CHILLER DESIGN & OPERATION

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INTRODUCTION

The chilling of dressed carcasses to minimise the growth of contaminating bacteria is an essential step in meat processing.

The obvious success of chilling in minimising bacterial growth, combined with the fact that fast cooling reduces weight loss from the carcass during chilling, has encouraged the use of air at low temperature and high velocity to achieve faster cooling rates.

Unfortunately, the fast cooling which reduces weight loss induces "cold shortening" (muscle contraction), and therefore increases toughness unless steps are taken to prevent or minimise the effect.

These include conditioning, "altered posture" suspension, and electrical stimulation. Of these three methods the one most likely to be accepted by industry in the long term is electrical stimulation because it requires a minimum of modifications to existing procedures, plant and equipment.

The introduction of electrical stimulation has the potential to revolutionise the meat industry. For example, if muscles are removed from a carcass soon after slaughter (hot boning) and placed in a chiller, the muscles, free of their skeletal attachments, have the ability to contract markedly, and the muscles become very tough. Electrical stimulation of the carcass inhibits this contraction, and the benefits of hot boning (rapid processing, smaller chiller requirements, energy savings) can be realized.

Electrical stimulation of carcasses, however, is not yet fully commercialised. Its most likely immediate application would be to prevent cold shortening of meat on carcasses during chilling.

In this paper only those factors which influence the design and operation of traditional chillers are considered.

SOURCES OF HEAT IN CHILLERS

In any carcass chiller the ability of the system to cope with varying conditions is dependent on the heat loads contributed by various sources and the cooling capacity of the system.

There are many sources of heat into chillers. Heat is introduced by transmission through walls, floor and ceiling; electrical power units such as fans and lighting; personnel working in the room; entry of air through door openings; and carcasses to be cooled. Although most of the heat comes from the carcasses, the other sources cannot be ignored.

Transmission through walls, floors, and ceiling

Most chillers are now constructed from panels formed from an expanded insulation sandwiched between two metal faces. It is usual for these panels to have a total thickness of 50 mm and a typical thermal conductivity value of 0.016 w. m^{-1} $^{o}C^{-1}$. The panels are ideally suited for use within other building structures. However, because they can be constructed from a range of facing materials, some suitable for external use, they are frequently used to form external walls and roof. The use of panels in these situations can result in problems due to high temperatures on the external surface of the panels caused by solar radiation.

High surface temperatures can result in buckling of the panels due to differential expansion; delamination of the sandwich structure, particularly at faces where adhesive is used to bond adjacent materials; increased heat transmission because of large temperature differentials, and increased thermal conductivity of the insulating materials at high temperatures.

Where external walls and ceilings are formed from insulated panels, they should be protected with a weather roof. There should be sufficient space between the roof and panels to allow good air circulation and the structure should be located such that the longest wall does not lie in the north/south axis. Where walls are exposed to full solar radiation, the thickness of the insulation should be increased.

It should be noted that the maximum operating temperature recommended for expanded polystyrene insulating material is 85^{o}C.

Electrical power

Faster cooling rates of carcasses are normally associated with lower air temperatures and higher air velocities. These conditions can only be met by increased power inputs at the fan.

A lighting level of at least 220 lux is required in chillers. This must be increased to 550 lux at work stations if operations, such as trimming, are done in chillers.

To minimise the power requirements for lighting, the light source having the highest luminous ouput per unit of energy should be used. For example, fluorescent lamps which have a luminous output of 60 lumens/watt would be preferred to incandescent lamps at 11-12 lumens/watt.

All electric power inputs are direct heat loads to the refrigeration system.

Personnel

The heat from personnel is generally insignificant when compared with other sources, each person contributing less than 0.25 kW.

Infiltration of air

The movement of warm air into chillers through open doorways is a major heat source, requiring the extraction of both heat and moisture.

The quantity of heat to be removed from air at various temperatures when cooled to a temperature of 0^{o}C is shown in Figure 1. The quantity of moisture removed under similar conditions is also shown.

Air leakage into a chiller is a direct load on the refrigeration system. However, the greatest problem caused, or aggravated, by air leakage is condensation. Air at, say, 25°C dry bulb temperature (D.B.) and 70% relative humidity (R.H.) has a dew point of 19.1°C and a moisture content of $16g/m^3$. This means that the moisture contained in the air will be deposited on any surface which is at a temperature below 19.1°C. Most surfaces in a chiller are below 10°C and very often air temperatures are higher than 25°C with high R.H.

An investigation of heat and moisture gains to a chiller (1) has shown that in a chiller designed and situated as detailed in Figure 2, the peak heat input to the chiller from air leakage was 34.5 kW and the moisture gain was 14.4 kg/hr. The relationships between door openings, air temperatures, and heat and moisture loads in the chiller are shown in Figure 3.

The leakage of air into chillers can best be restricted by incorporating several features at the design stage. These are:

a) Chiller doors should not open directly to any area where the air temperature and humidity may be high (e.g. kill floors, external loading docks).

b) Chiller doors should be protected by air locks or corridors. If corridors are used they should be provided with refrigeration coils selected to maintain a temperature between the external ambient and chiller air temperatures.

