CHAPTER

18

Temperature-Controlled Transport for Air, Land, and Sea

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18.1 INTRODUCTION

Fresh produce has been historically grown in areas where quality and yield can be optimized. As great distances often separate high population bases from seasonal production areas, transcontinental and transoceanic shipments of produce by air, land, and sea have been necessary. Much of this produce can be successfully sold and shipped to domestic and foreign markets via air, land, and sea transportation only if the right combination of climate control technology, services, and all-in landed costs[1] are available to shippers, buyers, transporters, and others. Concurrently, global demand for fresh and wholesome fruits and vegetables has continued to grow due to the consumer's appetite for wholesome fresh produce. Furthermore the consumer's desire for previously underexploited fruits and vegetables from distant production areas has been augmented by more disposable income and an evolving appreciation for the nutritive value of fresh produce. As a result, hundreds of thousands of loads of fresh produce and other perishable foods have been shipped around the world via air, land, and sea in refrigerated intermodal containers, trailers, railcars, and airfreight containers. While the preponderance of these shipments arrives in marketable condition, a considerable number of loads have been plagued by assumed temperature and atmosphere management issues and undesirable quality characteristics by the time they reach the consignee (Brecht et al., 2009).

In this chapter, we explore the various types of temperature-controlled transport equipment utilized to maintain the wholesomeness, freshness, organoleptic quality, and nutritive

[1] "All-in landed costs" are the total costs associated with importing a product, such as the cost of the perishable cargo, marine cargo insurance, import duties, transportation, and other services.

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value of perishable foods during the transport segment of the cool chain that is required to maintain product quality. We also introduce the use of selected best practices as a means of making the delivery of perishable foods to market less problematic. Furthermore, we discuss the regulatory landscape and technological solutions regarding the sanitary transportation of food and worldwide attention to food safety. We also examine expert systems, telematics, and temperature and atmosphere management systems and technologies.

18.2 TRANSPORT REFRIGERATION BASICS

18.2.1 Heat Transfer

Maintaining the proper temperature is critical for the successful transport of perishable foods. Living cargo (e.g., fresh produce) generates heat from respiration. Heat from the environment outside of the transport equipment can enter the cargo space. The purpose of transport refrigeration is to remove excess heat and provide temperature control for the shipment of perishable food products in transport equipment.

Refrigeration systems force heat to flow from inside a transport insulated cargo compartment to the outside ambient environment under most conditions. The conditioned air that intercepts heat inside the refrigerated box is freely drawn from the compartment by the fans via return air screen openings in the refrigeration unit's partition. The air that returns from the cargo compartment is forced across evaporator (cooling) coils, thus lowering the air temperature. The cool conditioned air is then moved from the refrigeration unit via the container T-bar floor, railcar celling plenum, or the truck trailer top-air delivery chute to the cargo. The refrigeration system also contains a heater, which is used during defrost cycles (see Section 18.2.3) and when the return air temperature needs to be raised rather than lowered to maintain the desired cargo temperature.

Temperature is a term that describes the amount of heat in a substance. Temperature is measured in degrees Fahrenheit or Celsius. In the Fahrenheit scale, water freezes at 32° and boils at 212°. The Celsius scale is set with 0° as the freezing temperature of water and 100° as the boiling temperature of water.

Heat is measured as calories or, in the metric (SI) system, as *joules.* In the English system, heat is measured as British thermal units, abbreviated as Btu. A measure of the flow of heat through the transport box surface area and insulation is described by a factor called the UA value. The lower the UA value, the lower the rate of heat gain across the transport box wall.

Heat is a measurable form of energy that flows from a high temperature to a low temperature source. Temperature gradients control the direction of heat flow, which can occur by three means: conduction, convection, and radiation. For example, heat naturally flows on a warm day from the outside to the inside of a refrigerated transit vehicle.

Conduction is the movement of heat through solid objects, such as the transit vehicle's insulated walls, ceilings, and doors, or between solid objects that are in direct contact with each other, such as from cargo to the walls of the cartons containing the cargo.

Convection occurs when warmer areas of gases and liquids rise to cooler areas of the gas or liquid, thus creating convection currents that mix the warmer and cooler areas. For instance, refrigerated airflow moves heat generated from respiring produce and heat transferred from interior walls to the transport vehicle's cooling unit.

Radiation is the transfer of heat though a gaseous medium or even an empty space, such as the transfer of radiant heat generated from the sun or hot roadways to the exterior of the transport vehicle.

The nature of a transport refrigeration unit, commonly called a "reefer unit," is that a temperature differential exists between the air entering the reefer unit, (i.e., the return air), and the air exiting the unit, (i.e., the discharge or supply air) due to heat removal or addition as the return air passes through the reefer unit. The supply air usually warms as it circulates around the cargo space, picking up heat from the cargo and surfaces of walls, ceiling, and doors as it makes its way back to the reefer. However, the supply air can also cool in extreme cold environments if heat from the cargo box is lost across the walls, ceiling, and doors. This temperature differential is distributed within an "insulated box" and results in temperature variances and "microenvironments"[2] within the cargo itself and the air surrounding the cargo. This means that the cargo itself and the air surrounding the cargo are exposed to a range of temperatures and atmospheres during transit. Controlling, modifying, and monitoring the characteristics of environments inside insulated boxes are critical to maximizing the shelf life of the cargo and, in the case of perishable foods, to optimizing the wholesomeness, safety, and quality of the food.

18.2.2 Refrigeration Cooling System

All transport reefer units are equipped with microprocessors that are interfaced with temperature sensors to control the supply air and return air temperatures that are located inside the reefer unit (not inside the insulated cargo box). Supply and return air temperatures and other parameters are generally controlled and measured from inside the refrigeration units and not inside the insulated cargo box. These sensors can control the conditioned air as it is delivered to the refrigerated cargo space in the insulated "box" and returns back to the reefer unit to be recooled (or heated) and then recirculated back to the cargo space. These sensors do not control the microenvironments that develop inside the cargo compartments of insulated boxes.

As illustrated in Fig. 18.1 a refrigeration cooling system is basically comprised of a refrigeration compressor, an evaporator, a condenser, an expansion valve, piping, and a refrigerant. The refrigeration system operates on the principle of the vapor-compression cycle. This refers to the physical principle that all substances must gain energy (heat) in order to change from solid to liquid and liquid to gas phases, and release energy (heat) when changing phase in the opposite direction. The temperature at which phase changes occur are characteristic of the substance and vary according to pressure; that is, increasing the pressure thus increases the temperature at which the phase change occurs. Refrigerants are chosen based on their high heat capacity and ability to change phase between liquid and gas at the desired temperature.

[2] A microenvironment has its own temperature, humidity, and gaseous composition. See Section 18.11.

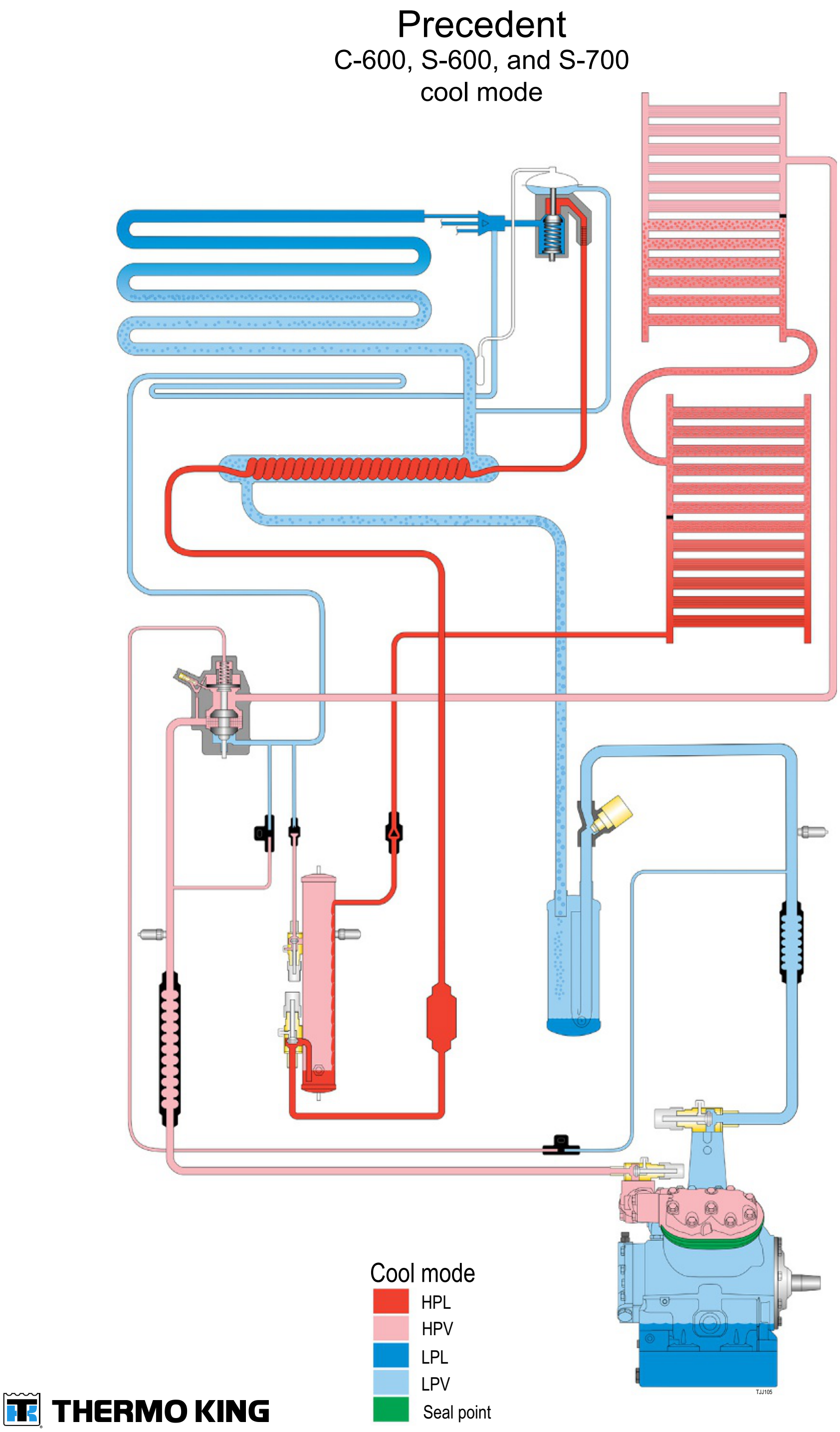


FIG. 18.1 Transport refrigerated cooling system. *Source: Thermo King Corp.*

18.2.3 Defrost

A refrigeration unit's evaporator coil facilitates heat transfer from the circulating air from the cargo compartment to a refrigerant that is circulated within the refrigeration system. When moisture carried from warmer air returns from the cargo compartment, it condenses on the cooler evaporator coil surface, causing moisture or ice to accumulate on the coil. Ice accumulation on the evaporator coil will eventually adversely impact conditioned airflow and refrigeration capacity. To correct this condition, manual, periodic (timed), and "on demand" defrosts are required to clear the ice from the evaporator coil.

Inadequately precooled cargo, product loaded in moist or wet conditions, excessive fresh air exchange settings, leaking gaskets and/or door seals, and hot humid air favor moisture accumulation and icing on the evaporator coils once the doors are closed and the reefer unit is turned on. A significant source of moisture is released from fresh produce, especially if it is not precooled to the desired carrying temperature. The cold evaporator coil removes the field heat, respiratory heat, and moisture produced by the cargo as well as the moisture from warm humid air. A typical load of produce stowed in a 40′ reefer container can contain roughly 35,000 lbs. of water (the moisture content of produce varies from about 80% to 96%). Additional water may be present if produce is wet when loaded or if ice is included in the cartons of produce.

Failure to adequately defrost the coil can result in poor temperature management, quality and food safety issues, and load rejections.

18.3 TYPES OF TRANSPORT EQUIPMENT

18.3.1 Refrigerated Containers

A refrigerated container, also known as an integral reefer container, is an intermodal shipping container that is used for the transportation of temperature sensitive cargoes. The container's reefer unit is located inside the cargo compartment (Fig. 18.2). Refrigerated containers can be transported over land and sea by trains, trucks, and vessels.

The three main components of a refrigerated container are the refrigeration system, the microprocessor controller, and the air circulation system (chilled or heated air system).

A reefer container is a metal box with polyurethane insulation and an attached electric-powered cooling (refrigeration) unit. Reefer containers are equipped with a microprocessor/data logger function that controls the operation of the reefer machinery, documents the pretrips (system maintenance and diagnostic checks), and records temperatures and various events during transit.

Reefer containers are equipped with a bottom-air delivery system, also known as reverse air flow. The conditioned air is delivered from the reefer unit located at the front of the reefer container, along the floor, through the "T" floor channels, and up vertically through the cargo so that the air is driven around and through the load to maintain product temperatures (Fig. 18.3). This type of airflow system pressurizes the "T" floor with conditioned air when the cargo is properly stowed in the container. The pressurized air is forced a short distance up and through the cargo vertically from the "T" floor to the top of the load and back to the reefer unit.

FIG. 18.2 External views of refrigerated containers showing an integral refrigeration unit attached to an insulated container (box) and a chassis. *Source: PEB Commodities, Inc.*

FIG. 18.3 Interior view of a refrigerated container showing corrugated sidewalls, "T" bar floor, return air register, and front bulkhead. *Source: PEB Commodities, Inc.*

FIG. 18.4 Picture illustrating manual fresh air exchange within a reefer container. *Source: PEB Commodities, Inc.*

A bulkhead (plenum or false wall) at the front of the container directs the discharged air out at floor level and allows the return air to flow back to the reefer only at ceiling level.

Reefer containers have an adjustable fresh air exchange opening that is set to avoid potentially injurious depletion of oxygen (O_2) and/or build-up of carbon dioxide (CO_2) and ethylene (C_2H_4) gases. Fig. 18.4 shows a picture of a fresh air exchange device on a marine container to allow varying rates of gas exchange to occur. The fresh air exchange is usually set manually, but automated systems are also available that are controlled by the refrigeration system microprocessor. Automated fresh air exchange systems are able to keep the fresh air exchange closed as much as possible to improve temperature pull-down, reduce fuel usage, maintain a beneficial atmosphere of O_2 and CO_2, and avoid an infiltration of warm, humid, or freezing or chilling outside air that may damage the products being carried.

The reefer unit is self-contained, but it does require a power source. The operation of integral reefer units relies on electrical power sources, such as land-based sites, container ships, and diesel-powered generators (known as "gen sets") that attach to the container. Powering the refrigeration unit is achieved by connecting the reefer container to an electrical supply through the container's electrical plug. The electrical power supply must be either 380 V/50 hertz or 440 V/60 hertz and the power cables must have standard ISO plugs. Gen sets can attach to either the upper forward end of the container (clip-on gen set, see Fig. 18.5) or the chassis (underslung gen set) while on road or rail journeys. Gen sets have a fuel tank capacity of 39–120 gal, which equates to a running time of about 1½ to 5 days.

