap to condensate receiver should be properly sized and sloped to reduce back pressure and permit drainage. Much simpler operation can be obtained by using antifreeze instead of steam.

(c) Recirculating air. An effective ventilation system can be provided by reheating return air and mixing it with outside air. This system should be considered if less outside air is needed during winter than summer, and wherever coil freezing is to be avoided. A system that mixes return air with outside air before it goes to the heating coil could also be used. Freezing can occur, however, when cold air and return air do not mix properly before going through the heating coil. Air stratification can occur even after air passes through a centrifugal circulation fan. To reduce stratification, warm air should be brought in at the bottom, and cold air at the top, of the mixing box. Parallel blade mixing dampers should be set to maximize mixing action.

(d) Heat recovery system. Another effective ventilation system uses an air-to-air heat recovery coil or a run-around coil heat recovery system. These systems should be considered where ventilation requires use of 100 percent outside air and exhaust, for example, in maintenance shops or fuel storage areas. These systems extract heat from the exhaust air stream and transfer it to the cold incoming outside air stream. This transfer preheats the incoming outside air before it goes through the fan and heating coil assembly. These types of systems must be evaluated on a life cycle cost basis.

(2) *Outside air openings.* Ventilation requires outside air openings for both intake and exhaust. Improperly designed openings cause many problems in arctic areas, as high winds, blowing snow, and rain come through these openings. Hoods, when used, should be protected from falling ice or constructed to withstand damage from it.

(a) Exhaust openings. In low wind areas, exhaust openings of normal design will be adequate. The openings can be designed with stormproof louvers. If hoods are used, they should extend a minimum of 1 foot below the opening, and be sized to allow air passage without excessive flow loss. Even with fans operating, high winds can prevent air exit. Winds blowing against the building horizontally can move upward and into the hood. This can cause the exhaust fan to rotate backwards when not in operation, and the screens can clog with frost or snow, preventing the system from functioning as

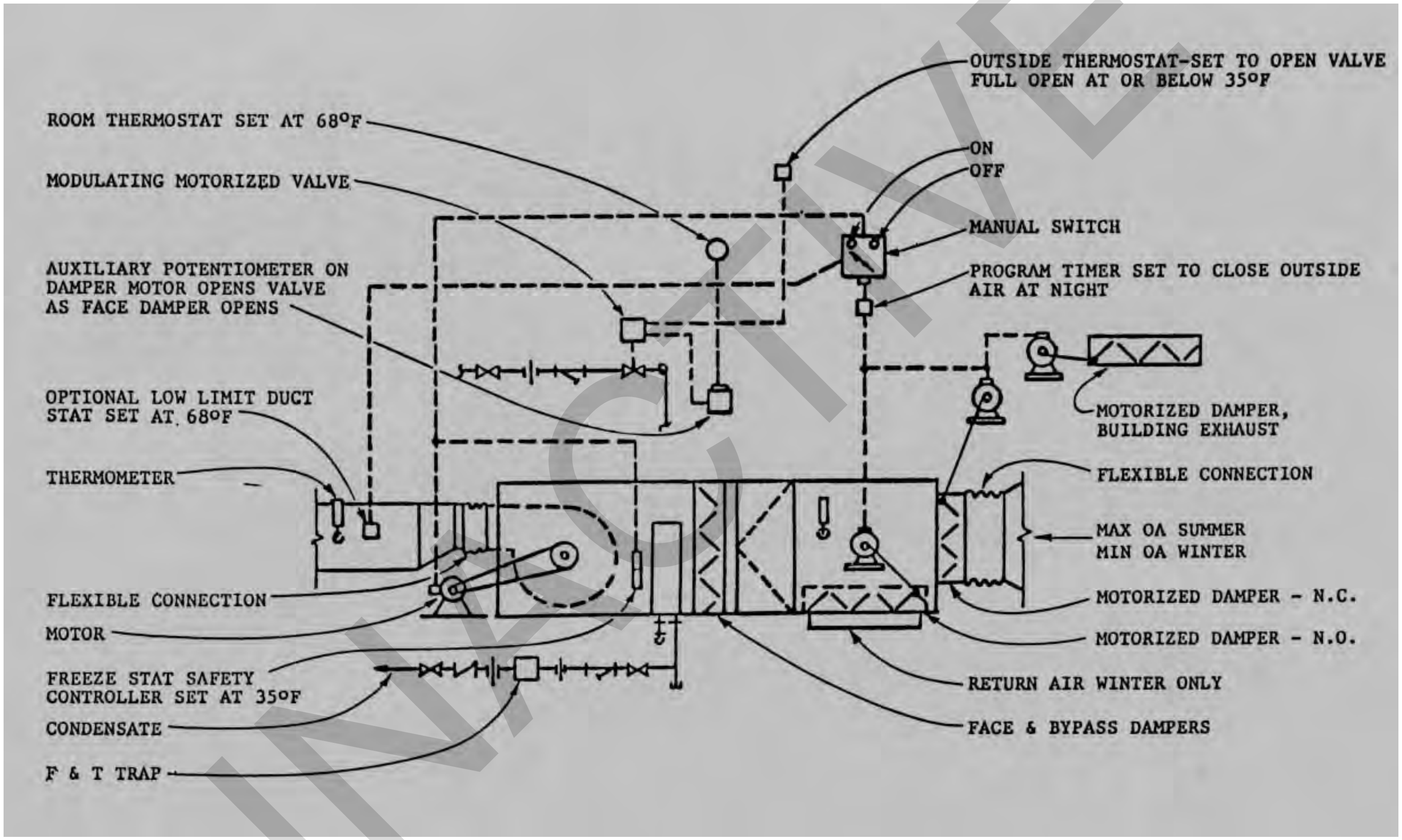


Figure 4-1. Heating and ventilation unit with face and bypass temperature control.

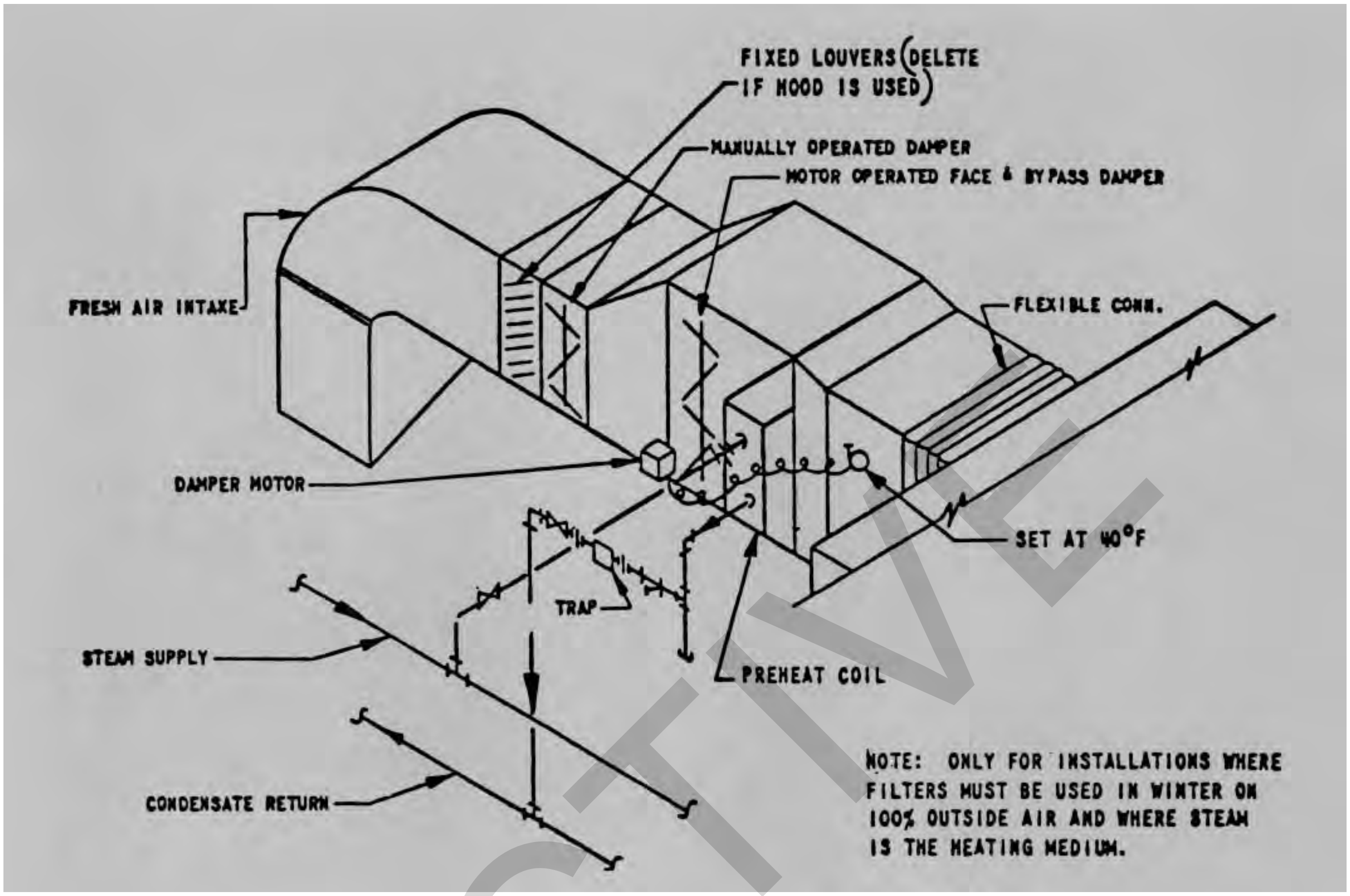


Figure 4-2. Steam preheat coil installation with damper control.

intended. During design, various locations, orientations, and structural features should be considered to minimize these problems. If possible, the exhaust should be located on the downwind side of the building. Exhaust openings can be installed through the roof or, where buildings are elevated on piles above grade, through the floor. Under-floor and wall exhausts should be directed horizontally to keep heated air from contacting pilings or the ground, and degrading the building foundation. Figure 4-3 illustrates what can happen when moist air condenses on the cold metal surfaces and accumulates into a frozen ice mass. Buildings should be slightly pressurized to reduce or eliminate draft through exhaust and other openings.

