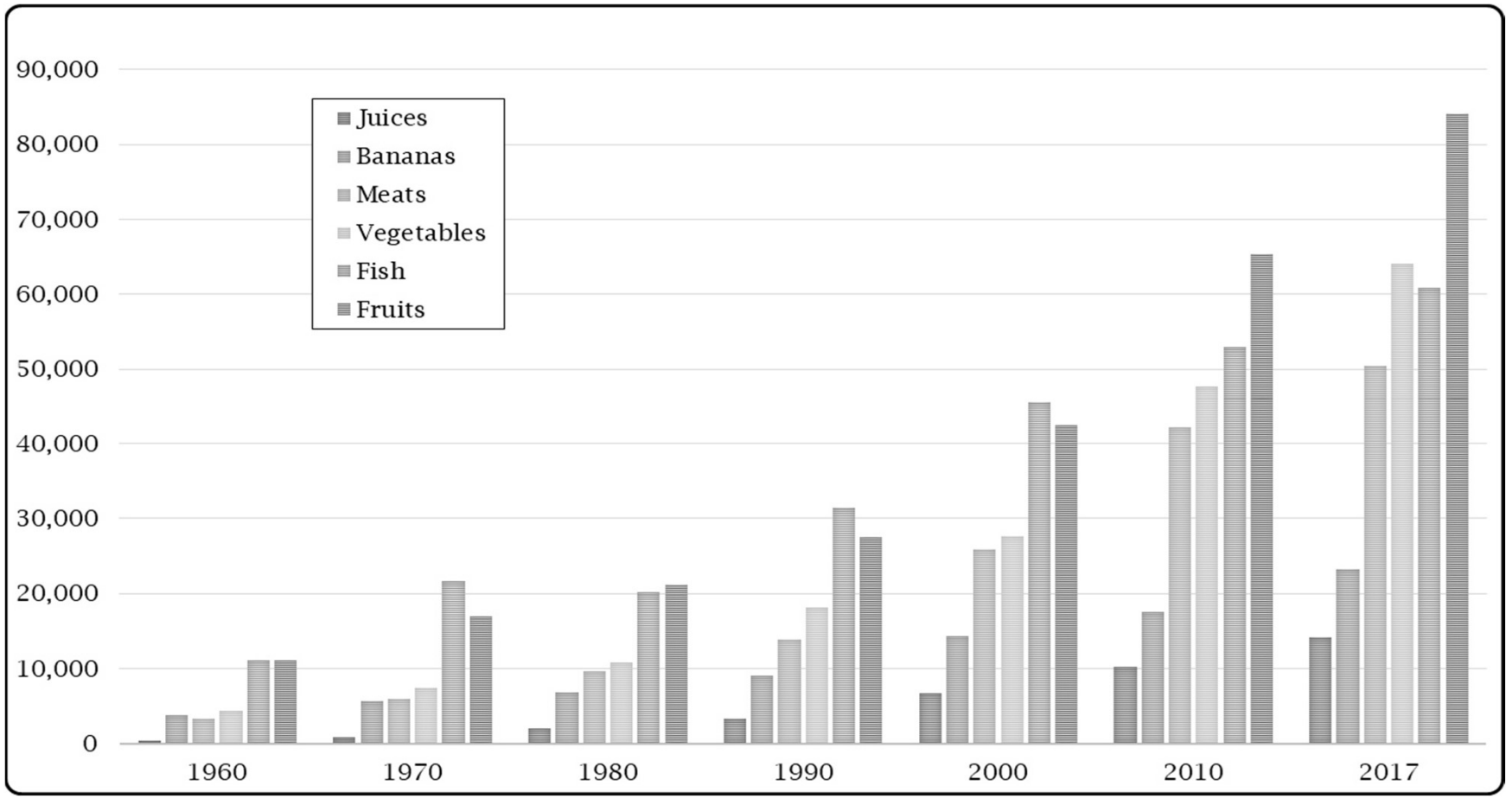
Chapter 18
Refrigerated Goods Transportation

Refrigerated Goods

All goods that are perishable (have a short shelf life) are considered “refrigerated goods:”

- Fruits and vegetables
- Meats and fish
- Juices, Wine
- Flowers
- Some medical products (vaccines, for example)

These goods travel through the “cold chain.”