Reefer containers are intermodal in that they can be loaded onto container vessels for marine transport, then upon arrival at a port they can be transferred to a flatbed trailer for over-the-road truck transport (Fig. 18.6), or transferred to a rail flatcar stacked one or two high for rail transport (Fig. 18.7).

FIG. 18.5 Clip-on gen set mounted to a refrigerated container. *Source: PEB Commodities, Inc.*

FIG. 18.6 A reefer container on a flatbed trailer, being hauled by truck. *Courtesy of A.P. Moller-Maersk.*

18.3.2 Refrigerated Trailers

Reefer trailers generally consist of an insulated trailer (box) on wheels and a direct drive reefer unit that is located outside the refrigerated trailer's cargo compartment (Fig. 18.8). Reefer trailers are mostly used only for over-the-road truck transport, but they may also be carried by rail. Reefer trailers carried on a rail flatcar are referred to as piggyback trailers.

FIG. 18.7 Reefer containers double-stacked on rail flatcars. *Source: From Thermo King Corp.*

FIG. 18.8 External view of trailer, refrigeration unit and insulated trailer. *Source: Thermo King Corp.*

In contrast to reefer containers, reefer trailers are routinely equipped with a top-air delivery system, which means that the air is delivered from the reefer unit to the cargo space via an air delivery chute attached to the trailer's ceiling (Fig. 18.9). The conditioned delivery air from the reefer flows horizontally over the load to the rear doors, then passively back through and around the load and along the floor, through an opening at the bottom of the front bulkhead, and back to the reefer unit. The placement of heat generating cargo must permit the conditioned air to pass between the load, the walls, and the floor. Frozen cargo is loaded into the trailer as a solid block in such a way that the conditioned air can flow around the outside of the cargo to intercept heat from outside the trailer before it can affect the cargo. The air returns

FIG. 18.9 Interior view of refrigerated trailer showing flat sidewalls, a duct extension, an air delivery chute attached to the ceiling of the reefer trailer, and the pressurized return air bulkhead. *Source: Thermo King Corp.*

horizontally around the cargo, under the front bulkhead, and back to the reefer unit. The horizontal airflow system moves conditioned air passively while picking up heat along the way from the rear of the load to the front bulkhead.

Like reefer containers, reefer trailers are equipped with a microprocessor/data logger function that controls the operation of the reefer machinery, documents the pretrips (system maintenance and diagnostic checks), and records temperatures and various events during transit. Intelligent reefer trailers are equipped with an array of options, including the creation of product profiles by adjusting the system's full set of operating parameters to fit the individual perishable commodities that are transported on a regular basis.

18.3.3 Multitemperature Refrigerated Trailers

Multitemperature reefer trailers are reefer trailers that can typically be divided into two or three compartments to allow transport of cargo simultaneously in different temperature zones. The reefer unit has one condenser with separate remote evaporators, fans, and

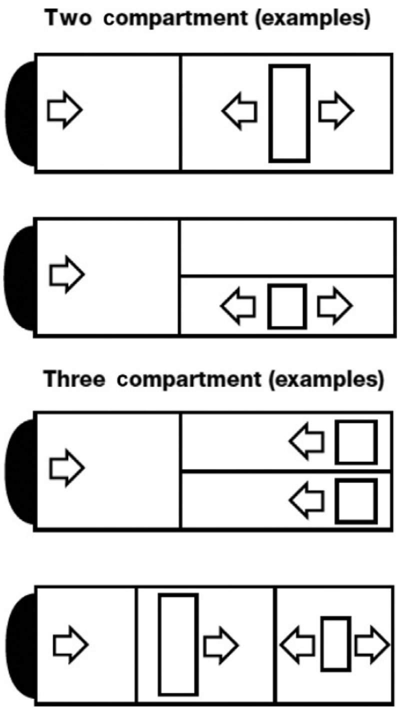


FIG. 18.10 Possible configurations for multitemperature refrigerated trailers showing use of remote evaporators with single-discharge and dual-discharge airflows. *Source: Carrier Corp.*

controllers dedicated for each compartment. The intermediate bulkheads (dividers) are insulated to isolate the compartments from each other. The bulkheads are hinged and attached to the trailer ceiling on tracks to allow for raising, lowering, and positioning forwards and backwards according to loading needs (Fig. 18.10). The trailers are equipped with side doors so that the individual compartments can be loaded and unloaded independently.

18.3.4 Refrigerated Railcars

Railcars utilize the same basic refrigeration units as truck trailers with computerized controlling and recording devices (Fig. 18.11). The refrigeration unit's data logger records and controls the supply and return air temperatures in the front bulkhead of the refrigeration unit (i.e., "A" end of railcar).

Refrigerated railcars are equipped with a top-air delivery system, which means that the air is delivered from the refrigeration unit to the cargo compartment via a vented air delivery plenum that is attached to the ceiling (Fig. 18.12). The conditioned air flows between the load, the sidewalls, and the rear doors, then back along a floor plenum to the refrigeration unit though the bulkhead. The placement of cargo and pallets must permit the conditioned air to pass between the load, the walls, and the floor. An illustration of the components of a refrigerated railcar is shown in Fig. 18.13.

FIG. 18.11 External view of refrigerated railcar. *Source: Thermo King Corp.*

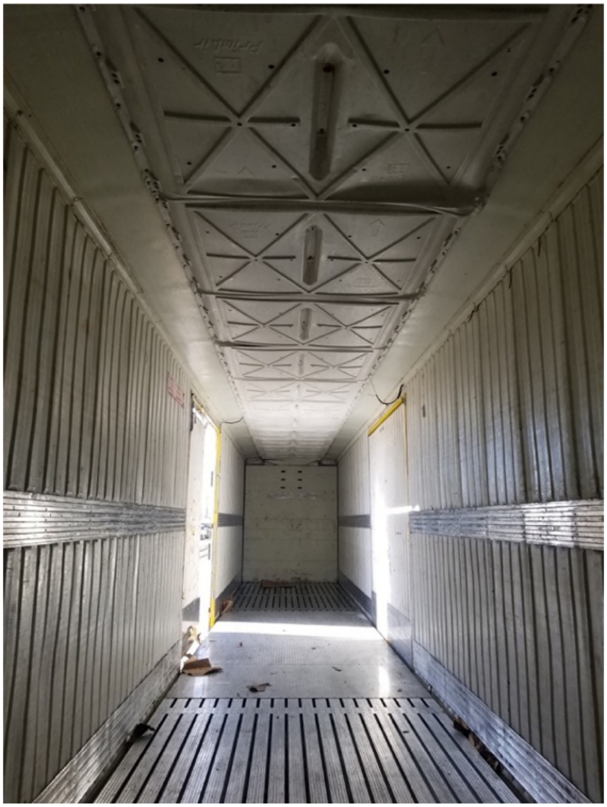


FIG. 18.12 Internal view of a refrigerated railcar. *Source: PEB Commodities, Inc.*

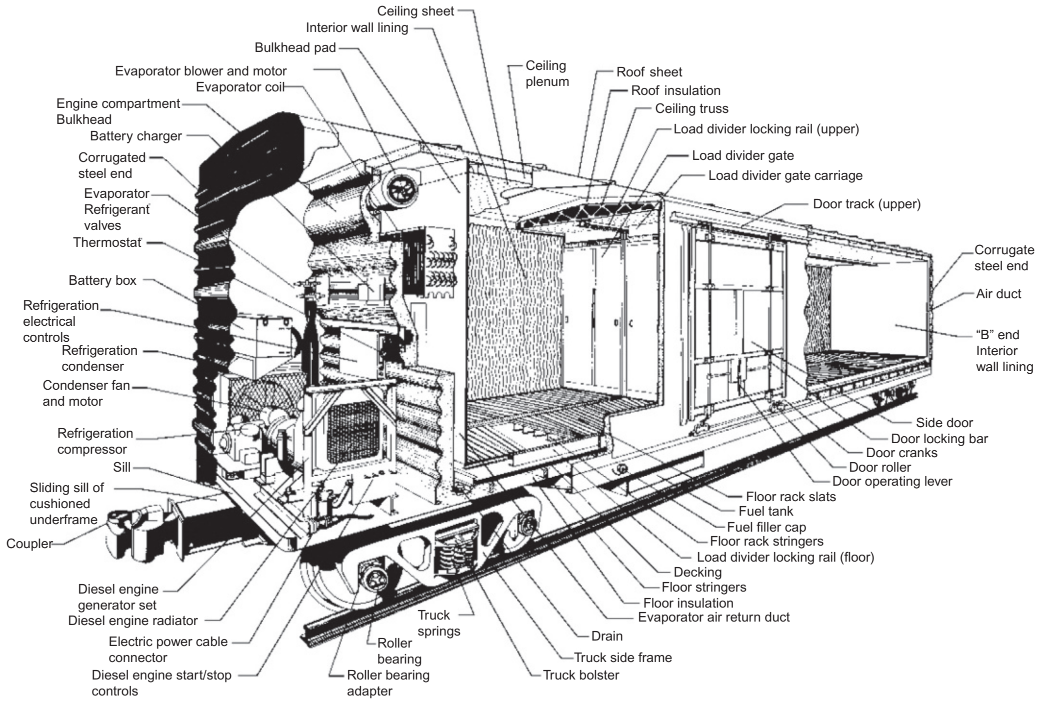


FIG. 18.13 Illustration of a refrigerated railcar. *Source: American Association of Railroads.*

Like reefer containers and trailers, intelligent refrigerated railcars can be equipped with an array of options, including the creation of product profiles by adjusting the system's full set of operating parameters to fit the individual perishable commodities that are transported on a regular basis.

18.3.5 Refrigerated Air Containers

Airfreight allows products to be quickly transported over long distances. The short transit times allow producers to quickly respond to market needs. It also allows for highly perishable products to reach distant markets that cannot be serviced by land or marine transport.

Airfreight is commonly used for high-value pharmaceutical items and horticultural products including cut flowers, other ornamental products, fresh produce, and fresh-cut fruits and vegetables. Chilled and frozen meats and seafood and dairy products are also common airfreight products. However, only a small amount of perishable products are shipped by air because it is considerably more expensive than land or marine transport. Additionally, airfreight is expensive (up to 10 times more than ocean transportation) and sometimes lacks adequate, if any, temperature control.

Air cargo is transported using unit load devices (ULDs) that are either open pallets or enclosed container ULDs (Fig. 18.14). The loading of the ULDs involves the use of special wraps, insulation, dry ice coolants, or active temperature control units. Covering and insulating pallets of chilled produce or utilizing insulated ULDs slows heat transfer to the perishable items.

One of the most effective means for maintaining the cool chain for products shipped by the air cargo mode is to use active temperature-controlled ULDs. Active temperature-controlled ULDs are insulated containers with built-in refrigeration systems.

Temperature-controlled ULD containers enable the transportation of commodities, both via air and on the ground, thereby enhancing the life of temperature-sensitive commodities by preserving the cool chain during the end-to-end transportation process. These containers work by an active temperature-controlled system based on compressor cooling and electric heating equipment or alternatively they use a temperature-controlled system based on dry ice refrigeration.

The active units are powered by rechargeable batteries. Active ULD air containers are similar in shape and size to the dry ice containers, except they use a different technology vis-a-vis compressor cooling and electric heating.

18.3.6 Nonrefrigerated Transport

A relatively small proportion of the perishable cargo volume is transported without refrigeration. The largest amount of perishable cargo transported without refrigeration is by air, mainly international shipments of cut flowers, in which the speed of the service is considered to compensate for the lack of temperature control. There is also some international air transport of high-value fruit and vegetable crops (e.g., asparagus) and certain small fruits and tropical fruits. This is, however, a lower volume than that which is air shipped in temperature-controlled ULDs. Lack of temperature control for air-shipped perishables is especially critical during the periods when the products are at airports, often exposed on the tarmac, waiting for loading or transfer. The environmental temperatures to which the products may be exposed, either on pallets or in ULDs, may be either too high and risk spoilage or “cooking” or too low and risk chilling and freezing. Sun exposure exacerbates high temperature issues, because

FIG. 18.14 Transport refrigerated cooling system. *Source: Thermo King Corp.*

products exposed to solar radiation may easily reach temperatures 20–40°C above the ambient air temperature. Upon final arrival in the importing country, air-shipped products are immediately cooled, and further transport is done in refrigerated truck trailers.

A few of the less perishable fruits and vegetables may be transported domestically by truck or rail without refrigeration, such as potatoes, onions, garlic, watermelons, winter squash, and citrus fruits. These products may or may not be cooled or cured, as the case may be, prior to transport. Much of these products' potential storage life may be lost during such transport. Thus the practice or nonrefrigerated transport is usually not advisable when the products have been stored previously or will be stored after shipping. The nonrefrigerated transport of perishable food crops is more common in less developed parts of the world due to strictly economic reasons and contributes significantly to food waste and losses in those countries.

International shipping companies transport winter squash, onions, garlic, and other perishables in dry (nonrefrigerated) vented trailers and dry (nonrefrigerated) containers with one door off to facilitate air circulation and to help minimize condensation-related outturn problems, such as mold. The removal of two (2) doors from dry vans generally is not exercised because of serious operating limitations relating to the structural and stacking strength of dry containers. Squash, onions, and garlic are also moved in operating refrigerated trailers and containers at increased freight rates.

The movement of perishable cargoes in dry containers with or without venting or door removal can be very risky, given that nonrefrigerated transport equipment does not protect the perishable cargoes from extreme weather conditions and/or control carrying temperatures, air flow, and humidity like with refrigerated equipment. Notwithstanding the movement of selected perishable cargoes in nonrefrigerated dry vans has been an "economical" albeit risky alternative to the higher freight rates levied for the use of refrigerated containers.

Based on custom and practice, shippers must take appropriate action to ensure that the cargo is secured within the container when one door is removed. The open-door space at the rear door of the container must be sufficiently blocked, braced, and secured to ensure that the cargo doesn't fall out of the container. The removal of the door can result in perishable cargo being subjected to rain, green (salt) water oversprays, radiant heat load of the sun, and high and low temperature extremes.

18.4 TRANSPORT TEMPERATURE MANAGEMENT

Temperature management plays the most significant role for extending the market life of perishable foods. Bringing the product to its desired carrying temperature as quickly as possible and maintaining uniform temperatures is paramount for domestic and global distribution. The practice of maintaining optimum temperatures throughout the perishables distribution system without any breaks is often referred to as "maintaining the cool chain."

Refrigeration units for containers, trailers, and railcars are equipped with computerized controls and recording capabilities. The computer or microprocessor is sometimes referred to as a Data Management System (DMS) or a data logger. Computerized refrigeration units offer significant benefits to transportation companies, drivers, shippers, and receivers. To wit, the microprocessor controls, tracks, and records operations of the refrigeration system including, in part, the temperature set point, return air sensing, discharge air sensing, operating modes, safety alarms, and probe sensing. Temperatures can be recorded in either degrees Celsius (°C) or Fahrenheit (°F). The microprocessor also performs pretrips and diagnostics of the refrigeration unit and records operational events and alarm codes. The refrigeration unit's computer system offers various levels of guarded access, thereby protecting the refrigeration unit from tampering and unwelcome changes. Trip data can be retrieved (but not erased) from the microprocessor memory.

