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Design Of Poultry Slaughterhouse – Engineered Ventilation For Biosecurity & Efficiency

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Preface

The topic *Design of Poultry Slaughterhouse* has been divided into three chapters, namely (1) *Layout, Geometry & Construction Methods* (2) *Materials & Safety* and (3) *Engineered Ventilation For Biosecurity & Efficiency.* This is the third chapter. It has been divided into five parts.

This chapter is written specially for tropical conditions prevailing in South Asia. Comparisons are occasionally made with conditions prevailing in temperate climates, particularly in the context of South Asian designers' unfortunate propensity to simply copy their temperate counterparts' practices.

Part 1 of this chapter discusses the role of ventilation and different engineered methods of implementing them in the poultry slaughterhouse.

Part 2 dwells in detail on the interplay of humidity and temperature on conditions inside a slaughterhouse. To help the reader understand the concepts we draw references to the weather and natural weather conditions that explain the interplay of these factors on the outcome. We believe that once the reader understands these concepts in the more familiar context of weather systems in general, he will be better able to appreciate what these two variables can cause within the micro-environment of his slaughterhouse.

Next, **part 3** discusses human physiology in the context of air quality and temperature of the work place. Without a clear understanding of this, your ventilation system cannot be engineered to meet the needs and comfort of your workers, specially the large number of whom you deploy in the portioning & packing hall. Simple definitions and data related to human need for ventilation, access to oxygen and responses to elevated levels of carbon dioxide mentioned here can help a plant manager to achieve very high performance levels among his workers. Our emphasis here is to relate conditions inside the slaughterhouse and human physiological needs in quantities and magnitudes that we are better able to grasp than mere abstract figures.

Part 4 discusses the contaminants and biosecurity risks common to the slaughter environment. Most contaminants are too tiny and it is difficult for us to visualize them at spatial dimensions that we are familiar with. At the microscopic scales that they exist in, even simple actions like locomotion follows a totally unfamiliar, non-intuitive mode. So naturally, because these things are difficult for us to visualize, we fail to recognise the scale of damage that they may cause, nor rig up hurdles to overcome the microbes. In part 4 we also address frequently asked questions related to ventilation and biosecurity.

The last section is a compendium of concepts and definitions designed to help the advanced professional design a good ventilation system. It not only defines terms, it also attempts to present them in more familiar contexts. It is followed by a bibliography of references.

If they wish, plant owners and managers can get by with a reading of parts 1 through 4 and may skip the last section. However, unless they study this entire chapter rather thoroughly, they may remain under the illusion that a good slaughterhouse may be designed with no more skill, understanding and experience than one needs for design and construction of residences and warehouses.

You don't really understand something unless you can explain it to your grandmother. This quote, attributed to Albert Einstein, explains how we may communicate useful concepts of science and technology to managers and supervisors who lack the time, training and motivation to grasp the true nature of their common problems. We have accordingly used simple language and narrated common observations to illustrate our points in this chapter.

1 How Does One Ventilate A Slaughterhouse?

How does one ventilate a slaughterhouse? One way is to let nature do it. But that may not provide adequate and controlled ventilation. Another way is to **engineer** an air movement or ventilation regime in the slaughterhouse. We favour the latter and we will discover how we can engineer the regime in such a way as to achieve every requirement - efficiency, comfort, hygiene and reduced operating cost. But first we need to be familiar with the organisation of the slaughterhouse.

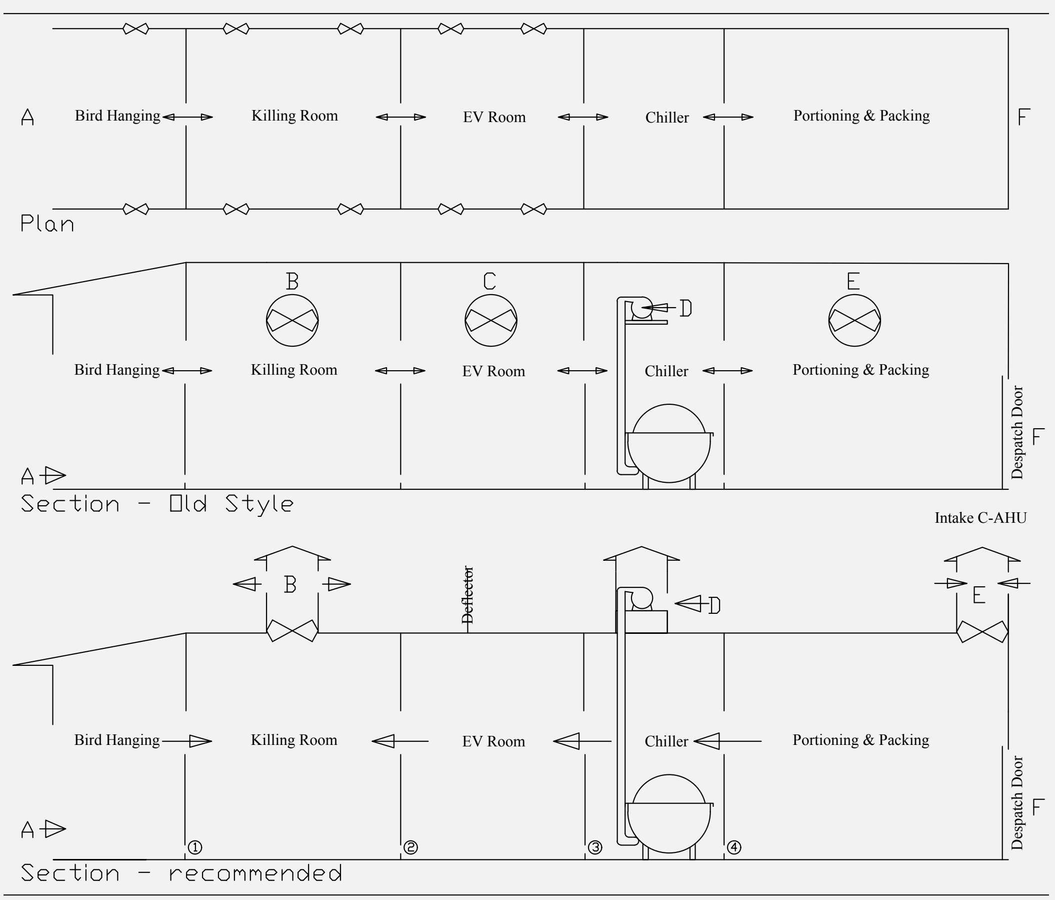


Figure 1 The top two illustrations (Plan and Section – old style) show the conventional ventilation system in which fresh air is sucked in from one side wall and stale air is exhausted from the opposite wall. In the bottom drawing (Section view of the recommended system) we have proposed an improved air movement regime in the slaughterhouse. Here air is taken in through E and exits at A and B. Note that there are openings like (i) doors between halls, (ii) wall openings to let the overhead track through and (iii) floor gutters (represented as 1, 2, 3, & 4 in the illustration. EV means evisceration.[1]

Figure 1 shows three sectional views through a typical poultry slaughterhouse. Live birds arrive at "A" and are hung up onto shackles in an overhead conveyor or overhead line. From here they move to the killing room. After which the carcasses move into the evisceration room and are then dropped from the overhead conveyor line into the screw chiller. On exiting the screw chiller the carcasses are graded by weight and dropped onto manual work-stations in the portioning and packing hall. Every transition from one room to the next is through wall openings which also allow air to move through, unhindered, in either direction.

> Why must air be bubbled through the bath in the screw chillers? A detailed discussion occurs in the chapter on chilling poultry. Here we need merely mention that when a multitude of air bubbles fill the bath, the effective specific gravity of the bath falls below that of water and chicken carcasses, which have a density close to that of water, then tend to submerge and thus make good thermal contact with the cooling medium

Finally the product moves to the packing stations and then into a chill store, or through a blast freezer into the frozen product store, before being shipped out. All rooms from arrival to EV operate at ambient temperature and need fans for workers to function comfortably in tropical climates. The screw chillers hold large quantities of very cold water, with some ice and a constant stream of air is bubbled through each chiller. Because of this, the room is naturally very cold and humid, with humidity reaching saturation levels. The portioning & packing hall is the largest one in the slaughterhouse. Its temperature must be maintained at 12ºC and the air must be very dry.

The dirtiest part of the slaughterhouse is the live bird arrival area and the cleanest part is the portioning & packing hall. In other words the product progresses from a dirty zone to a clean zone. Therefore it stands to reason that air must not move in the same direction as the product. If it does, it will carry smell, bioaerosols and microbes from the dirty zone to the clean zone. On the other hand if air is made to move in the opposite direction (counter-current movement), then that stream of air will progressively strip these undesirables from the carcass. The carcass will get cleaner as it progresses through the slaughterhouse. Or in other words we will have improved biosecurity. Therefore our task is to engineer movement of air in the workplace to match the bottom illustration in figure 1. To sum up, we need to:

- restrict free movement of contaminating aerosols,
- remove heat load and carbon dioxide
- curtail humidity in the packing hall.

Bioaerosols, saturation humidity, dry air and other terms are explained in the glossary at the end of this chapter.

Of the three sub-tasks listed above, it may not immediately become clear why it is felt necessary to curtail humidity in the portioning & packing hall. We will return to this point later. At the moment we must ask ourselves, "How can we design an air flow system that ensures comfort, efficiency and a high level of biosecurity at the minimum cost?"

1.1 The Conventional System of Ventilation

The conventional engineered system of air movement is shown in figure 1, top and middle parts. Here in each ambient temperature process room (hanging, killing and EV), air is sucked in from one side and stale air is exhausted from the opposite side. In such a situation, you absolutely require both sides of the row of process rooms to face open air – there should not be any construction to restrict intake and exhaust of air. Or in other words you cannot have any rooms or corridors on either side of the row of process rooms.

For example, assume that there was a corridor along one side and beyond the corridor was a workers' toilet. Chances are that you would suck in air from the toilets into the work spaces when ever any toilet door was opened! And when all the toilet doors were shut, your intake fans would have no access to the outside and therefore could not suck in fresh air. Of course, we know what that means – the exit door is opened by a worker almost immediately after he pulls the flush and this in turn generates a cloud of aerosol particles just above the toilet seat. And that cloud of aerosols gets sucked into the process area!