International trade in refrigerated goods (in thousands of tonnes)
Source: United Nations Food and Agricultural Organization

The first shipments of perishable goods were made under ice, with icing stations along the trip allowing for continuous cooling.
Source: Russell Lee

Blocks of ice were placed on top of the cargo.
Source: Russell Lee

Historical Development

First shipment of fresh beef from the United States to Great Britain in 1873 and first shipment of frozen beef from Argentina (Buenos Aires) to France (Rouen) in 1877.

By 1901, as many as 300 ships operated with ammonia-based refrigeration systems. Bananas were the primary crop.

In 1940, Thermo-King created the mobile refrigeration system that allowed refrigerated truck trailers and refrigerated railcars.

Temperatures of refrigerated goods could be controlled.

Optimal Transportation Temperatures

Commodity	Carrying Temperatures		Min/Max Temperatures		Freezing Temperatures		Shelf Lives
	˚C	˚F	˚C	˚F	˚C	˚F	days
Avocado	+7.0	45	+4.5/+13.0	40/56	-0.5	31	30
Banana	+12.0	54	+12.0/+13.5	54/56	-1	30	24
Cherry	-0.5	31	-1.0/0.0	30/32	-1.5	29	20
Grape	-0.5	31	-0.5/0.0	31/32	-1.5	29	20
Kiwi	-0.5	31	-0.5/+0.5	31/33	-2.0	28	50-75
Orange	+4.5	40	+3.0/+7.0	37/45	-1.0	30	40-50
Pineapple	+8.5	47	+7.0/+10.0	45/50	-1.0	30	30

Optimal Transportation temperatures for selected fruits.
Source: IRR's *Guide to Refrigerated Transport*

Optimal Transportation Temperatures

Commodity	Carrying Temperatures		Min/Max Temperatures		Freezing Temperatures		Shelf Lives
	˚C	˚F	˚C	˚F	˚C	˚F	days
Artichoke	0.0	32	-0.5/+4.0	31/39	-1.0	30	60
Broccoli	0.0	32	0.0/+1.0	32/34	-0.5	31	10
Green Bean	0.0	32	0.0/+7.0	32/45	-0.5	31	20
Onion	0.0	32	0.0/+1.0	32/34	-0.5	31	30-120
Potato	+7.0	45	+4.5/+10.0	40/50	-0.5	31	60+
Sweet Potato	+13.0	55	+13.0/+16.0	55/61	-1.0	30	120
Tomato	+7.0	45	+7.0/+10.0	45/50	-0.5	31	14

Optimal Transportation temperatures for selected vegetables.
Source: IRR's *Guide to Refrigerated Transport*

Optimal Transportation Temperatures

Commodity	Carrying Temperatures		Min/Max Temperatures		Freezing Temperatures		Shelf Lives
	˚C	˚F	˚C	˚F	˚C	˚F	days
Beef	-1.5	29	-1.5/0.0	29/32	can freeze		70
Cheese	+2.0	36	0.0/+10.0	32/50	can freeze		–
Egg	0.0	32	-1.0/+0.5	30/33	-2.5	27	180
Lamb/Mutton	-1.5	29	-1.5/0.0	29/32	can freeze		30
Seafood	-0.5	31	-2.0/0.0	28/32	can freeze		14
Pork	-1.5	29	-1.5/0.0	29/32	can freeze		14
Poultry	-1.0	30	-1.5/+1.5	29/35	can freeze		14