The DMS also permits the operator to set up predetermined temperature management conditions including upper and lower critical control limits for perishable foods. Product storage guidelines can be utilized to help set up carrying temperature parameters for perishable and temperature-sensitive products transported using containers, trailers, and railcars equipped with these refrigeration units.

As explained in Section 18.2 in a refrigerated transport unit a temperature differential exists between the air entering the refrigeration unit (i.e., the return air) and the air exiting the unit, (i.e., the supply air). This temperature differential continues into the cargo space, creating microenvironments within the cargo and the air surrounding the cargo. Microenvironments represent distinct and unique environments within the cargo space of the refrigerated container, trailer, truck, railcar, or air container. Controlling, modifying, and monitoring the characteristics of microenvironments inside insulated boxes are critical to maximizing the shelf life of the perishable cargo and optimizing the wholesomeness, safety, and quality of food.

A transport refrigeration system must have sufficient cooling capacity to remove the heat generated from all sources. Heat transfer into an insulated transport box is augmented by differences between outside and inside air temperatures, surface area of the insulated box, color of exterior finishes, amount and effectiveness of insulation (UA values) in walls, ceilings, floors, and doors, excessive air leakage into the insulated box caused by poor door seals and wall damage, and warm air infiltration when doors are opened and/or when the fresh air exchange vent setting is excessive.

As insulated trailers, railcars, and containers age, their UA value increases as insulation deteriorates with age, and they become more susceptible to air leakage especially around doors. It follows that older insulated transport boxes have less insulation capacity than newer ones. As a result, older transport boxes have a greater potential to enable perishable product warming and require more fuel to power refrigeration units than newer units. Notwithstanding, transport refrigeration units are often equipped with extra refrigeration capacity to help compensate for diminished UA values as the insulated boxes age.

18.5 AIRFLOW MANAGEMENT

Frozen products are stowed as a solid block, centered within the cargo space so that conditioned air envelopes the cargo to isolate it from outside heat sources. When shipping heat-generating fresh produce in refrigerated equipment, special packaging and loading practices are required. Proper product packaging, carton designs, unitization, and stowage are needed to ensure that the conditioned air is capable of evenly and effectively removing heat while maintaining noninjurious or beneficial levels of gases (e.g., CO_2, O_2, and C_2H_4) within the load. This means that fresh produce packaging must have an adequately vented area, with the venting oriented to match the transportation equipment airflow pattern in order to facilitate conditioned air flow through the product mass. In some cases, fresh produce containers are stowed so as to create air channels between the produce containers that facilitate airflow through the product mass. If the conditioned air does not reach the produce within the middle of the load, heating will occur, leading to quality deterioration.

Air, like any gas, will follow the path of least resistance. The airflow in reefer trailers ("top-air;" Fig. 18.15) and reefer containers ("bottom-air"; Fig. 18.16) are in opposite directions, If the cargo in refrigerated equipment is stowed in such a way as to allow conditioned air to prematurely return back to the refrigeration unit (short cycling), then the perishable items stowed progressively away from the refrigeration unit will not receive the climate control protection required (Fig. 18.16).

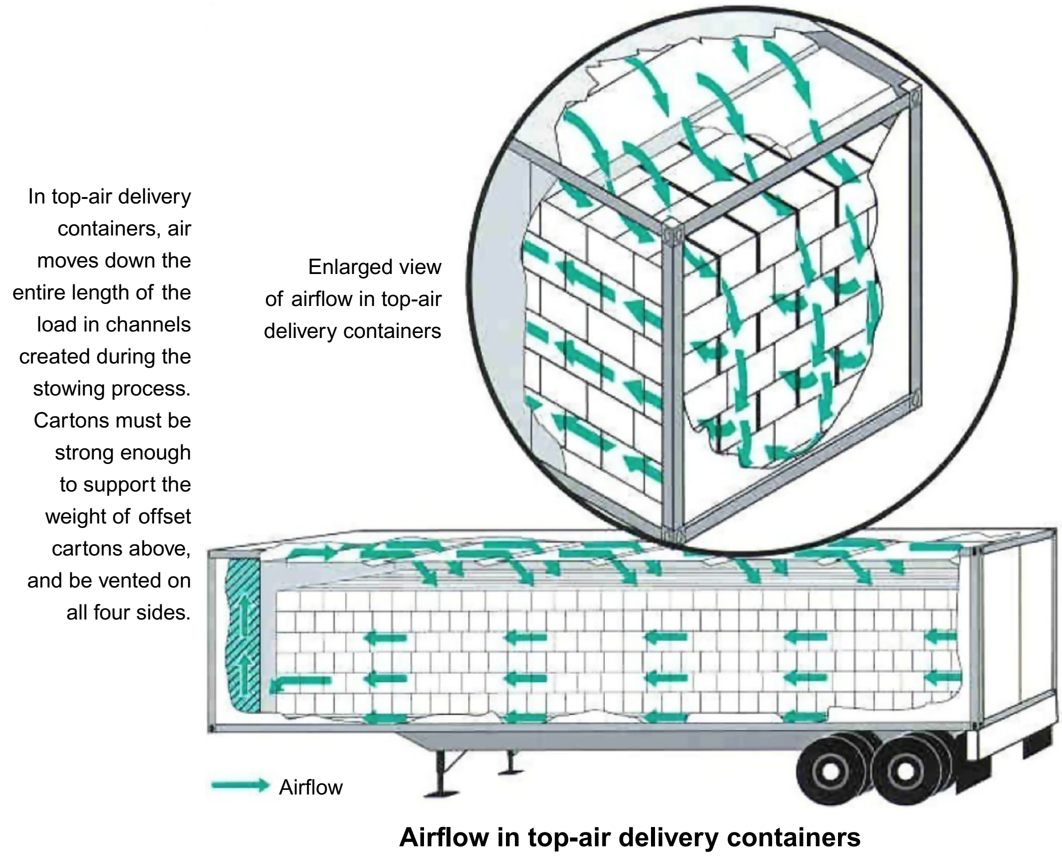
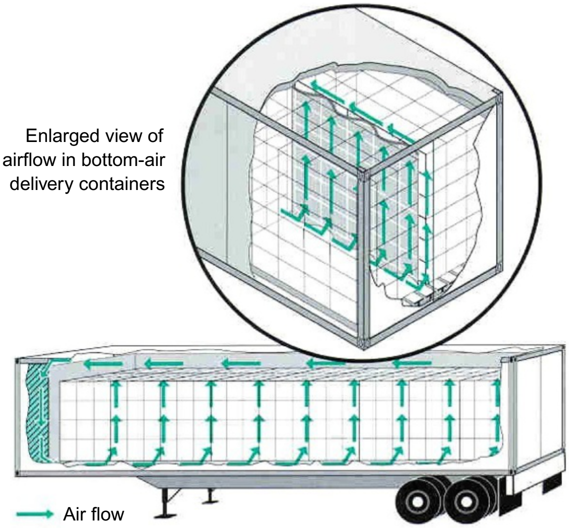


FIG. 18.15 Diagrams illustrating the top-air flow of conditioned air within a reefer trailer. *From Brecht, P.E., 1992. Shipping Special Commodities. American President Lines, Oakland, CA.*



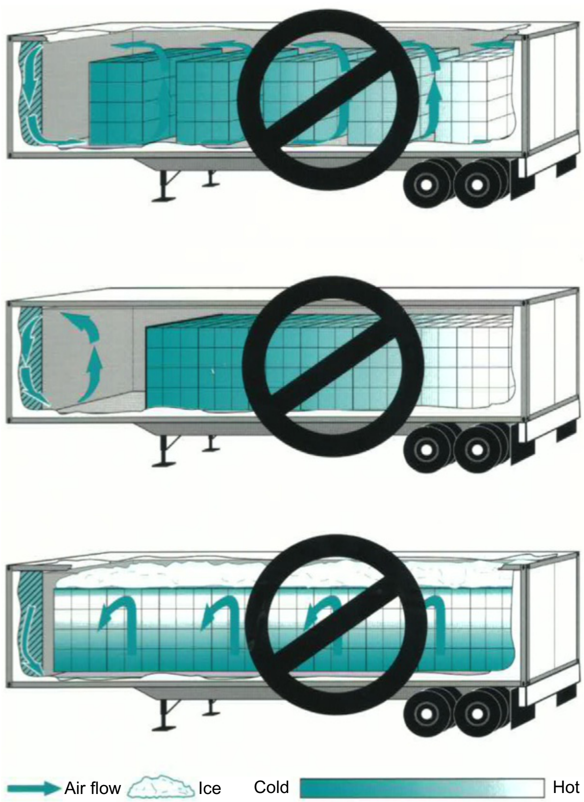


FIG. 18.16 Diagrams illustrating bottom-air flow within a reefer container and short cycling of conditioned air. *From Brecht, P.E., 1992. Shipping Special Commodities. American President Lines. Oakland, CA.*

The goal of good airflow management is to circulate air around and through each chilled perishable item and to surround the entire load with conditioned air. The key to success is to permit conditioned air to flow unrestricted around the perishable items within the packages and to all six sides of the load. To optimize airflow management, proper stowage of the cargo in the transport vehicles is essential (see Section 18.7).

Transport refrigeration units are designed to maintain desired temperatures and generally have plenty of cooling capacity to remove produce respiratory heat and heat conducted across the walls, doors, ceiling, and floor of the transit vehicle. With very few exceptions, such as fresh bananas, which are carried at relatively high temperatures to avoid chilling injury, the refrigeration units do not typically possess sufficient cooling capacity to remove field heat from fresh produce in order to bring the cargo temperature down to the proper carrying temperature. Perishable products should therefore already be at or very near their desired carrying temperature at the time they are loaded into the transport equipment. In any case, proper air distribution in transport vehicles is essential to remove respiratory and environmental heat and uniformly maintain air and product temperatures throughout the load. Inadequate air distribution is a major cause of perishable cargo losses, even with optimally designed refrigerated units and trailers.

18.6 ATMOSPHERE MANAGEMENT: MODIFIED AND CONTROLLED ATMOSPHERES (MA/CA)

18.6.1 Atmosphere Management Basics

Respiration of living products involves the consumption of O_2 and release of CO_2 coupled with energy production that is used to support life processes. Reducing the O_2 and increasing the CO_2 content of the atmosphere surrounding those products inhibits respiration and thus slows the rate of the metabolic processes that lead to quality deterioration. Altering the atmosphere in refrigerated transport equipment to desired levels as a supplement to good temperature control can potentially add days or even weeks to the shelf life of a large number of flowers, vegetables, and fruits, thereby allowing the produce to travel longer distances and bringing a greater selection of produce to consumers around the world.

Modified atmosphere (MA) and controlled atmosphere (CA) technologies have been in existence since the 1920s as a result of the classic work of Kidd and West. The terms CA and MA signify that the atmospheric composition surrounding fresh produce is different from that of normal air in a transit vehicle. Although MA and CA both involve the manipulation of CO_2, O_2, and nitrogen (N_2), MA differs from CA in how precisely the gas partial pressures are controlled. The distinction is that CA is more precise than MA because CA systems employ feedback control of the gas concentrations (Brecht, 1980). Removal of C_2H_4, a gaseous plant hormone that promotes ripening and aging processes, from the atmosphere surrounding produce is also sometimes included within the definition of MA and CA.

Atmosphere technologies are generally found only in reefer containers. Refrigerated highway trailers and railcars with MA or CA control technologies are rarely available. In the commercial reefer container trade, there are four basic approaches to altering reefer container atmospheres during transit, namely CA, MA, "Automated Fresh-air Management," and "Manual Fresh-air Exchange." Figs. 18.17 and 18.18 illustrate the operation of manual fresh air exchange and CA in reefer containers.

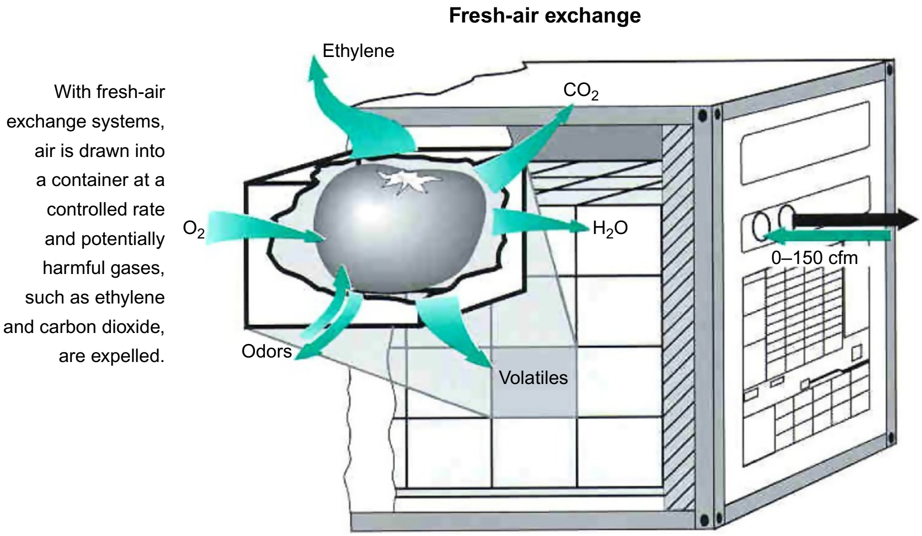


FIG. 18.17 Diagram illustrating manual fresh air exchange within a reefer container. *From Brecht, P.E., 1992. Shipping Special Commodities. American President Lines, Oakland, CA.*

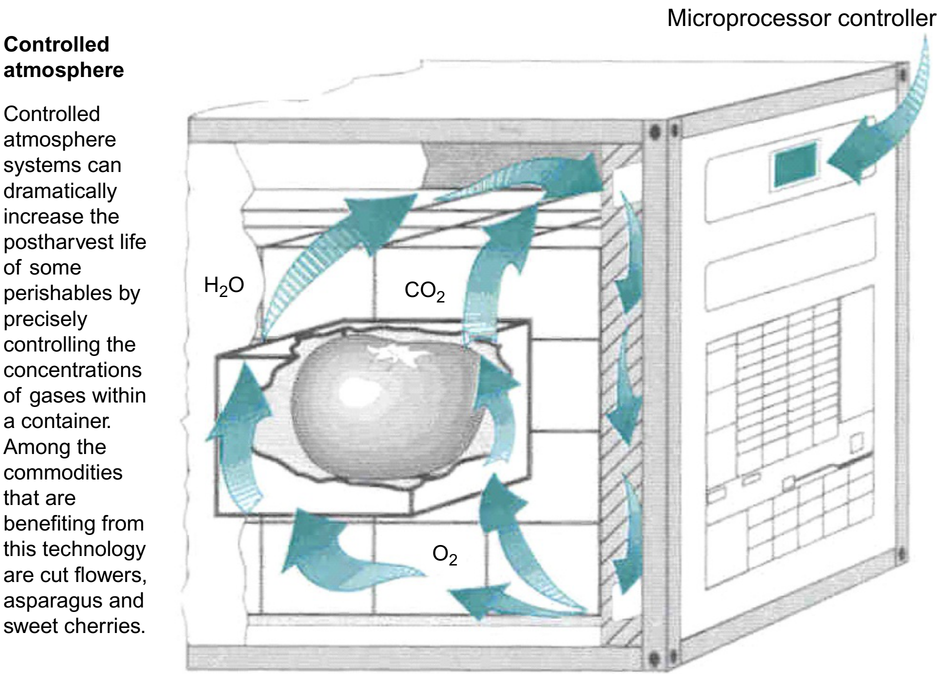


FIG. 18.18 Diagram illustrating controlled atmosphere obtained within a reefer container by feedback from O_2 and CO_2 sensors in the cargo space via the refrigeration system microprocessor. *From Brecht, P.E., 1992. Shipping Special Commodities. American President Lines, Oakland, CA.*

Although MA and CA systems and services have been in use for decades, the commercial use of these systems during transport has been primarily limited to international movements of select vegetables and fruits. The use of a manually operated fresh air exchange as a means of altering the atmosphere by restricting gas exchange between, inside, and outside the container cargo space has been available to reefer container operators and shippers for many years; it is the most common means of altering the atmosphere. Automated fresh air management was introduced about two decades ago.

