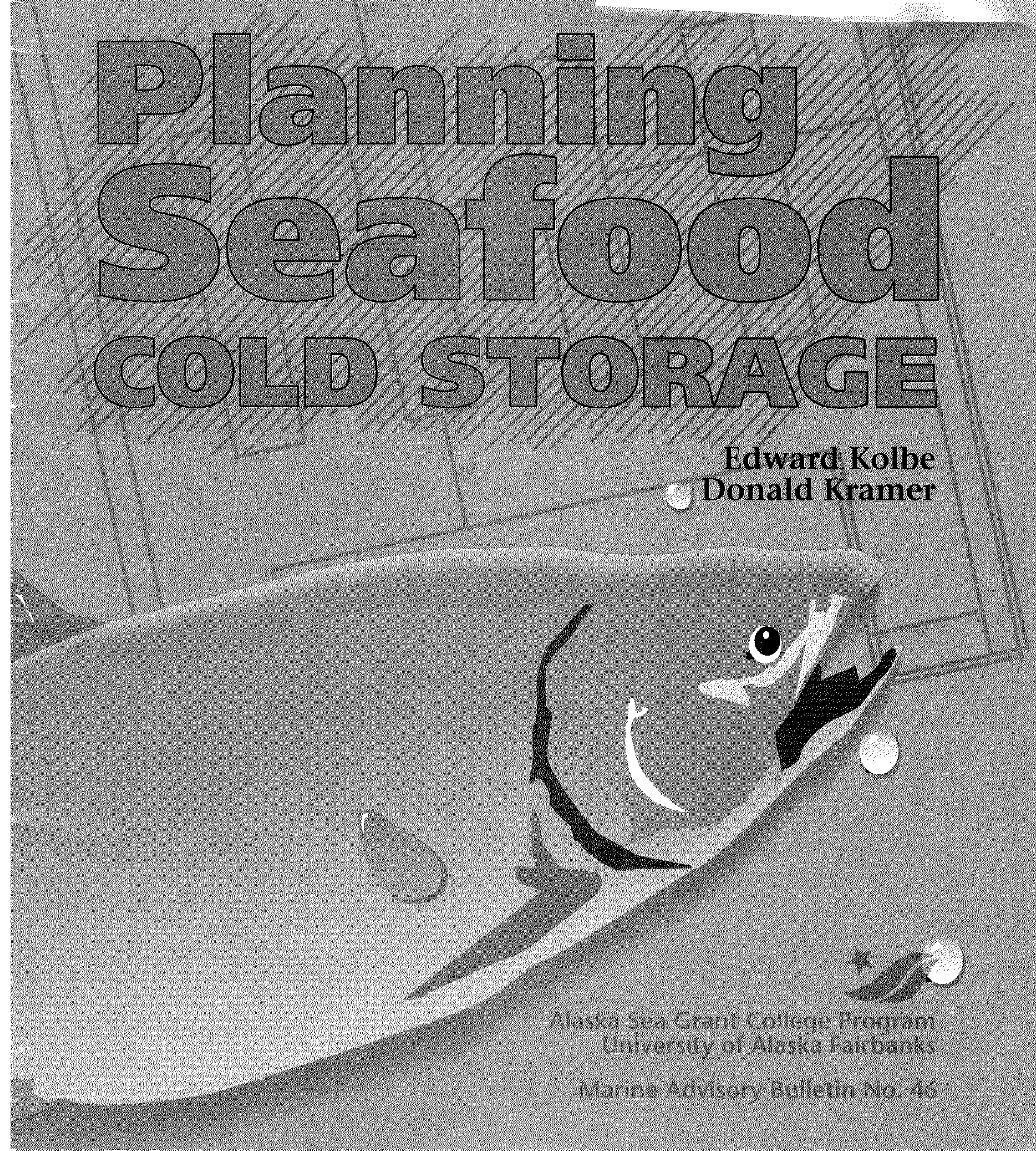
Planning Seafood COLD STORAGE

Edward Kolbe
Donald Kramer



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Introduction

Current seafood processing improvements such as controlled freezing, transport, and storage are resulting in a continuing increase in quality. Freezing and storage help to even out seasonal catch rates, providing a more uniform supply of high quality raw material to consumers and to secondary processors. Some of this secondary value-added processing is now getting under way in Alaska. Processors are recognizing the need to exercise greater control over their products as they are shipped to international customers. Many look to high quality storage as a means of stabilizing temperatures and accumulating complete lots which might then be shipped directly to buyers with minimal repacking, transfer, and temperature fluctuation.

All of this points to a need for cold storage facilities that are carefully planned, constructed, and operated and that support maximum seafood quality at feasible costs. Information on cold storage planning and design is available through a variety of sources. These include books (e.g., Dellino, 1990; Hallowell, 1980); some excellent reports written for the Food and Agriculture Organization (FAO) of the United Nations (these include Graham, 1977, 1984; and Löndahl, 1981); various reports from the engineering literature; and of course the advice of contractors, consultants, and manufacturers who have demonstrated experience with cold storage design.

The appendix of this report lists U.S. companies producing modular-panel cold storage facilities. In many cases the product literature supplied by these companies is a valuable source of design and planning information. For recommendations on storage temperature and duration for seafood species, see Part II, Storing Frozen Product, Tables 22 and 23 on pages 40 and 41.

This report is written for seafood processors in the cold storage planning stage. It is based on information and recommendations from all of the sources noted in the acknowledgments and from the literature cited above.

Although the optimum size of a cold storage facility may be in the range of 500,000 to 2 million cubic feet (specified by Löndahl, 1981, presumably referring to an optimum cost per unit of stored material), most Alaska needs are smaller than that. We've limited the scope of this report to include room sizes capable of storing between 5,000 and 1 million pounds of product which could be stored in a room of about 140,000 cubic feet. And although most discussion focuses on facilities to support *frozen* storage temperatures, some of this information might be adapted to chilled (unfrozen) storage as well. There are several motivations for constructing such facilities: maintaining high quality aquaculture feeds and fresh seafoods; potential shellfish sanitation rulings that may require product storage at temperatures below 38°F (Paust, 1990); and the potential in some regions of storing natural ice during summer months.

a checklist for planning a cold storage facility

Suppose you've decided to build a cold storage facility adjacent to your plant.

- *What is the nature of the building site? What will it take to prepare it for construction? What will the foundation involve? How far is the site from freezers, and how much temperature increase can you tolerate between freezer and cold store? Will trucks, ships, or barges have easy access for rapid discharge of goods?*
- *How big will the storage be? How much product must be stored at any one time? How accessible do the products need to be, so how many aisles or racks must be included? How much will it cost to build?*
- *What kind of electrical (or fuel) power will be required and is currently available? What are the anticipated costs of power and other operating expenses?*
- *What products will be stored and how will they be packaged? How long will they be stored and what temperature must be held in the room? How much temperature fluctuation can these products tolerate, so how uniform must the room temperature be held?*
- *Who will install and maintain the refrigeration? What are the good and bad points of various refrigerants? What kinds of heat loads must you anticipate for the refrigeration contractor? Will product loaded into the room have a higher temperature than that maintained in the room? How often will doors be opened or lift trucks and workers be present? What kinds of insulation is necessary in the walls?*

Contemplating these and many other questions is an important first step in planning a cold storage facility. This report addresses some of the points to help processors formulate ideas, plans, and questions as they deal with contractors and suppliers. The ultimate goal is to encourage well designed cold storage facilities that will support high quality and affordable seafoods from Alaska.

Part 1 Designing the Facilities

Chapter 1: Buildings

The initial step in a cold store plan is to consider the structure—its size, capacity, construction, and its ability to keep out the heat.

GENERAL DESCRIPTION

All buildings discussed in this report are single-story structures, following current practice. Walls and ceiling typically consist of insulated panels similar to those in Figure 1. Outside surfaces can be stainless or galvanized steel, or coated steel or aluminum. Selection depends on needs for toughness, brightness of color, ease of cleaning, or perhaps some requirement to satisfy a local sanitation ordinance. Prices vary.

Generally panels are assembled on-site, in many cases with the aid of a latching system built into the edges of the panels. For the system shown in Figure 2, the assembler uses a large hexagonal set-screw wrench to tighten a cam-operated lock that holds panels together, often against a gasket sealing the joint. In this way, walls, ceiling, and floor can be bound into a finished, pre-designed box such as the small walk-in model shown in Figure 3. Cam locks, when used, are typically spaced every 4 feet along the panel's edge. Designers have used various schemes to transmit the holding force throughout the panel to prevent the latch from pulling out. In some cases, the latch mechanism is attached to a heavy wood or high density foam frame. At least one manufacturer has tied latch mechanisms together with metal straps imbedded in the insulation. The quality of panels, based on uniform shape and fit, surface coatings, latch mechanisms, and homogeneous insulation, are best judged by inspection and by interviewing past customers.

The building in Figure 3 is typical of small structures that can support themselves without external or internal framing. For buildings bigger than 3,000 cubic feet (approximately 375 square feet of floor space), ceiling spans must exceed 12 to 15 feet and

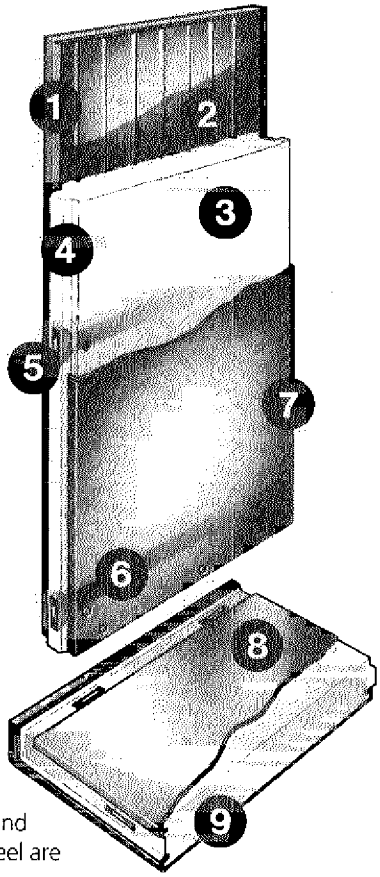
Figure 1. **One manufacturer's insulated panel design**

(courtesy Bally Engineered Structures, Inc.)

1. Outside metal skin. Galvanized steel, patterned aluminum, white or sand tan polyester over galvanized steel, Galvalume or stainless steel.

2. Bally wash primer for optimum foam adhesion.

3. Urethane insulation, foamed-in-place (poured, not frothed). R-value: 34 for 4" panel; 42 for 5" panel.



4. Tongues and grooves on panel edges are accurately molded urethane.

5. Patented cam-action Speed-Lok joining mechanism.

6. Heavy-gauge steel straps connect locking arms with locking pins on opposite edges of each panel.

7. Interior metal skin. Galvanized steel, patterned aluminum, white or sand tan polyester over galvanized steel, Galvalume or stainless steel.

8. Interior metal floor panel skin. Heavy-gauge galvanized steel, optional smooth aluminum or stainless steel.

9. Exterior metal floor panel skin. Usually supplied in same finish as vertical panels. Edges capped with matching metal when stainless steel, white or sand tan polyester over galvanized steel are specified for verticals.

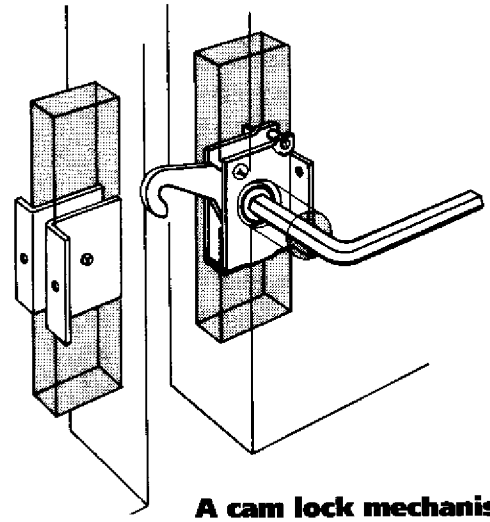
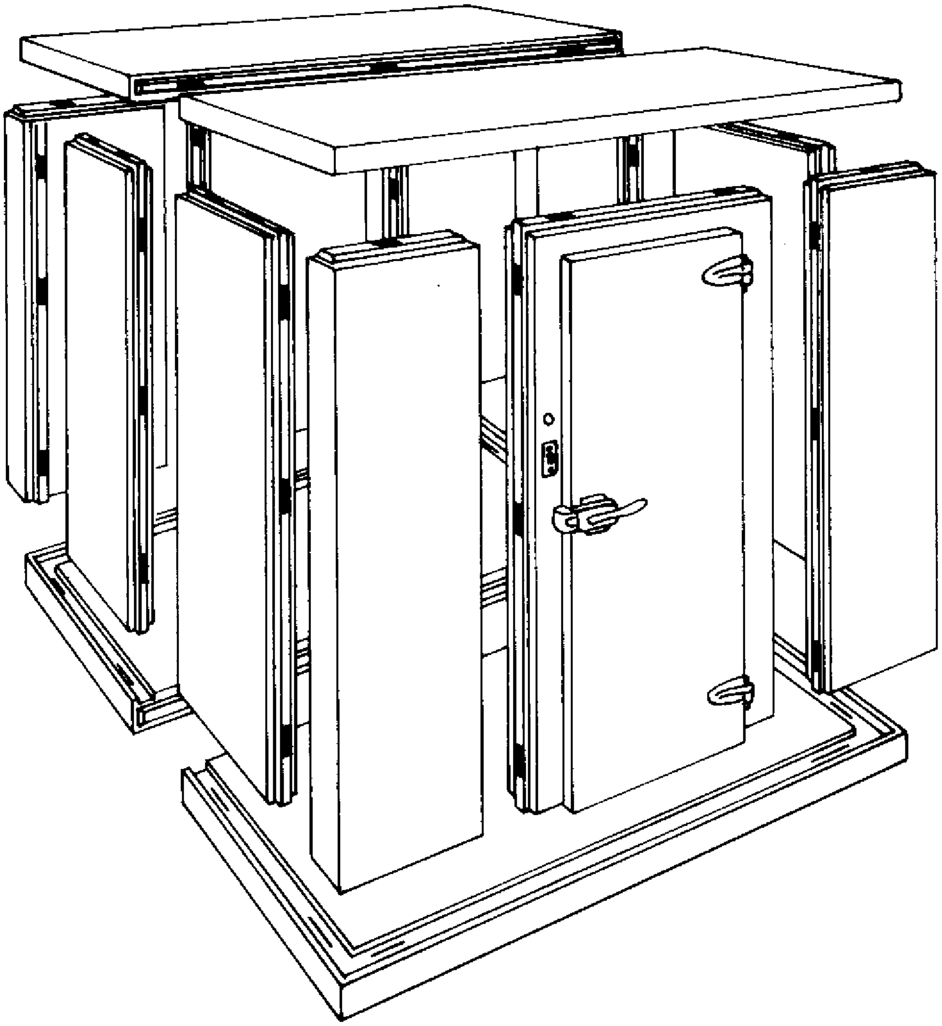


Figure 2. A cam lock mechanism for joining panels

(courtesy Hussman Corp.)

Figure 3. A typical modular walk-in

(courtesy Ram Freezers and Coolers Mfg. Inc.)



additional steel or wood framing is required. This is especially true for externally constructed buildings subjected to high wind and snow loads. The framing can be internal (Figure 4) or external (Figure 5).

Many companies manufacture components for insulated cold storage buildings. The appendix contains an incomplete listing of 22 manufacturers in the United States and Canada, plus three companies in the business of leasing refrigerated vans or railroad cars. Many of these companies can supply useful materials and can advise on system layout and design.

SIZING AND LAYOUT

The focus of this report is on single-story modular systems, such as those supplied by manufacturers in the appendix. But cold storage units can be built in the shape of a multi-story cube, which keeps the surface-to-volume ratio low and minimizes heat gain from the outside. Buildings of this type also maximize the amount that could be stored on a given piece of land. Two disadvantages of the multi-story design are cost and more difficult loading and unloading access (ASHRAE, 1982). Given the current high quality insulations available, attempts to minimize surface area may not be worthwhile from a heat leakage point of view.

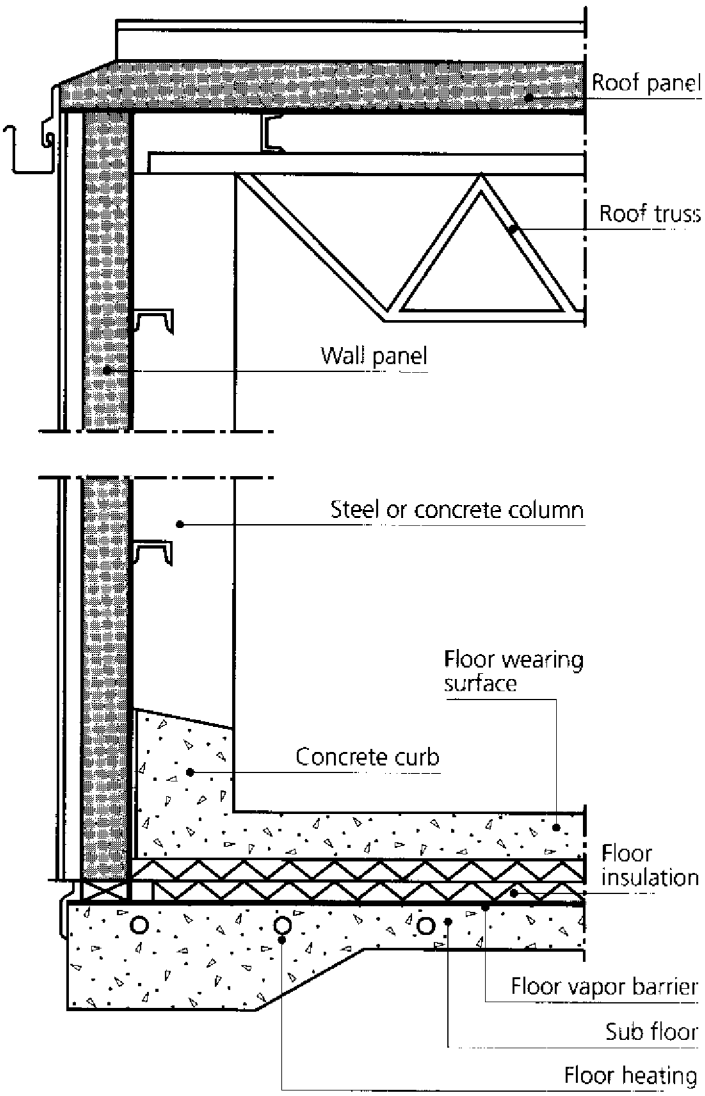
Table 1. **Densities of frozen seafood loaded on pallets**

Product	Density (lb/ft^3)
IQF fillets in polystyrene trays with stretch wrap, in cartons	8 - 11
IQF fillets in bulk catering packs, in cartons	15 - 21
Fish portions, in cartons	18 - 27
Fish portions in sauce, in cartons	25 - 27
Fillet blocks	37 - 52
Whole, gutted cod in large blocks	40 - 55
Whole, gutted cod, stowed as single fish	25 - 30
Whole, gutted halibut, in wooden boxes	30 - 35
Whole salmon, stowed loose in wooden boxes	33 - 35
Shelled shrimp in blocks	45 - 55
Breaded shrimp in consumer packs, master carton	25 - 30

IQF = Individually quick frozen
Source: Graham, 1984

Figure 4. **Panel-built cold store with internal structure**

(from Löndahl, 1981)

