11

Chilled and frozen retail display

In general, display cabinets have to accommodate three types of meat and meat products: (1) chilled wrapped, (2) chilled unwrapped and (3) frozen wrapped products. The required display life and consequent environmental conditions for wrapped chilled products differ from those for unwrapped products. The desired chilled display life for wrapped meat and meat products ranges from a few days to many weeks and is primarily limited by microbiological considerations. Retailers of unwrapped meat and delicatessen products, for example sliced meats and paté, normally require a display life of one working day. Frozen products can remain on display for many weeks.

11.1 Chilled display of wrapped meat and meat products

To achieve the display life of days to weeks required for wrapped chilled meat, the product should be maintained at a temperature as close to its initial freezing point, –1.5 °C, as possible. To maintain product temperature in the range –1–0 °C is the stated aim of at least one manufacturer of multi-deck display cases for wrapped meat (Brolls, 1986). Growth of *Salmonella* is prevented by temperatures below 7 °C. Whilst growth of *Listeria monocytogenes* is slowed by refrigeration, it still multiplies very slowly even at 1 °C unless the pH is below *ca*. 5.0. Consequently displaying meat at temperatures consistently in the –1–3 °C range would substantially improve product safety.

Air movement and relative humidity (RH) have little effect on the display life of a wrapped product, but the degree of temperature control can be important especially with transparent, controlled atmosphere packs. During any control cycle, the cabinet temperature rises, heat enters the pack, the atmosphere inside the pack warms with consequent reduction in relative humidity and increase in the surface temperature of the product. As the surface temperature rises so does its saturation vapour pressure (a factor controlling evaporation) and more water evaporates into the sealed atmosphere of the pack. If the cabinet temperature was stabilised then evaporation would continue until the atmosphere became saturated. However, in practice the cabinet air temperature cycles and as it is reduced the wrapping film is cooled. If it reaches a temperature below the dew point of the atmosphere inside the pack, then water vapour will condense on the inner surface of the pack. This film of water can obscure the product and consequently reduce consumer appeal. As the cycling process continues the appearance of the product deteriorates.

To maintain product temperatures close to 0 °C, the air off the coil must typically be –4 °C and any ingress of humid air from within the store will quickly cause the coil to ice up. Frequent defrosts are often required and even in a well maintained unit the cabinet temperature will then rise to 10–12 °C and the temperature of the product will rise by at least 3 °C (Brolls, 1986). External factors such as the store ambient temperature, the siting of the cabinet and poor pretreatment and placement of products substantially affect cabinet performance. Warm and humid ambient air and loading with insufficiently cooled products can also overload the refrigeration system. Even if the food is at its correct temperature, uneven loading or too much product can disturb the air flow patterns and destroy the insulating layer of cooled air surrounding the product. An in-store survey of 299 prepackaged meat products in chilled retail displays found product temperatures in the range –8.0–14.0 °C, with a mean of 5.3 °C and 18% above 9 °C (Rose, 1986). Other surveys (Bøgh-Sørensen, 1980; Malton, 1971) have shown that temperatures of packs from the top of stacks were appreciably higher than those from below owing to radiant heat pick up from store and cabinet lighting. It has also been stated that products in transparent film overwrapped packs can achieve temperatures above that of the surrounding refrigerated air owing to radiant heat trapped in the package by the 'greenhouse' effect. However, specific investigations failed to demonstrate this effect (Gill, 1988).

11.1.1 Factors affecting display life

The display life of wrapped meat can be affected by the diet of the animal and the treatment of the meat before display. During display for 8 days at 4 °C TBARS values were lower and Hunter 'a' values higher in pork chops from pigs fed with a high 100–200 mg α-tocopherol acetate per kilogram diet than those fed with 10 mg kg^{-1} (Monahan *et al.*, 1994). Lipid oxidation and colour deterioration were also faster during display of chops that had been previously frozen and thawed before display. Overageing of meat can limit its display life. Bell *et al*. (1996) found that hot-boned bull beef aged at 5 °C for 6 days could only be displayed for 24 h at 5 °C before it was unacceptable because of its dull dark lean tissue and grey to green discoloration of the fat. Similar meat that was unaged but also stored for 70 days at –1.0 ± 0.5 °C could be displayed for 48 h.

Retail display characteristics of steaks from hot-boned logissimus dorsi (LD) and M. semimembranosus (SM) muscles from electrically stimulated sides were found to be similar to those from cold-boned unstimulated sides (Griffin *et al*., 1992). Whole muscles from both treatments were stored for up to 21 days before cutting into steaks. The colour of the lean from meat stored for 21 days was brighter than that stored for 7 or 14 days. Lean colour, fat colour and overall appearance scores all decreased with time over the 5 day display period.

Previous storage will reduce the display life of meat and it is better to store meat in large pieces. Meat that had been minced before storage lost its red colour more rapidly during display than that minced immediately before display (Madden and Moss, 1987). The addition of carbon dioxide (CO_2) prior to storage has a beneficial effect on colour and bacterial growth during display. Additions of 2–4 g of solid CO_2 per kilogram of meat resulted in growth of total viable bacterial counts similar to that of unstored controls. However, total anaerobic levels were much higher than controls.

