Mechanical Engineering Overview

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Heating, Ventilating, Refrigeration, and Air Conditioning

I. INTRODUCTION AND SHORT HISTORY OF HVAC

A. Heating ventilating and air conditioning, as far as the history of Mechanical Engineering is concerned, is relatively new. The development of readily useable calculations and applicable equipment occurred in the early part of the 1900's. Prior to this time buildings were sometimes built over caves that emanated cold air, used ice brought down from the mountains with a manually operated fan to force air over the ice, or letting cold water run down gauze curtains at windows so that the entering air would be cooled down.

B. The first mechanical operated air conditioner was in Apalachicola, Florida in 1848 and was invented by Dr. John Gorrie. He built a two stage air cycle system to provide air conditioning for his small hospital. He found that ice could be made with the machinery and had it patented as an ice making machine in 1851.

C. Refrigeration for food preservation was developed during the late 1800's mainly using ammonia as the refrigerant. Most of the earliest air conditioning systems utilized ammonia systems to chill water that could then be used for comfort cooling or to manufacture ice banks that would then be used to chill circulating water to enable smaller refrigeration equipment to be utilized. One of first major air conditioning systems was designed by New York mechanical engineer Alford Wolff in 1902. The system was for the New York Stock Exchange and was 450 tons.

Dr. Willis Carrier invented the psychrometric chart which greatly simplified the calculations required for the pyschrometric process. He probably contributed more to the engineering aspect of air conditioning than any other individual. During this time air washers were used as cooling units with the cold water spray being the cooling coil.

E. In 1928 Freon was invented which made it possible to have direct expansion cooling and refrigeration without a secondary brine, was not poisonous, and operated at low pressures. This resulted in individual smaller system capability, household refrigerators, etc. at much reduced first cost. During this same period of time systems of over 10 to 15 tons were designed by mechanical engineers and the application and selection of all the related components for each application was done on an individual basis. This was the generally accepted practice until after World War II.

F. After the War the use of air conditioning and refrigeration in business, industry, residences, automobiles, manufacturing etc.

grew exponentially. As a result much new equipment was developed and utilized. Since then the manufacturers of HVAC equipment have standardized much of their equipment so that "off the shelf" availability has, in many cases sped, up the construction process.

G. In this day and age, as we leave our air conditioned residence in our air conditioned vehicle, to go to our air conditioned workplace and then to our air conditioned club or restaurant, people have become much more critical of temperature, humidity, and noise levels of the HVAC systems. Unfortunately, many mechanical engineers have not received the necessary course work to properly address these problems.

H. During the development of all the various packaged air conditioning equipment many higher education institutions have either dropped or greatly reduced the availability of HVAC courses and its related laboratory work. As a result, many engineers can only learn about air conditioning by working with older experienced engineers and taking advantage of technical courses, sponsored by technical societies or manufacturers.

J. This course is not intended to give a person a detailed intensive lesson in the basics of HVAC or how to design every type of system; but is a review of the basics for those with a lot of experience and to perhaps arouse, in younger engineers, the interest to further enhance their knowledge. This can be done by pursuing higher education from universities as well as technical societies such as the American Society of Heating, Refrigerating, Air Conditioning Engineers.

II. REFRIGERATION

A. All air conditioning and refrigeration systems require a method of utilizing refrigerants so that their energy level can be raised in a process called the refrigeration cycle. In thermodynamics this is called "the reverse Carnot cycle". The compressor that accomplishes this is the "heart" of the system. The most commonly used compressors are centrifugal, reciprocating, scroll, and screw; but their operating principles are very similar. It is assumed that basic thermodynamics has been taken and terminology such as Btu, enthalpy, entropy, etc. are understood.

B. Of course there are other types of systems such as evaporative, absorption, and adsorption. The main method most commonly used is the compression process, which can be used for both heating and cooling. This study guide does not go into the very fine points of the process but will act as a review of the principles and operating characteristics as well as delving into items that should be considered when applying compressors for specific systems. Refrigeration is usually expressed in "tons" of cooling capacity which is 12000 Btu/hour (which is based on one ton of ice melting in a 24 hour period). It is also listed in Btuh, MBH, and KW.

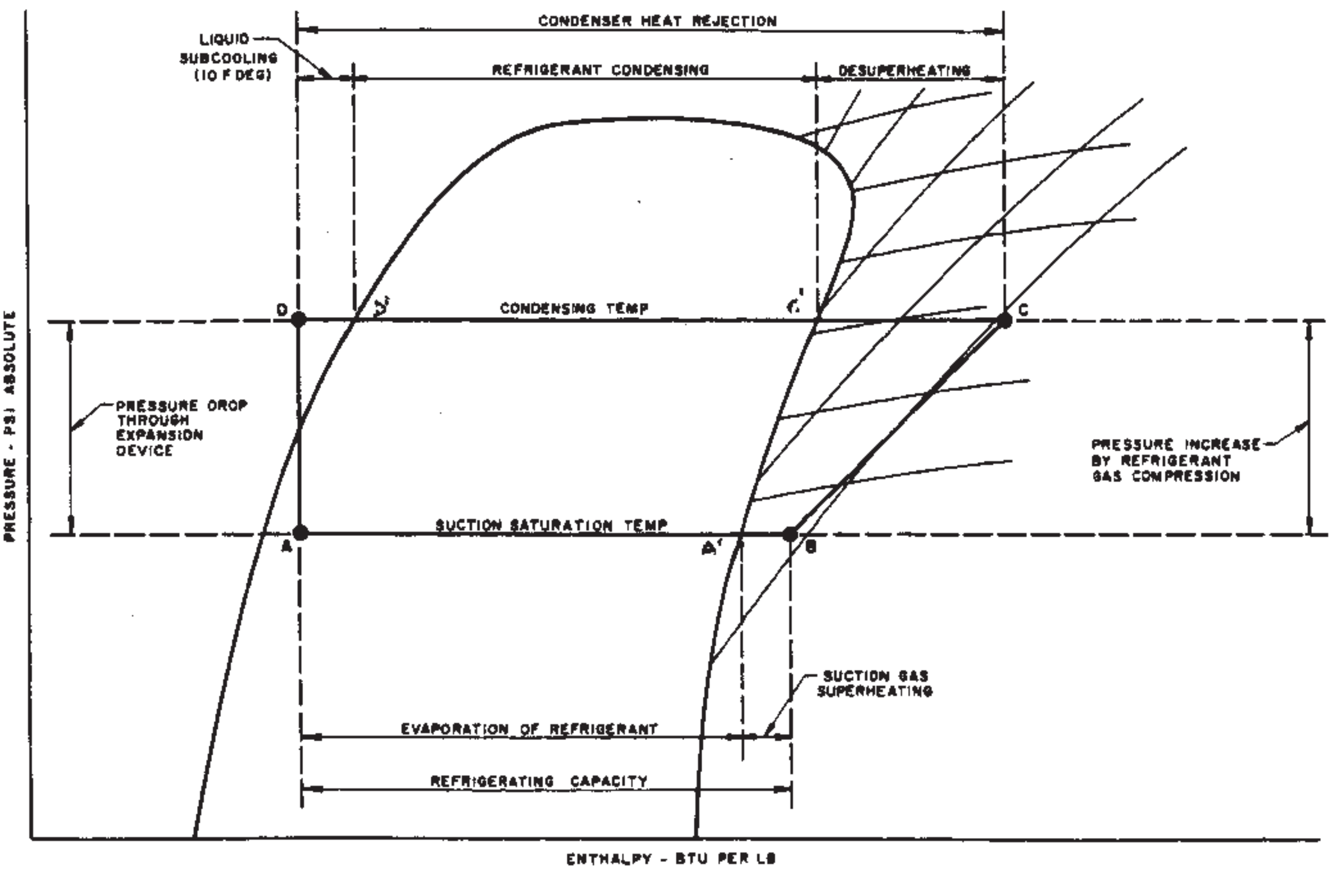
C. The refrigeration process consists of expansion, evaporation (or boiling), compression of superheated vapor, desuperheating, condensing, and usually subcooling. This is all accomplished with the basic components of an expansion device, a cooling coil or evaporator, a compressor, and a condenser (air or water cooled).