(b) Intake openings. Where no high winds occur, intakes can be installed directly to the outside with a stormproof louver. Hoods with a series of baffles should be used where there are high winds. The baffles are placed to cause the air path to change, which drops most of the snow, rain, and other foreign particles out of the air stream before it enters the intake duct. Refer to paragraph 2-9 in this manual for additional information and Figures 2-4 and 2-5 on hood design.

(c) Bird screens. To reduce frost closure, install bird screens only (no insect screens) on intake and exhaust openings. In temperatures below approximately 20°F, frost accumulation may close the insect screen openings very rapidly. At - 30°F, a 1/2-inch-square mesh bird screen has frozen closed in 6 hours. To reduce such closure, install a 1-inch-square mesh screen which can be removed during summer operations. Removable insect screens can be utilized during warm weather.

(3) *Frosting of filters in ventilation systems.* Icing and frost closure occur when saturated freezing air, usually below - 20°F, is brought in through the filter. The same problem can occur when fresh air intakes are too close to the exhaust openings and plumbing vents. Since fresh air intakes, including filter banks, are generally under negative pressure, care should be taken to seal openings and penetrations that permit more humid air to enter the intake duct or filter bank. Several methods of correction are possible. A preheat coil can be installed ahead of the filter to heat the air to 30 ° F, but that coil can plug with dirt, lint, and other material during normal summer operation. Best results can be obtained by

Figure 4-3. Ductwork installed in a cold attic.

removing the air filters completely during the winter months. Icing and thawing have caused throwaway-type filters to get wet, collapse, and jam the face and bypass dampers. Filter icing has completely choked off an opening in 8 to 10 hours of operation.

(4) Insulation of ducts and pipes handling cold air. Pipes and ducts subjected to cold air must be provided with insulation and sealed at the vapor retarder penetration. The ventilating unit should also be insulated up to the heating coil, or to a point where a suitable mixed air temperature is achieved. Insulation should be sufficiently thick to eliminate condensation on the room surface at the duct.

(5) Special ventilation requirements.

(a) Barracks ventilation. Living quarters are normally provided with fresh air and ideally the relative humidity should be between 30 and 40 percent. In cold weather, the outside air tends to be very dry and cold. The use of outside air for ventilation results in the loss of heat and humidity, both of which must be replaced to maintain healthy and comfortable living spaces. In very cold weather humidifiers may be required to maintain humidity at acceptable levels. On the other hand, troops hanging large quantities of wet clothes tend to provide temporary and localized areas of very high humidity which can cause condensation problems.

(b) Shower room ventilation. Exhaust fans should be installed to remove the moisture from shower or bath areas. Exhaust fans should not be placed within individual shower stalls as this causes cold drafts: the best location is just outside the shower room door. In gang showers, ventilation openings can be in the shower room, but should be near the exit.

(6) Dining hall/kitchen exhaust systems. Exhaust fans should not be installed on the roof or the exterior of the building, or immediately above the grease filters where the ambient temperatures may be too extreme for the electric motors. Also, grease which passes the filters is deposited within and on the exhaust fan motor and belt drive. It is difficult to clean all spaces within the hood and the discharge ducts. Grease can accumulate and drip down through the seams and onto the ranges. Properly designed stainless steel ducts should be used. In all kitchen hood designs, provide openings to allow easy cleaning of discharge ducts. Fans should be kept readily accessible for frequent cleaning and maintenance by installing them inside the building, with only the fan rotor exposed to grease accumulation. Hood designs should minimize grease collection features and facilitate cleaning. Hoods on systems with intermittent fan operation should be designed so that cold air cannot enter the duct system and cause condensation on the exposed surfaces. Package kitchen hood, fan, grease extraction, and heat recovery units should be investigated from the standpoint of energy conservation savings. This type of system installation may be feasible based on the facility size and operation time. Package systems will usually require a heated enclosure (penthouse) to prevent freeze-up problems with the heat recovery and during grease wash-down cycle.

(7) Exterior fans. When using or specifying exterior fans, be sure they will operate in the cold ambient temperatures which will occur at the individual site. If specified fans and motors cannot operate in the ambient temperature, they should be installed on the interior of the building.

4-4. Central heating and electric power plants.

a. Central plants. Where several facilities are built together or in the same general area, consideration should be given to heating these buildings or composite camps from a central source. Utility design shall be in accordance with TM 5-852-5/AFR 88-19 Vol. 5, although the need for a central distribution system in arctic areas is stressed in this manual. Consideration should be given to installing a central system for several reasons: (1) because most facilities are remote, expert maintenance personnel may not be available at the site; (2) consolidation of facilities reduces maintenance; (3) necessary parts and supplies are in short availability; (4) there are fewer fire hazards in a central plant; and (5) maintaining supply in one fuel tank versus separate fuel tanks minimizes the number of personnel exposed to the cold weather. If a central heating plant has trouble, however, the whole base is in trouble. Therefore, redundancy of vulnerable systems can be important, but complete backup is not essential.

b. Heat recovery systems. In general, arctic facilities are in isolated locations. Since supplies are transported to most of these sites by airplane or annual supply ships, economy dictates reduced fuel consumption. As pointed out previously, additional insulation can cut fuel needs to a certain degree. Since electric power is generated at most sites by diesel generating plants, consideration should be given to the feasibility of using waste heat recovery equipment. Waste heat from diesel generators can be used for space heating, melting snow, or domestic hot water heating. Low pressure steam or hot water can be generated by waste heat recovery equipment. Engine jacket water can be used directly in building heating systems, or indirectly, through heat exchangers which heat a secondary liquid used in the building heating system. The indirect method is preferred because this: eliminates interference with engine jacket water flow; achieves better temperature control; and eliminates thermal shock to the engine. Heat recovery from the engine jacket water and exhaust gases can increase the diesel engine thermal efficiency by 30 to 60 percent. In remote areas, fuel costs (including shipment) can be extremely high, making maximum utilization of heat recovery systems important.

4-5. Humidity.

a. General. In the arctic, control of relative humidity for occupied spaces is important. The following discussion of the effects of high and low humidities illustrates the need for effective control.

b. Low humidity. Cold air contains very small amounts of moisture. For example, if outside air at - 29°F and 100 percent saturation is heated to 70°F, the resultant relative humidity would be approximately 1 percent. The effects of low humidity are:

(1) *Effects on human comfort.* When the air is dry, moisture evaporates more readily from skin and makes people feel chilly even with inside temperatures of 75 ° F or more. Dry air removes moisture from the nasal passages and throat, causing an uncomfortably tight irritated feeling. Doctors state that

relative humidity in the 35 to 50 percent range reduces susceptibility to colds and other respiratory disorders. Hospital studies have shown that bacteria carried by personnel, including certain resistant strains, thrive in dry air with less than 35 percent relative humidity and in moist air with greater than 65 percent relative humidity. These same bacteria languish and die in the middle zone. In addition, moisture evaporation from the body causes the blood to thicken and reduces effective circulation. These problems can be eliminated by adding moisture to the air to maintain a relative humidity between 30 and 40 percent. Hospitals, computer rooms and other facilities that require or generate higher relative humidities should have moisture resistant designs.

(2) Static electricity. Although static electricity is being generated constantly, it does not become a problem unless it has a chance to accumulate. When relative humidity is sufficiently high, an invisible film of moisture forms on room surfaces. In the presence of normal impurities, this moisture film becomes a conductor and carries static electricity harmlessly away before it can become a hazard. With low relative humidities, however, static electricity can pose fire and explosion hazards. Control of humidity and finish materials should be designed to reduce static electricity.

(3) Deterioration of materials and equipment. Dryness causes brittleness and cracking of many materials including rugs, paper, and wood, which increases the combustion rate of building materials and the deterioration rate of furnishings. Dryness causes dust particles to break loose and enter the air stream.

c. High humidity. Although higher relative humidities are extremely desirable in cold climates, excessive amounts of humidity can cause serious damage. The maximum humidity to which areas should be maintained depends upon the dew point of the coldest room surface. In turn, the coldest surface depends upon the outside temperature and the type of construction. For instance, higher humidities can be maintained by using triple-glazed windows rather than double glass windows.

(1) Condensation. Condensation can cause structural damage when excessive humidities are maintained within the building, or within the building walls or ceilings. Condensation will occur on a cold surface whenever the temperature falls below the dew point of the air and will appear first on windows, since they will be first to reach the dew point temperature. Condensation within building walls can be effectively reduced or eliminated by a vapor retarder.

(2) Control of relative humidity. To maintain a reasonably controlled atmosphere, the maximum relative humidity should not exceed the amount which causes condensation. Table 2-1 shows relative humidities at which condensation will appear on different types of windows at a room temperature of 70°F. The table was developed from basic data in the ASHRAE Handbook of Fundamentals. Higher limits are possible if constant circulation forced air induction units are used underneath windows.

4-6. Plumbing.

a. General. Plumbing design, unless stated differently herein, shall be in accordance with TM 5-810-5/AFM 88-8, chapter 4, and the National Standard Plumbing Code.

b. Special considerations for arctic areas. Where adequate water supplies are available and normal sewage systems can be installed, interior plumbing facilities vary little from those used in temperate climates. Water, however, is not always readily available in arctic areas, and sewage treatment and disposal is difficult in permafrost areas. For remote buildings and those infrequently occupied, tank type toilets with marine handpumps, floor mounted chemical toilets, incinerator type toilets, composting toilets, and recirculation type toilets should be considered. Electrical incinerating toilets installed in conjunction with gray water-black water systems have been particularly successful at some remote sites on Alaska's North Slope. In this type of system, the black water (human waste) is separated from the gray water (laundry, shower, etc.). Each type of waste water is separately collected, conveyed, and treated. Under "combined" systems, all wastes can be piped into a sewage storage tank for ultimate conveyance to treatment and/or disposal facilities. Figure 4-4 shows an isometric piping diagram of a typical sewage system. Figure 4-5 is a typical fresh water flow diagram. Collecting small waste flows and discharging them in slugs, rather than allowing the sewage to trickle by gravity and glaciate the lines, should be considered. A water storage tank can also be installed to supply water for the domestic plumbing and fire protection systems. The water storage tank should be heated to prevent freezing. Figure 4-6 is a fire protection schematic. Figure 4-7 is a water tank heating and circulation system schematic. Water should be piped to individual buildings by the most economical method. A utilidor system may be used to distribute water along with heating and sewer lines. Utilidor design shall be in accordance with TM 5-852-5/AFR 88-19, chapter 5. An analysis of site operating capabilities, reliability of the water supply system, and fire protection requirements should be used to determine the size and type of storage tanks used for water systems. One method used to eliminate long exterior water supply lines is to drill a water well either directly in the building to be served or immediately adjacent to it.