A similar set of circumstances attends the system where roof extractors form the components of an engineered ventilation system. We have examined the dubious role of roof extractors in section 1.6

Now look at the general layout drawings in figure 2. You will observe that when we design a poultry slaughterhouse we simply do not have the luxury of leaving both sides of the workspaces open to the outside because we need to build plenty of utility and service facilities on each side of these workspaces for proper functioning of the slaughterhouse. Furthermore, since we propose to build a

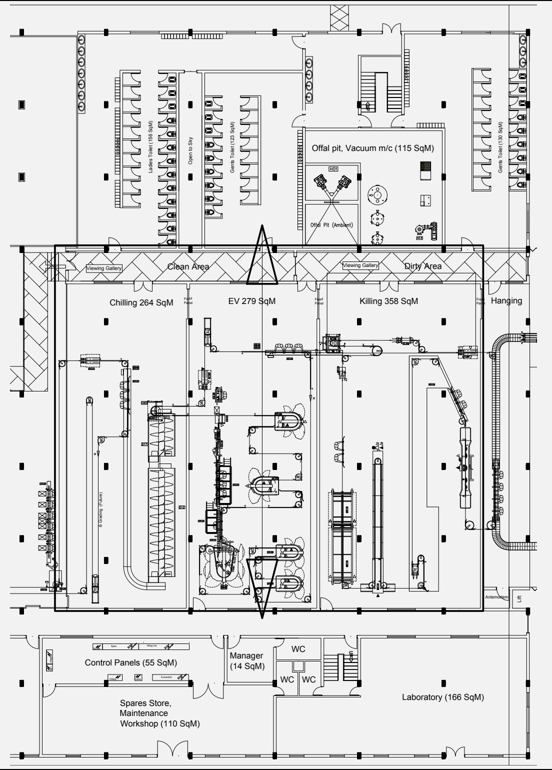


Figure 2 Showing how it is necessary to place several utility and service areas on both sides of the central row of process rooms, comprising, in this illustration, of killing and defeathering, evisceration & water chilling. This row of processing rooms has been highlighted as a dark rectangle here and the arrow bisecting it shows the direction of air flow that one would like to establish here with the conventional engineered air movement system. But if one were to use roof extractors instead of fans mounted in opposite walls as in the top two illustrations in figure 1, of course, one would expect air to be drawn in from both sides of this rectangle and exhausted upwards through the roof.

viewing gallery on one side, we also do not have the luxury of mounting fans at a reasonable height, close to the ceiling, in the row of process rooms as a means of gaining access to outside air.

If you were to relocate the electrical control room some distance away, you would create obstacles and inefficiencies in plant operation and possibly even situations leading to accidents. If you moved the offal pit some distance away, you might experience difficulties in feather movement in the floor gutter. Also, taking the offal pit further away would increase the height to which the offal slurry pump would have to work and this would increase your power consumption. Similarly you would build inefficiencies in operation if you moved the workers' rest area away. The chapter on *Design of Poultry Slaughterhouse - Layout, Geometry & Construction Methods* covers the theoretical reasons why a poultry slaughterhouse invariably takes this general shape with utilities and services located adjacent to the row of process rooms.

Let us further examine in detail what happens in actual practice with the conventional ventilation system. Table 3 shows this.

Table 3 Ventilation and biosecurity performance using the conventional arrangement of fans as shown in top and middle illustrations in figure 1 or a system of roof extractors or a combination of the two.

Using Old Conventional Style Engineered Ventilation		**Resulting ventilation, biosecurity**
Operating condition of system	**Possible air movement path**	
All sidewall or roof extractor fans work as designed	Fresh air comes in, stale air exits	Good ventilation, biosecurity
Excess air intake in Killing room	Air from killing flows into EV, Chilling	Bad ventilation & biosecurity
Excess air intake in EV room	Air from EV flows into chilling, packing	Bad ventilation & biosecurity
Excess air exhausted from Killing room	Air from hanging flows into killing, EV	Bad ventilation & biosecurity
Excess air exhausted from EV room	Air from killing, Chilling flows into EV	Bad ventilation & biosecurity
Outside air flow changes from basic design assumptions or blows in fits and starts	Unpredictable air flow always resulting in suboptimal ventilation & biosecurity	
This system will work satisfactorily only when all design assumptions are met. Any of the remaining conditions listed here will cause malfunction of engineered air flow and result in incorrect direction in which odour, exhaled carbon dioxide, bioaerosols and contaminants will flow. These conditions could be (a) wrong sequence in which different fans are switched on, (b) failure to switch on any one or more of the fans, (c) mechanical or electrical failure of any fan, (d) replacement of any failed fan with one of another rating, brand or size, (e) differential ageing of electrolytic capacitor in the fan motors, (f) differential in state of lubrication in the bearings, (g) obstruction through differential deposition of dirt on fan blades and cowlings, (h) differential external wind load on any one side of the building, (i) mismatch between opened doors along the sides of the building, (j) external breeze moves in fits and starts and so on.		

Similar to the above situation, if a series of **roof extractors** (or any other forced-in or extract-out arrangement of fans that you can think of) is located on the roof or wall, net negative or net positive pressures may prevail in one or more rooms, given the several permutations and combinations of malfunctions listed in the last row of table 3. When a net positive pressure occurs, aerosols within that room and in adjacent rooms would get pushed out in both directions through openings. Likewise when a net negative pressure occurs, aerosols from adjacent rooms on both sides get drawn in.

In effect, with these methods, you have very little control over which direction aerosols, exhaled carbon dioxide, odour and warm air move. You may be drawing them from dirty areas deep into clean areas and likewise you may be drawing moisture from saturated areas into relatively dry areas. You may likewise be drawing carbon dioxide, odour and warm or cold air in unwanted directions.

You also need to appreciate that a volume of air (confined within a workspace, as in this case) also has mass and therefore exhibits two common properties associated with mass – **momentum** and **inertia**. This accounts for some of the unexpected and uncontrollable behaviour of such a volume of air when you use a conventional engineered ventilation

Inset 4 Momentum and inertia explained in the context of volume of air in the process halls

Supposing you are cycling at a fast pace and stop pedalling. You will still continue moving for some time because you and your bicycle together possess kinetic energy which continues to propel you. This is called the combined **momentum** of you and your bicycle. Similarly a volume of moving air also exhibits momentum. When you stop propelling it in one direction, it continues moving for some time before coming to a halt.

When you start pedalling from standstill, it takes a lot more effort to reach some speed. The tendency for a person at rest to gain speed by spending a lot of energy is called his **inertia**. Once you have gained motion, it takes less energy to continue moving. Similarly a volume of air also exhibits **inertia**. It takes a while for a fan to cause a mass of air to move in one direction.

In each case there is a time lag between the force applied and the motion of a mass of air. And the larger the volume of air the force acts upon, the longer this time lag.

system to control its movement. Regardless of whether your system has a series of cross ventilation fans along the walls or a series of roof extractors, without going deeper into the physics of their behaviour, we can try to explain things with the help of the example in inset 4.

Both momentum and inertia of air confined in the process halls further exacerbate effectiveness of control. When the movement of this mass of air either accelerates or decelerates in any direction, these properties increase the response time of controls. For instance, when drawn by negative pressure, air, together with its contaminants, continues to move some distance even when decelerated. Likewise, when forced out by positive pressure, it takes time to reach the desired velocity. This causes oscillation of air within the halls, particularly on a mildly windy day when outside air moves in fits and starts and the control mechanism responds, always a moment too late.

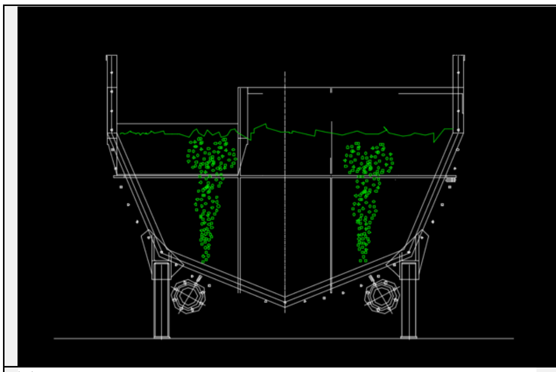
In control theory this kind of control problem is called ‘hunting’. Here the system first overcorrects itself in one direction and then overcorrects itself in the opposite direction. And because of the inherent time lag introduced by momentum and inertia of the mass of air within the system, hunting in this case merely results in oscillation – attended with complete loss of control. Standard methods of controlling hunting are ineffective here.

Instead, if one were to employ a ventilation system involving a **unidirectional** motion control system, one would achieve a much better control and several added benefits in the bargain. We will learn more about such a system in the following section. Meanwhile, summing up, we can conclude that conventional ventilation systems are at best inefficient and at worst cause more problems than they solve, in this context.

1.2 The Recommended System of Ventilation

In these paragraphs we will design an improved ventilation system for the entire plant. As we progress, we will encounter new concepts and learn their fundamentals. For designing such a system, we will need to look at the design of the portioning & packing hall, (i) its dimensions (ii) its occupancy, and (iii) calculate the number of times air contained in it must be replaced with fresh air per hour to meet the needs of workers within. Then we will look at the other plant sections (e.g. ‘A’ through ‘D’ in figure 1) and decide whether there are enough openings between them to allow this air to flow through, starting from the portioning & packing hall and exiting at the arrival area. Of there are not enough openings, we will drill new 200mm diameter openings in the partition walls, close to the ceiling. Finally (iv) we will need to know whether this flowing air can get mixed thoroughly with the ambience in those rooms to facilitate a good exchange in each hall and if not, discover ways to ensure mixing.

Now look at the bottom illustration in figure 1. Here we assume only one air intake – at “E”. This fresh air is taken into the room after passing it through a couple of evaporators or AHUs so as to chill it down (or warm it up) to 12ºC. Also note that in this illustration we have installed two exhausts – one each in the hanging area and in the killing-defeathering hall. In the bottom illustration our system has two intakes (at E in the refrigeration AHU intake over the chiller room and D in the air intake for the screw chiller). The exits for this air taken into our system are at A and B. Despatch doors at F exist as part of the system but they are normally shut except when loading despatch trucks. Even so, they hardly enter the picture, as we will understand shortly.



The atmosphere exerts a pressure of 101.33 kilo Pascals (kPa) or 14.7 pounds per square inch at sea level. This pressure is also called a bar and is equal to the pressure caused by the weight of a column of water of approximately 10.3 m (33.8 ft). Therefore the blower in a screw chiller must generate an air pressure of at least 1.01 bar to overcome this pressure of water in it and cause bubbles of air to appear.

Figure 5 Blowers cause air to bubble through the screw chiller bath.

Outside air in a typical city environment contains 35 million particles per cubic meter of 0.5 micron or larger in diameter, made up of dust, insects, fungal spores, pollen, airborne microbes, aerosol particles, chemicals and their vapour, dust and so on. To rid the intake air of these undesirables, the outside air must be drawn through **HEPA** (high efficiency particulate air) filters. These filters are made with a special kind of paper and are available in different filtration efficiencies. Type 100 class of clean environment is desired in the portioning & packing hall. Choosing this class means that air drawn through this filter will not contain more than 100 such particles per cubic metre. Filters covered with this class of paper are employed at the air intake end of E.

1.3 Advantage - Blowers for Screw Chillers

A kilogram of chicken carcass weighs roughly the same as a litre of water. So the carcass floats on water. But to ensure proper cooling, the carcass must be made to sink in so that more surface area of the carcass makes contact with cold water. To achieve this, screw chillers are designed to bubble large quantities of air through water, so that the **effective** density or specific gravity of water reduces and the carcass sinks.

