CHILLER EFFICIENCY AND CONDENSATION

By

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Introduction

Dressed carcasses must be chilled to minimise the growth of contaminating bacteria. Because chilling also affects meat tenderness and the quality of the end product, it is perhaps the most important step in meat processing.

Satisfactory chilling can only be achieved if the chiller has adequate refrigeration capacity and good air circulation. It should also be well constructed, properly maintained and correctly operated.

Refrigeration capacity

Ideally, refrigeration capacity should be such that the rise in air temperature in the chiller during peak loading is minimal. In practice, however, this ideal is unrealistic. When a hot beef carcass is transferred to a chiller held at an air temperature of, say, $0^{\circ}C$, the initial heat load from the carcass is equivalent to approximately 4.2 kW.

If the refrigeration system was designed to cope with the initial heat load, there would be an excess of refrigeration capacity for most of the chilling period. A compromise is therefore necessary. The refrigeration capacity is often determined by averaging the total heat load of the carcasses over the entire chilling period. Allowance is also made for heat loads from lighting and air leakage and heat gains through the structure. In addition, allowances are made for chiller unloading, cleaning and defrosting.

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 (1) 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 $0^{\circ}C$ during loading.

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 subsequent loss of capacity during the loading and early chilling periods.

Table 1. Measured values of temperature and relative humidity in chillers*

Plant	Air temperature during most of chill °C	Air temperature during carcass loading °C	Relative humidity 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	97

Inadequate refrigeration capacity leads to high air temperatures and relative humidities in chillers, particularly during the carcass loading phase. This causes fogging and condensation of moisture on the chiller structure.

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.

It is normal practice to select air handling capacities on the basis of required air circulation rates, i.e. the number of times the total volvume 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.

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

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 Fig 1.

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.

