



Forced Draft Air Coolers or Bunker Coils for Cold Storages

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Introduction

Government initiatives in encouraging investment for preservation of fruit and vegetables as a part of cold chain development and the substantial subsidies provided have resulted in a sudden spurt in cold storage construction. In order to improve the traditional methods of designing and executing cold storage projects, and also for bringing about uniformity in designs, standards are being formulated, and this has resulted in many controversies and debates between what has been followed traditionally and what is suggested in the new guidelines.

Potato cold storages working with ammonia refrigerant traditionally use ceiling coils popularly known as bunker coils as evaporators for cooling the produce, and the use of bunker coils is claimed to consume less energy without sacrificing the quality of the stored produce, compared to forced draft air

coolers currently being recommended.

The article in the *Cold Chain* supplement of *ISHRAE Journal* reprinted in the July - September 2011 issue on Forced Draft Air Coolers has further prompted me to write this article, since the air cooler is the most important component of the refrigeration system and is currently a hot topic for discussion.

The above article explains that the selection of proper Temperature Difference (TD) is important and many manufacturers interpret it differently. In the pre-concluding paragraph it states, "It is much easier to compare the essentials of unit coolers such as *surface area*, air volume and fin spacing".

In my opinion, the term surface area also needs to be clearly understood and it is not necessary that a manufacturer offering a higher surface area may have a more efficient cooler.

The question then is, what is meant

by surface area? Is it the secondary area, meaning fin surface area? Is it the effective area involved in heat transfer? Is it the face area of the coil? Or is it the primary surface area of the tube through which the refrigerant flows?

I, therefore, thought it appropriate to revisit the basics, particularly with reference to surface area and compare the designs, merits and demerits of forced draft air coolers *vis-a-vis* ceiling bunker coils.

About the Author

Ramesh Paranjpey is a mechanical engineer with an M.Tech in refrigeration from IIT Bombay with over 35 years experience. He has worked in very senior positions starting with Kirloskar Pneumatic in Pune, Carrier Transicold in Bangalore and Singapore as well as Voltas-Air International Pune. Presently, he works for himself as a technical advisor and consultant. He is an ASHRAE Fellow, past president ASHRAE W.I. chapter and past president ISHRAE Pune chapter. He can be contacted at ramesh.paranjpey@gmail.com



Figure 1: Air coolers (fan coil evaporators)

Air coolers or unit coolers consist of compact and highly efficient coils enclosed in housings with fans that draw the room air or warm return air through the coil at high velocities. In the process, the air is cooled and the low temperature refrigerant inside the coil evaporates.

Many cold storages are equipped with pipe coils, mostly plain or in some cases finned, which are traditionally preferred by warehouse men. The cooling process depends on the network of piping through which liquid ammonia circulates, served with a flooded accumulator and a hand expansion valve at the inlet. The pipe normally used is 32 mm NB, black heavy plain ended steel pipe. Every ton of refrigeration requires approximately 300 ft of pipe, or in layman's language each bag of 50 kg needs 4.5 inch long 32 NB pipe. For example, the standard practice is to use, for a 1500 ton potato cold storage room, 9000 rft plain pipe with primary surface area of 2943 sq ft and 20 ceiling fans of 75W each with 3 blades, to provide gentle air circulation. See Photo on first page of this article.

In case air coolers are used, normally 4 air coolers each of 9-10 TR capacity are used for each cold room storing 1250-1500 ton potatoes; each cooler has an approximate surface area of 2270 sq ft comprising of 191.5 sq ft bare tube area and 2078.5 sq ft fin



Figure 2: Ceiling suspended coils (bunker coils)

area. One can observe that the fin area is nearly 91% of the total area. For 4 coolers, the primary area would be 766 sq ft and the secondary area would be 8314 sq ft.

We shall now analyze the effect of different areas on the efficiency of the cooler/ evaporator.

Evaporator Performance

The standard equation for heat flow is

$$Q = (A_o \times U \times \Delta T) \dots\dots\dots \text{Equation 1}$$

Where 'Q' = Total heat to be transferred per unit time (kW).

'U' is the overall heat transfer coefficient and is a characteristic of the coil based on its design, and the application engineer has a limited role in its selection.

An application engineer, while selecting the air coolers, uses different combinations of ΔT and A_o to arrive at a cost effective and appropriate solution of air cooler to suit the particular commodity storage requirements.

In the evaporator, the heat flows in series through three thermal resistances.

1. From the room air to the outside surface of the evaporator, or fins in case of finned coolers – R_f
2. From the outside surface to the inside surface of the evaporator – R_m
3. From the inside surface of the evaporator to the refrigerant – R_r

The heat flow can be compared to an electrical current passing through a series of resistances as shown in Figure 3.