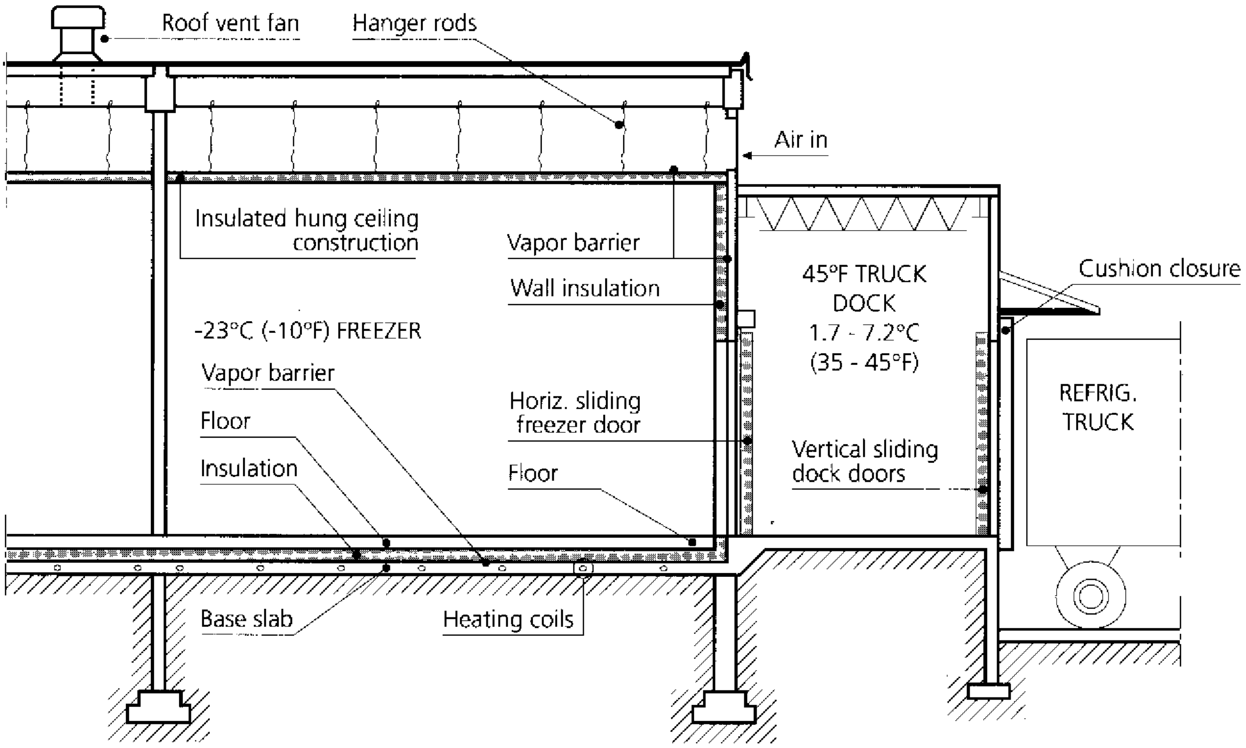


Several factors influence the size of the building. At the top of the list are the space and money available. To determine those requirements, you must first determine how much product will be stored at a time, the projected production rate through the freezers, the amount to be stored for others on contract, storage time for various products, and the time and frequency at which a product will be shipped out.

The volume occupied by a product depends on

Figure 5. **Typical one-story external frame construction with insulated hung ceiling**

(from ASHRAE, 1982)



packaging and product form. Graham (1984) gives "stowage rates" (product densities) for a long list of packaged and unpackaged seafoods. Table 1 provides a few examples of how this value varies. Note that the density of fish muscle might be on the order of 64 pounds per cubic feet.

The building will not be filled with product—aisle spaces must be available for lift trucks or carts. The more product diversity and turnover, the more storage must be managed to get at things. This means a higher percentage of space is required for aisles. Rack framework is often required, particularly if pallets are to be stacked more than two high (e.g., Figure 6). Spacing at the outer walls results from curbs (e.g., Figure 4), often recommended to prevent wall damage from lift trucks and pallets. Good cold air circulation between pallets and the outer wall also requires a space of 6 to 12 inches (Young, 1990). Graham (1977) recommended 4 inches of clearance on the floor and 8 inches of clearance at the walls to minimize local heat gain that leads to sublimation (freezer burn) and quality loss. Ceiling space must also accommodate structure, air handling or coil systems, lights, and in some cases, a sprinkler system.

Graham's 1984 report presents a number of cold storage layouts for different mixes of the products listed in Table 1. The two examples of smaller capacity rooms (220,000 pounds) in Figure 7 demonstrate several points. First, pallets (represented by the small rectangles) are stacked against a curb away from the wall, to allow cold air circulation between the product and wall. Second, aisles are most efficient if laid out in a straight line. Widths must be sufficient to accommodate the turning radius of whatever carts or forklift trucks are to be used. Of the two examples shown in Figure 8, the "counter balance truck" tends to have a wider (25 to 40 percent) turning radius requirement than the "reach truck" (Löndahl, 1981).

A third point demonstrated in Figure 7 is that loading patterns depend entirely on the products and their requirements for access. Figure 7a shows access to each pallet. Total store density (or stowage rate) when full would be 5.3 pounds per cubic foot. The packing in the store of Figure 7b shows less access but a higher total density of 7 pounds per cubic foot. Table 2 shows density and other dimensions of interest, taken from the examples presented in Graham's report. Maximum stowage rates in working cold stores are obviously much lower than stowage rates (product densities) of Table 1, and generally higher in larger stores.

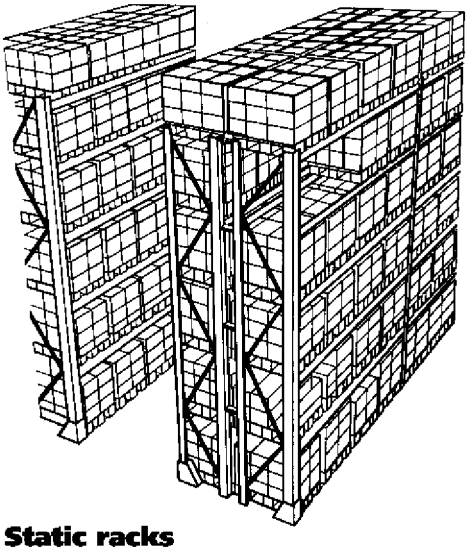


Figure 6. **Static racks**

(from Toole, 1990)

INSULATION

It is the insulation in walls, ceiling, and floor that minimizes the influx of heat. The type and thickness will influence both the cost and effectiveness of the cold store.

Two types of insulation are commonly available in panels for frozen storage: urethane foam and expanded polystyrene (EPS). A few panel manufacturers also list fiberglass, although this material is most commonly specified for coolers with temperatures above freezing (Hallowell, 1980). Some contractors have found that fiberglass, without an effective and long-lasting moisture barrier, will take up water, sag, and lose its insulating quality. All three insulation types will work if installed and maintained correctly. As stated by the American Society of Heating, Refrigerating and Air Conditioning Engineers, "The success or failure of an insulation envelope is due directly and entirely to the vapor

Table 2. **Specifications for cold store layouts**

Nominal capacity (lb)	Total floor area curb to curb (ft^2)	Total room volume (ft^3)	Approx. inside total dimension L x W x H (ft)	Number of pallets high	Approximate stowage rate (lb/ft^3)
220,000	2,700	43,700	69 x 40½ x 15½	2	5.4
220,000	2,060	33,480	69 x 31 x 15½	2	7.1
1,100,000	11,300	179,070	171½ x 67 x 15½	2	6.4
1,100,000	7,290	115,740	89 x 81½ x 15½	2	10.1
1,100,000	6,920	179,770	148½ x 46½ x 25	4	6.6
1,100,000	5,790	150,080	78 x 74½ x 25	4	7.6
1,100,000	4,490	108,740	77½ x 59½ x 23½	4	10.9
1,100,000	5,520	177,050	119½ x 47½ x 31	5	6.6
1,100,000	4,680	150,200	76 x 63 x 31	5	7.9
1,100,000	3,740	112,040	64½ x 59½ x 29	5	10.9
4,400,000	10,730	319,280	116 x 94 x 29	5	14.2

Source: Graham, 1984

barrier systems to prevent water vapor transmission into and through the insulation" (ASHRAE, 1982).

Urethane, also called polyurethane, is a rigid, usually buff-colored foam that forms in a mold when chemical components are mixed. One of the components is a chlorofluorocarbon refrigerant gas, either R-11 or R-12, that acts as a blowing agent to fill the cells in the foam. These gases are being phased out because of their highly detrimental effect on atmospheric ozone. Foam manufacturers are seeking workable substitutes.

Figure 7. **Two layouts for 220,000 lb capacity**

(from Graham, 1984)

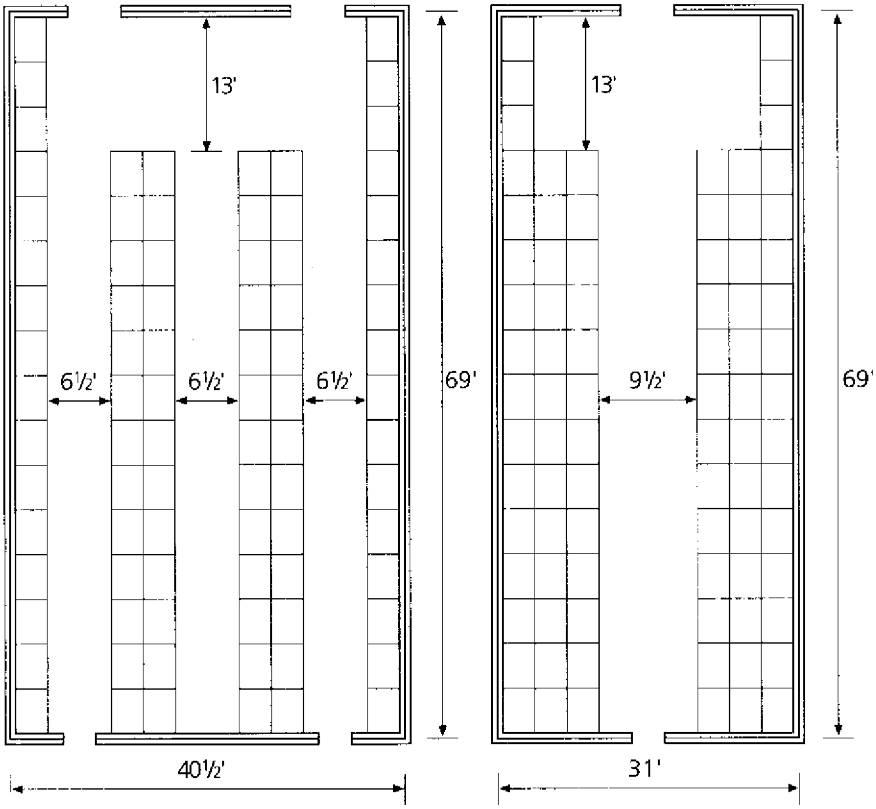


Figure 7a.
Access to each pallet. Pallets stacked two high; 15½' ceiling.

Figure 7b.
Access to five different products. Pallets stacked two high; 15½' ceiling.

Although urethane foam is sometimes sprayed onto surfaces with a gun (as in a fish hold or existing structure), panels are more often "foamed in place" or "poured in place." With the right technique, a predetermined amount of chemicals poured into the bottom of a vertical mold will react and expand (about 30-fold) into a uniform-density foam. The foam fills the void and adheres to the panel skin, which is typically made of coated sheet metal. Panels are available in thicknesses between 2 inches and 8 inches depending on the manufacturer. Urethane used for wall panels is frequently advertised as being "closed cell," implying that water vapor is effectively (although not completely) sealed out. The sheet metal skin acts as an additional moisture barrier.

Varying the chemical components will vary the density. This in turn affects the heat-insulating properties and the compressive strength of the foam. For foam panels to be used as insulation, densities are typically around 2 pounds per cubic foot. The insulating properties (or thermal conductivity value) are affected somewhat by age, as air slowly diffuses into the cells and replaces the gas originally used as a blowing agent (ASHRAE, 1985).

Although urethane will not readily burn with a match, uncoated or unlined urethane can burn violently in small enclosures (such as fish holds). Foam additives are generally designed to limit flammability to meet local codes.

Some panel manufacturers use the terms isocyanurate and polyisocyanurate to describe their urethane foam insulation. According to one insulation supplier, isocyanurate refers to a slight chemical variation of urethane that allows use under higher temperature conditions (McKay, 1991).

Insulation characteristics are the same (Russell, 1990; Fabian, 1991).

A second common insulation used in modular panels is expanded polystyrene (EPS), sometimes referred to as styrene in product literature. This low density plastic material forms in a mold when high pressure-high temperature steam is applied to small polystyrene beads. Thus the blowing agent in this insulation fills the void cavities with water vapor, which is soon replaced by air. Manufacturers say EPS has insulating properties that are fairly constant over time.

EPS is usually less dense than urethane—typically 1 pound per cubic foot, versus 2 pounds per cubic foot for urethane. Since its insulating properties are not as good as urethane, a greater wall thickness is required to achieve the same insulating value. Nevertheless, suppliers claim it is still less expensive than urethane. EPS adheres well (or can be laminated) to metal, wood or sheetrock, thus giving panels reasonable strength in construction.

About R-value

The property describing the ease with which heat conducts through a material is its thermal conductivity, k. In English units, k is the rate of heat flow (Btu per hour) that will pass through a unit area (1 square foot) of the insulation, which is one unit (1 inch) thick, when a temperature difference of one unit (1°F) exists between its back and front surfaces.

A good insulating material has a low thermal conductivity value in the neighborhood of $k = 0.2$. This is in contrast to plywood $k = 0.8$, cement $k = 5.0$, and steel $k = 314$.

The R-value is the reciprocal of k multiplied by the material thickness. All the R-values reported in the United States result from k described in English units, and thickness expressed in inches. While k describes how well heat will flow through a material, R describes how good an insulator it is. For insulation 1 inch thick, the R-value is

$$R = \frac{1}{k} \times L = \left(\frac{1}{0.2}\right)(1) = 5.$$

A 4-inch-thick piece of that insulation would have an R-value of 5 x 4 = 20.

About Flame Spread

Most manufacturers give a "flame spread" value or "flame spread index" (FSI) for the insulating material. A typical value reported for urethane panels is 25. The index results from a test standardized by the American Society for Testing and Materials (ASTM, 1989). In this test the insulation material is mounted on the ceiling of a 24 foot regulation tunnel ventilated with moving air. After a gas burner ignites the

Figure 8. **Counterbalance forklift truck (left), and reach truck (right)**

(from Löndahl, 1981)

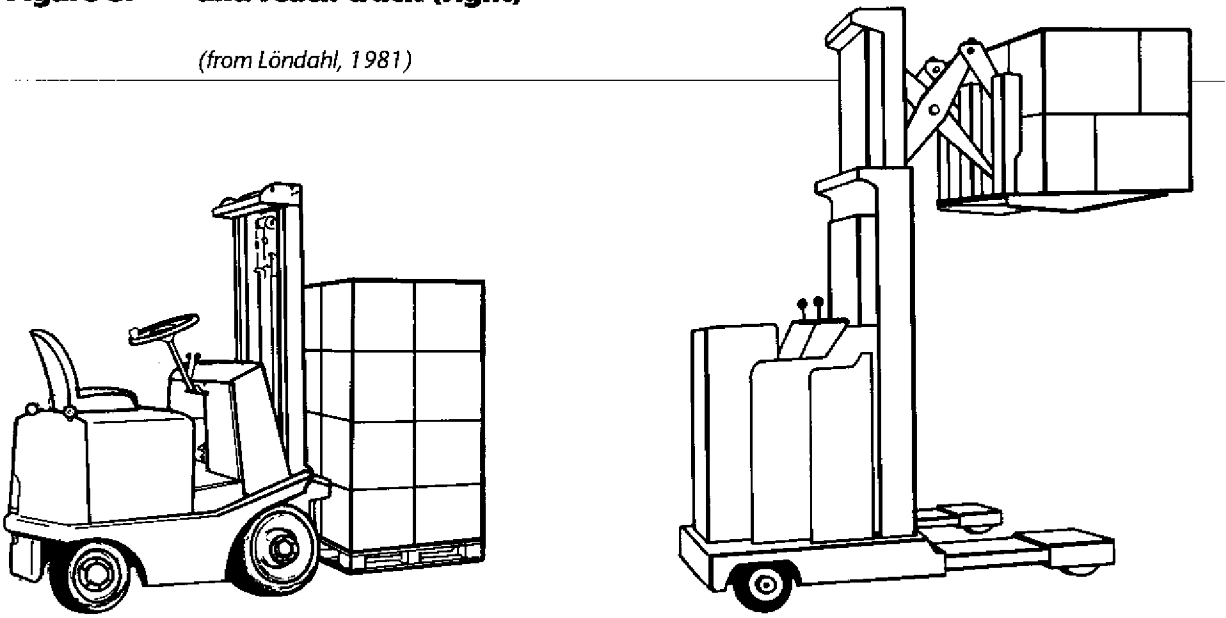


Table 3. Insulation properties

	Urethane 2lb/ft^3	EPS 1lb/ft^3	EPS 1.5lb/ft^3	Fiberglass 1lb/ft^3
Thermal conductivity k[a]	0.14[b] (0.16[e])	0.24[c]	0.22[c]	0.25[d]
R-value for 1" thickness	7.1 (6.5[e])	4.17	4.54	4.0
Compressive strength (psi, at 10% deformation)	14.5[f] (30[h])	10 - 14[g]	15 - 21[g]	

NOTES:

a. k expressed as Btu per (hour) (sq. ft.) (°F temperature difference per inch).

b. For 25°F aged urethane faced with aluminum foil; source: ASHRAE, 1985.

c. Measured at 25°F; source: ASHRAE, 1985.

d. Normally manufactured with binder to make semi-rigid batt; source: ASHRAE, 1985.

e. For 25°F, aged, unfaced urethane foam originally expanded with R-11 refrigerant; source: ASHRAE, 1985. Note that literature gives urethane k values over a range of 0.11 to 0.17.

f. Source: Russell, 1990.

g. Source: Insulfoam Corp.

h. Source: Burtin Corp. (Fabian, 1991).

ceiling at one end, data on the spread of the flame along the length of the tunnel are used to calculate an FSI relative to two other materials. One is a non-flammable cement board, FSI = 0; the other is a select grade red oak, FSI = 100. The amount of smoke developed during burning and the fuel used in the gas burners are also recorded with this test.

Specifications

Thermal conductivity values vary with density, temperature, and age (as with urethane). Values differ somewhat according to the source of the information. Table 3 gives some specifications for three insulating materials. Note that the total *R*-value for a 4 inch wall of urethane, according to this table, is 4 x 7.1 = 28.6. To achieve the same *R*-value with low-density EPS, a wall thickness of 28.6/4.17 = 7 inches is needed. Note also that if a manufacturer reports an *R*-value of 34 for the urethane insulation in their 4 inch panel, it means that the manufacturer is assuming the thermal conductivity (*k*) to be about 0.12 (instead of 0.14 used in Table 3). Such a low value is generally expected for new insulation. One manufacturer has reported that metal-sheathed wall panels will maintain a *k*-value as low as 0.11 regardless of their age because cell gases are unable to escape through the metal skin (Fabian, 1991).