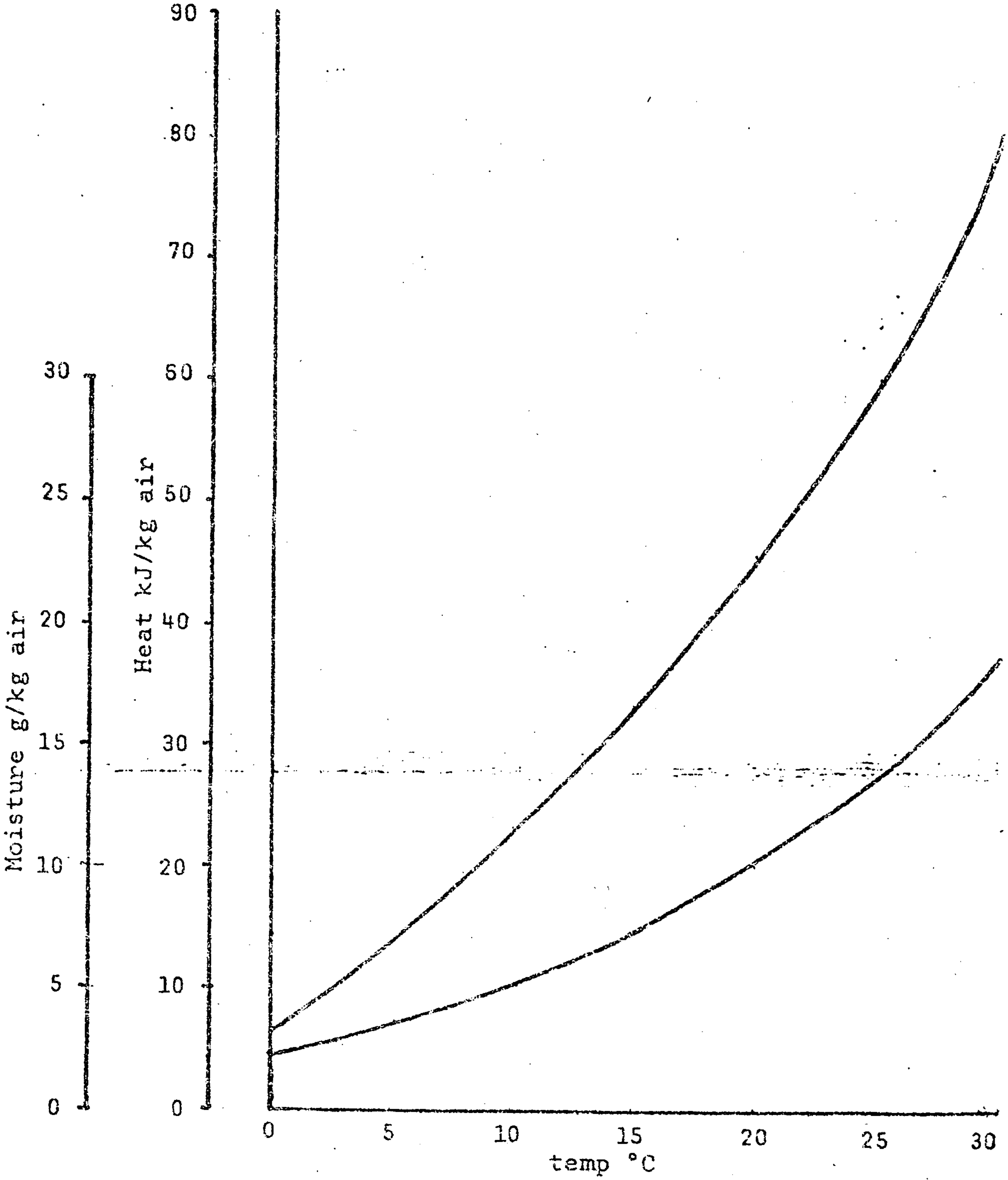
c) All chiller doors should be provided with equipment to mechanically assist door opening and closing.

d) All carcass rails through doorways should be fixed as shown in Figure 4.

Features a) and b) form a barrier between external and chiller environments, thereby providing some protection to the chiller. Features c) and d) would make it convenient for personnel working in the chiller to close the door when the chiller is not in use. It is better to load carcasses in batches than to leave chiller doors open for extended periods while carcasses are loaded individually.