D. When liquid refrigerant at its saturation pressure has its pressure reduced through an expansion device it will absorb heat from its surroundings and evaporate by changing state from a liquid to a vapor. This is called the "refrigeration effect" and is used to determine the necessary refrigerant flow in lbs. mass in order to properly select the equipment for the required process.

E. The refrigerant vapor that absorbs the heat energy in the evaporater is then introduced through the suction line to the compressor where it is compressed to the discharge pressure. This is the part of the system where energy is input in order to accomplish the desired results. This change of energy, an enthalpy increase, is theoretically done at constant entropy. In the real world there are inefficiencies, cylinder wall heat, etc. that causes the discharge conditions to be higher than the ideal.

F. This hot superheated gas is then passed through a condenser, which may be either air or water cooled, so that the heat from both the evaporator and compression process are removed so that a change of state from gas to liquid is accomplished. There is generally some extra heat exchange surface in the condensers to provide some liquid subcooling.

G. The subcooled liquid is then fed to an expansion device, which can be an automatic expansion valve, a capillary tube, or a float valve. These are used to reduce the high pressure liquid so that when it enters the evaporator it will absorb the heat thereby cooling down the air, water, etc. and start the process over again. All this is illustrated in the following pressure - enthalpy, PH, chart below:



REFRIGERANT PROCESS ON THE PH CHART

H. PH charts for the various refrigerants are readily available in various technical publications. The charts and their accompanying tables will give more on the physical characteristics of a specific refrigerant. The tables give more accurate values than the chart but both will work.

The prior PH chart indicates the basic refrigerant cycle, however there are certain aspects of this that at times have to be considered during specific applications.

J. The refrigerant effect (R.E.) in Btuh is determined from load calculations, whether it is air conditioning a building or freezing chickens. This R.E. is from the subcooled liquid line (A-A') to the saturated vapor line as this is where the change of state occurs. The small superheating of the vapor (A'-B) to the compressor suction helps in the cooling process but does not require additional refrigerant in the process.

K. This superheat is mainly to insure against liquid carry over being introduced into the compressor so that "slugging" will not occur, which can cause severe damage to the compressor. This is most critical on reciprocating compressors than other types. Centrifugal compressors have "mist eliminators" to prevent droplets of refrigerant from entering the impellers and, because of the very short suction piping, generally have saturated vapor entering the wheel. An expansion valve is mainly a superheat control device to prevent slugging and is not a capacity control valve. Other expansion devices such as capillary tubes are "critically charged" systems and require careful refrigerant charging so as to prevent over or under charging.

L. The compressor in a system operates at various compression ratios ($Psia_d$ / $Psia_s$) because of variations in both suction and discharge pressures caused by variations in indoor and outdoor conditions. Standard compressor ratings are based on a maximum design condition determined by the design engineer. It is easy to see that higher suction pressure and lower discharge pressure will result in lower compression ratios. This allows the compressor to have a higher volumetric efficiency and thereby be able to pump more refrigerant at no increase of input energy. This principle is used to increase or improve the EER (energy efficiency ratio) or COP (coefficient of performance) of a system.

M. One of the more serious maintenance problems with reciprocating compressors is the discharge valves. These valves are spring loaded and actuated by pressure differential, and are critical when it comes to slugging or operation at reduced refrigerant charge. Slugging, as previously described, can break valves due to operation at a low refrigerant charge which results in very high discharge temperatures which can take the temper out of the valve thereby not allowing it to close properly. These conditions reduce the pumping capacity with its associated lower refrigeration capacity. Semi-hermetic or open type compressor design allow access to the valves for easy replacement if a problem occurs.

N. Desuperheating and condensing (C- C'- D')is done in condensers and are usually either air or water cooled, finned tube coils with condenser fans, or shell and tube units with water from a source. The water cooled condensers generally allow lower discharge pressures but water treatment can be an expensive continuing extra cost. The discharge or "head pressure" control is done on air cooled units with fan staging and/or variable fan speeds; water cooled by tower fan control or water regulating valves.

O. Control of discharge pressure is critical for proper system operation and especially at lower outdoor conditions. If the discharge pressure is too low the typical expansion valve, which is a fixed orifice, will not provide enough refrigerant to the compressor, as the lower pressure differential reduces the mass flow.
This causes the suction pressure and temperature to lower to critical values. This can result in frozen coils or heat exchangers which, in turn, can cause slugging of the compressor because not enough refrigerant is being evaporated; thereby allowing liquid to enter the compressor suction. There is usually a low pressure cut-out switch but it is mainly to prevent compressor operation upon complete loss of refrigerant.

P. Condensers can very easily provide sub-cooling of liquid refrigerant. This is a desirable feature as it provides several benefits. Sub-cooling will provide more R.E. as noted on the previous PH chart as points D'and D. This is done at no increase in compressor energy input. If an evaporator coil is located at an elevation considerably higher than the condenser; there can be enough loss in pressure drop of the liquid line and reduction in pressure due to height so that flash gas can occur prior to the expansion device, with the resulting loss of capacity. The pound mass flow of a gas is far less than a liquid through a fixed orifice.

Q. There are electronically controlled expansion valves that can vary orfice opening to allow increased refrigerant flow at low pressure differentials. These can be used to enhance EER ratings at low capacities and outdoor temperatures with the resulting low condensing temperatures and pressures.

R. To summarize this thermodynamic cycle the following conditions on the prior PH chart are noted:

1. R.E. = $h_{A'} - h_A$ = Btu/lb;
   lb/min refr.flow = (200Btu/min/ton)(tons)/(h_2-h_1)

2. Available R.E. = $h_B - h_A$

3. Work input to compressor = $h_C - h_B$

4. Energy removed in condenser = $h_C - h_D$

5. Sub-cooling of liquid = $h_{D'} - h_D$

6. Expansion process at constant enthalpy = $h_A = h_D$

7. Coefficient of performance = C.O.P. = R.E./input = $(h_B - h_A)/h_C - h_B)$

8, C.O.P. for heating = (condensing+heat of compr)/heat of compression = $(h_C - h_D)/h_C - h_B)$

9. EER = energy efficiency rating = C.O.P. X 3.413

S. From this review it should be obvious that by raising the suction pressure by using more heat transfer area, and more surface in the condenser to lower the head pressure, there will be a reduction in energy costs that are beneficial to the owner for the life of the equipment. This is not readily achieved in standard packaged equipment.

III Psychrometrics

A. The thermodynamics of moist air is called psychrometrics and a psychrometric chart is a graphical representation of a range of air-water vapor mixtures. It was invented by Dr. Willis Carrier in 1911. It indicates dry bulb and wet bulb temperatures, dew point temperatures, relative humidity, absolute humidity, cubic feet per pound, and total heat in a mixture. This data will vary with elevation and has to be considered when being used. These charts can and should be used to plot the air conditioning process for each design project. This helps the design engineer insure that the proposed design will properly function and is achievable with the equipment being considered and specified.

Definitions of the various components of a psychrometric chart:

1. Dry bulb - is the temperature recorded by an ordinary mercury thermometer; the sensible heat of a space.

2. Wet bulb - the temperature when a thermometer has its bulb encased in a wet cloth and when exposed in an air stream is the lowest temperature attained. This is an indication of the content of the air.

3. Dew point - is the temperature at which moisture will begin to condense out of the air.

4. Relative humidity - An expression of the amount of water vapor in an air-vapor mixture compared to the maximum amount that it is capable of holding, in percent.