Storing prepacked meat in a gas flushed 'mother' bag has been advocated as a method of extending the chilled storage life without reducing the retail display life of the packs. Scholtz *et al*. (1992) packed pork loin chops in individually overwrapped Styrofoam trays which were then bulk packed in vacuum bags which were subsequently inflated with 100% CO_2. After up to 21 days storage in the mother bags at 0 °C the packs had a subsequent retail display life of 4 days. A retail display life of 4 days could only be attained after storage for 14 days in modified atmosphere packs or for 7 days in vacuum skin packs.

A display life of 6 days can be achieved in pork loin chops obtained from fresh pork loins and vacuum packed in high oxygen-barrier films (Vrana *et al*., 1985). The chops were displayed at 2 ± 2 °C for cycles of 14 h under an illumination of 1614 lux, followed by 10 h in the dark. Under similar conditions chops packed in high oxygen-permeable film had a display life of 4 days.

11.1.2 Layout of chilled cabinet

A typical cabinet has a refrigeration unit behind the display area. The chilled air from the refrigeration unit is blown by a fan and delivered to the relevant area by duct work behind the display area (Fig. 11.1). After the air has been delivered to the display area it is then drawn back into the duct through a grille and is refrigerated again to continue the cycle.

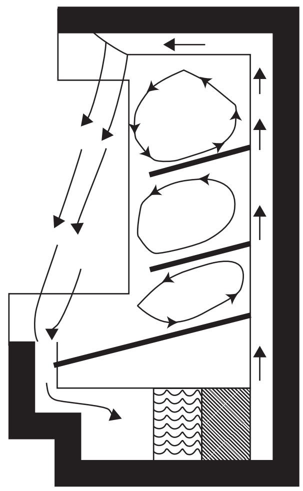


Fig. 11.1 Multi-deck display cabinet for wrapped products.

The duct provides two functions: (1) to provide cold air through the holes in the rear panel and (2) to provide an air curtain at the front of the cabinet. The holes in the rear panel direct chilled air over the food and the air curtain provides a thermal barrier between the chilled display area and the store.

A 'perfect' cabinet would have its chilled air form a closed cycle, much like a domestic refrigerator when the door is closed. In reality warm moist air from the surrounding store entrains with chilled air from the air curtain causing a loss of chilled air from the cabinet and a gain of warm air and moisture.

11.1.3 Air curtain

The air curtain differs from a solid door as it provides no physical barrier between customer and product, but is similar to a door in that it does provide a thermal barrier. The air curtain is a jet of chilled air of about $1\,m\,s^{-1}$ that exits the duct at the top of the cabinet and falls down the face of the cabinet to the return grille. Owing to the fact that the temperature of the air from the air curtain is lower than the surrounding air, it is denser and therefore is aided by natural convection in its downward motion.

The air curtain is very sensitive and its effectiveness has other implications. An ineffective air curtain is likely to have the following effects:

- Increased temperature of product,
- Increased icing up and therefore more defrosts of the refrigeration coil,

- Increased energy consumption of the refrigeration compressor. About 60% of electricity consumed in modern supermarkets is used by display cabinets for frozen and chilled foodstuffs,
- Decreased temperature in the store next to the cabinet. This is described as the 'cold feet effect' and can lead to temperatures as low as 10 °C in the centre of refrigerated aisles.

The are many variables affecting the efficiency of the air curtain, for example:

- The temperature difference between the chilled air and the store air,
- The velocity of the air curtain,
- The thickness of the air curtain,
- The pressures either side of the curtain,
- Obstructions in the path of the air curtain.

Some cabinets use a dual air curtain which has an extra jet of air parallel to the first jet but on the store side. This jet has the same velocity as the first jet but the air is not refrigerated as it is taken from the store and is therefore at store temperature.

The idea behind the dual air curtain is that there will be little entrainment between the two air jets as they are travelling at the same speed. Therefore there will be little heat gain through the barrier between the two air curtains. The entrainment will take place at the interface between the second curtain and the store, and because there is no temperature difference between this jet and the store there will be no heat infiltration.

One of the difficulties of dual air curtains is getting them to stay together all the way down the front of the cabinet. As the first curtain is chilled it will be forced downwards due to natural convection but this will not happen to the second curtain because it is not colder than the surroundings.

11.1.4 Cabinet development

Getting the air curtain to work properly is critical to the correct operation of the cabinet. Temperatures of the food simulants inside the cabinet can be monitored within specified store conditions to see if the cabinets meet the required specifications. British Standard methods of test for commercial refrigerated cabinets are contained in parts 1–8 of BS 6148 with part 3 covering the determination of temperature. The determinations are carried out in a controlled environment corresponding to the climatic class of interest. Temperatures are measured in M-packages, $50 \times 100 \times 100$ mm packages of a meat simulant, positioned at defined positions in the cabinet. Set positions are 150 mm from the centre line and within 150 mm of one end with additional positions for large cabinets. The standard also states 'In addition to these M-packages, two extra M-packages shall be located within the useful net volume so that the maximum and minimum test package temperatures will be recorded.' The difficulty of achieving this requirement has already been described in papers by Marriott (1992) and Gigiel and James (1992). These two papers also clearly reveal the need for test procedures that will relate to the likely performance of the cabinets within the retail environment.