These air blowers send approximately 160 cubic metres of compressed air at just over 0.1 bar of pressure per hour, to bubble through roughly a metre high column of water. (This column of water within the screw chiller represents around 1/10 of a bar of pressure, because normal atmospheric pressure can support a 10.3 metre water column in the chillers). As you can see in the middle illustration of figure 1, this blower is mounted inside the chiller room, so it generates zero net air pressure in relation to the outside. However, if the blower was mounted outside the chiller room, as shown in the bottom illustration, bubbles of air would emerge from the chiller at a net pressure just in excess of 0.1 bar. This pressure would drive ambient air out of the chiller room. And this tendency of the air inside the chiller room could then be used gainfully by us as part of our engineered ventilation system for no additional running cost whatsoever!

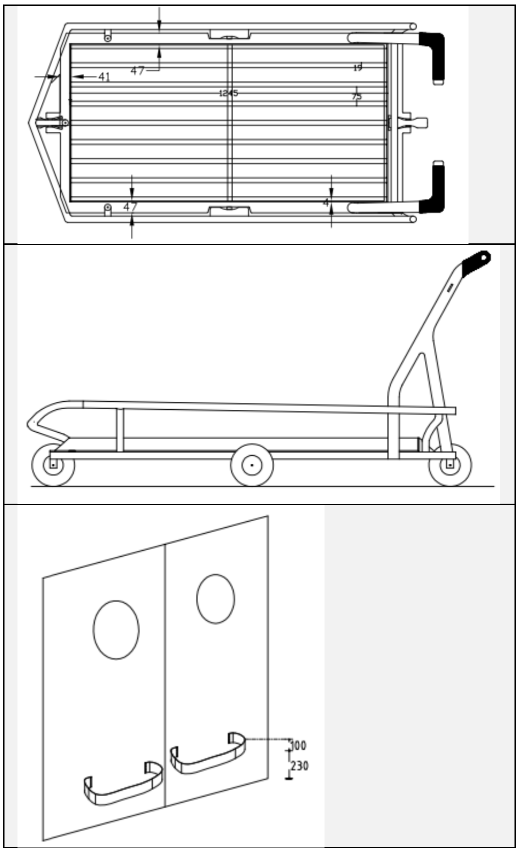


Figure 6 Plan and elevation of the trolley designed by Aptec. The third frame shows a door consisting of a pair of swing panels. Door bumpers are made of hard rubber, such as sections cut out of old rubber tyres. The V shaped trolley anterior engages with these bumpers and forces the door to swing open. After the worker takes the trolley beyond the door, it swings shut automatically.

Of course, air intake of the blower would have to be through HEPA filter to prevent intake of particulates as mentioned in paragraph 1.2. This arrangement has another positive effect – elimination of noise from the chiller room. Air compressors make a deafening noise and working in such conditions can permanently impair workers' hearing. OSHA (Occupational Safety and Health Administration of the United States) makes particular mention of this.

Meanwhile we do have to take the precaution to prevent the blower pushing saturated air from the chiller room to the portioning & packing hall – exactly in the direction we do not want it to go! But this generally ought not to happen because doors leading out of the latter are sealed (the dispatch doors at F are only very infrequently opened) whereas the path towards A and B presents no obstacles. To further ensure proper flow of air, however, doors at "F" will have to be spring loaded so they cannot be left in the open state by mistake.

For this purpose Aptec designed a blast freezing trolley which engages with self-closing doors fitted with springs or hydraulic door closing fixtures at the despatch end of the blast freezing and chill store areas. We have covered this design in detail in the chapter on chilling poultry. Here we show the specific features of the trolley that work with spring-loaded or hydraulic door closing fixtures. The trolley design is equally efficient for use in a blast freezer as it is for general transport of chicken carcasses and portions in standard plastic product crates within the premises. Detailed drawing of the trolley designed by Aptec can be e-mailed free of cost to those who are interested in fabricating it on a commercial scale.

1.4 Wind Factor

Let us return to the top two rows in figure 1 and assume that both sides of the row of process rooms are open to the exterior and fresh air is sucked in from one of the sides, say west side and exhausted on the east side. What happens when the air is blowing from the west? You will get an excess of air into the workspaces. If air is blowing from the east, your fans will not be able to exhaust stale air. So we can say that the conventional system of ventilation has no control over natural direction and speed of wind.

On the other hand, with the air being sucked in at roof-top at points ‘E’ and ‘D’ in the recommended system, direction and speed of natural wind will impose no problems on our system. All we need to do is to control the air intake suction with the help of a damper in the intake circuit.

But air pressure on the arrival end ‘A’ of the process will affect the performance of our system. This is however, easier to control with the help of speed regulators on fans in ‘B’ which normally remain off, but swing into action when air pressure at ‘A’ tends to slow down or reverse the air speed inside the process area.

1.5 Skin Effect

While we are examining the performance of the air intake systems, let us also understand the skin effect. When you exhaust air from the interior of a building, that exhausted air has a tendency to adhere around and close to the external surfaces of the building for some time, till it eventually diffuses or is blown away by natural wind. So in effect if a fresh air intake happens to be working nearby, it will suck in some of that stale air. This can be prevented by exhausting stale air through a chimney, at some distance from the building wall or roof, and/or constructing a deflector wall or plate as shown on the roof of bottom illustration in figure 1.

1.6 Why We Do Not Approve Of Roof Extractors

When deployed on the roof of large covered railway platforms or dry goods warehouses, roof extractors serve some role, if only to prevent pigeons from entering the premises, albeit fairly inefficiently. But as components of a well engineered ventilation system, such as the one we are discussing here, they are worse than useless. Why?

Figure 7 A roof extractor

Roof extraction uses two principles for removal of air from a work space. The first is the **chimney effect** and the second is the **venturi effect.** The chimney effect causes removal of air not just because it is stale, but almost certainly also because it is warm. Because warm air is lighter than cold air, it rises and hugs the ceiling. So if you have perforations in the ceiling, they function like chimneys. They let the stale, warm air rise out of the work space through these perforations. To replace this lost volume of stale and warm air, fresh air comes in through windows and open doors.

If you have sprayed insecticide with the help of a pump type sprayer, you will be familiar with the **venturi effect** although you may not remember the phrase. When you pump the sprayer it creates a rapid jet of air flowing across and above a thin tube that dips into the liquid insecticide in the reservoir. This rapid jet of air creates a low pressure zone or a partial vacuum at the top of the thin tube and this partial vacuum makes the liquid rise in the tube and get atomized as it encounters the jet of air. This is called the venturi effect.

Similarly when you make a hole in the roof to mount a roof extractor, this hole itself is enough to cause both the chimney effect and the venturi effect. The latter occurs when a horizontal gust of air flows above the roof. It sucks out some of the stale and warm air gathered close to the ceiling. Mounting a roof extractor above this hole has no effect on the venturi. It merely adds an unwanted and entirely counter-productive time lag to the venturi effect owing to the inertia of the roof extractor rotor. And because of these reasons, extraction of stale air with the use of roof extractors is entirely dependent on the probability that there is a suitable breeze blowing above your roof - your ventilation system depends on **chance** and not on your **needs**.

Figure 8. A hand pump type insecticide sprayer uses the **venturi effect** to create an aerosol

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2 How Humidity Alters The Properties of Air In Your Work Space

Through the rest of this section we will use terms and phrases from our everyday vocabulary, not as casual words but the way heating-ventilation-air-conditioning (HVAC) professionals do.

Energy Use by Type-of-Use Within U.S. Climate Regions

Climate Region	Space Heating[1]	Water Heating	Air Conditioning	Refrigerators	Other[2]
Very Cold/Cold	53.6%	16.3%	1.4%	3.8%	24.9%
Mixed-Humid	40.7%	17.6%	6.6%	4.9%	30.1%
Mixed-Dry/Hot-Dry	23.9%	22.7%	9.6%	5.8%	37.9%
Hot-Humid	16.6%	17.6%	21.1%	6.5%	38.3%
Marine	37.4%	21.6%	0.7%	6.0%	34.3%

[1] Includes main (primary) and secondary space heating.
[2] "Other" includes end uses not shown separately, e.g. cooking, appliances, clothes washers, dryers, dishwashers, televisions, computers, small electronic devices, pools, hot tubs and lighting. Source: US Energy Information Administration, Residential Energy Consumption Survey [2]showing household consumption by climatic regions

Figure 9 The picture on the left shows **dew** droplets on a glass surface. Note how the tiny droplets coalesce into bigger drops till they become heavy and slide down. Something like this also happens on the surface of the sandwich panel ceiling in the portioning & packing hall of your slaughterhouse. The tabulation on the right compares the energy required to heat dry and humid air. It has been reproduced from a post by EnergyForums.net
This post goes on to say "The reason water cools more slowly is due to..[its]..**thermal mass**. Water has more thermal mass than air. [So].. it can store more heat [than an equivalent mass of air]… Humid air has more water in it than dry air, so which do you think requires more energy to cool?... This same concept applies to heating – it takes more energy to heat humid air than dry air.…[This is clear from this chart in which]… hot and humid areas use 21.1% of their energy budget on air conditioning,.. while hot and dry areas only use 9.6% of their energy budget to air condition.
It's a wonderful thing that water condenses out of the air as it is cooled..[because].. humans are most comfortable in a relative humidity of 40% to 60%...[whereas]… mould needs an environment of greater than 60% relative humidity to live. So it is vitally important to keep building environments at or below 60% relative humidity..[particularly so in food processing environments] to keep mould at bay…. Cooling air squeezes the water out of it and gives us some control over humidity."

Air almost always contains some amount of water in the form of **water vapour**. Water is visible to us, but in the vapour form it is not visible. In coastal areas, the amount of water vapour contained in air is quite high and in deserts it is quite low. Figure 10 shows the relationship between the maximum moisture air can hold at different temperatures. When water vapour content is very high and temperature is also high, we say the **weather** is **sultry**, we sweat a great deal and tire easily when performing heavy work. When the weather gets sultry it may **rain** and eventually cool everything down.

