

CARCASS CHILLER DESIGN

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The choice of the most suitable carcass-chilling procedure should follow from the analysis of complex legislative, economic and technical issues. These issues are summarised in Table 1.

Table 1: Factors which influence carcass chilling

Legislative:	Export Meat Orders should be regarded as the minimum standard.
Economic:	Weight loss by evaporation and drip. Capital, operating and maintenance costs of chillers and refrigeration plant.
Productive:	Chilling cycle must suit production schedule. Chilled carcasses must be suitable for further processing – quartering, boning, freezing.
Quality:	Microbiological standards: <ul style="list-style-type: none"> • Appearance • Toughness • Condensation

1. Legislation

In Australia, the most common standards for carcass chilling are set out in the Export Meat Orders – current edition 25 June 1992. These should be regarded as the minimum requirements for both export and domestic operators. The following is a summary of this standard.

General – EMO 250.1

No deleterious effect is imported to the prescribed goods during chilling operations.

Chillers must not be overloaded.

Hot product shall not be loaded into a chiller already holding chilled product.

There shall be no overhead condensation dripping onto carcasses.

Chiller sanitation practices must be of a good standard.

Carcasses to be chilled shall be placed in an active chiller and shall be reduced in temperature, from the time that they were first placed under refrigeration, to a meat temperature of not more than:

- (a) 20°C within 20 hours for cattle, calves of more than 40 kg, buffalo, solipeds, pigs of more than 100 kg and deer; or
- (b) 20°C within 8 hours for calves of not more than 40 kg, sheep, lambs, goats and pigs of not more than 100 kg;

and, after being reduced to that temperature that goods shall be held in a chiller that is operated at a temperature that ensures that the surface temperature of the goods does not exceed a temperature of:

- (c) in the case of mutton carcasses in fat class 4 or 5 - 12°C; or
- (d) in any other case – 10°C;

for a period of more than 3 hours.

Holding Chillers – EMO 250.2

Goods that are to be held in a chilled state shall, unless intended for boning or preparation as a meat product:

- (a) be further chilled, with a minimum of delay, to a meat temperature of 4°C or lower; and
- (b) then subsequently be held under conditions of refrigeration that ensure the temperature of the goods is not more than 4°C and not less than minus 1.5°C at any point within the goods during storage.

Bone-in Quarter Beef

For bone-in quarter beef for export a "Management Code of Practice" has been issued. This Code of Practice has introduced modified chilling practices for this product summarised as follows:

- A deep-butt temperature of 16°C shall be reached within 20 hours of being placed under refrigeration. Opening of the stifle joint is recommended as an aid to achieving rapid chilling.
- Optional procedures are given if this chilling rate cannot be achieved. However, following recent complaints of bone- marrow taint, CSIRO recommends that the optional procedures should be ignored;
- A deep-butt temperature of 7°C shall be reached within 48 hours of slaughter.

CSIRO further recommends that the deep-butt is brought to less than 30°C as quickly as possible after slaughter, within a maximum of 10 hours. This will minimise weep, particularly in vacuum-packed meats.

On large cattle with heavy fat cover, these cooling rates are not easily achieved. Figures 1 and 2 illustrate typical cooling rates for 100, 250 and 400 kg carcasses in constant air velocities of 0.5 and 2.0 m/sec.

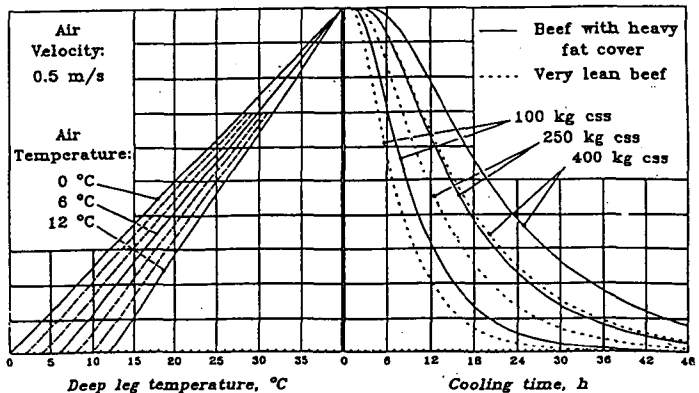


Figure 1: Cooling time for beef carcasses. Air velocity 0.5 m/sec.