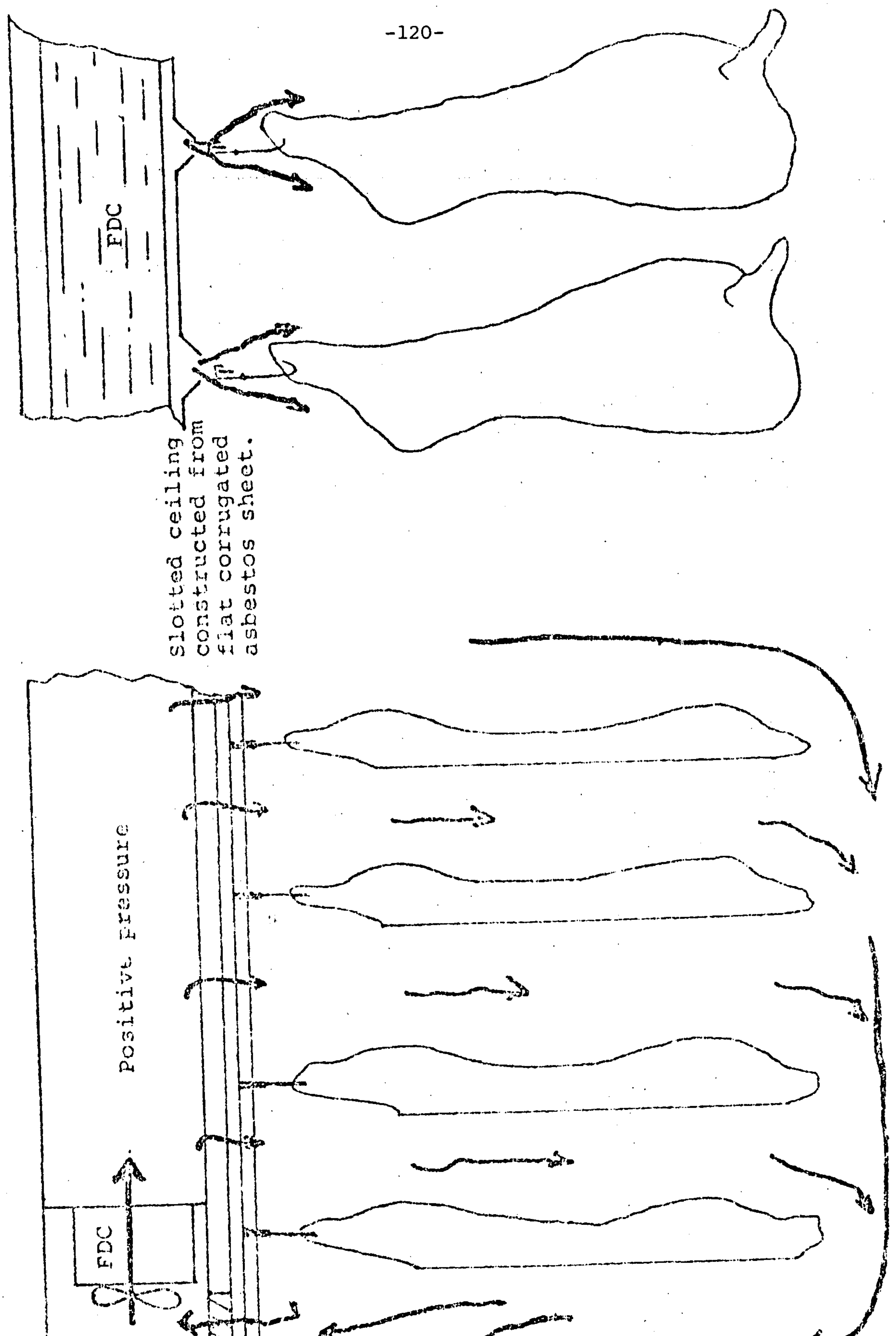
Chiller construction

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 1800 mm.
- Floors must be smooth, impervious to water and graded to facilitate drainage.
- The wall/floor junction must be covered. 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.

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 ration. 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.



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

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 nonconducting 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 requirement 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 (2). 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 (2), 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 small stock 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.

Table 2. Batch chilling procedures beef sides, 140 kg, 20 hour chill

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

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°C and 1 m/s for 10 hours and then for 10 hours at 10°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°C. Any procedure used to chill beef sides to 7°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.

<u>Condensation</u>

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.

Water vapour is a normal constituent of the atmosphere, the actual quantity varying during the day and throughout the year, depending on climatic conditions. The important point is that the quantity of water vapour in the air is directly dependent on the air temperature. The higher the air temperature the greater is its capacity to hold vapour. Conversely, if the air temperature falls, its capacity to hold vapour is reduced.

If a volume of air is cooled, it will reach a temperature at which water will appear either as droplets in the air (fog) or as liquid water on solid surfaces in contact with the air. The temperature at which water vapour starts to appear is termed the DEW POINT of the air. In a sense, the dew point is a measure of the amount of water vapour in a particular sample of air. If water vapour is added or removed, the dew point will change.

The dew point is related to the air temperature and relative humidity. If the dew point is known, the relative humidity (RH) can be calculated at any temperature. When the temperature is of a volume of moist air reaches its dew point, its RH is 100% and it is said to be saturated.

Condensation will take place on a surface if its temperature is below the dew point of the surrounding air.

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 carried 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 area. The entry of warm, moist air may result in considerable condensation on all low temperature surfaces.

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. 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 13,000 MJ 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.

Case studies

Over the years the Industry Section at Cannon Hill has received many requests for advice on chilling and condensation problems. The following are a few examples of some of the problems and possible solutions.

Example 1.

Problem: Condensation on suspended ceiling and inadequate cooling of carcasses in small stock and beef chillers

The layout of the chillers is shown in Fig 2. Condensation was most noticeable on the ceiling adjacent to the air outlet. Measurements of horizontal air velocities at different levels from the floor upwards showed that between the suspended carcasses air movement was low at the level of the hindquarters for sheep (Fig 3) and beef (Fig 4).