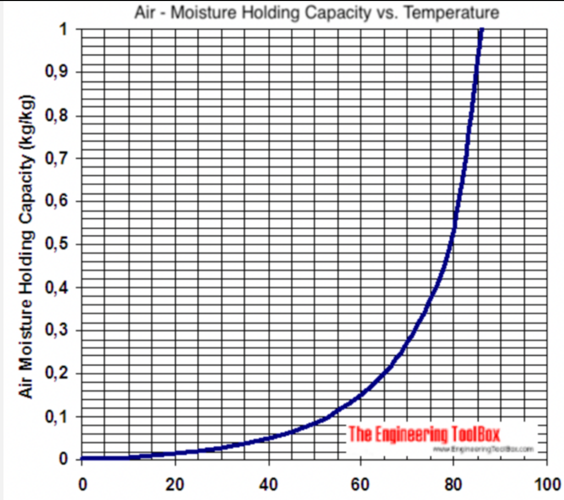
In tropical environments ambient temperature in all processing departments preceding the portioning & packing hall is typically from 25º to 35ºC and saturated with moisture, this, ranging from some 75% to 100% owing to the extensive use of water in poultry processing. But in the portioning & packing hall we need a temperature of 12ºC. So we refrigerate the air to reach this temperature. Additionally, in this hall air needs to be as dry as possible. These requirements pose severe engineering challenges at the design stage and call for strict operating conditions to be followed throughout the life of the plant.

Why does **moisture** collect in the form of **droplets** (similar to what is shown in figure 9) on the sandwich panel ceiling or your glass of chilled beer? And what are **fog** and **dew**? All these have one simple explanation. Water vapour is normally present as one of the several component gases in air in an **invisible form**. Air can hold only a limited amount of water vapour in this form. Just like your glass of cooling drink can dissolve (make invisible) only a limited amount of sugar. If you add more sugar than it can dissolve, the remainder will sit at the bottom and be **visible** to you as crystals of sugar. Similarly air can hold a limited amount of invisible water vapour. When there is an excess of vapour, it separates from air and becomes visible as **fog, dew, rain** or **snow**.

When it deposits on your glass of beer or on grass in a lawn early in the morning, it is called **dew**. When it manifests as **tiny droplets (**which are not heavy enough to come down on their own) it is called **fog.** Fog existing at a reasonable height in the sky is called a **cloud,** and when these fog droplets coalesce to form large drops, we call it **rain**. When such fog particles coalesce as droplets that freeze instantly, we call it **snow**. When fog or cloud coalesces into drops that pass on their way down through a zone of very cold air, they freeze to form **hail**.

Now let us return to the sugar solution. If you want the remaining crystals to dissolve, you heat the contents. As the temperature rises, less and less of crystals remain at the bottom. This means that 'dissolved-sugar-holding-capacity' of water **increases** with rise in temperature. It is also the same with 'vapour-holding-capacity' of air. At 0ºC a cubic metre of air can hold a maximum of just under 5 grams of water vapour as shown in figure 10. We say **air is dry** at that temperature.

At 25ºC it can hold 20 grams of vapour per cubic metre. When it does hold exactly that much at that temperature, we say **air is saturated**. When it holds half as much as it can at that temperature, we say it is **unsaturated** or is **at 50% saturation** level or at **50% relative humidity**. It can then absorb more moisture if water was available. So we say it has the ability to dry something – say a freshly washed T shirt. If it is saturated, it has no ability to dry that T shirt.



Temp (deg. C)	Maximum water content (grams per cubic metre)
-25	0.64
-20	1.05
-15	1.58
-10	2.31
-5	3.37
0	4.89
+5	6.82
+10	9.39
+15	12.8
+20	17.3
+25	20.16
+30	30.4
+35	38
+40	51.1
+45	70

Figure 10 Moisture holding capacity of air at different temperatures at sea level. At sea level air has the highest density. It falls as you increase the elevation. Since poultry processing plants in India are generally rather close to sea level, this point may be ignored here. **Source:** The Engineering Toolbox. To be able to calculate these figures as well as a host of others from a psychometric chart, visit https://socratic.org/earth sciences/questions/.

2.1 Condensation On The Ceiling

Why does condensation in the form of dew form on cold surfaces? To understand this, look again at figure 10. It tells you how many grams of water in the form of water vapour a cubic metre of air at a given temperature can hold. So as air cools, there comes a stage at which the excess quantity of water that it held at a higher temperature must eventually come out.

In the packing hall, such condensation is not only noticed on machines, but also on the false ceiling. It is metallic, being made of a GI or stainless steel sheet laminated to an insulating matrix. Over time this condensate on the false ceiling drips down on work surfaces and on carcasses and causes cross contamination **because that drop is always a rich culture of contaminants and live bacteria**.

Figure 11 Mould growth on a wet wall. Here the infestation is excessive. But on your panel ceilings you may see only faint black rings – they mark the start of the process and at that stage already they are enough to cause product contamination.

Air in the screw chiller room is always either saturated or very close to saturation. And since the screw chiller room is not refrigerated, it is almost always between 25 and 35ºC and holds a substantial weight of water vapour (look it up in figure 10 after measuring the actual temperature of your screw chiller room and you can tell how much moisture air in your screw chiller room holds). Meanwhile air in the portioning & packing hall is at 12ºC. So when saturated air from the screw chiller room migrates into the portioning & packing hall, it cools to some intermediate temperature and expels the excess water vapour in the form of dew onto metallic surfaces.

There are several important reasons to keep the ambience of the portioning & packing hall at low temperature and humidity levels: +12ºC temperature and humidity to as close to completely dry air as possible. Why?

(a) A high humidity level of air increases your refrigeration bill. Humid air takes a lot more energy to cool than dry air does. Read figure 9 and section 2.3 on thermal mass to understand why. To reduce operating cost you need to avoid high humidity levels.

(b) High humidity levels are unhealthy for workers. High humidity levels encourage growth of mould. See figure 9. Humans are comfortable at humidity levels of less than 60% while moulds thrive at humidity levels upwards of 60%.

(c) Processed chicken must leave the slaughterhouse in their packs with as little surface moisture as possible. Presence of surface water facilitates microbial multiplication – the growth activity due to surface moisture being designated **A_w** or **water activity**. With very low surface moisture levels, microbes may stay alive, but they cannot multiply. Therefore not maintaining a dry ambience in the portioning & packing hall results in low shelf life of your product.

Being able to achieve a very low A_w value by air-chilling of poultry is the reason we are able to achieve longer shelf-life for air chilled poultry. By ensuring low humidity levels in the portioning & packing hall, we can come close to such A_w levels even with water chilled carcasses.

(d) Next, saturation increases product contamination. Figure 11 shows a very common observation which is always associated with condensate dripping from the false ceiling. It is a fungal growth on a wet surface. Remember how the dew drop condensed on the false ceiling! That dew drop slowly coalesces into a big drop of water – not yet big enough to fall down, but big enough to absorb contaminating particles, such as aerosols generated in machines like scalder, plucker, vent cutter, bleeding troughs, chain and shackle washer, gizzard processing, badly designed floor gutters and even just swinging movement of carcasses on overhead lines.

(e) Finally, ensuring evacuation of air from the cut-up room and replenishment of the same with fresh outside air ensures evacuation of carbon dioxide. This is essential to ensure a healthy working condition and to raise productivity. We will dwell in detail on this aspect later.

Would we better manage to maintain the temperature of air in the portioning-packing hall at 12°C if it was saturated or if it was dry? If you agree that it would be cheaper if it was dry, then ask yourself if it would serve any useful purpose to allow saturated vapour from the screw chiller room to diffuse into portioning & packing.

Now if you were to take a graph paper and plot the maximum amount of vapour air can hold at different temperatures, using the data given in figure 10 you will notice the non-linear relationship shown by the accompanying graph. We will return to this non-linearity later in our discussion.

2.2 Sensible & Latent Heat

Let us return to your drying T shirt. As it dries, it feels cool to the touch. Wrap a part of your T shirt over your thermometer's bulb and take a reading. This reading is called a **sensible temperature reading** because you can **sense** or feel the temperature that is being measured by simply touching the T shirt.

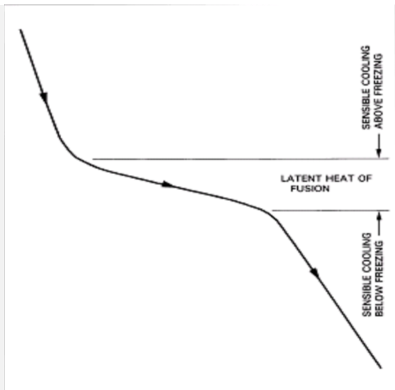


Figure 12 Graph showing three phases of chilling up to and beyond freezing point.[3] The longest time is taken is the actual phase change where with practically no change in sensible temperature, latent heat of fusion of poultry (~ same as water, or 80 calories/gram is abstracted per gram). Whereas, for sensible cooling of water in the liquid phase, only 1 calorie/gram/°C needs to be abstracted.

Now consider water at close to 2°C. As you cool it in a refrigerator, you spend energy. First that water cools from (a sensible heat level of) +2°C to 0°C. You continue to spend energy trying to cool it further. After some time it turns into ice and at that time you again take the (sensible heat) reading and find that it is still at 0°C. What happened? Why did that extra action of the refrigerator compressor not further lower the sensible temperature of that water?

When water is in the liquid form its molecules are in a state of random motion. But when it freezes to form ice, the molecules of water must line up like soldiers on drill – in a lattice format. This process of lining up requires the removal of energy in the form of heat, and it is a very slow process, requiring the refrigerator compressor to work for a long time. Figure 12 is a graph of time and temperature readings during the freezing process. Time is on the horizontal axis – you begin noting the time at the left hand bottom and end at the right hand bottom. And temperature readings are on the vertical axis on the left. You began at +2°C at left hand top and reached, say, -6°C at left hand bottom. As you can see, during the freezing phase, the temperature remained more or less constant for a long time (within the two horizontal lines in the middle of the graph, as the molecules slowly moved into a lattice format to form ice.

In this example the refrigerator compressor removed one calorie of sensible temperature from a gram of water by one degree Centigrade. **To cause freezing, the compressor had to remove 80 calories of heat energy per gram of water while the water remained more or less at the same temperature**. Thereafter the compressor had to remove 0.5 calories of energy per gram of ice to bring about a reduction of sensible temperature by one degree Centigrade, taking the temperature all the way down in this manner to -6ºC.

The figure of 80 calories for freezing a gram of water into ice is called the **latent heat of fusion**. It needs 80 calories of energy input to thaw a gram of ice and extraction of the same number of calories to freeze a gram of water. Remember there is a **latent heat of evaporation** also. To turn water at 100ºC, into steam (at constant temperature), requires you to supply 540 calories per gram. You supply the calories by heating that quantity of water.

2.3 Thermal Mass of Water Vapour

You may have noticed that it takes far longer and a whole lot more energy to heat water than it does to heat air. Likewise it takes a lot longer and more energy to cool water than it does to cool air. The tabulation in figure 9 shows that the US population uses 21.1% of the energy budget on air conditioning in hot and humid areas while in hot and dry areas it uses only 9.6% of the energy budget for the same task. In humid areas air contains more water vapour at a given temperature and volume. So it needs more energy to cool it. Why? Because **water has a very large thermal mass –** much large than air does. The additional water content in the air in hot humid climates takes that much more energy to cool by air conditioning by increasing the total thermal mass of air thus being cooled.