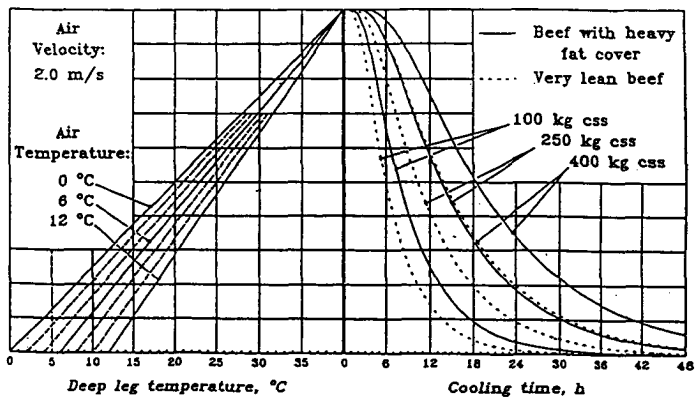


Figure 2: Cooling time for beef carcasses. Air velocity 2.0 m/sec

Table 2: Estimated cool times for 400 kg carcass, heavy fat cover

Air Velocity	Air Temperature	Cool time (hours) to		
		30°C	20°C	16°C
0.5	0	13.0	20.0	23.5
0.5	6	14.0	23.0	27.5
2.0	0	12.0	19.0	22.0
2.0	6	13.0	21.0	26.0

The following points are emphasised from this data:

1. The cooling times are determined from the start of **active refrigeration** (not time of slaughter).
2. The Code of Practice specifically recommends that **30°C is achieved within 10 hours of slaughter.**

3. The data is for **constant air temperatures**. In reality, 0°C air temperatures are not achieved in fully loaded chillers until a minimum of two hours from the start of the chilling cycle, even with a **quality refrigeration system**.
4. An increase of air velocity from 0.5 to 2.0 m/sec reduced cooling times by <10%. This small improvement in cooling times is due to the fact that once the surface temperatures of a carcass have reached the chiller air temperature, the conductivity of the meat limits the cooling rate.

Wrapped Carcasses and Vacuum-packed Product – EMO 250A.1, 250A.2, 250A.3

Wrapped carcasses are required to be chilled as per EMO 250.1 (see "General" above).

The requirements for vacuum-packed product are as follows.

- Carcasses to be chilled to below 20°C before vacuum packing.
- Following vacuum packing, the following time/temperature relationships shall be achieved during subsequent cooling and holding:
 - <7°C within 20 hours
 - <3°C "minimum of delay"
 - 2°C to 3°C for storage.

Edible Chilled Offal EMO 251.1, 251.2

Edible chilled offal shall be reduced to a maximum of 7°C within 12 hours of removal from the carcass and maintained at <7°C in subsequent holding.

In addition to the above, for vacuum-packed offal, packaging must be completed within 36 hours of removal from the carcass and held under refrigeration at -1.5°C to 0°C.

2. Typical Chiller-Construction Costs

Quality carcass-chiller construction and refrigeration represents a significant capital cost to an abattoir. Operators seek to maximise the utilisation of their facilities. This often leads to overloading existing chiller facilities with deteriorating results in terms of cooling rates and microbiological quality.

Eventually, the owner is faced with a choice:

- maintain or reduce production; or
- construct new hot-carcass chilling facilities.

The following example illustrates the estimated cost, 1993, of a beef-carcass chiller:

Capacity:	80 bodies @ 250 kg dressed carcass weight
Refrigeration system:	Ammonia
Room dimensions:	18 metres x 6 metres
Rails:	5 rails x 16 metres

A plan view of this chiller is illustrated in Figure 3, which indicates 4 forced-draft evaporators mounted above the chiller rails.

