PRINCIPLES OF REFRIGERATION - CHILLER EFFICIENCY & CONDENSATION

by PM Husband

One of the most important items of equipment in a meat processing and handling establishment is the refrigeration system. Not only do we need refrigeration to satisfy the need for shelf life, but we need to know how to use the refrigeration system to maintain the product in an acceptable condition. Acceptable to the customer in terms of appearance, and acceptable to ourselves in terms of shelf life and yield.

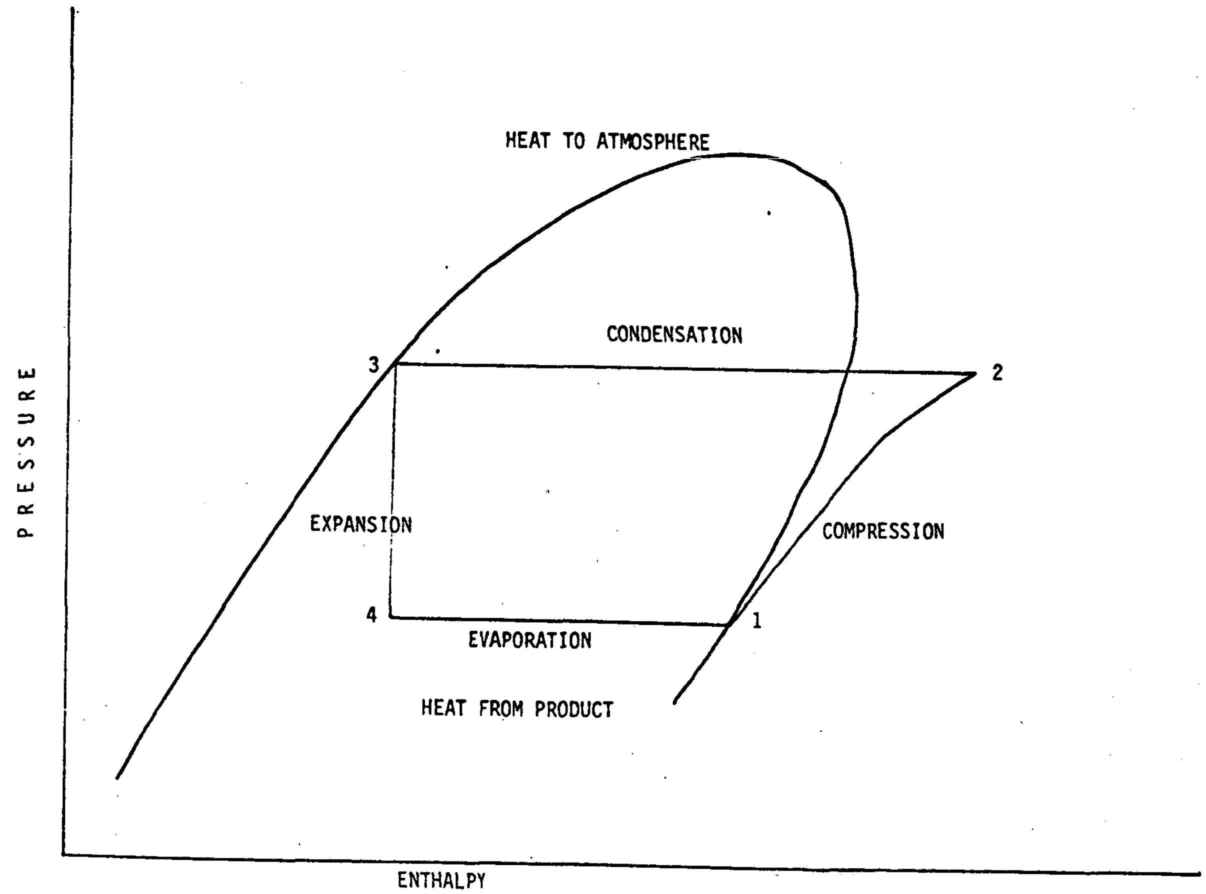
To achieve these goals we must understand basic principles of the refrigeration system and how the various components work. We must also understand how, by operating the system properly, we can maintain the efficiency of the chilling operation and control problems such as condensation. It is important to remember that refrigeration does not add anything to the quality of the final product, it simply inhibits microbiological and biochemical changes which result in spoilage. Final product quality is determined by initial quality, standard of hygiene during all stages of processing, temperature, and duration of storage.

The Refrigeration System

There are many methods available to achieve the refrigeration or cooling effect. These include ice, liquified gases (cryogenics), absorption and so on, but throughout the meat industry the method used is the mechanical vapour compression system. The essential components of a simple vapour compression system are the refrigerant, compressor, refrigerant expansion device, condenser and evaporator.