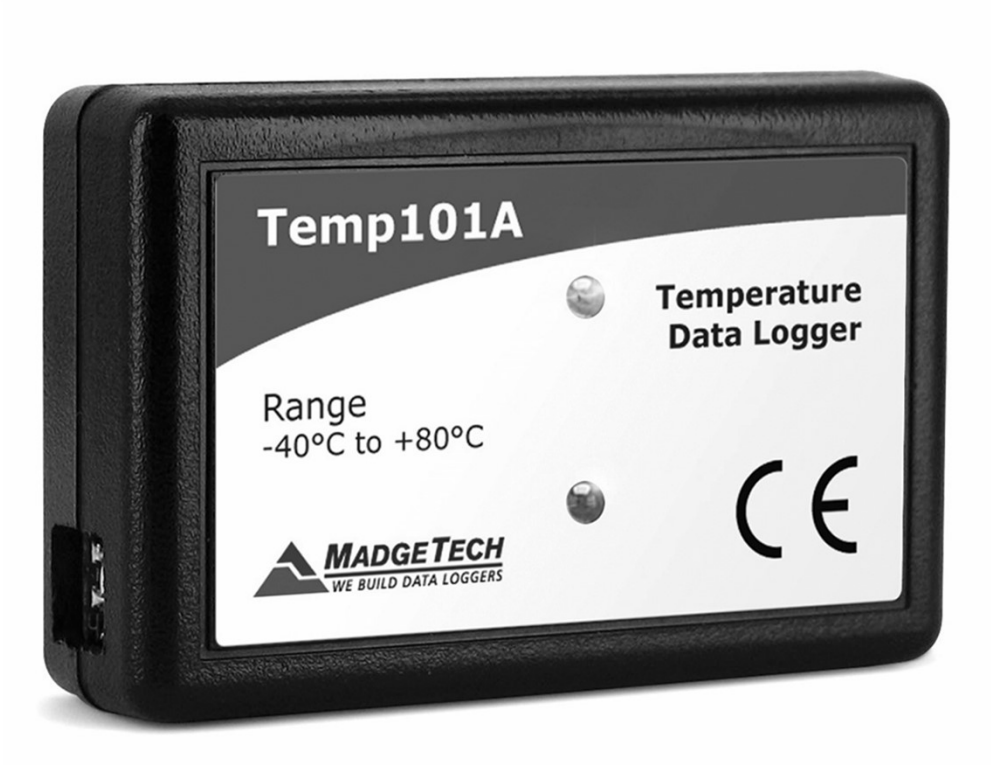
Optimal Transportation temperatures for selected animal products.
Source: IRR's *Guide to Refrigerated Transport*

Temperature Monitoring

It is fundamentally important to ensure that the goods remain at their optimal temperature during their voyage.

As much as 50 percent of the refrigerated goods are damaged (not to the point of not being sellable, but to the point that they may not taste their best) during transport and transfer between modes of transportation.

Monitoring temperature is done through temperature-logging and monitoring devices.



A temperature monitoring device that can be placed with the cargo.
Source: MadgeTech

Understanding Heat

Many fruits and vegetables are climacteric. They continue ripening after harvest. This generates heat, called **respiratory heat.**

Latent heat is the heat that is removed from a substance when it changes phase (from liquid to solid). The substance does not change temperature when it changes phase.

Sensible heat is the heat that is removed from a substance when it is cooled, but does not cause a phase change

Refrigerated containers and trucks can only remove respiratory heat. Fruits and vegetables must be cooled (sensible and latent heat) before refrigerated transport.

Respiratory Heat

Commodities	At 0°C
Asparagus, Corn, Mushroom, Spinach	≥ 13,200
Broccoli, Cut Flowers, Passion Fruit	8,800 – 13,200
Avocado, Cauliflower, Strawberry	4,400 – 8,800
Apricot, Banana, Cherry, Plum, Tomato	2,200 – 4,400
Apple, Grape, Kiwi, Sweet Potato	1,100 – 2,200

Respiratory heat of selected perishable commodities, in BTUs per ton.
Source: Adel Kader

Impact of Mode of Transportation

Temperatures in trucks and containers can be precisely monitored and controlled. Temperatures in aircrafts have much greater variation, as few ULDs are refrigerated.