5. Absolute humidity - the actual weight of moisture in air expressed as lb/lb,dry air, or in grains/lb (7000 grains/lb)

6. Cubic feet per pound - the volume of air at various temperatures and humidity per pound.

7. Total heat - the sum of sensible and latent heat values in air mixtures and closely follows the wet bulb temperature - it is in Btu/lb.

8. ADP - (apparatus dew point) is the average coil surface temperature and is determined on the psychrometric chart where the coil sensible heat ratio line intersects the saturation line.

B. The various processes that can be plotted on the chart are:

1. Cooling
2. Heating
3. Dehumidification
4. Humidification
5. ADP
6. Air mixing

These are illustrated on the following chart Fig. 1.

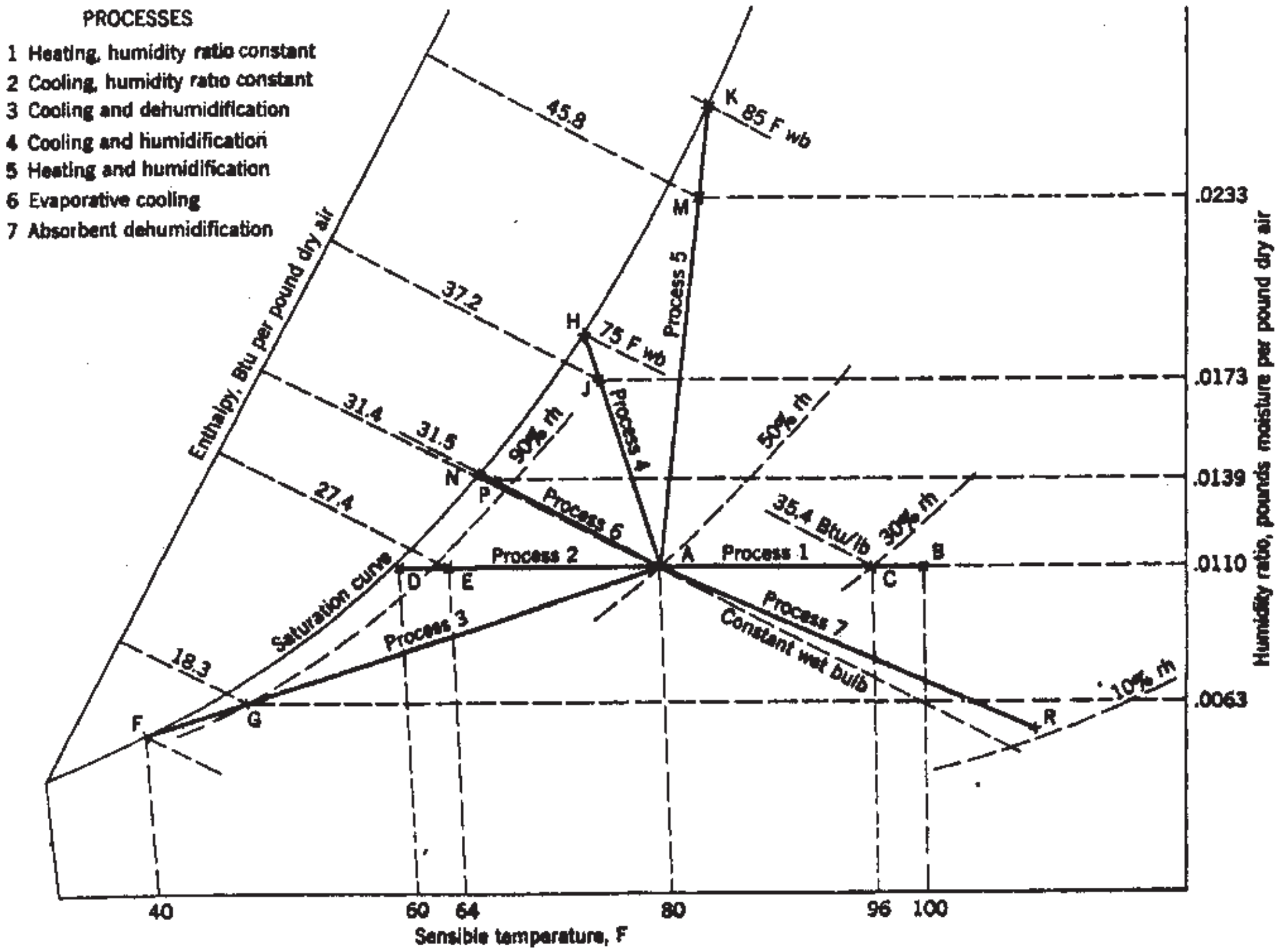


Fig. 1 Basic processes are easily comprehended when plotted on chart.

Note: To make the illustrated charts easier to read, duct gains and fan motor heat were not indicated.

C. To help use these charts and to utilize calculations to verify the process some useful formulas are used;

1. Sensible heat = $Btuh_s$ = 1.1(CFM)ΔT; where ΔT is in ^oF and 1.1 = (0.245 sp.ht. X 60 min/hr)/13.33 ft^3/lb.

2. Latent heat = $Btuh_l$ = 4840(CFM)ΔW; where W is lb. of moisture/lb of dry air, and 4840 = (60 min/hr X 1076 Btu/lb water vapor)/13.33 ft^3/lb of dry air

   OR

   0.68(CFM)Δgr; where 0.68 = 60 min/hr X 1076 Btu/lb)/7000 grains/ lb of water.

3. Total or coil load in Btuh = 4.5 (CFM) Δh ; where 4.5 = 60 min/hr / 13.33 ft^3/lb and Δh is the enthalpy difference in the air being cooled and dehumidified etc.

4. $Btuh_t$ = $Btuh_s$ + $Btuh_l$ [with no O.A.(outside air)] OR $Btuh_s$ + $Btuh_l$ + $Btuh_{oa}$ = $Btuh_t$

5. Supply air CFM = Btuh/1.1(Δt).

D. A standard air conditioning system with outside air being introduced into the return air is illustrated on the following Fig. "A" and it is assumed that everyone taking this review course is familiar with it.

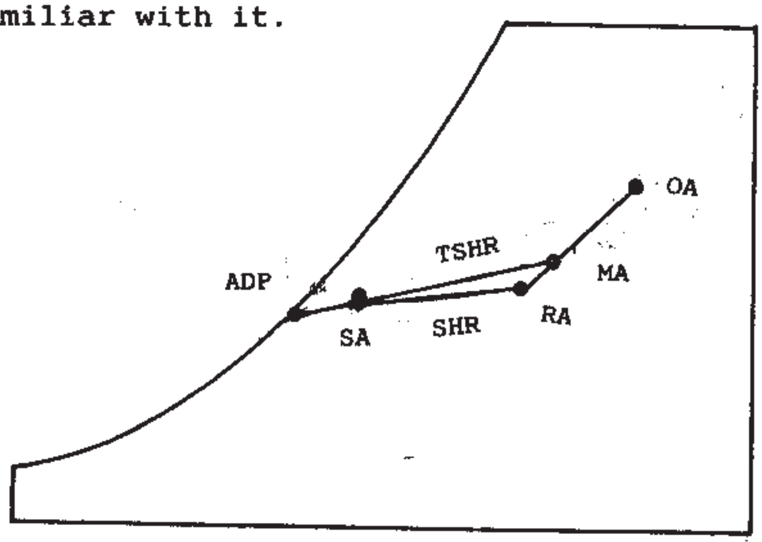


Fig. A

E. In the latest codes that have been adopted pertaining to the amount of outside air (O/A) that is required per person, this standard cycle can have psychrometric problems. The large amounts of O/A generally has so much moisture that the latent load causes the SHR line not to intersect with the saturation line on the chart. This is illustrated on the psych. chart Fig. "B" below:

