EVAPORATORS(AIR COOLERS)
By
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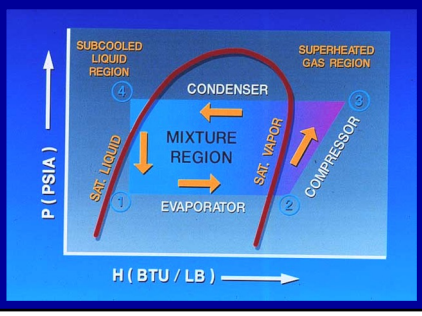
1

BASIC COMPONENTS OF A REFRIGERATION SYSTEM

- EVAPORATOR
- CONDENSER
- COMPRESSOR
- LIQUID METERING DEVICE

2

P-H DIAGRAM

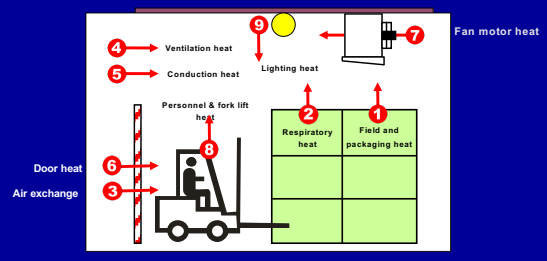


3

THE EVAPORATOR IS A DEVICE FOR ABSORBING HEAT INTO THE REFRIGERATOR SYSTEM.

4

HEAT TO BE EXTRACTED BY THE EVAPORATOR



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IMPORTANT CONSIDERATIONS-COIL DESIGN-AIR CIRCULATION, FAN SELECION



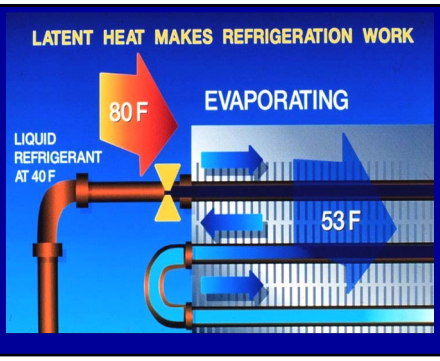
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AIR COOLERS IN COLD STORAGE



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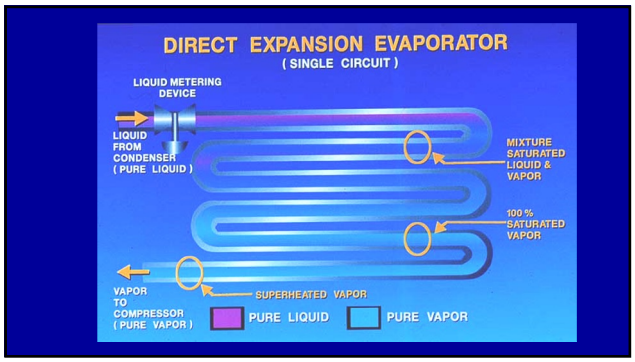
LATENT HEAT MAKES REFRIGERATION WORK



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Direct Expansion Air Coil

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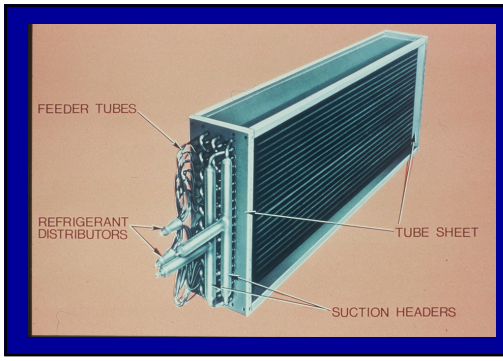


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OLD – BUNKER SYSTEM-FLOODED COIL



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DX COIL

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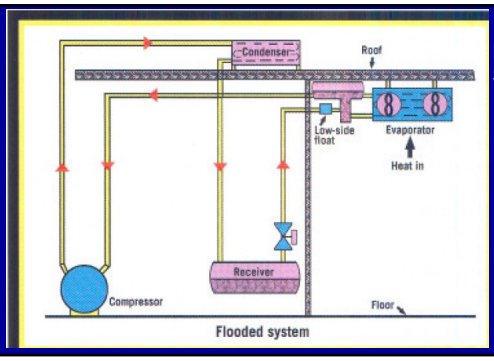
COIL HAVING FOUR ROWS DEEP
TWELVE PIPIE HIGH

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Flooded Air Coil

NOTE:-COIL IS FULL OF LIQUID FROM ENTRY TO EXIT

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FLOODED SYSTEM

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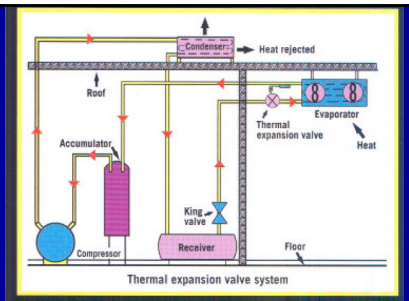


Figure 1. Although they are less efficient, the TXV systems are simpler in design, require less refrigerant charge, cost less initially and usually have less oil-logging problems.

DIRECT EXPANSION SYSTEM

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FLOODED SUBMERGED EVAPOATOR IN THE TANK

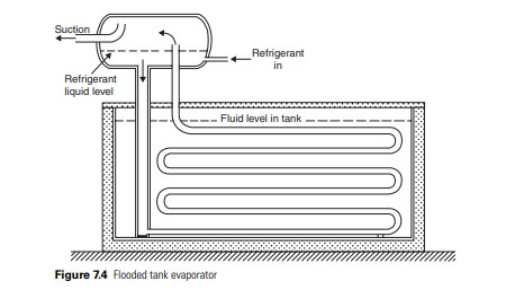


Figure 7.4 Flooded tank evaporator

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SUCTION –LIQUID LINE SIZING-GRAVITY FLOODED COOLERS

- When we select cooler based on capacity –especially for **low temperature applications**, The initial cool down load is very high when we start cooling form ambient temperature. There is very vigorous boiling and if line sizes are not designed for this load, the liquid instead entering the air cooler, it directly goes to accumulator and then onwards to the compressor in gravity flooded system and one has to stop the plant.
- Always design line sizes of inlet/outlet of air cooler for initial load situation
- In case of problem always think why suction gas is not getting released from air cooler rather than worrying about why liquid is not entering coolers-Liquid will enter automatically by gravity from the accumulator once the space is created by gas going out-Valuable advice by Bruce Griffiths

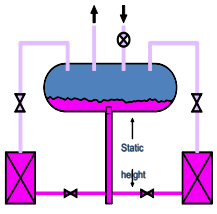
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EXAMPLE

- If one is designing for -20 deg. C cold room for the storage of frozen products, the refrigeration load during storage is very low as there is no product load.
- During initial cooler down , when we start cooling the room from ambient temperature of 40Deg C, the Refrigeration load is very high and the pipe line sizes selected from operating conditions become too small, hence liquid entering in the air coolers becomes difficult at it follows least resistance path and enters to the accumulator through stand pipe and then to compressor.
- The inlet/outlet connections of evaporator must be therefore selected of much bigger diameter.