When the products do not meet the required temperatures it is often the air curtain that is to blame. The air curtain is invisible and so it needs to be made visible to check that it is doing what is required.

Smoke is probably the most used method to view the air curtain. When smoke is blown into the air curtain it can be clearly seen. The cabinet can now be modified and its effect viewed using smoke.

11.1.5 Computer modelling

Developing a cabinet can be a very lengthy process. The cabinet temperatures are not steady with time, as the cabinet's coil ices up and then defrosts. Any movement in front of the cabinet will have an effect on the air curtain and product temperatures. Any changes made to the cabinet may not have an immediate effect on product temperatures, therefore a number of small changes to a display cabinet can be a time-consuming and costly process.

Computational fluid dynamics (CFD) is becoming widely accepted as a tool that can be used to aid development of display cabinets. CFD allows the user to make changes to a computer model of the cabinet and see its effect before changing the real thing. If computing resources allow it, a number of changes can be made to a computer model relatively quickly and the best case tried on a real cabinet.

CFD has been used to show the effect of removing shelves from a retail display cabinet (Foster, 1995). A two-dimensional model of a chilled cabinet was used to predict the effect of removing shelves from the cabinet (Fig. 11.2). The predictions showed that the refrigeration consumption was least (570 W per metre length of cabinet) when the case was fully loaded. As shelves were removed from either the top downwards or bottom upwards, the energy consumption increased to a maximum of 653 $W\,m^{-1}$ when all of the shelves were removed. CFD predictions of the cabinet with different configurations of shelving demonstrate that when shelves are removed, pressure differences between the cold cabinet and the store cause the air curtain to bend inwards. This causes more mixing between the cold and warm air, increasing product temperature, reducing store temperatures and increasing energy consumption.

11.1.6 Store conditions

One factor that can greatly effect the operation of a retail display cabinet is its positioning relative to the store's heating and ventilation system (Foster, 1997). Because of the cold feet effect, supermarket stores are keen

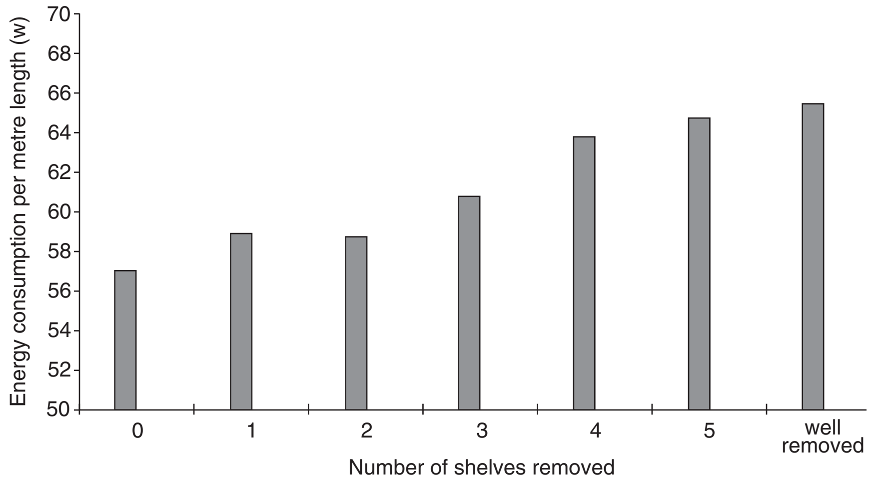


Fig. 11.2 Refrigeration load per metre length of cabinet as shelves are removed from the top downwards (source: Foster, 1997).

to put heat into the store near the cabinets. This has to be carefully controlled, as fast moving air near an air curtain will disrupt it. If the air is also warm it can greatly affect the temperature of the product inside.

11.2 Retail display of unwrapped meat and delicatessen products

The market for delicatessen meat products in the UK was estimated to be worth *ca*. £3 billion in 1992. The demand for delicatessen products has been influenced by a number of factors over the last few decades, ranging from demographic changes to membership of the European Union (MLC, 1992). The delicatessen market as a whole has benefited from the belief that delicatessen products are fresh and natural, and for their convenience, all of which make them attractive to the consumer.

It has been recognised for many years that temperatures close to the initial freezing point ($0 \pm 1.0\,°C$) are required to provide a long display life for unwrapped meat. Studies have shown that control of relative humidity over the surface of sliced meats and other delicatessen products is critical if a high quality display life is to be achieved.

Surveys carried out in a number of EU countries revealed retail display cabinets to be the weakest link in the chill chain (Malton, 1972; Moerman, 1972; Bøgh-Sørensen, 1980; Lyons and Drew, 1985). Product temperatures in Denmark (Fig. 11.3) were very similar to those measured in Sweden and the UK. Poor temperature control, either in terms of a temperature