This drawback is compensated by the short transit time.

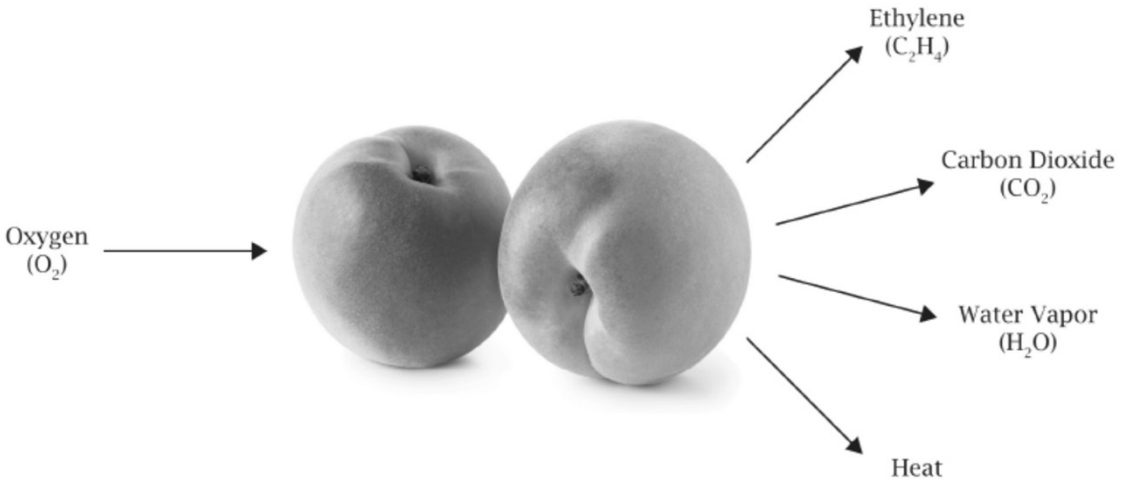
If the entire cargo aircraft capacity is used for a single crop (flowers), then the temperature can be controlled well.

The decreased air pressure in aircrafts also present challenges with the amount of humidity that can be maintained in the cargo hold.

Atmospheric Requirements

Climacteric fruits generate heat, but also ethylene, water vapor, and carbon dioxide

The mix depends on the goods, but also their botanical variety, as well as the time of the year at which they are harvested.



Atmospheric Requirements

In addition, fruits and vegetables are affected by their atmospheric environments.

They must be transported under:

Controlled Atmosphere, in which the concentration of carbon dioxide, water vapor, ethylene, oxygen is regulated and closely monitored. Concentration levels are replenished or eliminated.

Modified Atmosphere, in which the concentration of these gases are set at the beginning of the journey, but not replenished.

Some commodities are sensitive to the gasses they emit (ethylene). In that case, ethylene scrubbers can be added to the shipment.

Ethylene Production and Sensitivity

Commodity	Ethylene Production	Ethylene Sensitivity
Avocado	High	Great
Banana	Moderate	Great
Grape	Very low	Low
Grapefruit	Very low	Moderate
Kiwi	Low	Great
Eggplant	Low	Low
Green Bean	Low	Moderate
Sweet Pepper	Low	Low
Cut Flower	Very low	High

Ethylene production and sensitivity of selected perishable commodities.
Source: Jeffery Brecht

Relative Humidity Requirements

Commodity	Relative Humidity	Commodity	Relative Humidity	Commodity	Relative Humidity
Avocado	85 – 90 %	Orange	85 – 90 %	Onion	95 – 100 %
Banana	90 – 95 %	Pineapple	85 – 90 %	Potato	90 %
Cherry	90 – 95 %	Artichoke	95 – 100 %	Sweet Corn	95 – 98 %
Grape	85 %	Broccoli	95 – 100 %	Tomato	90 – 95 %
Kiwi	90 – 95 %	Green Bean	95 %	Watermelon	90 %