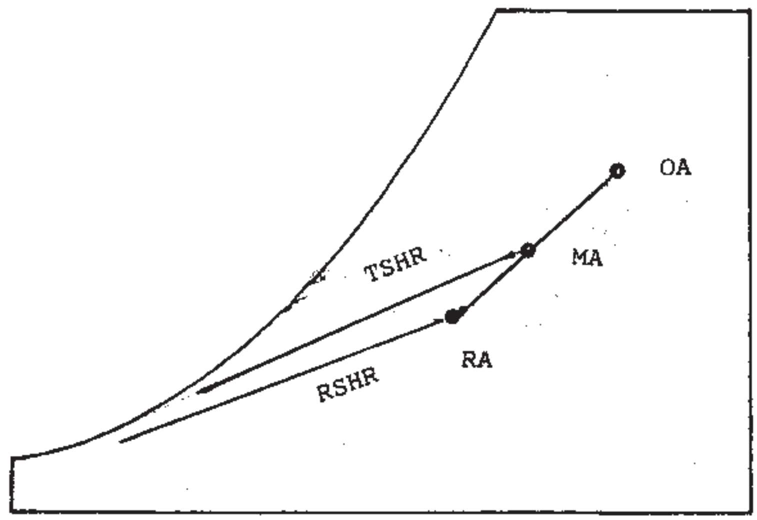


Fig. B

F. This causes problems when selecting cooling coils that need to satisfy the required supply air (S/A) conditions of Fdb and Fwb. This can be resolved by several different methods.

1. The first and easiest solution is to look at the selected design conditions. Room design of 50% RH can be increased to up to 60% RH and still meet comfort conditions. This changes the SHR line so that it can perhaps intersect the saturation line. See Fig. C.

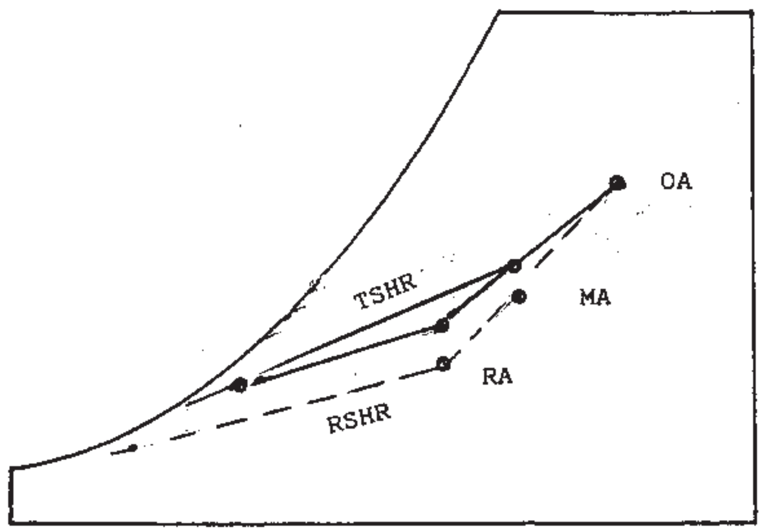


Fig. C

2. Make sure that the O/A design wet bulb is not just an arbitrary number but is indicative of the locality. This can seriously affect the latent loads that the coil has to cool and dehumidify, this can be seen on Fig. "D"

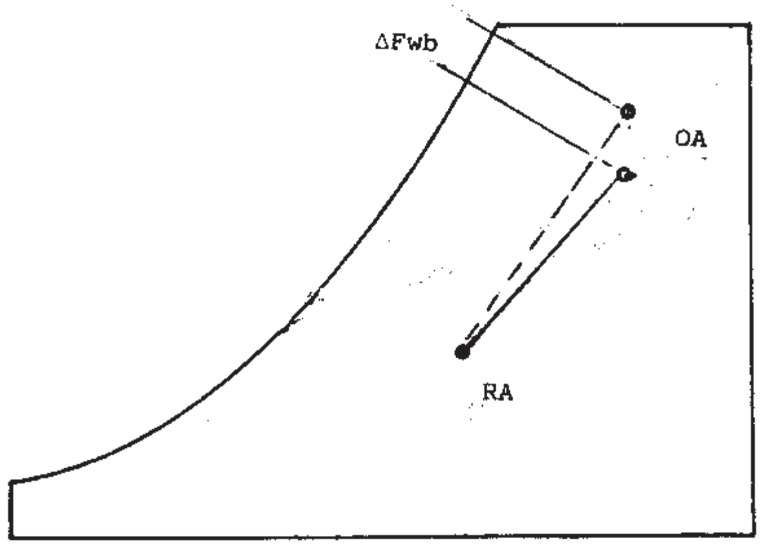


Fig. D

3. Large quantities of O/A that are required and are then mainly exhausted through various exhaust systems can be pre-treated by special air conditioning units that are designed to handle only 100% O/A. These units have special coils, controls, head pressure controls, etc. and can provide cooled and dehumidified air at room conditions which is then mixed with the return air which then is introduced to the system air conditioner. See Fig. "E".

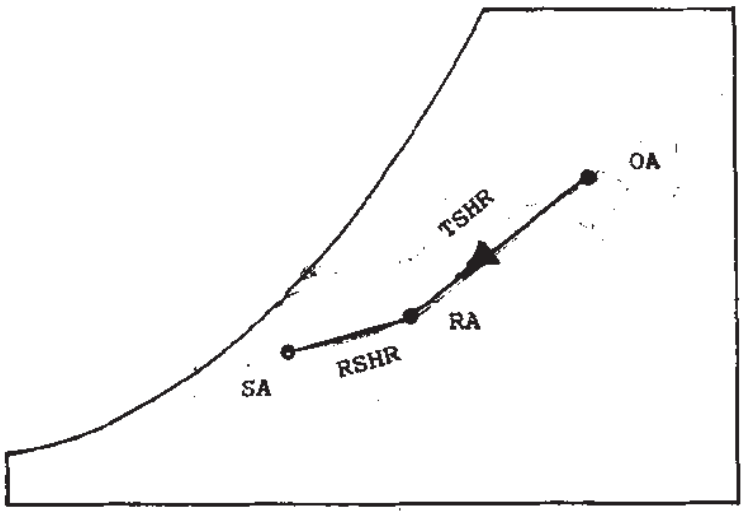


Fig. E

4. Another solution is energy recovery devices that utilize a media to recover exhaust sensible and latent energy. This recovered energy is then used to cool and dehumidify the entering O/A. This type of device reduces the air conditioning cooling and heating capacity of the designed system. The energy savings are usually great enough to provide a payback in a short time period, and sometimes can result in a lower overall first cost. See Fig "F".

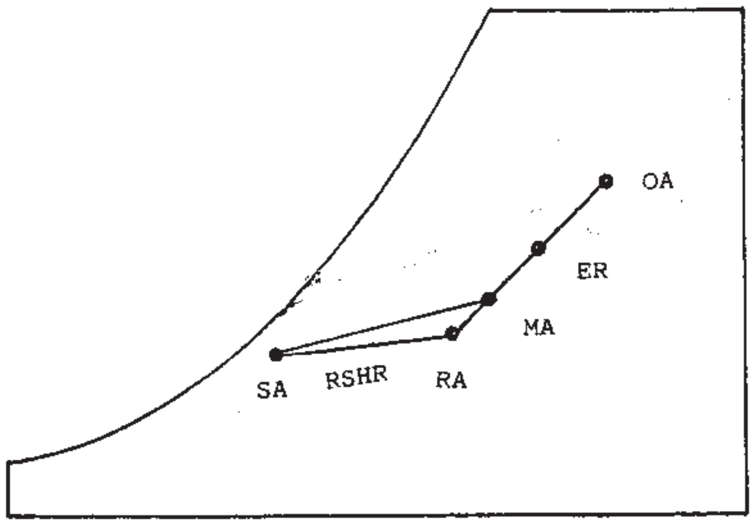


Fig. F

G. Another type of system that is generally not too well understood and can cause design problems is the system that requires reheat (when allowed by code). This is used in special applications that require 100% O/A or have extremely high latent loads, or have some very accurate temperature-humidity requirements. When plotted on a psych. chart the SHR line does not intersect the saturation line. This then requires that the cooling coil leaving air temperatures (LAT) "overshoots" or "overcools" so much so, that the required room conditions can not be met. Reheat is then used to provide the right supply air conditions. Unfortunately this requires that extra cooling of the air is required plus the extra reheat energy for increased operating costs. See Fig "G".