ACCESSORIES

Cold storage rooms, from the smallest walk-ins to the largest warehouses, consist of a foundation, an enclosure, and a refrigeration system. The pieces that remain are called accessories.

Doors

Many of the manufacturers listed in the appendix make or sell freezer doors. Some doors are hinged, some are sliding, and some come built into panels that then become part of the wall (Figure 3). All hinged doors have an option of a heater wire installed in the jamb (Figure 9). This is important to prevent the build-up of ice. Sliding doors are common on larger rooms where forklift trucks move product in and out. An important door accessory is a pattern of protective posts (Figure 10), without which door damage is almost assured.

Pressure Relief Ports

As doors suddenly open or temperatures go up or down, a slight change in pressure can produce a destructive force on the doors. This is particularly true for small, tight rooms. A ¼ psi pressure difference will apply a 1,300 pound force on a 5' x 7' door. To prevent this, room designers specify an appropriate number of pressure relief ports to equalize this pressure (see example in Figure 11). The relief ports also have heater wires to prevent ice blockage.

Shelves or Racks

Every processor has a different idea of an appropriate shelf system on which to stack products, and racks to support pallet loads. The design depends on the layout of the room, the product mix and weight, how accessible different products have to be, and the strength and size uniformity of cartons and pallets. Many vendors of small walk-ins supply shelving as an extra. Racks in big rooms are regarded as a separate expense. The rack system for a recent 5-million-pound facility was listed at $42,000 (Williams, 1991), and higher costs have been noted for smaller facilities.

Lighting

Manufacturers of small walk-ins have various guidelines on how much lighting is appropriate. One, for example, recommends a 100 watt light for each 100 square feet of floor space. The Alaska Department of Environmental Conservation (1990) requires that storage areas have lighting to provide "at least 20 foot-candles of light, evenly distributed, measured 30 inches from the floor." One plan for a 5-million-pound storage facility with a 20 foot ceiling called for about 52 watts of lighting per 100 square feet in the form of "low profile high pressure sodium

Figure 9. **Three heater wires shown in a manufacturer's door design**

(courtesy Bally Engineered Structures, Inc.)

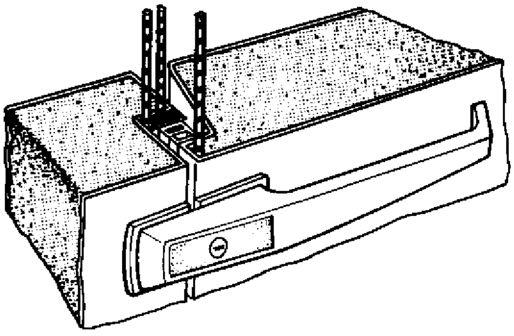
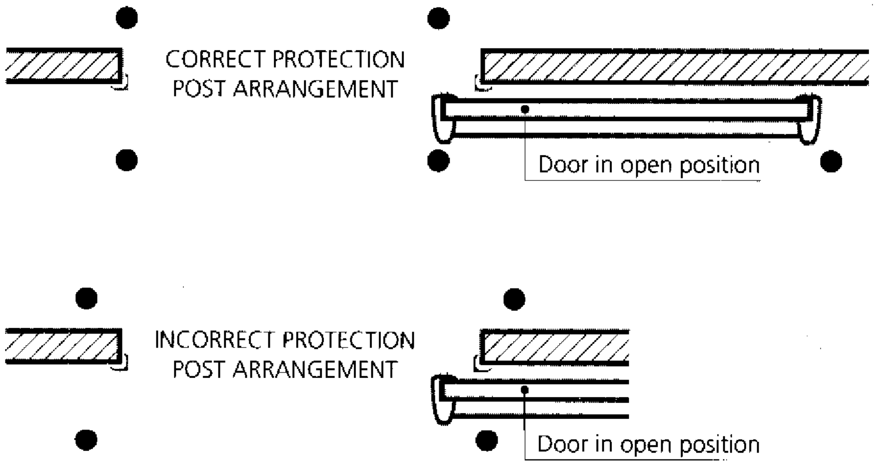


Figure 10. **Position of protective posts recommended for sliding storage doors**

(from VanderSpek and Atkinson, 1990)



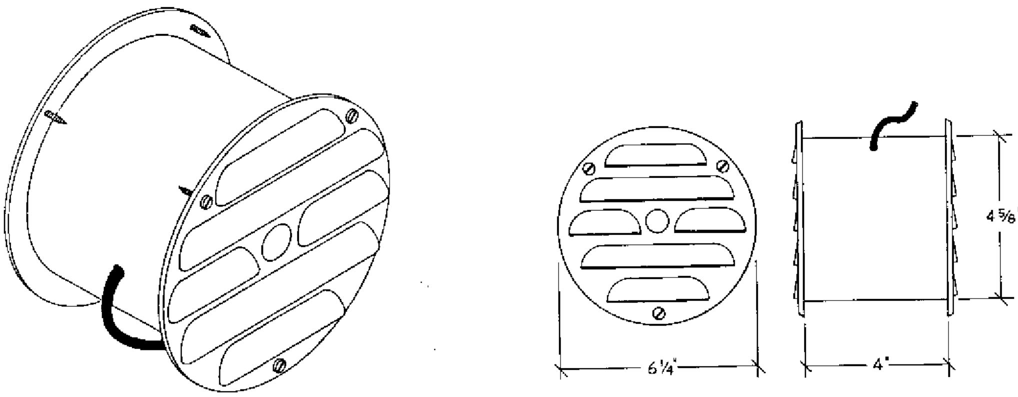


Figure 11. **Heated pressure relief port (Kason heated ventilator port)**

(courtesy W.A. Brown & Son, Inc.)

lights" (Kornelias, 1990).

Options for large rooms include several types of low temperature fixtures with safety globes to prevent broken glass from contaminating food items—another DEC requirement. Any details need to be worked out with the help of designers.

Fire Protection

Particularly with the urethane and EPS foams used as insulation, most rooms having a floor area larger than 400 square feet will require some kind of fire protection. Options include either a dry sprinkler system or an approved thermal barrier on the surface of the walls. If the room is located within another building, these measures are required both inside and outside the cold store.

Sprinklers mounted to the ceiling are generally adequate. With high-piled storage in a room with a high ceiling (e.g., 25 feet or greater), pallets at the lower rack levels may be hidden from the sprinkler spray patterns, and the fire marshal may require spray heads at multiple levels.

The alternative to sprinkler systems is thermal barriers on panel surfaces—typically ½ inch sheet rock or ¾ inch plywood. (Note that these surfaces require coatings that meet approved sanitation standards.) Although such a barrier adds weight and cost to the panel, there may be an overall cost benefit if a sprinkler does not have to be installed and maintained. Kornelias (1990) reported a 5 million pound cold store plan, where the sprinkler system supplies 200 gallons per minute of water at 45 pounds per square inch. The projected total sprinkler system cost is $240,000 or about $8 per square foot, based on the entire building with an engine room. A recently constructed large storage facility in Sitka, Alaska, has no sprinkler system but walls lined with a thermal barrier (Williams, 1991).

Fire protection measures are less stringent for rooms with less than 400 square feet of floor space, and with flame spread index of less than 25 for the insulation panels. In these cases, the Alaska State Fire Marshal generally follows the recommendation of the Uniform Building Code and waives requirements for sprinklers or thermal barriers (McGary, 1991). The general recommendation is to clear building plans with the appropriate fire inspection office before proceeding too far.

Miscellaneous

Many additional accessories are available that improve convenience, safety, and product quality:

- *Digital readout or dial indicating thermometers and recorders—note that the U.S. Food and Drug Administration requires an accurate temperature-monitoring device inside the room (Peterson, 1992).*
- *Alarms that indicate when temperatures rise above a danger level.*
- *Thermostats to control optimum door heater temperatures.*
- *Plastic air curtains in doorways to minimize air infiltration.*
- *Special floor surfacing or matting to prevent slipping.*
- *Heavy "kick plates" on doors and bumper guards or curbs inside the room to minimize door and wall damage.*

- *Inside safety push handles or automatic openers for doors.*
- *Foot-operated treadles (pedals) for hands-free door opening.*
- *Various roof kits and door awnings or drip shields (rain hoods) for outdoor installation of small walk-ins.*

FOUNDATIONS

The foundation for the cold store must meet several criteria. First, it must support the weight of the room or building. Second, it must provide good underground drainage, ventilation, and in many cases, heat. Third, it must be insulated. And fourth, it must have an inside load-bearing surface strong enough for the product and loading equipment being used.

For all but the smallest walk-ins you should consult a reputable design engineer to lay out the required foundation for the room or building. The foundation can be a conventional network of concrete footings or a "floating" reinforced concrete slab. The permafrost of western Alaska may require a frame resting on pilings, or maybe a series of wooden cribs that rest on the surface (Henzler, 1990). In any case, the foundation must support the weight of the building and its contents with enough safety margin to withstand local earthquake hazards.

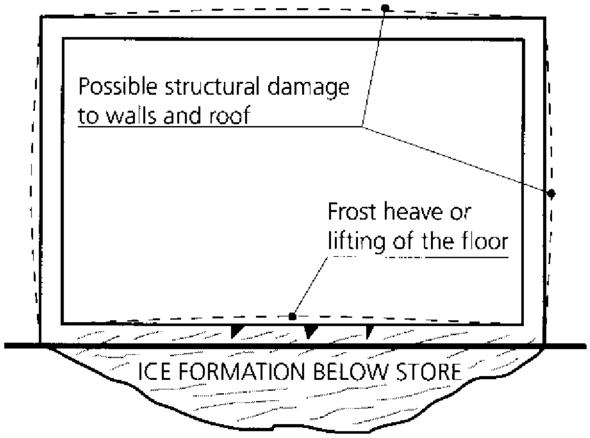


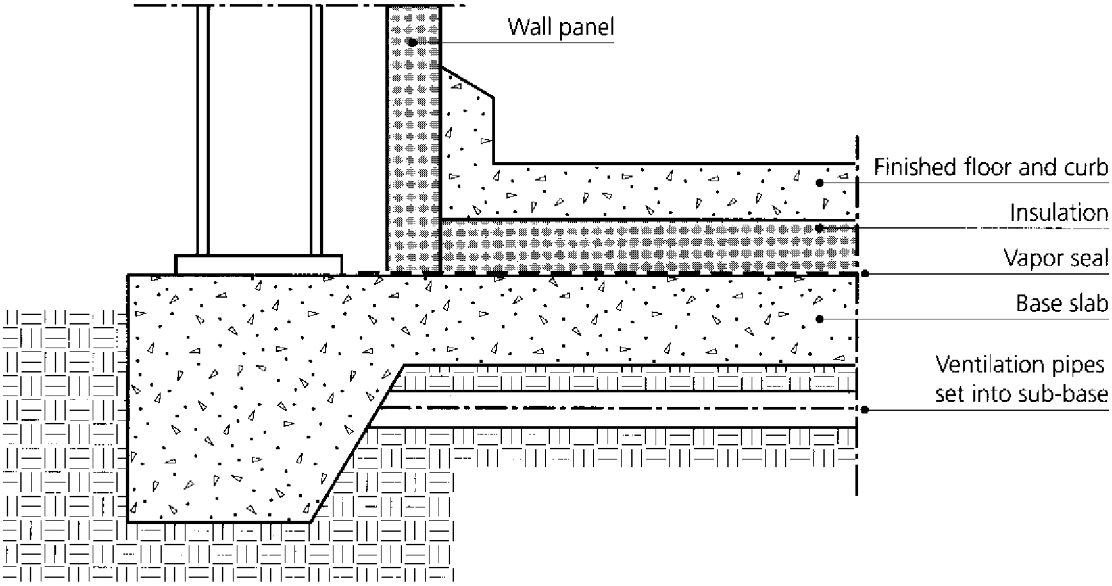
Figure 12. **Ice formation resulting in the frost heave of a cold store**

(from Graham, 1977)

Particularly for frozen storage rooms, it is important that the floor of the building be insulated and that moisture be excluded. Without a proper moisture barrier and drainage, water will collect under the floor and turn to ice at the point where the temperature falls below 32°F. As ice begins to accumulate, it can heave and crack the floor, potentially distorting the building, as shown by Graham (1977)

Figure 13. **Gravity vent systems or forced draft vent system**

(from Russell, 1990)



in Figure 12. This problem is similar to lack of proper moisture barrier in walls and ceilings.

The solution to this is proper insulation in the floor (4 inches is typical), a good vapor barrier, ground water drainage, and in many cases, some source of heat or a supply of warm ambient air. Figure 13 shows a foundation that lets air circulate under the insulated floor and ensures good drainage. One vendor suggests this type of construction for floor areas that exceed 225 square feet. The ventilation pipes are typically 4 inch or 6 inch diameter perforated drainage pipe on 6 foot centers. In Figure 13 the insulated enclosure rests on top of the concrete slab. An alternative is the pit type construction of Figure 14, which places the cold store floor at the same level as that of the floor outside. Note that in both cases, a "thermal break" minimizes the conduction heat leakage coming from the warm floor outside the room. The thermal conductivity of concrete is about 30 times that of insulative materials.

Figure 14. **A pit or depressed pad type of insulated floor**

(courtesy Bally Engineered Structures, Inc.)

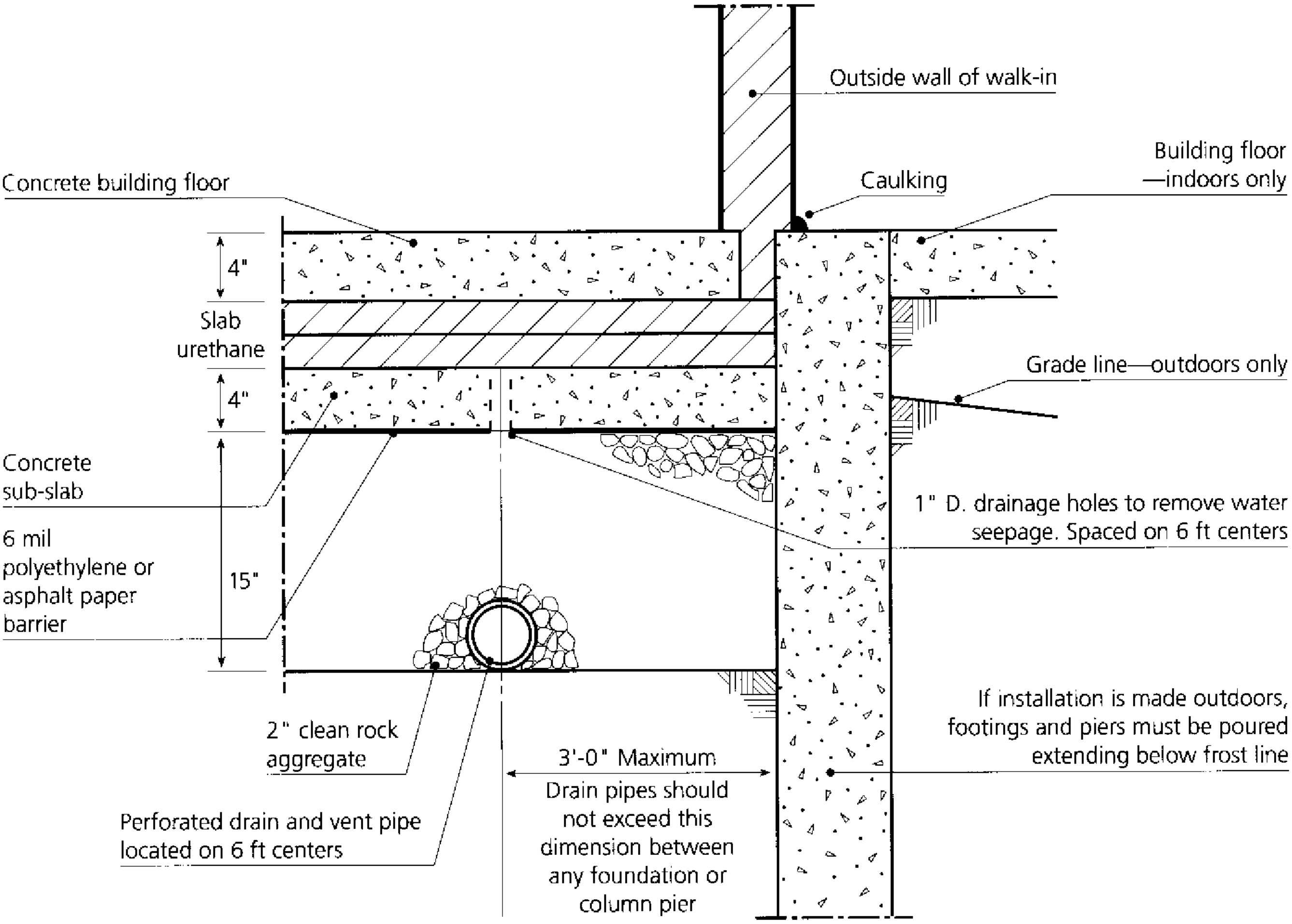


Table 4. Estimates for a 5 million lb cold store in Kenai (1991 dollars)

Land costs	220,000
Site preparation (surveying, engineering, clear and fill)	252,000
Engineering and architecture services	77,000
Foundation/loading dock	252,000
Pre-engineered metal building (including refrigeration equipment space)	453,000
Cold store room	483,000
Refrigeration (250 HP)	403,000
Sprinkler system	220,000
Miscellaneous (utilities, well/water storage, monitoring system, etc)	147,000
Contingency 5%	125,000
TOTAL	**$2,632,000**

The combination of a cold, damp atmosphere and high ground water tables is characteristic of many Alaska locations. It is under these conditions that frozen storage foundation heating becomes necessary. A few Alaska cold storage projects have employed some form of heat source. In fact, one building industry advisory board recommended that "a decision to omit a heat-input system under freezer areas must be a calculated risk by the owner and designer" (National Research Council, 1963).

One option is to cast a grid of plastic tubing into the sub-slab and circulate warm ethylene glycol. A logical heat source is waste heat from the compressor—possibly the cylinder head coolers in an ammonia system. Another option is to blow air heated by the refrigeration condenser through a system of ventilation tubes as in Figures 13 and 14. A third is an electrical resistance heater mat located under the foundation insulation. Where heaters are needed, it is also important to install thermocouples to monitor foundation temperatures periodically.

For small walk-ins a foundation heater is not usually required. But many vendors recommend that an air space be provided between the floor and foundation using wooden spacers. Note that with raised flooring, interior or exterior ramps are needed when using loading carts (Figure 15). Such ramps can be a nuisance if carts or pallet jacks are in use. Loads become hard to move and can easily tip if a wheel goes off the edge.

All insulations used in the floor—particularly urethane and EPS—are rigid enough to handle the total distributed loads imposed by products, lift trucks, and workers. Manufacturers and designers tend to divide wearing surface recommendations into three categories. If products are carried in by hand, as in small walk-ins, a wear surface of 14 or 16 gauge galvanized or stainless steel is adequate. Overall load bearing capacities of 600 pounds per square foot are common. On floors supporting hand lift trucks, ¼ inch steel or aluminum diamond tread, or ¾ inch plywood, is often employed. Higher loads and the use of mechanical fork lift trucks generally call for a floor wear surface consisting of 4 inches of reinforced concrete as shown in Figures 13 and 14. A 1½-inch coated plywood floor resting on 2 by 6's spaced on 12 inch centers has also been employed for this situation (Young, 1990). A minimum 6-inch curb at the edge is effective in protecting the wall from machinery and in ensuring an air gap between stored material and the wall.