Relative humidity requirements of selected perishable commodities.
Source: Jeffery Brecht

Carbon Dioxide Requirements

Commodity	CO_2 Maximum Level	Commodity	CO_2 Maximum Level	Commodity	CO_2 Maximum Level
Avocado	14 %	Apple	5 %	Onion	10 %
Banana	6 %	Peach	5 %	Potato	10 %
Cherry	10 %	Artichoke	2 %	Sweet Corn	20 %
Strawberry	20 %	Broccoli	15 %	Tomato	2 %
Pear	1 %	Green Bean	10 %	Lettuce	1 %

Carbon dioxide maximum concentrations of selected perishable commodities.
Source: IRR's *Guide to Refrigerated Transport*

Incompatibilities

Commodity	Commodities Affected
Apple	Cabbage, carrot, celery, onion
Avocado	Pineapple
Carrot	Celery
Leek	Figs, grapes
Onion	Citrus, grape, mushroom, corn
Green Pepper	Avocado, bean, pineapple
Potato	Apple, pear

Incompatibilities of selected perishable commodities.
Source: Jeffery Brecht

Sanitation Requirements

Finally, the container must be clean and commodities require one of three levels:

Physically clean refers to apparent cleanliness, with surfaces swept, rinsed, and clear of foreign matters

Chemically clean refers to cleanliness that removes surface residues that could favor bacterial growth, with soaps and chemicals, and then rinsed.

Microbiological clean refers to surfaces clear of any pathogens or biological agents. This is achieved with aggressive disinfectants.

Examples of refrigerated goods in international trade

The temperature and atmospheric requirements of each commodity make it a challenge to ship perishable goods internationally.

International trade in refrigerated goods is dominated by several commodities.

For fruits, they are bananas, citrus, apples, and grapes. For vegetables, tomatoes and green peppers.

Bananas

- 23 million tonnes shipped in 2017.
- Main exporters are Ecuador, the Philippines, Costa Rica, Guatemala, and Colombia.
- Main importers are the United States, Russia, United Kingdom, Japan, the European Union.
- Primarily imported through the Port of Wilmington, DE, in the United States (Chiquita and Dole).
- Shipped between 13˚C and 14˚C (56˚F to 58˚C) with ethylene scrubbers.

The banana terminal in the Port of Wilmington, Delaware, USA.
Source: Port of Wilmington

A banana ship, loaded with reefer containers.
Source: Adrian Hobson

Citrus

Oranges, grapefruits, tangerines and clementines, limes, and lemons

- 17 million tonnes shipped in 2017
- Main exporters are Spain, South Africa, Turkey, China, the United States
- Main importers are Russia, the United States, China, the United Kingdom, Saudi Arabia
- Citrus fruits are both odor emitters and odor absorbers, and the requirements differ substantially between varieties

A shipment of kinnows (a hybrid mandarin) from Pakistan, ready for export.
Source: Sir Sadiq

Apples

Very different trade, with most of exports from temperate-climate countries

- 11 million tonnes shipped in 2017
- Main exporters are China, Poland, Italy, the United States, Chile
- Main importers are Russia, the United Kingdom, Belarus, China, the European Union
- Shipping requirements differ substantially between varieties

Apples are harvested, stored, and shipped in large wooden crates.
Source: Karl Ahnee

Grapes

- 5 million tonnes shipped in 2017
- Transported in an atmosphere rich in sulfur dioxide to prevent mold formation
- Main exporters are Chile, Italy, China, the United States, South Africa
- Main importers are the United States, China, Russia, the United Kingdom, the European Union
- U.S. market dominated by two varieties only

Grapes are often shipped in small vented plastic boxes to allow good ventilation .
Source: imagedb

Blueberries

- 187,000 tonnes shipped in 2017. A small international commodity, but with an annual increase of 7 percent since 2000.