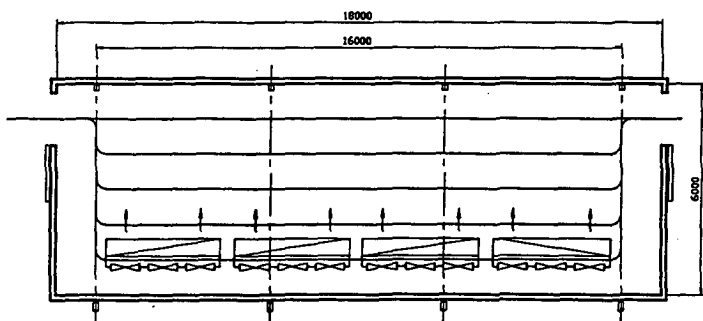


Figure 3: Plan view of beef chiller for 80 bodies

Table 3: Typical chiller construction costs

Excavation	108 m ² @ \$ 30 = \$ 3,240	
Drains	108 m ² @ \$ 50 = \$ 5,400	
Concrete	108 m ² @ \$ 300 = \$ 32,400	
Steel	108 m ² @ \$ 160 = \$ 17,280	
Rails	85M @ \$ 240 = \$ 20,400	
Panel	240 m ² @ \$ 80 = \$ 19,200	
Roof	108 m ² @ \$ 30 = \$ 3,240	
Lighting	108 m ² @ \$ 30 = \$ 3,240	
Doors	2 @ \$2,000 = \$ 4,000	
		\$ 108,400
Evaporators	= \$ 60,000	
Power and Controls (wiring, valves, etc)	= \$ 20,000	
Variable speed fans	= \$ 7,000	\$ 87,000
	TOTAL	\$ 195,400

The total estimated cost is \$195,400. Savings may be achievable by using suitable secondhand materials such as insulated panel, rails and refrigeration evaporators. However, for new materials, potential savings may be at the expense of quality of the refrigeration plant.

In this example, evaporator capacity could be reduced and controls simplified. This may save perhaps \$10,000 in the estimated refrigeration-plant cost. The result may be:

- Evaporator capacity reduced by 20%;
- Temperature drop across evaporator will increase;
- Weight loss will increase from approximately 1% to 1.2%.

This 0.2% loss will cost \$28,800 per year calculated as follows:

80 bodies/day @ 250 kg	=	20,000 kg/day
0.2%	=	40 kg/day
Value @ \$3.00 kg	=	\$120/day
	=	\$28,800/year (240 days).

This example serves as a reminder to designers and users that marginal costs of options in the supply of refrigeration plant should be carefully evaluated. Once an installation is complete, modifications are costly and often impractical.

Before evaporators and controls are purchased for a new chiller, demand your contractor provides the following information:

- Heat load calculation for room;
- Technical and Performance Specification for Evaporators and Controls. This should include the following data:
 - evaporator surface area and dimensions;
 - fans – performance and power requirements;
 - valves and controls;
 - pipework (including existing pipework);
 - estimated chiller time to nominated deep-butt temperature;
 - performance specification and refrigeration plant requirements; and
 - estimated guarantee of weight loss;
- Review of the effect of the chiller on the existing refrigeration-plant performance.

In recent years, the use of ducted systems has increased in the construction of new chillers. Ducting, usually of insulated panel construction, adds to building costs – typical panel costs are \$80 to \$100 per square metre.

The CSIRO experimental chiller at MRA, Brisbane, achieved 0.6% weight loss without the use of ducted systems although air distribution was uneven using a design based on Figure 1 and Figure 4. Ceiling baffles are, however, being considered to improve air distribution.

The total cost of ducting, baffling and evaporators should be considered. Superior results may well be achieved, at less cost, by enlarging evaporators and placement of fans to improve air distribution.

3. Design Considerations

The regulations governing the performance requirements of carcass chillers leave the designer with many options. The many chiller designs which have been constructed in Australia and overseas reflect the efforts and experiments by designers for improved performance. Some designs have, of course, been more successful than others.

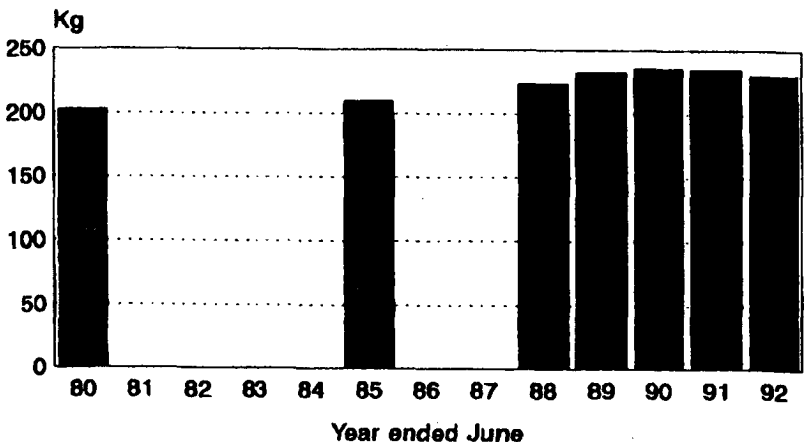
The carcass chiller is the integration of the building and its refrigeration plant. Only when the refrigeration requirements have been assessed should the building be finalised and construction commenced.

Hot Carcass Chilling or Holding Chiller?