R_f is the resistance to heat flow on the air side and is dependent on air velocity, fin configuration, type of fins and fin spacing.

η is fin efficiency; if the entire fin were at the same temperature as the tube, fin effectiveness would be 100%. However, it is not the case and the temperature increases progressively as we move away from the tube. All the air side area is therefore not 100% effective or efficient. The effectiveness of the fin is given by η and the value varies from 0.3 to 0.7 for commercial coils depending upon fin material, thickness and type.

R_m is the resistance to heat flow due to metal conductivity and thickness of the tube = x/k .

R_r is the resistance to heat flow on the refrigerant side and depends upon the refrigerant used, its velocity and tube diameter.

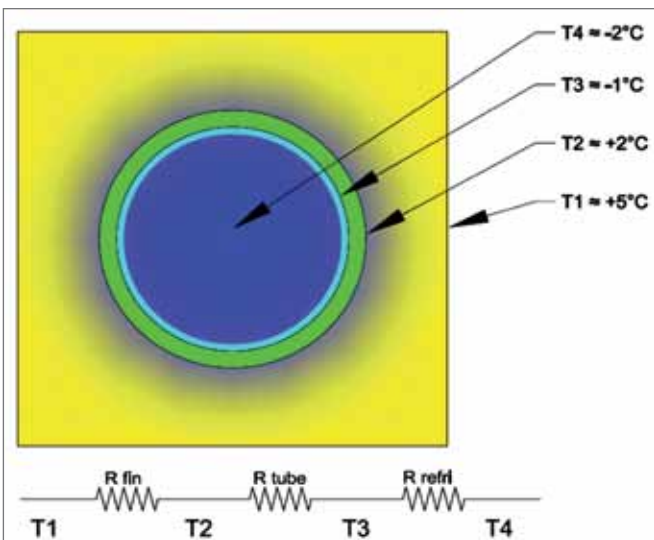


Figure 3: Cross section of a typical fin

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The overall heat transfer coefficient **U** is sum of the reciprocal of all resistances and depends upon (a) the heat exchanger configuration, (b) the ratio of primary to secondary surface area, (c) air velocity, temperature and density, (d) refrigerant properties and its velocity, (e) tube and fin material and (f) fouling factors on either side.

$$U = \frac{1}{(R_f + R_m + R_r)}$$

The heat flow can also be described as under:

1. $Q = A_o \times U \times (T_1 - T_4)$
2. $Q = h_f \times \eta \times A_o \times (T_1 - T_2)$
3. $Q = \frac{k}{x} \times A_m \times (T_2 - T_3)$
4. $Q = h_r \times A_i \times (T_3 - T_4)$

Where,

$$h_f \text{ is the heat transfer coefficient on the air side} = \frac{1}{R_f} \text{ (W/m}^2\text{.K)}$$

$$h_r \text{ is the heat transfer coefficient on refrigerant side} = \frac{1}{R_r} \text{ (W/m}^2\text{.K)}$$

$$h_m \text{ is the heat transfer coefficient of the tube} = \frac{1}{R_m} \text{ (W/m}^2\text{.K)}$$

k is the conductivity of the material, (W/m.K)

x is the thickness of tube, **m**

A_o is the outside or fin area which is the tube external area in case of plain tubes or **secondary area, m²**

A_i is the inside area of the evaporator through which the refrigerant flows or **primary area, m²**

$$\text{Equation 1 can be rearranged as: } (T_1 - T_4) = \frac{Q}{A_o \times U}$$

($T_1 - T_4$) can also be expressed as [($T_1 - T_2$) + ($T_2 - T_3$) + ($T_3 - T_4$)]

Substituting ($T_1 - T_4$), ($T_1 - T_2$), ($T_2 - T_3$) and ($T_3 - T_4$) from equations 1, 2, 3 and 4 respectively,

$$\therefore \frac{Q}{A_o \times U} = \frac{Q}{h_f \times \eta \times A_o} + \frac{Q}{\frac{k}{x} \times A_m} + \frac{Q}{h_r \times A_i}$$

$$\therefore \frac{1}{A_o \times U} = \frac{1}{h_f \times \eta \times A_o} + \frac{1}{\frac{k}{x} \times A_m} + \frac{1}{h_r \times A_i}$$

$$\therefore \frac{1}{U} = \frac{1}{h_f \times \eta} + \frac{x}{k} \times \frac{A_o}{A_m} + \frac{A_o}{A_i} \times \frac{1}{h_r}$$

$$\therefore \frac{1}{U} = \frac{R_f}{\eta} + R_m \times \frac{A_o}{A_m} + R_r \times \frac{A_o}{A_i}$$

The heat transfer coefficient **U** should be as high as possible, to make the evaporator compact and efficient, which means the sum of the resistances mentioned above should be as small as possible.