As a general rule, atmosphere modification techniques involving reefer containers utilize atmospheric generation and/or commodity-modified atmospheres. With atmospheric generation, O_2 partial pressures can be reduced by purging with N_2 and/or CO_2 to desired set points. For commodities that derive benefits from elevated CO_2, this gas is metered into the reefer container. Commodity-modified atmospheres are established when actively respiring and metabolizing produce reduces the O_2 and increases the CO_2 partial pressures in the ambient air within a sealed reefer container, primarily when barriers and restrictions to gas exchange exist, such as a closed fresh air exchange. Ethylene and CO_2 "scrubbers" are often used to chemically or physically remove these gases when either of these components is considered potentially injurious to the commodity quality.

18.6.2 Types of MA/CA Systems and Their Operation

18.6.2.1 Manual Fresh Air Exchange

Manually adjustable fresh air exchange ports are available on all reefer containers. These fresh air exchange systems are designed to introduce fresh air into the reefer container while replenishing oxygen and removing carbon dioxide, ethylene, and trace volatiles from the cargo space (Fig. 18.17). For the most efficient operation of the reefer system, it is desirable to keep the fresh air exchange closed so as to minimize infiltration of outside air, the temperature of which likely must be adjusted by the reefer system. However, the fresh air exchange ports of containers loaded with respiring and ethylene-producing products are usually kept at least partly open to prevent depletion of oxygen and build-up of carbon dioxide and ethylene, all of which may injure the products. If the fresh air exchange is left closed, then the atmosphere within the container will develop a modified atmosphere, with the gas levels are determined by the respiration and ethylene production rates of the products, along with the leak rate of the equipment.

Fresh air exchange is a simple and inexpensive means of altering the atmosphere and maintaining a safe environment. However, it is a relatively crude system for achieving MA conditions and is not really designed for that purpose. The atmospheres that can be established within the cargo space are highly dependent on uncontrolled variables, such as the void volume within the container, the incoming pulp temperature of the produce, the amount of cargo, and the leak rate of the reefer container. Furthermore, the rates of oxygen consumption and carbon dioxide and ethylene production by fresh fruits and vegetables changes over time, while the setting of the fresh air exchange is selected and set at the time the container is loaded with product and is not typically changed at any time during shipping. Also, if mistakes are made in setting the fresh air exchange, there can be potentially undesirable consequences.

18.6.2.2 Automated Fresh Air Exchange

This type of system links the fresh air exchange in reefer containers to gas sensors via the microprocessor so that the fresh air exchange can be opened and closed automatically (typically within about 10 s) in order to maintain desired atmospheres. Once the maximum carbon dioxide or minimum oxygen set point is sensed, the system opens the mechanized fresh air exchange ports that draw outside ambient air into the container, thereby replenishing oxygen and removing excess carbon dioxide. As automated fresh air exchange systems depend on ambient atmospheres (normal air) and fruits and vegetables typically respire equal amounts of oxygen and carbon dioxide, the reduction in oxygen will approximately equal the increase in carbon dioxide. Starting air at approximately 21% oxygen and 0% carbon dioxide, this limits the potential gas mixtures that can be achieved to a very small number of O_2/CO_2 combinations, such as, 11/10, 6/15, 2/19, etc.

In practice the fresh air exchange in these automated systems is kept closed as much as possible to minimize the refrigeration load contributed by infiltration of outside air into the conditioned container space, as well as to maintain high humidity levels in the container in order to minimize product shrivel. This means the fresh air exchange is always closed during and immediately after when the container is loaded, helping the reefer to more efficiently perform the initial cooling of the container. Opening of the fresh air exchange occurs only when the oxygen or carbon dioxide limit for the specific commodity being carried is reached so as to avoid potentially injurious levels of those gases. Due to the relative sensitivities of fruits and vegetables to the two gases, carbon dioxide rather than oxygen levels usually determines when the fresh air exchange ports must be opened. Some of these systems include passive carbon dioxide (hydrated lime bed) and ethylene (potassium permanganate-infused pellets) scrubbers so as to allow oxygen to reach lower and more beneficial concentrations without risking excessive accumulation of the other gases.

18.6.2.3 Modified Atmosphere Systems

Modified atmosphere containers and trailers have been primarily used for low-respiring fresh produce items transported over short distances, domestically, or to overseas markets. The entire trailer or container is sealed compared with the pallet MA system, in which large bags are used to cover and seal individual pallets of produce. MA marine containers and MA truck trailers are no longer common, having been largely replaced by modified atmosphere packaging. Pallet MA is the primary approach now used for truck transport, most commonly for strawberries and other small fruit. MA systems lack precise control of atmospheric gases compared with CA, and as a result, MA systems are intended only to maintain the oxygen and carbon dioxide concentrations within an acceptable range during transit. Actually the gas environment typically continues to change during transit due to the changing respiratory activity of the produce, the performance of carbon dioxide and ethylene scrubbers (if used), and the leak rate of the pallet cover, trailer, or container. However, MA is a less costly investment and operating alternative to CA.

To set up transport in MA for trailers or containers, they must first pass an air leakage test before being dispatched for loading. Once the fresh produce is loaded, passive carbon dioxide and ethylene scrubber systems may be placed in the trailer or container. A plastic curtain is then installed to seal the rear doors, and the trailer or container is flushed via the purging port with a beneficial mixture of nitrogen and carbon dioxide. For pallet-level systems the pallet is covered with a large plastic bag, which is sealed to a plastic-covered pallet to create an air-tight package. The bag is then pierced with the nozzle of a specialized machine that is used to first draw a slight vacuum, then inject carbon dioxide gas to reach a desired level; finally the hole made by the nozzle is sealed with tape. After establishing the atmosphere with these systems, any changes to the atmosphere during transport happen passively and without direct control.

Regardless of the systems, atmosphere levels within a MA reefer container can vary greatly according to many variables, including the leak rate of the container, variable air space volume (void volume), loading patterns, load mix, packaging, carton design, time in transit, and product maturity or ripeness stages, as well as the amount, type, and temperature of the product. Partially loaded containers are associated with inferior temperature control, larger void volumes, and reduced modification of respiratory gases, which are not conducive to optimizing atmosphere management for MA systems.

18.6.2.4 Controlled Atmosphere Systems

Transport CA systems are used only with marine containers. This technology is used for high-value commodities that need to be shipped long distances, which severely challenge their postharvest storage potential. Examples include asparagus, cherries, cut flowers, lettuce, avocadoes, bananas, plantains, and mangoes. While almost 2% of the world's fleet of reefer containers is fitted with "stand-alone" CA technology, there is a possibility of expansion, as approximately 25% of today's fleet is capable of utilizing MA or CA services (Dohring, 2006). All CA systems are characterized by their ability to actively control the atmosphere. This capability overcomes much of the problem with atmospheres varying over time that are found with MA systems. The systems available for marine transport differ in how the atmospheres are initially established and then maintained.

The two types of CA systems are referred to as active and passive. Active CA systems both establish and maintain the atmosphere within a reefer container and are permanently built into the refrigeration unit. Passive CA systems only maintain the atmosphere after it has been established by gas purging, and the monitoring and control parts of passive CA systems are transferable from one container to another. Active CA systems draw outside air and separate the nitrogen from it using a membrane system to establish a desirable level of oxygen inside the container, adding carbon dioxide as needed from a supplemental compressed gas tank. Passive CA systems require that liquid or gaseous nitrogen be pumped into the container to establish the initial low oxygen atmosphere and typically do not involve adding carbon dioxide.

Once the initial atmosphere has been established the oxygen and carbon dioxide concentrations are continuously monitored and adjusted as needed. Active CA systems can respond to an oxygen concentration that is too high by generating a nitrogen-rich gas stream into the container. Both the active and passive systems respond to dangerously low oxygen by allowing the entry of outside air. Active CA systems are able to respond to a carbon dioxide concentration that is too low by injecting additional gas; passive CA systems are limited to the amount of carbon dioxide generated by product respiration. When carbon dioxide is too high, both types of CA systems can remove carbon dioxide using scrubbers. The scrubber may be passive or it may be controlled by the CA system's carbon dioxide monitoring components. Active CA systems also have the capability to reduce carbon dioxide levels through the high nitrogen/low oxygen purging process. However, high capital and operational costs have limited the use of active CA systems.

All transport CA systems include the capability to remove ethylene using potassium permanganate scrubbers.

The optimum CA for products during transportation can differ from the optimum CA for long-term storage. The optimum CA may vary according to the storage (transit) period, which means that better results may be obtained by using an atmosphere that is different (i.e., more extreme) than what research has determined to be the best for the longest possible storage of that product (Brecht et al., 2003). Also, while long-term CA storage usually requires that the product be at the minimal maturity or ripeness to retain acceptable consumer sensory quality for the longest possible time, the same product may be transported at a more advanced stage of development that has different atmosphere tolerances. This requires that the steamship lines and shippers have a level of expertise in their sales, operations, and maintenance departments in order to properly utilize the technology.

18.7 CARGO STOWAGE

Proper loading practices and achieving good airflow distribution are essential for the maintenance of desired temperatures within refrigerated transport equipment. Adequate airflow throughout the refrigerated equipment is critical in maintaining good product quality. The goal of good airflow management is to permit conditioned air to flow unrestricted around the perishable items and to all six sides of the load. Improper stowage that restricts air circulation is a leading cause of poor temperature management and cargo losses.

Refrigeration units generally have plenty of cooling capacity to remove heat from precooled cargo and its surroundings. However, the refrigerated air delivered to the cargo space from the refrigeration unit sometimes can’t remove the heat from the perishable cargo and from all sides of the load and then return the heat back to the refrigeration unit because of poor loading practices, ice and water accumulation on the interior surface and floor of the insulated box, and insufficient blocking and bracing. Consequently, proper loading practices and good airflow distribution are essential for the maintenance of desired temperatures throughout the load. Physical obstructions or restrictions within the box, such as cargo improperly stowed higher than the industrywide load limit line (red line) can cause inferior airflow and result in product “hot spots.”

The refrigeration unit performance is based on the temperature of the air that returns back to the reefer’s thermostat control sensors. When the cargo is loaded properly, the refrigeration unit’s thermostat senses the temperature of air returning from the entire load. When the load is stowed incorrectly the refrigeration unit may not be operating at the desired performance level because the thermostat senses air that has been blocked or has bypassed some or most of the cargo. The majority of temperature management problems are preventable. Proper loading practices and achieving good airflow distribution are essential for the maintenance of desired temperatures uniformly distributed throughout the load.

When frozen cargoes are properly stowed in refrigerated equipment (solid block stowage), unrestricted conditioned air circulates around the entire load in the space between the walls, ceiling, and floor as well as the outside of the stowed cargo.

18.7.1 Refrigerated Container

In a properly stowed reefer container, conditioned air is delivered from the refrigeration unit located in the front (nose) of the container, along the floor, through the T-channels, and up vertically through the hand-stowed or palletized packages so that the air is driven vertically around and through the packages to maintain product temperatures. A primary reason for the improved temperature management with the bottom-air delivery (i.e., vertical) airflow system over the top-air delivery (i.e., horizontal) airflow system is that in the former system, the reefer container "T" floor is pressurized and the conditioned air is then forced a relatively short distance up and through the cargo, vertically from the "T" floor to the top of the load and back to the reefer unit versus having to travel the full length of the trailer to reach the reefer unit in the latter system.

Uniform temperature can be maintained in the load only if the container floor is completely covered with pallets, cartons, and/or solid material from the front bulkhead to the end of the T floor near the rear doors. When the floor is covered, conditioned air is forced up through and around the packages. Vertical gaps in the stowage of reefer containers permit conditioned air to "short cycle" through these gaps and flow prematurely back to the refrigeration unit without adequately cooling the entire load. Poor stowage results in elevated cargo temperatures progressively towards the rear of the loads and in the center portions of the palletized cargoes. Fig. 18.19 is an illustrative example of bottom-air flow in a properly stowed reefer container.

Fig. 18.20 shows examples of fruit that are correctly block stowed in bottom-air reefers to completely cover the floor area, as is required for chilled cargo. In the case of chilled cargo, covering the entire floor with cargo forces the cool air to uniformly flow through and around the vented cartons containing the product.

When stowing frozen cargo, the cargo is loaded in such a manner that the cold air flows around the cargo rather than through it, blanketing the mass of unvented cartons, intercepting and removing any heat that enters the reefer container through the walls.

In order to force air up and through chilled cargo, the parts of the container floor not covered by cargo should be covered with a filler such as dunnage, cardboard, or foam

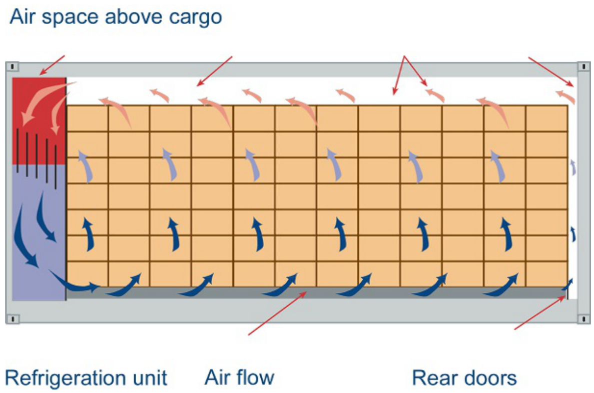


FIG. 18.19 The pattern of airflow in a properly stowed bottom-air delivery reefer container. *Source: Horizon Lines; Diagram courtesy of Patrick E. Brecht, P.E.B. Commodities, Inc.*

FIG. 18.20 Pictures of the correct stowing of palletized fruit in a bottom-air delivery reefer container. The upper picture shows initial stowage of pallets covering the floor with no vertical channels or gaps. The lower picture illustrates the rear of a load stowed with a 9′ × 11′ pallet configuration. *Sources: National Mango Board and PEB Commodities, Inc.*

(see Fig. 18.21). As illustrated in the top two loading diagrams in Fig. 18.21, the floor of the container is covered from the front bulkhead to the end of the T-floor with cargo and fillers. A filler should be used where the cargo does not cover the floor. Neither the cargo nor the filler should be stowed past the end of the T-floor.