If there is a future requirement for hot-carcass chilling, then allow for this in the design.

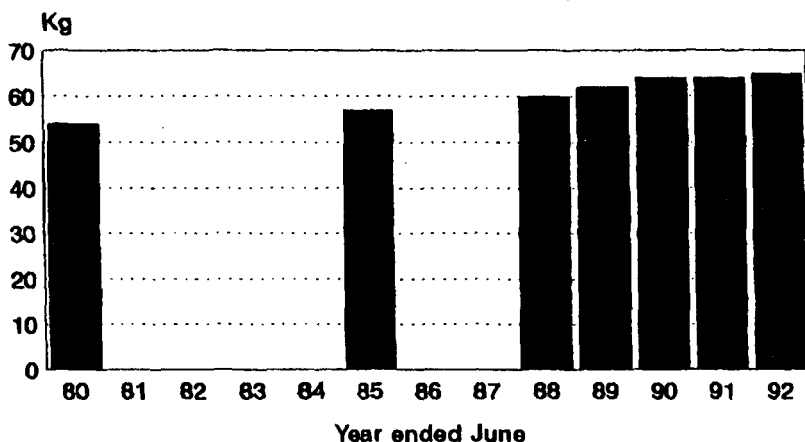
Carcass Freezing

If the room is to be used for both chilling and freezing, both the building and the refrigeration plant must be designed for low-temperature operation.



1980, 1985 - Average 5 years

Figure 4: Australian cattle – average carcass dressed weight



1980, 1985 - Average 5 years

Figure 5: Australian Pigs – Average Carcass Dressed Weight

Number and weight of carcasses

During the 1980s, there was a significant increase in the dressed carcass weight of all classes of stock as Figures 4 and 5 for cattle and pigs respectively indicate.

The most significant increases have been in cattle (13.3%) and pigs (18.5%). This means that many chillers designed in the 1970s are now found to perform inadequately due to this increase in dressed carcass weight.

Most operators overload carcass chillers periodically, either by heavier stock or extra numbers. The penalty is slower cooling and increased weight loss. When selecting refrigeration equipment, consideration may need to be given to possible chiller overloading. The additional refrigeration capacity would be provided at a small marginal cost.

Sizing Carcass Chillers

One large chiller will cost substantially less to construct than two smaller units of the same total capacity.

There should be sufficient flexibility in design and operation to allow each hot-carcass chiller to be emptied, cleaned and sanitised daily.

Excessive loading times of large chillers increases weight loss owing to the delay in starting a fast-chill cycle.

Loading Rate

There is often a lack of appreciation of the actual instantaneous refrigeration load at the commencement of the chilling cycle. Some designers only calculate the average heat load and then apply an arbitrary factor, say 1.5, to allow for this initial load. Unless some consideration is given to the chiller loading rate, there may be a serious lack of capacity during the initial chilling cycle or during loading of the chillers.

Indications of a lack of capacity during loading are:

- Condensation problems;
- Inability to control temperatures during loading; and
- Excessive weight loss.

The ratio of peak load to average load can be as high as 4.3:1 when a chiller is loaded in two hours compared to 2.5:1 if the same chiller takes six hours to load. Generally, a load factor of 1.5 is sufficient, provided the chiller is not overloaded during normal operation.

Maintenance Access

Provide space to install controls and valves to permit access for maintenance without the necessity to open the chiller. In the case of export works, this may avoid periodic out-of-hours calls for DPIE inspection staff.

Defrost System

Periodically, the refrigeration system must be shut down to permit defrosting. There are four basic methods of defrosting carcass-chiller refrigerator evaporators:

- Air defrost
- Hot gas
- Electric heating elements
- Water.

Air defrost is often suitable for carcass chillers. Hot gas is usually a preferred option for freezers, but defrost cycles must match the capacity and operation of the refrigeration plant.

Forced-Draft (FDC) or Induced-Draft Fans (IDC)

Figure 6 illustrates the difference between forced-draft and induced-draft fan positions. Irrespective of their positions, fans raise the temperature of the air and lower the relative humidity very slightly. This is, however, a marginal consideration.

FDC

- Fans are located on the upstream side of cooling coils.
- No reheating of air after discharge from the cooler
 - higher humidity (marginal)
 - reduced weight loss (marginal)
 - low face velocity.

IDC

- Fans are on downstream side of cooling coils.
- High discharge velocity (advantage where long throw required).
- Approximately 5% increase in heat transfer efficiency.