PERMITS AND CODES

Any building project will require permits from a number of agencies. The list may depend on the location. This section addresses only a few of the permits and codes involved.

A local building permit is required, and the local fire marshal must approve the project and may require an internal sprinkler system.

The Alaska Department of Environmental Conservation (DEC) oversees fish processing plants. DEC requires that a new cold storage facility pass standards outlined in the appropriate regulation (Alaska DEC, 1990). Although not specific in detail, these regulations generally seek to ensure proper sanitation and related food safety measures. For a new cold store facility, DEC regulations would require that walls and flooring have nontoxic coatings and that surfaces be easily cleaned, that floors be well drained and corners filled to allow adequate cleaning, that fixtures provide adequate lighting and be shielded to avoid the possibility of falling glass, and that a thermometer be mounted to indicate room temperature.

One organization frequently cited in manufacturers' literature is National Sanitation Foundation (NSF), a nonprofit private organization that tests and certifies products. The NSF "Standard No. 7," covering food service refrigerators and storage freezers, addresses many of the same sanitation and safety issues covered by DEC, but generally in terms of much more specific numbers and design details (NSF, 1990). NSF approval is in most cases sufficient to gain approval by DEC (Soares, 1991).

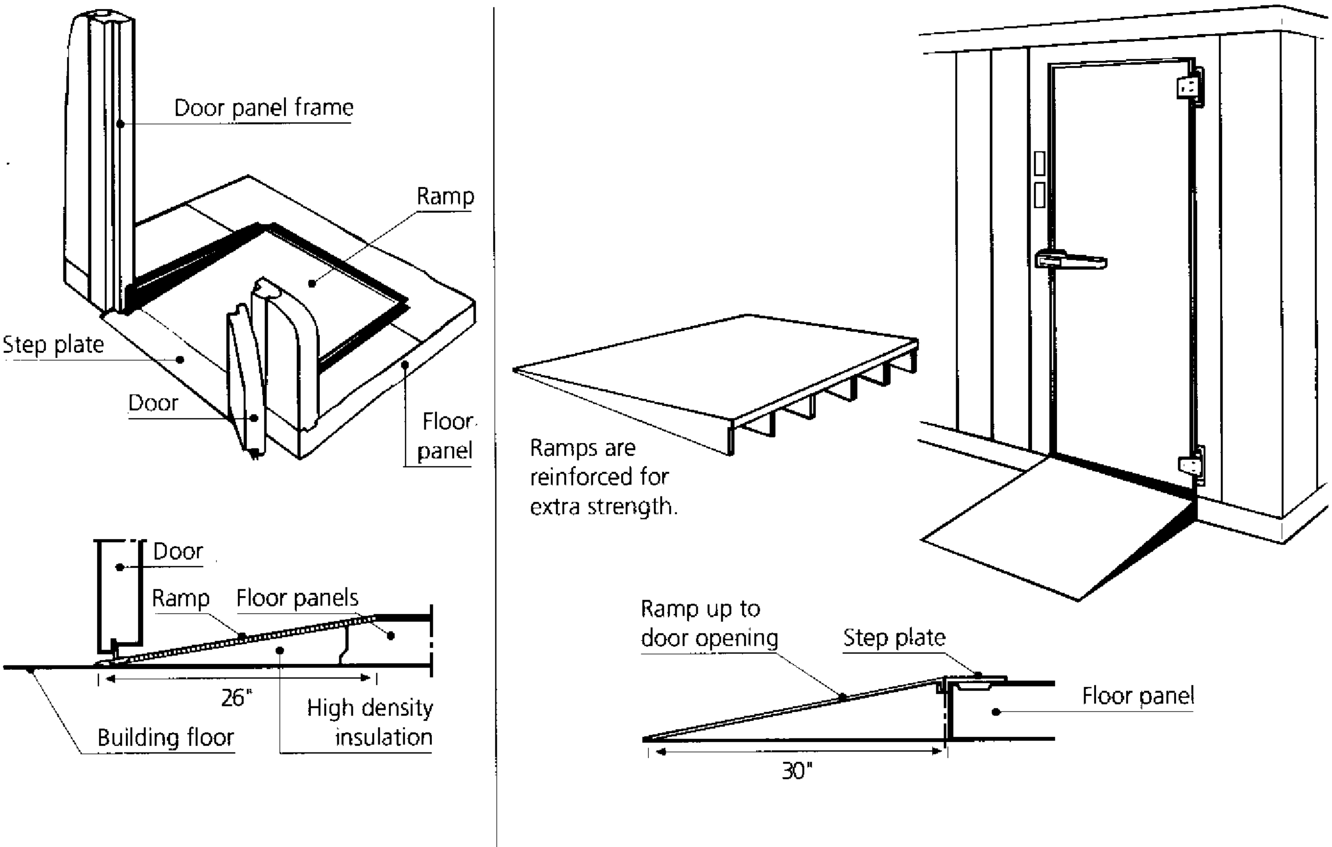
COSTS

As room size grows so does the difficulty in predicting costs. For example, Graham (1984) projected the cost of a 4.4-million-pound store to be about $420,000 (corrected to 1991 dollars by Means, 1991). But his figure assumed the store would be built within an existing building, presumably with an existing foundation, and assumed the site to be within 200 miles of the major equipment suppliers. In contrast, two recent plans for 5-million-pound Alaska cold stores estimated costs of close to $2.2 million and $2.6 million when all the parts are taken into consideration. One of these plants in Kenai (never constructed) included the estimates shown in Table 4, corrected to 1991 dollars (Kornelias, 1990).

What this shows is that as the building project

Figure 15. **Interior and exterior ramps used on small walk-ins**

(courtesy Bally Engineered Structures, Inc.)



Interior ramps

Exterior ramps

Table 5. Estimated costs of cold storage construction in Alaska

Floor space (ft^2)	Estimated volume (ft^3)	Estimated capacity (lbs)	Estimated cost (1991 dollars)	Specific cost (Dollars/ft^2)	Specific cost (Dollars/ft^3)
80	640	5,000	$11,000	$137	$17.20
280	2,250	20,000	40,000	143	17.80
1,520	15,200	200,000	149,000	98	9.80
2,068	37,200	500,000	356,000	172	9.60
5,328	133,200	1,000,000	884,000	166	6.60

Costs include foundation, building, and refrigeration constructed at various Alaska sites, and are based on averages from the scenarios in Chapter 3. They do not include site purchase or preparation, electrical service panels, adjoining offices/work areas, or water sources for fire protection.

increases in size and scope, more costs arise relating to extra accessories and the unique features of that building. For example, engineering, site acquisition and preparation, and miscellaneous and contingency costs represent almost a third of the total estimate. Without these costs, the Kenai cold store project estimate mentioned previously would have been $1.81 million. The manager of one recent cold store project commented that estimating equipment costs was easy; more difficult were the extras and unplanned events (like hauling trash to the dump, and buying a battery charger for the fork lift) for which you must add about 20 percent (Sund, 1990).

A further difficulty in estimating cold storage construction costs is that the unit is often combined with shared missions—for example, a new fish-processing room housed in the same building or new loading docks to serve the entire plant.

Thus the cost estimates presented in Table 5 reflect the relatively easy part—i.e., equipment and foundations with a 10 percent contingency added on. They are based on industry estimates collected for five scenarios described in more detail in Chapter 3. Building capacities range from 5,000 to one million pounds of seafood. As expected, the construction costs per volume steadily decrease as the building increases in size. The costs calculated on the basis of floor space are not so well defined, and appear to be somewhat meaningless when buildings of such a range in volume and ceiling height are compared.

Chapter 2: Refrigeration

The vast topic of refrigeration is changing as we grow more concerned with costs and efficiencies, energy utilization, and environmental issues. The intent of this report is to aid seafood processors in planning and in making decisions. While most refrigeration issues are best addressed by industry engineers, designers, and contractors, reflection on a few topics may help the buyer or planner resolve questions as the design and selection proceeds.

The load and power estimates in Chapters 2 and 3 assume that one refrigeration unit is designated for a single cold store, even though cold storage rooms added to existing plants often share refrigeration equipment with other storage or freezing operations.

HEAT LOADS

Designers will size the refrigeration system to remove heat from many sources, typically under worst case conditions. Graham (1977) calculated the daily average heat load on a 35,000 cubic foot room (2,150 square foot floor) at about 100,000 Btu per hour. He listed the contributions of each source (see Table 6).

Heat flow through boundaries depends primarily on the overall temperature difference, and on insulation thickness and quality. This well-insulated example room was maintained at -22°F, with an outside temperature of 95°F.

The optimum insulation thickness reflects a tradeoff between costs of insulation, refrigeration machinery, and refrigeration energy, among other factors. Designers and engineers can evaluate those tradeoffs for each situation. In addition to an optimum thickness, Graham (1984) recommends maintaining a thickness minimum. This is the value that will maintain a sufficiently high outside skin temperature to prevent moisture condensation. The minimum is generally less than the optimum. Condensation depends on relative humidity (dewpoint temperature) and wind conditions as well. Graham's general recommendations are shown in Table 7.

Air infiltration through open or poorly fitting doors adds a significant heat load. Although open doors caused 19 percent of the heat gain in this example building, open doors can account for 70 percent of the total heat load in older, multi-story buildings (Fleming, 1976). Plastic curtains, automatic closers, air curtains, and air locks are important energy savers. Besides adding a heat load detrimental to the products, warm air brings moisture that frosts refrigeration coils, lowering efficiency and requiring more frequent defrosting (Figure 16). Graham's calculations assume 2.7 air changes per 24 hours. VanderSpek and Atkinson (1990) and ASHRAE (1985) summarize a number of empirical equations (or models) that predict air infiltration loads under different conditions.

Lights contribute the heat equivalent of the power supplied—1,000 watts in Table 6.

Personnel working in the room generate heat that must be removed by the system. This example assumed two men generating a heat load at rates commonly listed in handbooks such as ASHRAE (1985). The use of mechanical loading equipment was not considered.

Table 6. Heat loads calculated for a room of 35,000 cubic feet

Heat flow through the boundaries	32%
Air infiltration	19%
Lights	4%
Personnel	3%
New product loaded	33%
Fans	4%
Defrost	5%

Source: Graham, 1971

When new product is loaded, it will typically have a temperature higher than the storage temperature. That heat must be removed by the storage room system. An ASHRAE (1982) handbook suggests that designers ought to assume that product will be 10-20°F warmer than the room. Graham used a value of 18°F warmer than the room to arrive at the above load calculation. It is important to keep this temperature difference as low as possible. Removing heat to bring a product from -12 to -22°F, for example, is a minor cooling load but can have some effect on product quality if the heat is not removed. Sometimes due to delays or to an overloaded freezer, product will be loaded into storage at a temperature above 20-25°F. This is a problem. Temperature of the new product is still in the latent heat zone. Completion of slow freezing in the cold store will have a detrimental effect on that product's texture and quality. In any event, product in storage may experience a heat gain that will lead to desiccation —drying due to surface ice sublimation, also called freezer burn.

Fans will generate the heat equivalent of the horsepower used to operate them—three ⅓ HP fans in Table 6.

Defrost heat might be applied for an hour or so each day. Electric resistance heaters, hot refrigerant gas, and warm water are all used to melt and remove frost from coils and fins.

If the total amount of heat averaged over 24 hours were removed by machinery operating 18 hours per day, refrigeration capacity would have to be 133,000 Btu per hour (24/18 x 100,000), or 147,000 Btu per hour if a 10 percent safety factor is employed (ASHRAE, 1985). This is the same as 12.2 refrigeration tons (one ton is 12,000 Btu per hour). And according to refrigeration performance data, this system would require a driver supplying close to 40 HP (Carrier, 1984).

The above procedure is representative of that used by designers, although all have their own variations, safety factors, and rules of thumb based on experience. Hallowell (1980) suggested the following rules for cold storage heat loads, assuming minimal new product load and room temperatures above -10°F.

- *For walk-ins having less than 1,000 square feet of floor space and ceilings lower than 10 feet high, try one ton per 225 square feet of floor space.*
- *For intermediate rooms up to 5,000 square feet with 15 to 20 foot ceilings, try one ton per 200 square feet of floor.*

A West Coast designer has suggested a ton for each 250 square feet of floor space on these kinds of units. In any case, Hallowell's rules should be considered only as rough starting points. Good design procedures can be found in a number of handbooks supplied by equipment manufacturers, such as those by Krack (1977) and Bohn (undated).

Figure 16. **Flowing cold and warm air masses that occur when typical freezer doors are open**

(from ASHRAE, 1985)

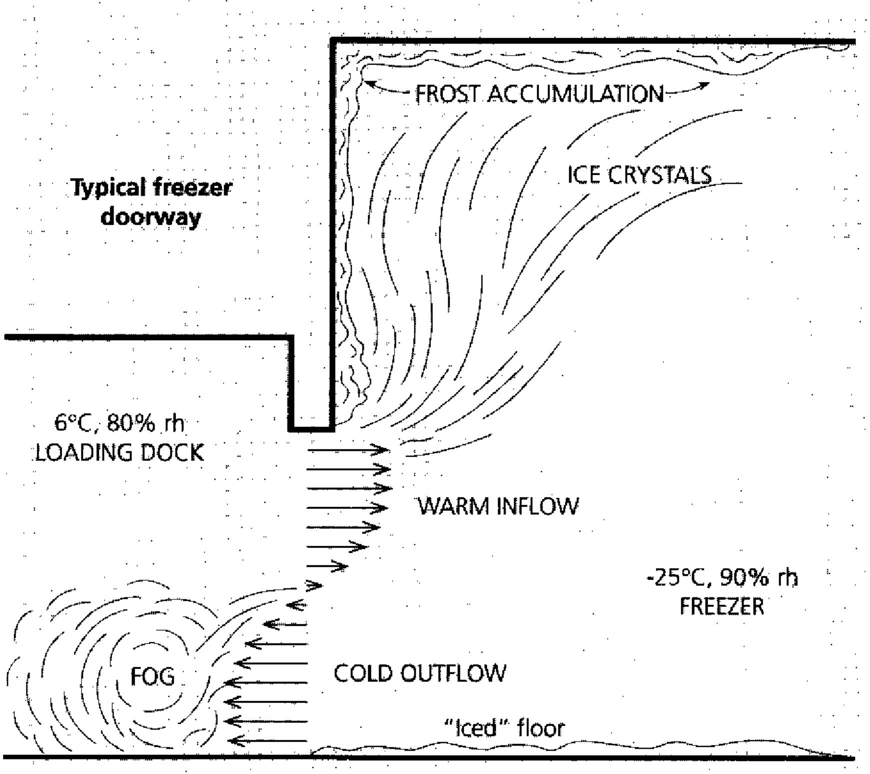


Table 7. **Recommended minimum thickness (inches) for cold store insulation**

Material	Assumed thermal conductivity	Ambient temp. (°F)	Storage temp. (°F)					
			14	0	-4	-13	-22	-58
Polystyrene	$k^a = 0.242$	68	5	6	7	8	9	11
		86	7	8	9	9	9	13
		104	9	9	9	10	11	14
Polyurethane	$k = 0.16$	68	4	4	5	5	6	7
		86	5	5	6	6	6	8
		104	6	6	6	7	7	9

a. *k expressed as Btu per (hour) (sq. ft.) (°F temperature difference per inch)*
Source: Graham, 1984

MACHINERY OPTIONS

Most of the small systems considered here are powered by refrigeration units of less than 15 or 20 HP, meaning that a 15 or 20 HP motor is sufficiently large to drive the compressor. The largest room we consider requires a 62 HP system (see Table 8). Almost all of these small systems would use a reciprocating (piston) compressor with a direct (dry) expansion evaporator: refrigerant sprayed into the low-pressure evaporator coils collects heat from the room air as it evaporates, leaving the coil as refrigerant gas. Some of these small compressors are hermetic or semi-hermetic, while others are open-type. Hermetics have the motor and compressor sealed in a single, welded-shell housing. Semi-hermetics have the motor and compressor in a housing that encloses the shaft. Semi-hermetics can be disassembled easily for repair; hermetics cannot. In both of these cases, the compressor turns at motor speed, and refrigerant rarely leaks from the compressor because no shaft seals are required.

Open-type compressors have an exposed shaft and a greater chance of leakage, but do have some advantages. Speed can be controlled so the compressor can be run at a slower speed to make it last longer. They tend to be more efficient, because refrigerant gas is not being used to cool the motor, as in the hermetics. It is also easier to modify and control motors for a graduated (soft) start in those small systems where the available power (primarily high starting current) is limited.

Table 8. **Refrigeration capacity and power recommended by vendors for the range of scenarios in Chapter 3**

Approximate maximum ambient = 73°F; all examples assume continuous loading of some relatively warm product.
Refrigerant is R-502; SDT[a] = 90°F.

Scenario	Floor (ft²)	Ceiling (ft)	Room volume (ft³)	Storage temp. (°F)	Refrigeration (tons @ SST)[b]	Refrigeration (HP)	Resulting floor area per ton (ft²/ton)
1	80	8	640	-10	0.8 @-20	2	100
2	280	8	2,250	-10	1.8 @-20	3	155
3	1,520	10	15,200	-10	3.5-4.65 @-20	7½-12	430-320
4	2,068	18	37,200	-20	13.2 @-30	30	157
5	5,328	25	133,200	-20	27.5 @-30	62	194

a. *SDT = Saturated discharge temperature*
b. *SST = Saturated suction temperature*

Table 9. Refrigerant effect on atmospheric ozone

Refrigerant	Ozone depletion potential (ODP)
R-11	1.0
R-12	1.0
R-115	0.6
R-22	0.05
R-717 (ammonia)	0.0

Source: Schoemaker, 1990

As systems exceed about 20 HP, other options become worthwhile to consider in the interest of efficiency. Multi-stage refrigeration cycles, flooded systems (instead of dry expansion), and the use of screw compressors may all have some merit, particularly for large systems and when the cold store is operated with other units such as plate freezers or chill rooms. In some Alaska areas with limited or expensive electrical power, it may also make sense to consider engine or even turbine drives as alternatives to electric motors.

REFRIGERANTS

The common refrigerants used for low temperature storage are R-502 for small systems, and ammonia for large systems. Refrigerant 22 (R-22) also is used occasionally. Which is best? It depends on cost, safety, local supplies, local refrigeration sources, service experience, other refrigerants used in the plant, and system efficiency. Another factor that affects the use of refrigerants is environmental safety.

There is evidence that atmospheric ozone is being depleted, leading to action against a few of the everyday chemicals like R-22 and R-502. United Nations Protocols in 1987 and 1990 identified relative dangers and called for the complete ban of some of these substances in developed countries by the year 2000. Several commonly used refrigerants and their ozone depletion potential appear in Table 9. Refrigerants with a value of 1.0 are the most dangerous. R-502 is a mixture of two refrigerants, R-22 (48.8%) and R-115 (51.2%).

The U.S. Clean Air Act and various state laws have followed the UN lead. In general, R-11, 12, 115, and 502 will be unavailable by the year 2000, perhaps sooner. In fact, since July 1, 1992, it has been against the law to vent these refrigerants to the atmosphere. The U.S. Government has placed excise taxes on several refrigerants, the worst being R-11, a blowing agent in urethane foam insulation, and R-12, a refrigerant in higher temperature air conditioning and chilling applications. One wholesale supplier lists refrigerant tax rates—rates that will nearly triple by 1995 (Table 10). This excise tax is meant to encourage use of alternative refrigerants and to collect money for research and education.