The refrigeration cycle can be explained by the pressure/enthalphy diagram (figure 1). Enthalphy is a property of a system related to its internal energy. The word is derived from Greek, meaning 'warm'. Starting at Position 1 on the diagram, vapour at low pressure and low temperature is fed into the compressor. The compressor, in doing work, increases the pressure and the temperature of the vapour (Position 2). The vapour at high pressure and temperature then passes to the condenser where it is cooled, giving up its latent heat, so that it condenses back to its liquid form (Position 3). The high pressure liquid from the condenser is then expanded through an expansion valve (Position 4). At this point the refrigerant is now at a low pressure and is mostly liquid. It has a low boiling point due to the low pressure. When it enters the evaporator coils, the liquid refrigerant boils, absorbing the necessary latent heat of evaporation from the surrounding air. The vapour at low pressure and low temperature then passes to the suction side of the compressor (Position 1) and the whole process repeats itself. The pressure/temperature conditions at the condenser, and the evaporation, are the two most important conditions in the entire cycle.

We will deal with the various components of the system, one at a time. In doing so we will see more clearly the role each one plays in the heat transfer, or heat pump cycle.



PRESSURE/ENTHALPY DIAGRAM FOR VAPOUR COMPRESSION CYCLE
FIGURE 1

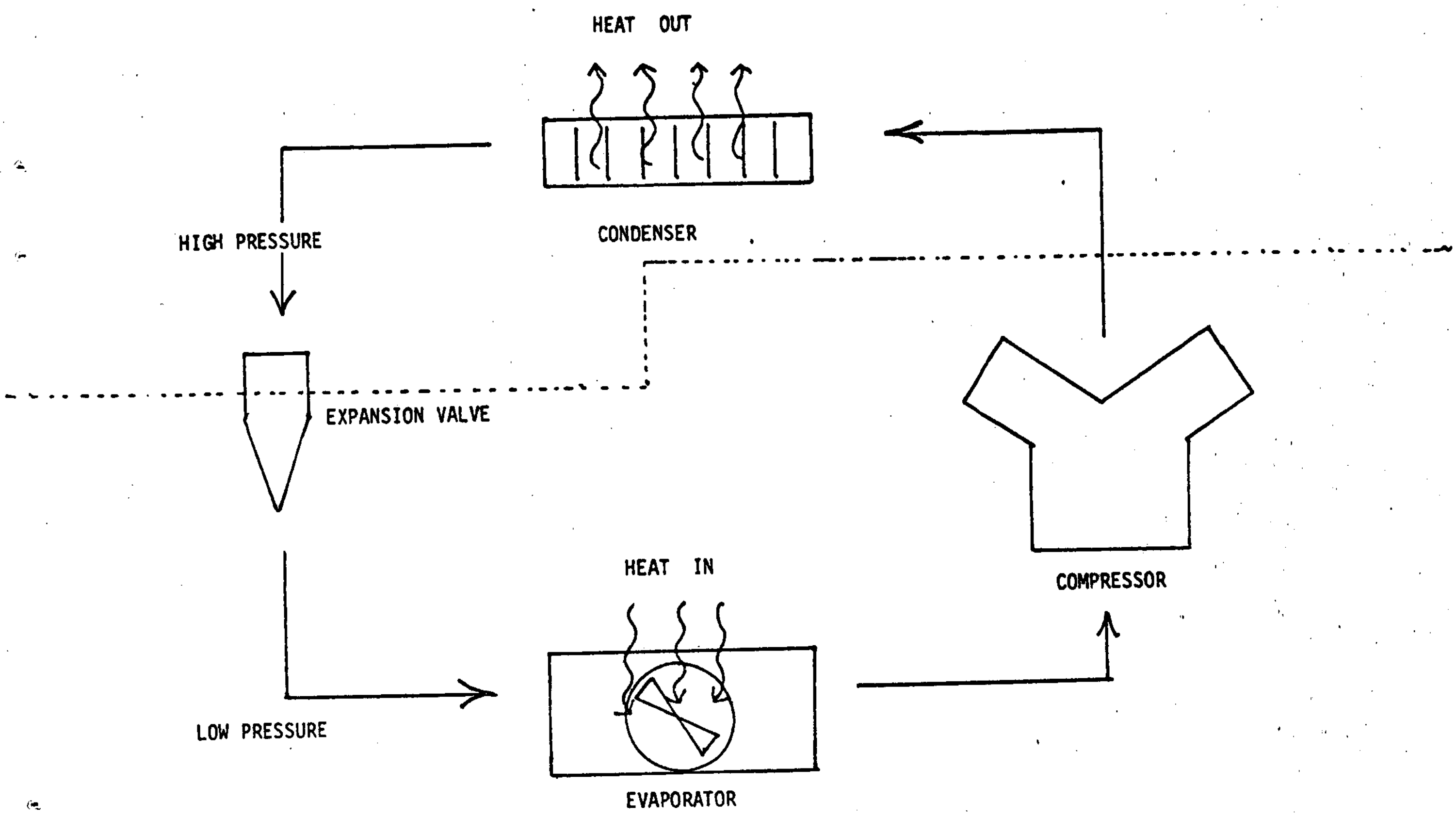


FIGURE 2 THE VAPOUR COMPRESSION REFRIGERATION SYSTEM

The Refrigerant

The refrigerant is the working fluid of the cycle. It vaporises as it absorbs heat, and condenses as it gives up heat. Broadly, the ideal requirements of a refrigerant are:

(1) A high latent heat of vaporisation,

(2) A low specific heat of liquid,

(3) A relatively high vapour density,

(4) Safety, i.e. it should not be toxic or explosive,

(5) Low cost.

Both (1) and (2) influence the refrigeration effect possible for a given mass of refrigerant circulated. (3) influences the size of compressor required for a given refrigeration effect.

Ammonia is the most common refrigerant used in the meat industry because it meets most of the ideal requirements. Smaller installations, such as retail butcher shops, usually use freon.

The one disadvantage of ammonia is its toxicity. Fortunately, personnel are repulsed by its strong, pungent smell long before exposure becomes dangerous. There is little risk in its use where proper precautions in design and installation are observed. In Australia its safety record is extremely good.

The compressor

The energy input in the refrigeration cycle is provided by the compressor. The amount of energy required depends on the volume of refrigerant being circulated and the increase in pressure required to condense the refrigerant vapour. Lowering the temperature in the evaporator, or increasing the temperature in the condenser, results in greater pressure differences between evaporator and condenser. This increases the power requirements of the compressor. Lowering the temperature in the evaporator increases the volume per unit weight of the refrigerant. This results in a reduction in the refrigeration capacity of the compressor.