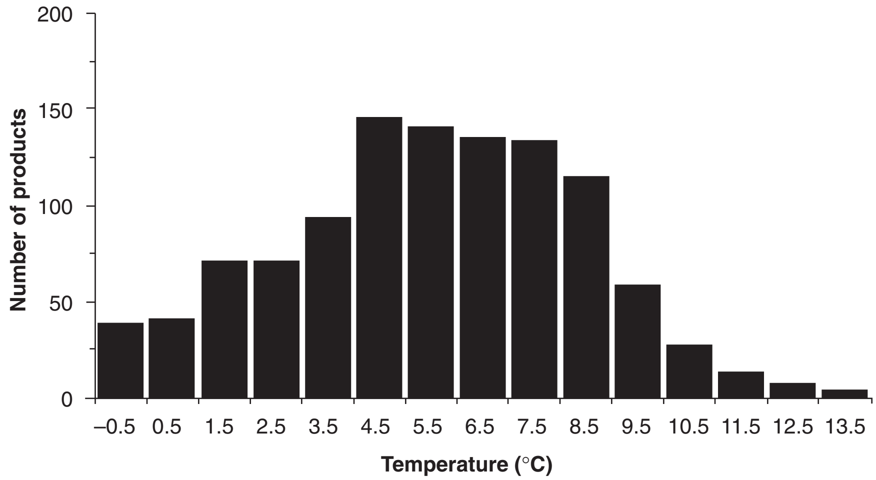


Fig. 11.3 Product temperatures in chilled display cabinets in Denmark (source: Bøgh-Sørensen, 1980).

gradient within a cabinet or due to fluctuations in temperature, is one of the problems when using retail display cabinets (James and Swain, 1986). Many practical problems associated with retail display of meat and meat products arise from failure to ensure that display cabinets are suitable for the product.

11.2.1 Types of cabinet

Considerable quantities of chilled unwrapped meat and sliced delicatessen products are now sold from refrigerated display cabinets of one type or another. Display cabinets for delicatessen products are available with gravity or forced convection coils and the glass fronts may be nearly vertical or angled up to 20 degrees. Sections through three of the commonest types of delicatessen cabinet are shown in Fig. 11.4. In the gravity cabinet (Fig. 11.4a), cooled air from the raised rear mounted evaporator coil descends into the display well by natural convection and the warm air rises back to the evaporator. In the forced circulation cabinets (Fig. 11.4b and c), air is drawn through an evaporator coil by a fan. It is then ducted into the rear of the display, returning to the coil after passing directly over the products (Fig. 11.4b), or forming an air curtain (Fig. 11.4c), via a slot in the front of the cabinet and a duct under the display shelf (James, 1996).

11.2.2 Appearance changes

Changes in appearance are normally the criteria that limit display of unwrapped products rather than microbiological considerations. Deterio-

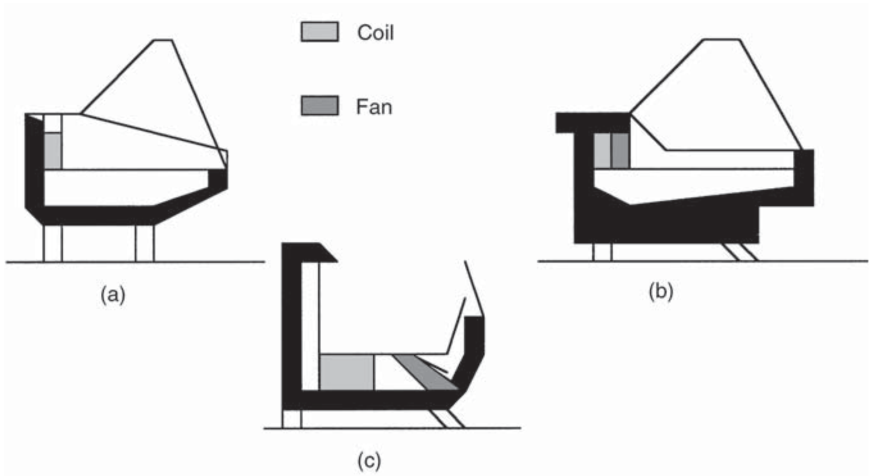


Fig. 11.4 Three types of retail display cabinet for unwrapped products.

Table 11.1 Relationship between evaporative weight loss and appearance of sliced beef topside after display for 6 h

Evaporative loss ($g\,cm^{-2}$)	Change in appearance
up to 0.01	Red, attractive and still wet; may lose some brightness
0.015–0.025	Surface becoming drier, still attractive but darker
0.025–0.035	Distinct obvious darkening, becoming dry and leathery
0.05	Dry, blackening
0.05–0.10	Black

Source: James and Swain, 1986.

ration in the appearance of unwrapped meats has been related to the degree of dehydration (Table 11.1), which makes the product unattractive to consumers (James and Swain, 1986). Weight loss on its own cannot only be a measure of performance but also has important economic considerations to the retailers. In the UK, the direct cost of evaporative weight loss from unwrapped products in chilled display cabinets was estimated to be in excess of 6.25 m euros per annum (James and Swain, 1986).