Four examples of improperly loaded perishable cargo are illustrated below (Fig. 18.22). Air characteristically takes the path of least resistance, thereby resulting in the short cycling of conditioned air. The top three diagrams in Fig. 18.22 illustrate the short cycling of conditioned air in which the air flows past the cartons rather than flowing around and through them. In the lowermost diagram, airflow is restricted due to top ice.

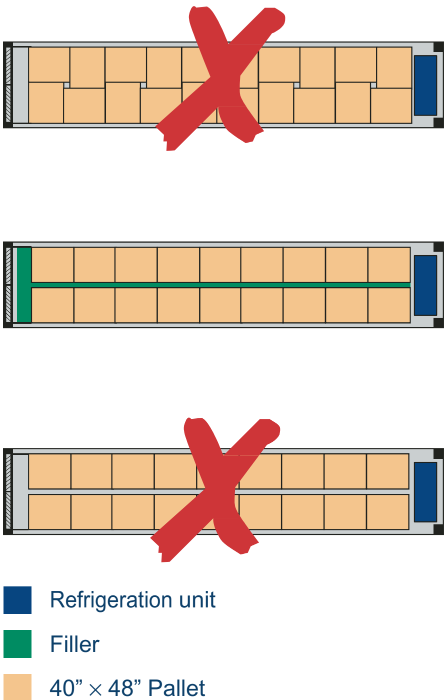


FIG. 18.21 Top-view diagrams illustrating the correct and incorrect ways to stow a reefer container. The second diagram from the top illustrates a 9′ × 11′ pallet stowage, which is a preferred loading pattern as it permits optimum airflow up, around, and through the load. *Source: Horizon Lines; Diagrams courtesy of Patrick E. Brecht, P.E.B. Commodities, Inc.*

18.7.2 Refrigerated Trailer

Top-air delivery reefer trailers require a horizontal airflow loading pattern.

The load can be stacked to within 7.5 cm (3 in.) of the air distribution plenum (air delivery chute) in the ceiling of the trailer, provided that the total weight of the cargo permits many cartons to be loaded safely and legally. The movement of conditioned air in a top-air delivery trailer is passive and not pressurized. Because conditioned air delivered from the reefer unit takes the path of least

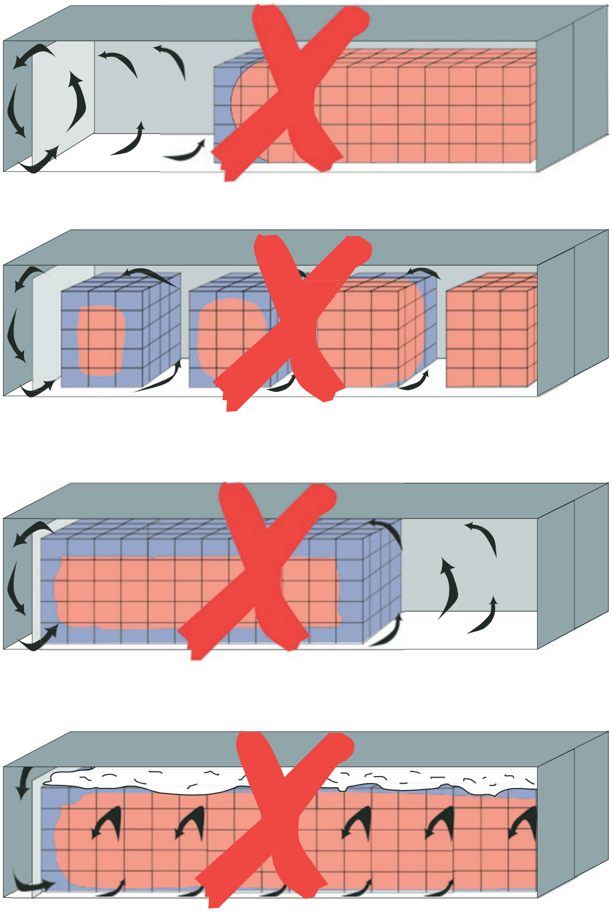


FIG. 18.22 Top-view diagrams illustrating improperly loaded perishable cargo. *Source: Horizon Lines; Diagrams courtesy of Patrick E. Brecht, P.E.B. Commodities, Inc.*

resistance, all air passages should be approximately the same size. Nonuniform spacing between pallets or cartons can cause undesirable temperature variations throughout the load. Conditioned air passages should be clear of loose material or debris that may restrict air movement. The floors should be cleaned and cleared of all loose material before the reefer trailer is loaded.

Stacking cargo directly on the floor or against the sidewalls can cause product warming or chilling due to conductive heat transfer. Proper stowage of cargo pallets with what is known as a "centerline load" pattern (Fig. 18.23) ensures that the cargo is held away from the sidewall and floor surfaces so there is no warming or cooling of the cargo due to contact with the sidewall or floor surface. Avoiding contact between the cargo and sidewall and floor surfaces is more critical in refrigerated trailers than it is in refrigerated marine containers; this is because containers are designed to have greater insulative capacity than trailers to allow for the stowage of cargo covering the entire floor with no vertical channels or gaps.

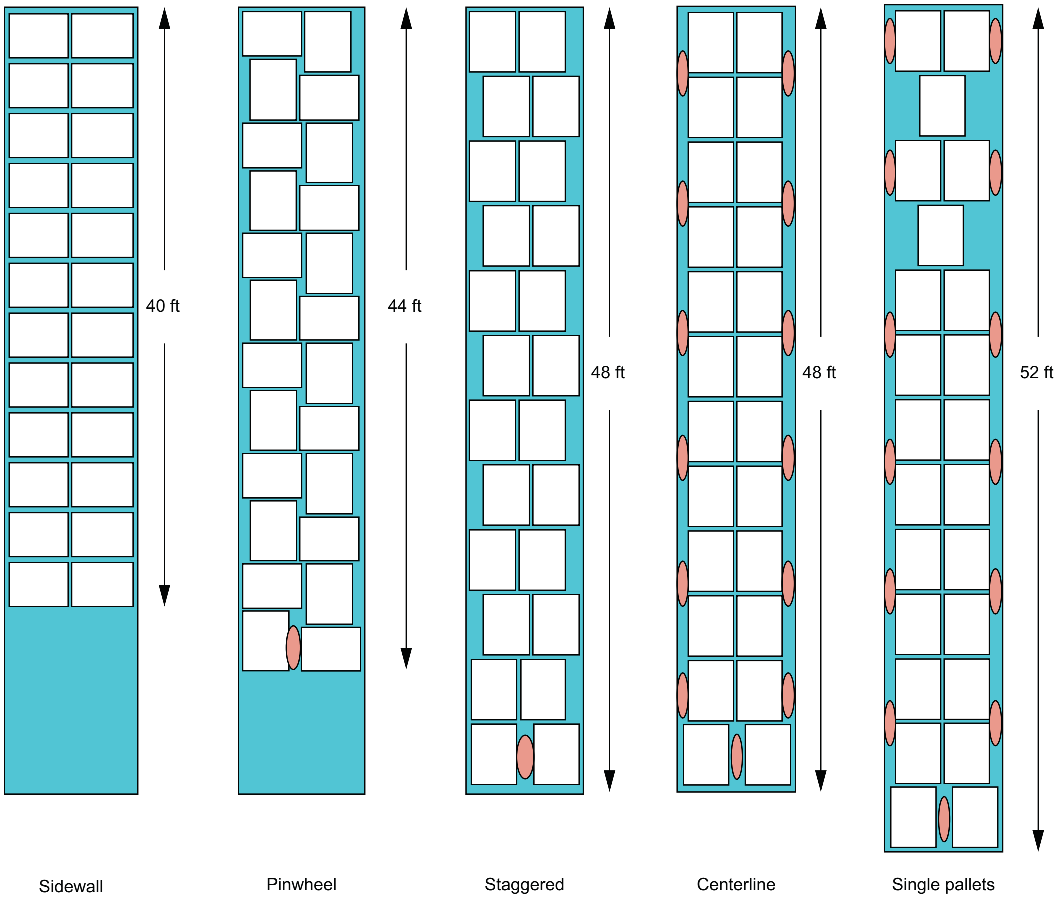


FIG. 18.23 Diagram illustrating pallet load arrangements within a reefer trailer. *From Thompson, J.F., Brecht, P.E., Hinsch, T., 2002. Refrigerated Trailer Transport of Perishable Products. University of California Div. of Agricultural & Natural Resources. Pub. No. 21614. https://ucanr.edu/sites/Postharvest_Technology_Center_/files/235470.pdf.*

The pallet-loading pattern (pallet placement) in a trailer must allow conditioned air to pass between the load, the walls, and the floor. Air flows between the walls and the load only if the pallets or cargo are not touching the walls. Additionally, cargo height should not extend high enough to touch the air chute because air space above the load and unrestricted air flow are needed to distribute conditioned air to the walls, floor, cargo, and rear of the trailer.

Physical obstructions or restrictions within the trailer, such as cargo improperly stowed higher than the industrywide load limit line, can cause inferior airflow and result in product "hot spots" with loads of heat-generating products, such as fresh produce. Furthermore, the load must have a bottom air path to prevent product heating because a great deal of heat can enter the trailer from the floor due to the radiant heat from the road. It follows that airflow should not be blocked underneath the load and that the pallet forklift openings not be covered.

Fig. 18.23 illustrates top views of pallet arrangements for five loading patterns in refrigerated trailers. Centerline loading is a preferred loading pattern because it permits airflow between the walls and the load, using inflatable airbags, foam blocks, or other materials to keep the pallets stabilized in the trailer without touching the walls. This type of loading pattern maximizes the exposure of the cargo to the flow of circulating conditioned air. Moreover, centerline loading is a very effective way of stowing chilled and frozen cargo in reefer trailers, as 24–26 pallets can be stowed (if the resulting weight is road legal) in a 53′ trailer without touching the sidewalls. Air bags, foam blocks, or other dunnage should be used to stabilize the pallets and keep the cargo away from the sidewalls and rear doors of the trailer. Frozen cargo should always be centerline loaded in reefer trailers to maintain a cold air envelope around all six sides of the load.

18.7.3 Refrigerated Railcars

Perishable products must be loaded in a railcar to allow for a minimum of 12 in. clear space between the top of the load and the inside car ceiling. Too little space between the top of the load and the inside car ceiling can cause a reduction in conditioned airflow around the load. Short cycling of conditioned air due to poor stowage can lead to hot spots in the load, which in turn can cause a myriad of types of cargo losses. Furthermore, cargo should not be placed directly in front of or tightly up against the refrigeration unit, walls, or doors. Moreover, dunnage (blocking and bracing) should be placed between the cargo and each door to facilitate airflow and good temperature management.

The majority of railcars are equipped with load dividers to provide a means of blocking and bracing shipments. However, the load dividers can have a direct effect on air circulation and can be a major cause of hot spots in the load resulting from short cycling of conditioned air. The following illustration (Fig. 18.24) demonstrates the right and wrong ways to load the cargo into railcars with load dividers. The upper diagram demonstrates the correct way to facilitate normal airflow and uniform temperature management by positioning the load divider door away from the "B" (rear) end of the railcar. The lower diagram illustrates the wrong way to load a railcar; in this case, short cycling of conditioned air occurs when the load divider door is position away from the "A" (front) end of the railcar. When short cycling is experienced the refrigeration unit shuts off and the load receives little or no cooling. Short cycling is a leading cause of temperature abuse and quality deterioration of perishable cargos.

18.8 FOOD SAFETY AND SANITARY TRANSPORTATION

The importance of food safety during transportation has taken on a new meaning with worldwide attention to the sanitary transportation of food. In 2016 the US Food and Drug Administration (FDA) implemented the Sanitary Transportation of Human and Animal Food (STF) rule. The rule established requirements for shippers, loaders, carriers by motor or rail vehicle, and receivers involved in the transportation of human and animal food to use documented sanitary practices to ensure the safety of that food. The rule was part of the FDA's larger effort to focus on the prevention of food safety problems throughout the food

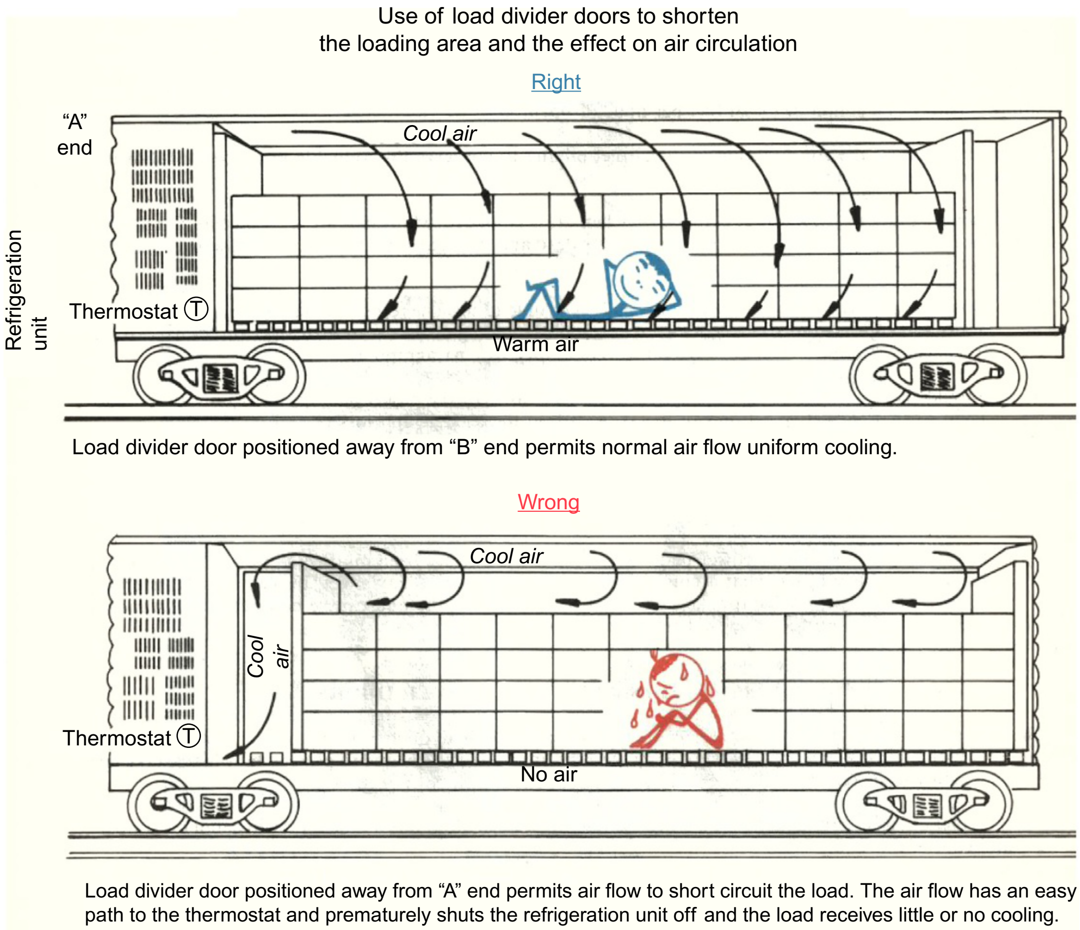


FIG. 18.24 Correct and incorrect ways to load a railcar. *Source: American Association of Railroads.*

chain and is part of their implementation of the Sanitary Food Transportation Act of 2005 (2005 SFTA) and the Food Safety Modernization Act of 2011 (FSMA).