The condenser

When the vapour is compressed, its pressure and temperature are increased. It is then transferred to the condenser where the hot, high pressure vapour is cooled, losing its latent heat. The vapour then returns to a liquid, still at a high pressure.

In the meat industry. the evaporative condenser is the most common type used. Because water sprays are used to aid cooling, its capacity is influenced by the ambient wet bulb temperature. In most parts of Australia, particularly at times when ambient temperatures are high, the wet bulb temperature is significantly lower than the dry bulb temperature. This gives the evaporative condenser its greatest advantage over the air cooled condenser. In the retail butcher shop situation of course it is necessary to use the air-cooled condenser because of the difficulties associated with the evaporative type in a confined space. Both types of condenser require free circulation of air over the coils for effective cooling. Ideally, condensers should be located well clear of buildings and structures which could restrict air flow.

The evaporative condenser requires a supply of good quality water for its operation. As water is continuously being evaporated from the cooling coil surface, scale will be formed by precipitation of salts. If this scale is allowed to build up, heat transfer rates will be reduced, causing an increase in refrigerant temperature. The same problems will occur with an air-cooled condenser if the coils or fins are allowed to become fouled with rubbish of any sort. Effective cooling can then only be maintained if the compressor operates at higher pressure, which in turn will result in greater power use. The condenser must have sufficient cooling to dissipate both the heat extracted by the evaporator and the heat added by the compressor.

The expansion device

This device maintains the pressure differential between evaporators and condensers necessary for the correct operation of the refrigeration system. It allows the refrigerant to expand from the high pressure side to the low pressure side of the system.

The evaporator

After passing through the expansion device, the refrigerant, now at a low pressure, is fed through evaporators, banks of coiled tubes with their surface areas increased by the addition of fins. The air to be cooled is passed over the banks of finned tubes. The refrigerant extracts heat from the air, and vaporises. Fans are used to blow air over the finned tubes. This increases the rate of heat transfer and achieves the desired air distribution pattern in the chiller. The cooling capacity of the evaporator depends on the surface area of the coils, the temperature difference between the refrigerant and the air being cooled, and the rate of heat transfer through the coil.