11.2.3 Effects of environmental conditions

The rate of dehydration is a function of the temperature, velocity and relative humidity of the air passing over the surface of the food. James and Swain (1986) found that changes in relative humidity had a substantial effect with a reduction from 95 to 40% causing increasing weight loss over a 6 h display period by a factor of between 14 and 18 (Fig. 11.5). The effect of air velocity on weight loss was compounded by that of relative

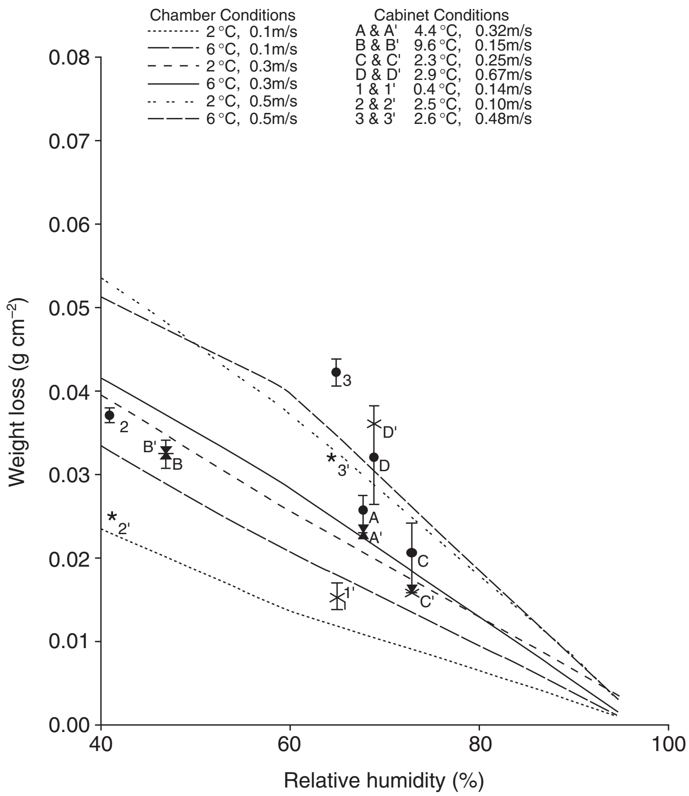


Fig. 11.5 Mean weight loss of samples of corned beef after display for 6 h at different relative humidities, air velocities and temperatures (source: James and Swain, 1986).

humidity. Raising the air velocity from $0.1\,m\,s^{-1}$ to $0.5\,m\,s^{-1}$ had little effect on the weight loss at 95% RH, however, the magnitude of the effect increased as relative humidity decreased producing maximum changes at 40% RH. When changing the temperature from 2 to 6 °C the effect on the weight loss was far smaller than the changes in relative humidity or air velocity.

In their mathematical prediction of weight loss, Fulton *et al*. (1987) and James *et al*. (1988a and b) showed that fluctuations in temperature or relative humidity had little effect on weight loss. The weight loss under fluctuating conditions was identical to that experienced under the mean of the fluctuations.

Evans and Russell (1994a, b) also showed that relative humidity was the main factor controlling weight loss in the display life of delicatessen products. At a relative humidity of 40% the effect of surface drying became apparent after *ca*. 100 min. At 85% RH the products could be displayed for

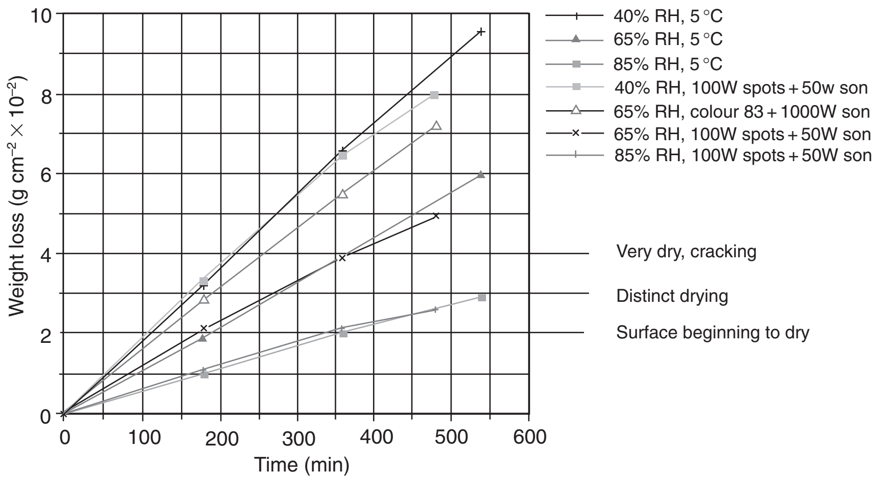


Fig. 11.6 Comparison of mean weight loss at different relative humidities and lighting regimes for delicatessen products (source: Evans and Russell, 1994).

between 4 to 6 h before surface drying could be noted. The overall weight loss at 40% RH was approximately 3 times that at a relative humidity of 85%.

In the same work Evans and Russell also found that changing the lighting combination of 50 W sons and 100 W halogen lights to 100 W sons and a colour 83 fluorescent significantly increased the weight loss. The increase was similar in magnitude to that produced by a 20% reduction in relative humidity. On average the rate of weight loss under the combination of 50 W sons and 100 W halogen (spot) lights was approximately 1.4 times less than the 100 W sons and colour 83 fluorescent lighting (Fig. 11.6).

11.3 Retail display of frozen wrapped meat

Frozen display of meat is part of the frozen chain that includes freezing, storage and transportation, retail display and finally domestic storage.

The purpose of retail display is to present the meat to the consumer in the most attractive way, whilst maintaining the quality of the frozen product. As long as the meat or meat product is maintained below –12 °C its bacterial state will not deteriorate. Its taste, texture and appearance are the main quality factors that can deteriorate during frozen display.