What does this mean for your cold storage plan? First of all, R-502 will begin to get scarce and more expensive. Second, R-22 may be a temporary option to consider for the smaller system. It is an environmentally safer fluorocarbon refrigerant, because its chemical structure does not lead to the more serious ozone destruction committed by R-12 and others. But it is eventually scheduled for production limits in 2015 or earlier, and for complete phase-out in the year 2030.

Third, ammonia ought to be more strongly considered, and certainly for the larger system—that is, greater than 20 HP. Although it has its own safety problems, ammonia is environmentally harmless and, with care, can be a relatively safe, cheap, and energy-efficient option.

EVAPORATORS AND CONDENSERS

For most air blast systems, evaporators (the heat exchangers removing heat from the air) consist of a finned tube bundle. Air is circulated by a fan, which not only creates a high velocity through the fins but also throws air throughout the room. One

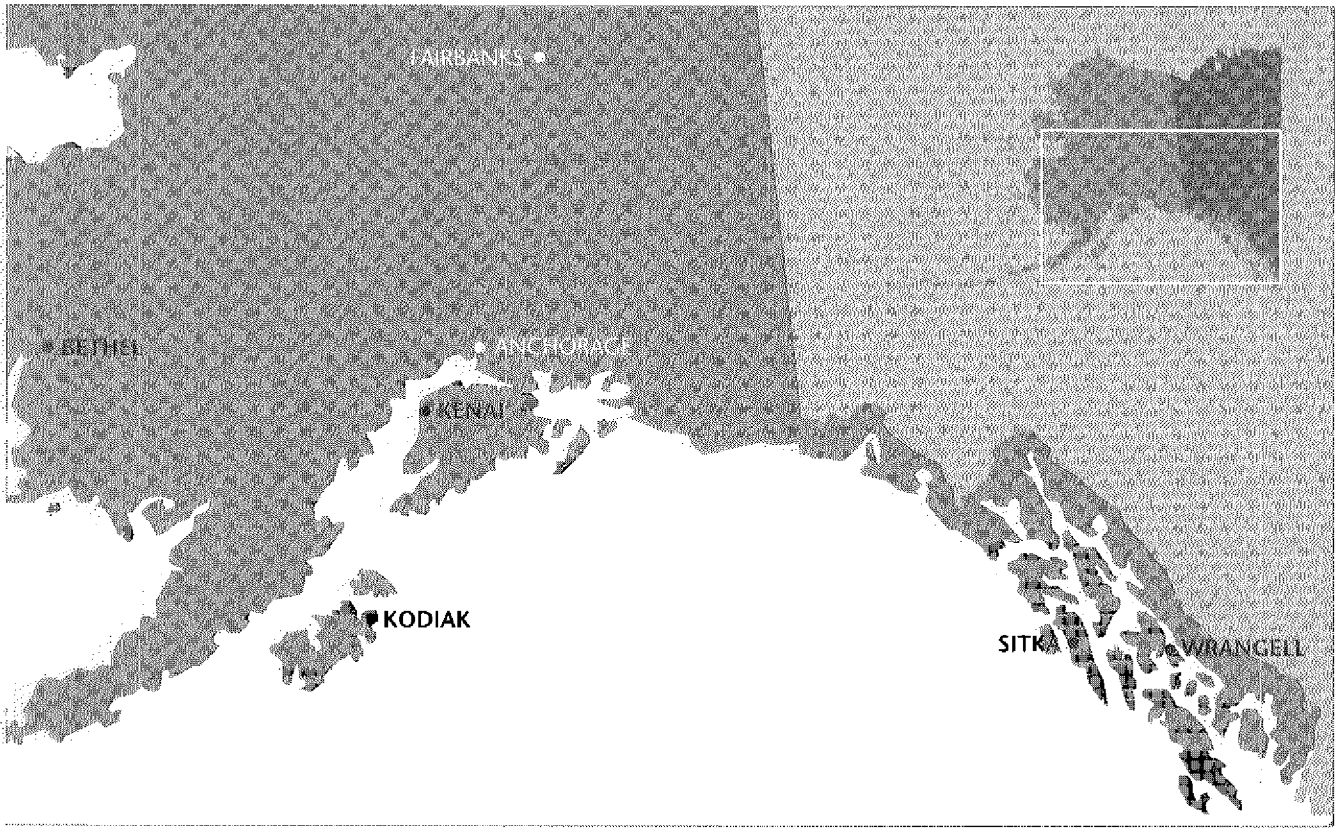
Table 10. U.S. federal excise taxes on refrigerants

Refrigerant	1991 excise taxes/lb
R-11	$1.37
R-12	$1.37
R-115	$.82
R-502	$.42
R-22	$.00
R-717 (ammonia)	$.00

Source: Refrigeration Sales, 1991

alternative is a ducting system to distribute the air. Although this takes up some space, it saves fan energy and decreases room air velocities (Daniels and Page, 1990).

Condensers for the small systems considered in this report are almost always air-cooled finned coils, typically mounted on the roof. In larger capacity systems, water-cooled shell-and-tube condensers are more common, with the cooling water itself often cooled in a rooftop spray tower. Löndahl (1981) suggests that systems smaller than 15-20 HP are more economical with air-cooled condensers. Water-cooled condensers enable operation with a lower "high side" pressure, which is an important and controllable operating characteristic that influences overall energy efficiency. Care must be taken to insure that a combination of low outdoor temperatures and low refrigeration load will not lead to freezing of condenser water, which circulates through an external system. The relative costs, influences on energy efficiency, and other tradeoffs are outside the scope of this report and can be best addressed by a reputable refrigeration engineer.



Locations for five hypothetical cold storage units in coastal Alaska

Chapter 3: Five Cold Storage Units in Alaska

This chapter describes five scenarios to convey some idea of the relevant components, layout, and costs of a small cold storage project. Although hypothetical, they result from interviews with Alaska processors and planners and are thus representative.

Environmental influences: Ground snow loads at different Alaska locations came from the *Midwest Plan Service Handbook* (1983) and project maximum expected roof loads, in pounds per square foot. Maximum wind loads were taken from a wind speed map given in the same source. Maximum external temperature design values came from ASHRAE (1985). Not included were earthquake considerations which may influence building design in some areas. For every new project, an engineering consultant and designer should be contacted concerning such uncertainties.

Layout: Each example includes a layout suggestion that will accommodate the projected use. We assumed pallet dimensions to be about 3' x 3½' (Baumeister and Marks, 1967).

Costs: Each project description and an estimate request were sent to at least three of the vendors listed in the appendix. Not all were willing to supply this data, but a sufficient response supports the information given. For some tasks, use of the *1991 Means Square Foot Costs* handbook provided estimates of construction costs adjusted approximately 27 percent higher for Alaska locations (Means, 1991).

In most cases shipping costs from the manufacturer must include barge transportation from Seattle. Estimates for this were obtained from two Seattle-based shipping companies. Where foundation and building costs were not completely supplied by vendors, these costs were estimated using the Means handbooks. A 9 percent engineering and architecture cost was also added to foundation costs and, for larger buildings, to the structure costs as well. Unless noted below each table, the estimates are supplied by vendors of the cold storage equipment.

In all cases, costs do not include major renovations of electrical service and switching equipment to accommodate the new loads, nor of site preparation (excavation and fill), which is very site-specific. The costs reflect those of a basic design and layout focused strictly on the cold storage task described. They do not include sales taxes or variations that are typical of many such projects. Not included, for example, would be loading docks, an engine/compressor room for refrigeration machinery, office space, a control room, locker/rest rooms for workers, or a pump room for the sprinkler system.

In summary, these costs should be used only as general guidelines. As the size of the building increases, so do the uncertainties and need for required extras. At the very least, you can note both the itemized estimate plus its source, then go to work on selected items to arrive at a more accurate range for your own project.

WRANGELL WALK-IN

A -10°F frozen storage for 5,000 pounds (or more) of herring to be used for bait would be located in Wrangell, Alaska. The project description appears in Table 12; room layout is in Figure 17. The owner would build shelves along each side of the room.

The room would sit on a concrete slab or leveled gravel foundation. Two vendors recommended refrigeration systems using R-502 refrigerant and powered by a 2 HP motor. Assembly for vendor 1 would take one man-day. Installing utilities would require one man-day each for a refrigeration contractor and electrician. Although this building is to be located outside, some cost saving due primarily to a lighter roof can result from locating it inside an existing building. Vendor 1 estimated a difference of $700 if the walk-in were located inside.

Figure 17. **Layout for small Wrangell Walk-in**

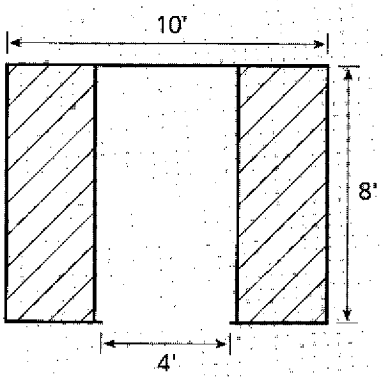


Table 11. Estimated costs for Wrangell Walk-in

	Vendor 1	Vendor 2	Vendor 3
Box	5,060	9,200 (includes refrigeration)	
Refrigeration	2,040		
Road transportation to Seattle	500[a]	1,400	
Barge to Wrangell from Seattle	700[b]	700[b]	
Assembly/utilities	980[c]	360[c]	
10% contingency	930	1,170	
TOTAL	**$10,210**	**$12,830**	**$10,000**[d]

a. *Estimated by commercial trucking company*
b. *Estimated by commercial barging company*
c. *Estimated by author*
d. *A rough estimate based on vendor's recent experience*

Table 12. Cold Storage Project 1 Wrangell, Alaska

General	
Type of store	Small walk-in; out-of-doors adjoining existing building
Location	Wrangell, Alaska
Application	
Amount and type of product	5,000 lb of fishing bait (herring)
Storage temperature	-10°F
Rate and temperature of new product loaded	1,000 lb per day of 10°F product loaded in April
Number of door openings per day	10
Worker and machinery activity in room	1 worker in the room for brief periods with hand-truck
Construction and Assembly	
Estimated total room volume	640 ft^3
Suggested layout	10'x8'x8'ceiling, single door at one end, product loaded in shelves on each side of the door
Maximum snow load	50 psf
Maximum wind	90 mph
Door	Hinged, 4 ft (min.) width
Accessories	Door jamb heater, lights, pressure equalizer port, dial thermometer on exterior wall, external ramp. Buyer will supply shelving.
Foundation preparation	Insulated/ventilated concrete, as necessary
Method of shipping construction goods	Barge from Seattle
Assembly	Buyer will assemble
Foundation	Buyer will prepare foundation according to vendor's recommendation
Hook up refrigeration	Buyer will hire local refrigeration contractor
Local codes that may influence	None
Refrigeration	
Maximum summer temperature	73°F (dry bulb); 61°F (wet bulb)
Minimum winter temperature	-4°F
Electrical supply	Single phase, 110 or 220 v
Condenser unit	Air cooled

SITKA COLD ROOM

This scenario describes frozen storage of processed salmon or halibut portions in a Sitka secondary processing operation. The project description is in Table 14; room layout is in Figure 18. The product would be hand-stacked on shelves supplied by the owner.

Both vendors suggested a 3 HP R-502 refrigeration system, although detailed calculations by vendor 1 showed a tradeoff between refrigeration power and insulation thickness. The estimate shown assumes 5½ inches of urethane insulation in the walls and ceiling. For a thinner, 4 inch layer, this vendor would have specified a 6 HP refrigeration system.

Installation costs are significantly different for the two vendors because the unit of vendor 2 (actually a 12' x 28' room) is assembled at the factory. In both cases, the cost of a slab foundation with a strip footing is included. The foundation of vendor 1 also includes a recessed insulated floor with a heavy wooden working floor on joists.

Minor cost savings would result from locating these two installations indoors: $430 could be saved for roofing from vendor 1; a savings of $2,000 for structural reinforcing would be gained from vendor 2.

Figure 18. Floor plan for the Sitka Cold Room

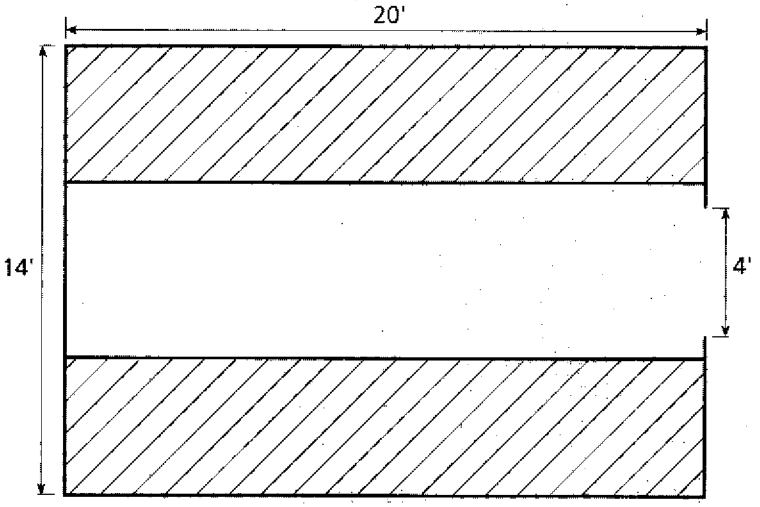


Table 13. Estimated costs for Sitka Cold Room

	Vendor 1	Vendor 2
Box	9,130	28,000
Roofing	430[a]	(includes refrigeration, assembly)
Refrigeration equipment	5,550	
Trucking to Seattle	430[b]	3,100
Sea shipping from Seattle	1,320	1,520[c]
Foundation	4,220[a]	2,630
Installation (box and refrigeration)	15,210	1,730[a]
10% contingency	3,630	3,700
TOTAL	**$39,920**	**$40,680**

a. *Estimated by author*
b. *Estimated by commercial trucking company*
c. *Estimated by commercial shipping company*

Table 14. Cold Storage Project 2 Sitka, Alaska

General	
Type of store	Outdoor single story, adjoined to existing building on gravel lot
Location	Sitka, Alaska
Application	
Amount and type of product	20,000 lb, processed salmon or halibut portions
Storage temperature	-20°F
Rate and temperature of new product loaded	1,000 lb per day at 5°F
Number of door openings per day	10
Worker and machinery activity in room	1 worker, brief periods, electric pallet truck
Construction and Assembly	
Estimated total room volume	2,250 ft^3
Suggested layout	14'x20'x8'ceiling, door at one end
Maximum snow load	30 psf
Maximum wind	100 mph
Door	Hinged, 4 foot (min.) width
Accessories	Door frame heater, lights, pressure-equalizer port, dial thermometer on external wall
Foundation preparation	Insulated/ventilated concrete, as necessary
Method of shipping construction goods	Barge from Seattle
Assembly	Vendor will subcontract
Foundation	Vendor will subcontract
Hook up refrigeration	Vendor will subcontract
Local codes that may influence	Sanitation (Alaska Department of Environmental Conservation)
Refrigeration	
Maximum summer temperature	73°F (dry bulb); 61°F (wet bulb)
Minimum winter temperature	- 4°F
Electrical supply	One or three phase available
Condenser unit	Air cooled

BETHEL BUILDING

This scenario describes a 38' x 40' room located in Bethel, Alaska, expected to hold 200,000 pounds of headed and gutted salmon at -10°F. Refrigeration in all cases uses R-502 refrigerant: vendor 1 specified a 7.5 HP refrigeration unit and vendor 2 specified two 6 HP units.

The foundation would be a wood beam-and-joist structure capable of supporting a fully loaded building with a safety factor of 1.3. Costs, support loads, and architects and engineers fee were taken from Means (1991). It is assumed that such a wooden foundation is necessary in the permafrost conditions of western Alaska.

Because floor space for this freezer exceeds 400 square feet, the cost of a dry pipe sprinkler system (ordinary hazard, which includes applications to cold storage systems) is estimated according to Means (1991). The estimate includes a 4 inch standpipe, distribution, and valving. It does not include external pumps and attachments that may be necessary.

Figure 19. **Room layout for Bethel Building**

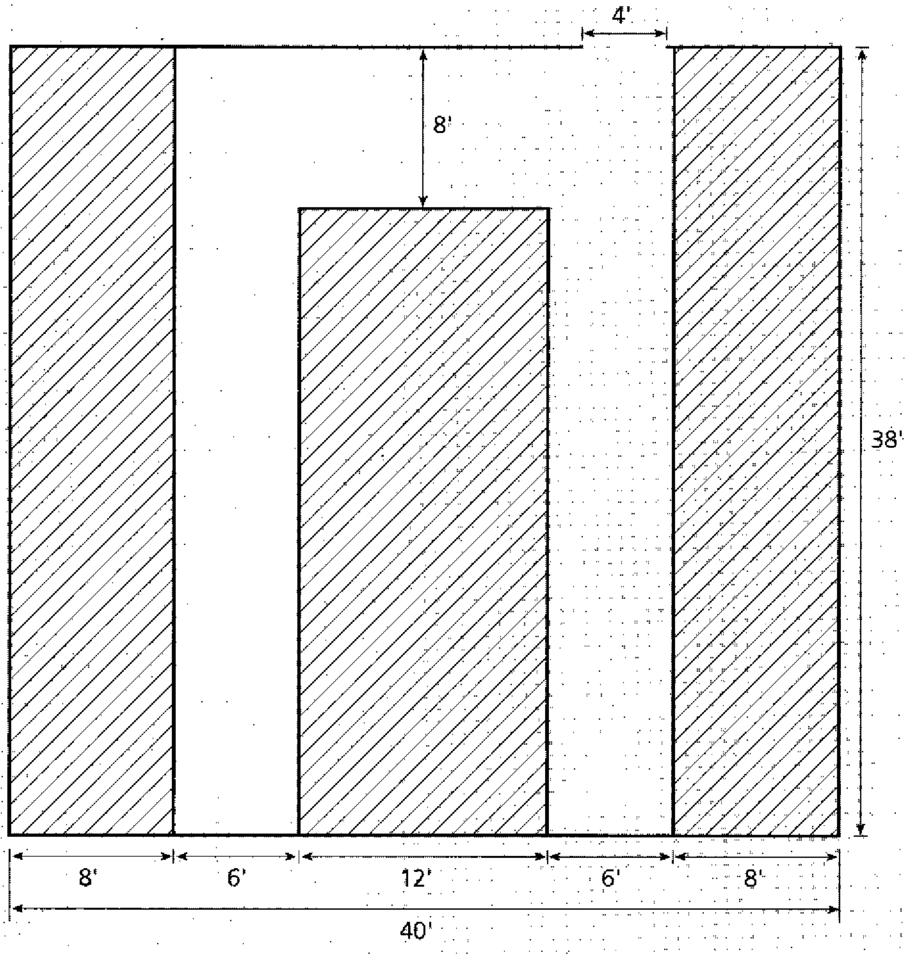


Table 15. Estimated costs for Bethel Building

	Vendor 1	Vendor 2	Vendor 3
Box	87,750	43,220	54,130
Lights	260	included	included
Warranties	1,000		
Refrigeration equipment	15,810	13,680	14,000[a]
Trucking to Seattle and in Bethel	2,210	900	200[a]
Barge to Bethel	11,310[b]	15,500	5,400
Foundation	23,450[a]	23,450[a]	23,450[a]
A&E (9% of foundation and box)	2,110[a]	2,110[a]	2,110[a]
Sprinkler system	9,270[a]	9,270[a]	9,270[a]
Installation (box and refrigeration)	12,560[a]	12,560[a]	12,560[a]
10% contingency	16,570	12,070	12,110
TOTAL	**$182,300**	**$132,760**	**$133,230**

a. Estimated by author
b. Estimated by commercial shipping company
A&E = Architecture and Engineering

Table 16. Cold Storage Project 3
Bethel, Alaska

General	
Type of store	Outdoor, free-standing, single-story building
Location	Bethel, Alaska
Application	
Amount and type of product	200,000 lb, headed/gutted salmon in cartons
Storage temperature	-10°F
Rate and temperature of new product loaded	Max. of 3,500 lb per day at 5°F
Number of door openings per day	Max. of 10
Worker and machinery activity in room	1 worker, brief periods, electric pallet truck
Construction and Assembly	
Estimated total room volume	15,200 ft^3
Suggested layout	40'x38'x10'ceiling, door at one end
Maximum snow load	25 psf
Maximum wind	100 mph
Door	Hinged, 4 foot (min.) width
Accessories	Door frame heater, lights, pressure equalizer ports, dial thermometer on external wall
Foundation preparation	On wooden/piling foundation appropriate to local permafrost restrictions
Method of shipping construction goods	Barge from Seattle
Assembly	Vendor will subcontract
Foundation	Buyer will subcontract
Hook up refrigeration	Buyer will subcontract
Local codes that may influence	Sanitation (Alaska Department of Environmental Conservation)
Refrigeration	
Maximum summer temperature	70°F (dry bulb); 59°F (wet bulb)
Minimum winter temperature	- 27°F
Electrical supply	One or three phase available
Condenser unit	Air-cooled

KENAI COLD STORE

The Kenai Cold Store is a single story facility in Kenai that can store up to 500,000 pounds of headed and gutted salmon and dressed halibut in cartons at -20°F. Table 18 defines this scenario in some detail; the layout is in Figure 20.