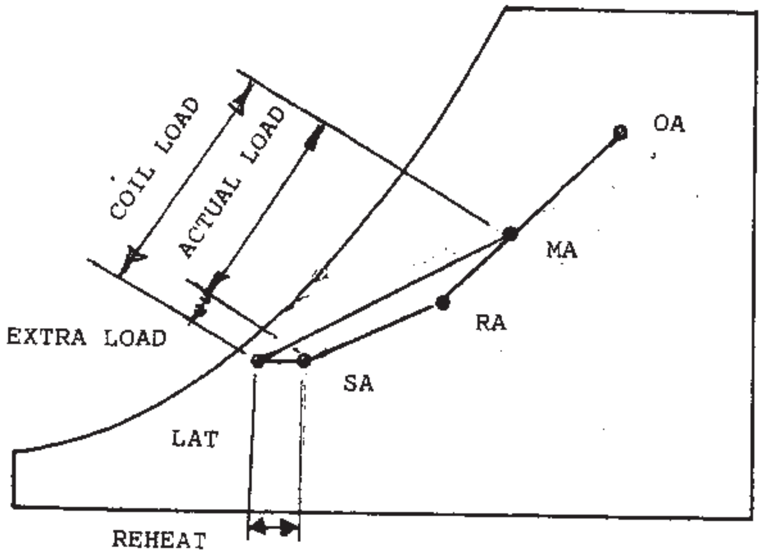


Fig. G

H. The use of psychrometric charts in the design of any air conditioning system is an excellent method of evaluating an intended design as well as back-up information for records. Some computer programs will do this if requested and can print out a chart showing the results.

J. Proper utilization and the use of good design criteria in the early stages of a project will result in systems that will be a success. Sometimes the psychrometric aspect of a design is overlooked and this can lead to disastrous results. Many times it will show up when knowledgeable engineers with a manufacturer lets you know that your specified design is not possible and you have to issue a rather lengthy addendum.

K. Another design situation that is often overlooked has to do with systems that utilize return air through the light fixtures into a return air plenum system above the ceiling. This is a design that requires more thought and different design calculations. The return air through the lights usually will intercept ±65% of the heat of the lights; this means only ±35% of the heat enters the room load. A plenum return on a single story building also intercepts most of the roof and wall heat gains again reducing the heat gain to the space. Of course the air temperature in the plenum is higher than in the air conditioned space and thereby transmits a small amount of heat through the ceiling into the room. It is an easy calculation and has to be considered. This is shown in Fig."H".

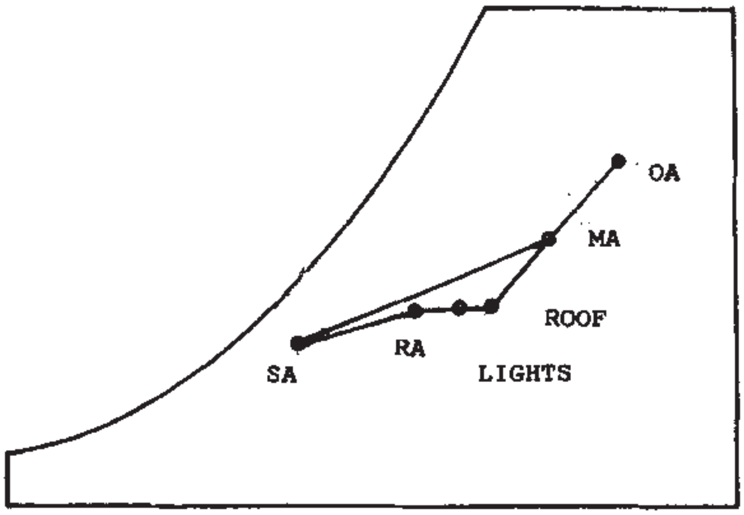


Fig. H

L. This type of system requires less CFM per square foot, smaller duct work, less fan HP, and generally a smaller air handling unit. Many times, because of higher entering air conditions, a more economical cooling coil can be selected. Both first cost and operating costs are to the benefit of the owner. Another secondary benefit is the increased lumen output from the lights as well as increased longevity of the lights and their ballasts.

M. Another caution has to do when so called "value engineering" is involved. This is sometimes called for by the owner, sometimes by the general contractor, sometimes the architect. HVAC is usually the largest of the sub-contracts and a jaundiced eyeball is always cast upon it. Many times a mechanical contractor, eager to retain the contract, will gladly co-operate, and will propose alternate equipment. This will generally be for "packaged" or "off the shelf" equipment for "X" number of dollars in savings.

N. You are then asked to evaluate this proposal. You first notice notice that the cooling coil only has four (4) rows not the six (6) rows specified. A layout on the psychrometric chart can quickly show that the humidity in the space will be approximately 65%, and not the 50-55% designed. This exceeds design parameters as well as recommended maximums and will encourage mold and mildew growth. A friendly letter to all parties, with a return receipt, will do much to reduce your probability of litigation.

IV Load Calculations

A. In order to be able to properly size and specify HVAC equipment, calculations of the space(s) that are to be cooled, dehumidified, heated, humidified etc. have to be accurately done. This is necessary whether the project is a residence, a school, an office building, assembly buildings, storage buildings, and even refrigerated storage or frozen food warehouses.

B. These calculations evolved over time and increased as more and better testing methods and equipment were developed. There are tables and graphs that were in use in the beginning of the 20th century but as knowledge increased, different and better methods were devised. The heat properties of building materials was accurately determined and testing of the various components was achieved. Tables were developed with regards to outside air temperature, and the related solar load, and their impact on the various types of construction. These tables were used for many years with much success.

C. During the 1930's tables were developed for various latitudes and orientations for walls, roofs, and glass. In 1967 ASHRAE developed the "total equivalent temperature differential method with time averaging" (TETD/TA). This method has proved to be very reliable and was used in earlier computer programs. The "transfer function method" (TFM) was introduced in 1972 by ASHRAE but required many calculations and proved more useful in determining average loads rather than peak loads. This in 1977 evolved into the "cooling load temperature differential" (CLTD), "solar cooling load factor" (SCL), and "internal cooling load factors" (CLF). These tables can still be used in hand calculations.

D. At present two methods are presented in ASHRAE, one is the "heat balance method" (HB) and the other is the "radiant time series" (RTS). These are for computer programs and the RTS is a simplified method of the HB method for peak load calculations. The results of any of these methods are very close to each other.

E. No matter which method of calculation is used, certain basics are involved and these are:

1. Building Characteristics and Configuration.
2. Inside and outside conditions including operating schedules, date, time of day, and latitude.
3. People and their activities.
4. Lighting.
5. Type of return air system.
6. Internal equipment and appliances.
7. Outside air quantities and condition.
8. Miscellaneous such as infiltration, fan motors, duct location, pumps,etc.

F. Building characteristics has to do with the construction of walls roofs, fenestration, shading, compass orientation etc. This can be very critical as a change of building orientation such that a large northern glass exposure that is changed to a west or east exposure will drastically change the building load as well as air quantities. Insulation requirements along with vapor barrier locations are very important. In the humid south the placement of the vapor barrier is the reverse of northern climates. Our problem is moisture migrating into the structure from the outside, which can be trapped in interior cavities resulting in mildew on interior walls and behind vapor proof wall coverings.