The goal of the STF rule is to prevent practices during transportation that create food safety risks, such as failure to properly refrigerate food, inadequate cleaning of vehicles between loads, and failure to properly protect the food from contamination and spoilage.

The safety, wholesomeness, and suitability of perishable foods for human consumption is dependent in great part on instituting preventive measures and best handling practices, such as training personnel, instituting refrigerated equipment maintenance, sanitation and cleaning programs, assuring adequate cargo and equipment precooling, verifying suitable cargo stowage, and assuring the maintenance of specified internal product temperatures during transport and storage. The FSMA Preventive Controls Rules for human and animal food require the manufacturer of a food to consider the transportation needs of foods that they manufacture when they develop their food safety plans. The food safety plan must be prepared, or its preparation overseen by at least one preventive controls qualified individual, also known as a PCQI. The PCQI identifies the hazards requiring preventive controls associated with the facility and the food it stores and transports, as well as the appropriate preventive controls and preventive control management components. A facility that identifies temperature control, including during transportation, as a preventive control must communicate the need for appropriate temperature control to the person transporting the food. Additionally the shipper, in accordance with the Preventive Controls rules, must maintain written procedures as part of its food safety plan to ensure that the adequate cleanout of transport vehicles is performed and documented. Moreover, storage and transportation of food must be under conditions that will protect against allergen cross-contact in addition to protecting against food contamination.

If times and temperatures exceed specified limits, food poisoning organisms can proliferate, potentially causing foodborne illness (i.e., food poisoning) when food is consumed that has been contaminated by pathogenic microorganisms and/or their toxins. It follows that maintaining proper temperature is critical for upholding the quality and safety of any perishable food items that are likely to support the growth of food pathogens.

The importance of monitoring and controlling product temperatures during transit can be illustrated with packaged fresh-cut produce. The FDA Food Code requires that packaged leafy greens, sprouts, and fresh-cut melons and tomatoes, as well as other foods that can support the proliferation of pathogenic microorganisms, must be maintained no warmer than 41°F/5°C at all times to ensure food safety. However, refrigerated transport units present challenges to compliance with this regulation due to the possible variations in air and product temperatures within the cargo compartment during transit that have been pointed out elsewhere in this chapter. In-transit air and product temperatures depend on the refrigerated transport equipment design, performance, and age; the cargo stowage methods; the spatial location of the cargo in the load; the thermostat setting; the upper and lower critical control point temperatures; continuous run/start-stop settings; defrost intervals and durations; and an array of other factors. The technical challenge to achieving compliance with the food code is that while maintaining the product at or below 41°F/5°C is required to comply with the food code, the product temperatures must at the same time not be allowed to fall below around 32°F/0°C to avoid freezing injury of produce items, such as packaged leafy greens.

In practical terms, decisions to accept or reject packaged produce and other perishable food items are often erroneously made based on generalized air temperatures and not the air temperatures or internal temperatures of the produce located in the diverse microenvironments of the insulated box. Moreover, it is a common misconception that recorded elevated ambient air temperatures in a specific location within the cargo space of a reefer container or trailer are the same as the internal product temperatures stowed in various microenvironments within the insulated transport box. Internal product temperatures change much more slowly than air temperatures due to the thermal inertia of high water content perishable cargoes; thus generalized air temperatures should not be considered the same as internal product temperatures. As a practical matter, recorded air temperatures and other environmental factors that are monitored and controlled inside the reefer unit are typically not the same as the internal product and air temperatures inside the microenvironments within the insulated box.

To wit, the placement and stacking of the manifest cargo within the truck/trailer/container, air infiltration into the truck/trailer/container, the airflow and temperature stratification in the load, and other factors, all affect the temperature and other environmental factors inside the various environments (i.e., microenvironments) in the insulated box.

There are endless opportunities available for integrating advanced truck trailer/railcar/container refrigeration (reefer) technologies and telematics with food safety programs. Computerized reefer units offer significant benefits to transportation companies, shippers, and receivers who intend to implement HACCP and HARPC[3] programs for the sanitary transportation of food in order to comply with the FSMA Preventive Controls Rules.

The reefer's computerized temperature management system computer includes various levels of guarded access, thereby protecting selected food safety-related critical control limits from tampering and unwelcome changes. The computerized system also permits an operator, such as a truck driver, to set up predetermined temperature management and food safety conditions for various foods. The advanced microprocessors and air distribution systems available for refrigerated trailers and containers offer transportation companies valuable "off-the-shelf" food safety, HACCP, and HARPC solutions.

Microprocessor-driven reefer units offer technological advances that can reduce human errors, the need for operator decision-making, and the need for operator intervention. Some of the features of computerized truck trailer and marine container refrigeration units for compliance with food safety rules are listed below. These technological advances plus others are available with modern computerized refrigeration units and can be incorporated directly into the carrier and shipper's plan for the sanitary transportation of food. In addition, these features help reduce problems that can result in food quality losses irrespective of food safety issues.

- *Operator decisions*. Operator-related errors can be reduced because tasks like thermostat setting, upper and lower temperature limits, rate of temperature reduction, operating modes, and defrost initiation can be preprogrammed into the reefer unit's microprocessor, so they are made easier and simpler than ever for vessel crew, truck drivers, and others.
- *Expert systems*. Expert systems utilize the knowledge of experts to set up custom-tailored equipment and computerized food safety systems and solutions, such as a preprogrammed data logger and/or apps for establishing sanitary transportation settings and limits for specific types of food with unique sanitary food transportation requirements. The computerized reefer units can also be utilized to take complex commodity and food safety related decision-making out of the hands of the operator and others by utilizing the knowledge of engineers, scientists, and food safety experts to assist the carrier in setting up custom-tailored computerized systems in response to shipper and FDA-specified requirements for the safe and sanitary transport of food.
- *Start of trip*. The "start of trip" feature is simple to use and is a critical ingredient for establishing when the carrier started the trip and potentially when the carrier assumed care

[3]HACCP means Hazard Analysis and Critical Control Point. HARPC means Hazard Analysis Risk-Based Preventive Controls.

and custody of the food. The "start of trip" is the beginning of a sanitary food transportation road map to memorialize when the accountability shifts from the shipper to the carrier to the receiver.

- *Computerized pretrip*. This technological advance can be incorporated directly into a sanitary food transportation plan and HARPC. The pretrip is a functionality test of the refrigeration unit and a critical control point in a food safety HACCP plan. Electronic pretrips reportedly can identify in excess of 95% of the issues with a refrigeration unit. Pretripping the reefer unit and documenting the time and date of the pretrip is a key ingredient to a sanitary food transportation plan and to preventing losses and mitigating claims.
- *Antitampering and flashing set point*. Improper thermostat set points rank very high on the list of food safety controls and reasons that cargoes are damaged. One of the key food safety critical controls is setting the thermostat and temperature upper and lower limits correctly. Truck trailer and rail car computerized refrigeration units offer a set point antitampering feature that prevents the set point temperature from being inadvertently or maliciously changed. In addition, reefer units feature flashing set points and audible signals that warn the operator that he/she needs to enter the set point. Use of a combination of antitampering, audible alarms, and visual signals can be incorporated directly into the sanitary food transportation plan.
- *Confusion over °Fahrenheit vs. Celsius*. Temperatures can be recorded by the transportation refrigeration unit in degrees Celsius (°C, formerly known as Centigrade) or in degrees Fahrenheit (°F). The computerized guarded access feature of a reefer unit ensures that large °F or °C symbols are prominently shown on the screen and limits authority to preprogram the reefer unit using either °F or °C for the carrier company management only. This feature helps eliminate human error and confusion.
- *Proper stowage*. The short cycling of conditioned air due to poor stowage and damaged air delivery chutes in trailers can lead to hot spots in a load, which in turn increases the risk of a food poisoning event and a myriad of types of cargo losses. Improper stowage is a leading cause of poor temperature management and cargo losses. Inadequate airflow resulting from poor stowage of food can also be a root cause of food safety problems and violations.
- *Upper and lower thermostat set point limits*. The advantages of setting and locking critical upper and lower temperature limits are substantial. The upper critical limit is the temperature that, if exceeded, the safety of the product may be compromised. In practice the typical operating limit for a carrier of food would be more restrictive than the critical limit. If the operating limit is triggered a carrier can take corrective action to fix a problem before it becomes "critical." Upper temperature limits are critical for the control of the development of food poisoning toxins and food spoilage and the growth of food poisoning organisms. Lower limits are essential for minimizing unwanted freeze and chill damage. The growth of most food poisoning pathogens ceases at or about 38–41°F (3.3–5.0°F) or lower with the exception of listeria, which can grow at lower temperatures. Consequently, setting the upper temperature limit for foods like packaged leafy produce at 41°F would help prevent a hazard from occurring. However, setting the operating limit at 38°F would give the carrier a safety margin and an opportunity to correct a problem in advance of a potential disaster.

- *Record keeping and verification*. The reefer unit's microprocessor/data logger provides the required record keeping and verification that carriers can utilize for their HACCP and HARPC plans for the sanitary transportation of food. Data loggers also offer a means for fast retrieval and storage of information, as well as graphs, tables, and printouts for recording and verifying times and temperatures and many other events during transit.

18.9 BEST PRACTICES

18.9.1 Training

Investigations and studies have found that human error accounts for up to 80% of cargo losses during transportation. Although human-related errors can be reduced because tasks like thermostat setting, upper and lower temperature limits, rate of temperature reduction, operating modes, and defrost initiation can be pre-programmed into the reefer unit's microprocessor, there is no substitute for training and providing human beings with the tools to do their job.

18.9.2 Quality Assurance and Quality Control

The goal of quality assurance is to prevent problems from occurring so as not to be confronted with the need to determine the cause and origin of problems after the fact. Stated differently, action should be taken to proactively prevent problems before they are experienced, as opposed to reactively trying to determine the cause and origin of the problem after the damage is done. The purpose of quality control is to identify problems in support of determining their cause and origin in order to correct the problems and prevent their recurrence.

All those involved in the handling and transportation of perishable cargoes can help contribute to improved temperature and atmosphere management during transit and to prevent more cargo losses by making sure that loading and devanning (unloading) inspections are conducted and quality control checklists are utilized. Trailers, railcars, and containers should be inspected and monitored before, during, and after each trip.

In the context of quality control inspection, the terms "quality" and "condition" as applied to the cargo being inspected need to be defined because they have specific and different meanings. *Quality* and "quality defects" refer to aspects of the produce that are inherent or permanent, such as its shape or a defect (e.g., hollow heart in potatoes) that won't change over time. *Condition* and "condition defects" can progress over time and include such things as color, bruising, and decay. This is different from common usage in which quality is often considered to change over time.

There are four basic types of transport-related inspections and surveys:

- Preload inspection
- Tailgate inspection
- Outturn inspections
- Outturn surveys

A *preload product inspection* is a quality assurance check conducted at the loading point of the cargo into a refrigerated container, trailer, or railcar. This may take place at a packing house, cold storage facility, or off-dock container freight station (CFS). Within the broad scope of a preload inspection, the inspector may be required to perform one or more of a series of specific activities as follows:

- Perform a series of routine inspections and issue reports on the quality and condition of produce within the inspector's area of coverage. This would include a detailed examination of selected cartons or packages of produce at each facility and the collection or verification of condition, quality, weight, size, and quantity information.
- Evaluate and recommend a specific lot of produce from a series of lots currently available from a number of local packing houses or cold storage facilities. The inspector may be asked to provide either a verbal or written recommendation. Digital photographs may also be required.
- Inspect and report on a specific lot of produce in a specific facility or select a specific group of pallets from a larger lot of available product. This may include the verification of condition, quality, weight, and size information, as well as the taking of product temperature readings and digital photographs of selected and prepared samples.
- Witness and/or supervise the loading of products into a reefer container, trailer, or railcar for shipment. This would include a detailed report on the stowage pattern of the pallets within the vehicle, the details of the vehicle itself and its refrigeration machinery and settings, and the locations and nature of any portable temperature recorders, ethylene scrubbers, dunnage, or other apparatus within the load. This would also include digital photographs of vital elements as well as the collection of relevant documentation, such as bills of lading, packing lists, and commercial invoices.

A *tailgate inspection* is a quality control check conducted at some midpoint or end point in the transport chain, such as a receiver, terminal, railhead, depot, or trucking yard. This involves opening the door of the refrigerated equipment to check the status of the packaging and stowage of the load and to remove cargo samples for inspection. This process also involves taking pulp temperature readings and photographs, as well as performing a routine check of the transport equipment, temperature, and other settings.

An *outturn inspection* is a quality control check at some point where the cargo is removed from the transport equipment, such as a cold storage facility, buyer's warehouse, distribution center, or retail facility. This process involves similar procedures to the preload inspection, including inspection and photographs of cargo, packaging, stowage, and equipment, as well as taking pulp temperatures and other measurements as needed.

An *outturn survey* may be requested and conducted if a problem with the cargo itself is discovered at any time during transport. Such a survey involves the collection of facts concerning the shipment and condition of the cargo for submission to the customer and possibly experts in order to establish the root causes and origins of loss.

A checklist can be used to ensure that a reefer container or other type of transport equipment is suitable for loading of perishable cargo and that the settings and stowage are correct (Fig. 18.25).

Refrigerated container loading check list

Shipper	____________	Temperature setting (°F)	____
Commodity	____________	Air exchange (cfm)	____
Carrier	____________	Carton count	____
Container ID	____________	Pulp temperatures (°F)	____
Truckers B/L#	____________	Security seal	________
Temp. recorder # (s)	____________	CA Setting	________

Container check list	Yes (✓)	No (✓)
Container precooled to carrying temperature		
Partlow chart attached		
Microprocessor reefer unit		
Portable temperature recorder(s)		
MGset attached (nose or belly mount)		
Thermostat setting correct		
Fresh air exchange correct		
Hand stow—correct loading pattern		
Palletized—correct loading pattern		

Container Condition	Okay (✓)	Problem (✓)	Describe Problem
Interior cleanliness			
Interior odor			
Damage			
Rear doors			
Door seals			
Floor drains and kazoos			
Reefer unit operational			
MGset unit operational			
Adequate MGset fuel			
Photos (see photo exhibits)			

Inspector signature ________________

Driver signature ________________

FIG. 18.25 Sample of a loading checklist for a refrigerated container. *Source: PEB Commodities.*

18.9.3 Precooling Cargo and Equipment

The practice of rapidly removing heat from produce in order to lower the product temperature to near its optimum postharvest storage temperature is called “precooling.” As a general rule, perishable products should be precooled to the shipper’s specified carrying temperature prior to loading.