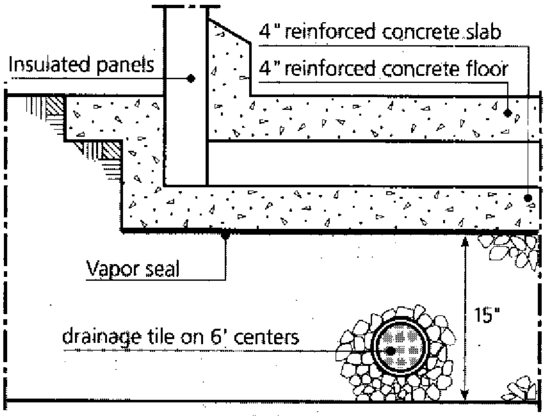
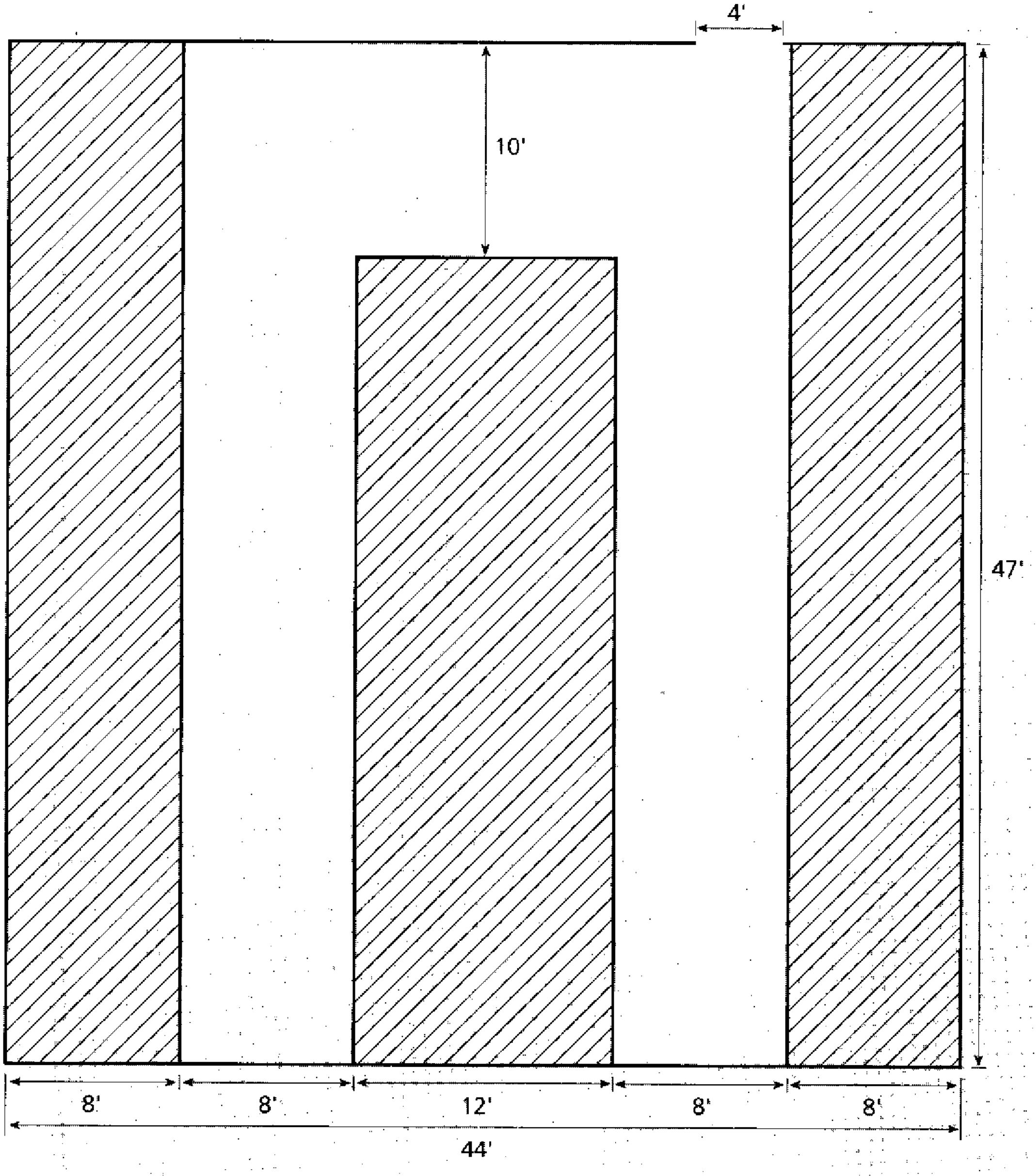


Figure 20. **Layout for storage of Kenai Cold Store**

Figure 21. **Foundation assumed for Kenai and Kodiak Cold Stores**



A diagram of the foundation, the cost of which was estimated from Means (1991), appears in Figure 21. Design includes one footing (3' x 3' x 12" deep) under each support post (12 in Kenai Cold Store, 30 in Kodiak Cold Store).

The vendor in Table 17 specified 4 inches of urethane insulation all around, a single, manually operated sliding door, and a single 30 HP refrigeration compressor using R-502. Shipping was calculated based on a total equipment weight of 54,000 pounds (with an assumed loading density of 13 pounds per cubic foot). Costs for racks to allow stacks of four pallets were estimated from the square foot costs of an existing project.

Table 17. Estimated costs for Kenai Cold Store

	Vendor 1
Box	141,300
Lights	690
Racks	20,680[a]
Refrigeration equipment	59,390
Trucking to Seattle	3,410
Sea shipping to Anchorage	19,190[b]
Trucking, Anchorage to Kenai	4,920[b]
Foundation	20,170[a]
A&E (9% of foundation and box)	14,530
Sprinkler system	13,220[a]
Installation (box and refrigeration)	26,400[c]
10% contingency	32,390
TOTAL	**$356,290**

a. *Estimated by author*
b. *Estimated by commercial shipping company*
c. *Estimated by author with input from refrigeration contractor*
A&E = Architecture and Engineering

Table 18. Cold Storage Project 4 Kenai, Alaska

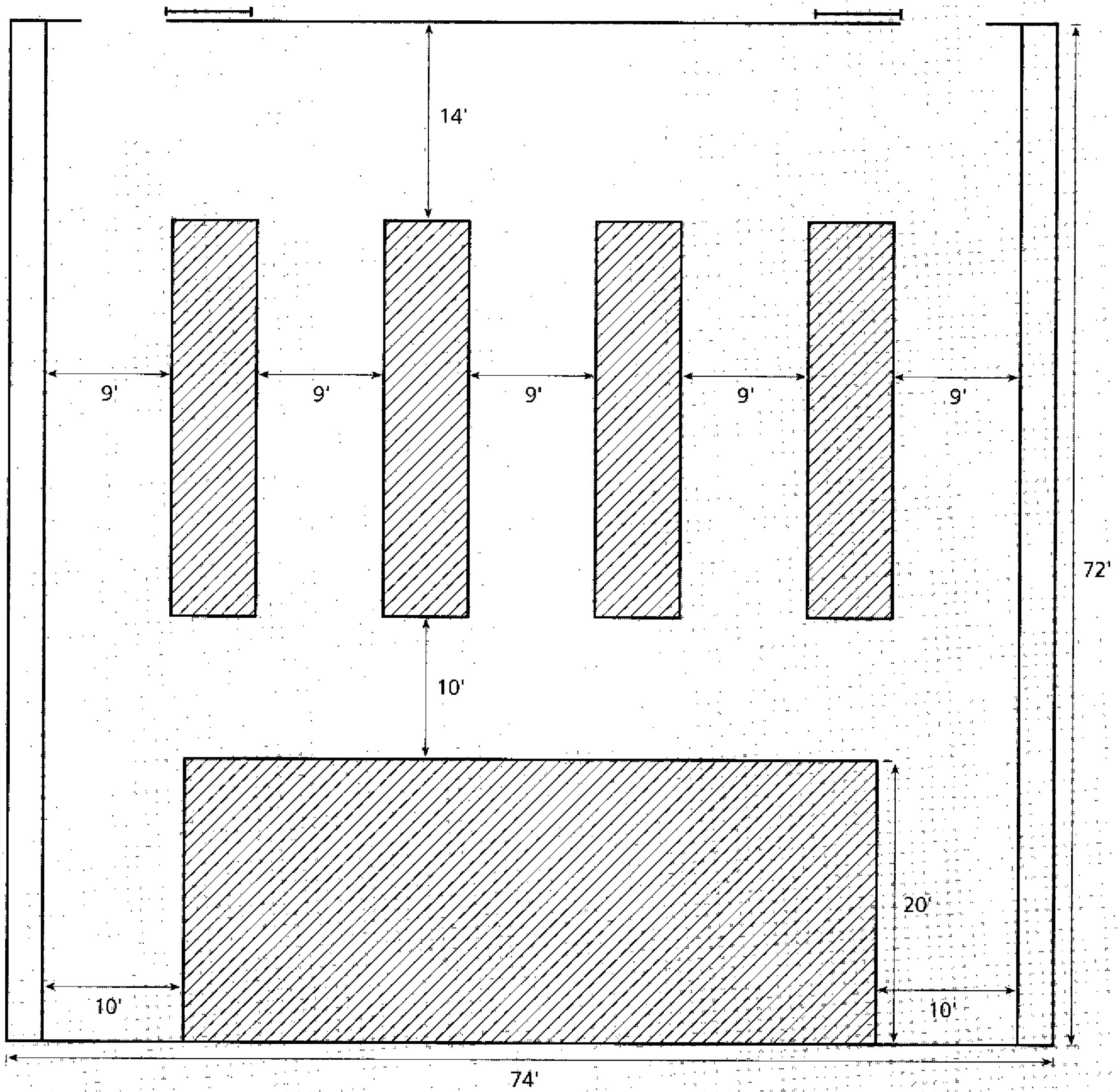
General	
Type of store	Outdoor, free-standing, single-story building
Location	Kenai, Alaska
Application	
Amount and type of product	500,000 lb, headed/gutted salmon in cartons, halibut in boxes
Storage temperature	-20°F
Rate and temperature of new product loaded	Max. of 20,000 lb per day at 5°F
Number of door openings per day	Max. of 50
Worker and machinery activity in room	2 workers and electric forklifts
Construction and Assembly	
Estimated total room volume	37,200 ft^3
Suggested layout	44'x47'x18' ceiling, door at one end
Maximum snow load	40 psf
Maximum wind	100 mph
Door	Sliding on track, 6' (min.) width
Accessories	Lights, pressure-equalizer ports, external-reading thermometers for two internal locations. Vendor will supply racks to permit 4-high pallet stacks (2 and 2).
Foundation preparation	Insulated/ventilated concrete as necessary
Method of shipping construction goods	Barge from Seattle (trucking also possible)
Assembly	Vendor will subcontract
Foundation	Vendor will subcontract
Hook up refrigeration	Vendor will subcontract
Local codes that may influence	Sanitation (Alaska Department of Environmental Conservation), fire protection/sprinkler system
Refrigeration	
Maximum summer temperature	71°F (dry bulb); 58°F (wet bulb)
Minimum winter temperature	- 7°F
Electrical supply	Three phase available
Condenser unit	Air-cooled roof units

KODIAK COLD STORE

The Kodiak Cold Store consists of a one million pound capacity, -20°F storage room in Kodiak according to the specifications of Table 20. The layout of Figure 22 allows access to a variety of products on a rack system supporting 4-high pallet loading. Two manual sliding doors are included in the box design and estimate. One vendor supplied a partial list of cost estimates, which are included in Table 19. A second vendor gave an estimate of $122,450 (FOB Seattle dock) for just the panels, doors, and floor and ceiling insulation. This would have to be housed and installed within a metal building constructed for the job.

The refrigeration is supplied by two 31 HP units operating on R-502. The foundation is

Figure 22. **Layout plan for Kodiak Cold Store**



constructed as a double insulated slab as shown in Figure 21. In this case, 30 columns and footings are included to support an internal steel frame similar to that shown in Figure 4. Because of the complexity of the structure with 25-foot ceilings, the 9 percent architecture and engineering cost was calculated on the basis of both the foundation and the box structure.

Table 19. Estimated costs for Kodiak Cold Store

	Vendor 1
Box	407,590
Lights	1,720
Racks	54,300
Refrigeration equipment	139,220
Trucking to Seattle and in Kodiak	10,690
Sea shipping to Kodiak	21,890[a]
Foundation	52,870[b]
A&E (9% of foundation and box)	41,440
Sprinkler system	23,320[b]
Installation (box and refrigeration)	50,470[b]
10% contingency	80,350
TOTAL	**$883,860**

a. Estimated by commercial shipping company
b. Estimated by author
A&E = Architecture and Engineering

Table 20. Cold Storage Project 5 Kodiak, Alaska

General	
Type of store	Outdoor, free-standing, single-story building
Location	Kodiak, Alaska
Application	
Amount and type of product	1,000,000 lb of mixed products to include headed/gutted fish, packaged fillets, blocks
Storage temperature	- 20°F
Rate and temperature of new product loaded	Max. of 60,000 lb per day at 0°F
Number of door openings per day	100
Worker and machinery activity in room	Daily activity with two electric fork-lift trucks
Construction and Assembly	
Estimated total room volume	133,200 ft^3
Suggested layout	74'x72'x25'ceiling; two doors in one side
Maximum snow load	20 psf
Maximum wind	110 mph
Door	Sliding on track; 8' width
Accessories	Door heaters. Lights, pressure equalizer ports, external-reading thermometers for two internal locations. Vendor will supply rack system to permit 4-high stacking (2 and 2) according to suggested layout.
Foundation preparation	Insulated/ventilated concrete as necessary
Method of shipping construction goods	Barge or container ship from Seattle
Assembly	Vendor will subcontract
Foundation	Vendor will subcontract
Hook up refrigeration	Vendor will subcontract
Local codes that may influence	Sanitation (Alaska Department of Environmental Conservation), fire protection/sprinkler system
Refrigeration	
Maximum summer temperature	70°F (dry bulb); 57°F (wet bulb)
Minimum winter temperature	10°F
Electrical supply	Three phase available
Condenser unit	Air-cooled roof units

Part II Storing Frozen Product

Chapter 4: Seafood Temperature and Shelf Life

When chilled storage of seafood does not allow enough holding time, the best way to preserve quality is to freeze it and hold it in frozen storage. Chilled storage provides at best a few weeks of shelf life, whereas frozen storage provides a few months to more than a year for fishery products that have good storage characteristics.

Frozen storage has several important advantages:

- *Fishing vessels can harvest on grounds farther from the port where they will be landing the catch, and they can fish longer when necessary to get a large-enough catch to make the trip profitable.*
- *The large increase in storage life allows processors and wholesalers to hold inventories for a longer time.*
- *The increased storage life allows products to be shipped greater distances, with the potential of opening up new markets.*
- *Frozen storage allows year-round marketing for species such as salmon, which are harvested over a short time each year.*
- *If freezing is carried out soon after harvest, a higher quality product results than for fish kept in chilled storage until marketed.*
- *Building internal freezing and cold storage facilities in developing countries provides export opportunities for a wider range of fishery products. The same is true for Alaska, which is a long distance from the markets for its seafood products.*

THE PROCESSES OF QUALITY LOSS

During frozen storage, food is held at a temperature where bacterial changes are stopped and enzyme action is greatly retarded. Freezing and frozen storage conditions are much more critical for seafood than for other foods. Although freezing conditions are not discussed in this report, it is certainly important to use proper freezing procedures, especially to avoid slow freezing rates. A freezing rate at which the product is frozen in 8 hours or less is satisfactory. However, most deteriorative changes occur during frozen storage rather than during freezing, and these changes are the subject of this chapter.

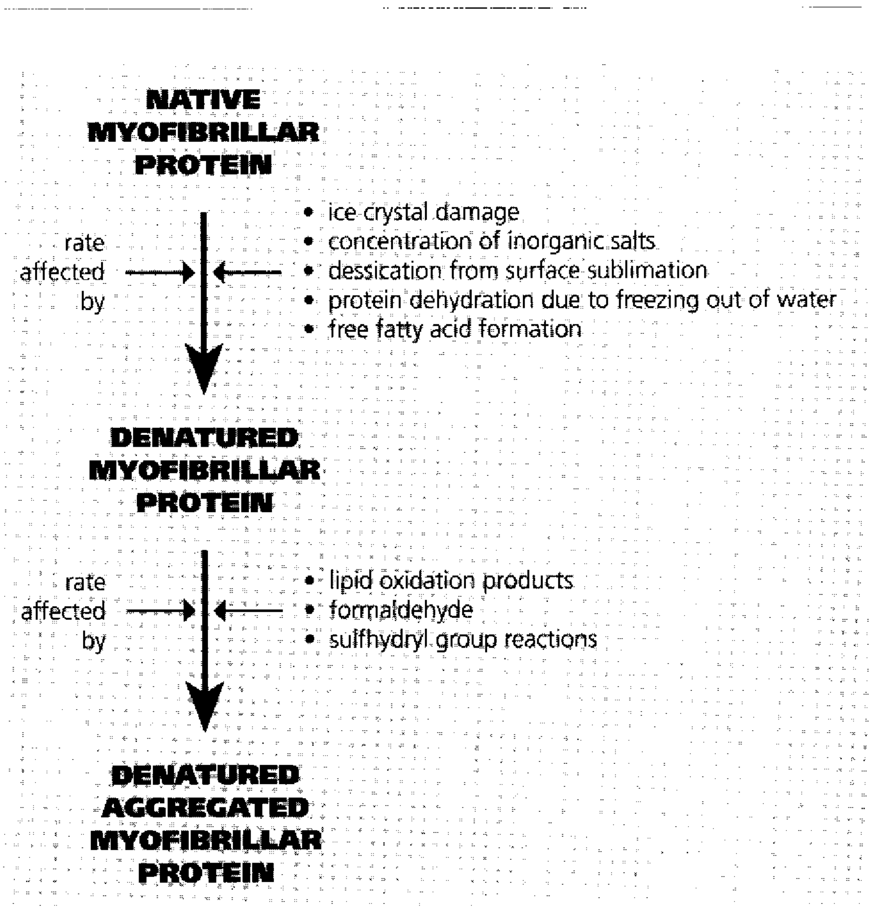
In today's world market, competition from farmed fish and shellfish makes it necessary for frozen fishery products to be of the highest quality, especially frozen salmon and frozen shrimp. Storing seafood below 15°F stops the growth and multiplication of bacteria. Enzyme action, however, is not slowed sufficiently to make this a good temperature for storing frozen seafood. For very short storage periods, 0°F or lower is needed. For longer storage times or for fishery products that do not have very good storage characteristics, a holding temperature of -20°F or lower is necessary.