(1) *Underfloor piping.* Buildings in permafrost areas are usually elevated above ground on a piling system. The area under the floor, therefore, is exposed to the cold arctic air and underfloor piping must be protected from freezing. This protection can be accomplished in several ways.

(a) The utility lines underneath the building can be placed in insulated enclosures and the pipes protected by heat to prevent freezing. See Figure 4-8 for a discussion on the advantages and disadvantages of heat tracing methods. Heat can be applied by four methods:

First method: Heat cables made of a nonmetallic sheath can be wrapped spirally around the pipe between it and the insulation. This technique provides uniform heating regardless of the quantity of liquid within the pipe. Pipe insulation must be removed and reinstalled to replace the heating element.

Second method: A commonly used method is installation of a mineral insulated (MI)-type, copper jacketed heat cable immersed in the liquid inside the pipe. Proper installation of the MI cable is critical to provide long service life. Improperly installed MI cables have failed after being in service 1 to 2 years, whereas properly installed cables last indefinitely. Proper installation involves the maximum use of straight pipe runs with minimum cable bending. The cable must be factory fabricated to the proper

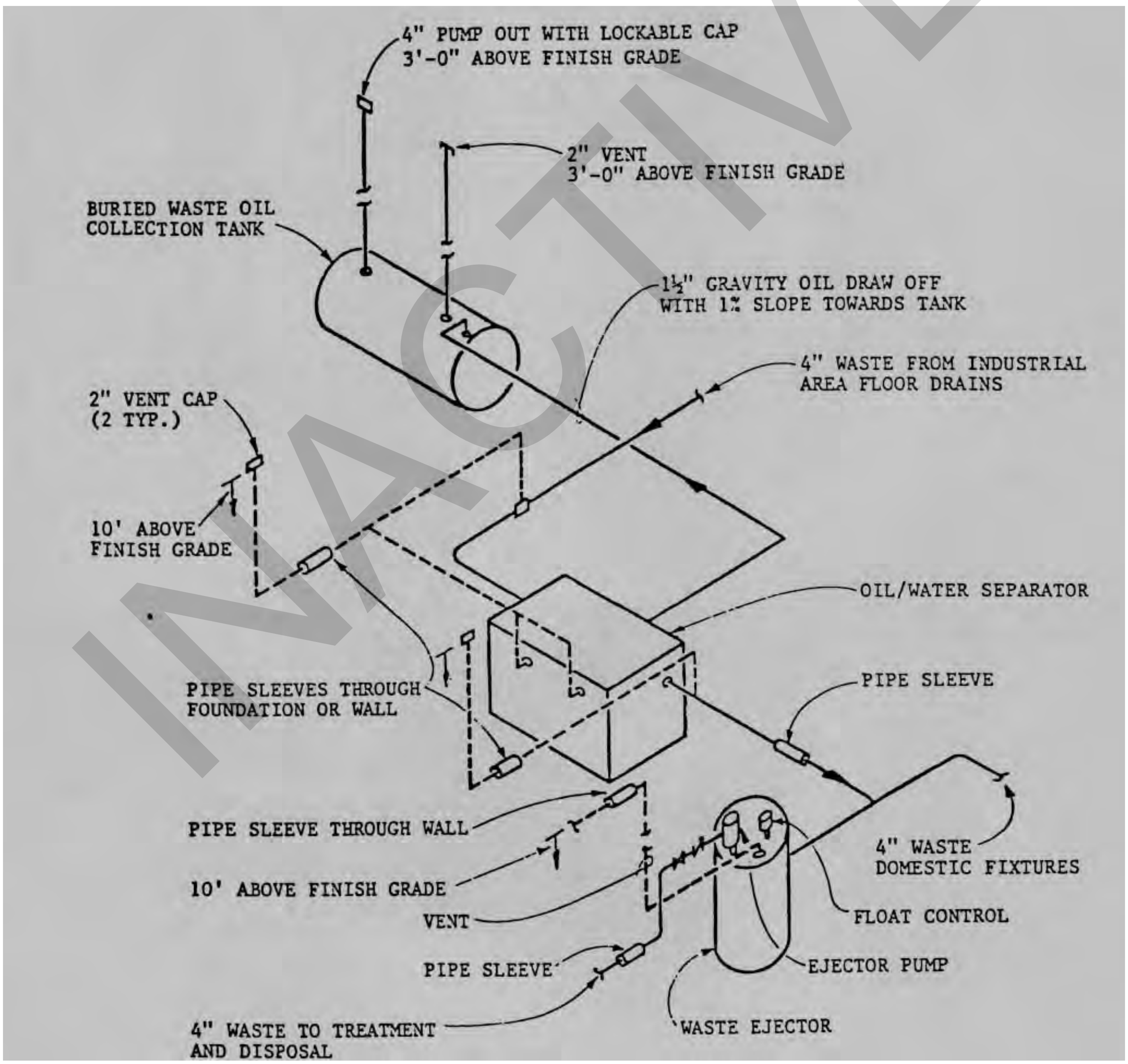


Figure 4-4. Waste water and oil separator piping isometric.