2.4 The Psychrometric Chart

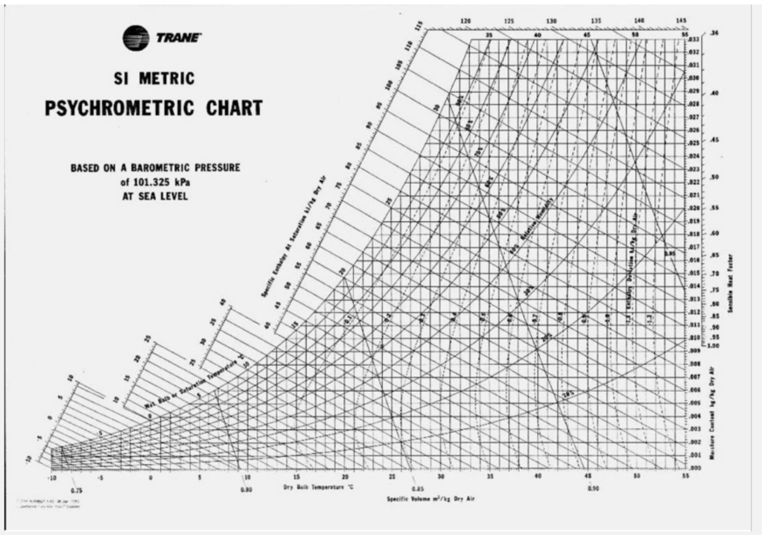


Figure 13 A Psychrometric Chart.

By now we have learnt many concepts relating to air, temperature and humidity and understood several weather concepts in terms of these three variables. In the following pages we will also learn many facts relating to human needs from the surrounding air around him, its temperature, the amount of humidity that air holds and the amount of physical work which that person is engaged in.

HVAC engineers are often found referring a chart which relates all these factors on a single page of curves. This is called the psychrometric chart. We present a copy here but the chart contains so much information that you must always refer to a large print of it, so as to be able to read off values from it. Download such a large and clearly legible copy of it from the internet and examine it if you are keen to learn more on the subject. We will not cover the chart in detail here because we have already covered the principal facts related to it. However, by using this chart you can explore and arrive at answers to many calculations. Here is a link that guides you on usage of a psychrometric chart[4]

2.5 Dry & Wet Bulb Temperatures

Dry-bulb temperature (Tdb, DBT or Td on the psychrometric chart), is the correct air temperature because the thermometer bulb is dry and therefore the reading does not vary with the moisture content of the air. **Wet-bulb temperature reading** (off a thermometer that has its bulb wrapped in cloth moistened with distilled water) corresponds to that air if it were at a relative humidity of 100% or if the water in the cloth did not further cool the bulb by evaporating, but otherwise will be lower than dry bulb temperature due to the cooling effect of evaporation (described as wet-bulb depression).

It follows therefore that the wet and dry bulb temperatures read off in a 100% relative humidity room would be exactly the same because no reduction in reading would occur by cooling effect of moist cloth around the bulb.

Therefore comparing the dry and wet bulb temperature readings allows one to measure the level of relative humidity. A **sling psychrometer** holds a wet-bulb thermometer and a dry-bulb thermometer.

Table 14 Sensible Heat And Latent Heat at Different RH levels

Dry Bulb Temperature (ºC)	**10**	**14**	**18**	**22**	**26**	**30**	**34**
Sensible heat (watts/hr)	135	112	100	95	84	59	29
Latent heat (watts/hr)	22	22	22	24	34	59	90
Total heat (watts/hr)	157	134	122	118	118	118	119

Heat load from a person at room temperatures ranging from 19°C to 34°C is approximately 118 watts. At 12°C, which is the correct operating temperature for section (f), it is approximately 150 watts per person (sedentary) or around 170 watts (active). Sensible heat is that which can be measured with a thermometer. Latent heat is the heat carried away by perspiration and so cannot be directly measured.[5]

In the modern context, we do not use actual mercury-in-glass thermometers and sling psychrometers. We use their more convenient electronic counterparts. However, often HVAC professionals make use of these legacy terms and we have mentioned, described and explained them here to help you follow their talk.

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3 You Need To Engineer The Environment to Suit Human Physiology

We covered the interaction of air, temperature and humidity and understood many concepts in section 2. How do these relate to our preoccupation with proper design and maintenance of a poultry slaughterhouse where humans work? With respect to the environment humans work in, two factors play the most crucial role in ensuring comfort. These are supply of fresh air and maintenance of a suitable temperature. We will now understand the role the composition of air plays in human well-being so that you can derive the maximum efficiency from your workers.

An average adult at rest respires 15-18 times a minute, exchanging 0.5 litre of air in that period, or 300 litres in an hour. When he works hard, he may consume 3 to 6 times as much, or 0.9 CuM to 1.8 CuM of air per hour. But an average person engaged in your portioning & packing hall performs medium to light work, and therefore we assume that his **requirement is 1.2 CuM of fresh air per hour**.

Table 15 given alongside shows the proportion of different gases in fresh air. This is the air we breathe in. The next row shows the proportion of gases in exhaled air. Notice how the concentration of carbon dioxide rises a hundred fold, but the concentration of oxygen does not fall so drastically. A tabulation of the physiological effects of carbon dioxide concentration in ambient air is presented in table 16

Gases in Air	Oxygen	Carbon dioxide	Nitrogen	Argon	Total
Fresh air (%)	21	0.04	78	1	100
Exhaled air (%)	16.5	4	78	1	~100

Table 15 The job of the HVAC engineer is to supply 2.7 CuM of fresh air per person per minute. This is equivalent to 816.5 CuM of oxygen per person per 24 hour day.
The average exhaled air, in contrast to fresh air, has 4% carbon dioxide, which, compared to inhaled air, is 100 times larger. So don't disbelieve the keen gardener's remark that "potted plants grow better when you talk to them." By talking the gardener is giving them plenty of food, which is carbon dioxide.
If a person were to continue breathing his own exhaled air, he would not run short of oxygen – 16.5% oxygen content is quite enough. Instead, he would start experiencing **carbon dioxide toxicity**, for which ASHRAE and many other standards prescribe an upper limit of 5%. Table 17, (which stops at 3% carbon dioxide content), gives more details. The task of HVAC engineers is therefore to supply enough fresh air so that the carbon dioxide toxicity level is not reached[6].

Just how frequently you need to replace the entire air in a room to prevent carbon dioxide toxicity is called the **air exchange rate**. The recommended air exchange rate has been mentioned in table 15. Carbon dioxide toxicity results in drowsiness and loss of attention. So if you do not take care of air quality in the process room, especially in the portioning room, you are not getting the best performance from your workers.

The human body is automatically maintained at an average temperature of 37°C. We gain or lose heat energy to the ambience depending on the difference between our body temperature and ambient temperature – a large difference allows large loss of heat energy and a small difference allows small loss of heat energy. As the ambience rises in temperature, the body needs to lose more heat energy by radiation and convection, but cannot. So the body begins losing latent heat energy through perspiration.

CO_2 level in PPM	Effect on Human Physiology
350 - 450 ppm	Normal outdoor level. Healthy
< 600 ppm	Acceptable levels
600 - 1000 ppm	Complaints of stiffness
1000 - 2500 ppm	General drowsiness
2500 - 5000 ppm	Adverse health effects may be expected
5000 - 10000	Maximum allowed concentration in an 8 hour working period
30000 ppm	Maximum allowed concentration in a 15 minute working period

Table 16 ASHRAE and OSHA standards showing effect of carbon dioxide concentration on humans. 5000 PPM means 0.5%

37°C is a critical temperature, as workers who are required to carry out reasonably active physical work at this temperature, or above, irrespective of acclimatisation to high temperatures, will be at significant risk of increasing their body temperature to the point where they are in danger of heat stroke.

Inset 17 Why 37°C is critical[7]

The quantity of heat a man loses through perspiration increases with increase in ambient temperature – going up from 22 watts to 90 watts as the ambient temperature rises from 10°C to 32°C. This form of losing heat is called latent heat loss. To give you a grasp on the magnitudes we may note that when a gram of water evaporates at 100°C, it takes away 540 calories of energy or 0.63 watt-hours of power (or 0.63 watts of energy applied for the duration of 1 hour). One gram of perspiration from your body, which is at 37°C, takes away approximately 603 calories of energy when it dries.

Throughout the rest of this section we present figures from the physical world and compare them with magnitudes we can comprehend from our everyday experience. This is one useful method of remembering facts related to this subject.

From the human physiology point of view, perspiration equals work done by the body. So the human body may devote more energy to the job at hand if some of it is not spent maintaining optimum body temperature through perspiration. This statement holds true for ambient temperatures significantly above or below normal human body temperature of 37°C.

Office temperature has a significant bearing on both your productivity and your overall comfort. Surprisingly a 2006 study by Helsinki University of Technology and the Lawrence Berkeley National Laboratory showing the optimal temperature of between 21-22 Celsius was shown by later research to be too low and an improved estimate of 25°C was indicated through a study by Cornell University.

Inset 18 Optimal temperature for workers' comfort[8]

You will have noticed that perspiration evaporates more easily when there is an ambient breeze and more so if that ambient breeze is dry. Recall how you perspire heavily on a hot day and a light breeze can then rapidly cool you! In that instant the breeze removed a lot of latent heat from your body and that loss of heat energy caused your body temperature to drop rapidly. Conversely perspiration fails to dry when the air is humid. In coastal areas you perspire more and your clothes get soaking wet. This is because the coastal air already contains close to saturation humidity and consequently cannot readily dry your body by drawing away more moisture[9]. Meanwhile your body works on an automatic mode – releasing more and more perspiration in a futile attempt to cool you down.

Finally, one must also remember that the optimum normal for a human should be determined not only on ambience but also on the clothing and physical activity of the individual.

Regulation 7 of the UK's Workplace (Health, Safety and Welfare) Regulations 1992	</= 16°C sedentary, 13°C for work
CIBSE, UK (air conditioned workplaces)	21- 23°C (winter), 22-24°C (summer)
CIBSE, UK (non-airconditioned workplaces)	Not to exceed 25°C for > 5% of the annual occupied period

Table 19 International Workplace International Ventilation and temperature regulation[10]

In a poultry slaughterhouse the largest number of workers operate in the packing hall because much of the portioning, deboning and packing are off-line activities, less amenable to automation. This is not true in some plants that only produce whole carcasses, but the majority do. Therefore, because many workers operate in this section, it is necessary to change the ambient air several times per hour. Discuss these issues with your HVAC vendor and determine the correct air exchange rate for your specific operational needs.

Finally, because every person is also a source of heat, the ambient temperature in the portioning & packing hall increases beyond the prescribed 12ºC. Also some heat load is contributed by machines such as packing machines, portioning disc cutters, cone deboning machines etc. Were this heat load not removed, the ambient temperature would also rise, contributing to reduction of product shelf life. So be sure to account for these values when you collaborate with your HVAC vendor in designing a good engineered ventilation system for your plant.