1. Looking at individual resistances, it means **R_f** should be as low as possible and fin efficiency **η** should also be as high as possible. As the fin area increases, its efficiency reduces since the area away from primary tube area is not as effective as area near the tube as mentioned above.
2. **R_r** should be as low as possible.

3. **A_o / A_i should be as low as possible (lower external secondary fin area A_o and more internal primary area A_i).**

The above equations lead to the very important conclusion that the coil which has more primary surface area and less secondary surface area will have higher heat transfer efficiency.

The ceiling suspended bunker coil has more primary area compared to finned air cooling units, and therefore, it is more efficient compared to finned air coolers having a combination of reduced primary tube area and large secondary fin surface area.

While reaching this conclusion, it is assumed that both the evaporators work at the same evaporating temperature.

We shall now look at the energy consumed in each type of evaporator.

Table 1: Energy consumption comparison

Power consumption comparison – storing 1250-1500 ton potatoes per room		
	Forced circulation air coolers	Bunker/ ceiling coils
Electrical motors, kW	4 coolers per room, two fans each cooler having 0.75kW motor	20 fans – 3 blades, 0.075kW each
Installed Power per room, kW	4 x 2x 0.75 = 6	20 x 0.075=1.5
Power consumed per room, kW	4 x 2x 0.669 = 5.352	0.069 x 20=1.38
Additional power consumed with forced air coolers, kW	5.352-1.38 = 3.972	
Additional refrigeration load due to fan power	1.129 TR	
Additional power required to generate this cooling (based on 0.8 kW/Ton), kW	1.129x0.8 = 0.903	
Total additional power, kW	3.972 + 0.903 = 4.875	
Running time for fans and motors per season – would vary for each installation and owner	18 hrs during pull down for 90 days, and 10 hrs for 180 days during holding = 3420 hrs	
Additional power cost @ Rs.5 per kW	3420 x 4.875 x 5 = Rs.83362.50	
Additional cost per season for 4 rooms (5000 ton storage)	Rs.3,33,450	

Note: The heat generated by motors at lower temperatures as indicated in *ASHRAE Refrigeration Handbook* page 20.2 is much higher, but for simplicity this factor has been ignored.

The exact amount is not important – it would vary from place to place and the time for which each owner would operate the fans. Data for one year for fan power consumption needs to be collected and compared. It is, however, evident that the electricity bill would be more in case of forced circulation air coolers compared to ceiling coils.

While looking for some authentic document to support the

conclusion that ceiling coil is more efficient than forced circulation air cooler and consumes less power, I came across an old ASHRAE handbook and found the following information:

Extract from ASRE 1959 Handbook (at that time ASRE was the American Society of Refrigerating Engineers and not ASHRAE), page 22-10 reads as under:

Room Cooling Equipment

Heat transfer equipment through which the refrigerating medium is circulated to cool the air in the storage or freezing rooms may be either pipe coils distributed over the room area to induce low velocity convection cooling, or unit coolers.

A unit cooler consists of a compact and highly efficient coil enclosed in a housing with fans that draw air through the coil at high velocity. The air temperature drop through the coil should be not more than 3 to 4°F. The cooled air is returned to the room space and should be distributed through the duct system to give a diffused and gentle, but positive air change in the storage room. This positive air change at very low velocities assures uniform air temperatures without adverse effects associated with high velocity air movement.

Some cold storage space is equipped with pipe coils, plain or finned, which are generally preferred by warehouse men. The low air velocity is recommended for many stored commodities because of the reduced dehydrating effect.

Ceiling coils in freezer space have long life and are simple and economical in operation, requiring no fan maintenance or cost for fan power. Defrosting of coils is more difficult and requires more labor than for unit coolers, **but it is required much less frequently.** In many operations defrosting is required only once or twice in a year with prime surface coils.

Diffusers or Unit Coolers

Since forced air circulation is used in this design, it is more important that the cooling surfaces of the units be of sufficient extent so that a small temperature difference can be maintained between the circulating air and the refrigerant. It is also important that air temperature drop through the coil be small to maintain high humidity in the room. **Experience has shown that the air of a forced circulating system must be at a higher relative humidity than air circulation by convection currents, or perishables will lose much moisture.**

Since the refrigerant side heat transfer coefficient is already high, several methods to improve air side heat transfer coefficient are used such as increasing the air velocity, increasing the turbulence by introducing irregularities in the heat transfer surface. Increasing the air velocity will increase heat transfer coefficient but at the cost of additional fan power.