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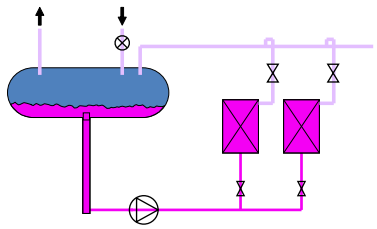
Gravity Flooded System



Static height to overcome coil pressure drop & to ensure refrigerant flow movement-normal circulation rate-1.5 to 2 Times depending on the coil pressure drop

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Pumped System



Circulation rate varies from 3 to 8 depending on application & processing equipment

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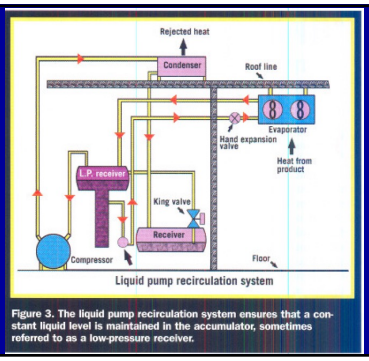
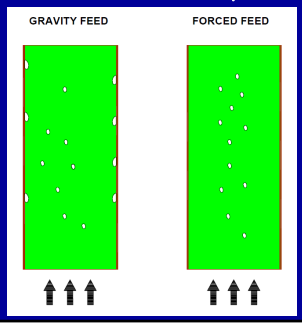


Figure 3. The liquid pump recirculation system ensures that a constant liquid level is maintained in the accumulator, sometimes referred to as a low-pressure receiver.

PUMPED FORCE FEED SYSTEM

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GRAVITY FLOW V/S PUMPED FLOW



In pump circulation system gas bubbles are entrapped in excess liquid flow, walls are always in contact with liquid hence better heat transfer(refer separate presentation on pump circulation systems for more details)

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KEY POINTS FOR SELECTING RIGHT SIZE EVAPORATOR

1. Material of Construction
2. Tube diameter/fin thickness/Fin Pitch
3. Selection of temperature difference
4. Refrigerant evaporation temperature in the coil-(S.E.T.) it is different than SST
5. Fin Pitch-Square or Triangular-For low temp. application sq. pitch preferred
6. Coil capacity selection-Based on TD1 or LMTD or MTD
7. Air Flow Direction-Blow Through or Draw Through
8. Air cooler surface area which includes fin area or only coil internal volume/length of coil without headers?
9. Coil face velocity at the air outlet
10. External static pressure available
11. No. of rows deep more or coil face area more ?-inlet/out connection sizes
12. Defrost system-Hot gas/water/electrical heaters/reverse cycle or on/off

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KEY POINTS FOR SELECTING RIGHT SIZE EVAPORATOR

- **Materials normally used for Construction**

1. Stainless steel tubes, casing as well as drain pan & and Al fins
2. Entire construction in stainless steel +Aluminium
3. C.S. Tubes with hot deep galvanizing and aluminium fins
4. Any other material to suit surrounding conditions and refrigerant

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CHOICE OF MATERIAL

1. Hot Dip Galvanized Steel (Steel/Zn)- (SA179)
2. 304 S.S. Tubes with Aluminium Fins (SST/Al)- (SA249)
3. 3003 Gr. Aluminum Tubes with Aluminum Fins (Al/Al)- (SA210)

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MATERIAL PROPERTIES

Metal	Density Lbs/cft.	Thermal conductivity Btu/sq.ft°F/ft.	Specific heat Btu/lb. °F	Tensile strength kJ	Allowable Temperature °F
C.S.(SA179)	490	26	0.107	47	-20 to +500
304L S.S. (SA249)	501	9.4	0.120	70	-320 to +320
3003 Al(SA210)	16.5	117	0.215	14	-452 TO +300

Advantages Aluminium Coolers
1. Light weight-30% lighter
2. Heat transfer-Better-30% more compact
3. Cost-30% Cheaper

Disadvantages:
1. Cannot be repaired at site
2. Delicate-not yet popular

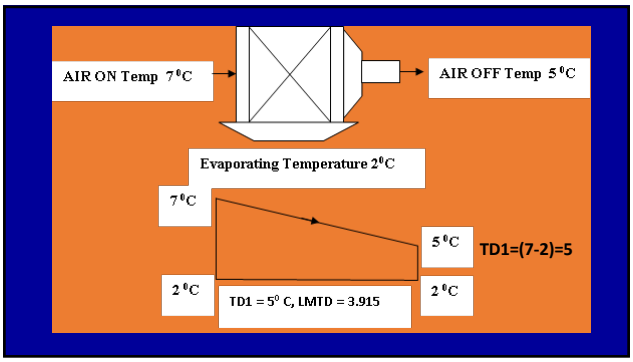
Ref: Colmac Coil-USA

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HEAT TRANSFER EQUATION

- Q= U * A * LMTD or A=Q÷(U*LMTD)
- TD1 is method is based on the difference between the air temperature entering the evaporator coil (equal to room Temperature)and the corresponding refrigerant temperature of the saturated suction pressure measured at the outlet of the evaporator.
- -Selection by DT1 gives adequate and bigger air cooler compared to LMTD and hence should be used.
- High humidity requirements will require coils with large surface areas and less number of rows & must be run at low TD's.
- Low humidity requirements will require coils with smaller surface
- areas and more rows deep coil & and greater TD's.

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TD1 or LMTD or TM

- TD1 =Air On Temperature–Saturated Coil outlet Temperature
- LMTD=Log_e TD1(Coil entering temperature-Evaporating temperature)
  TD2(coil leaving temperature-evaporating temperature)
- TM=Average(."Room.")Air Temperature.–Coil Evaporator Temperature
- Although Lower LMTD leads to bigger area, all manufacturers of coil design based on TD1 method.hence selction should be done with TD1
- LMTD or TM coils would be smaller and cheaper but not adequate.
- **ALWAYS SELECT COOLER ON THE BASIS OF TD1**

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TD1 is the entering-air temperature minus the ammonia evaporating temperature.