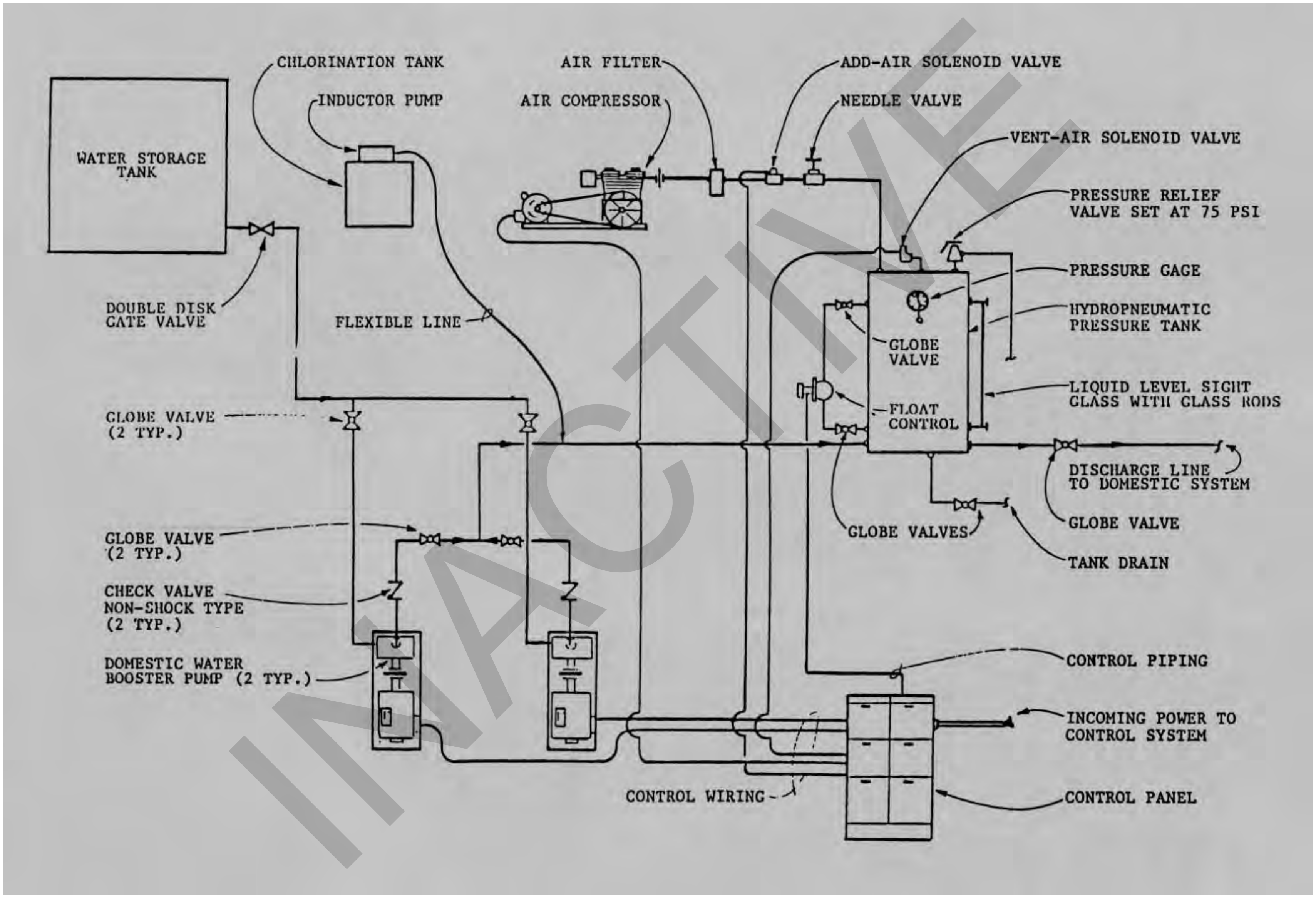


Figure 4-5. Domestic hydropneumatic water system flow diagram

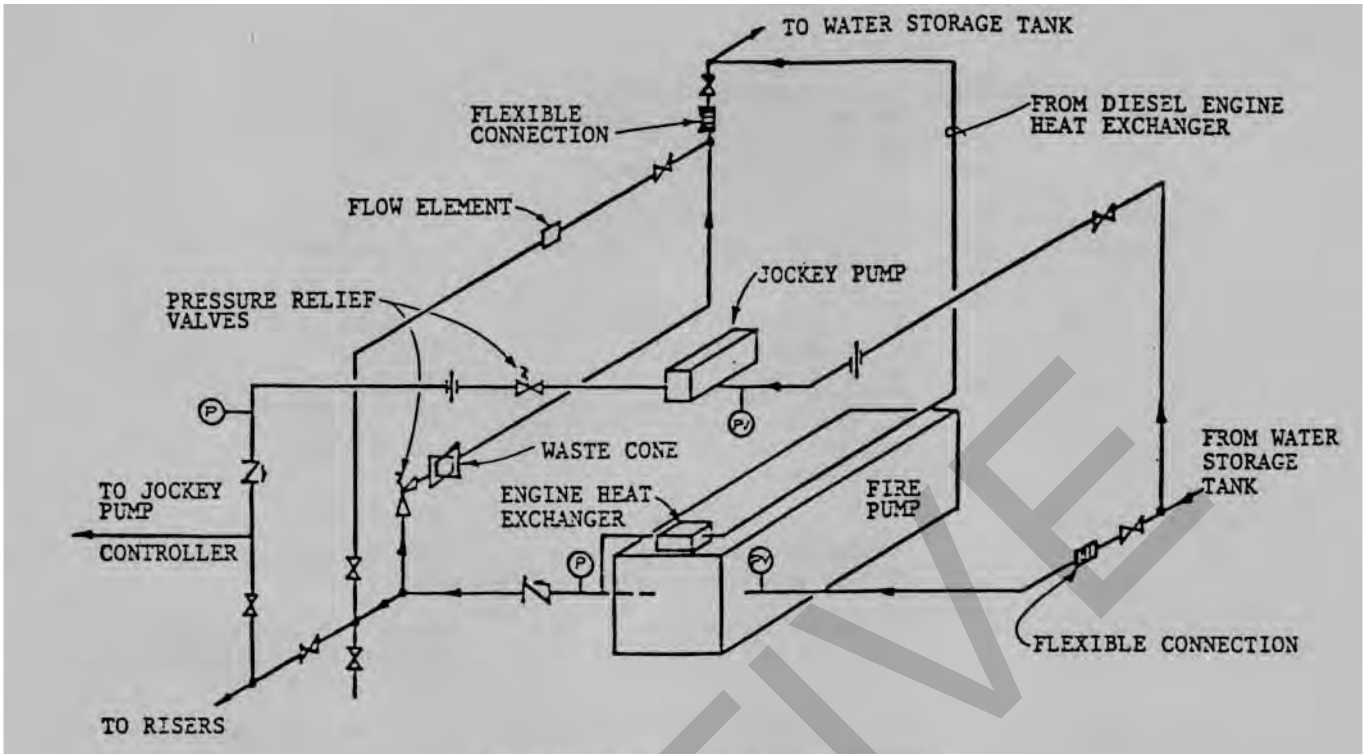


Figure 4-6. Fire protection system schematic.

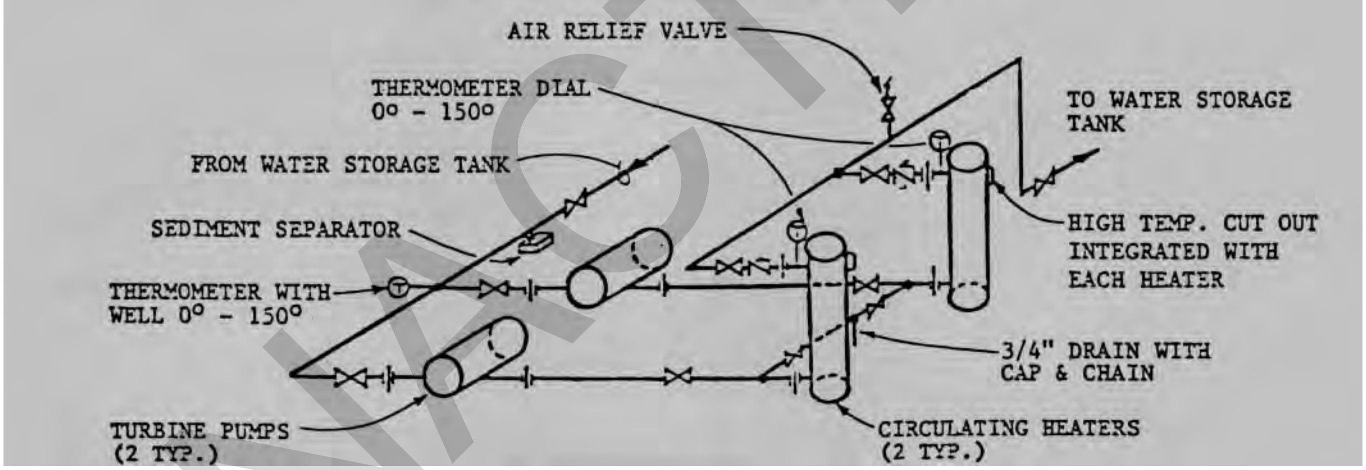


Figure 4-7. Water tank heating aria circulation system schematic.

length because field fabrication and assembly can easily damage the cable or its terminations. The cable is inserted into a pipe run at a tee or wye fitting with a compression gland connector. Electrical connections can be made external to the pipe in a dry junction box. Temperature is monitored with either an immersion thermostat or a thermostat bulb installed under the insulation against the pipe. This method is appropriate for water lines but should be avoided in sewage lines because of its tendency to cause clogs and blockages.

Third method: Also commonly used is installation of heat cables in small diameter conduits attached directly to, or in close proximity to, the carrier pipe and under the insulation. This method has been used successfully with both water and sewer lines. The heat cable lies loose in the conduit, allowing easy installation and removal. Steam, hot water, or a heated glycol solution may be substituted in lieu of electric heat cables.

Fourth method: The fourth method of freeze prevention is to preheat the liquid before it enters the pipeline. This method is suitable for both water and sewer lines. Circulation heaters, immersion heaters, tank type water heaters, or recirculating coil (electric or glycol solution) type heaters may be used, depending on the fluid and system type.

A. FLUIDS	ADVANTAGES	DISAINANTAMS
1. Heat transfer fluids	Precise temperature control.	
a. Glycols	Can retrofit a steam system to use aqueous glycol solutions. represses freezing point of water.	Needs *a* circulating system.
b. Heat process fluids (organics)	Precise temperature control. Wide temperature range. Law freezing temperatures.	Relatively expensive. Needs *a* circulating system.
2. Steam	Can take advantage of waste steam. Rugged. No danger of arcing in explosive environments. High heat transfer rates are possible (can provide rapid melt-out). Does not need a reliable electric power source.	Non-uniform distribution of beat. Expensive to install and maintain. Temperature control is not precise. Not always practical above *200°(400°F)* due to high vapor pressures involved.
B. ELECTRICITY	Precise temperature control. Various temperature control options	Needs a reliable electric power source.
1. Resistance	Relatively inexpensive.	Exposure to high temperatures and/or moisture will damage sate insulation and cables.
a. Series	Rugged. Capable of high temperatures.	Cannot be field-cut. One break in the cable causes an open circuit. Will burn out if crossed over itself.
b. Parallel	Can be field-cut. If a resistor fails, beating circuit is still maintained.	Relatively fragile.
1) Continuous and zonal		Will burn out if crossed over itself.
2) Self-limiting	Will not burn out if crossed over itself. Responsive to local heat demands.	Somewhat more expensive than other forms of parallel beat tape.
2. Skin effect	Simple components (i.e. easy to construct and repair). Rugged. Needs relatively fed energy inputs. *Can* be part of prefabricated insulated pipe bundle.	Impractical for applications less than *150 m (500* ft) long.
3. Impedence	High heat transfer rates are possible. Can be easily retrofitted on existing metal pipeline systems. High temperatures are possible. Beating element (pipeline) cannot burn out.	Neel to insulate pipe surface in order to avoid electrical hazard to personnel. May need to electrically isolate flanges and pipeline from support structure. Requires specific design for each application.
4. Inductance	High temperatures are possible. High heat transfer rates are possible. Heating element cannot burn out.	Very expensive. Irregularities such as valves and flanges difficult to design for. Requires specific design for each application.

Figure 4-8. Advantages and disadvantages of available beat tracing methods.*

*An Introduction to Heat Tracing, by Karen Henry, Cold Regions Technical Digest No. 85-2, August 1985.

*Figure 4-8. Advantages and disadvantages of available heat tracing methods. **

*An Introduction to Heat Tracing, by Karen Henry, Cold Regions Technical Digest No. 85-2, August 1985.

(b) A special enclosed heated crawl space immediately below the ground floor elevation may be provided in arctic building design. Its floor can be constructed with removable insulated panels. All piping, including hot and cold water, heating lines, and waste piping, can be run in this space. The area must be tightly sealed to avoid air infiltration. This system has several benefits: piping is readily accessible for maintenance; it can be replaced easily; and the space provides a buffer zone to warm the floor above.

(2) *Disposal of roof and floor drainage.* Drainage from roof and floor drains should not be piped to the sewage system since this would increase sewage treatment requirements. This drainage must be disposed of separately. As discussed in (b) below, an exception is allowed. Although no perfect disposal method has been developed for all situations, several usable systems are presented below.

(a) Dry wells are underground manmade cavities below the seasonal frost level. They can be constructed by burying concrete pipes, concrete rings, or pockets of large stones or gravel capable of holding large volumes of water. Dry well use is limited to subarctic areas with free draining soil free of permafrost. If wells or connecting drains freeze, they will back up water toward the roof and create leaks within the building. Silt, leaves, and other foreign materials deposited on roofs are carried through the strainers into the roof drain system. This material seals off dry wells so that no leaching occurs after a few years. Oil can also seal off drainage in dry wells. Dry wells which become inoperative must then be replaced with new wells.

(b) Roof drain lines which discharge through an exterior wall onto a splash block cause glaciation. When this glaciation occurs on paved vehicular or aircraft traffic areas, one solution is to use a concrete trench with a grate cover to move water and glaciation away from the area. Frequently the exterior wall outlets freeze solid, backing up water in the rain leader. For this reason, an overflow line from the rain leader is connected to the sanitary sewer inside the building to allow the back up water to escape. Usually cyclic freezing occurs in the outlet during breakup conditions. Overflow drains are not included in the building waste water fixtures unit calculations.

(c) Floor or trench drains in shops collect considerable mud, gravel, sticks, and vegetation brought in by tracked and wheeled vehicles. Baskets, strainers, and sand and oil traps must be provided to keep these drains operational. Drains, traps, and underfloor piping are difficult and costly to install and maintain, but floor and trench drains are generally essential to carry away melted snow carried in by vehicles.

(3) *Roof drains.* Exterior roof drains may be damaged by snow and ice accumulation. When required, roof drains should be a minimum 4 inches in diameter to reduce probability of closure by ice and frost. Interior roof drains should be provided or roof drains should be eliminated and the roofs sloped to the eaves.

(4) *Roof vents.* In subarctic regions, vent pipes should be increased one pipe size to prevent complete frost closure. The minimum vent size should be 3 inches as required by TM 5-810-5. In true arctic areas, vents should be insulated along their full length to their termination above the roof.