Condensation was caused by moisture gains from the door being deposited on the ceiling. The method used to seal the end of the insulated panel ceiling ensured that the panel ceiling was alwyas at a temperature below that of the room.

The best solution, which was rejected because of cost, would have been to remove the ceiling and replace it with a slotted or perforated ceiling. The chosen solution was to direct the air flow into the hanging carcasses with moveable guide vanes on the floor.

Example 2.

Problem: Heavy condensation on chiller ceiling

The layout of the chiller is shown in Fig 5. The plant was old and the chillers were constructed from brick with a concrete ceiling and floor. The evaporator surface was bare coils, mounted in a box above the ceiling.

The design of the evaporator coil required very low refrigerant temperatures which resulted in a rapid build up of ice on the coils. Frequent defrosting was necessary.

Temperature measurements on the ceiling indicated that the cork insulation was ineffective. On examination of the battery box it was found that the lead sheeting which formed the floor of the battery box had cracked at all joints. Defrost water had leaked through, saturating the cork insulation, and was also leaking through the ceiling.

It was suggested that the bare coil evaporator be replaced by a finned tube evaporator with a larger surface area. This would allow refrigerant temperatures to be raised, reducing the frequency of defrosting and also reduced running costs. The cork insulation on the ceiling had to be replaced.

Example 3

Problem: Heavy condensation on boning room ceiling

The position of the boning room relative to other refrigerated areas is shown in Fig 6. The chillers directly over the boning room had been constructed with sufficient refrigeration capacity and evaporator surface area to allow chiller air temperatures to be held at below 2°C, even during the loading phase.

Temperature measurements on the ceiling confirmed that the heat transfer rates from the boning room into the chiller via the ceiling were sufficient to maintain the ceiling temperature below the dew point of the boning room air.

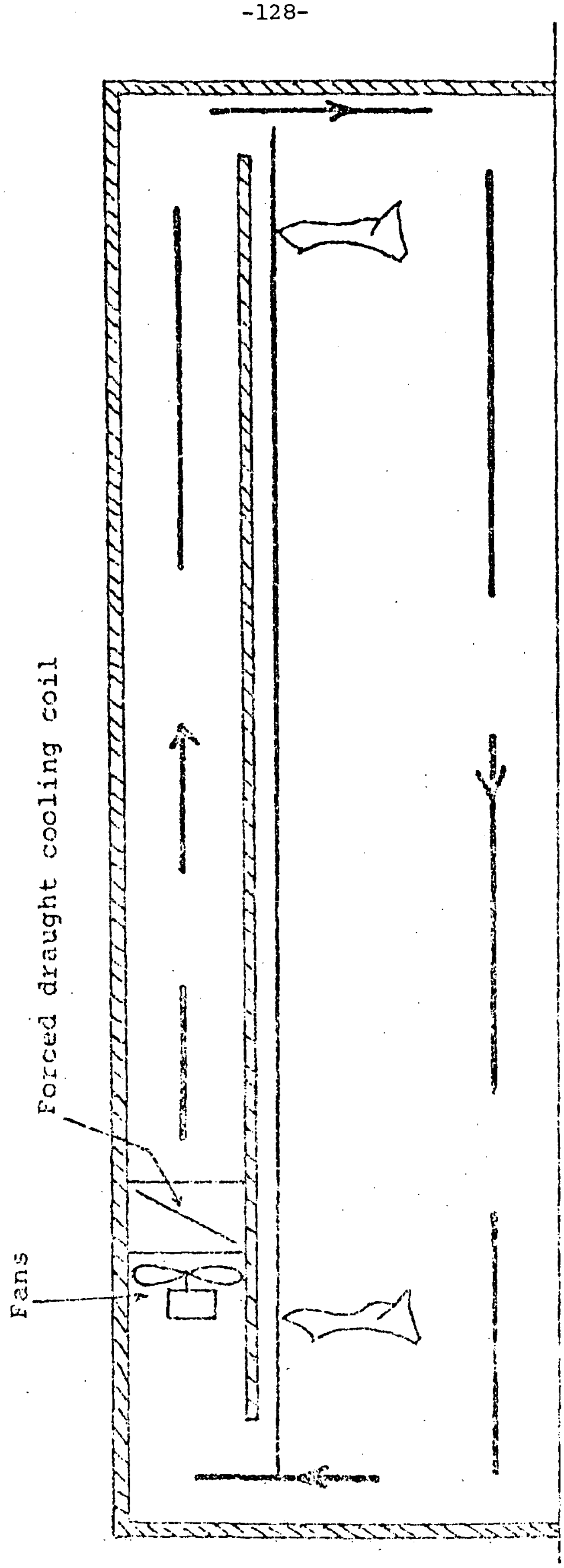
The calculated moisture gains to the boning room confirmed that the only source of moisture sufficient to maintain condensation at the noted rate was the air being supplied by the forced draught cooler (FDC) which supply was intended to cool fresh air. On checking it was found that the FDC was not connected to the refrigeration system. Hot, moist air was being continuously directed against the ceiling where the moisture condensed.