In both cases, it is important that fans be mounted well clear of coil blocks with the diameter near that of the coil depth. This will ensure that air distribution and velocity is evenly distributed across the coil. Poor air distribution through an evaporator can seriously affect performance.

Selection of variable speed fans, usually by means of an electronic speed control system, will improve chiller control.

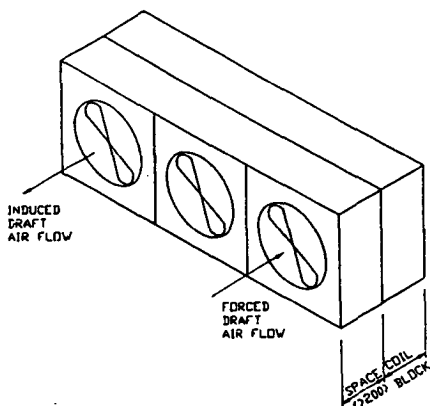


Figure 6: Forced-draft and induced-draft evaporators

Noise

Noise is generally only a consideration during chiller loading. Since two-speed or variable-speed control of fans is preferred for optimum chilling conditions, low-speed operation may be used during loading, depending on loading rate and refrigeration capacity.

Condensation

Condensation can occur in the following circumstances:

- Chiller loading with warm, moist carcasses;
- Reheating too quickly from a low temperature;
- During cleaning and sanitising operations; and
- Warm, moist air entering from passages.

Condensation during chiller loading can be avoided by:

- No, or limited, pre-chilling of the room;
- Adequate refrigeration to remove water vapour generated from the carcasses; and
- Loading from a refrigerated passage.

Re-heat for Boning

Re-heating to soften fat for boners has been developed at the CSIRO experimental chiller at MRA Brisbane. The system in use utilises a total of 24 kW capacity electric heating elements. Such a system is easier to control than via a hot-gas system.

4. Chiller and Evaporator Systems

Examples of some current chiller and evaporator designs are presented. All may be used for beef, sheep and pigs.

For each case, advantages and disadvantages are given.

Direction of Air Circulation

Some recent ducted systems (e.g. Figures 9 and 10) direct the coldest air direct from the evaporators to the forequarters rather than the hindquarters. Two comments may be made on such systems:

- the air is warmed as it passes upwards through the carcasses. This temperature increase aids the natural path of air circulation but is a minor factor in hot carcass chilling;
- the cooling rate of hindquarters is reduced because of this warming. This of lesser importance in sheep and pigs but can extend the cooling time of the deep-butt of heavy beef carcasses by up to one hour.

Therefore, if the aim is to maximise the cooling rate, the coldest air that is discharged from the evaporator should be directed to the hindquarter.

Weight Loss

The factor which most influences weight loss is evaporator capacity and geometry of the evaporator. Design standards have changed in the last 20 years. A 1977 review of Australian chillers gave the following results for total weight loss (hot/wet weight to cold/dry weight after chilling):

Sheep	2.0 to 2.3%
Pig Sides	2.2 to 2.4%
Beef Sides	2.1 to 2.4% (air circulated continuously)
	1.5 to 2.0% (air circulation not continuous)

Recent designs of hot beef carcass chillers have demonstrated that with appropriate selection of evaporators and control systems, 1% or less weight loss is achievable.

Deep coil blocks result in higher weight loss than shallow depth coil blocks of the same total surface area.

Examples of some chiller and evaporator systems are given in Figures 7 - 12.