11.3.1 Factors controlling display life

The many factors that control the display life of frozen meat start with the live animal and the treatment of the meat prior to freezing. During display, temperature, temperature fluctuations and packaging are the main display parameters that control the quality factors.

11.3.1.1 Prefreezing treatments
Lanari *et al*. (1994) have shown that dietary vitamin E supplement fed to the live animal improved pigment and lipid stability of frozen beef stored under illumination and in the dark at −20 °C. These results complemented their earlier publication (Lanari *et al*., 1993) which showed that the colour of control samples of longissimus lumborum deteriorated in 1 day compared with 11 days for treated samples stored in the dark. Under an illumination of 1614 lux the treated samples deteriorated after 38 days. The advantages of using vitamin E supplementation in the extension of chilled and frozen storage life was reviewed by Liu *et al*. (1995).

Further studies (Lanari *et al*., 1995) have shown that blooming time, the atmosphere used for blooming, vitamin E supplementation and illumination (1614 lux) all affect the colour display life of beef (Table 11.2).

11.3.1.2 Display temperature
The operating temperature of a retail display cabinet is a compromise between the operating economics, quality factors and legislation.

The Quick Frozen Foodstuff Regulations (1990) are fundamentally quality based and among the main provisions is temperature control of the product. Essentially a quick frozen product must be maintained at or colder than −18 °C throughout the cold chain. The only exception is in retail cabi-

Table 11.2 Mean and 95% confidence interval (CI) of display life based on colour changes during frozen display

	Gas	Bloom	Display life (days)			
			In Dark		Illuminated	
			Mean	CI	Mean	CI
Control	Air	1	62	56–68	0	–
		6	79	73–85	0	–
		48	0	–	1	0–2
Control	O_2	1	65	61–69	0	–
		6	85	79–90	10	9–12
		48	45	38–51	25	22–29
E supplement	Air	1	96	72–119	7	2–12
		6	125	108–141	9	8–10
		48	118	88–148	32	27–38
E supplement	O_2	1	83	75–91	15	12–17
		6	182	157–206	21	18–23
		48	212	181–243	73	68–78

Source: Lanari *et al*., 1995.

nets where temperatures warmer than –18 °C are tolerated, consistent with good storage practice but not warmer than –12 °C. During testing, cabinets have to achieve slightly more stringent criteria. European retail cabinet standards (EN441-6:1994, in the above), state that using food simulant 'M' Packs, the highest temperature of the warmest M-package should be equal to or lower than –15 °C. They also state that the lowest temperature of the warmest M-package should be equal to or lower than –18 °C. No lowest temperature is quoted for the coldest package.

11.3.1.3 Temperature fluctuations

Temperature fluctuations can increase the rate of weight loss from meat. Cutting & Malton (1974) reported that a retail cabinet operating at –15 °C produced greater product dehydration than another cabinet operating at –8 °C. This was shown to be due to the much wider air temperature fluctuation in the –15 °C cabinet, ranging from –5 to –21 °C compared with ±1.5 °C in the –8 °C cabinet. Successive evaporation and condensation (as frost) caused by such a wide temperature differential resulted in exaggerated in-package dehydration.

However, it is not clear if temperature fluctuations actually reduce storage life. Gortner *et al*. (1948) found that fluctuations in temperature of pork between –17.8 and –6.7 °C produced the effect of an average temperature of –12.2 °C. They also suggested that exposure to temperatures warmer than –18 °C rather than temperature fluctuations may be the major factor influencing quality deterioration.

The extent of temperature fluctuations will be dependent upon the air temperature over the product, the product packaging and the level of radiant heat. Retail display packs' heat sources change. These can be from store and display lighting, defrost cycles and heat infiltration from the store environment. In products where air gaps exist between the packaging and the meat, sublimation of ice within the product leads to condensation on the inside of the packaging, resulting in a build up of frost. This dehydration causes small fissures in the surface of the meat, allowing the ingress of any packaging gases into the meat. This can aid the acceleration of oxidative rancidity within the product. Minor product temperature fluctuations are generally considered to be unimportant, especially if the product is stored below –18 °C and fluctuations do not exceed 2 °C.

11.3.1.4 Packaging material

All frozen meat and meat products are wrapped before they are placed in retail display. The principal reason for packaging meat during frozen storage is to minimise moisture loss. Moisture loss causes deleterious effects on the texture, flavour and colour of the meat. Molecular oxygen in contact with the meat surface produces metmyoglobin, an undesirable dark discolouration of the meat. This can be reduced by shrink-wrapping of packaging onto the surface.

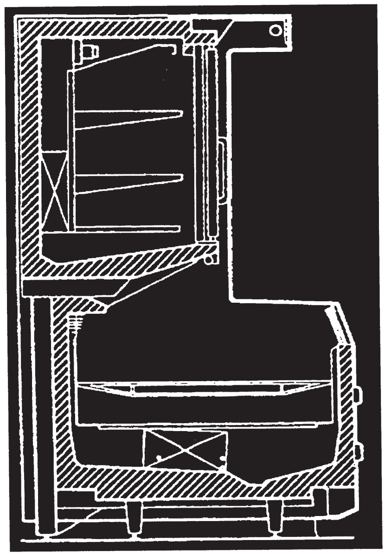
In moisture-permeable packs, condensation onto the refrigeration coil in the cabinet reduces its effectiveness, by reducing the heat transfer rate and restricting the mass flow of air through the heat exchanger. In moisture-impermeable packs the overall weight of each pack remains the same, but they will suffer from frosting, reducing the visual appeal and possibly inducing a dry texture. The high reflectance of small ice crystals on the surface of frozen meats and on the packaging can make the meat appear unacceptably light in colour. The requirements for protection are to provide low permeability to oxygen and water, and a high resistance to tearing under impact and shear, to reduce the incidence of dehydration from the meat surface, which can lead to undesirable effects, such as freezer burn. Packaging can act to dampen the effects of external temperature fluctuations.