Design of refrigeration systems

When refrigeration systems are being purchased, a good deal of thought should be given to the alternatives which are available. I am not referring to different brands as much as I am to different combinations of equipment, costs and sizes. This is especially important today when the cost of energy is rapidly increasing. What appears to be the cheapest refrigeration system to purchase and install may prove to be highly unsatisfactory and indeed the most expensive in the long run.

In any refrigeration system the temperatures at which the refrigerant condenses or evaporates determine the capacity, power used, and overall efficiency. The relationship between the temperatures at which the refrigerant condenses or evaporates and power consumption is shown in figure 3. For example, at a condensing temperature of 35°C and evaporating temperature of 0°C, the power consumption is 0.9kW for each MJ of refrigeration capacity. At the same condensing temperature and an evaporating temperature of -20°C the power consumption increases to 1.8kW for each MJ of refrigeration capacity. The temperature at which the refrigerant condenses depends on the ambient temperature, condenser capacity and the condition of the cooling coil surface.

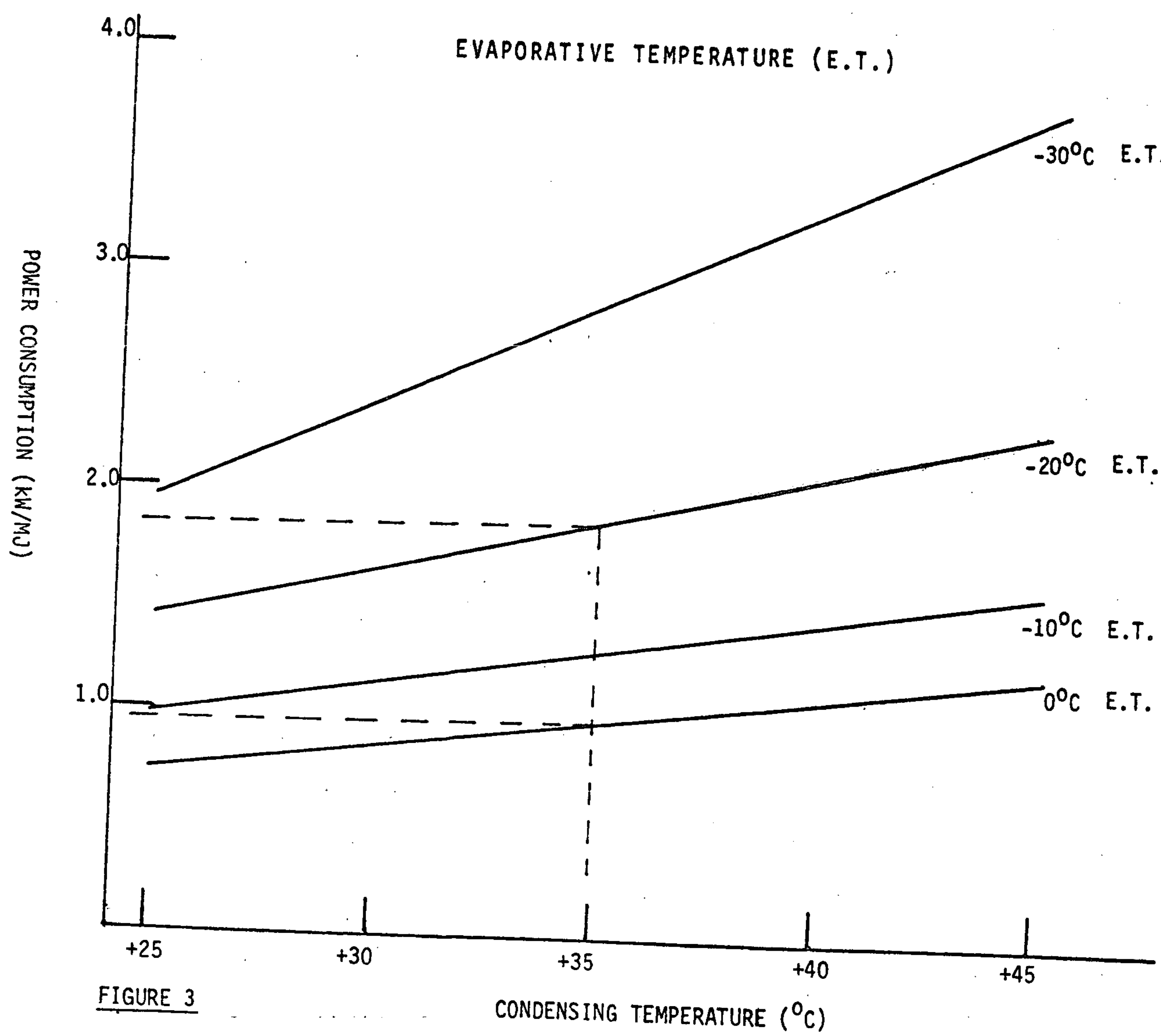


FIGURE 3

The temperature at which the refrigerant evaporates is determined when the system is designed and the temperature difference between the refrigerant and the cooling air is selected. If a large temperature differential is selected, smaller evaporator coils can be used. This is usually the method adopted to reduce the cost of a refrigerating system. The consequences are low humidity of the cooling air, which results in increased weight loss from carcasses, rapid icing of the cooling coil, which means that the system must be frequently shut down for defrosting, and high air velocities at the discharge face of the coil, which can result in contamination of the product due to carry-over of moisture droplets.

Before the introduction of finned tubes for use in the construction of evaporator coils, plain tubes were used. To reduce the length of tubing needed to transfer the heat load it was a common practice to use an evaporating temperature of $-16^{o}C$ in evaporators located in chillers. The use of $-16^{o}C$ evaporating temperatures in chillers is still common in the meat industry. This is in spite of the fact that evaporator coils constructed from finned tubes allow evaporating temperatures to be increased to approximately $-5^{o}C$. Coils operating at $-5^{o}C$ will need to have about 250% more surface area than at $-16^{o}C$.

If power costs alone are considered, it can be shown that the additional cost of evaporators designed to operate at $-5^{o}C$ as against $-16^{o}C$ can be recovered in less than two years.

Chiller efficiency

Chiller efficiency from the point of view of operating cost has just been dealt with. What we will consider now is the efficiency of the chiller in terms of its ability to maintain meat quality. The first consideration is refrigeration capacity.

Refrigeration capacity

Ideally, a chiller would be designed to cater for the maximum load demand which is ever likely to be made on it. Unfortunately it would be far too expensive to have that amount of spare capacity available, doing nothing for most of the time. By the same token it would be disasterous to have a grossly under-designed chiller, so the ideal happy medium is a compromise between the two extremes. Refrigeration capacity is often determined by averaging the total heat load of the entire working period. Allowance is also made for heat loads from lighting, air leakage, and heat gains through the structure. In addition, allowances are made for chiller unloading, cleaning