Method of heat energy contribution by workers	**Heat energy contribution**	
	As % of total heat load	**Watts/worker**
By conduction & convection	25	29.5
By radiation	43	50.7
By evaporation	30	35.4
By exhaled air	2	2.4
Total	100	118

Figure 20 Heat transfer from the body of a worker to the ambience. Evaporation constitutes latent heat of evaporation of sweat and contributes to the moisture content of the air. We have used the thumb-rule heat load of 118 watts per worker here[11].

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4 Contaminants And Biosecurity

4.1 Chicken Bring Their Own Contaminants

Most of the microbes in a slaughterhouse are brought in by the chicken themselves, on the skin and in the guts. It is the role of good plant layout and machine design to separate this load from the final product. Contaminants from workers and ambient loads are relatively smaller and easier to tackle, although the quantities are by no means small!

Chicken carry a yellow dandruff like powdery substance on their skin and in their feathers- a sort of fine epidermal debris. When they flap their wings, as they do when they are hung in shackles, they release this powder. It tends to fly around and coat all surfaces and is prone to spread all over and into the plant interior and cause serious contamination. This dust is also a health hazard for workers engaged in live bird hanging. Examine the drive motor fan cowling in the killing line and you will notice that it is covered with this substance.

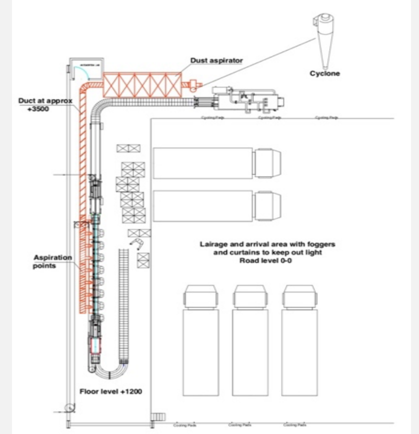


Figure 21 Dust aspiration system (shown in brown) for an 8000 BPH layout. Note also the presence of fan and pad coolers and foggers for stress-free lairaging of live birds.

Particularly in large plants the best way is to suck this yellow dust with the help of an aspiration system installed over the live bird hanging station. Figure 21 shows such an arrangement. The aspirated dust is compacted in a cyclone and disposed off from time to time.

There is now a global concern to identify and curtail contamination introduced by the ventilation system within poultry processing plants. This is because of the particulate load in ambient air, specially for plants located in industrial estates which have heavy pollution. Several means to suppress these contaminants are increasingly being used. They include filtration, chemical fogging and UV radiation. This reference also has a caveat for plants in green fields – in which context the authors add: "Most severe contamination is from vegetables and fruits growing on or in soils. Chicken likewise bring in soil related contaminants. Besides feather and guts carry heavy loads of contaminants."

4.2 Aerosols & Bioaerosols

In the dirty sections, the bleeding trough is the biggest source of smell and aerosols in a poultry processing establishment. During bleeding, birds often shudder and flap and this releases blood droplets as aerosols. One effective method of removing this odour and aerosol load is to place an aspiration hood over the trough and aspirate the air, to be vented at some height and distance from the premises. But our engineered air movement method solves this problem nearly as well, as you will see.

Aerosols contain nutrients – for growth and sustenance of microbes including bacteria and fungi. Aerosols also contain proteins, which come from the surface of poultry or from their interiors. When aerosols get absorbed in these droplets, microbial colonies form and thrive in them. Eventually, when they fall on to the product, there is absolutely nothing you can do. Your product has already reached the final process step – you do not wash it before it goes to the consumer.

At this point you may ask, "Bacteria, fungal spores chicken dust and viruses are too tiny for a face mask to stop – weaving gaps in the fabric of a mask are too large to accomplish this. So why were all experts unanimous about the use of face masks in restricting the spread of Covid-19?"

Because these pathogens do not float around on their own in air. They are so tiny that physical properties of water in which they exist prevent their liberation as airborne, free-gliding Olympian sky-divers. They are present and viable only in coughed or sneezed-out water droplets, known to us as aerosols, or in this context, as bioaerosols generated within the dirty areas of the plant. And bioaerosols are large enough to contain thousands of such microorganisms under viable conditions. Although they are so tiny, they may be stopped by simple mechanical means like face-masks, or in our case, by ensuring proper directional flow of air. Watch Richard Feynman to grasp the concept[12].

After becoming airborne, a microorganism may have a very short life, its stability being influenced by RH, temperature, oxygen levels, solar and ultraviolet (UV) radiation, and chemical factors.

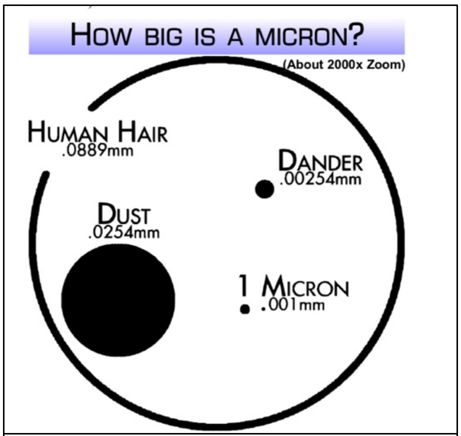


Figure 22 Size comparison. Some bacteria are as small as a tenth of a nanometre or a ten thousandth of a micron

We have assumed that the reader can grasp the scale at which microbes exist. Here is a graphic that puts it in perspective. Just how big is a micron, for instance? It is a thousandths of a millimetre and consequently a millionth of a metre. All bacteria known to date belong to the phylogenetic groups proteobacteria, chlamydia, gram-positive bacteria, spirochetes, and verrucomicrobia. The spirochetes contain the tiniest bacteria with some species having cell diameters of about 0.1 to 0.15 nanometre. A nanometre is a thousandth of a micron.

Regarding contaminants from workers it has been found by Schmitt[13] that a slowly gesturing person generates approximately 500 000 particles/min and a rapidly gesturing person generates 5,000,000 particles/min. What could these particles be? These are fibres, dust and starch particles from his apparel and dandruff or sloughed-off particles of dead skin, dust from his person and aerosols created by coughing, sneezing or speaking.

Now you know how trained dogs can track a person – they simply sniff out dead skin particles which a fleeing person drops as he attempts an escape.

Since humans have this tendency to add contamination to their environment, there is nothing you can do about it, except to follow the rules of personal hygiene and implement social hygiene in your plant.

5 Implementing The Recommended Ventilation System

The typical poultry processing plant can be divided into the dirty area comprising arrival and lairage, hanging, stunning, slaughter, bleeding, scalding and defeathering, evisceration, chilling, portioning, deboning and packing; and finally storage and dispatch. Of these, arrival to evisceration are considered dirty areas, typically held at ambient temperature, while portioning onwards are designated clean areas and held at around 12°C. The last area before dispatch is storage and is actually not a work area, as it remains for the most part unoccupied by workers.

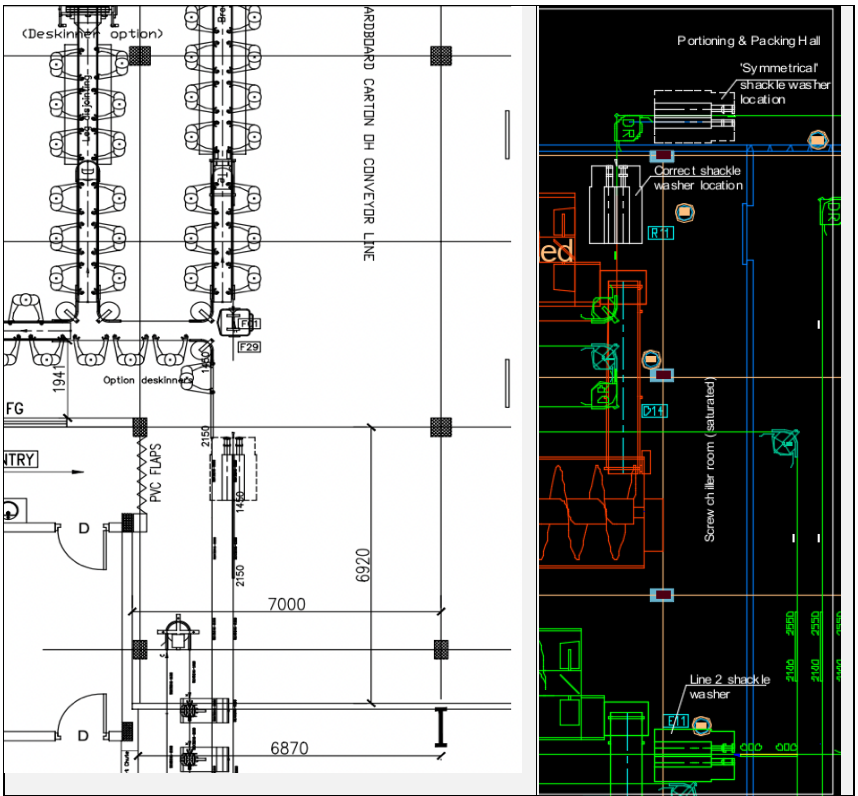


Figure 23 Two real life instances where incorrect placement of shackle washer adds to the moisture levels in the portioning & packing hall. The drawing on the left shows a shackle washer placed in the portioning & packing hall, unilaterally by the plant engineers, without consulting this author. On the right you see three shackle washers. The one at the bottom is for weigh line A. At the top are two alternative positions for the second shackle washer for weigh line B. To prevent contribution of moisture in the portioning & packing-hall on the right, the shackle washer was placed inside the screw-chiller room. A draftsman with 20 years of design experience with a world leader in the field "improved" the layout by moving it out of the chiller room, ostensibly to "maintain symmetry"! This kind of bad engineering is not limited to just one poultry industry world leader: figure 24 shows how a similar action was taken by the other industry leader with respect to the screw chiller and dewatering drum, both of which add humidity to the portioning & packing hall.

Since we aim to keep the portioning & packing hall as dry as possible, we need to ensure that the wrong kinds of machines, such as those that use large quantities of water are not placed there.

Figures 23 and 24 shows two layout drawings inadvertently adding moisture to the packing hall. The one on the left in figure 23 shows a wrong position of the chain & shackle washer owing to a bad layout initiative taken by plant engineers in the packing hall. The one on the right is a deliberate "correction" of proper placement of this machine back into the packing hall by an ignorant draftsman. In figure 24 we see a repetition of the same error, this time placing the screw chiller and dewatering drum on the portioning & packing hall. **A chain and shackle washer is in effect a very efficient humidifier**. No other machine in use in a poultry processing plant comes close to it. Both screw chiller and dewatering drum rank second in this ability. For draftsmen to ignore this fact when making layout drawings is regrettable.