The problem of condensation was solved by connecting the FDC unit to the refrigeration system and operating it to give an air temperature at exit of 5°C.

References

1. Lovett, D.A., *CSIRO Food Research Report No. 45*, "Condensation in Australian Abattoirs" Part I Survey Report, Part II Technical Appendices, 1971.

2. Herbert, L.S., *CSIRO Meat Research Report No. 9/77*, "Carcass Chilling in Australian Abattoirs - Summary of Survey," 1977.



DIAGRAMMATIC LAYOUT OF A SMALLSTOCK CHILLER

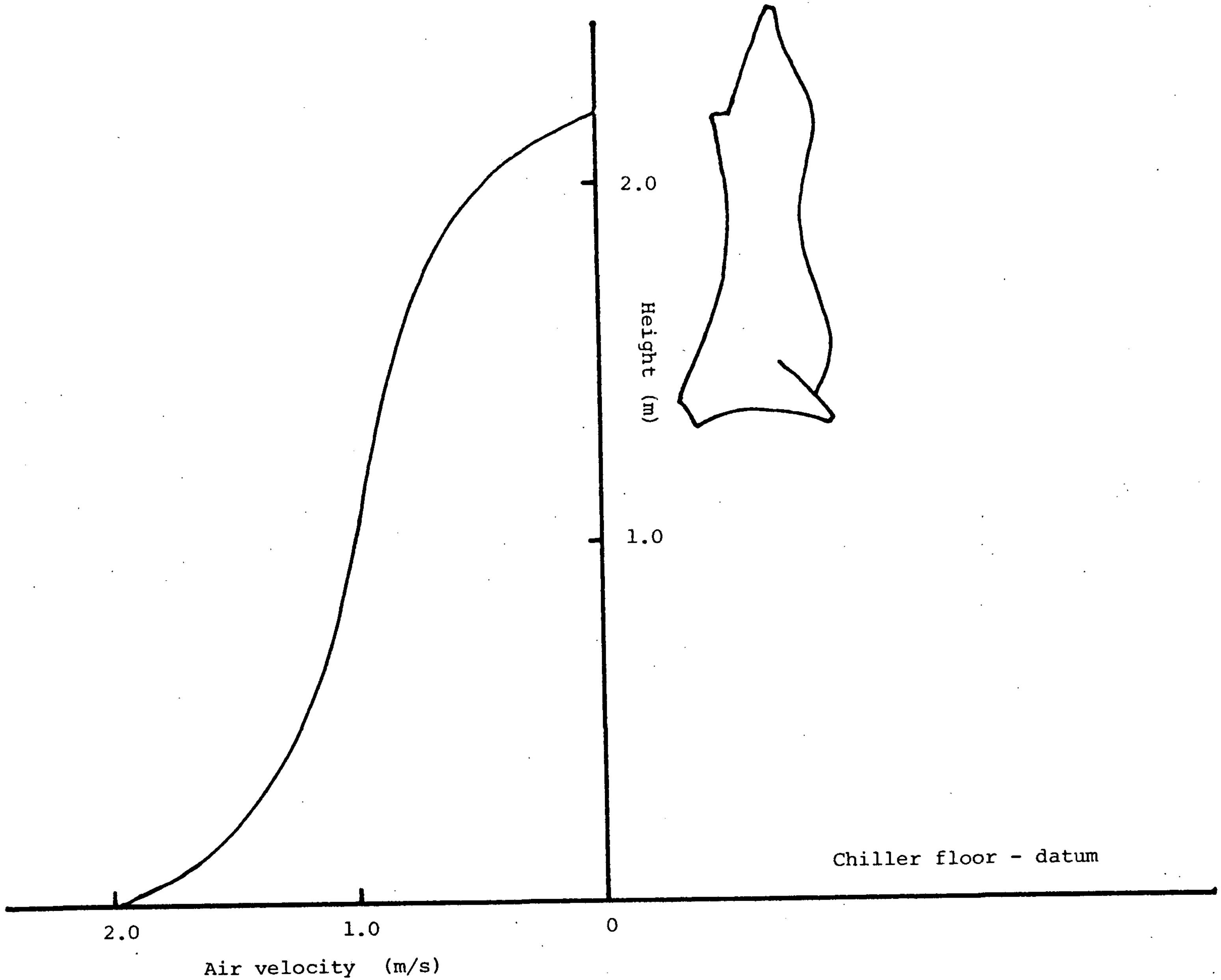


Fig 3. Vertical air velocity profile in a smallstock chiller

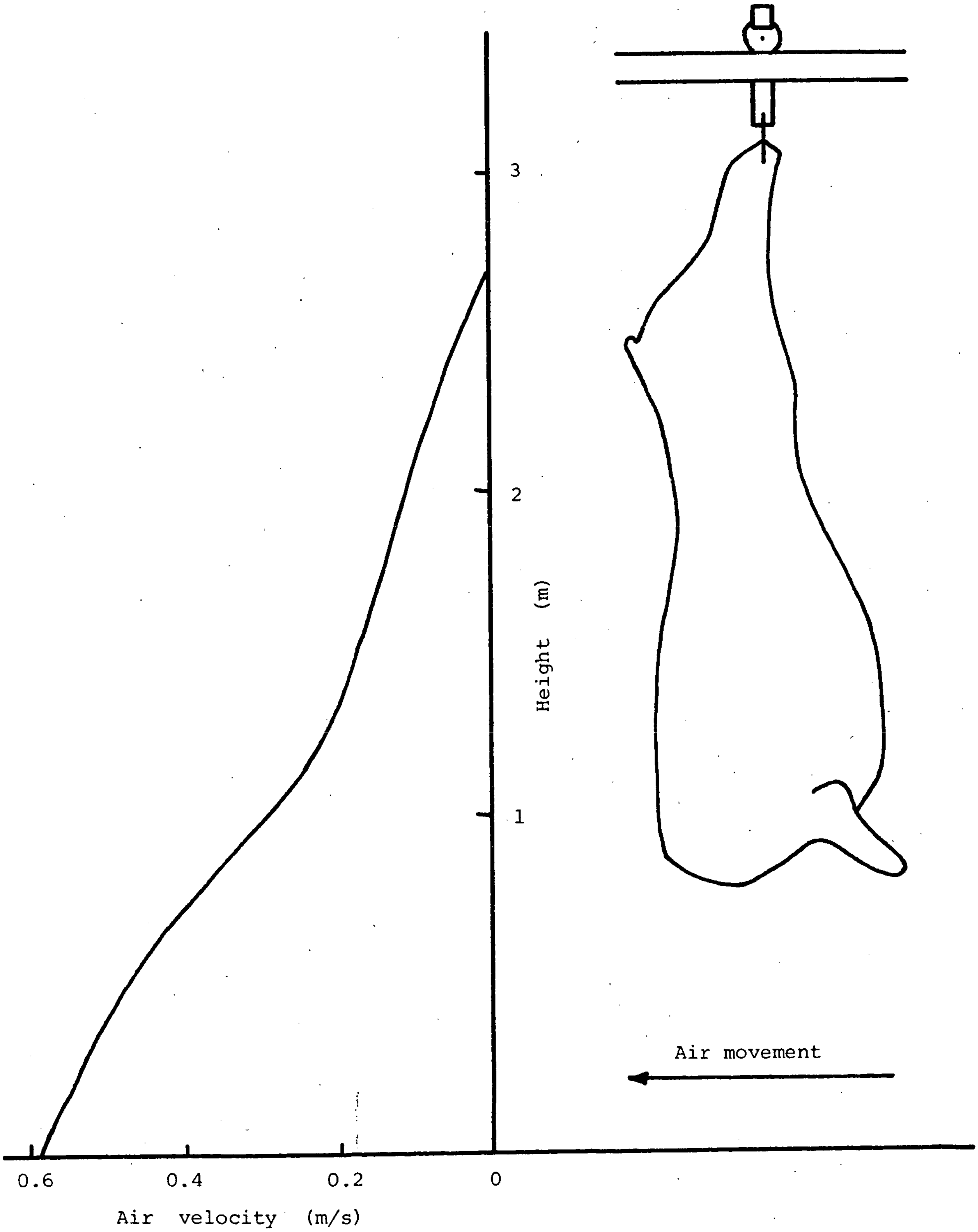
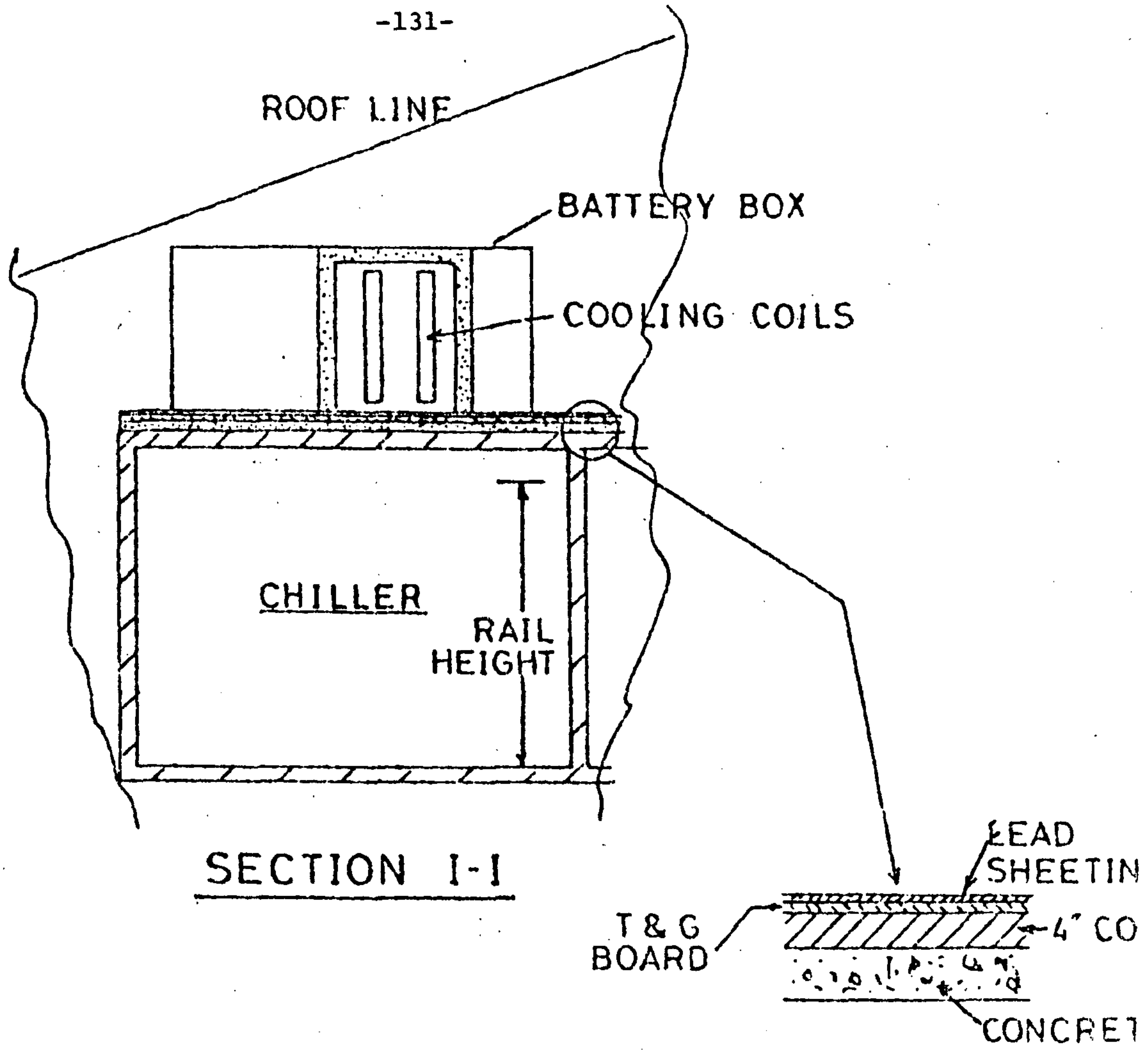