LMTD accounts for the temperature difference at both ends of the coil.

DTM/TM commonly uses average room-air temperature minus evaporating temperature.

Manufacturers such as Colmac recommend selection using DT1
One subtle but important correction: LMTD is not inherently an inferior selection method. For a heat exchanger with known inlet and outlet temperatures, LMTD is the appropriate theoretical mean temperature difference under the usual heat-exchanger assumptions.

TD1 is instead a practical, conservative rating basis for selecting air coolers. Recommendation is to select an ammonia air cooler using the manufacturer's TD1-rated capacity at the actual design conditions, including the required humidity, airflow and frost allowance.

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TD1
=AIR ON TEMP.(ROOM TEMP.) MINUS-SATURATED EVAPORATING TEMP. AT COIL OUTLET

Application		$TD1=T_{air,in}-T_{refrig.}$
Positive temperature above freezing	High Humidity	2.2 to 4.4 deg. C
Positive Temperature	Low Humidity	5 deg. C(Preferred)
Negative temperature storage	-	5.5 deg. C to 6 deg. C

Ref: Stocker-Industrial Refrigeration-Page 207

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CONCLUSION-TD1 OR LMTD OR TM

- Q= U * A * LMTD or A=Q÷(U*LMTD)
- TD1 is method is based on the difference between the air temperature entering the evaporator coil (room Temperature)and the corresponding temperature of the saturated suction pressure of the refrigerant measured at the outlet of the evaporator.
- -Selection by TD1 gives adequate and bigger air cooler compared to TM and hence should always be used.
- High humidity requirements will require coils with large surface areas and must be run at low TD's.
- Low humidity requirements will require coils with smaller surface
- areas and greater TD's.

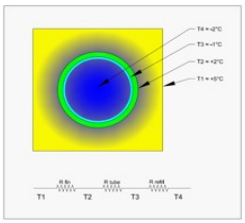
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COIL AREA-FIN AREA OR TUBE AREA?

- Air cooler Area-Which area to be considered?
- surface area which includes fin area or coil internal volume/length of coil without headers?
- Tube area is only either Tube surface area or length of tubing or tube internal volume without headers

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Cross Section of Typical Fin

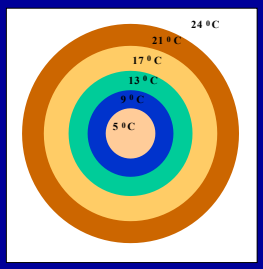


A_o-EXTERNAL AREA

A_i-INTERNAL AREA

Tube Volume and Tube external area more Effective & important than fin area-IF-A_0/A_i LESS, MORE EEFFECTIVE IS THE COIL

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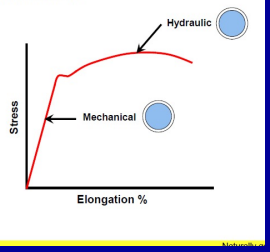


CROSS SECTION OF PLATE FIN COIL

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HYDRAULIC EXPANSION

- Controlled expansion of the tubes.
- Long lasting maximum contact between tube and fin, therefore guarantee of (life-time) capacity.
- Competitors solutions – decrease of capacity in time



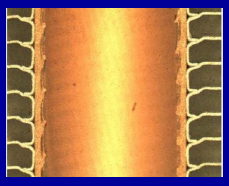
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1. Stainless Steel needs to be elongated beyond its yield point during expansion.
2. If that is done , it does not come to its original shape.
3. As per Kelvion Goedhart , in mechanical expansion this is not achieved.
4. The tubes are subject to thermal stress of low temp during cooling and high temp while defrosting

Hence over a period of time the bonding between tubes and fins gets loosened & eventually loosing capacity – in case of mechanical expansion

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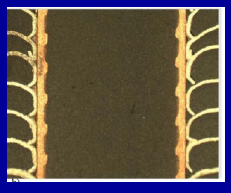
HYDRAULIC EXPANSION- Better contact



The pressure expansion process provides superior consistency in tube/fin bond

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Mechanical expansion



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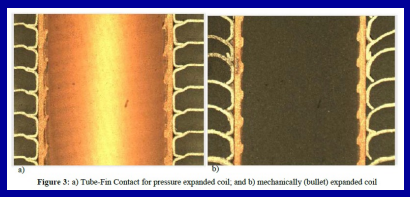


Figure 3: a) Tube-Fin Contact for pressure expanded coil; and b) mechanically (bullet) expanded coil

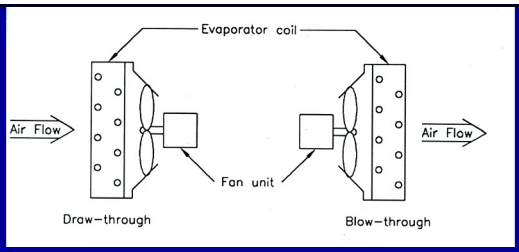
Based on a series of physical measurements, visual inspections, and coil tests, the new pressure expansion method shows significant improvements and potential over more traditional mechanical expansion processes. Measurements of tube diameter show that pressure expanded coils have a more consistent expanded diameter than their mechanicallyexpanded counterparts.

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AIR FLOW

- AIR FLOW DIRECTION-
- DRAW THROUGH OR BLOW THROUGH

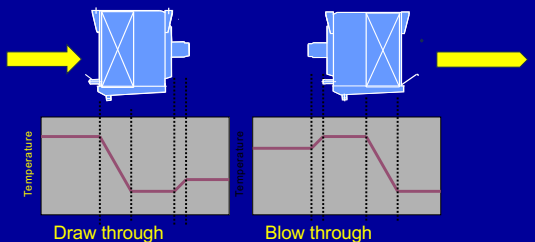
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Draw through or blow through evaporator – fan configurations

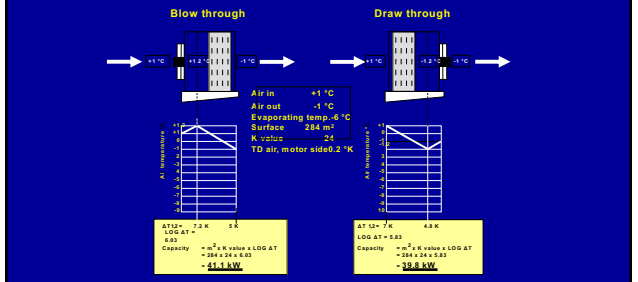
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BLOW THROUGH OR DRAW THROUGH



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BLOW-THROUGH & DRAW THROUGH AIR COOLERS