The fan motor power ultimately appears as refrigeration load, and perhaps 10 to 20% of the heat removed by the air coil was ultimately introduced by the fan power and its motor.

Table 3 in the next column summarizes comparative advantages to be considered in using ceiling type coils or air units (air coolers).

Table 3: Comparison of Ceiling Coils and Air Units

Item	Coils	Air Units
Initial Costs	Higher	Lower
Operating Costs	Lower	Higher
Maintenance Costs	Lower	Higher
Uniform Temperature	Yes	Yes
Product warm up		Yes
Automatic Defrosting		Yes
Positive Humidity Control		yes

Based on the above information we shall now try to reach some useful conclusions:

1. Lower the ratio of secondary area to primary area (A_0/A_1), better is the efficiency, and in plain tubes without internal finning the bare tube has the lowest A_0/A_1 ratio, therefore it is the most efficient.
2. In order to improve heat transfer coefficient in finned coils on the air side, several methods are used in forced circulation air coolers. Since the refrigerant side heat transfer coefficient is already high, to improve air side heat transfer coefficient, increasing the air velocity and increasing the turbulence by introducing irregularities in the heat transfer surface are normal practices.
3. However, it leads to increased fan power. This adds to the electricity bill. In addition, this fan power gets converted to heat and requires additional refrigeration capacity which translates into a still higher electricity bill.
4. Higher air velocity over the product tends to dehydrate it and leads to higher weight loss, compared to natural convection in the case of ceiling coils.
5. The ceiling coil installation would have lower running costs due to lower electrical power consumption as well as maintenance.

The question then arises as to why most of the cold storage facilities are opting for forced circulation air coolers?

The advantages of forced circulation air coolers are:

1. They are compact and occupy less space, thus more quantity of product can be stored within the same volume.
2. They are factory manufactured with the latest technologies, thus their quality is superior to site-fabricated coils.
3. Stainless tube with aluminum fin technology used in modern air coolers prevents rusting due to moisture, which is always present in cold rooms, and makes the coolers much lighter.
4. Defrosting is much easier and faster, but more frequent compared to ceiling coils.
5. Fans can be provided with VFDs to reduce power consumption when the load reduces.
6. The installation becomes simpler and chances of moisture dripping on the product are eliminated.
7. Product cooling is much faster compared to ceiling coils, which is essential for most products barring a few like potatoes.

8. Cost of air cooler vs. ceiling coils is debatable and needs to be analyzed on a case to case basis.

The current cold storages use ceiling coils, many of which perform poorly because of the following deficiencies:

1. These are generally fabricated at site by lay persons and the refrigerant circuiting is, therefore, not properly designed leading to higher pressure drop in the coil, lower suction pressures, compressor operating inefficiently and increasing power consumption.
2. Oil accumulates in the coil and is not drained frequently, again leading to lower compressor suction pressure and higher power consumption.
3. Lower suction pressure leads to frost formation on the coils, reducing its heat transfer capability.
4. As the load reduces, suction pressure drops leading to higher power consumption and frost build up. Both these can be prevented if an evaporator pressure regulator is installed to maintain constant evaporating pressure irrespective of load.

All these disadvantages can easily be taken care of by using liquid ammonia pump circulation system, but at the cost of additional pumping power.

When we compare air coolers and ceiling coils, we can conclude:

1. For produce that does not deteriorate with a slow cooling rate over a period of approximately 20 days, bunker/ ceiling coils using ammonia refrigerant can give equally good performance and save considerable power and installed

refrigeration capacity.

2. For product requiring storage above 2°C i.e. positive temperature where chances of coil accumulating frost are minimal, ceiling coils can be used effectively.

Considering the above, we conclude that bunker/ ceiling coils can be a viable, efficient and power saving alternative to forced draft air coolers for certain products like potatoes.

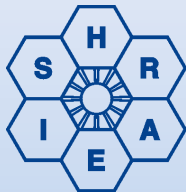
More studies are needed to capture actual data from running plants with accurate instrumentation and independent inspecting agencies to arrive at realistic values. All other parameters such as type of insulation, location, method of stocking the produce, quality of produce after storage etc., need to be maintained identical.

Since more than 85% cold storages in India are potato storages, it would be worthwhile to carry out a detailed analysis to come to proper conclusions. Potatoes being a low cost commodity and the common man's staple food, it is important that modern technologies insisted upon do not increase the end product cost and be affordable to the cold storage owner as well as the consumer.

This article is based on my own analysis and study and I would welcome feedback.

References

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2. ASHRAE Refrigeration Handbook
3. W F Stoecker, Refrigeration Handbook, page 176
4. Design Essentials for Refrigerated Storage Facilities, page 130
5. Tata Pipes information on Evaporator Pipes or Bunker Coils ❖



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