Protein Denaturation

One of the two major losses of quality in fish muscle during frozen storage is the development of a toughness and dryness that is related to protein denaturation (Sikorski et al., 1976). It is the major cause of quality loss during frozen storage of lean fish. Taste panels describe the cooked fish as tough, fibrous, chewy, and rubbery. The cause of the toughness is protein denaturation and aggregation accompanied by loss of water-holding capacity. This results in high thaw drip loss and cook drip loss. Ice crystallization contributes to denaturation of the protein by disrupting the water structure around hydrophobic areas of the protein and by breaking up the water-mediated hydrophobic-hydrophilic interactions (Sikorski and Kolakowska, 1990).

Protein denaturation involves the myofibrillar protein, specifically the actin-myosin-actomyosin system, tropomyosin, and whole myofibrils. Denaturation consists of an alteration of the secondary and tertiary protein structure with the breaking of hydrogen, hydrophobic, and ionic bonds but not covalent bonds. Subsequently, there is some reformation of bonds, leading to protein aggregation. This aggregation may be due to non-covalent cross-linking (both intermolecular and intramolecular) of muscle proteins, in particular myosin.

Figure 23. **Protein denaturation and aggregation**



During freezing and frozen storage of fish, adverse effects leading to protein denaturation and aggregation are caused by several factors. These include the concentration of inorganic salts, free fatty acid formation, reaction with the products of lipid oxidation, and formation of formaldehyde in some members of the family Gadidae by the enzymic breakdown of trimethylamine oxide (Tokunaga, 1974). These relationships appear in Figure 23.

Reducing the rate and amount of protein denaturation depends on good quality raw material, low storage temperatures with minimum temperature fluctuation, and proper packaging to prevent desiccation. The rate of protein denaturation decreases as storage temperature decreases. Seafood studies have shown that a storage temperature of -20°F or lower is needed to provide a long storage time.

Oxidation Reactions

The second of the two major causes of quality loss during frozen storage of seafood is lipid oxidation, the most important cause of quality loss in fatty fish. Lipid oxidation causes loss of flavor and nutrition. The result is the unpleasant odor and flavor called rancidity. In chill-stored fish, bacterial spoilage lowers the quality to "poor" before appreciable lipid oxidation occurs. Bacterial spoilage is retarded in fish stored frozen, and very often rancidity becomes a problem. Fatty fish such as herring can become rancid in a month or less if storage conditions are not controlled.

Seafood lipids are healthful, but they are susceptible to oxidation because the fatty acids are highly unsaturated. In fish, as much as one-third of the fatty acids are unsaturated. The oxidation of unsaturated fatty acids proceeds by a free-radical mechanism involving the formation of hydroperoxides and their subsequent breakdown to aldehydes, ketones, alcohols, short-chain fatty acids, and other hydrocarbons. Volatile carbonyl compounds are thought to cause rancid odor and flavor.

The rate of oxidation depends on lipid composition, the presence of catalysts or antioxidants, pH, and storage temperature. Free fatty acids formed by the hydrolysis of triglycerides are more susceptible to oxidation, whereas those formed by hydrolysis of phospholipids are less susceptible.

Oxidation reactions also cause undesirable color changes. Oxidation of carotenoid pigments is responsible for fading flesh color in fish such as salmon and of skin color in several species of rockfish and some shellfish. In some fish and shellfish with white or creamy white flesh, oxidation reactions cause yellowing or darkening during long-term cold storage. The term "rust" or "rusting" refers to the migration of oil to the surface of fish during cold storage, giving a yellow or light brown discoloration. The rust discoloration has been attributed to Maillard-type reactions of amino acids or free amino groups of proteins with reducing sugars or with some lipid oxidation products.

To prevent undesirable oxidative changes, keep oxygen away from the seafood product. This can be done by glazing to provide a covering of ice, packaging with an oxygen-impermeable material, and using an antioxidant in a dip or glaze. The most effective protection is vacuum packaging, using a film with low permeability to oxygen in combination with an antioxidant dip such as sodium erythorbate.

Enzyme Activity

Freezing does not inactivate the enzymes in food. In fact, enzymes are responsible for destructive changes that take place during freezing and frozen storage. An example is soft texture caused by breakdown of muscle connective tissue by proteolytic enzyme action. For vegetables, blanching or applying enough heat to inactivate enzymes provides longer frozen storage life. Except for crab and shrimp, however, most seafood is frozen without heat treatment.

Low temperature is important in reducing unwanted enzyme activity. Below about 15°F, enzyme-catalyzed reaction rates decrease. At 0°F, they are slow enough to allow short storage times for fishery products with good-to-excellent frozen storage characteristics. For longer frozen storage times and for fishery products with fair-to-poor storage characteristics, a temperature of -20°F or lower is needed. Species with fair-to-poor storage characteristics include those with high lipid content and those with enzymes that catalyze the change of trimethylamine oxide to dimethylamine and formaldehyde.

The usual effect of lower temperature on a chemical reaction is to decrease the reaction rate. Experimental work with several different enzymes in fish and shellfish shows that reaction rates are higher when fish muscle is partially frozen in the 15 to 30°F temperature range (French et al., 1988; Nowlan and Dyer, 1969; Toyomizu and Shono, 1972). Protein hydrolysis is fastest at 26 to 28°F, phospholipid hydrolysis is most rapid at about 25°F, ATP breakdown is highest at about 29°F, and glycoside breakdown at 25 to 26°F. These high rates are due to a concentration of enzymes and reactants caused by the freezing of water molecules. Also, large ice crystals disrupt cells, releasing enzymes and increasing the susceptibility of the tissue to enzyme breakdown.

The temperature zone from 30° down to 23 or 24°F has been called the "critical zone." Avoid long, slow freezing conditions that hold the product in the critical zone longer than absolutely necessary. Holding at partial freezing or superchilling temperatures has been used successfully to transport salmon intended for canning, because bacterial action is greatly reduced at these temperatures and is very slow at the low end of this range. Fish intended to be frozen, however, should never be kept in the critical zone.

Lipid Hydrolysis

During frozen storage of fish, lipids hydrolyze to free fatty acids. Both phospholipids and triglycerides are hydrolyzed, with the phospholipids being the more susceptible of the two. Cholesterol esters and waxes undergo very little change during frozen storage. The rates of phospholipid and triglyceride hydrolysis vary with species and storage temperature.

The fish lipases that hydrolyze lipids resist low temperatures and continue to be active in frozen tissue. In some cases, there is an increase in the amount of active enzymes released during freezing. However, the usual effect of temperature on chemical reactions, including those catalyzed by enzymes, is a slowing of the reaction rate as the temperature is lowered. An exception is the temperature zone a few degrees below the freezing point of water, where the reaction rate of lipid hydrolysis *increases* rather than decreases. Below 15°F the reaction rate decreases gradually, although lipid hydrolysis doesn't stop completely even at -20°F.

The free fatty acids formed in seafoods by lipid hydrolysis do not themselves lower product quality. The increase in free fatty acids is associated with the denaturation of myofibrillar protein and the resulting undesirable texture. The increase of free fatty acids also affects the rate of oxidative lipid changes.

Dessication

Dehydration of frozen seafood products is a common cause of quality loss, but it is much more easily prevented than protein denaturation and lipid oxidation. Moisture loss shows up as frost on freezer walls, cooling coils, and the inside of packages prepared for retail markets.

Moisture loss results in undesirable changes in texture and flavor loss due to loss of volatile components. Weight loss is also an economic loss. In products prepared for retail market, this weight loss can cause packages to fall below the declared weights. Dehydration in an advanced state is called freezer burn. In extreme freezer burn, the skin of the fish has a dry, wrinkled look, the surface takes on a dull, chalky-white color, and the flesh becomes dry and tough. Desiccation of seafood accelerates the rate of both protein denaturation and lipid oxidation.

Prevent desiccation by glazing or by packaging with material having low permeability to water vapor. Fluctuating storage temperatures increase moisture loss, and should be minimized. The operator must avoid fluctuations in cold storage temperature caused by (1) adding warmer products, (2) leaving doors open, (3) starting and stopping refrigeration machinery, (4) lack of air curtains, and (5) small package size. To avoid dehydration of unwrapped, unglazed fish or fish products, keep the relative humidity as high as possible. A relative humidity of 85 to 90 percent usually is adequate, but special design of the cold store can give a relative humidity of 98 percent or higher if needed. Generally, operating a cold store with high humidity is not advisable because of ice buildup. Avoid the need for high humidity by storing seafood wrapped or glazed.

THE CAUSES OF QUALITY LOSS

> *Most quality deterioration in frozen seafood occurs after freezing, unless unusually slow freezing rates are used and the product is held for a long time in the critical zone (23 to 30°F). The rate of quality loss of frozen seafood depends on the storage temperature and amount of temperature fluctuation.*
>
> *The quality of any frozen food also depends on the "PPP" factors, or product-processing-packaging. "Product" refers to quality of the raw material, "processing" refers to the product form, and "packaging" refers to the protection used to avoid the problems of desiccation and oxidation.*

Raw Material Quality

The production of high quality frozen seafood products is critical to meet the standards imposed by producing companies, by customers, by country of origin, and by importing countries. Freezing does not improve fish quality. If freezing and cold storage are properly carried out, however, the quality of the fish will be maintained very close to what it was at the time of freezing. Consequently, good quality frozen seafood requires good quality raw material. There are two aspects of raw material quality: (1) intrinsic quality, and (2) prefreezing treatment.

Intrinsic quality is the quality or value of the fish when it is harvested. The harvester can't change or control intrinsic quality. Important factors that affect intrinsic quality are species, sex, fishing ground, nutritional condition, size, maturity, season, food consumed, parasites, and environmental contaminants. They all affect the raw material quality and the price the fisherman gets for his catch.

Prefreezing treatment is handling and storage of the raw material between catching and freezing. The fisherman and fish processor control the prefreezing treatment, which includes:

- *length of time between harvesting and freezing*
- *holding temperature*
- *stage of rigor mortis when freezing*
- *processing procedures (product form)*

These factors are just as important as intrinsic quality factors. Fish subjected to improper prefreezing treatment will not be of high quality even if they get excellent treatment during freezing and frozen storage.

Seafood treatment should be as good for fish in-

Table 21. **Relative rates of seafood spoilage and loss of equivalent days on ice for different temperatures and times**

Temperature		Relative rate of spoilage = r	Equivalent days on ice as a function of initial time at elevated temperature							
°C	°F		4 hr	8 hr	12 hr	18 hr	24 hr	36 hr	48 hr	72 hr
-2	28.4	0.64	0.1	0.2	0.3	0.5	0.6	1.0	1.3	1.9
0	32.0	1.00	0.7	0.3	0.5	0.7	1.0	1.5	2.0	3.0
2	35.6	1.44	0.2	0.5	0.7	1.1	1.4	2.7	2.9	4.3
4	39.2	1.96	0.3	0.6	1.0	1.5	2.0	2.9	3.9	5.9
6	42.8	2.56	0.4	0.8	1.3	1.9	2.6	3.8	5.1	7.9
8	46.4	3.24	0.5	1.1	1.6	2.4	3.2	4.9	6.5	9.7
10	50.0	4.00	0.7	1.3	2.0	3.0	4.0	6.0	8.0	12.0
12	53.6	4.84	0.8	1.6	2.4	3.6	4.8	7.3	9.9	14.5
15	59.0	6.25	1.0	2.1	3.1	4.7	6.2	9.4	12.5	18.7

A relative spoilage rate (r) is a comparison to the rate for a product held at 32°F for 24 hours (where r is equal to 1). Because of biological variability within a species, numbers are only meaningful to one place past the decimal point.

tended to be frozen as for fish intended for the fresh market. All fish and shellfish should be chilled quickly and completely immediately after catching, with ice or with chilled or refrigerated sea water. Hold raw herring and other small or fatty fish at 32°F for 1 day or less. Hold raw halibut and other species with good-to-excellent frozen characteristics at 32°F for 3 to 5 days or less. Estimate loss of raw material quality from holding at higher temperatures from Table 21 (Doyle, 1989). It is important to keep the chilled storage temperature as close as possible to 32°F, and to keep the chilled storage time as short as possible.

Only the highest quality raw material should be used to prepare frozen products. Poor quality frozen seafood is too often caused by freezing stale fish. The practice of freezing seafood near the end of its chilled storage life must be eliminated. When lower quality frozen seafood is the result of a delay in freezing, the product should be labeled and sold as a cheaper brand in markets where lower quality is acceptable.

Holding Temperature

Holding temperature affects the storage life of frozen seafood more than any other factor. The holding temperature must be low enough to stop or greatly retard bacterial action, enzyme changes, and nonenzyme chemical reactions.

Lowering the temperature of frozen seafood decreases the rate of deterioration at all temperatures except in the critical freezing zone (23 to 30°F), where enzyme-catalyzed reactions increase. Below about 15°F, bacterial growth and replication stops. At 0°F, enzyme and other chemical reactions are slow enough to allow storing frozen seafood for short periods. A storage temperature of -20°F is needed to store frozen seafood for longer periods, and to store fish or shellfish with high lipid content or high enzyme activity. Higher temperatures cause flavor loss and nutritional loss.

Tables 22 and 23 give frozen storage characteristics of some Pacific fish and shellfish. Species differ considerably in the length of time they will retain high quality in frozen storage. For many species, an extremely wide range of frozen storage times is reported in the literature. This is due to variation in intrinsic quality and handling of the raw material, and variation in how the end point of storage life is determined. Learson and Licciardello (1986) found literature values for the shelf life of haddock at 0°F to range from 24 to 72 weeks, a three-fold difference.

When using Tables 22 and 23, it is important to consider the following points:

1. The time and temperature values in the tables are from scientific literature, and from fish processors and fisheries technologists involved in handling and storage research. Few references give values that can be put directly into the tables, since a variety of methods were used to determine end of shelf life. Some researchers used sensory methods, while others used chemical methods. Those who used sensory methods evaluated raw fish in some cases and cooked fish in other cases. Consequently, literature values were used only as a starting point and were modified after input from processors and researchers. The modified values appear in the tables.

2. Experimental values for storage life of frozen seafood are often not comparable. Chemical analysis data often does not correlate with sensory analysis data. In addition, sample size and control samples are sometimes not adequate to measure quality loss.

3. The storage times given in the tables should be regarded as the best attainable. The raw material is top quality, handling and processing are as good as possible, and protection is provided during storage by glazing or by packaging in material with low oxygen and water vapor permeability. Under normal commercial conditions, seafood may not store as well as indicated by the tables.

4. The maximum storage temperature values in the first two columns of Tables 22 and 23 are not comparable to the storage life values in the second two columns (see the two footnotes for these tables). Temperatures in the first two columns provide what Sikorski and Kolakowska (1990) called high quality life (HQL). HQL is the storage time of initially high quality product to the moment when the first statistically significant difference in quality appears. The product is maintained very close to the quality of a properly chilled fresh product no more than a few days after harvest.

The shelf life values in the second two columns give what Sikorski and Kolakowska called practical storage life (PSL). PSL is the storage time during which the product retains its suitability for human consumption. The ratio of PSL over HQL is usually between 2 and 5. The storage life values in the second two columns of the tables may be slightly lower than the PSL of Sikorski and Kolakowska, as the definition of practical shelf life used here presumes the quality is not simply suitable for consumption but is high enough to be considered "good" and a consumer would likely purchase it again.

5. Although we give single values in the two tables rather than a range of temperatures or storage times, the variation within species is large enough so that in some cases a range may be much more appropriate. For example, chinook salmon from the Yukon River may have very different storage characteristics from chinook salmon from Cook Inlet.

Although cold storage temperature is the most important influence on storage life of frozen seafood, other factors can also be very important. The seafood industry has a great need for the manual proposed by Learson and Licciardello (1986), with standardized methods of measuring frozen storage life of seafood.

Temperature Fluctuation

Storage temperature fluctuation is another factor that decreases frozen shelf life. It is impossible to keep food in frozen storage at a constant temperature, because of the cyclical operation of the refrigeration equipment and movement of product in and out of storage during transport from processor to wholesaler to retailer.

For fish or fish fillets stored at 0°F, fluctuations in temperature to 15°F (as may occur during transport) are very detrimental (Dyer et al., 1957). Considerable deterioration takes place, reducing shelf life greatly. For seafood products held at -20°F, fluctuations to -15 or -10°F cut storage life to one-half and fluctuations to 0° cut shelf life to one-third. The effects of temperature fluctuation are cumulative. Shelf life loss can be estimated if a record of storage temperature is kept and storage characteristics of the species are known.

The problems with quality loss caused by fluctuating storage temperature are mainly due to ice recrystallization, moisture loss, and enzyme or other deteriorative chemical reactions. Reformation of ice crystals damages tissue structure and may lead to undesirable texture. The tissue damage increases the rates of dehydration and deteriorative chemical changes. Moisture loss due to sublimation of the ice at or near the product surface can be a serious problem in unpackaged raw material and in products with poor packaging. Frost or ice may form on the inside of seafood retail packages as the

Table 22. Frozen storage temperature and storage life for marine fish and fish products

Product		Maximum storage temperature (°F)		Storage life (months)		References
		2 months to consumption	6 months to consumption	0°F	-20°F	
H&G salmon	Chinook	-10	-20	8	14	6, 21, 27, 32, 39, 51, 89
	Chum	-15	-20	4	8	
	Coho	-10	-20	6	10	
	Pink	-15	-30	3	6	
	Sockeye	-10	-20	7	12	
Pacific cod	H&G	-5	-15	9	18	6, 21, 27, 32, 33, 34, 43, 44, 48, 51, 81
	IQF fillets	-10	-20	7	12	
	Fillet blocks	-10	-20	8	15	
Alaska pollock	H&G	-10	-20	8	14	6, 7, 19, 27, 33, 34, 42, 48, 85
	IQF fillets	-15	-20	6	10	
	Fillet blocks	-10	-20	7	12	
	Surimi	-22	-22	6	12	
Pacific halibut	H&G	0	-10	10	20	21, 27, 34, 48, 49, 81, 82
	Fletches	-10	-20	8	16	
Flounder/sole	Arrowtooth	-10	-20	6	10	27, 33, 34, 51, 81
	Dover	0	-10	10	18	
	Flathead	0	-15	10	18	
	Greenland turbot	-10	-20	8	14	
	Rock	0	-10	10	18	
	Yellowfin	5	-20	9	16	
Rockfish	Pacific ocean perch	0	-10	8	14	21, 32, 48, 49, 51, 81
	Yelloweye	0	-10	8	14	
	Dusky	-20	-30	5	9	
Sablefish		-5	-15	8	14	21, 27, 34, 81
Herring		-20	-30	2	6	9, 10, 27, 34, 43, 48
Herring roe		-10	-20	8	14	6
Salmon shark		-10	-20	9	12	

H&G = Headed and gutted. IQF = Individually quick frozen

Storage temperatures given are the highest that will still allow minimal loss of quality. At the end of the frozen storage period, the product will be almost as good as fresh fish that has been held properly chilled and is within a few days after harvest.