G. Proper selection of outdoor air and room air conditions is especially important as it will seriously affect the calculations. The proper consideration of the buildings operations and usage can result in peak loads that may not coincide with the peak outdoor conditions. A computer load calculation with all of its quick iterations that are possible will determine this very quickly.

H. The number of people and their type of activity is important for both the sensible and latent components of load calculations. The proper selection of a cooling coil is very important and is readily affected by this data. This is most critical in assembly structures such as churches, theaters etc.

J. Lights contribute the largest continuous sensible heat gain to the HVAC load. How it contributes to the load is of importance. Fluorescent and metal halide lights use much less electrical energy than incandescent lights for equivalent lumen output. Return air drawn through the light fixtures to a return air plenum above the ceiling results in savings that were previously described. There is also a time delay effect of lighting as to when all of the heat actually contributes to the space, and most computer programs do take this into consideration. If the calculations are done by hand, this should be considered.

K. Internal loads from computers, appliances, equipment, motors etc. have to be accounted for as to when these items will be used, how many, and how long. Schedules indicating these operations in computer programs is a must.

L. Outside air contributes greatly to the air conditioning load calculations and, depending on the time of day, can have large latent loads that during an on-off thermostat operation will result in higher levels of indoor humudity than is acceptable. Outside air in the load calculation process is determined by cooling and dehumidifying it to the design room conditions, not the supply air temperature off the cooling coil.

M. Under miscellaneous loads, consideration has to be given to infiltration due to door openings, window leakage, building construction, and other aspects that can cause outside air to infiltrate into the building and is then part of the cooling or heating calculations. There is also heat gain or loss from adjacent unconditioned spaces.

N. The proper attention to all of these inputs is required for accurate calculations and will result in good useable data that is required for the equipment and their selection thereof. Too much safety factor will result in oversize equipment that costs the owner more money and, depending on the type of system, may not work well under part load conditions. In general it is better to have a system that is as close to design as possible. A system that is slightly smaller in capacity than design generally has better humidity results because of longer operational periods especially during high temperature humidity hours.

O. The calculation of heating loads is easier and is basically due to temperature loss through the walls, roof, windows, and outside air due to ventilation requirements and infiltration. Of importance is the outside air design temperature that is relevant to the area. Design conditions are quite different for the Florida Keys compared to North West Florida,

P. Most of the heat gain loss or gain for a given structure is based on the classic $Q = U(A)\Delta t$, where Q is the quantity of energy in Btuh, "A" is the area in ft^2 , Δt is temperature and/or Sol-air temperature in ^0F, and U is the reciprocal of R_T or the total resistance of the building components being considered and is in Btuh-$ft^2 \cdot {}^oF$, and is sometimes called the "overall coefficient of heat transfer". Remember also that heat gain through fenestration consists of two components; heat transfer and solar gain. Solar heat is usually the predominant value, but by use of shading, special glass and orientation can be a much lesser amount.

Q. Careful calculations will result in data that has to be used for the proper selection of equipment that is to be used in any given project. The use of "rules of thumb" cannot be an excuse for good engineering calculations. Most of these such as; "400 CFM/ton", "500 ft^2 / ton, or "use a 20 X 12 register because the room is 20 X 12", are contractor evolved and are not to be used in the real world of Mechanical Engineering.

R. Also remember that when utilizing computer calculations, wrong data in will always result in bad output - "garbage in equals garbage out". Experience helps one to realize when results are realistic. But as in any engineering project, checking input and output is a basic requirement. When doing the calculations room by room the sum of their total results should be very close to an overall building calculation.

S. Skilled engineers are still required in order to apply engineering methods correctly and intelligently.

V Equipment

A. Basics

(1) One of the most important functions of the design professional engineer is the selection and specifying of the equipment for use in the designed project. All the calculations and thought given to a HVAC system will be for naught if equipment is not carefully selected and specified.

B. Refrigeration Equipment

(1) The refrigeration equipment usually used is the vapor compression type. This is accomplished with reciprocating, screw, scroll, or centrifugal compressors. There is also absorption units that at times is an economical choice if there is an abundance of waste heat available.

(2) The compression process as detailed in Chapter II should be looked at for several conditions of operation. Standard ratings for energy use of air cooled equipment is usually 95F outside air and 45F suction. By careful selection of cooling coils or the chiller barrel it is possible to raise the suction temperature by several degrees thereby increasing the cooling capacity and lowering the energy input. On water cooled condensers a lower condensing temperature will also give similar results. If both are accomplished even greater savings can be realized.

(3) On air cooled units discharge, or head pressure control, is usually required in order to have the expansion device operate properly and to keep the evaporator from freezing up. There is also electronically controlled expansion devices that will allow head pressure to vary so that pressures much lower than normal can be used which results in very low compression ratios and will increase EER ratings to over 15. In this day and age data is readily available from manufacturers' computer programs for these varying conditions. If units are near salt water, coating the coils and utilizing stainless steel fasteners is advisable to provide a longer life.

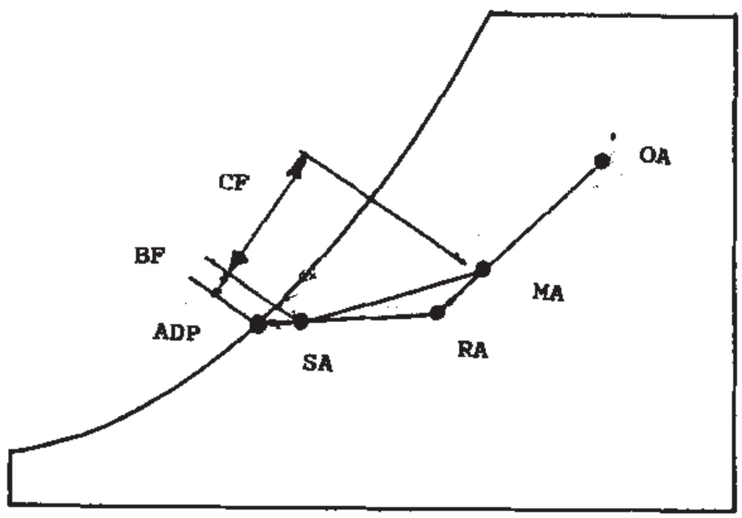
(4) In general reciprocating units have more friction to overcome from piston rings, bearings, wrist pins etc. By not having all these parts in screw, scroll, and centrifugal machines, they will have less horsepower input requirements.

C. Coils and Heat Exchangers

(1) The evaporators in most systems are generally either finned tube air cooling coils or shell and tube heat exchangers using water or a secondary brine.

(2) Cooling coils usually have copper tubes with aluminum fins bonded mechanically to the tubes. The number of rows can vary from 3 to 8; and the fins from 8 to 14 per inch. The heat transfer is dependent on these variables, the air velocity, and refrigerant conditions. A coil will produce different cooling results because of these. A 6 row coil will always remove more moisture than a 3 row coil with other conditions remaining the same.

(3) With all of these variables it is most important to properly select a coil to meet the conditions that were determined from the load calculations and the psychrometrics. An easy way to illustrate this relationship is by the use of "contact factor" or, conversely, the "bypass factor". The "contact factor" is the amount of air going through the cooling coil that contacts the cold surface; whereas the "bypass factor" is the amount that goes through without contacting a cold surface. Of course a 100% coil, which is impossible, would be at ADP. This will vary depending on the coil, but will be in the order of 0.80 C.F. for a 3 row coil to 0.95 C.F for an 8 row coil. This is illustrated on the psychrometric chart below;



CONTACT FACTOR AND BYPASS FACTOR

(4) Coils also should be considered for routine cleaning as most filters do not remove the very fine particles. With fins more than 12 per inch it will be more difficult to properly clean them. If the air has some chemical content that cannot be filtered out and can attack the aluminum fins, a protective

coating is a good investment. But remember, this will have a slight negative effect on cooling capacity. Coils, with chilled water for the cooling source, work the same way but have a more constant temperature and can be used to more readily control air temperatures and removal of humidity.