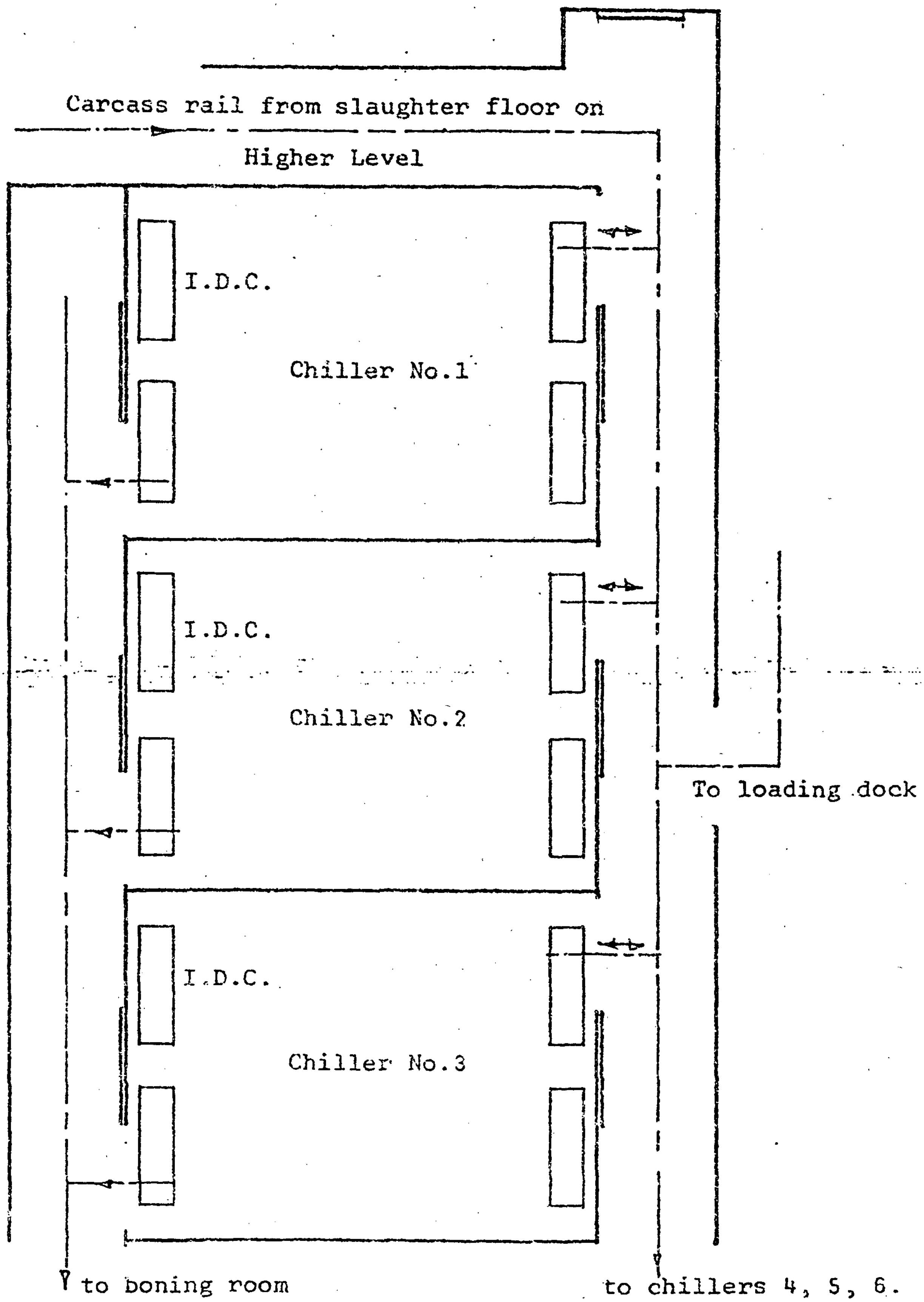
Product load

The product load is the largest heat source in conventional carcass chillers. It is also the most variable over the chilling period. At the start of chilling the heat load from the carcasses is extremely high, but this falls off rapidly after the first few hours of chilling. It is the average heat load contributed by the carcasses over the chilling period which is generally used, with all other heat loads, to calculate the refrigeration capacity of the system (2).



HEAT & MOISTURE CONTENT OF AIR AT DIFFERENT TEMPERATURES WITH CONSTANT RELATIVE HUMIDITY OF 70%

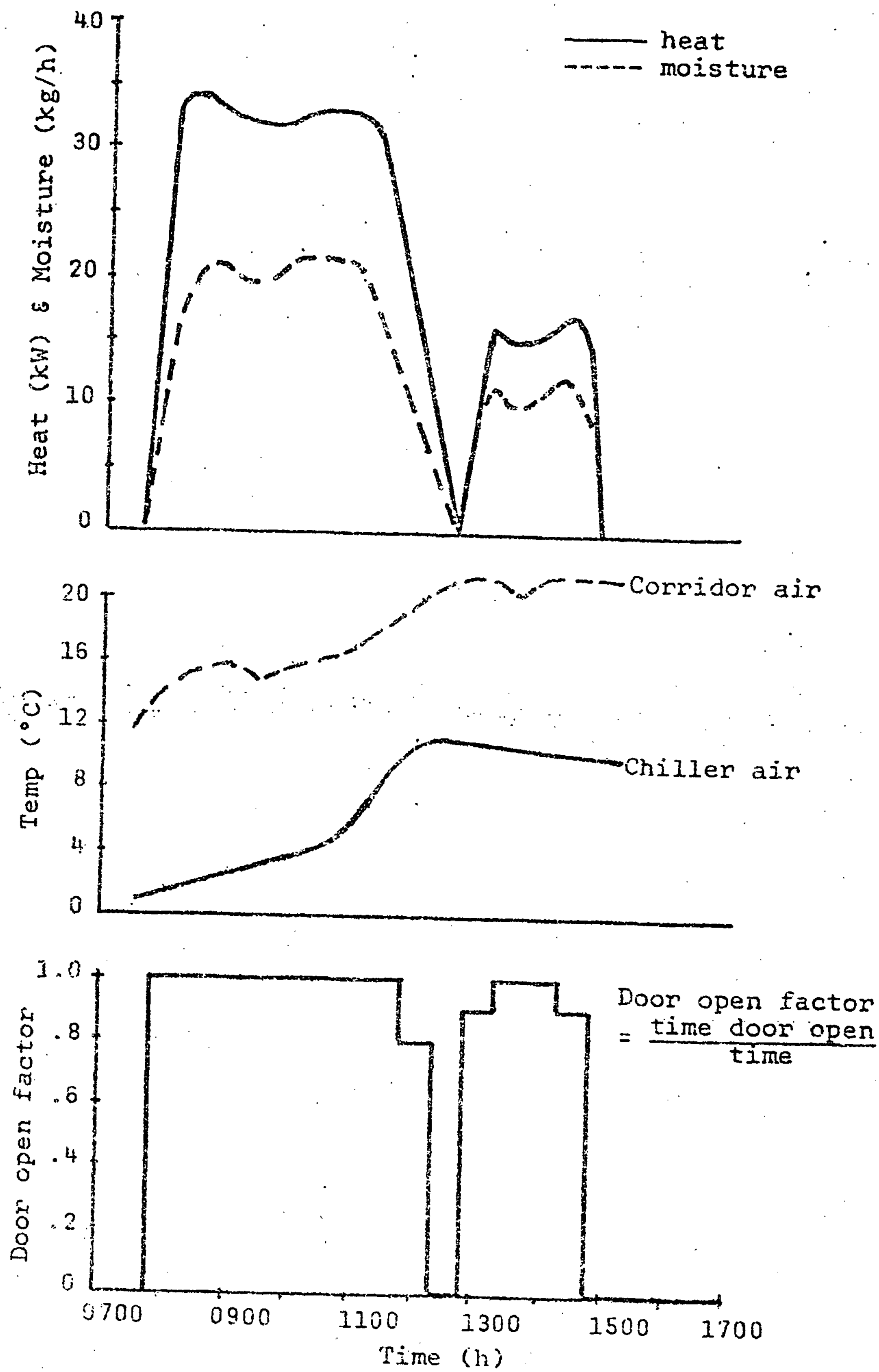
FIG.1



LAYOUT OF CHILLER AREA

(Source G.L.J. Wescombe, Ref.1)