Lighting, especially ultraviolet, can also increase fat oxidation. The inclusion of an ultraviolet-light barrier in the packaging material significantly improved the colour stability of minced beef during frozen display at –18 °C (Anderson *et al.*, 1989). The use of a barrier that excluded light below 350 nm would improve display at temperatures up to 5 °C. Trials were conducted at FRPERC (Food Refrigeration and Process Engineering Research Centre, University of Bristol) to determine packaging characteristics to minimise the transmission of radiant energy. The results indicated that lighter colours, for example, yellow and white, absorbed less radiant heat (absorption values ranging from 0.12 to 0.21) and darker colours absorbed more radiant heat (values from 0.4 to 0.82). Shiny gloss surface finishes exhibited lower absorption values (0.15) in contrast to matt finishes (0.34). Under similar conditions the absorption coefficient of a dark matt material was 500% greater than a light coloured shiny material (615 compared with 105 W m^{-2}).

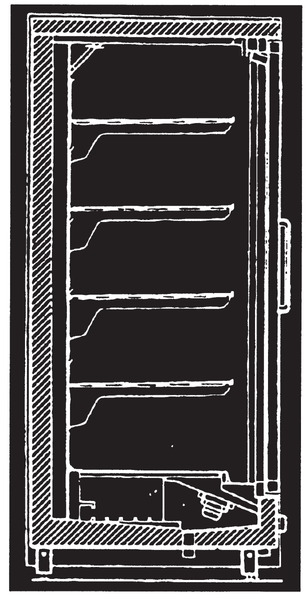
11.4 Overall cabinet design

There are a number of different types of display cabinet. Under the EU save programme 'Energy labeling of supermarket refrigerated cabinets', cabinets are categorised according to the service rendered to the user. Examples are shown in Fig. 11.7. The categories are:

- Open top/glass top well type – refrigerated display cabinet, open top, with products stored generally on one horizontal shelf. Chest type, no access to products all round the cabinet,
- Island site – refrigerated open top display cabinet with access to products all round,
- Multi-deck open fronted – refrigerated display cabinet incorporating a number of tiered shelves (graduated or horizontal) for the storage of food products, with open front access,



(a)



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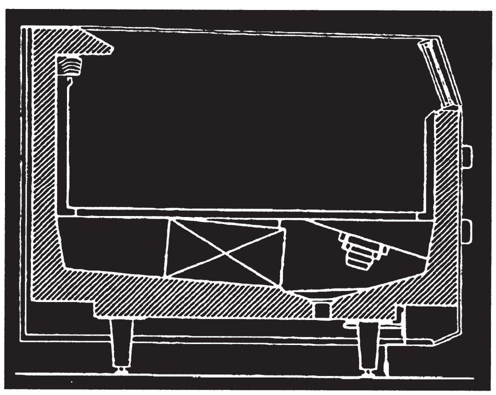

(b)

Fig. 11.7 Types of display cabinet. (a) Combined multi-deck glass fronted upper section connected to open top well-type. (b) Open top well-type and island site. (c) Multi-deck glass or open fronted.

- Multi-deck glass fronted – upright refrigerated display cabinet with a minimum of one glass wall (glass door cabinet).

11.4.1 Air circulation and temperatures

The air in a display cabinet gains heat from interaction with the warm ambient air and the product, which itself warms owing to radiant heat gain. Cabinets using natural convection to maintain product temperatures have exposed coils at the front and the rear situated above the product loading level. This design produces recirculation from the sides to the centre of the cabinet, with the cooler air falling onto the product and rising as it absorbs energy, then being drawn back toward the heat exchanger. The air velocity is low ($<0.2\,m\,s^{-1}$) which is desirable to reduce interaction with the store ambient air, but is susceptible to external influence such as drafts and customer interaction. Supermarkets do not use cabinets that are cooled by convection solely, but make use of this by forcing recirculation of the chilled cabinet air behind metallic panels underneath the product which assist in maintaining product temperatures at the base and sides of the load.

The purpose of air flow over the products is to provide an effective barrier to warm ambient air and to provide limited heat extraction from the product surface. The major thrust in cabinet design has been to reduce the warming of the refrigerated air as it flows over the product. This has resulted in the development of devices for air movement to ensure a uniform distribution of air across the cabinet length. The most popular methods use axial or propeller fans. Variations in the velocity of the air 'curtain' will increase shear with ambient air and induce localised mixing. This is exaggerated by differences in product loading height, merchandising labels, restriction in air flow by icing and frosting of heat exchanger coils. Cabinets should be designed to use air flows as low as possible to maintain cabinet air temperatures at the desired levels. This will minimise ambient air mixing, ideally the air should 'roll' over the product, typically at velocities of $0.5\,m\,s^{-1}$.