(5) *Installation of plumbing vents.* In high snowfall areas, plumbing vents on gable-type metal roofs with cold attics should be installed near the roof ridge or should be reinforced to withstand snow and ice loads. Figure 4-9 shows snow accumulation on a roof of this type in a subarctic area. Snow or ice slides may break off vents and other projections.

(6) *Heating grease and oil traps.* If the water in grease and oil traps freezes, the traps will become inoperative. Heating is required to keep these traps operational. These traps may be installed inside the building to prevent freezing.

(7) *Use of lightweight material.* Lightweight materials should be considered when air transportation to the site is required. Materials to reduce installation costs, such as copper or plastic piping, should also be considered. Current guide specifications should be checked for restrictions on the use of plastic pipe which must be able to withstand extremely low temperatures. There must be adequate design considerations for plastic's higher coefficient of expansion. Pressed steel or lightweight fiberglass plumbing fixtures are available and are more suitable for transport by air than the heavier cast iron fixtures. Such materials, however, must meet minimum operational requirements.

(8) *Garbage disposals.* At small, remote installations where sewage treatment and disposal are particularly difficult, garbage disposals are generally not installed. If disposals are installed, grease removal must be considered. Grease may congeal and clog cold sewer lines, and may also create operation and maintenance problems at the sewage treatment facility. Oversized exterior grease traps have been used to remove grease, but frequent cleaning is required. The normal foodstuffs run through a

garbage disposal also have a tendency to reduce the life of a septic system drain field or leach pit.

(9) *Utilidor entrances to buildings.* Where high pressure steam lines enter a building through a utilidor, a utilidor cutoff (separation) wall must be provided to assure that steam leaking from the main lines does not enter the building. Cutoff walls are generally cast concrete, and the piping passes through calked wall sleeves.

4-7. Refrigeration.

a. General. Refrigeration design for cold storage should be in accordance with TM 5-810-3/AFM 88-8, chapter 2, and refrigeration design for air conditioning systems should be in accordance with TM 5-810-1, except as modified herein.

b. Special considerations. Standard refrigeration systems can be used very effectively if a few precautionary procedures are followed.

(1) *Remote air condensers.* Dissipating heat from refrigeration systems is a serious problem in arctic environments. Water condensers normally are precluded, since water is not always available and the waste water disposal is difficult. Air condensers are used but their operation is limited unless controls are provided for low ambient temperatures. The head pressures on air cooled condensers must be kept from dropping so low that the thermostatic expansion valve ceases to feed refrigerant. Crankcase heaters, pump-down control, and liquid receivers are often required for cold weather operation. Many methods can be used to control system head pressure. Some of these methods are discussed in the following paragraphs.

(a) Shutter control. Shutters which control air flow across the condenser coils will only control the system down to 20°F to 30°F. Consequently, shutters are not satisfactory for most winter operations and should not be used.

(b) Pressure type controls. Several standard methods can successfully control head pressure in a refrigeration system. One method which controls fan operation with a pressure sensor is satisfactory down to approximately 10°F. Another method utilizes a back pressure valve which bypasses and recirculates hot gas into the liquid line. This method is by far the most successful and can effectively operate down to 0°F.

(c) Enclosures with recirculating dampers. For temperatures below 0°F, a condenser enclosure must be provided so that the condenser can operate within a closed system. The temperature within the enclosure is then controlled by operation of the bypass exhaust air and fresh air dampers. Heat must be provided within the enclosure to control minimum temperatures during the off cycles. The combination of enclosure and recirculating damper has proven to be the most successful head pressure control system.

(2) *Outside air for air conditioning.* Air conditioning is frequently required in the subarctic and arctic regions to cool electronic equipment or provide climate control for scientific operations. Adequate cooling and temperature control can usually be achieved by using one of the following systems.

(a) Mixing outside air and return air. Cool outside air can be mixed with return air to obtain the desired cooling temperature or can be heated to the desired temperature with a heating coil. When temperatures exceed approximately 55°F, the system must sometimes be supplemented with mechanical refrigeration. An outside thermostat can be used to change over automatically from mechanical refrigeration to outside air cooling. One of the drawbacks to using outside air for cooling computer room equipment is that the air must be free of dust. Large air filter banks are used to filter the incoming outside air. An efficiency of 99 percent plus with a 5 micron particle size is usually required.

(b) Package air conditioning units with glycols. A package air conditioning system consists of an air conditioning unit with a mechanical refrigeration unit, an economy cycle glycol unit, and a glycol drycooler. The drycooler is located outside the structure. A single sensing control element to automatically control the temperature of both the freecooling coil and the refrigeration cycle shall be used to provide proper operation sequence. The control system will direct cool glycol solution from the drycooler to the freecooling coil as long as the glycol solution from the drycooler is providing adequate cooling capacity. The compressor operation will only switch on when the freecooling coil cannot handle the total cooling requirements. This type of system works well in arctic climates because of the cold outside temperatures. Most package systems of this type can operate up to 10 or 11 months of the year.

(3) *Cooling towers.* Water from cooling towers used in arctic climates must be drained into a sump during cold weather. The tower itself generally is not heated.

4-8. Miscellaneous. The following subtopics relate to many types of systems and are grouped here for simplification purposes.

a. Economical insulation thickness. The cost of supplying fuel to arctic sites is extremely high when it has to be airlifted. For this reason, a special economic analysis needs to be made to determine the proper insulation thickness based on a balance between reduced fuel costs and increased construction costs. The optimum U-value should be determined from a life cycle cost analysis that includes a consideration of all initial, operational, and energy costs. For buildings where heating loads will be met predominantly by space heating rather than internal gains, the following procedure is recommended to determine the most economical insulation thickness. This procedure is based on CRREL Report 82-27. Buildings with significant internal gains, the potential for using heat exchangers, or complex heating and ventilation requirements should be subject to a more sophisticated analysis than that outlined below.

(1) Calculate a climate-heating cost parameter (CHC) which will pertain to any building sharing the same site and heating costs by using the equation 4-1:

$$CHC = (24)\ (5/6)\ (HDD)\ ((P/B)\ FC \quad (P/A)\ OMC))/FE \qquad \text{(eq 4-1)}$$

where: 24 = factor converting days to hours
5/6 = factor accounting for internal heat gain (alter appropriately)
HDD = heating degree-days (65°F base)
P/B = present worth factor* for escalating fuel costs
FC = fuel cost ($/Btu)
P/A = present worth factor for uniform series (O&M costs)
OMC = plant operation and maintenance costs
FE = combined efficiency of plant and distribution system.

**Note:* The use of present worth factors is found in National Bureau of Standards (NBS) Handbook 135 and cited in Defense Energy Program Policy Memorandum 85-2.

(2) Choose a minimum acceptable R-value (Ri) and per square foot construction cost (CCi) for each construction component (e.g., walls, roofs, exposed floors).

(3) Establish the higher R-values (Rf) and per square foot construction cost (CCf) for each alternative improvement to the minimum identified in paragraph (2).

(4) Calculate the savings-to-investment ratio (SIR) for each alternative improvement using the equation 4-2:

$$SIR = (CHC)\frac{(1/Ri - 1/Rf)}{(CCi - CCf)} \qquad \text{(eq 4-2)}$$

(5) Choose the option with the highest SIR.

b. Low temperature lubricants. Fans or other moving equipment mounted on a building's exterior or located within unheated portions of the building should be capable of operating at the lowest ambient temperature. The lowest operating temperatures for the piece of equipment should be stated in the specifications. Special low temperature lubricants must be used. Manufacturers should be required to guarantee their equipment under the extreme weather conditions expected at the site.

c. Air compressors and their operation. The following suggestions for air compressor system operation and design apply to both instrument air and compressed air in shops and hangars. Water vapor, if not removed, can freeze and cause the system to quit functioning. Pneumatic control systems require dry air to function properly. Exterior air should be the air source for large compressors. The cold outdoor air contains less moisture, and therefore less water must be removed from the system. For example, heated room air at 70°F and 10 percent relative humidity has .0015 pounds of moisture per pound of dry air, while outside air at - 20°F and 100 percent relative humidity has .00025 pounds of moisture per pound of dry air. At these conditions, the room air has six times as much moisture as the outside air.

CHAPTER 5

ELECTRICAL

5-1. General. Electrical system design for buildings located in arctic and subarctic regions require some special considerations. The following items require special treatment.

5-2. Grounding. It is very difficult to obtain an effective electrical ground in arctic and subarctic regions because of soil and climatic conditions. The chance of finding and developing a low resistance grounding site decreases greatly with movement towards polar regions from the zone of seasonal frost, to discontinuous and then into continuous permafrost. Large seasonal variations in the resistance to ground can be expected in areas of frozen ground. Grounding may not be difficult during summer months, but will likely become a problem during the winter with seasonal freezing of the surface layer. Poor grounding results from an arid climate, permafrost, and glacial till or other well drained soils. The normal practice is to ground at the service entrance to the metallic water system piping. If satisfactory metallic water piping is not available, a driven ground rod with a maximum allowable resistance of 25 ohms is required. If this 25-ohm requirement is not met with one rod, up to three additional rods spaced a minimum of 10 feet apart should be driven to bring the resistance down. Ground resistance can also be reduced by increasing the length of the ground rod. If these measures fail to reduce the ground resistance sufficiently, the soil around the rod may be chemically treated. Chemical treatment is a temporary measure and must be repeated periodically, with the time between treatments depending on the rate of leaching by ground water. An effective ground cannot be achieved if the ground electrode is completely enclosed in frozen soil. If a low resistance ground is vital in areas where the soil is subject to freezing to great depths (8 feet or more), other methods of reducing ground resistance, such as construction of ground wells or counterpoises are necessary. Natural thaw zones beneath lakes and streams, the ocean, steel reinforcing bars, or metal well casings can provide good grounding alternatives. In the final analysis, it may be impossible to achieve an adequate ground because of ice and snow cover. In that case, electrical hazards may be minimized by obtaining surface area contact with the earth, or bonding all electrical equipment. Using either method, extra safety precautions should be taken.

5-3. Lighting. The design of interior illumination for any heated building in arctic and subarctic regions is the same as for other regions. In general, lighting intensities should be as recommended in the Illuminating Engineering Society (IES) Lighting Handbook, subject to modifications and clarifications specified in AFM 88-15. The type of lighting must be coordinated with the architectural design to achieve the best psychological effect, as noted in Chapter 2 of this manual. Where low ambient temperatures will normally be encountered in interior and exterior areas, fluorescent or high intensity discharge type lighting fixtures with low temperature ballasts should be used. On an economical basis, selection will be made by comparing initial installation versus relamping maintenance costs. In design analyses, lighting loads will be used with 100 percent load factor.