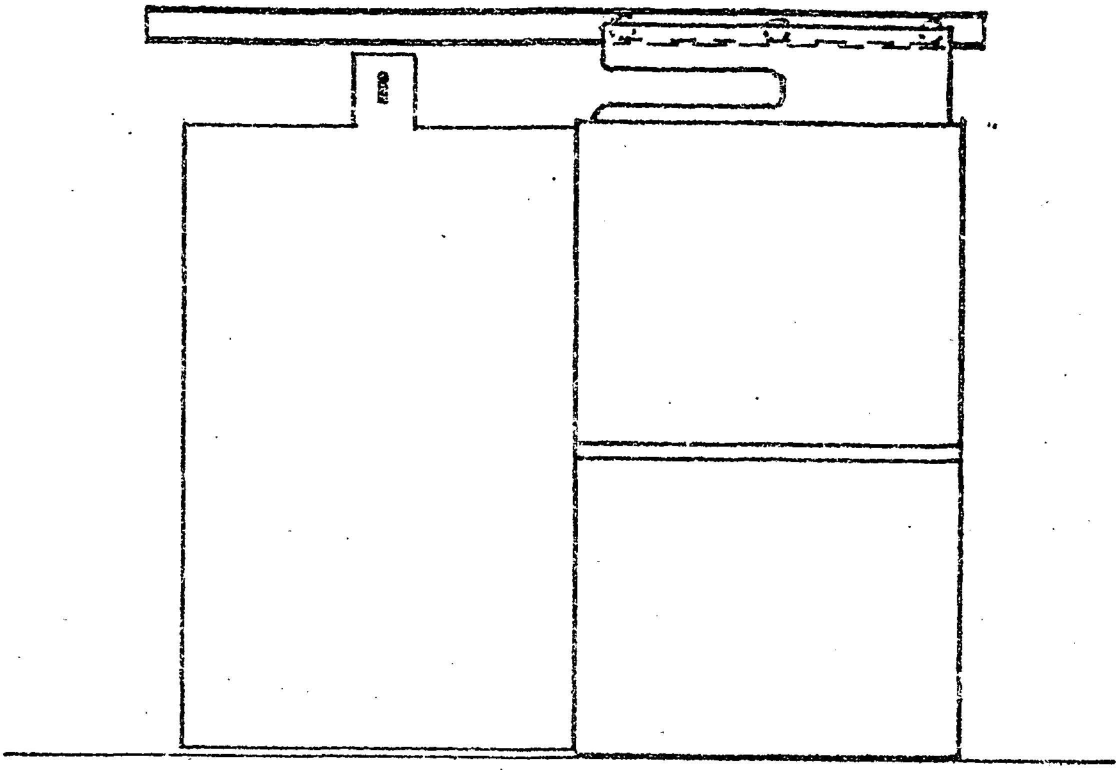
FIG.2



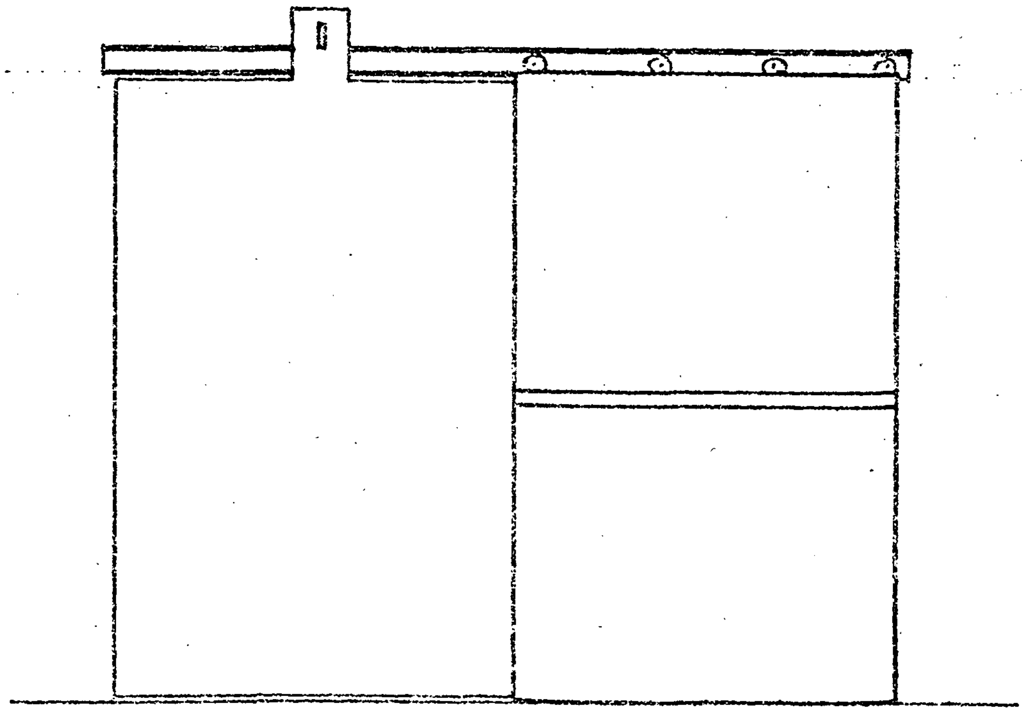
RELATIONSHIP BETWEEN DOOR OPENINGS, AIR TEMPERATURES, HEAT & MOISTURE LOADS IN CHILLER

(Source G.L.J. Wescombe, Ref.1)

FIG.3



Door with Cantilevered Bracket



Door with Gap in Door Track

ALTERNATIVE DOOR DESIGNS TO ACCOMMODATE
FIXED CARCASS RAIL

FIG. 4

This method can, however, underestimate refrigeration requirements. Because most of the heat load occurs in the first four to six hours of chilling, the use of average hourly figures to determine the refrigeration capacity can result in insufficient capacity to meet the demands in the early part of the chilling cycle. If this is combined with inadequate allowances for other heat gains, particularly air leakage due to extended loading times, then the result is a large increase in chiller air temperature on loading. Some values of air temperatures and humidities in chillers are shown in Table 1.