The development of low radiant energy transmission glass and high insulation techniques has encouraged the adoption of more glass to increase product visibility. This has necessitated the use of antimist heating to keep the glass clear, which increases energy use, unless heat can be recovered from another part of system.

11.4.2 Effect of doors and lids

Cabinets are evaluated under ISO climate class conditions determined by the type of climate in which they are to be used. For example, for temperate climates the external conditions are 25 °C and 60% RH, for tropical climates, 40 °C and 40% RH. Blinds and lids have been shown to provide the greatest benefit to cabinets using natural convection. These are mostly applied out of retail hours, such as overnight. Results of trials comparing the refrigeration effect using different types of blinds indicated that the major difference was caused by the infiltration load, which is a function of the area of the front opening (caused by gaps at the side of blinds). Typically the blinds reduced the heat removed by the evaporator from 8.8 to 3.6 kWh.

The application of permanent doors or sliding lids provides significant benefits over open fronted or top cabinets, by maintaining the temperature of the exposed product for longer periods, although in poorly performing cabinets, these will only extend the storage period and not maintain the desired temperature. Generally, over an 8 h test period with 12 s door openings every 10 min to simulate customer usage, only the exposed products experienced an increase in temperature, this being a function of the air velocity, temperature and distribution. Permanent or sliding doors also offer energy benefits, imposing a reduced load on the refrigeration system together with reduced infiltration of moist air which results in less frosting and icing on the coil, therefore maintaining the air distribution and imposing a lower defrost energy requirement.

11.4.3 Effect of radiant heat

The absorption of heat at the product surface of exposed packs results in localised warming of the product surface caused by the 'greenhouse effect'. A joint ECE/Codex Alimentarius group of experts agreed to accept a margin of 10 °C between the top layer of product and the air temperature in the cabinet to take into account exterior influences such as radiant heat. Therefore it is important not only to select packaging to minimise the transmission and absorption of radiant heat but to reduce its incidence on the product surface, from both cabinet and store lighting, as well as from solar radiation.

Temperatures within meat simulant packs should be measured both at the centre position and the surface. The surface location will provide an indication of the direct effect of external influences, such as defrosts and radiant heat during simulated retail conditions. The centre location is a measure of the average product temperature as the effect of external influences are modified by the thermal properties of the meat.

Cabinet air temperatures cannot therefore be used as an accurate representation of product temperature, as product surface temperatures can be warmer than the return air temperature.

11.4.4 Measurement methods

Continuous control and measurement of cabinet performance is related either to the temperature of the evaporative heat exchanger and/or the temperature of the air returning to the heat exchanger. A more sophisticated method is to produce a weighted average of the air off and air return temperatures, to simulate an average product temperature. A few systems also use a food simulant pack to monitor the centre product temperature. Owing to the reasons discussed earlier, none of these methods will quantify localised product warming. These current methods assume that the cabinet is operating effectively and research has shown that this is not necessarily the case.

Inexpensive methods of quantifying cabinet performance were evaluated by FRPERC. The results indicated that thermochromic liquid display indicators (LCDs) could be used to indicate cabinet operational status, such as breakdowns in fan operation, defrosts and the subsequent recovery period (up to 22 min) and icing of the evaporator. Product overloading was detected by LCDs positioned on the merchandising strip on the front of the shelf or on the front Perspex riser of a well-type cabinet. However, LCDs could not be used as accurate indicators of product temperatures. Radiant heat levels measured at the exposed surface of the frozen meat were 22.6 $W m^{-2}$, provided by four fluorescent tubes (116 W). This level did not affect the temperature at which the colour transition occurred. The most rapid method of providing an indication of cabinet performance is to use infrared spectroscopy to scan product surfaces for localised hot spots. These measurements should be confirmed with single point thermocouples connected to hand-held digital thermometers.

11.5 Conclusions

The performance requirements and specifications of a cabinet need to be defined in advance, to determine the cabinet's fitness for purpose. These include the maximum quantity of meat to be displayed, meat packaging, loading pattern and temperature on loading. Environmental conditions such as climate class, radiant heat and proximity to draughts also need to be taken into account. This information allows manufacturers and retailers to evaluate the performance of the cabinets under representative conditions.

In general:

1 It is essential to maintain relative humidity in display cabinets of at least 85% or above to achieve display periods for unwrapped meat and meat products of 6–9 h.
2 Types of lighting are also an important point to be considered with lower heat output lighting producing lower weight losses. Certain delicatessen products are particularly sensitive to radiant heat gains from illumination and therefore it is essential to evaluate each product individually in order to determine the ideal display conditions.

Recent developments in commercial retail cabinets have been concentrated in two main areas:

1 The application of new refrigeration techniques to produce more energy efficient, environmentally friendly and reliable systems: this has been investigated using secondary refrigerants, eutectic plates and air cycle refrigeration using direct injection of refrigerated air, obviating the need for fans.
2 Improving the operational effectiveness by reducing the refrigeration

load: this can be achieved by improving the air distribution and minimising the interaction and infiltration of the ambient air. Reducing radiant heat gain using optical fibres, low energy bulbs and modified packaging, and the application of physical barriers including doors and lids will also reduce heat gains.

11.6 References

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