- Transport is done by air, because the berries have a very limited shelf life (2 weeks) under optimal conditions, and are very sensitive to temperature variations.

- They are shipped in controlled-atmosphere bags around pallets.

Blueberries are shipped in controlled-atmosphere pallets.
Source: Besseling Group

Durians

- A delicacy that can only be found in South-East Asia
- The fruit is so pungent that it can only be sold outdoors
- Frequently transported only in frozen state
- Some countries, including China, now allow fresh-fruit imports

Durians are so pungent that, in Thailand, they can only be sold in the streets.
Source: Kevin Hellon

Tomatoes

- 8 million tonnes shipped in 2017
- Exporters are either warm-weather countries (field tomatoes) or cold-weather countries (greenhouse tomatoes). Exporters are Mexico, the Netherlands, Spain, Iran, Morocco, Canada
- Main importers are the United States, Russia, Iraq, the United Kingdom, the European Union
- Roma (large tomatoes) are harvested green, but cherry tomatoes are harvested and shipped “mostly ripe.”

Some of the variety in commercially available tomatoes. They are transported under different conditions.
Source: Bonnie Plants

Juice

- Juice is shipped either single-strength---no processing--- (11 million tonnes) or in concentrated form (3.4 million tonnes)
- Orange juice dominates (6 million tonnes), then apple, pineapple, grape.
- Juices are shipped in “juicers,” ships that carry it in bulk form

Orange juice can be transported in bulk.
Source: Peter Beentjes

Meats

- Very high volume: 40 million tonnes
- Three quarters of that is poultry (16 million tonnes) and pork (14 million tonnes)
- Beef is 8.5 million tonnes
- The rest is mutton (1 million tonnes), horse, goat, game
- Sanitation is most important for this cargo

Refrigerated pork, shipped “hanging.”
Source: Konstantin Gushcha

Milk, Eggs, and Cheese

- Milk, cheese, and eggs are mostly traded between neighboring countries
- 23 million tonnes
- Generally not transported frozen
- Cheese cargoes generate so much carbon dioxide that containers must be ventilated before being unloaded

Fish

- Very large international trade (64 million tonnes), even though most of the 178 million tonnes production is consumed locally
- Wild-caught fish in great decrease, farm-raised fish in great increase
- Dominant species are shrimp, tuna, salmon, squid, tilapia

Tuna in Japan

- Wild-caught tuna of some species can be sold at extremely high prices in Japan
- Blue-fin tuna (frozen) can reach $10,000 a kg
- The Toyosu Market has a tuna auction that attracts so many visitors that the observation deck is limited to 10 minutes

The red-tuna fishing season in the Mediterranean Sea is less than a month long, with almost all of the catch going to Japan
Source: Martinez Constructions Navales

The frozen-tuna auction at the Tsukiji Market in Tokyo, where prices reach $3000 per pound regularly for blue-fin tuna
Source: Michael von Aichberger

Packaging of Refrigerated Goods

Packaging of the goods must allow air circulation (at least holes on five percent of package's surface).

Packages must cover the entire pallet (no other place for air to go but through the goods).

Pallets must cover the entire floor.

A shipment of endives that covers the entire truck floor
Source: Photoagriculture

Refrigerated Trucks and Containers

Refrigerated trucks are powered by a unit mounted on the trailer. They do not depend on the truck's engine for power.

They are used for relatively short distances (less than 1,500 km [1,000 miles].