Lovett (3) suggested that approximately 3.5 kW of refrigeration capacity is required for every four beef sides or 15 mutton carcasses. This capacity should maintain chiller temperatures at approximately 0°C during loading.

Cox & Bailey (4) have examined the product heat loads for the chilling of beef carcasses. Their conclusions were that the peak heat load can be in excess of three times the average heat load, the peak load being influenced by loading times, chilling air temperature, and velocity (Fig.5).

One factor which can compound the problem of under-capacity in abattoir refrigeration systems is the common practice of using large temperature differentials between the refrigerant and the cooling air. This results in a rapid build-up of ice on the evaporator coil and consequent loss of capacity during the loading and early chilling periods.

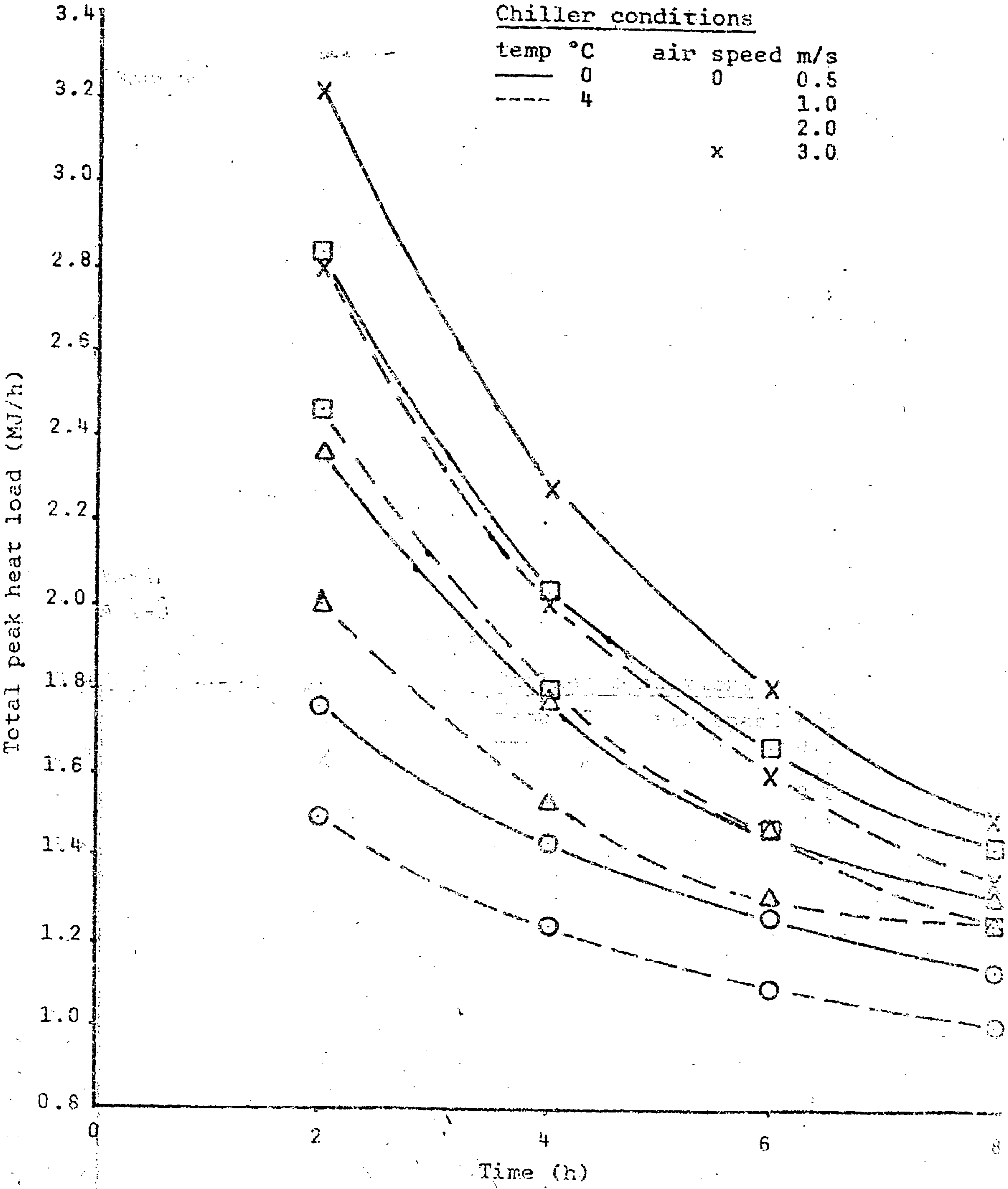
The extraction of latent heat in freezing the moisture on the coils is also an additional load on the refrigeration system.

TABLE 1

MEASURED VALUES OF TEMPERATURE & RELATIVE HUMIDITY IN CHILLERS*

Plant	Air temperature during most of chill °C	Air temperature during carcass loading °C	Relative humdity during carcass loading %
A	4	16	100
B	4	15	98
C	3	9	99
D	3	16	99
E	3	10	82
F	5	9	96
G	1	9	93

*Source: Lovett, D.A., Condensation in Australian Abattoirs, Part II - Technical Appendices, *CSIRO Food Research Report No.46*, 1971.