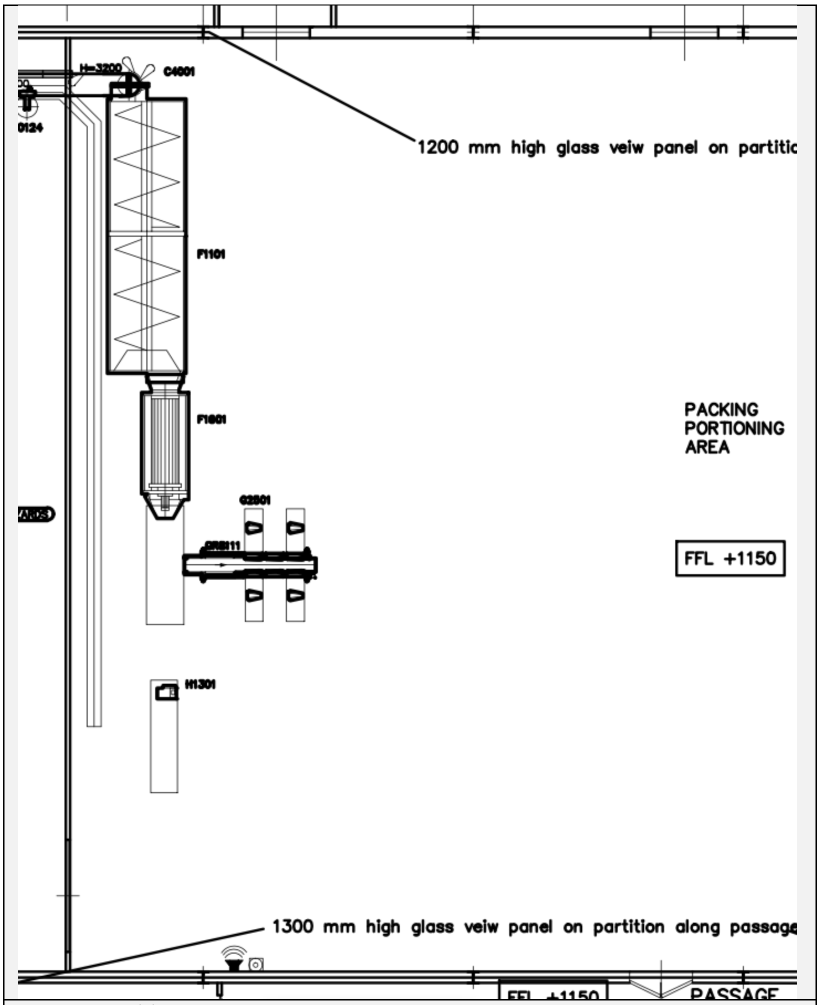


Figure 24 The tendency to share the screw chiller (and the dewatering machine) with the packing area is common to the draftsmen in both the leading poultry slaughterhouse equipment manufacturers and designers. Shown here is how Aptec's original design was 'improved' by this Dutch vendor for a plant in Sri Lanka. The draftsmen also reduced the ceiling height of the packing room thereby adding to the problem. A 6 metre clear height had been specified in Aptec's original design. A few months following commissioning of this plant, the owner sought this author's advice for solving condensation problem in the packing hall. Aptec replied with instructions to do away with the "improvements".

The following nine steps summarise the process of engineering the desired ventilation scheme

First. it is assumed that doors leading to the portioning & packing hall, either directly or indirectly, are provided with self-closing doors.

Second. Implement positive air movement from the packing hall to the screw chiller room, onwards to the evisceration room to killing and defeathering and then on to live bird hanging, in that order. Such a regime of forced air movement will dictate the direction of movement of aerosols and ensure that they do not enter the portioning & packing hall. To move plant air in this way, an air-pressure control system is required to maintain a positive air pressure in areas where the final product is exposed so as to minimize the contamination rate. An over-pressure of 45 Pascals (Pa) at the cleanest area, 30 Pa at a less clean zone, 15 Pa in the change area and 5 to15 Pa in the facility room give a good pressure gradient[14].

Third. remember that air vents, where provided, are placed sufficiently above the roof surface. Exhausted air tends to hug the nearest surface and it has been shown that foul air from the toilet block exhausted by the help of ventilation fans can get sucked back through the air intake HEPA filters provided for AHU intake and screw chiller intake[15].

Fourth. Do factor in an asymmetrical wind load on the building walls and roof. Wind blows in specific directions in monsoon lands – it is not random. It exhibits seasonality.

Fifth. Ensure that there is a wall separating the screw chiller room from the packing room. Some layouts, made even by industry leaders, ignore this (figure 24 is an example). In other words, separate the screw chiller and dewatering or dripping areas from the portioning & packing hall.

Sixth. Design refrigerated workspaces with high ceilings. This increases the volume of air in these spaces and consequently makes it more difficult for the air to get saturated. Aptec recommends 6 metre clear height. It is unfortunate that many plant owners allow themselves to get persuaded about the heat loss being greater with a high ceiling. The chapter on *Layout, Geometry & Construction Methods* rubbishes this plea.

Seventh. Design air exchange system keeping in mind saturation and recommended carbon dioxide limits. A thoughtful and purpose-designed air movement regime will ensure evacuation of carbon dioxide from the portioning & packing hall which has a large number of workers. Use internationally accepted norms to achieve this. Should your HVAC engineer seek help on this, recommend to him the following, which can be downloaded from the Internet:

1. ANSI/ASHRAE Addenda a, b, c, d, and g to ANSI/ASHRAE Standard 62.1-2004 Ventilation for Acceptable Indoor Air Quality

2. Addendum n to ANSI/ASHRAE Standard 62.1-2004 Ventilation for Acceptable Indoor Air Quality

3. UK Health and Safety Executive Report

Eighth. Ducts and openings in partition walls for overhead tracks and similar openings for floor gutters and doors also allow movement of air in the plant. Be sure you take their role into account when you design the counter-current airflow. Maintain uniform temperature within the workspace, avoiding drafts.

Ninth. Ensure that placement of machines does not inadvertently add to increase of humidity and heat load in the portioning & packing hall.

6 Frequently Asked Questions

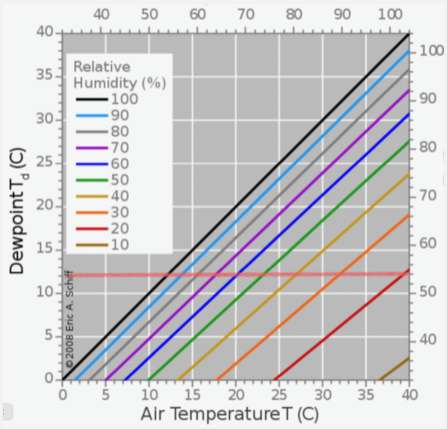
Table 25 **FAQ**

	Symptom	Possible Reason and Remedy
1	When investing for the first time in India we chose air chilling over water chilling - as a quality innovation in this market. But to our surprise there were no takers for our product! So we modified the air chill chamber by significantly increasing delivery of water through the fogging system. Now our weighing/grading system does not work and our chilling system (which was designed and supplied by Johnson Controls, a world leader in this field) seems insufficient. What went wrong?	Market response to your actions relate to two events – when you were trying to sell air-chilled poultry and when you were trying to push the solution to the market by modifying the fogging system. We will address both. In the first instance the Indian market rejected air-chilled carcasses because it is very conservative and is familiar with and trusts water chilled carcasses. In the second case by adding lots of water to the carcasses in the air-chill tunnel and failing to remove the excess by allowing it to drip, your product was shipped with excess surface moisture. In this case you did precisely what this chapter argues against, besides earning the dubious distinction of printing inflated carcass weight on the pack. In India complete elimination of water chilling (which permits chlorination to suppress salmonella and other pathogens) is very undesirable because of the structure of farming practices. It will take several years for this situation to improve. That is why we have always recommend water chilling for at least 10 minutes followed by air chilling if you are fundamentally in favour of air chilled poultry for reasons based on your international experience. The Indian market is very conservative. Remember even today the Indian consumer prefers deskinned carcasses because he is familiar with the age-old wet market practice of deskinning as a method of defeathering. So he thinks skin-off carcass is a quality product and deskinning is a quality attribute. Indian consumers dislike air-chilled products because the dry surface suggests that the product is very old – it has probably been in storage for a long time. When investing in a difficult market like India your strategy must be based not only on your international experience but also on specific features of the Indian market. When in doubt, you should conduct a market survey to give your plans a reasonable chance of success.

		Your decision to modify the air chill chamber into a water-chilling facility causes two problems – the carcasses emerge dripping heavily. Therefore the weighing system does not work properly because post-weighing dripping reduces the product weight and you may then be accused of cheating. In addition introducing large amount of water as spray in the air-chill chamber raises the refrigeration load as the system now has to additionally freeze large quantities of water into ice. The solution for you is to install a stage of water chilling and either eliminate air chilling altogether or reduce the duration of air chilling so that the product does not look too dry. And you must absolutely discontinue the practice of spraying excess quantity of water in the fogging system.
2	Our killing-defeathering hall carries a strong and unbearable odour. The odour is strongest over the bleeding trough. How can we solve this problem?	The worst stench in a poultry slaughterhouse arises from the bleeding trough. The only way to improve this situation is to implement the engineered ventilation system recommended in this chapter. This system was first implemented in India, following persistent and repeated advice from the author, by Kwality Animal Feeds at Belgaum. You can request them for a visit and if they grant your wish you can check this out for yourself.
3	Our layout simply does not have any space for a shackle washer in the screw chiller room. We are therefore forced to install it in the packing hall. Since this could add a heavy and undesirable load of moisture to the ambient air, what do you suggest?	Consider building a closed chamber in which you can mount the shackle washer and at the opening and exit install air curtains to prevent escape of saturated air from the chamber into the portioning & packing hall.
4	Our refrigeration system vendor refuses to retrofit a fresh air intake system in our portioning & packing hall because he insists that it will involve addition of new compressors and consequently an increase in power consumption	Naturally, new compressors will be needed to implement the system suggested here, assuming that the existing system supplied by your vendor has no spare capacity, and you will need to spend money for it. If you do not accept this, nothing will be achieved by blaming your vendor and expecting hm to bear the cost of the upgrade. And your power bill will not increase – the vendor is only saying this to avoid having to give you a free upgrade. If your system is inadequate, you cannot escape investing to make it good. Pressuring the refrigeration vendor to do it free of cost is not going to yield any result. There is no free lunch in life.