5-4. Wiring methods. Except for the special requirements discussed below, wiring will be installed in accordance with guide specifications. Conduit runs will be installed to provide sufficient water drainage. Where fittings are installed on surface mounted raceways on exposed walls or floors, the roofs of heated buildings, or in areas exterior to heated buildings, they will be of cast metal. Where outlet boxes are installed flush with the exposed exterior surfaces of heated buildings, they may be of sheet metal with gasketed cast metal covers. Exterior wiring will consist of insulated conductors installed in zinc-coated rigid steel conduits.

5-5. Vapor retarder penetrations. Frost buildup from moisture condensation on the heated side of roofs, exterior walls, and floors must be prevented to the maximum practicable extent wherever electrical wiring penetrates the vapor retarders of these surfaces. The following steps must be taken:

a. Conduits will be sealed, including interior voids between conductors and cables, and exterior voids between raceways and building components.

b. Flush mounted boxes will be sealed for the full width and depth of voids between boxes and building components.

c. Back-to-back installation of boxes and equipment will not be permitted in roofs, exterior walls, or floors.

d. On the warm side of boxes, vapor retarder and insulation will be compressed as required without fractures.

e. Nonhardening material will be used for sealing raceways and boxes so that it can be moved without damaging electrical wiring, raceways, boxes, etc.

f Vapor retarder will be sealed to boxes and equipment wherever practicable.

g. Boxes and raceways will be installed on the warm side of vapor retarder where practicable.

5-6. Electrical insulation. The insulation on electric wires will be of cross-linked polyethylene, or silicone rubber, or other moisture-resistant type that has been proven satisfactory for arctic low-temperature use.

5-7. Switches. Some switches are affected by the ambient temperature. Mercury switches should not be specified for use where the temperature drops to - 40°F, as mercury solidifies at this temperature, and switches will not function.

5-8. Miscellaneous items.

a. Thermally operated protective devices. A thermally operated protective device is located such that the ambient temperature is approximately the same for the device and the conductor; therefore, low temperatures are no problem. If the protective device is located outside of a heated building and the conductors are inside, however, the temperature differential must be considered. Ambient compensated circuit breakers which are effective to a temperature of about - 20 ° F are available. In unheated areas, enclosures for switches and circuit breakers should be gasketed and weatherproofed to keep the devices moisture free.

b. Service entrance. Underground service will be provided wherever practicable. Where required, an overhead service entrance should be located so that it will not be subject to damage from ice forming on eaves. A service entrance should be installed in the gable end of the building or on the roof by bringing a conduit up through the roof overhang and mounting a weatherhead on top. The gable location is preferred because of flashing and support problems introduced by the roof penetration.

c. Transformer vaults. In some subarctic areas, corrosive conditions resulting from wind driven rain, snow, and salt spray are so severe that it is desirable to provide vault space inside buildings for transformers and associated service equipment.

CHAPTER 6

FIRE PREVENTION AND PROTECTION

6-1. General. The need for fire prevention and protection is generally more critical in polar regions than in temperate climates. Each site must be evaluated in terms of the following parameters when determining the extent of required fire protection facilities.

a. Isolation. Fire hazards must be especially guarded against at isolated sites because the loss of facilities and materials during extreme low temperatures constitutes a major threat to survival. The fire hazard at each site should be evaluated in terms of distance to other facilities, and the availability and reliability of alternate forms of transportation.

b. Climate. Each building should be evaluated in terms of the effects of local winds and temperatures on fire fighting capability and on the survivors of a major fire.

(1) Wind. Strong winds can occur for extended periods, making fires spread rapidly and control difficult.

(2) Cold. The fire itself will burn more rapidly at colder temperatures for two reasons: the weight of a unit volume of air will increase with a decrease in temperature, making more oxygen available to the fire at low temperatures; and the increased thermal gradient between the fire and surrounding air produces an updraft or "fire storm." Wind velocities at the edge of a large fire can reach 100 miles per hour. Cold also hampers fire fighting because of decreased personnel efficiency, and the increased possibility that fire fighting water may be frozen.

6-2. Fire prevention. Information and criteria on noncombustible and fire retardant materials are available in AFM 88-15, TM 5-812-1, the National Fire Codes, the Uniform Building Code, and the National Building Code. Fire ratings for various materials are given in the Underwriters' Building Materials List. These materials can do much to prevent and retard fires and their use should be given special consideration in arctic regions. The use of many of the common noncombustible building materials may become prohibitive in isolated locations, however, because of their weight. Fire retardant materials should be considered to obtain the maximum degree of protection where noncombustible materials cannot be utilized because of economic considerations. Fire retardant materials should be used sparingly, however, since the adverse climate causes these materials to leach and deteriorate at an accelerated rate. Consideration should also be given to materials with fire retardant, intumescent coatings. New noncombustible or fire retardant products should be considered for arctic construction.

6-3. Fire protection. Fire protection facilities should be provided in accordance with AFM 88-15, TM 5-812-1 and the National Fire Codes. Design for water supplies should be based on TM 5-852-5/AFR 88-19, Chapter 5. Detailed discussions are presented in each of those references. A short summary is given below.

a. Water supply lines. Outside water supply lines can be protected from freezing by several possible combinations of heat cables, insulation, circulation, and heat exchangers.

b. Water storage. Underground water sources are often not available in arctic regions. Surface sources are normally usable only during summer months and winter storage is required. Under these conditions, the storage tank must have the capacity to store several months' supply of domestic water, in addition to reserve water for fire fighting. Excessive domestic use can result in partial depletion or consumption of the fire reserve before new supplies are available in the spring. Therefore, the storage tank should be designed to make it difficult to draw water for domestic use from the reserve supply. Water storage tanks exposed to severe cold must be heated and insulated, and the water circulated continuously. The heat source is normally steam or electricity, with cost and availability being the determining selection factors. Heating techniques include circulating tank water through a heat exchanger or flow-through type electric heater. In coastal locations, where heavy ice buildup can be expected, water storage tank design should include special protection for the tank vent. Driving winds have also been known to block a 6-inch vent, and the vacuum then produced as water is drawn can cause the tank to collapse. Protection can be provided by venting the tank in the pumphouse and not having an exterior vent.

c. Fire protection systems. Fire protection systems generally considered where freezing could be a problem are dry fire lines, dry sprinkler systems, sprinkler systems charged with antifreeze solutions, or inert gas systems. The installations should be designed and installed in accordance with the appropriate

National Fire Protection Association standards for fire protection systems. Special precautions must be taken to prevent back-siphonage if antifreeze solutions are used in sprinkler systems. If inert-gas systems are installed in areas occupied by personnel, special precautions must be taken against suffocation. Under special conditions, dry chemical extinguishers might be practicable. High-expansion foam systems may be used to conserve water or where obstructions such as airplane surfaces would restrict sprinkler effectiveness.

NUM,

d *Fire detection and alarm systems.* Fire detection and alarm systems can be used effectively for early detection and control. Although several types of detection devices are available, the most satisfactory devices in general use are the rate-compensated/fixed-temperature units. These devices should be the type which automatically reset after temperature is reduced. Products-of-combustion detectors are effective if located properly and kept clean; however, they are most expensive and are not easily serviced.

CHAPTER 7

OPERATION AND MAINTENANCE

7-1. General. Good operation and maintenance manuals (O&M) are important because most arctic and subarctic sites may be isolated by weather conditions for 2 to 3 weeks at a time. During these periods, the survival of personnel at remote sites depends upon self-sufficient operation. Personnel rotation increases training and maintenance problems; some incoming personnel may be inexperienced. Repair parts may be scarce. Operation and maintenance manuals should cover the system components and should be explicit. O&M manuals, such as the sample manual shown in appendix B, should be developed to supplement shop drawings and equipment manuals prepared by the construction contractor. Additional manuals described herein should be prepared by the designers to cover complete operation of the various systems. A manual should describe how and why the system functions and what will happen if it is not operated as intended. Operation and maintenance requirements *vary* among architectural, structural, mechanical, and electrical systems. Specific aspects of each of these four systems are discussed in separate paragraphs below.

7-2. Architectural.

a. Exits. All exterior and exit doors should be kept in operable condition at all times. Snow and ice should be cleared from stoops, steps, and walks leading to entrances. Door sills should be kept ice free, and exterior doors, when not in use, should be completely closed to prevent drifting snow from entering vestibules. Snow drifts covering first floor windows should be removed so potential exit routes are not blocked in case of fire. High condensation on the surfaces and perimeters of exterior doors, especially emergency exit doors that may not have frequent use, can freeze them shut. Therefore, infrequently opened doors should be checked periodically for such icing.

b. Roof penetrations. Designers try to limit penetrations; therefore, no new roof penetrations should be made for any reason until the proposed installation has been reviewed and approved by competent personnel. Failure to conform to this direction can result in leakage within the building.

c. Roofs and roof drains. Roofs and roof drains should be kept clean and clear of debris at all times to prevent water ponding of the roof. All debris (such as the cans, lumber, bottles, cardboard boxes, paper, rope, broken glass, etc., which have been found on many roofs) should be removed and periodic examinations should be performed. Nonessential foot traffic should be prohibited.

d. Removal of ice dams at eaves. Ice dams at the eaves should not be removed unless a problem exists from ponded water or hazardous overhang. Hot water or steam may be used to melt channels to drain the water behind the ice. Extreme care should be exercised when removing ice dams to avoid puncturing or damaging the roof membrane or flashing.

e. Bird screens. Bird screens at intake and exhaust hood openings should be removed periodically for cleaning and repair work. The screens should be kept free from frost buildup which reduces the hood capacity and restricts system operation.

Ridge and eave vents. Normally, ridge and eave vents on buildings having cold attic spaces experience little or no stoppage from snow or ice buildup; however, these vents should be regularly checked and physical blockage should be eliminated. If these vents are closed or plugged up, personnel in charge of the facility should be consulted to decide the method to be used to clear them, and maintenance should be performed as soon as possible. A delay in clearing vents may result in water leakage from the attic or roof.