BLOW THROUGH IS BETTER

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BLOW THROUGH-ADVANTAGES

1. Wide air outlet surface
2. Equal air distribution through the coil
3. Micro turbulence in the coil because of the fan turbulence resulting in better heat exchange
4. Frostbuilding visual
5. No condensation on inside of fanplate
6. Lower chill factor because lower air velocity

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MAIN DIFFERENCE

- **DRAW THROUGH**

- Relatively high air velocity on outlet of the cooler
- Relatively much turbulence because of the fan

- **BLOW THROUGH**

- Relatively low air velocity on outlet of the cooler
- Relatively less turbulence because of the fan

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ADVANTAGES AND DISADVANTAGES OF BLOW THROUGH/DRAW THROUGH UNITS

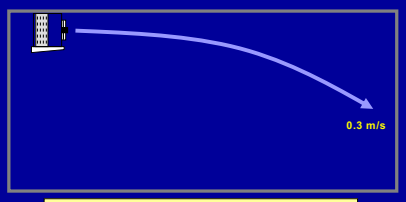
1. Blow through has higher efficiency
2. The air distribution pattern is less effective due to coil resistance
3. Blow through design has lower discharge velocity as entire coil is in the air path.-Throw of 11to 13 m possible
4. For longer discharge and more uniform air distribution draw through design preferred with 33m throw or more.
5. Draw through design uses normally propeller fans
6. Centrifugal or propeller fans can be used for blow through design, depending on depth of coil, fin spacing

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PROPER AIR CIRCULATION- AIR THROW & AIR SPREAD IMPORTANCE

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How is Air Throw defined



Most sources recommend a theoretical air speed of 0.3 m/s at the end of the room. This is pure theory, however, because any airflow of less than 0.5 m/s is dispersed and becomes impractical to measure.

Slide 50

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Calculating the range

Empirical equation:

$$\text{Air throw} = A \times V_{eo}^2 \times \frac{1.2}{W_s}$$

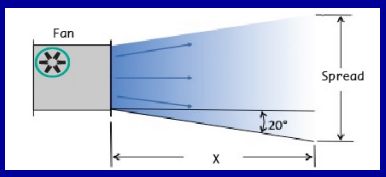
A = Correction factor, pressure/suction (depending on fan type and cooler design)

V_{eo} = Air speed at the evaporator outlet (m/s)

W_s = specific weight of the air

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AIR SPREAD



$S = D + .36X$

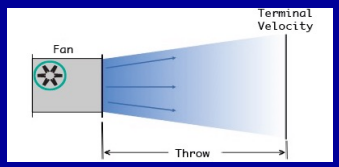
Where:

D = Diameter of the fan

X = Distance from the fan outlet

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AIR THROW



$$T = 5.556 \times \sqrt{\left(\frac{CFM}{\pi TV}\right)} - 2.778D$$

Where:

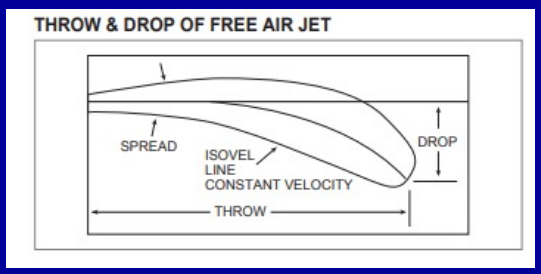
CFM = fan air flow volume

TV = desired average Terminal Velocity

D = Diameter of the fan

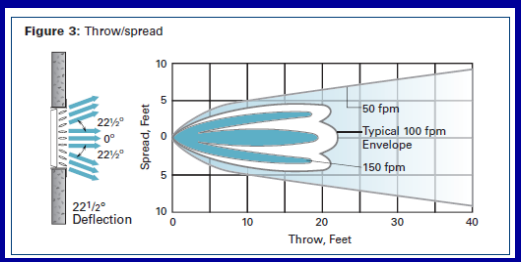
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AIR DROP



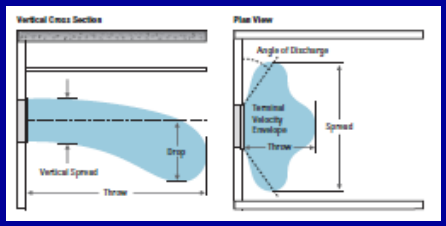
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AIR DISTRIBUTION BASICS

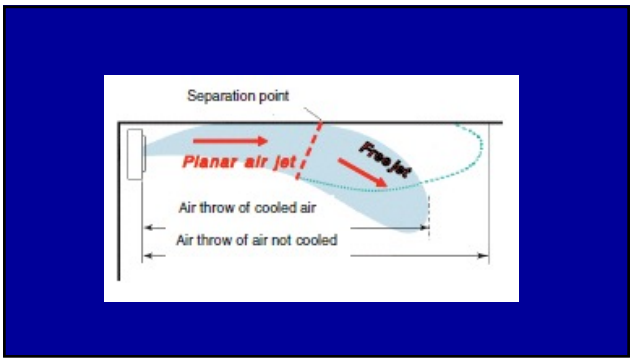


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AIR THROW & AIR SPREAD



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ALUMINUM COOLERS

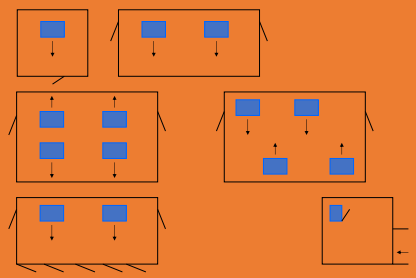


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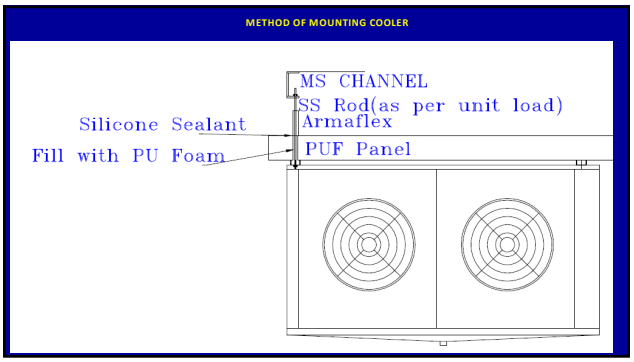
HOW TO LOCATE AND INSTALL AIR COOLERS PROPERLY