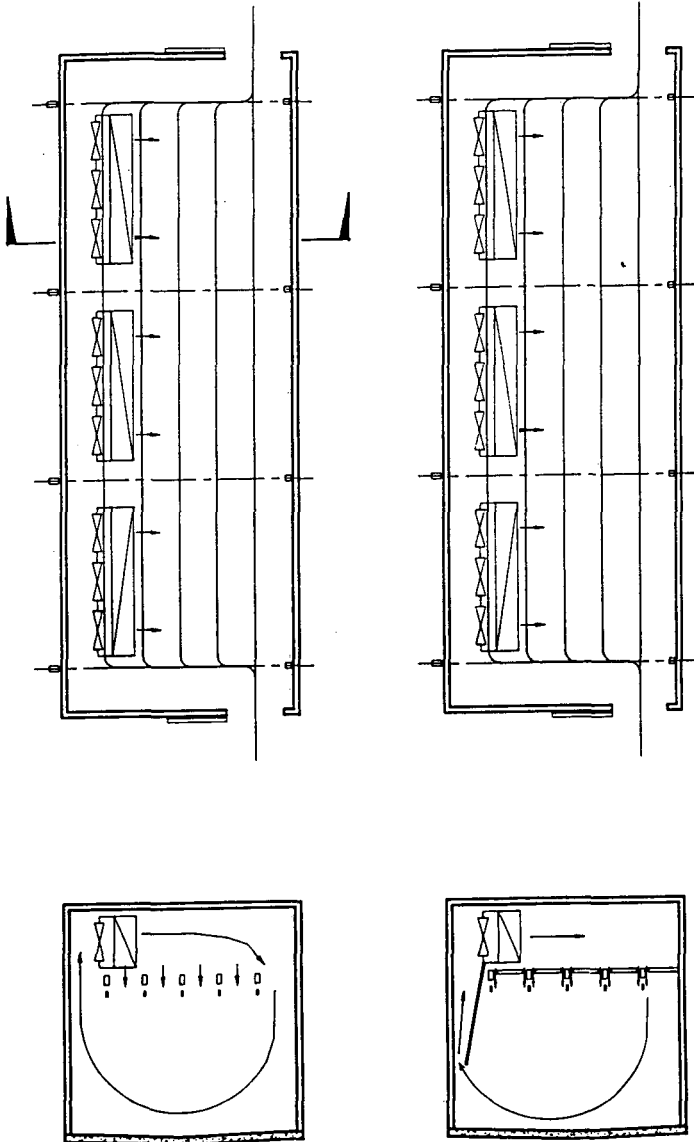


Figure 7a
(See page 36)

Figure 7b
(See page 36)

Figure 7a:

This is one of the most common systems used with evaporators mounted above the rails on one side of the chiller, preferably remote from entry and exit doors. The best results are achieved if the evaporators cover most of the rail length of the chiller, as indicated.

In this arrangement, the evaporators have a large face area, short coil depth and good air flow. Good results for chilling rates with low weight loss are achievable if an adequate evaporator surface area is provided.

The cooled air from the evaporators is discharged directly on to the deep-butt or hind quarter, thus maximising the cooling rate of this section of the carcass. The air velocity distribution is non-uniform, being maximum on the side wall of the room directly opposite the evaporators. This variation in air velocity will not have a major impact on temperature distribution, provided there are no dead spots in the chiller and the chiller is not overloaded.

Operators can take advantage of this air distribution pattern by placing heavy carcasses on the rail opposite the evaporator and lighter carcasses on the rails under the evaporator.

Such a room is also easy to clean.

This design is recommended as an economical design to suit most applications of hot meat chilling.

Figure 7b:

This example is similar to Figure 7a but baffles have been introduced in the form of a plenum chamber with slots in it above the rails and a side wall baffle to control the return air to the evaporator.

This design is intended to produce uniform air velocity over the hindquarter of the carcass.

Experiments are being conducted by the CSIRO Meat Research Laboratory to compare results from chillers designed on the basis of Figures 7a and 7b. These results will be published on completion of the project. However, two issues are pointed out:

1. The baffles increase the cost of construction and must be considered in the chilling cleaning program, and
2. The baffles increase the resistance of the air flow through the chiller and this may require additional evaporator-fan kilowatts.

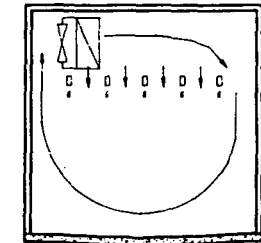
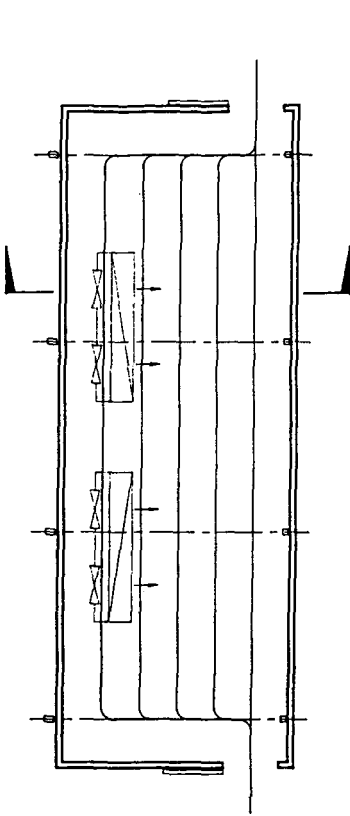


Figure 8
(See page 38)