7-3. Structural.

a. *Building design loadings.* The design loadings for the building (wind, snow, seismic, floor loadings, etc.) should be stated in the facility Operations and Maintenance Manual. If personnel from the using agency do not know the design capacities, they sometimes become alarmed when the structure is subjected to a heavier than normal loading. Heavy snow should not be removed unless it is clearly detrimental (overloading the roof or endangering personnel or equipment). A roof designed for a load of 30 psf can safely support an ice load approximately 8 inches thick over its entire surface. If it becomes necessary to remove snow from the roof, leave the lower six inches of snow in place to avoid damaging the membrane. Also leave snow in place around penetrations to protect the flashings. Personnel involved in snow removal shall not be placed at risk. If loads in excess of design loadings are realized or contemplated, refer the problem to a structural engineer for professional recommendations.

b. Foundation. The integrity of the building foundation must be preserved. If the structure is on piling, which requires a frozen foundation be preserved, no action should be taken which will tend to thaw this foundation. Open spaces under some structures have been skirted to maintain warm floors inside the building. This action has thawed the permafrost and caused foundation settlement and heaving. Sometimes structures have been skirted for the summer months when outside temperatures exceed the building temperatures. In this case, skirting should be removed when the exterior temperatures drop. If the foundation subgrade is a free draining material, unrestricted drainage must be maintained.

c. Paint and protective coatings. Protective coatings such as paints and rust inhibitors should be maintained to prevent structural deterioration or other adverse effects.

d. Condition of structural wood. In the dry arctic winter conditions, timbers tend to dry out, shrink, and crack. If checking cracks run diagonally across a member, they can destroy its strength. Shrinkage can loosen bolts and timber connectors. Methods of combating these conditions are: using clamps to force cracks shut and prevent their extension; drilling holes at ends of cracks to intercept them; adding moisture to the atmosphere; and reinforcing members by adding steel, plywood plates, or additional members. Bolted timber construction should be periodically inspected, and bolted connections tightened or shimmed to maintain joint tightness. This process reduces the possibilities of connectors becoming ineffective or members twisting. Proper maintenance and renewal of paint systems and seal coats will reduce the timber drying hazard.

e. Protecting the floors where tracked vehicles are housed. Frequently, arctic buildings that house tracked vehicles have certain floor areas reinforced with steel rails or plates to prevent floor damage from the steel cleats. Vehicles with chains or metal lugs should not be operated on unarmored floor areas. If such vehicles must be operated on unprotected floors, the floors should be planked, covered with metal plates, or protected by some other armoring means to prevent chipping or gouging.

f. Expansion and contraction joints. Expansion and contraction joints should be periodically inspected to ensure they are free of ice or other foreign materials which would restrict expansion and cause unanticipated stresses.

g. Inspection for ice jacking of slabs and foundations. Periodic inspections should be made of slabs on grade and foundations to detect jacking because of ice or settlement of foundation materials. Foundations, walls, columns, and connections should be inspected after seismic disturbances or flooding to detect any changed conditions. If there is any indication of damage to the structural integrity of the building, a structural engineer should be consulted.

7-4. Mechanical. The building contractor normally furnishes equipment manuals containing descriptive literature, parts lists, and installation, maintenance, and lubrication instructions. The following additional information on mechanical features is needed for proper operation and maintenance:

a. Heating and ventilating. A description of the operation of heating and ventilation, air conditioning, exhaust, and waste systems is needed. The control system or sequence should be explained, and the importance of maintaining the system design should be stressed.

b. Operating requirements. The design criteria needed for proper system operation should be stated. For example, how many vehicles, and of what type, is the exhaust system designed to handle? Users should be cautioned not to warm up vehicles in areas that were not designed for that purpose.

c. Anticipating trouble from incorrect operation. An explanation of what can happen if the system is not operated as designed should be included. For example, if the humidity is set too high, condensation will occur and the structure will deteriorate more rapidly than if humidity is regulated correctly.

d. Flow diagrams. Flow diagrams are required to simplify explanations of the system.

e. Maintenance instructions. Additional maintenance instructions beyond those recommended by the equipment manufacturer should be included, if required.

7-5. Electrical. Generally, electrical controls are an integral part of systems such as heating and ventilating systems, and they should be covered in the instructions for each particular system. Equipment manuals should be examined for accuracy and adequacy. If the manuals are not adequate to fully cover the electrical systems, additional material should be obtained. Instructions for specific items should refer to the material in the equipment manuals. Schematics and wiring diagrams are generally shown on the contract drawings and should be referred to in the operating instructions. If sufficient schematics and wiring diagrams are not shown, they should be added to the operating instructions. The system operation description should refer to schematic control diagrams and cover each diagram in detail, describing how and why the system functions. The instructions should explain exactly what will happen if the system is operated incorrectly. Special design limitations should also be noted. Where chemical soil treatment is necessary to obtain an acceptable ground, a yearly check should be made to see if a good ground is being maintained.

7-6. Sample operation and maintenance manual. Appendix B is a sample Operation and Maintenance Manual typical of those described in this chapter.

APPENDIX A

REFERENCES

Government Publications.

Department of Defense

Defense Energy Program Policy Memorandum 85-2	Energy Conservation Investment Program (ECIP) Guidance

Department of the Army, Department of the Air Force and Department of the Navy

TM 5-349	Arctic Construction
TM 5-618/NAVFAC MO-110/AFM 85-3	Paints and Protective Coatings
TM 5-785/AFM 88-29/NAVFAC P-89	Engineering Weather Data
TM 5-805-3	Roof Deck Systems
TM 5-805-6	Calking and Sealing
TM 5-805-14	Roofing Design
TM 5-809-1	Load Assumption for Buildings
TM 5-809-10/NAVFAC P-355/AFM 88-3, Chap. 13	Seismic Design for Buildings
TM 5-810-1/AFM 88-8 Chap. 1	Mechanical Design—Heating, Ventilating and Air Conditioning
TM 5-810-3/AFM 88-8, Chap. 2	Mechanical Refrigeration and Ventilation in Cold-Storage Facilities
TM 5-810-5/AFM 88-8, Chap. 4	Plumbing
TM 5-812-1	Fire Prevention Manual
TM 5-852-1/AFR 88-19, Vol. 1	Arctic and Subarctic Construction: General Provisions
TM 5-852-2/AFR 88-19, Vol. 2	Arctic and Subarctic Construction: Site Selection and Development
TM 5-852-4/AFM 88-19, Chap. 4	Arctic and Subarctic Construction: Foundations for Structures
TM 5-852-5/AFR 88-19, Vol. 5	Arctic and Subarctic Construction: Utilities
AFM 88-15	Criteria and Standards for Air Force Construction

Federal Specification

VV-F-800C	Fuel Oil, Diesel

Non-Government Publications.

American Concrete Institute, Box 19150, Detroit, Michigan 48219

ACI 306	Recommended Practice for Cold Weather Concreting 4

American Insurance Association, 85 John Street, New York, New York 10038

National Building Code

American National Standards Institute (ANSI), 1430 Broadway, New York, New York 10018

A58.1	Minimum Design Loads for Buildings and Other Structures 7

American Society for Testing and Materials (ASTM), 1916 Race St., Philadelphia, Pennsylvania 19103

C-578-85	Preformed, Cellular Polystyrene Thermal Insulation
D-2187-82	Physical and Chemical Properties of Particulate Ion Exchange Resins
E-283	Rate of Leakage Through Exterior Windows, Curtain Walls, and Doors

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) Handbook, Fundamentals, 1985

American Architectural Manufacturers Association (AAMA), Suite 118, 2700 River Road, Des Plaines, IL 60018

101-85	Voluntary Specification for Aluminum Prime Windows and Sliding Glass Doors

International Conference of Building Officials, 5360 South Workman Mill Road, Whittier, California 90601

Uniform Building Code

National Association of Plumbing-Heating-Cooling Contractors (PHCC), 1016 20th St., N.W., Washington, D.C. 20036

National Standard Plumbing Code

National Fire Protection Association (NFPA), Batterymarch Park, Quincy, Massachusetts 02269

National Fire Codes:

NFPA 80	Fire Doors and Windows
NFPA 101	Life Safety Code

National Woodwork Manufacturer's Association (NWMA)

I.S. 2-80	Wood Windows

APPENDIX B

SAMPLE

OPERATION AND MAINTENANCE MANUAL

MULTIPURPOSE RECREATION FACILITY
MURPHY DOME, ALASKA

Prepared by
U.S. Army Corps of Engineers
Alaska District
Anchorage, Alaska

28 January 1971
(SAMPLE)

1. General. This Operation and Maintenance Manual for the Multipurpose Recreation facility at Murphy Dome has been prepared by the U.S. Army Engineer District, Alaska.
2. Purpose. The information contained in this manual describes the intended operation for which this facility was designed and is intended to guide operating personnel in the operation and maintenance of the facility.
3. Scope. This manual has four major divisions: (1) Architectural, (2) Structural, (3) Mechanical, and (4) Electrical. Each division will discuss the required operating system operations and other problems areas which are incorporated into the building design. Also covered will be precautionary procedures which must be maintained in order to obtain desired system operation.
4. Supplementary material. As-built drawings of the facility, manufacturers' catalog cuts, shop drawings and maintenance instructions on specific pieces of installed equipment are not included as a part of this example but should be for any manual prepared.

1—ARCHITECTURAL

1-1. General. Common sense will provide good building maintenance, with special attention being given to the following:

a. Vapor barrier. Vapor barrier with sealed joints has been installed on ceiling and exterior walls between the insulation and interior finishes. All nail penetrations in the vapor barrier have been sealed with mastic during construction; thus theoretically a continuous vapor barrier is provided. The purpose of the vapor barrier is to prevent migration of moisture from inside the building into the insulation. If the insulation material gets wet and freezes, the insulation will be ineffective, and when the ambient temperature rises to about 32°F, water will drip into the building. Therefore, any damage to vapor barrier should be repaired before cold weather and the punching of holes through the vapor barrier should be avoided. If it is necessary to penetrate the vapor barrier, the hole must be sealed.

b. Exterior doors. All exterior doors, and particularly fire exit doors, should be kept free from an accumulation of drifting snow to prevent blockage. Melted snow freezes and causes the doors to become inoperative; therefore, periodic inspection of little used doors is recommended.