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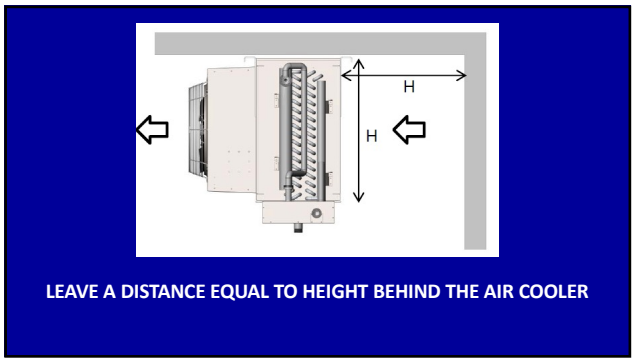
RECOMMENDED COOLER PLACEMENT



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METHOD OF MOUNTING COOLER
MS CHANNEL
SS Rod(as per unit load)
Armaflex
Silicone Sealant
Fill with PU Foam
PUF Panel

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H
H
LEAVE A DISTANCE EQUAL TO HEIGHT BEHIND THE AIR COOLER

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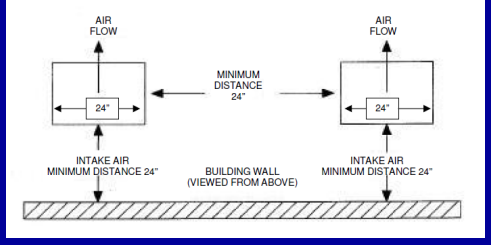

CEILING MOUNTED EVAPORATOR

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CEILING HUNG EVAPORATOR

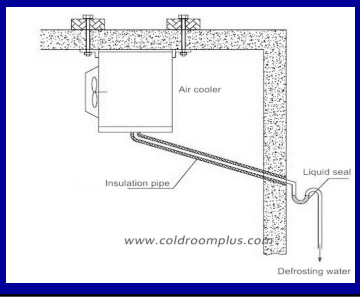
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Example of Multiple Units with Horizontal Airflow



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AIR COOLER DRAIN PIPING WITH LIQUID SEAL



66

AIR COOLER PIPING & CONTROLS OUTSIDE THE BUILDING ON TERRACE



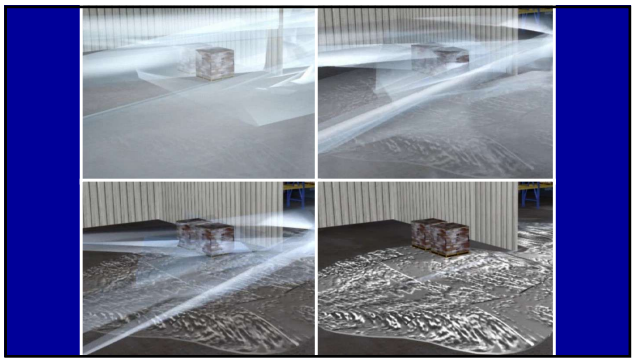
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DEFROSTING COILS

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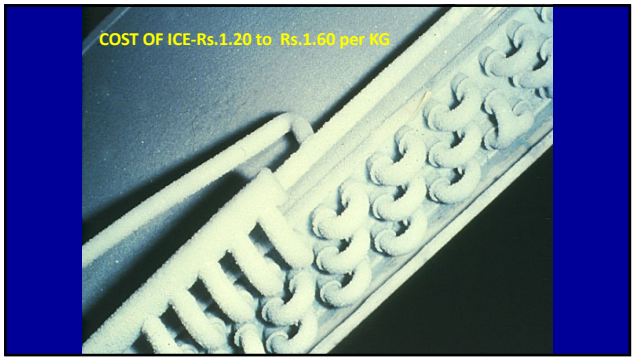
70

LATENT HEAT V/S SENSIBLE HEAT

- To Cool one kg of dry air requires 1.006 kJ/kg_{da}.K energy(0.24 Btu/lb)
- To condense one kg of Vapor requires 2500.77 kJ/kg_{da}.k energy(1076Btu/lb)

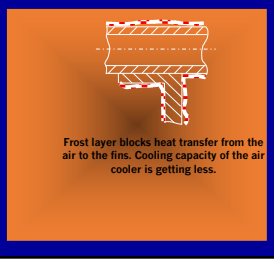
Latent heat requires 4500 times more energy per lb.

71

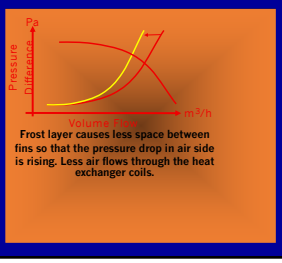


72

Effect of Frost



Frost layer blocks heat transfer from the air to the fins. Cooling capacity of the air cooler is getting less.



Frost layer causes less space between fins so that the pressure drop in air side is rising. Less air flows through the heat exchanger coils.

73

EVAPORATOR COIL ICING –OR-EXCESSIVE CONDENSATE REMOVAL-REASONS

- Coils running at too low a temperature
- Defrost system defective
- Storage RH is too high
- Inadequate air flow
- Coil design incorrect -high fin density, small tubing, more than required depth leading to removal of excess moisture than necessary
- Defective insulation-Air leakage through doors-holes

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Defrost Loads-Latent Loads-Btu/lb

1	Latent Heat Condensation	1076 Btu/lb
2	Sensible Heat to reduce Vapour Temp. From 104^{0}F to 32^{0}F	40 Btu/lb
3	Sensible Heat (32^{0}F to -15^{0}F)	23 Btu/lb
4	Latent heat of Frost	144 Btu/lb
5	Heat reqd. to Defrost raise Temperature from -15 to 32	23 Btu/lb
6	Latent heat of Frost	144 Btu/lb
7	Assuming Defrost Efficiency 25%	576 Btu/lb
8	Raise temp. From 32 to 42 (room temp)	10 Btu/lb
9	Sublimation (Frost to Vapour) 16% (of 5+6+7)	120 Btu/lb
10	Evaporation loss 14% (of 5+6+7)	106 Btu/lb
11	Total Energy Required	2262 Btu/lb
12	Actual Energy lost 2262/0.7lb of ice	3232 Btu/lb
13	Power required to Defrost 1 lb	0.7 kW/lb

75

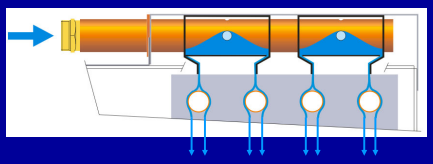
DEFROST LOADS-LATENT LOADS-BTU/0.7LB FROM COIL

		kWh
1	To produce Frost	0.21 kWh
2	To Defrost Frost	0.09 kWh
3	To remove Defrost Heat	0.16 kWh
4	Total power	0.46 kWh
6	Power required to remove 1 lb of Frost	0.46/0.7=0.66 kWh

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• WATER DEFROST SYSTEM

P_{water} = 0.03 bar

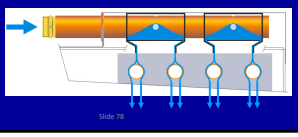


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WATER DEFROST

- Water is lead to gutters, located lengthwise above the cooler coil. One gutter per two tube rows.
- Water distribution openings in the gutter bottom plate ensure an even water distribution over the cooler tubes



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WATER DEFROST

- Required water flow is 0.6 m^3/h per meter gutter length. This flow will be reached with 0.03 bar water pressure in the distribution line *(+/- 30%, this means a 50% pre-pressure tolerance).*
- If too much water is supplied, part of the water flows to the wrong places and could splash outside the cooler casing. This may affect the defrosting process and will cause solid ice on undesirable locations.