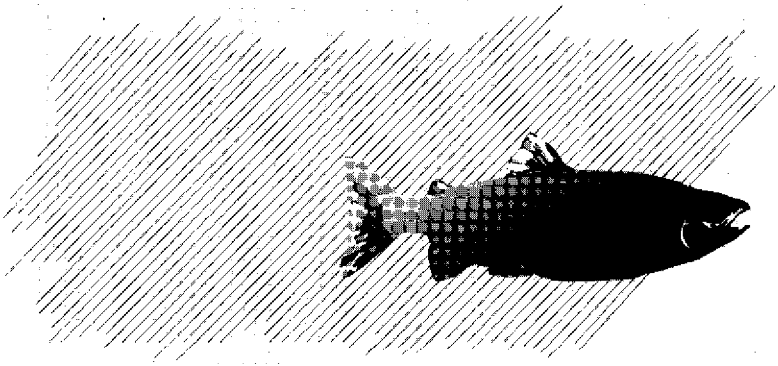
Storage life is defined as the length of time the product remains in a condition that can be described as good quality. Consumers purchasing this product would be likely to purchase it again. At longer storage times, the product will be of fair to poor quality. Although it may still be edible, it is not the quality of seafood that the industry should be marketing.

Table 23. Frozen storage temperature and storage life for shellfish and other marine invertebrates

Product		Maximum storage temperature (°F)		Storage life (months)		References
		2 months to consumption	6 months to consumption	0°F	-20°F	
Spot shrimp	Raw in shell	0	-10	10	15	21, 49
	Cooked meat	-20	-30	4	8	
Pink shrimp	Raw in shell	-10	-15	8	12	6, 18, 21, 49, 51, 65
	Cooked meat	-20	-30	3	6	
Sidestripe shrimp	Raw in shell	0	-10	9	14	
	Cooked meat	-20	-30	4	8	
King crab	Cooked in shell	-10	-20	9	15	6, 18, 21, 51
	Cooked meat	-10	-25	6	9	
Dungeness crab	Cooked in shell	-15	-20	4	8	
	Cooked meat	-20	-30	2	6	
Tanner/snow crab (bairdi)	Cooked in shell	-15	-20	6	12	
	Cooked meat	-15	-30	4	8	
Tanner/snow crab (opilio)	Cooked in shell	-15	-20	6	12	
	Cooked meat	-15	-30	4	8	
Sea cucumber	Raw	0	-5	8	14	75
	Boiled	0	-10	6	12	

Storage temperatures given are the highest that will still allow minimal loss of quality. At the end of the frozen storage period, the product will be almost as good as fresh shellfish that has been held properly chilled and is within a few days after harvest.

Storage life is defined as the length of time the product remains in a condition that can be described as good quality. Consumers purchasing this product would be likely to purchase it again. At longer storage times, the product will be of fair to poor quality; although it may still be edible, it is not the quality of seafood that the industry should be marketing.



result of temperature fluctuation, and consumers often won't buy these products. Fluctuating temperature accelerates a number of chemical changes in seafood. The most important are oxidative changes leading to rancidity (lipid oxidation) and discoloration.

Packaging

Almost as important as temperature control in obtaining maximum shelf life is protection by some type of packaging. The functions of packaging include the following:

- *Envelope the product to assist in moving it to market.*
- *Protect the product from dehydration, oxidation, contamination, and mechanical damage.*
- *Identify the product to assist in storage management and to provide consumer information.*

Frozen product should be packaged as soon as possible after freezing. The packaging should be strong, waterproof, stain-resistant, and should not contaminate the product. Closeness of fit is also an important property. The packaging material should be impermeable to fats and oils. To reduce the rate of dehydration, the material should have a low permeability to water vapor. To reduce the rate of oxidation, the material should have low oxygen permeability.

Reprocessing

Double freezing describes a storage and processing operation in which the product is frozen, then thawed or partly thawed to facilitate processing, then refrozen. Seafood processors often store fish and shellfish in bulk as frozen raw material, then thaw it to create the final products, and then refreeze some of those products. An example is frozen, dressed halibut, which is sometimes partially thawed for steaking, then frozen for storage.

There is some quality loss during freezing, even with quick freezing. However, if the initial quality is very high (that is, if the first freezing is done with very fresh fish), double freezing can still result in very good quality. Fish frozen at sea are suitable for processing methods in which a second freezing is necessary.

Studies on cod, flounder, and rockfish show that refreezing can result in a very good quality product, especially if the first freezing is done before rigor mortis sets in (MacCallum et al., 1969; Peters et al., 1968; Tomlinson et al., 1969 and 1973). Experimental work with pollock indicates that conditions for the first freezing and for thawing are more important than conditions for the second freezing to obtain a good quality product (Choe et al., 1975).

RECOMMENDED FROZEN STORAGE CONDITIONS

Damage to frozen food from high or fluctuating temperatures cannot be corrected. Temperature abuse fluctuations, even if they are not extreme, can cause a serious damage problem. The following guidelines are important to maintain the quality of frozen seafood.

Time-Temperature-Tolerance

The time-temperature-tolerance (TTT) concept was introduced very early in the study of frozen food stability. TTT uses the time-temperature history of frozen food during storage to describe shelf life (Edhborg, 1965). TTT is based on the following assumptions:

- *For every frozen product, there is a relationship between storage temperature and time stored at this temperature during which the product may change in quality.*
- *Quality loss at different frozen storage temperatures is irreversible and cumulative.*
- *The sequence of quality changes does not influence the total quality change.*

Data from frozen storage studies can be used to produce quality maintenance diagrams, referred to as TTT diagrams (see Figure 24). TTT diagrams show the relationship between storage life and storage temperature and have been developed for many food products. If the three assumptions above are correct, TTT diagrams can be used to evaluate the effect of fluctuating temperature on the quality of a frozen product and to estimate remaining shelf life.

Application of the TTT concept depends first on accurate time and temperature data. Many temperature recording devices are available that can give the needed data.

Second, a satisfactory method of determining the end of shelf life is needed. Storage life must be measured by overall acceptability, which has several limiting factors. The importance of these factors varies greatly depending on species, storage temperature, type of packaging, and others. Taste of the product is usually the limiting indicator, but other indicators (texture, for example) can become more important in overall desirability. Consequently, no single measure of quality, whether physical, chemical or sensory, can be used as a standard measure for all seafood. Because of this, frozen storage stability estimates vary depending on the quality indicator.

Most seafood researchers and processors believe that temperature fluctuation itself is detrimental to the quality of frozen seafood (see discussion of temperature fluctuation on page 39 and discussion of temperature control on page 44). This means that for seafood, quality loss during temperature fluctuation is more than simply a total of the loss at each holding temperature.

Recommended Holding Temperature

When designing a cold storage facility, you should consider all products that will be stored there and the length of time they will be held. If only a few species will be stored and the length of storage is known, Tables 22 and 23 will help in deciding on the holding temperature. A cold store operator should use the lowest practical storage temperature, since he may not know about all the species that will be stored, and some products may stay in storage longer than the time intended.

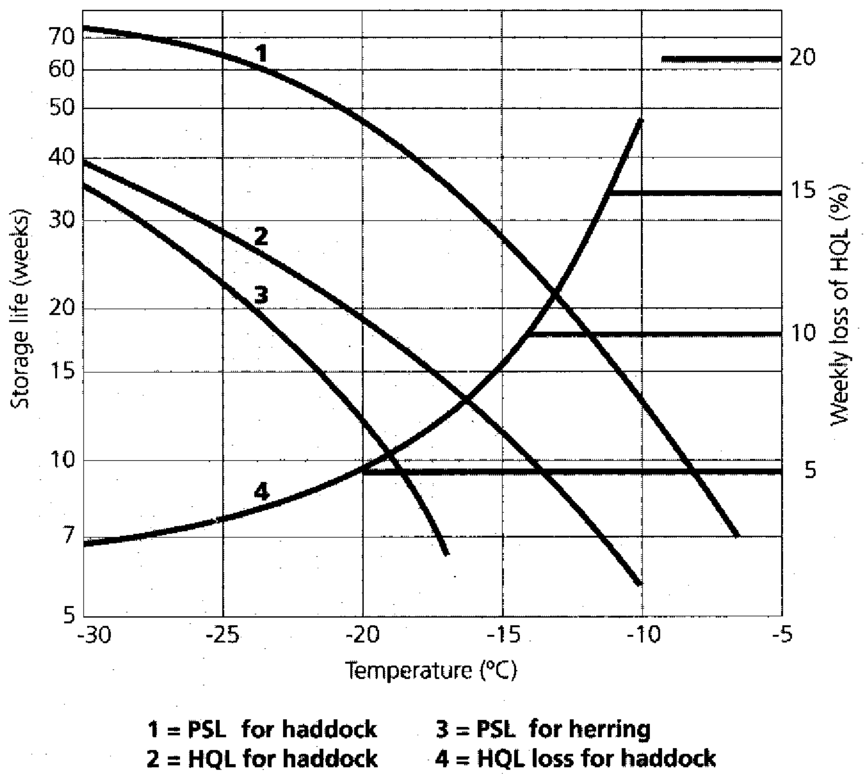
Temperature of the incoming product should be as close as possible to the temperature of the cold storage room to minimize temperature fluctuation in the product. Cold store operators should check temperatures frequently to be sure everything is operating properly and to have a continuous record of product temperature.

The American Frozen Food Institute, the National Fisheries Institute, and the National Frozen Food Association all recommend 0°F as a storage temperature for frozen food warehouses and retail display cases. This may be fine for most foods, but not for seafood. A storage temperature of 0°F is suitable only for some fish and shellfish species held for brief periods. For most species, storage at 0°F results in appreciably lower quality. And for long-term storage of all species, a lower temperature is needed. Any frozen storage temperature above 0°F is unacceptable for seafood.

It is strongly recommended that all seafood be held at -20°F

Figure 24. Time - Temperature - Tolerance (TTT) of frozen haddock and herring

(from Sikorski and Kolakowska, 1990)



HQL (high quality life) is defined as the time of storage of the initially high quality product to the moment when the first statistically significant ($p < 0.01$) difference in quality appears.

PSL (practical storage life) is defined as the period of storage during which the product retains its characteristic properties and suitability for human consumption or intended process.

or lower and that cold storage facilities be designed using this as a guideline. Although -20°F is considered a very good holding temperature for most seafood, even lower temperatures are better. Holding at temperatures below -20°F reduces quality loss and promotes longer shelf life, but it is not economical except in special cases. For extra storage life or for very demanding products (like fatty fish to be held for up to a year), a holding temperature of -30 to -40°F is needed. For fish or shellfish to be used as top grade sushi or sashimi, a storage temperature of -60 to -70°F is recommended.

Temperature Control: Limits of Fluctuation

Temperature fluctuation during frozen storage of seafood is detrimental to quality. It results in tissue damage caused by ice recrystallization and it promotes dehydration. If a frozen storage temperature fluctuates 5 or 10°F, the product storage life is reduced to one-half of what it could be.

Under commercial conditions, a 5 or 10°F fluctuation in frozen storage temperature is not unusual. To avoid temperature fluctuations:

- *Do not leave a door open longer than necessary when adding or removing products from the cold store.*
- *Do not put products into the cold store before they are frozen completely to below the cold store temperature.*

To reduce moisture loss, minimize fluctuations in seafood storage as much as possible. Keep temperature fluctuation to 5°F or less. With a recording thermometer, monitor the cold store and all transit temperatures. A good record of time and temperature during transit will let shippers know where warming of the product occurs and allow them to correct any problems.

Packaging Recommendations

Give considerable thought to the use of packaging to protect frozen seafood from dehydration, oxidation, and contamination. A good packaging material is strong, tight fitting, low in permeability to water vapor, low in permeability to oxygen, and inexpensive (low labor and material costs). The following types of packaging are discussed here:

- *glazing*
- *hydrocarbon polymer films*
- *films made from cellulose*
- *chlorinated polyvinyl chloride films*
- *hermetically sealed metal cans*

Glazing consists of adding a layer of ice to a product by dipping, spraying, or brushing. It is inexpensive, provides a tight fit, and has low permeability to both water vapor and oxygen. Consequently, it provides good protection against dehydration and oxidation. However, glazing is lost by sublimation, and periodic inspection and reglazing are necessary. The glaze is not very strong and will crack off if the product is mishandled. Additives, such as sugar, corn starch, salt, sodium alginate, and carboxymethylcellulose can be added to the glaze water to strengthen the glaze. Antioxidants such as ascorbic acid and sodium erythorbate are sometimes added. Glazing is now used primarily for whole fish. Fish or fish fillets packed as a shatter pack are glazed with an interweaving of waxed paper or plastic sheeting between fish or fillets so they can be taken apart without thawing.

Hydrocarbon polymer films such as polyethylene and polypropylene are strong and inexpensive, but they do not provide a good barrier to water vapor and oxygen. Therefore, they don't prevent dehydration and oxidation. Polyethylene bags are often used to hold glazed seafood products like individually quick frozen (IQF) fillets or shrimp. Also, small whole fish, fish fillets, and shrimp can be frozen with added water in polyethylene bags.

Films made from cellulose, such as cellophane, are not good packaging material for seafood because of their very high permeability to water vapor and relatively high permeability to oxygen.

Chlorinated polyvinyl chloride films (like polyvinylidene chloride or Saran wrap) provide very good protection against dehydration and oxidation, because their permeability to water vapor and oxygen is very low. These are shrink films and can be used in vacuum-packaging processes.

Packing seafood in a metal can that will be evacuated, hermetically sealed, and frozen is an excellent way of protecting against dehydration and oxidation. This process has been used commercially to pack picked crab and shrimp. It is not widely used except for institutional packs, possibly because consumers, mistaking the product for one that has been retorted, may believe it can be stored at room temperature.

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Cold Storage Equipment and Facility Suppliers

Codes for Specialty Services

S	Small walk-ins (to approx. 3,000 cubic feet)
I	Single-story intermediate-size buildings (to approx. 30,000 cubic feet)
L	Large buildings
R	Refrigeration equipment supplied
C	Refrigeration subcontracted

NOTE: This list of services was selected by the authors from literature supplied by each of the vendors. The reader should contact individual companies for a more specific and current range of products and services.

ACCUTEMP, Div. of Frost-Air Inc. (S)
4214 Bertsos Dr.
Las Vegas, NV 89103-3737
(702) 876-7699
(800) 232-2653
Fax (702) 364-2110

ADVANCE COOLER MFG., Div. of Advance Energy Tech. Inc. (S,I,L,R)
P.O. Box 387
Clifton Park, NY 12065
(518) 371-2140
Fax (518) 371-0737

ALCHEM, INC. (I,L)
3617 Strawberry Rd.
Anchorage, AK 99502
(907) 243-2177

BALLY ENGINEERED STRUCTURES, INC. (S,I,L,R)
P.O. Box 98
Bally, PA 19503
(215) 845-2311
(800) 242-2559
or
1675 Crane Way
Sparks, NV 89431
(702) 358-2321

W.A. BROWN (S,I,L)
2001 S. Main St.
Salisbury, NC 28144
(704) 636-5131
(800) 438-2316 (Outside of NC)

CHALLENGER, Div. of Johnson Building Systems Inc. (S,R)
519 MacDade Blvd.
Collingdale, PA 19023
(215) 532-8600
Fax (215) 532-2098

COOL-TEC (S,I,L)
117 23rd SE
Puyallup, WA
(206) 840-1631

ELIASON CORP. (S)
P.O. Box 2128
Kalamazoo, MI 49003
(616) 327-7003
(800) 828-3655
Fax (616) 327-7006

ELLIOTT-WILLIAMS CO. (S,I,L,R,C)
2900 N. Richard Ave
Indianapolis, IN 46219
(317) 545-2295
Fax (317) 545-1977

GLOECKLER REFRIGERATOR CO. (S,R)
P.O. Box 1154
Erie, PA 16512
(814) 838-1928
(800) 426-9566
Fax (814) 833-8642

HUSSMANN CORP. (S,I,L,R)
7272 1st Ave. South
Seattle, WA 98108
(206) 763-9050
(800) 562-8363

IMPERIAL MFG. (S,I,L,C)
10001 N. Polk Ave.
Portland, OR 97203
(503) 286-5816
(800) 238-4093

INTERNATIONAL COLD STORAGE CO. INC. (S,R)
2307 S. Oliver
Wichita, KS 67218
(316) 682-4581
(800) 835-0001
Fax (316) 682-4585

ISOLOC MFG. (S,I,L)
P.O. Box 61522
Vancouver, WA 98666-1522
(206) 695-3230

JOHNSON BUILDING SYSTEMS INC. (I)
4659 Street Rd.
P.O. Box 115
Trevose, PA 19047
(215) 673-6050

JORDON SCIENTIFIC PRODUCTS (S,R)
Div. of Fogel Commercial Refrigeration Co.
5400 Eadom St.
Philadelphia, PA 19137
(215) 535-8300
(800) 523-0171
Fax (215) 289-1597

KALT MFG. CO. INC. (S,I,R)
7320 N.E. 55th Ave.
Portland, OR 97218
P.O. Box 13420
Portland, OR 97213-0420
(503) 288-7311
(800) 547-8043
Fax (503) 249-8452

KYSOR/NEEDHAM (S,I)
4201 Janada St.
P.O. Box 14248
Fort Worth, TX 76117
(817) 281-5121
(800) 633-3426

DAVID A. LINGLE AND SON MFG. (S,I,R)
P.O. Box 519
Russellville, AR 72801
(501) 968-2500

RAM FREEZERS AND COOLERS MFG. INC. (S,I,L,C)
P.O. Box 1664
Miami Springs, FL 33266-1664
(305) 635-2989
(305) 887-1000
Fax (305) 882-1000

TMP ACQUISITION CO. INC. (S,I,R)
P.O. Box 269
Graham St.
Hyde, PA 16843
(814) 765-9615
(800) 233-1954
Fax (814) 765-5410

ZER-O-LOC INC. (I,L)
#119-9757 Juanita Drive NE
Kirkland, WA 98033
(206) 823-4588
Fax (206) 820-9749

SYSTEMS FOR LEASE

GREATLAND GROUP
P.O. Box 93582
Las Vegas, NV 89199-9998

This company leases converted railroad cars with built-in refrigeration equipment, including a diesel-driven electrical generator system for power, if needed. Advertised temperatures go to -20°F.

PORTABLE COLD STORAGE, INC.
7 Centre Drive, Suite 6
Jamesburg, NJ 08831
(609) 395-9279
(800) 535-2445
Fax (609) 395-9283
West Coast rep: Bob King, Marketing
(215) 248-9572

This company leases 20- and 40-foot refrigerated vans that operate on 208, 220, or 440 V 3-phase power. Advertised operating temperatures to -20°F.

STORE COLD DIV.
1601 Oceanic St.
Charleston, SC 29405
(803) 723-6188
Fax (803) 723-4941

This company leases 20- and 40-foot vans that are set on the ground. Refrigeration units operate on 230 or 480 3-phase power. Advertised temperatures to -10°F.

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