VARIATION OF THE PEAK HEAT LOAD WITH LOADING TIME IN CHILLING A 140 KG BEEF SIDE OF AVERAGE FATNESS (MRI GRADE 4), WITH AIR AT TEMPERATURES OF 0°C & 4°C, VELOCITIES OF 0.5, 1.0, 2.0 & 3.0 M/S AND RH AT 94%

AIR CIRCULATION

A system of air distribution which ensures that the chilled air can contact all surfaces of the carcass is as important as having adequate refrigeration capacity.

The evaporators (forced draught coolers) must have sufficient air handling capacity to circulate the air in the chiller, and the positioning of carcasses on hanging rails should be such that there is sufficient space between carcasses to allow cool air to move over all surfaces. The direction of air flow from the evaporators should prevent short-circuiting of the air either over or under the suspended carcasses.

Capacities are usually selected on the basis of required air circulation rates, i.e. the number of times the total volume of air in the chiller is circulated over the cooling coil.

For chillers, the circulation rate is usually about two every minute, i.e. 120 air changes per hour.

A common practice in Europe, particularly when chilling pigs in a cooling tunnel, is to direct the cooling air directly onto the carcass through nozzles or slot diffusers. This method has been successfully applied to the chilling of beef and smallstock in Australia. The general features of the system are shown in Figure 6.

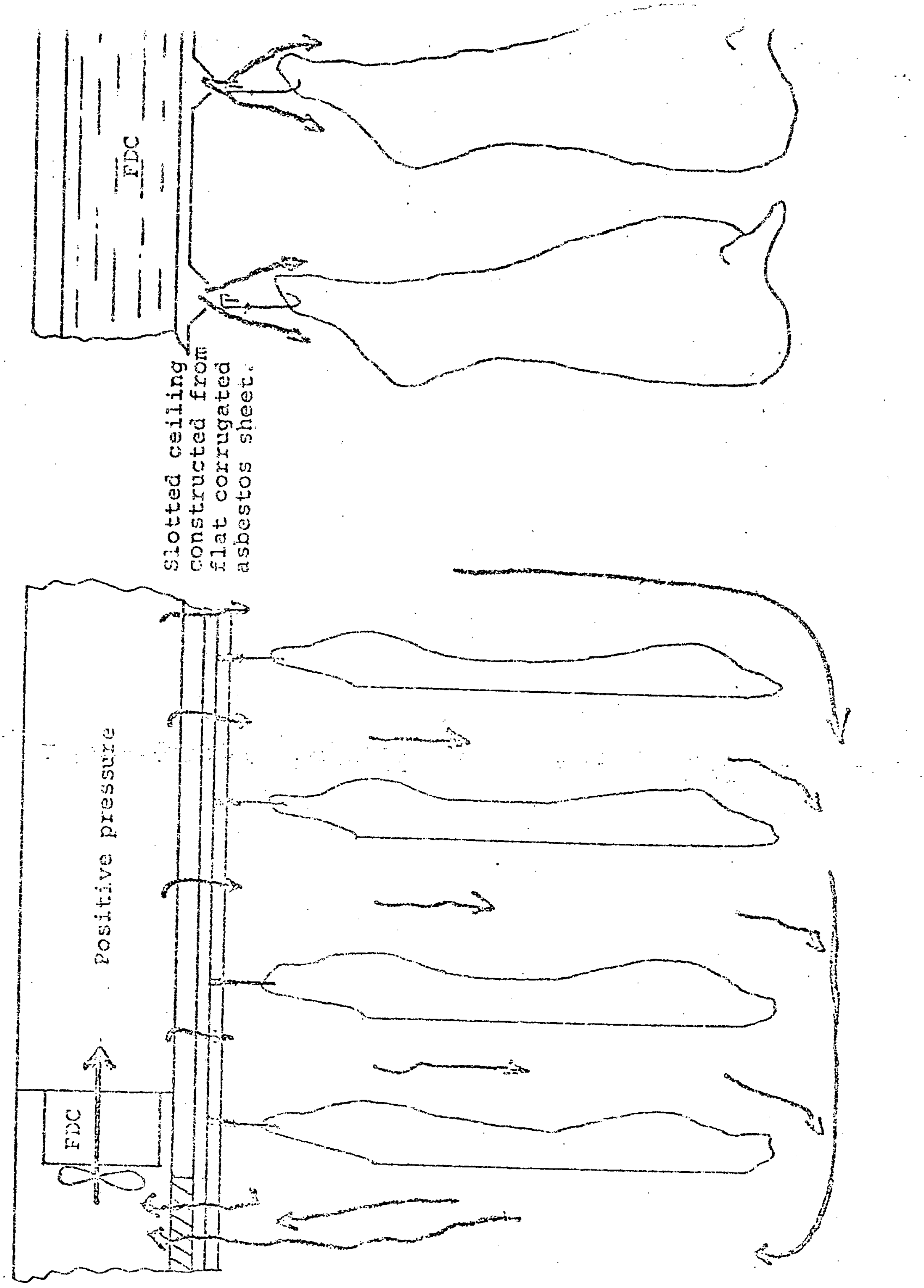
One of the major problems with evaporators is the possible ejection of water droplets from the coils onto carcasses. This difficulty is usually associated with coils sized to meet a specification of large temperature differentials between refrigerant and cooling air. The resulting small coil size results in higher air velocities at the outlet of the coil. Moisture condensing on the coil tends to be drawn away from the coil in the air stream as droplets.

During defrosting, particularly when water sprays are used, fans must be switched off to prevent carryover of defrost water. Fan controls must therefore be provided with off/on switches.