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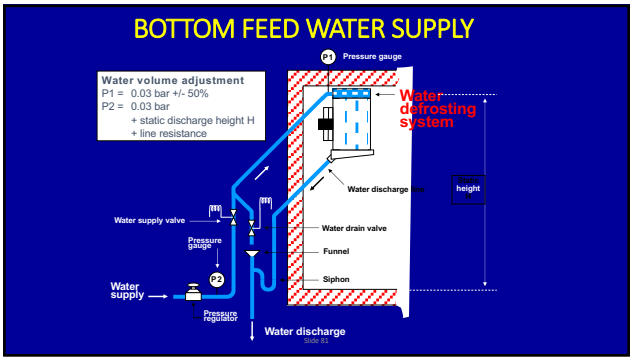
BOTTOM FEED WATER SUPPLY

- Water pressure is reduced by a pressure regulator down to 0.03 bar +/- allowed tolerance.
- After completion of the defrosting process, the water supply line is closed and at the same time the drain line is opened. When the system is fully drained, the drain line will be closed again.
- The water discharge line is equipped with a siphon (air trap) to avoid freezing of the discharge line where is passes through the cold room wall.

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BOTTOM FEED WATER SUPPLY



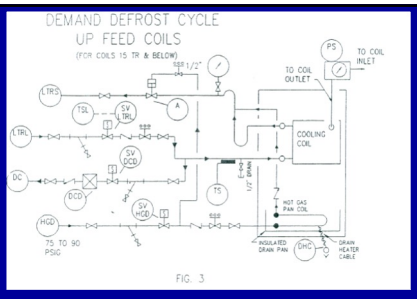
81

TOP FEED WATER SUPPLY

- Water supply is identical to Bottom Feed System.
- During defrost, a part of the added water will be lead to the sewer through the combined overflow drain line to avoid freezing of the pipe section inside the cold room.
- After completion of the drefrosting process, the water supply line is closed and the system will be drained directly using the combined overflow drain line.
- Both discharge lines are equipped with siphons to avoid freezing inside the cold room wall passages.
- An automatic aerator at the top of the pipe alignment is required to enable draining.

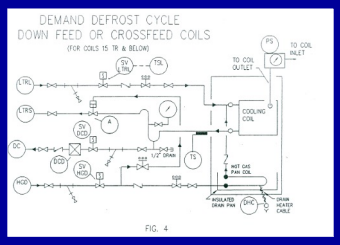
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HOT GAS Demand Defrost Cycle Up Feed Coils

83



HOT GAS Demand Defrost Cycle Down Feed Or Cross Feed Coils

84

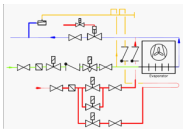
SUGGESTED FIN SPACING –RUN TIME-DEFROST FREQUENCY

SHR= S.H./(S.H.+L.H)	Fin Spacing	Design Running Time	Defrost Frequency- Nos. per day
0.65	2	14	9
0.75	3	16	8
0.85	4	16	6
0.95	4	18	2

As sensible Heat increases less defrost Frequency and closer fin spacing

85

Separate hot gas defrost line for defrost pans



Having a separate valve station for the defrost pan:

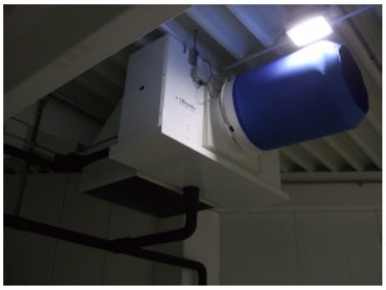
- Reduces the energy consumption since a smaller solenoid valve is necessary to heat the pan during the length of the defrost sequence
- Main hot gas solenoid valve will only be active for 10 minutes reducing the amount of heat added to the refrigerated space.

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AIR COOLER WITH A FLAP WHICH CLOSES DURING DEFROSTING

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FAN COVER

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FAN CLOSING CLOATH DUCT FLAP, DURING DEFROST TO AVOID WARM AIR COMING TO ROOM

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STANDARD POTATO COLD STORAGE-2000MT

- Chamber Size each -21m Lx16m Wx13.7m H Volume 4603 m^3, floor Area=226 m^2
- (Refrigeration load -85.32kW)-NHB DOCUMENT
- In each room normally there would be three air cooler units, each of 33kW, and air quantity of each is approx.39000 CMH, for 3 coolers it would be 1,17,000 CMH

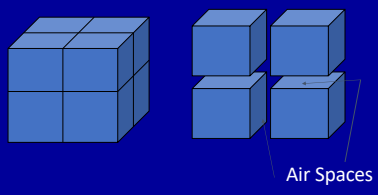
90

ADEQUATE AIR QUANTITY BASED ON ROOM SIZE

- If we consider the same room for storing frozen product which is frozen elsewhere and brought to the cold rooms.
- All other parameters remaining same as above except insulation which would be 150mm thick, instead 100mm since it is low temperature room and assuming that the product temperature while loading has increased to -15 deg. C, which was frozen earlier elsewhere at -20 deg. C-Refrigeration Load 24.8 kW
- There would be 2 air coolers each of 13kW having air volume as having Approx. 13000CMH each cooler, totaling to 26,000CMH as against positive temperature storage would have 39000CMHx3= 1,17,000 CMH
- **Conclusion-Air quantity Inadequate for room size-Always Select based on room Size-Considering -Throw-Spread-drop.-Velocity-0.5m/s at 85 to 90% distance**

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AIR SPACES BETWEEN PACKAGES



AIR SPACES AROUND THE PACKAGE ENSURES PRODUCT IS TOTALLY ENVELOPED BY COLD AIR

92

INCORRECT USE OF SPACE



Product stacked haphazardly in aisles due to a lack of suitable racking space.