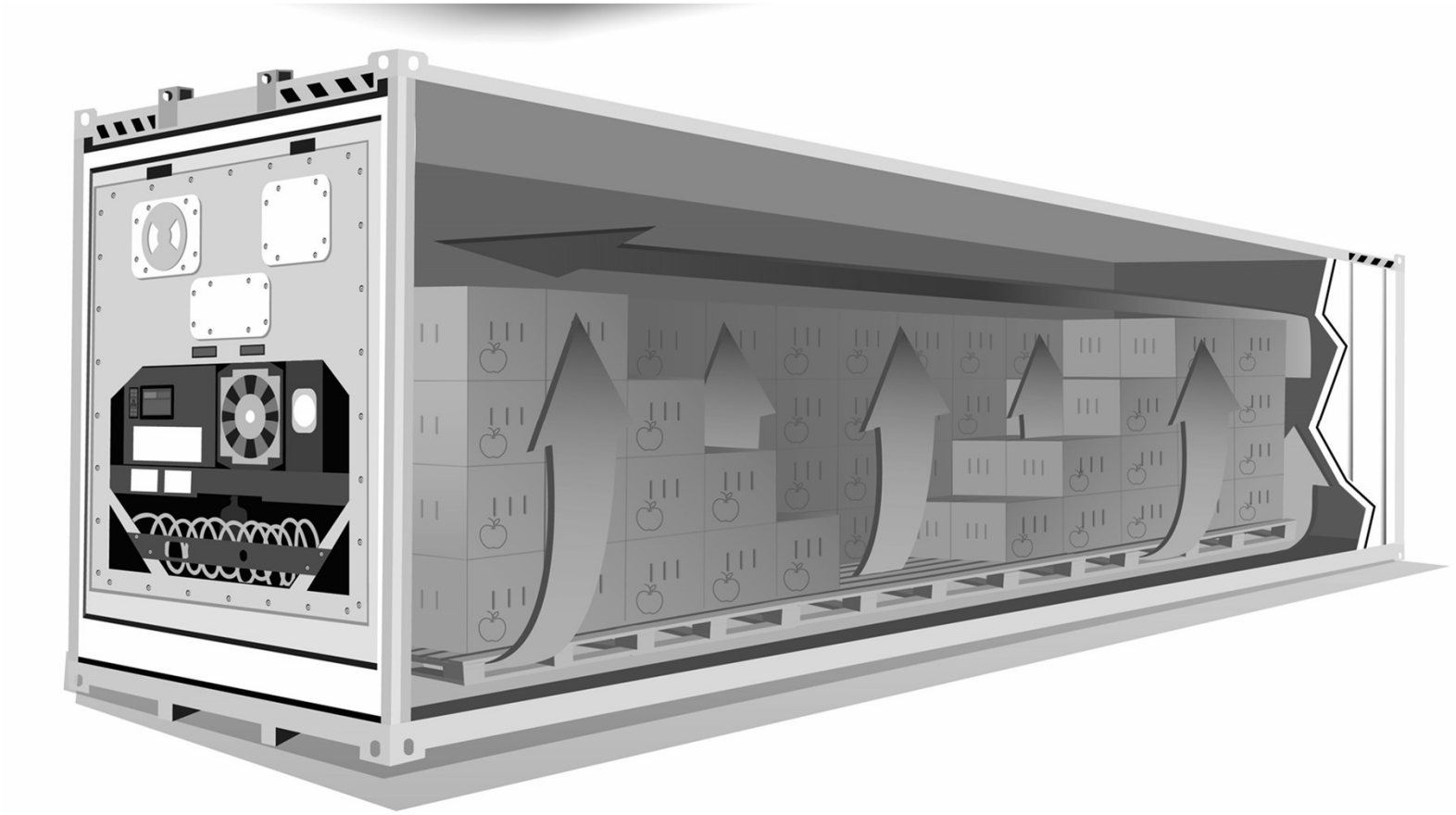
They are cooled "top-down."

Refrigerated containers are powered either by a unit mounted on the container or by power supplied by the port or the ship.

They are used for long distances (inter-continental).

They are cooled "bottom-up."

A refrigerated truck is cooled “top-down,” with the cooled air circulating above the goods and warm air recirculating toward the cooling unit through a baffle at the front of the trailer.
Source: Daisy Krokos



A refrigerated container is cooled “bottom-up,” with the cooled air circulating below the goods and warm air recirculating toward the cooling unit above the goods.
Source: Daisy Krokos