Transport equipment should also be precooled prior to loading cargo. The purpose of precooling transport equipment is to cool the interior surface of the refrigerated container, railcar, or truck trailer to the desired carrying temperature. This is accomplished by running the reefer unit when the trailer or container is empty. If the interior of the equipment is above the specified carrying temperature, the cargo can potentially be temperature abused by contact with the hot sidewalls and floors. Failure to precool refrigerated containers, railcars, or truck trailers can result in heat transfer from the container, railcar, or trailer body to the perishable products. For example, when cartons of package-iced broccoli come in contact with hot container interiors, the ice can melt and subsequently block the air returning to the reefer unit, adversely affecting the selling price, as the amount of ice remaining in a broccoli cartons influences the sales price. The result is “cooked” broccoli. Moreover, hand-stowed frozen cargo subjected to undesirably warm floor and sidewall temperatures can potentially be warmed sufficiently to cause texture changes that compromise its quality. Clearly, precooling the reefer container and trailer (with the doors closed) can help suppress temperature-induced damage to the perishable cargoes from hot floors and sidewalls.

Reefer trailers, railcars, and containers are not designed to adequately and uniformly cool most cargoes that are significantly above the desired shipping temperature at the time of loading. Rather, the equipment is designed to maintain the temperature of already precooled cargo during transport. The importance of precooling products is illustrated in Fig. 18.26. Using this example the temperature variation of fresh mangos loaded into a reefer trailer above specified temperature was about 16 °F (9 °C) for the entire trip.

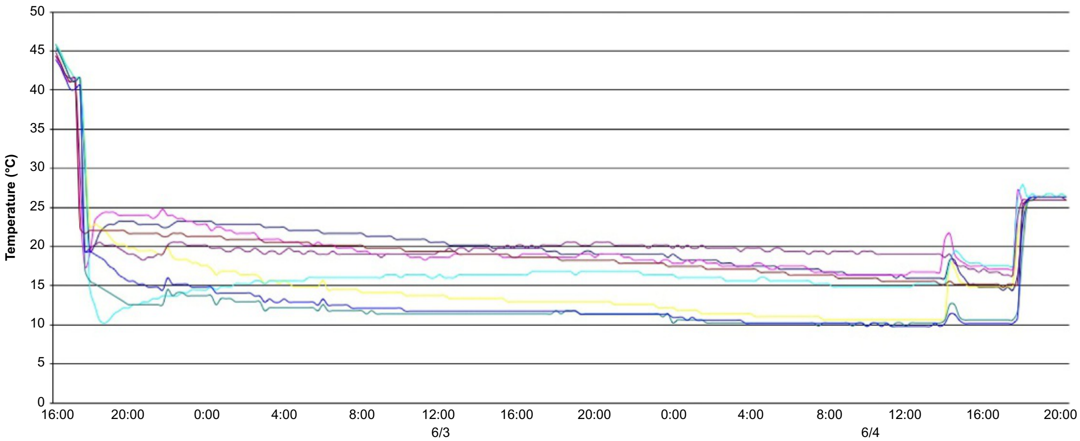


FIG. 18.26 Temperature variation in a reefer trailer shipment of mangoes. Fruit temperatures ranged from 45°F to 84°F (7°C to 29°C) when the mangoes were loaded into the truck trailer and maintained a range of at least 16°F (9°C) for the entire trip. *Source: National Mango Board.*

In open loading dock conditions with warm, humid air, condensation can form on the exposed surface of colder cartons (known as "cargo sweat"). Refrigerated cargo that is transferred from a cold room to a hot, humid dock or open space prior to loading the transportation equipment or unloaded from a cold reefer container or trailer onto a hot, humid dock or open space, is particularly vulnerable to cargo sweat damage. Cargo sweat weakens cartons, leading to their collapse, especially for those cartons in the lowest levels of pallets, thus causing the product they contain to be crushed by the weight of product in higher layers. Under hot, humid conditions, condensation can also form on the ceiling at the rear of the precooled transportation equipment. The concern is that moisture on the ceiling might drip onto the cartons and weaken them, or drip onto the produce within the cartons and cause food safety concerns. Loading or unloading reefer containers and trailers in a hot, humid, and open environment is a poor postharvest handling practice. Refrigerated loading docks with cold tunnels are recommended as a critical part of maintaining the cold chain. Cold tunnels prevent outside ambient air from entering the refrigerated dock and the interior of precooled trailers.

During precooling of the transport equipment the equipment doors must be closed. When the rear doors are opened after precooling transport equipment in hot, humid ambient environments, moist air can enter the interior of the trailers and containers. Moisture that condenses on the interior surfaces of the precooled trailer or container can drip on the cargo and cause quality and food safety issues and rejections.

18.9.4 Portable Temperature Recorders

Temperature recorders are used for capturing and saving records of temperature data. The usefulness and effectiveness of temperature recorders may vary based on the sensor's operating range, accuracy, and resolution, as well as where they are placed in the transport equipment. Temperature sensors inside the refrigerated cargo space may capture the temperature of the product, the temperature of the air surrounding the product, the cargo's return air temperature, or the cargo's supply air temperature. Temperature sensors may also be placed inside or outside the product's packaging.

Portable temperature recorders (also known as temperature monitors) are routinely used to establish if a shipment of perishable foods was maintained at the desired carrying temperature. They may be used at the direction of either the shipper or the receiver, but the responsibility for placing the recorders in the transport equipment falls to the shipper.

The shipper should input or mark the date and local time on the label or data file and document the specific location of each recorder in the load with a bright, identifying label on the outside of the carton and on a preloading form that is attached to cartons nearest the entry doors of the refrigerated equipment.

Temperature recorders should not be placed directly on the container, trailer, or railcar walls, as this may result in elevated readings that do not accurately reflect the air temperature in the load space due to heat transferred across the walls of reefer equipment.

The shipper should install the recorders inside cartons in three locations in the container, trailer, or railcar as follows (Fig. 18.27):

1. Inside the first pallet near the front bulkhead of the reefer unit to detect short cycling of refrigerated air

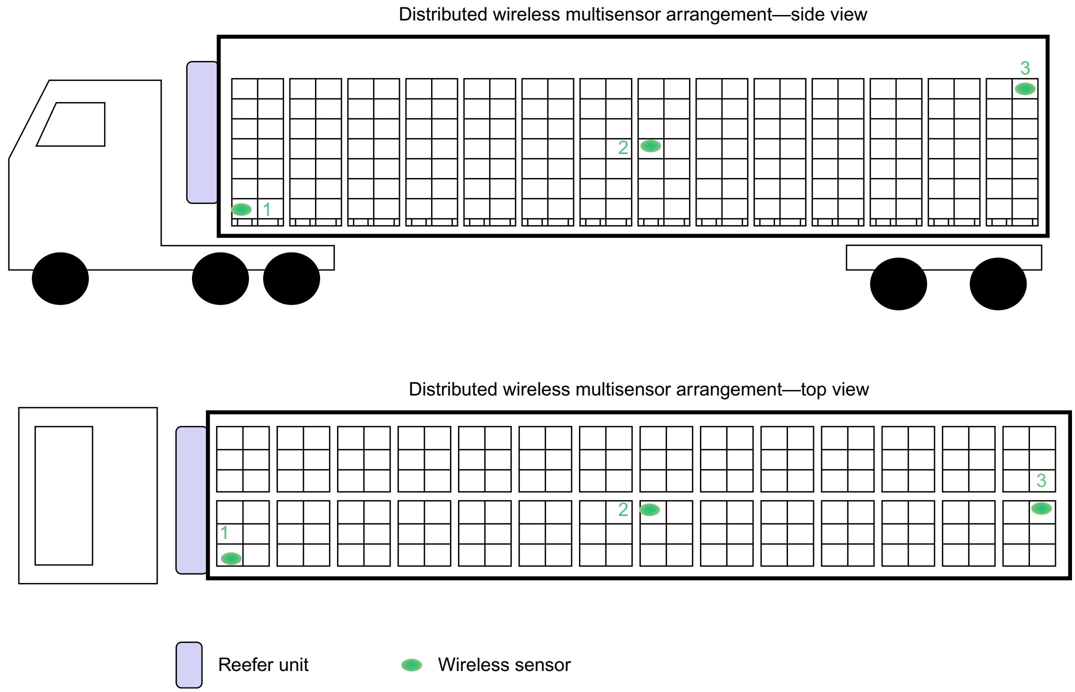


FIG. 18.27 Illustrations showing a side view (above) and a top view (below) of the recommended placement of temperature recorders in a reefer trailer. *Adapted from Ruiz-Garcia, L. et al., 2010. Testing ZigBee motes for monitoring refrigerated vegetable transportation under real conditions sensors. Sensors (Basel) 10 (5), 4968–4982, Published by MDPI AG, Basel, Switzerland; J. Saenz.*

2. Inside a pallet near the center of the load where product heating may most likely occur
3. Inside the last pallet nearest the doors at eye level to record air temperature at the farthest point from the reefer unit.

As stated previously, it is a common misconception that ambient air temperatures inside refrigerated transport equipment or in the return and supply air registers of the refrigeration unit are the same as the temperatures inside the cartons of product or the internal product (pulp) temperatures. This assumption is simply not universally correct. Air temperatures in the ambient space outside the cartons of perishable products change more quickly than internal product temperatures or the temperatures inside the cartons, which can lag significantly behind air temperature changes. More importantly, decisions to reject perishable products are often based on air temperatures recorded in the airspace outside cartons and not inside cartons of product, thereby resulting in unwarranted rejections of perishable food shipments. By way of affirmation, in-transit trials have demonstrated that perishable foods have been mistakenly rejected because recorders placed outside of the cartons were recording "warm" air temperatures, when in fact the temperatures recorded inside the cartons were perfectly normal. It follows that recorders should be placed inside the cartons to record more representative and defensible product temperatures.

18.10 TELEMATICS

In a broad sense, telematics is the term used to describe the transmission of information related to remote objects over a telecommunication network together with the computerized processing of this information.

There are many practical applications of vehicle telematics, such as: monitoring the location, movement, status, and behavior of a vehicle or fleet of vehicles, trailers, containers, and railcars.

The use of satellite navigation, which combines a global positioning system (GPS) with an electronic mapping software application plus the increasing miniaturization and utilization of sensors and cameras, enables additional applications such as: vehicle use-base insurance, fuel management, vehicle maintenance, cargo temperature monitoring, theft prevention, and lately, self-driving vehicles.

One application with significant impact for maintaining the quality and safety of horticultural products is remote temperature management (Fig. 18.28). The ability to remotely monitor the temperature of the refrigeration unit and/or the temperature of the cargo in real time can help minimize the negative effect of power outages on the cargo. It can also help a carrier demonstrate to shippers and receivers that it has maintained temperature conditions during the transportation operation consistent with those specified by the shipper.

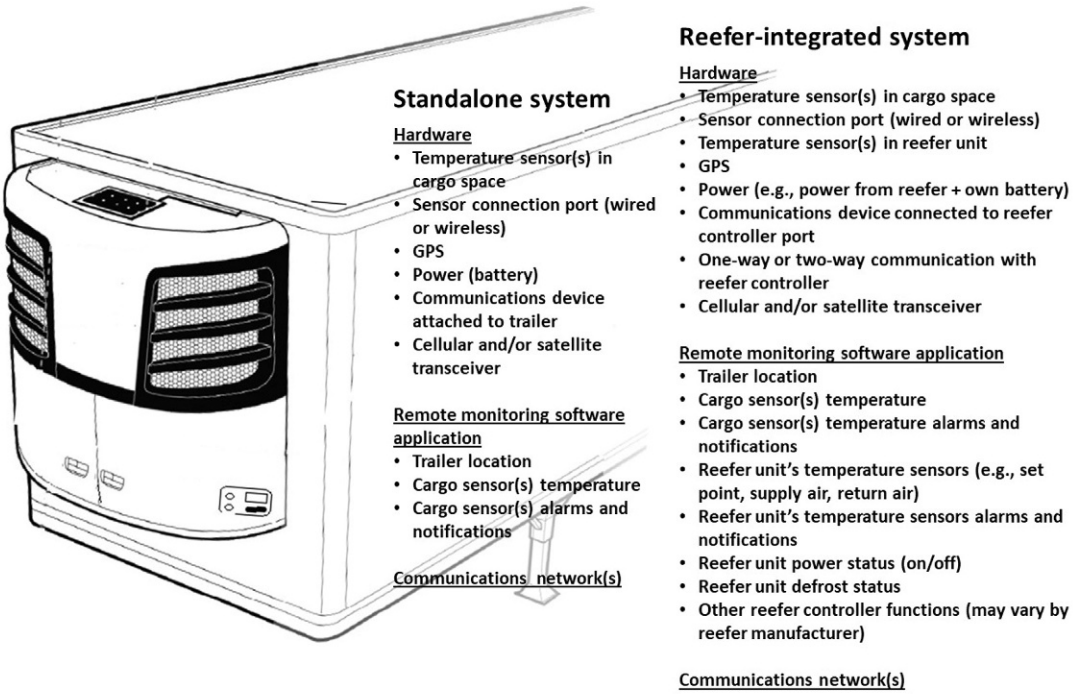


FIG. 18.28 Illustration showing a commercial remote temperature management system and describing its components. *Source: J. Saenz.*

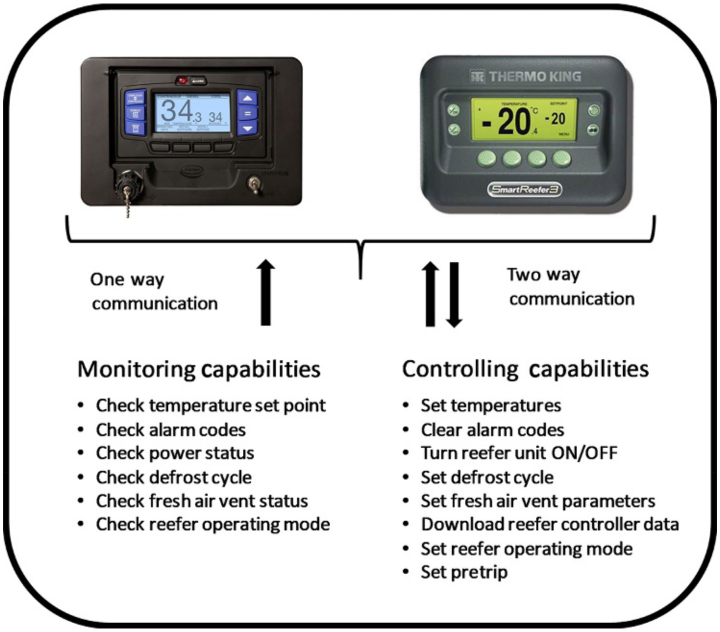


FIG. 18.29 Illustration showing a commercial remote temperature management system with controlling capabilities. *Adapted from Carrier Transicold and Thermo King online published reefer controller photos; J. Saenz.*

Some remote temperature management systems provide monitoring as well as controlling capabilities (Fig. 18.29). This is accomplished by remotely accessing the refrigeration unit's controller using two-way communications and a customized software application to modify the temperature set point based on input received from sensors located in the reefer unit and/or cargo space.