7 Glossary of Terms

Table 26 Glossary of Terms	
Aerosols, bioaerosols	Aerosol is a fog of particles. The familiar picture that it conjures is a person sneezing. A cough produces approximately 3000 droplets, whereas a sneeze releases an estimated 40,000 droplets. When they are small enough to remain afloat in air, they form aerosols. Such droplets may also be referred to as bioaerosols because they contain plenty of microorganisms. On the other hand, the fog produced by the use of a spray gun (figure 8) should be correctly called aerosol.
AHU	Air handling unit. This is the box-like blower arrangement located inside the building in a split air-conditioning system or a refrigeration system. Within it is a labyrinth of pipes carrying cold refrigerant liquid and in front of it or behind it is one or more high powered fans drawing ambient air past the labyrinth. In this process the ambient air cools down. The AHU is also called an evaporator because within the pipes the refrigerant turns into the vapour phase, having picked up heat from the stream of air drawn through the labyrinth.
Calorie	A calorie is a measure of energy. There are two calories, the one spelt with a small c or the **gram calorie** and the one spelt with a capital C or the **kilogram calorie** or **food calorie** or **nutritional calorie**– the latter being equal to 1000 small or gram calories. The calorie is generally used to measure energy in the setting of physical and chemical sciences whereas the Calorie is generally used to measure the energy content of foods and beverages. To give you a perspective of the latter an average person needs around 2500 Calories from his food and beverage intake everyday. The **small calorie** or **gram calorie** is defined as the amount of heat energy needed to cause the increase in temperature of one gram of water by one degree centigrade. For the purpose of measuring

	heat energy the calorie has fallen into disuse and instead the **Joule** is now frequently used. **One calorie equals 4.184 Joules**
Carbon dioxide toxicity	Refer table 15
Chimney effect	The chimney was invented by primitive man to cause a unidirectional movement of air in his dwelling. He wanted an inward horizontal movement of fresh air into his dwelling through windows and outward movement vertically through a tunnel perforating the roof. Because warm air is lighter than cold air, it rises and exits the dwelling through the vertical tunnel. This tunnel is a chimney. There are two ways to increase the flow of fresh air through the dwelling – (a) make the chimney taller or (b) raise the temperature of stale air by building a fire at the base of the chimney. And there is one way to control the flow rate – by the use of a damper inside the chimney.
Dew point & saturation, fog, mist and rain.	When clouds cool rapidly, they **saturate**, and then **rain**. When air cools slowly, it **saturates** and then **mist** and **fog** form. Then, excess moisture condenses as **dew.** 
Dry and wet bulb thermometer	**Dry-bulb temp** (Tdb, DBT or TD on the psychrometric chart) is the correct air temperature. In a **Wet-bulb thermometer** the bulb is wrapped by a wet cloth so it cools through evaporation. Both temperatures are identical at **relative humidity** of 100% (**saturation**).
HEPA filter.	**HEPA** refers to high efficiency particulate air filter. It is made of paper, fitted into the filter system and needs periodic replacement as it gets choked with particulates.
Humidity	There are three main measurements of humidity: relative, absolute and specific. **Absolute humidity** (units are grams of water vapor per cubic meter volume of air) is a measure of the actual amount of water vapor in the air, regardless of the air's temperature. **Relative humidity**, expressed as a percent, is a measure of the amount of water vapor that air is holding compared to the amount it can hold at a specific temperature. **Specific humidity** refers to the weight of water vapor contained in a unit weight (amount) of air (expressed as grams of water vapor per kilogram of air).
Hurdle method	Given the enormous range of harmful bacteria in the environment and on our foods, each of which uses one or more methods to defeat our effort to exterminate or overcome them, scientists have devised the **hurdle method** to control or reduce their harmful effects. In the hurdle method a bit of every means is deployed in industrial processes. Water activity is one such hurdle. Collectively other hurdles, such as pH, temperature, or modified atmosphere packaging, will limit microbial growth even at water activities higher than 0.91.
HVAC	Heating-ventilation-air-conditioning (HVAC).
Hygrometer	A device to measure relative humidity is called a hygrometer. The simplest hygrometer - a sling psychrometer - consists of two thermometers mounted together with a handle attached on a chain. One thermometer is ordinary. The other has a cloth wick over its bulb and is called a wet-bulb thermometer.
Inertia	Refer inset 4
Kinetic and potential energy	These concepts are similar in a way to sensible and latent heat. When an object exhibits motion, it displays kinetic energy, but when an object is capable of breaking out in a show of kinetic energy but does not, it is said to be possessing potential energy. Consider a large rock which you hold at shoulder height. It is capable of kinetic energy but does not display it as long as you hold it at that height. It is therefore possessed of potential energy which it exhibits as kinetic energy as soon as you let go.
Momentum	Refer inset 4
Mould	Also spelled mold, consists of the vegetative structures of various fungi, often of the genera Aspergillus, Penicillium, and Rhizopus. They are associated with food spoilage and plant diseases. Remember, penicillium mould had infected the petri dish culture of bacteria in the lab of Alexander Fleming which led him to the discovery and isolation of penicillin, the first antibiotic. Moulds compete with bacteria for dominance and the chemicals they use in this warfare are most of the antibiotics we isolate and use today.

OSHA	OSHA stands for the Occupational Safety and Health Administration of the United States. It is a section under the Department of Labour and has a body of regulations aimed at the safety and welfare of labour engaged in industries including poultry slaughter. In the absence of an India alternative Aptec regularly promotes the OSHA regulations.
Psychrometric chart.	The relationship between air temperature, air pressure and saturation humidity is best expressed in a **psychrometric** chart. You may download it from the internet.
Relative humidity (RH),	The amount of moisture air can hold at different temperatures varies – very little at freezing temperature and maximum at high temperatures. If the moisture content of air is a fraction of what it can hold, that fraction is the **relative humidity** of that air. Therefore comparing the dry and wet bulb temperature readings allows one to measure the level of **relative humidity.**
Roof extractor	Are entirely useless. Refer section 1.6.
Sensible heat and latent heat	**Sensible heat** is what we feel. **Latent heat** is what is there in, say, water vapour, in the form of energy, but we cannot feel it. It can be only understood in terms of the heat energy (as solar radiation) that went into converting a quality of ocean water and sent it up to form a cloud and rain at some later period.
Sling psychrometer	A **sling psychrometer** holds both wet and dry-bulb thermometers and can be used to express the physical and thermal properties of moist air on a psychrometric chart.
Specific gravity	Refer section 1.3. For a body to float in a liquid, it should displace a quantity of that liquid which weighs more than the body itself does. Should it displace less, it will sink. This is the physical principle discovered by Archimedes. When we speak of the weight of liquid in a given volume, we call that value the specific gravity of that liquid. When we refer to the weight of a solid in a given volume, we call that value its density. The specific gravity of water is 1.0 and the density of a chicken is also very close to 1.0. So a chicken does not sink – it floats.
Thermal mass	Refer figure 9.
Venturi effect	This has been explained in section 1.6. The scientific principle behind the venturi effect is Bernoulli's principle which is the basis of aircraft design and human flight.
Water activity A_w	Water activity is a measurement of the availability of water for biological reactions and is a variable which can be measured on a scale from 0 to 1.0. When water activity is close to zero, the ability of micro-organisms to grow and multiply decreases. Water on the surface of food may be present as chemically bound to the food or unbound - as a free substance. The more unbound water we have, the more likelihood we have of microbial spoilage. Unbound water exhibits a physical property called its vapour pressure, which the Water Activity (A_w) Meter measures and displays in the form of its A_w on a scale from 0 to 1.0. Scientists know, for instance that most bacteria do not grow at a water activity range below 0.91, and most moulds cease to grow at water activities below 0.70.
Watt	The watt is a measure of the rate of energy transfer over a unit of time, with one watt being equal to one joule (J) per second: W = J/s. When a watt is applied for the duration of an hour, it is called a watt-hour. When a thousand watts are applied for an hour, we say we have used a kilowatt-hour of energy. So, your 1 kilowatt immersion heater built into the electrical kettle will have consumed a kilowatt hour or one unit of electrical energy heating water for that period for your coffee.

[1] Ventilation of Poultry Slaughtering and Processing Plants by Heber, Zimmerman and Linton, Cooperative Extension work in Agriculture and Home Economics, state of Indiana, Purdue University, and U.S. Department of Agriculture Cooperating, in furtherance of the acts of May 8 and June 30, 1914. This is One of the most useful and insightful postings on the internet on this subject. Broadly the authors have cautioned against the use of conventional methods for maintaining a proper ventilation system in a poultry slaughterhouse. Aptec has made modifications to the original idea posted by this reference.

[2] EnergyForums.net https://energyforums.net/hvac/how-humidity-affects-heating-and-cooling/.

[3] Blast Freezing Applications in Conventional Rooms, Naci Şahin, Mechanical Engineer General Manager, Friterm, Termik Ciazhiar Sanayi ve Ticaret A.S.

[4] Link to a YouTube tutorial on the use of a psychrometric chart

[5] Modified from The Engineering Toolbox - Human Need of Air, www.EngineeringToolbox.com

[6] Ibid Human Need of Air.

[7] Public Service Association of New South Wales policy on heat and work, indoors and outdoors.

[8] The Optimal Office Temperature: A Definitive Conclusion to the Age-Old Debate, Chelsea Mize, May 11, 2016. Blog on www.pgi.com

[9] If the explanations does not convince you, perform this thought experiment:
Ask a friend to stand in a street of Mumbai at the same time that you stand 100 km east somewhere on the plains in Maharashtra. Do this on a cloudless summer day. Now take the temperature of the air. Mumbai will report 36^{o}C and the inland location will report 41^{o}C. The same sun is heating air in both locations Why this difference? The answer is that the sun has to heat a whole lot of moisture coming from the sea in Mumbai

while the inland location it is heating relatively dry air. Remember water or water vapour has a much higher thermal mass that dry air. What goes for heating air also goes for cooling air.

[10] International Workplace International Ventilation and temperature regulation, UK - https://www.internationalworkplace.com

[11] Ibid. Human Need of Air

[12] Imagine yourself as a bacterium trying to swim in a drop of water. At that scale your arms and legs could not propel you through water because water at that scale would behave like honey and you could not swing your limbs. Microbes have evolved different methods of locomotion to overcome this problem. Watch Richard Feynman's lecture "There's Plenty of Room at the Bottom" in https://www.youtube.com/watch?v=4eRCygdW--c, titled. Feynman, who received the Nobel prize for quantum electrodynamics, set the scene for development of nanotechnology with these concepts. It will also help you understand the nature of interaction between microbes and their environment

[13] Schmitt, 2000, as quoted in Clean Air Solutions in Food Processing.

[14] Ibid. Clean Air Solutions in Food Processing

[15] Ibid, Clean Air Solutions in Food Processing. At a typical food-processing plant, undesirable air is exhausted to the outdoors. Unfortunately, part of the discharged air often stays in the air-foil of the building, setting up a scenario in which exhausted contamination can partly re-enter the plant at another location. Roof exhaust stacks from heavily contaminated areas that do not have HEPA filters need to be high enough so that none of the exhausted air can be re-entrained. Exhaust stacks should be 1.3 to 2.0 times the height of the building, including any parapet or other roof equipment. Stronger winds increase the need for taller exhaust stacks.