2—STRUCTURAL

2-1. General. The building structure is of permanent noncombustible building materials. Therefore, no special maintenance is required. There are a few areas which may require minimal maintenance. These are as follows:

a. Eaves and overhangs. If sufficient glaciation occurs, water may enter the building by flowing under the roofing. If this happens, melt the ice dam (glacier) using heat which will not harm the building system. Condensed steam from continuous steam thawing may compound the problem caused by the water that has entered the building; therefore, caution should be exercised when using steam.

b. Drifting snow. Snow drifting against the building can cause problems when it melts. In some instances, the snowdrift acts as a dam holding water against the building wall. Drifting snow may also act as a bridge to the roof and subsequent drifting on the roof. Periodic removal of drifts from the exterior of the building will eliminate this problem.

2-2. Design loads. The design loads for the building are as follows:

Snow load is 30 pounds per square foot.
Wind load is 30 pounds per square foot.
Seismic zone is: Zone 3.

3—MECHANICAL

3-1. General. Included are certain precautions which must be followed if the system is to operate as designed.

3-2. Heating.

a. System operation. The heat for the building is supplied from the central steam system. The building heat is supplied by passing air through the ventilation unit. The room thermostat controls a set face and bypass damper ahead of the steam coil which regulates the amount of air passing through the coil. A duct-mounted low limit discharge controller overrides the room thermostat when necessary to prevent delivery of air below 60°F. Steam to the coil is controlled by an automatic steam valve which opens or closes as the face and bypass dampers open or close. When all the air is bypassing the coil, the steam valve should be completely closed. In addition, an outdoor thermostat overrides the damper control to assure that the steam valve is100 percent open when the outside temperature is below 35°F.

b. Precautions.

(1) If the outdoor thermostat to the steam control valve is set below 35°F, freezing of the steam coil may result.

✓ (2) If the bypass damper does not close the steam valve when in the full bypass position, the building will overheat.

(3) When the low limit discharge control is set too low, uncomfortable cold drafts will result. If the low limit is set too high, the buildings will overheat.

3-3. Ventilation.

a. System operation. The heating and ventilating unit also provides building ventilation. Ventilation is required to provide building ventilation. Ventilation is required to provide a clean healthful atmosphere and to prevent accumulation of excess humidity. Ventilation is provided by mixing outside air with return in a mixing box. The mixing box dampers are controlled by a thermostat which maintains mixed air within the mixing box at a constant 42°F. Thus as the outside temperature rises, the percentage of outside air increases to maintain comfortable conditions in the building. An auxiliary thermostat overrides the mixing box control and shuts off all outside air whenever the return temperature falls below 68°F. Whenever outside air is introduced, an equal amount of room air must be exhausted to prevent excess pressure accumulation inside the building. This is accomplished by means of a relief damper located at the end of the gym. As the outside air damper opens, the relief damper opens the same amount.

b. Precautions.

(1) If the mixing box control is set below 42°F, the heating coil may lack the capacity to maintain the room temperature at 70 ° F.

(2) If the mixing box control is set above 42°F, the building will not be adequately ventilated and damage may result from excess accumulation of moisture. The excess moisture condenses on cold surfaces and "rain" occurs inside the building during certain weather conditions.

(3) If the override is set above 68 ° F, the building will not be properly ventilated and the same results noted in paragraph (2) above may occur.

3-4. Humidification.

a. System operation. During cold weather, outside air is very dry. When the outside air is brought into the building and warmed, its relative humidity drops to uncomfortable levels. To offset this, a steam humidifier is installed in the duct downstream of the heating and ventilating unit. A room humidistat controls an automatic valve in the steam supply line to the humidifier. The room humidistat should be set at 20 percent to 30 percent.

b. Precautions.

(1) If the humidistat is set above 30 percent, excess humidity will condense on the building walls with the undesirable results noted in paragraph 3-3.

(2) If the humidistat is set too low, the air will dry out, causing human discomfort and causing shrinkage of the wood floors of the gym and bowling alley.

(3) Whenever the heating and ventilating unit fan is stopped, the manual valve on the steam supply to the humidifier should be closed to prevent serious accumulations of water in the ductwork.

4—ELECTRICAL

4-1. General. The electrical system consists of power and lighting system and a fire detection and alarm system.

4-2. Power system. The 480 volt, 3 phase, 60 hertz power to the building is supplied from a feeder which is tapped from Feeder F-15 inside the Operations Building through a 50 ampere, 600 volt circuit breaker. The feeder is routed through P-5 raceway to the Recreation, Multipurpose building. Inside the Recreation, Multipurpose building, the feeder branches, supplying the main building power through a 50 ampere, 600 volt circuit breaker and a 30 KVA, 420-120/208 volt, 3 phase dry type transformer. The other branch supplies the fire alarm and exit lights through a 20 ampere, 600 volt circuit breaker and a 250 VA, 480-120 volt single phase, dry type transformer.

a. Heating and ventilating. The power for the heating and ventilating unit is supplied from Panel "P". The control of the unit is described in the Mechanical Section.

b. Lighting. The power for the lighting power Panel "A" is supplied from Panel "P".

4-3. Fire detection and alarm system. The fire detection and alarm system consists of fixed temperature type detectors, alarm stations, alarm bells and a control unit. The system is connected to the base system. A local alarm will shut down all ventilating and exhaust fans through an interlocking relay.

4-4. Electrical system. The electrical system does not have any unusual maintenance requirements.

BIBLIOGRAPHY

Government Publications.

Army Technical Manual
TM 5-852-8
Arctic and Subarctic Construction: Terrain Evaluation in Arctic and Subarctic Regions

Department of Commerce, National Bureau of Standards
Technical Note No. 231
Solar Heating, Radiative Cooling, and Thermal Movement—Their Effects on Builtup Roofing

Handbook No. 135
Life Cycle Costing Manual for the Federal Energy Management Program

Department of the Navy
NAVFAC DM-9
Cold Regions Engineering, Design Manual

U.S. Army Engineer District, Eastern Ocean
"Architectural and Engineering Manual," prepared by Metcalf and Eddy, Boston, Massachusetts, May 1960

U.S. Army, Corps of Engineers, Cold Regions Research Laboratory (CRREL)
Malcom Mellor, "Cold Regions Science and Engineering," Part III, Section A3c, 'Blowing Snow'
Report No. 82-27
Least Life Cycle Costs for Insulation in Alaska

Non-Government Publications.

American Society of Civil Engineers, United Engineering Center, 345 East 47th Street, New York, New York 10017

Paper No. 3269
Wind Forces on Structures

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE), United Engineering Center, 345 East 47th Street, New York, New York 10017

Handbook of Fundamentals

American Architectural Manufacturers Association (AAMA), 35 East Wacker Drive, Chicago, Illinois 60601
ANSI-AAMA 302.9
Voluntary Specification for Aluminum Prime Windows

Armstrong Machine Works, Three Rivers, Michigan 49093
Catalog No. 502
Armstrong Humidification Book

Illuminating Engineering Society (IES), United Engineering Center, 345 East 47th Street, New York, New York 10017
IES Lighting Handbook

Bendix Research Laboratory, Southfield, Massachusetts 02110.
Technical Report AFWL-TR-67-146, Site Selection Technique, by Dr. R. B. Forrest

National Research Council of Canada, Associate Committee on Geotechnical Research, "Permafrost Engineering Design and Construction," Ed., G. H. Johnston, John Wiley and Sons, New York, New York 1981

National Woodwork Manufacturers Association (NWMA), 400 West Madison St., Chicago, Illinois 60606

I.S. 2-73 Industry Standards for Wood Windows

Steel Structures Painting Council (SSPC), 4400 Fifth Avenue, Pittsburgh, Pennsylvania 15213

Steel Structures Painting Manual

Underwriters' Laboratories, Inc. (UL), 207 East Ohio Street, Chicago, Illinois 60611

Building Materials Directory

Fire Protection Equipment Directory

Fire Resistance Directory

University of Alaska, Arctic Environmental Engineering Laboratory, College, Alaska 99701
Environmental Atlas of Alaska

GLOSSARY

Aerodynamic shade. an area protected from winds and strong air movements, an area of relatively calm conditions conducive to settling of snow.

Arctic. the northern region in which the mean temperature for the warmest month is less than 50 ° F and the mean annual temperature is below 32°F. In general, the arctic coincides with the tundra region north of the timberline.

Arctic entrance. an arctic entrance is similar to a vestibule. The exterior door is closed to shut out the cold air, high wind, or drifting snow before the inside door of the vestibule is opened.

Chimney effect. the natural draft produced from a difference in air pressures as a result of temperature differences, also called stack effect.

Downwind. in the direction that the wind is blowing.

Frost heave. the raising of a ground surface due to ice formation in the underlying soil. As the freeze front progresses downward, moisture migrates to the front, producing accelerated expansion and heaving.

Frost-susceptible soil. soils containing more than 3 percent by weight of grains finer than 0.02mm.

Glacial till. drift of clay, sand, boulders, and gravel left behind as a glacier retreats.

Glaciation. covering with a layer of ice; ice buildup.

Ice dam. an ice buildup on building eaves. This happens as snow melted by the heat of the building flows to the eaves and freezes when the air temperature drops to below 32°F.

Nom,

Ice fog. ice fog results when a dew point air temperature below 32°F meets an available supply of moisture. Ice fog can produce serious visibility impairment for extended periods of time.

Intumescent paint. a fire retardant paint.

Non frost-susceptible soil. inorganic soil containing less than 3 percent by weight of grains finer than 0.02mm.

Permafrost. perennially frozen ground; ground of any kind which stays colder than the freezing temperature of water throughout a period of several years.

Seasonal frost. ground frost that thaws annually.

Snowdrifts. snow formed into berms or mounds by wind.

Snow fences. lath-type fences designed to stop windblown snow and protect a downwind facility from snowdrifts.

Subarctic. the region adjacent to the Arctic in which the mean temperature for the coldest month is below 32°F, the mean temperature for the warmest month is above 50°F and where there are less than 4 months with a mean temperature above 50°F. In general, the subarctic areas coincide with the circumpolar belt of dominantly coniferous forest.

Thermal break. an area of low thermal conductivity between two areas of higher thermal conductivity. The opposite of a thermal bridge. A through-metal connection is a thermal bridge.

Thermal piles. a pile containing a passive or active refrigeration device to freeze back or overfreeze permafrost soils to prevent degradation.

U factor. overall heat-transfer coefficient.

Upwind. in the direction from which the wind is blowing.

Whiteout. an optical phenomenon occurring in arctic and subarctic regions in which the snow-covered ground blends with a uniformly white sky, blotting out shadows, clouds, horizon, etc., and destroying *all* sense of depth, direction, or distance.

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