Nevertheless, the lack of a remote temperature management system must not preclude carriers and shippers from recording and tracking product temperatures. Date-stamped product temperature data are essential for determining the root cause, location, and possession in case of cargo losses, as well as for noticing indicators and uncovering evidence that something is developing or changing. For example: (a) unexpected increases in product temperature due to new packaging, (b) accelerated ripening due to changes in harvest maturity, (c) increased product temperature variability due to a new crew's loading practices, etc.

18.11 MICROENVIRONMENTS

It is important to differentiate between sensors placed inside the transport equipment's cargo space from sensors placed inside the refrigeration unit. The latter are part of the reefer unit and are used by the reefer's controller to operate the refrigeration equipment and regulate the temperature of the air supplied to the cargo space. Neither the discharged air nor the

Intrinsic sources

- Pre harvest conditions
- Harvest conditions (e.g., weather, time of day)
- Harvest age and maturity
- Time to destination
- Amount of road heat and humidity
- Outside temperatures during transport
- Product's heat of respiration
- Product's ripeness level
- Product's ethylene production (i.e., climateric)

Extrinsic sources

- Post harvest practices
- Pre cooling (i.e., removing field heat)
- Packaging
- Age and condition of the refrigerated transport
- Refrigerated transport leak rate (i.e., air infiltration)
- Pre cooling refrigerated transport
- Stowage practices
- Temperature stratification in the load

FIG. 18.30 Illustration showing sources of variability in temperature and atmosphere distribution. *From Saenz and Brecht, 2017. Controlling cargo parameters in a microenvironment of a reefer during transit, US 9,829,898; J. Saenz.*

return air temperatures measured inside the reefer unit are necessarily accurate representations of temperatures within the cargo space.

Several published industry studies have illustrated the amount of temperature variability that could exist inside a transport's cargo space carrying horticultural products. There could be many reasons for this, both intrinsic to the horticultural product, such as with preharvest and harvest conditions and practices, and extrinsic to it, such as with postharvest practices, packaging, pretripping, precooling, handling, and stowage practices, and refrigerated transport equipment performance (Fig. 18.30).

The researchers conducting those studies utilized multiple wireless temperature recorders placed inside product cartons throughout the cargo space to capture and map product temperatures throughout the entire supply chain. This allowed high-temperature pockets, which have been referred to as microenvironments, to be identified.[4] A microenvironment may be the environment immediately within or surrounding a perishable item, package, carton, cargo, etc. in a localized area inside the cargo space of a reefer or an insulated box.

Microenvironments may be created by the variability in temperature and/or atmospheric distribution inside the cargo space of refrigerated transport equipment due to many factors, such as, but not limited to: leak rate; thermal efficiency; age and condition of the equipment; insufficient unitization; packaging and stowage of cargo; short cycling of conditioned air; product's field heat and heat of respiration; and condition, age, and/or maturity of cargo.

A microenvironment may be a very small, specific area distinguished from other microenvironments and potentially influenced differently by its immediate surroundings, such as the placement and stacking of the cargo within the truck/trailer/container, air infiltration into the truck/trailer/container, the airflow and temperature stratification in the load and other factors, as well as the amount of radiant heat load of the sun, road heat, humidity, rate of speed of the transit vehicle, and/or diurnal temperatures.

[4]Source: US 9,829,898 "Controlling Cargo Parameters in a Microenvironment of a Reefer during Transit", Saenz and Brecht. 2017.

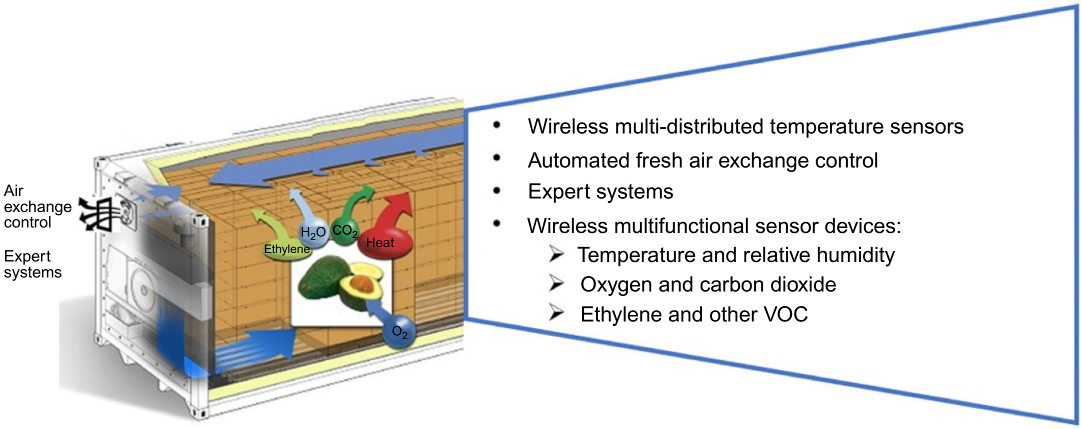


FIG. 18.31 Illustration showing an example of technology applications used for the remote monitoring of cargo conditions in microenvironments in a reefer container. *Adapted from illustration published on APL website; J. Saenz.*

Monitoring and controlling microenvironments in refrigerated transport equipment requires the use of wireless multidistributed temperature sensors in locations that best represent the temperature condition of the entire cargo (Fig. 18.31). Other technology applications, such as automated fresh air exchange controls, expert systems integrated into the reefer unit's microprocessor, and multifunctional sensing devices are also used for capturing key information about the cargo condition, as well as for enabling future value-added processes during transport (e.g., ripening, pest management treatment, etc.)

18.12 THE FUTURE OF TRANSPORT AND CLIMATE CONTROL TECHNOLOGY

The perishable food transport industry has reached a point now where the next advances will involve sanitary transportation, telematics, and computerized refrigeration systems. Advances will concentrate on how perishable food products can be safely and economically transported to markets with the best possible retention of wholesomeness, eating quality, and nutritional quality for consumers, no matter where they reside.

Future refrigerated equipment will most likely be complete climate control systems equipped with telematics, expert systems, feedback systems, and traceability. The refrigerated equipment will in all probability allow for remote management, control, and recording of multiple microenvironments such as: temperature; humidity; O_2; CO_2; N_2; and volatile organic compounds, including ethylene; as well as mold spores and pathogenic bacteria.

Understanding that an end goal of transport systems is to maintain the initial condition and thus extend the shelf life of wholesome perishable foods, there are significant opportunities for future developments in climate control management to establish prediction models for managing the shelf life of produce and other perishable items. Refrigeration and atmosphere control systems that respond to environmental and physiological changes in the product during transport will work in concert with those shelf life models to maintain the optimum environment for the product at every stage during distribution.

The interface between the refrigeration and atmosphere control systems and the product being carried may very well be biosensors that detect ethylene to detect stress or onset of ripening; ethanol, which is indicative of fermentative metabolism and stress; chlorophyll fluorescence, another stress indicator; microbe-generated volatiles related to decay and food safety; and others presently unimagined. Expert system software residing in the refrigeration system's microprocessor will control the system's response to these biological cues. Relating sensor control data to commodity physiology will allow for the early detection of physiological or pathological disorders, as well as residual shelf life prediction modeling with models that are unique to each product. However, this vision will require research to establish all of the possible limiting quality factors for each product that can change for different temperatures, atmospheres, varieties, origins, and maturity/ripeness stages.

The safety of transported food is a nonnegotiable expectation of customers and consumers at every stage of food distribution. In the near future, transport refrigeration and atmosphere control systems will minimize if not eliminate microbiological food safety risks by utilizing technologies for sanitizing the container and cargo based on the recorded microbial load. To illustrate, sanitizing the air that is circulating within the components and conditioned space of reefer equipment could reduce the presence of food spoilage and food poisoning organisms from the air and the surface of the refrigerated equipment components as well as the cargo. This could occur without any negative effect on the commodity or humans as long as the process is validated, monitored, and controlled.

In the future, information about the condition of the products being transported and the performance and control of the refrigeration systems during transport will be continuously available to stakeholders in real time with remote temperature management systems and satellite communication. This will be accomplished by remotely accessing the refrigeration unit's controller using two-way communications and a customized software application that monitors, controls, and modifies product temperature and other environmental conditions based on input received from sensors located in the reefer unit and/or the cargo space. The technology is available now to accomplish this. Future use of distributed sensor arrangements combined with real-time remote monitoring and controlling systems will provide holistic and robust tools for the effective management of refrigerated transport to ensure the wholesomeness and safety of horticultural products.

Future transport systems will be dynamically controlled to change as needed in response to physiological and microbiological cues from the cargo to continuously maintain macro and micro environmental conditions that best maintain the product quality. When problems do arise the availability of real-time information using telematics will permit operators to initiate manual interdiction to avert a problem, take corrective actions to adjust the system, or reroute the cargo to nearer destinations. Programs that allow for the prediction of the remaining shelf life of a product will allow receivers to make accept/reject decisions in real time without delayed downloads, as with traditional temperature data loggers.

References

Brecht, P.E., 1980. Use of controlled atmosphere to retard deterioration of produce. Food Technol. 34 (3), 45–50.

Brecht, J.K., Chau, K.V., Fonseca, S.C., Oliveira, F.A.R., Silva, F.M., Nunes, M.C.N., Bender, R.J., 2003. Maintaining optimal atmosphere conditions for fruits and vegetables throughout the postharvest handling chain. Postharvest Biol. Technol. 27 (1), 87–101.

Brecht, P.E., Dohring, S., Brecht, J.K., Benson, W., 2009. Transport technology and applications. Chapter 3. In: Yahia, E.M. (Ed.), Modified and Controlled Atmospheres for the Storage, Transportation, and Packaging of Horticultural Commodities. Taylor & Francis, New York.

Dohring, S., 2006. Modified and controlled atmosphere reefer container transport technologies. Stewart Postharv. Rev. 2 (5), 8.

Further Reading

Anon, 1976. Handling and Shipping Fresh Fruit and Vegetables by Rail. American Association of Railroads.

Anon, 1999. Controlled Atmosphere Handbook. A Guide for Shipment of Perishable Cargo in Refrigerated Containers, second ed. Carrier Transicold Division, Carrier Corp.

Anon, 2000. Perishable Cargo Handling Manual, third ed. International Air Transport Association, Montreal; Geneva.

Baxter, G., Kourousis, K., 2015. Temperature controlled aircraft unit load devices: the technological response to growing global air cargo cool chain requirements. J. Technol. Manag. Innov. 10 (1), 157–172.

Brecht, P.E., 1992. Shipping Special Commodities. American President Lines, Oakland, CA.

Brecht, P.E., 2001a. Food safety & transportation. London Market News XVIII(1).

Brecht, P.E., 2001b. Refrigeration technology to the rescue. London Market News XVIII(1).

Brecht, P.E., 2014. Technological Solutions for Sanitary Transport of Food. WFLO.

Brecht, P.E., Brecht, J.K., 2001. VFD AFAM™/AFAM+™ Setting Guide. Thermo King Corp, Minneapolis, MN.

Brecht, J.K., Sargent, S.A., Kader, A.A., Mitcham, E.A., Maul, F., Brecht, P.E., Menocal, O., 2014. In: Brecht, J.K. (Ed.), Mango Postharvest Best Management Practices Manual. National Mango Board and UF/IFAS, Gainesville, FL. HS1185.

Brecht, P.E., Durm, D., Rodowick, L., 2016a. Refrigerated Transportation Best Practices Guide. International Refrigerated Transportation Association.

Brecht, P.E., Durm, D., Rodowick, L., 2016b. Summary & User Guide: FDA's Sanitary Transportation of Food Final Rule Advancing the Sanitary Transportation of Human and Animal Food. International Refrigerated Transportation Association.

Brecht, P.E., Durm, D., Rodowick, L., 2016c. Sanitary Transportation of Food Compliance Matrix. International Refrigerated Transportation Association.

Daniels, R., 2000. Across the Continent: North American Railroad History. Indiana University Press, Bloomington, IN.

Dittmer, P., Veigt, M., Scholz-Reiter, B., 2012. The intelligent container as a part of the internet of things. A framework for quality-driven distribution for perishables. In: Proceedings of the 2012 IEEE International Conference on Cyber Technology in Automation, Control and Intelligent Systems, May 27–31, 2012, Bangkok, Thailand.

Goel, A., 2008. Fleet Telematics. Real Time Management and Planning of Commercial Vehicle Operations. Springer Science + Business Media, LLC.

Jedermann, R., Nicometo, M., Uysal, I., Lang, W., 2014. Reducing food losses by intelligent food logistics. Philos. Trans. R. Soc. 372 (20130302). 20 p.

Jiménez-Ariza, H.T., et al., 2013. The phase space as a new representation of the dynamical behavior of temperature and enthalpy in a reefer monitored with a multi distributed sensors network. Food Bioprocess Technol. 7 (6), 1793–1806.

Jiménez-Ariza, H.T., et al., 2015. Multi-distributed wireless sensors for monitoring a long-distance transport in a reefer container. Int. J. Postharv. Technol. Innov. 5 (2), 149–166.

Nunes, M.C.N., Nicometo, M., Emond, J.P., Badia Melis, R., Uysal, I., 2014. Improvement in fresh fruit and vegetable logistics quality: berry logistics field studies. Phil. Trans. R. Soc. A. 372 (20130307). 19 p.

Pelletier, W., Nunes, M.C.N., Émond, J.P., 2005. Air transportation of fruits and vegetables: an update. Stewart Postharv. Rev. online. 1 (1). 7 p.

Reid, M.S., Serek, M., 1999. Guide to Food Transport: Controlled Atmosphere. Mercantila, Copenhagen, Denmark, 152 p.

Ruiz-García, L., Barreiro, P., Rodríguez-Bermejo, J., Robla, J.I., 2007. Monitoring the intermodal refrigerated transport of fruit using sensor networks. Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA). Span. J. Agric. Res. 5 (2), 142–156.

Sales, M., 2013. The Air Logistics Handbook: Air Freight and the Global Supply Chain. Routledge, London.

Tanner, D., Smale, N., 2005. Sea transportation of fruits and vegetables: an update. Stewart Postharv. Rev. online. 1 (1). 9 p.

Thompson, J.F., Brecht, P.E., 2005. Innovations in transportation. In: Ben-Yehoshua, S. (Ed.), Environmentally Friendly Technologies for Agricultural Produce Quality. first ed. Taylor & Francis, New York, pp. 439–445.

Thompson, J.F., Brecht, P.E., Hinsch, T., Kader, A.A., 2000. Marine Container Transport of Chilled Perishable Produce. University of California Div. of Agricultural & Natural Resources Pub. No. 21595.

Thompson, J.F., Brecht, P.E., Hinsch, T., 2002. Refrigerated Trailer Transport of Perishable Products. University of California Div. of Agricultural & Natural Resources. Pub. No. 21614.

Thompson, J.F., Bishop, C., Brecht, P.E., 2004. Air Transport of Perishable Products. University of California Div. of Agricultural & Natural Resources. Pub. No. 21618.