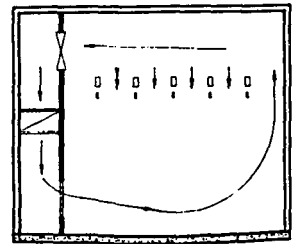
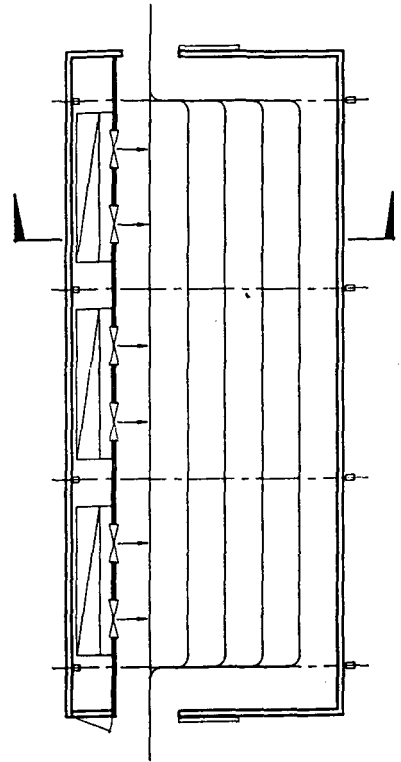


Figure 9
(See page 38)

Figure 8:

This is similar in concept to Figure 7a but indicates an evaporator length substantially less than the length of the chiller railings. In such a system, the evaporators are likely to be undersized and/or too deep, which will cause slow chilling rates and high weight loss. Air distribution will be poor. Designs of this type are not recommended for hot meat chilling but are satisfactory for holding chillers

Figure 9:

This chiller is constructed with a side plenum chamber with the cold air off the evaporator discharged to the floor of the chiller. That is, the coldest air is directed to the forequarter of the carcasses. Experiments in some beef chillers have indicated that in similar systems there is a temperature difference of as much as 4°C between the forequarter and the hindquarter at the start of the chilling cycle and this differential will result in a significant extension of the time it takes to cool the hindquarter or the deep-butt.

Such designs are not recommended for chilling heavy beef carcasses where there is a risk of development of bone or bone marrow taint. However, a design of this nature is suitable for smallstock and light beef.

There is good maintenance access through a separate access door to the coil blocks and controls. This access is available throughout the chilling cycle and is thus independent of AQIS security locks on the chiller doors.

There is no defrost drain tray and therefore defrost water is discharged directly to the floor drain.

Air velocity distribution with this system is non-uniform with high velocity zones adjacent to the wall opposite the evaporators.

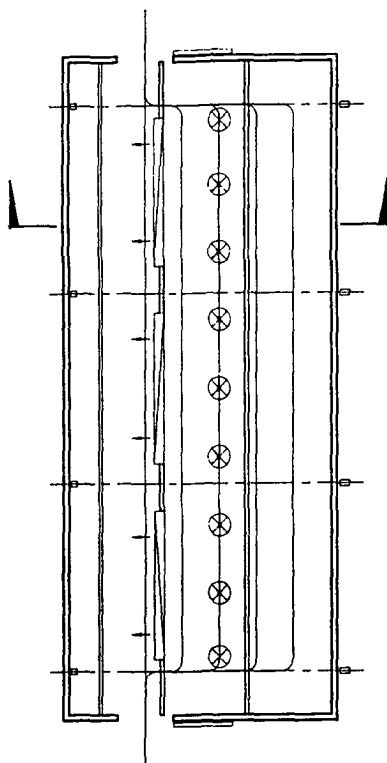


Figure 10
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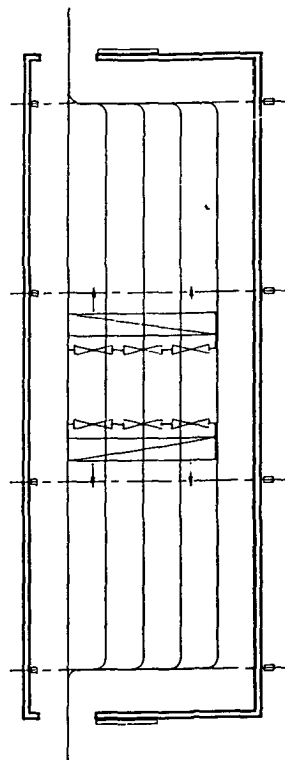
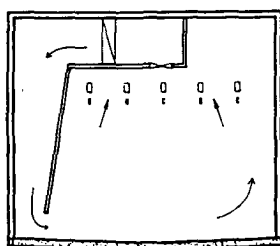