(5) Chiller barrels are of shell and tube construction with the refrigerant being inside the tubes on all compressors except centrifugals where the reverse is true. Centrifugals do not have oil circulating in the refrigerant so oil return is not a problem whereas the other compressors do have the oil return to contend with. Of course having water in the tubes allows for cleaning of the tubes compared to the water being on the outside. Remember that more surface will result in higher suction temperatures with resulting increase in capacity. The extra cost for this can usually be justified on long life units such as centrifugals.

D. AIR HANDLERS

(1) Air handlers can vary from small wall/ceiling mounted cabinet units with limited variations; air handlers that are factory packaged with no variables such as coils, fans, etc.,to units that have all components that can vary, and built up systems that are an integral part of a building. These last two options allow the professional engineer to meet design requirements. In the humid south it is wise to select units with galvanized construction and insulation that can readily be cleaned. Some manufacturers offer internal steel spring vibration isolators which eliminates the flexible connections that would be required at the ductwork.

(2) The fans in air handlers are generally forward curved and their operating conditions should be checked out on a fan curve to see that the fan is operating in a good stable, efficient, and quiet manner. This can result in lower HP requirements. Variable air volume (VAV) systems require variable air flow and attention has to be given to it. This can be accomplished by inlet guide vanes but is better with electronic speed control.

(3) The best way to control temperature and humidity on a constant volume system is with a face and bypass damper. This is where the return air is allowed to bypass the coil as load is reduced which allows the coil to remain cold and at lower air flows takes out more moisture from the air going through it. A valve control that varies the flow of water going through the coil loses control of humidity very quickly as the reduced water flow allows the coil to warm up to above the required ADP.

(4) The use of a modulating valve on a VAV system to control discharge temperature of supply air works well.

E. Condensers and Cooling Towers

(1) Condensers are usually air cooled or water cooled as previously described. Air cooled units should have a louver to guard the fins from vandalism and damage. The louver should also provide shade on the coil to keep the solar load to a minimum in the hot afternoons.

(2) Water cooled units usually utilize cooling towers, as fresh water is too costly and not in accordance with regulations. Most towers have a fan that pulls air through the wetted surfaces to evaporate the warm water in order to cool the remaining water down and these are usually of the upblast type. There are also atmospheric towers that use either induced air from the water distribution nozzles or a chimney effect to induce air flow. Water treatment is a necessity in certain areas to keep scaling and corrosion to a minimum and always should be specified.

F. Pumps

(1) Pumps are utilized in chilled and hot water systems as well as in cooling towers. The selection of these pumps can show considerable variations from the various manufacturers. Pump curves need to be reviewed carefully. Of importance is the efficiency and the location of the operating point on the curve, generally to the left of the peak efficiency. These two items can cause large differences in HP and the selection of pump motors. This can have a large impact on operating costs per year and needs to be analyzed. It is possible to reduce motor size from 20 HP down to 7½ HP by careful selection and analysis.

(2) Most chilled water or cooling tower pumps have to operate in order for the system to operate normally. If a pump fails, the system ceases to operate and sometimes can be out for a considerable period of time. The design of dual pumps in parallel can prevent this. This requires the development of a system curve, and the selection of pumps that can operate at design and at single pump operation. Careful selection of the pumps can result in 80 to 90% design flow if one pump goes down. The motor HP will have to be selected for the operation as a single pump; but this is a very good design requirement

(3) Certain components of pumps should be considered such as:

- (a) Base mounted so that a motor failure can be repaired more readily.
- (b) Use totally enclosed fan cooled (TEFC) motors when they are located outdoors or in wet areas. Make sure there is a safety factor rating on the motor.
- (c) Casing wear rings on large pumps make it easy to restore pump performance.
- (d) Use mechanical shaft seals on closed systems and stuffing box seals on cooling towers.
- (e) Impellers should be bronze.

(f) Flexible connections in the piping shall be parallel to the pump shaft.

G. Heating Equipment

(1) There is probably more electric strip heat used in the deep south than other means because of short mild winters and minimum heating requirements due to the well insulated building envelope required by State Energy Codes.

(2) Heat pumps are used mainly in residential systems and some times in light commercial. They are an efficient use of electricity as the amount of heat output is approximately three times the energy input. If these units are used in buildings that have large internal loads, the oversize heating capability will result in excessive cycling of units, which will reduce their longevity.

(3) Boilers are generally used for hot water heating in the south on large projects and are usually oil or gas fired with forced draft. There are various types of boiler construction such as fire tube vs. water tube. The advantages and disadvantages have to be considered during the selection process.

H. Miscellaneous

(1) There is more equipment that is used in HVAC systems but this Chapter was intended to cover the major components that are more critical and more often specified.

VI Air Distribution and Ductwork

A. General

(1) Air conditioning is more of a concern in the humid south due to the heat and humidity and the conditioned air is generally distributed to spaces with people being the recipients.

(2) The conditioned air is normally distributed through the duct work to the prescribed areas by air distribution devices.

B. Ductwork

(1) Ductwork can be made of a variety of materials but usually is fabricated from galvanized sheet metal and/or fiberglass.

(2) Sheet metal ductwork is shop fabricated in square or rectangular shapes and is assembled on the job site. This requires a knowledgeable sheet metal mechanic.

(3) Round and oval sheet metal duct is factory fabricated including the fittings and is assembled at the job site. This requires a sheet metal mechanic to assemble and install the components. This duct is also available with a liner for both acoustical and insulation purposes.

(4) Fiberglass ductwork is field fabricated and assembled using tape to connect duct joints, seams. fittings etc. Since skilled mechanics are not required the fabrication of fittings etc. is often not done in accordance with standards and as a result can cause air distribution problems.

(5) Most state energy codes require that all joints and seams of ductwork be sealed by the use of tape and/or mastics. Aluminum foil tape with a UL rating and an adhesive, whose strength increases with time, is a good choice. Grey duct tape does not meet this requirement.

(6) Flexible duct is used for main runs, branch ducts, and connectors to air distribution. Various types are available from vinyl lined and covered, with a coil spring, to an aluminum flex liner with insulation covered with aluminum foil. The later type is much better at holding its shape during installation and especially where elbows are required The major disadvantage is the much higher pressure drop than standard duct work. When used as run outs the short lengths are not critical.

C. Duct Insulation

(1) Shop fabricated sheet metal duct can be insulated with a liner prior to forming the duct to the desired size. This liner

should have a surface that will withstand erosion from air flow velocity, and not support mold and mildew growth. This method is not used as much as in the past, but it is still acceptable. There are advantages in its use such as the fact that no vapor barrier sealing is required and it can not be ripped or torn by other trades causing future wet and soggy insulation.

(2) Duct wrap insulation is accomplished after the duct has been installed at the job site. The insulation is usually fiberglass with an external vapor barrier jacket which is usually aluminum foil. This requires another step in the installation process and requires a quality tape to seal the joints, seams, staples etc. Unfortunately many times, because of hidden or hard to reach spots, the taping process is not properly done. It will take a while, but eventually moisture will migrate through the gaps, and the insulation will become soggy, will drip, and sometimes will even fall off. This can not happen with duct liner.

D. Air Distribution

(1) Duct work conveys and supplies the air to the areas to be conditioned where it is then distributed into the room. This can be done by:

- (a) Side wall registers
- (b) Ceiling diffusers
- (c) Slot diffusers
- (d) Floor registers
- (e) VAV Boxes

(2) Side wall registers should be of aluminum construction in humid areas (no rust), double deflection, and with an opposed blade damper. If they are installed on the side of a duct be sure to specify an air turning device or "rake off" to insure even air flow across the register. Use a reputable manufacturers engineering data for proper selection as to throw distance, noise criteria, and terminal velocity for human comfort.