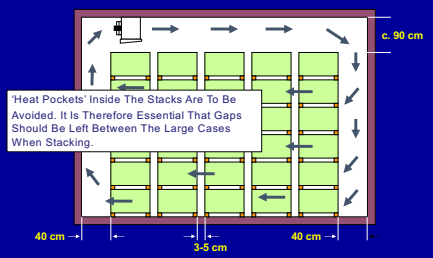
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NO PROPER AIR CIRCULATION ON PRODUCT



94

CORRECT AIR CIRCULATION IN THE COLDROOM



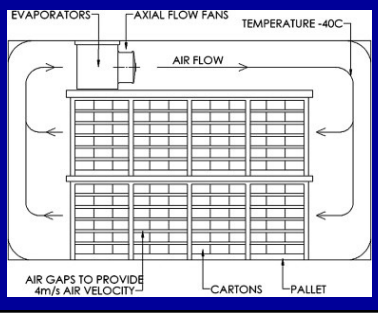
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AIR BLAST FREEZER

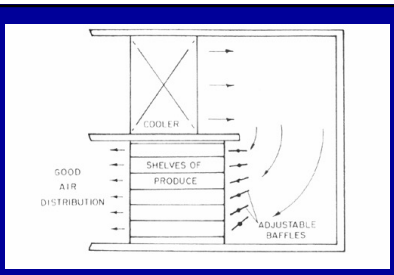


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AIR BLAST FREEZER



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CEILING SUSPENDED COOLER-GOOD AIR DISTRIBUTION

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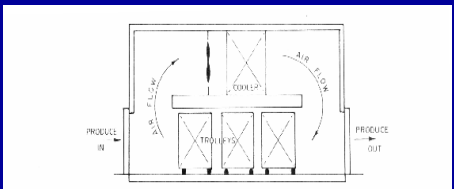
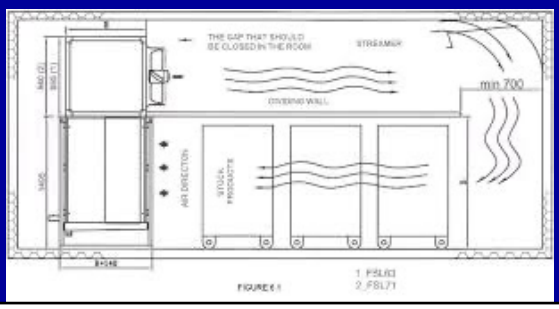


Figure 8 Batch-continuous air blast freezer with counterflow air circulation

GOOD AIR DISTIBUTION

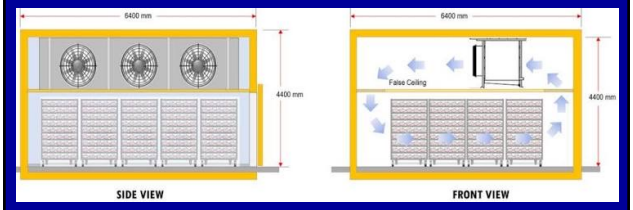
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FLOOR MOUNTED AIR BLAST FREEZER



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CEILING SUSPENDED BLST FREEZER



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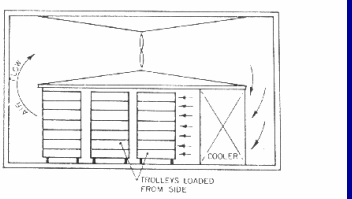
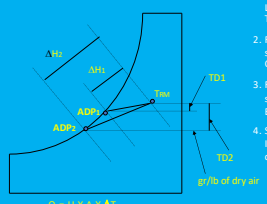


Figure 16 Air blast freezer arrangement showing the cooler acting as an air diffuser

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PSYCHROMETRIC ANALYSIS



1. Smaller TD less weight loss / Less Moisture Removed TD1<TD2
2. For same heat removal Q, smaller TD - More area, bigger Coil
3. For same Heat Removal Q, smaller ΔH – More cfm – Bigger fan
4. Smaller TD, More expensive Initial cost - lower power consumption / running cost

$Q = U \times A \times \Delta T$

$Q = 4.5 \times cfm \times \Delta H$

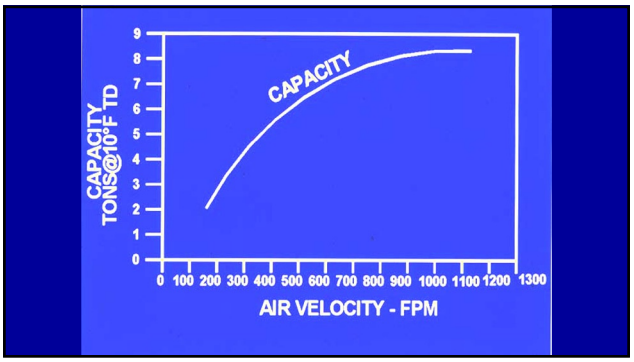
$TD = T_{RM} - T_{ADP}$ (T_{evap})

103

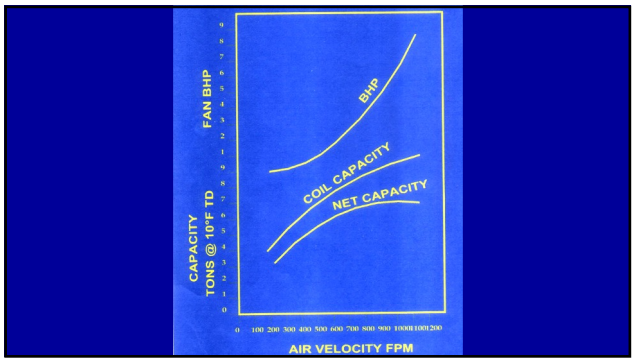
FAN LAWS

1. Volume flow:- $q_{v2} = q_{v1} \times \left(\frac{n_2}{n_1}\right)^1 \times \left(\frac{d_2}{d_1}\right)^3$
2. Pressure:- $p_2 = p_1 \times \left(\frac{n_2}{n_1}\right)^2 \times \left(\frac{d_2}{d_1}\right)^2 \times \left(\frac{\rho_2}{\rho_1}\right)^1$
3. Absorbed power:- $P_{R2} = P_{R1} \times \left(\frac{n_2}{n_1}\right)^3 \times \left(\frac{d_2}{d_1}\right)^5 \times \left(\frac{\rho_2}{\rho_1}\right)^1$