and defrosting. This method can lead to under-estimation of refrigeration requirements. Depending on the temperature of carcass meat which is loaded into the chiller, and the amount of time the door remains open during the loading operation and the couple of hours following it, most of your heat load could occur in the space of those couple of hours. The use of average hourly figures to determine refrigeration capacity to meet demand at that peak time. If this is combined with inadequate allowance for heat gains in other areas, then serious trouble could result. One factor which can compound the problem of under-capacity in the refrigeration system is the 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 coils, and a consequent loss of refrigeration capacity. Inadequate refrigeration capacity leads to high air temperature and relative humidity. This can cause 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 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.

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 carry-over of defrost water. Fan controls must therefore be provided with off-on switches.

Chiller construction

Guidelines for the standard of construction of chillers are contained in the relevant local and export regulations. These regulations refer to the following desirable features:

* Walls constructed of smooth materials impervious to liquids
* Floor smooth, impervious to water and graded to facilitate drainage
* Wall/floor junctions should be covered. Door and door surfaces should be of rust resistant material.
* Columns and walls should be protected from impact where necessary.
* Lightning levels should be at least 220 lux.

Chiller ceiling heights should be adequate, about 3 metres for a chiller, designed to handle beef quarters. The ceiling would need to be higher if the chiller was to accommodate full sides.

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 strctural 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 under evaporator coils should be large enough to contain defrost water. The drain from the tray should be over-sized to ensure rapid drainage and the drain tray must be heavily insulated to minimise condensation.

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 meat products. 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 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 (chiller) likely to be troubled with condensation. Typical examples are: 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.

There are areas in cold rooms which have intermittent contact with outside air. 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 humdities, 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 for 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 can occur during loading when the door may be left open for extended periods. Positive steps can be taken to limit the quantity of hot, moist, outside air entering refrigerated areas. The use of air curtains, or semi-automatic door opening and closing devices is recommended. These devices make it easy to close doors when you have your hands full and could not manually close the door.

In conclusion we can say that efficient chiller management comes from a combination of adequate design and good operation. The refrigeration system must be designed so that it has adequate capacity for the demands that are going to be made on it, and the various components of the system must be chosen carefully.

The construction of the chiller should be such that it can be kept clean. The structure should not be responsible for any excessive heat load, and access should be controlled to minimise the entry of hot, moist air from the outside. The day-to-day use of the chiller must be carefully managed.

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