Figure 11
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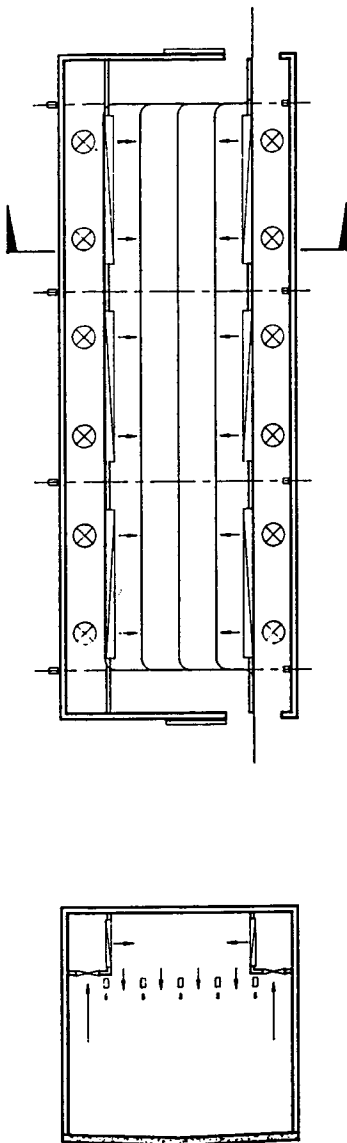


Figure 12
(See page 41)

Figure 10:

This is a further example of a plenum chamber design but has the evaporators located above the rails. Depending on the chiller construction, this design can also permit maintenance access to fan and coil blocks during operation without the need to effect security of the product in the room. With the fans located directly above the centre of the room, air velocity distribution is an improvement over the side plenum system indicated in Figure 9.

Figure 11:

This figure is included to show one example of coil blocks mounted above the rails in the centre of the room. Such systems are not suitable for long rooms where there may be insufficient air flow to reach the ends of the room.

Figure 12:

Figure 12 represents a new design, courtesy of Meateng Pty Ltd. Six coil blocks are mounted in small plenum chambers above the rails on either side of the room. This design can substantially increase the evaporator face area and total air flow within a carcass chiller. With sufficient total evaporator surface area, suction temperatures may be raised and the temperature differential across the coil reduced to produce low weight loss and minimal frosting on the coils. Jensen (private communication) has estimated that such a design has the capacity to complete a chilling cycle without the necessity for defrosting.

Note that the air flow off the coils is mixed above the rails and provides what is probably the most uniform air flow distribution of any of the designs discussed in this section, with the possible exception of Figure 7b.

5. References

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APPENDIX 1

CORE SAMPLING OF HINDQUARTER BEEF FOR BONE TAIN

The following points on core testing of hindquarters were compiled by Sydney Regional Office.

- The preferred site to sample for bone taint is an area on the anterior dorsal end of the femur just below the acetabulum - see diagram.
- To locate this site, a horizontal line is drawn from the anterior end of the pubic symphysis (the knob of the aitch bone) to the "front of the hindquarter". The drill is inserted 5 cm above this line in the midline. The drill is angled as shown in the diagram to contact the anterior dorsal end of the femur.
- An operator may wish to gain experience in locating this site by conducting trials using a metal skewer or drill on chilled carcass entering a boning room. During boning the site of contact between the skewer/drill and the femur can be ascertained and adjustments made accordingly.
- If the correct drilling method is used, the operator will feel contact with bone. If off target, the drill will be felt slipping sideways off the femur even in frozen carcasses.
- When coring frozen quarters, the sample must be placed in a labelled polythene bag, sealed and evaluated after thawing. The process only takes a few minutes.
- If coring thawed product, the moist residue on the drill bit is smelt immediately after removal from the quarter.
- Drill bits must be cleaned between quarters.

APPENDIX 2

MEASUREMENT OF DEEP-BUTT TEMPERATURE

The deep-butt meat temperature of a carcass may be obtained by pushing the thermometer through the pope's eye (Obturator Foramen) 150 mm slightly in the direction of the knuckle. Alternately, use the same location as for the drill/core test for bone taint (Appendix 1). That is, insert the thermometer into the tissue as per Appendix 1 to the base of the femur bone at its junction with the acetabulum.

Gradually withdraw the thermometer from either of these two sites about 10 mm at a time. This should result in the maximum temperature for the side of being recorded.