Fig 4. Air velocities in beef chiller



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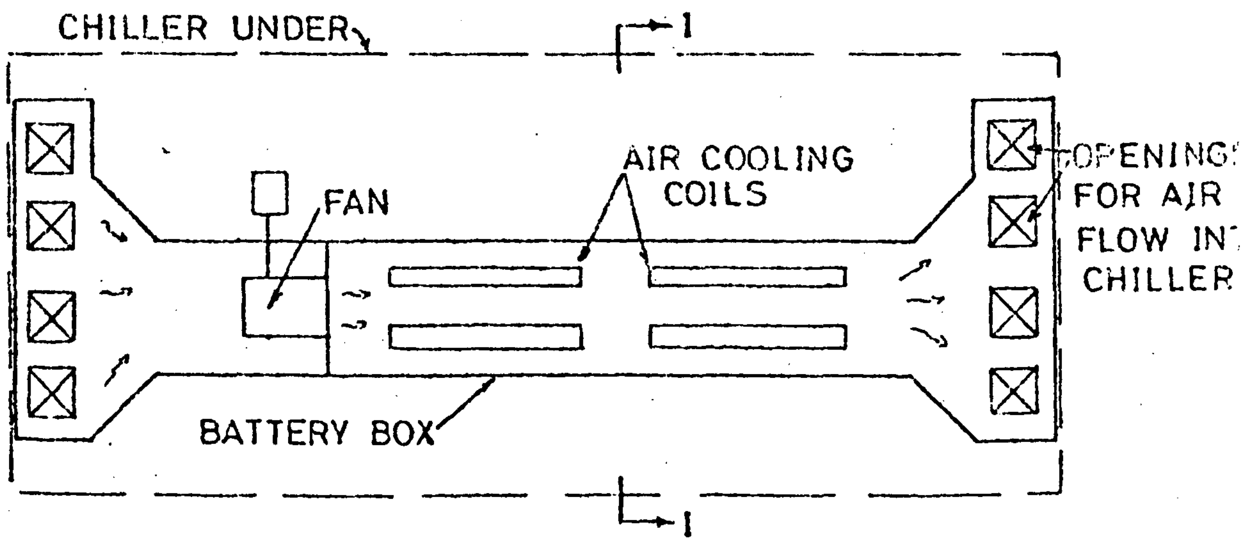