CHILLER CONSTRUCTION

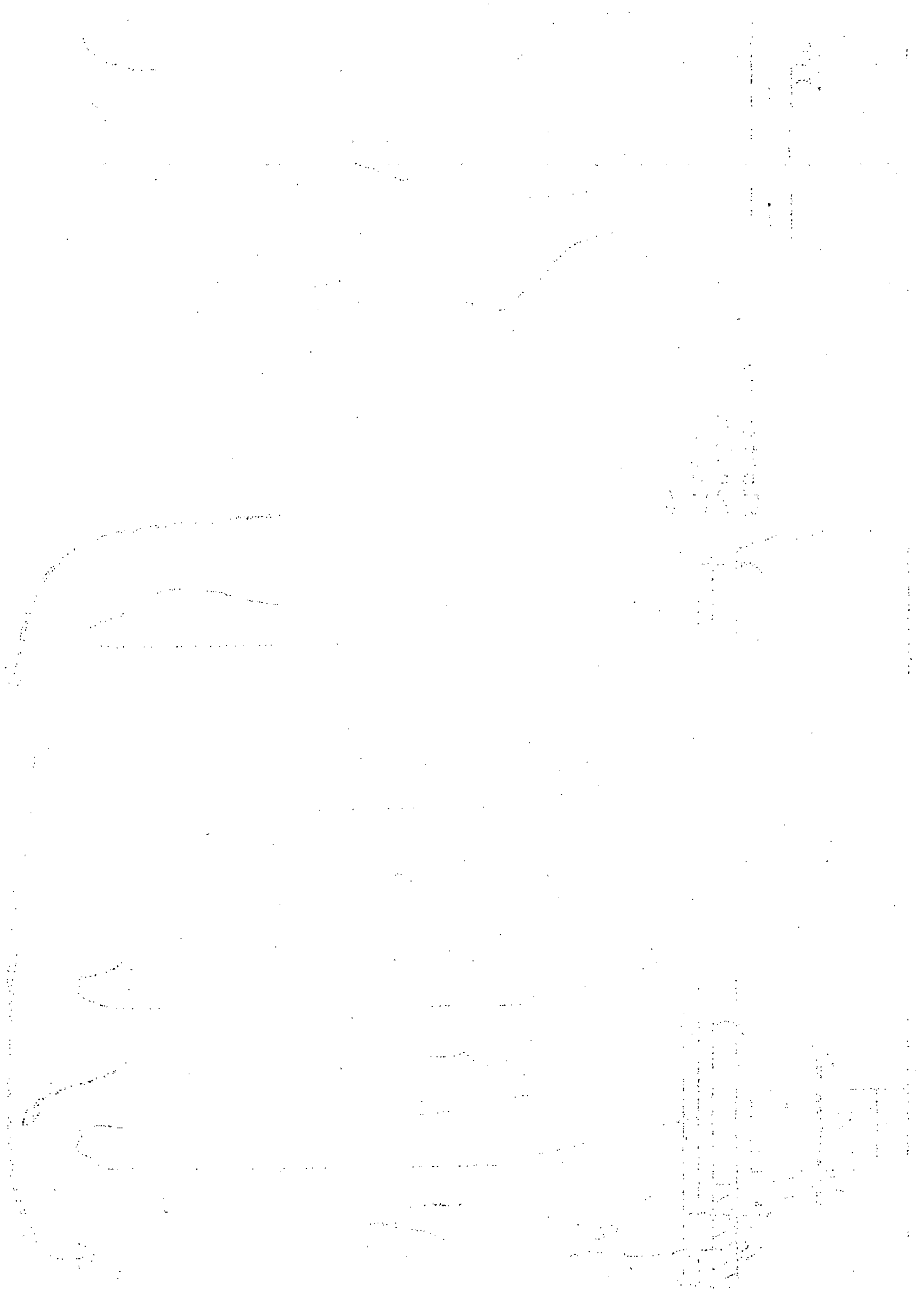
The standard of construction used in chillers is similar to that which applies to edible product areas, i.e.

- Walls must be smooth and impervious to liquids for a minimum height of 1,800 mm.
- Floors must be smooth, impervious to water and graded to facilitate drainage.
- The wall/floor junction must be coved. All doors and door jamb surfaces must be of rust-resistant material.
- All columns and walls should be protected from impact where necessary. This applies particularly where carcass hanging rails change direction.
- Lighting levels should be at least 220 lux and if any carcass trimming is done in the chiller, the lighting level at the work station should be 550 lux.



DETAILS OF SYSTEM USING SLOTTED CEILING TO
DIRECT CHILLING AIR ONTO CARCASSES

FIG.6



Chiller ceiling heights must not be less than 3 m. In chillers used for beef sides the ceilings must be higher to accommodate the hanging rail, rail supports and refrigeration equipment (if located above the rails).

All rails and equipment support structures should have a minimum thermal capacity with the maximum surface area-to-mass ratio. The ideal section for use as structural supports is the hollow (rectangular or square) metal tube. The low thermal capacity of this section will allow it to respond more quickly to temperature changes and should therefore reduce the risk of condensation forming on its surface.

All drain trays of evaporator coils should be large enough to contain defrost water. The drain from the tray should be oversized to ensure rapid drainage. The drain tray must be heavily insulated to minimise condensation.

If cooling air is distributed in ducting, this ducting should be located clear of the ceiling and isolated from the ceiling with thermally non-conducting materials. All ducting should be insulated.

Chillers should never be constructed above other chillers or any abattoir working area. There is always the possibility that the insulation between the upper and lower rooms may deteriorate. Very heavy condensation will then form on the ceiling of the lower space.

For the same reason chillers should never be located under other refrigerated areas, particularly freezers.