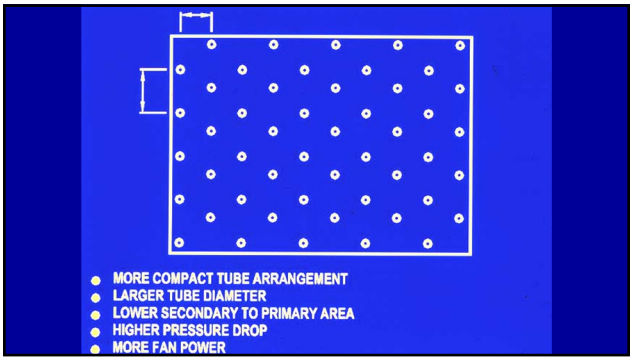
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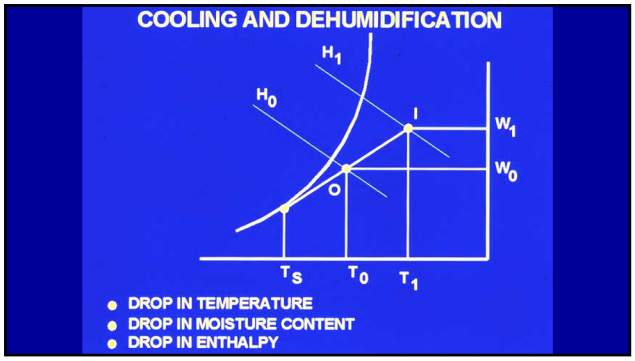
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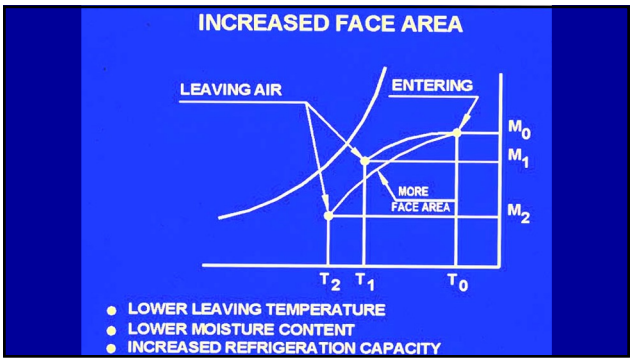
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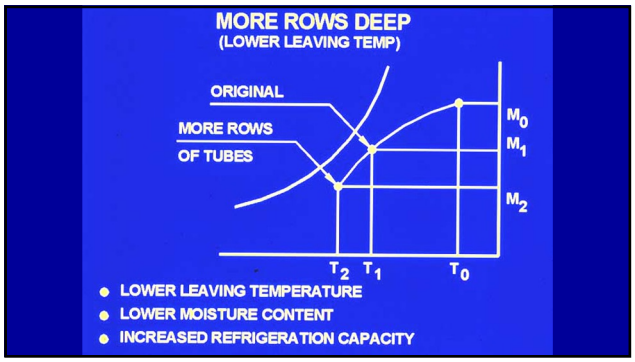
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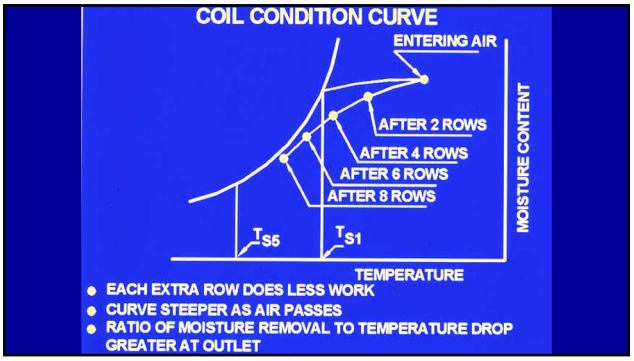
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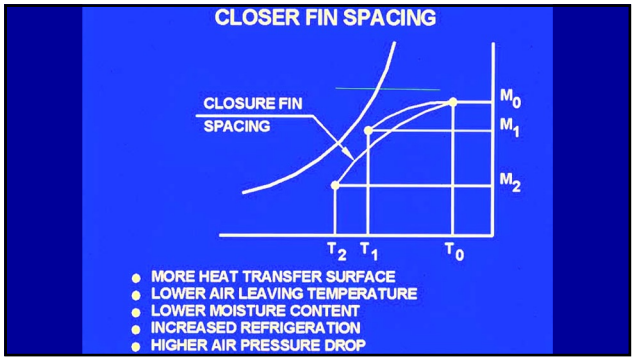
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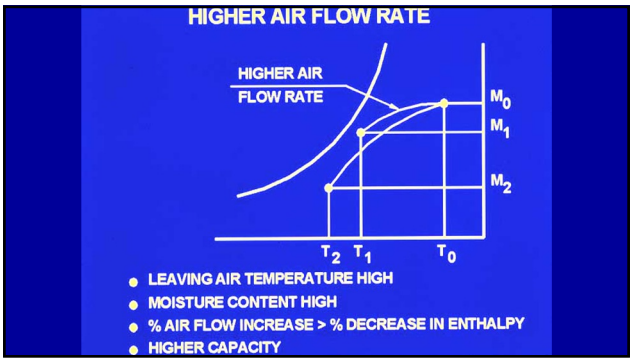
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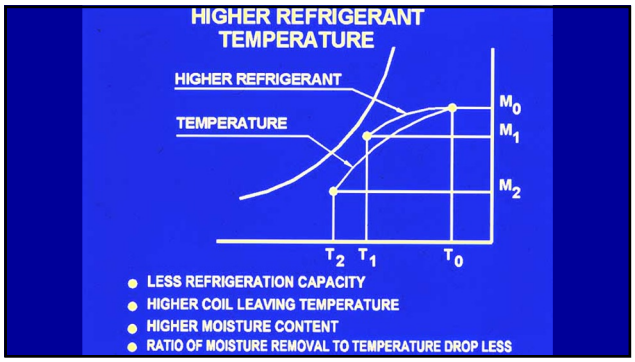
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HIGHER AIR FLOW RATE
HIGHER AIR FLOW RATE
M_0
M_1
M_2
T_2 T_1 T_0
LEAVING AIR TEMPERATURE HIGH
MOISTURE CONTENT HIGH
% AIR FLOW INCREASE > % DECREASE IN ENTHALPY
HIGHER CAPACITY

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HIGHER REFRIGERANT TEMPERATURE
HIGHER REFRIGERANT TEMPERATURE
M_0
M_1
M_2
T_2 T_1 T_0
LESS REFRIGERATION CAPACITY
HIGHER COIL LEAVING TEMPERATURE
HIGHER MOISTURE CONTENT
RATIO OF MOISTURE REMOVAL TO TEMPERATURE DROP LESS

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QUESTIONS?
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