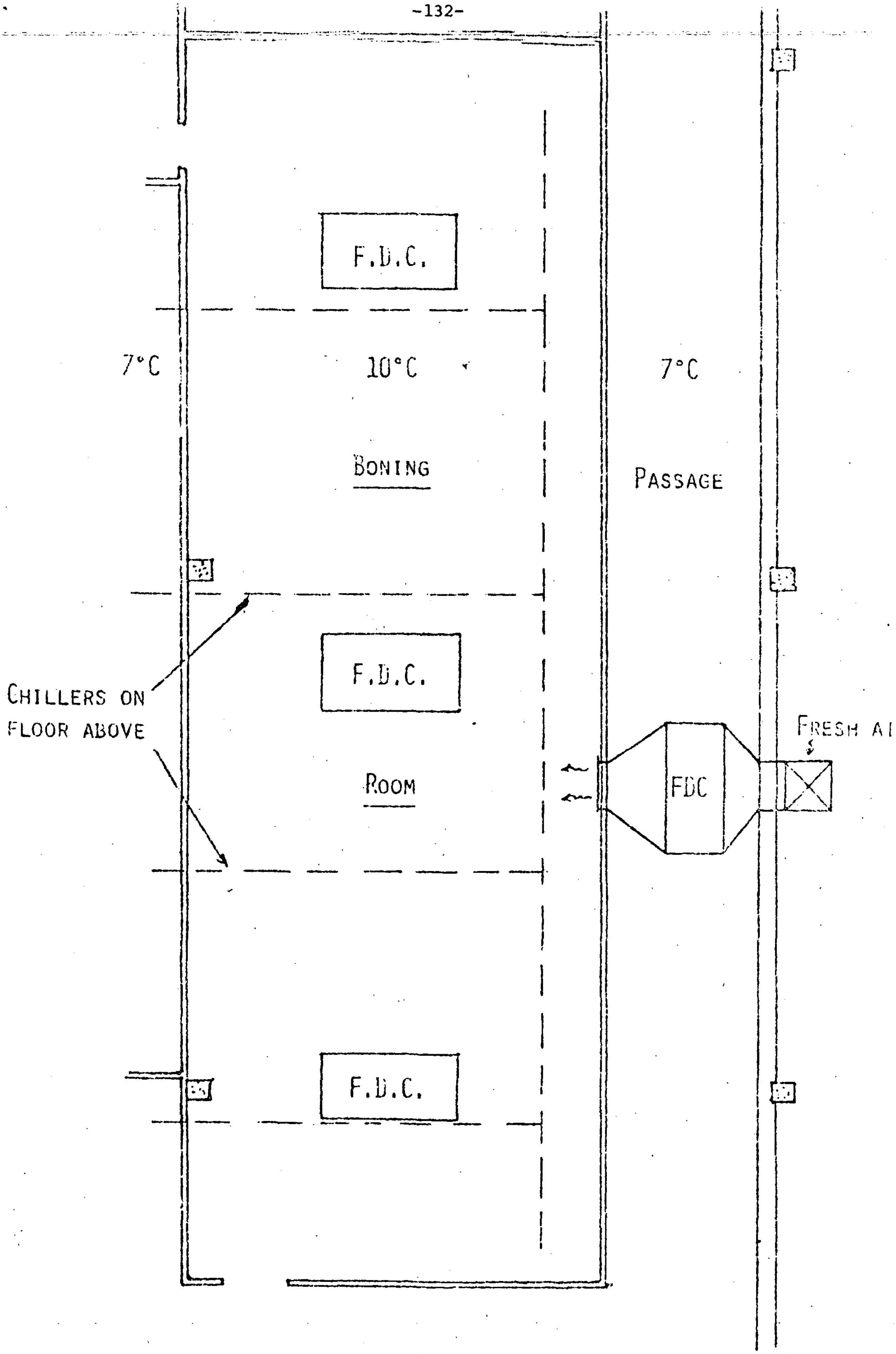


PLAN OF "BATTERY BOX" ABOVE CHILLER

FIG.5



POSITION OF BONING ROOM RELATIVE TO
OTHER REFRIGERATED AREAS

FIG.6