OPERATING PROCEDURES

The main requirements of the chiller operation is to achieve the deep butt temperature demanded by the regulatory authority. However, there are other factors to be considered in arriving at the most suitable operational procedure for any plant (5). These factors are:

Economic: weight lost from carcasses by evaporation and drip

operating and maintenance costs of refrigeration plant

Production: chilling cycle must suit production schedule

chilled carcasses must be acceptable for further processing, e.g. boning

Quality: bacterial growth

appearance (e.g. loss of bloom, condensation)

toughening

Herbert (5), in a study of the effects of different chilling procedures on microbial growth, fat hardness, toughening, weight loss, and final deep butt temperature, found that smallstock could be easily chilled to low deep butt temperatures in a one-day chilling period. He found that weight losses from sheep carcasses were minimised if they were chilled initially for three hours with air at $0^{o}C$ and 1 m/s, and then for 17 hours at $0^{o}C$ and 0.1 m/s.

Deep butt temperatures were reduced to below $7^{o}C$ by chilling in air at $0^{o}C$ and 1 m/s for five to six hours. Both chilling cycles, however, resulted in meat which was cold-shortened and had fat which was unacceptably hard. These problems could be avoided only by slower cooling, e.g. using air at $10^{o}C$ and 1 m/s for three hours, and then air at $10^{o}C$ and 0.1 m/s for a further 17 hours.

The results of a similar study with beef sides which had an average weight of 140 kg are given in Table 2. For batch chiller operations, procedure 2, i.e. chilling in air at $0^{o}C$ and 1 m/s for 10 hours and then for 10 hours at $10^{o}C$ and 0.1 m/s, resulted in reasonably good microbiological control, soft fat, cold shortening of only the thinner parts of the carcass, a weight loss of 2%, and a deep butt temperature of $15^{o}C$. Any procedure used to chill beef sides to $7^{o}C$ or lower (as required by EEC Third Country Directive) results in cold shortening and 'hard fat'.

In procedure 2 the temperature is allowed to rise half way through the chilling cycle. This could be an advantage when reloading the chiller as the higher chiller temperature would result in reduced condensation on the structure. Procedure 2, however, would require careful consideration of refrigeration and evaporator capacity, good control of air movement and automatic control of fans.

CONDENSATION

Condensation of moisture on chiller structures is one of the major refrigeration problems of the meat industry. The presence of condensation on overhead structures is considered unacceptable by the regulatory authorities for the simple reason that dripping condensate will result in contamination of the carcasses.

Condensation is the result of relatively warm, moist air coming in contact with a surface at a lower temperature.

It is possible to predict the areas in meat processing plants likely to be troubled with condensation. Typical examples are:

1. Drain trays below forced draught cooling units, and ducting which carries cold air. In both cases the surface temperatures are nearly always less than that of the surrounding air. This, in association with low room temperature and high relative humidity, results in continuous condensation.

2. Walls or ceilings between areas at different temperatures. In this situation the surface of the structure exposed to the warmer temperature can be maintained at a temperature below the ambient dew point due to heat leakage into the room at the lower temperature.

3. Areas in cold rooms which have intermittent contact with outside air. The entry of warm, moist air may result in considerable condensation on all surfaces at a lower temperature.

To minimise weight loss from carcasses, chiller air is usually maintained at high relative humidities, generally between 85% and 95%. Under such conditions the air in the chiller is almost saturated. It requires only a slight drop in temperature in any part of the structure or an increase in dew point of the air to cause condensation to occur.

The dew point of the air within a chiller can be raised by an increase in air temperature and relative humidity. This generally occurs during the loading stage when carcasses, which are hot and wet, are introduced.

Air temperatures as high as 16°C and relative humidities of 100% have been noted in some chillers during the loading stage. This is generally due to a totally inadequate refrigeration system. In some abattoirs, the chillers are precooled prior to loading. If the air temperature increases and is saturated during loading, then condensation is certain to form on all cooled surfaces. Practices which contribute both heat and moisture to chillers are leaving chiller doors open during the entire loading phase and cleaning chillers with hot water.

Positive steps can be taken to limit the quantity of hot, moist, outside air admitted to refrigerated areas. The use of high-speed air curtains, or air locks with double doors, is recommended. As noted earlier, it is better to load carcasses in batches than to leave chiller doors open for extended periods while carcasses are loaded individually.

To encourage personnel to close chiller doors, door opening and closing should be mechanically assisted.

Floors and walls should be washed only at times remote from the loading period. All surfaces should be dried after they have been washed.

CONCLUSION

To achieve a chilling system which meets the demands of the meat industry there are many factors which must be considered, both in the design of chillers and their operational procedures. The most important factors are:

- The refrigeration capacity should not be less than 3.6 kW for every four beef sides or 15 mutton carcasses.
- The length of rail in chillers must be sufficient to allow each carcass to be hung without contacting adjacent carcasses.
- The surface area of evaporator coils should be determined on the basis of a 5°C temperature difference between evaporating refrigerant and cooling air.
- All low-temperature surfaces, such as F.D.C. drain trays, should be heavily insulated.

- No work area which is to be held at a low temperature should be located over work areas which are held at a higher temperature, i.e. chillers should not be located over boning rooms, freezers should not be located over chillers or boning rooms.

- The temperature and velocity of the cooling air should be selected only after careful consideration of their effect on product quality.

- Carcasses should be loaded into chillers in batches.

- The opening and closing of chiller doors should be mechanically assisted.

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TABLE 2

BATCH CHILLING PROCEDURES

BEEF SIDES 140 KG. 20 HOUR CHILL

Procedure Number	Air Conditions: Velocity m/s	Air Conditions: Temperature °C	Duration (hours)	Microbiological Control	Condition of Surface Fat	Cold Shortening	Total Weight Loss %	Final Deep Butt Temp. -°C
1	1.0	0	10	Very Good	Hard	Most Meat	1.8	10
	0.1	0	10					
2	1.0	0	10	Good	Soft	Thin Meat	2.0	15
	0.1	10	10					
3	1.0	10	10	Fair	Soft	None	2.2	20
	0.1	10	10					
4	2.0	-10	5	Good	Soft	Most Meat	1.6	10
	0	rising to 10	15					