(3) Ceiling diffusers can be round, square, rectangular, and be of lay-in or surface mounted styles. They also need to be of aluminum construction in the south, except in fire rated ceiling assemblies. They also require even air flow at their necks to insure proper operation. All diffusers will eventually develop dust streaks on it and the adjacent ceiling area. This is not from dirt in the supply air, but is from the particles in the room air. This air is induced toward the diffuser where it makes a sharp turn and accelerates it enough to develop a static electric charge, causing it to "stick". This dirt effect is more pronounced on preforated panel outlets compared to a multi-cone outlets. Curved blade outlets can work well, but, because of their construction individuals will always "readjust" them to the detriment of their operation.

(4) Slot diffusers are less intrusive in a ceiling, are more costly, but work very well especially when colder than normal air is used. They induce secondary air quite readily and in VAV systems do not generally "dump" air. These outlets can have multiple openings and be adjusted for the desired direction of flow.

(5) Floor registers are similar to ceiling slots but are of more rigid construction due to the traffic. The throw direction cannot be adjusted and has to be determined and specified on the drawings. An opposed blade damper is also required for balancing purposes.

(6) Variable air volume (VAV) boxes are a method of providing individual temperature control to each individual space. The box controller is actuated by the thermostat in order to decrease or increase the amount of air to satisfy the required room condition. There are many varieties of boxes available, some utilize only the air in the system, some are fan powered to provide more circulation, some with heating capabilities etc., and their selection is determined by the required application. They also can be pressure dependent or pressure independent. Pressure independent is an advantage as the box will compensate for variations in duct pressures that are common in VAV sytems.

F. General

(1) The air diffusion performance index (ADPI) is a method of determining the proper layout and performance of an air distribution system, The proper use of it will generally result in satisfactory air distribution and be relatively draft free. There is a section in the ASHRAE guide about this as well as in the engineering section of air distribution manufacturers.

(2) The design of a duct system can be by one of several methods. One of the oldest types is the equal friction method, where a velocity is assumed at the beginning of the duct system, and the pressure drop/100 ft. value is then used to size the remaining duct work. This works, but is not self balancing, and requires more balancing at start up. Static regain and the T-Method both require iteration and are best suited for computer programs for quick and accurate calculations. A properly designed system, utilizing a computer program, will indicate where dampers are required - if any, and will result in economical, quiet, and generally self balancing systems.

(3) The last consideration is the subject of noise. Various types of spaces require different acceptable noise levels. A gymnasium and a library are quite different. Noise generated by fans, duct work rumble, VAV boxes, air distribution outlets etc. all have to be considered, and sometimes the use of sound absorbtion is required to achieve the required goals. It is easier during the design stages than to try and solve after job completion.

VII. Types of HVAC Systems

A. General

(1) Various types of systems are available and used for the different types of structures and their requirements.

(2) The size of the system will help determine the types to be considered and then selected and to be used in the design stages.

(3) Various major types of equipment

(a) Refrigeration
(b) Air handlers - cooling/heating
(c) Packaged units

B. Refrigeration

(1) Air cooled condensing units are used in systems from approximately 1½ tons and with multiple units up to several hundred tons. These systems generally have the lowest first cost, but capacity control can be a problem and coil temperatures can vary considerably. EER ratings can be up to 15±.

(2) Air cooled chillers up to 450± tons are available and will provide chilled water for a variety of air handling systems. These are relatively low maintenance and can have very high EER's at lower outside air conditions. They will deliver a relatively constant water temperature for good cooling coil conditions.

(3) Centrifugal chillers are available from approximately 100± tons to several 1000 tons. They will provide very low energy requirements. but pumps and cooling tower fans have to be figured in. These chillers can be either hermetic or open drive with an electric motor or a steam turbine. Cooling tower water requires chemical treatment however centrifugals have a very long life potential, and with proper maintenance a 30 to 40 year life is common.

C. Air Handling

(1) Small direct expansion (DX) systems up to about 15 to 20 tons generally will have available an "off the shelf" air handler that has no variables such as coils, fans, filter racks etc. These are used in residential and light commercial applications.

(2) Air handlers from approximately 10 tons and up to 100 tons are available with a wide variety of coil selections, fans, filters, arrangements, etc. Coils can be for DX or water, fan modulation or inlet guide vanes, face and by-pass control, multizone configuration, and other features. Most any condition

can be met with these types of units.

(3) Very large systems that exceed the capacity offered in factory units are built into a given mechanical room with coils, fans and motors, filters etc. all being field assembled. Since these are in effect custom units, most any conditioned requirement can be met.

D. Packaged Units

(1) Standard package roof top mounted air conditioners are factory assembled, with roof mounting curbs, are high volume production units and are up to 50± tons. These again are fairly standard with given coils, fans, etc. but can be available with various heat capabilities such as heat pump, electric, and gas. These types of units are readily used in all areas with low rise buildings and do not require interior floor space.

(2) There are also large roof top units available up to 150± tons, and these are factory built to meet the conditions determined by the engineer. These can be available for VAV use, have heat recovery, energy recovery systems, etc.

(3) There are also packaged units that are generally water cooled and that are used in a commercial store with a discharge plenum and air registers and no ductwork. These are also used on individual floors of multi-story buildings. They do require a condensing water source generally from a cooling tower or a well. There is also available air cooled condensers that are remotely mounted.

E. Combined Systems

(1) Condensing units used in conjunction with their standard air handlers are fairly common and are probably the lowest first cost for split system. They are designed to meet basic energy code requirements.

(2) Condensing units matched with the more custom air handlers will provide a better operating system and can meet more difficult operating requirements. They are usually of galvanized construction, can provide higher EER ratings, and will have a longer life than off the shelf items.

(3) Chilled water systems, whether using reciprocating or centrifugals, with the various air handlers available, can provide cooling capabilities for each specific requirement throughout the building. Many times there are internal loads that are not all simultaneous or that can move to different areas. A diversity factor can be applied to reduce the size of the chiller. This will reduce first cost and is good engineering practice - but it has to be engineered. The cost of chilled water systems is quite

a bit more than DX systems, but has a long life and is in general more "forgiving" for adjustments and any future changes required. Chilled water is a very good application for VAV systems as the coil leaving air temperature will be constant and will always properly condition the ventilation outside air.
(4) Rooftop packaged units have a place in most areas in the HVAC industry. With the many single story buildings being in existence, and being built, they are a priority with contractors. A definite advantage for service personnel is the easy access to all the components. Noise and vibration are two detriments that have to be addressed. Vibration from the unit can cause it to be transmitted to the roof structure while fan noise can emanate from the return air duct. This can be resolved with good engineering practice and many times is an economical choice for certain situations.

(5) The water cooled packaged units are not readily used in many areas due to the water requirements. Cooling towers can be used. There is also the noise from the indoor compressors and possibly structural vibration.

F. Summary

(1) Many times the requirements of the building layout and how it is to be used will dictate the type of system to be used. Sometimes the owner has a preference. At times there are considerations to be given to several types of systems. An energy analysis program to determine which type of system is most economical, for a typical year operation, can be accomplished readily. This is a computer calculation and is readily available from different sources. The better programs will calculate this on an hour to hour basis for a typical year and for the location where the project will be located. This is an interesting engineering aspect and many times will provide a result that is different from what was originally considered as the best choice.

VIII. Energy Conservation

A. General

(1) Energy conservation is a requirement of State Energy Codes for building construction and is required for all buildings that are heated or cooled. It should be one of the main concerns of a consulting professional engineer. Even before there was an energy code requirement, responsible engineers used sound engineering practice and good judgment, when designing and specifying, in order to provide an economical and efficient operating system. This is not always done when other groups are involved and are only looking at first cost.

B. Buildings

(1) The engineer should always be involved in, and consulted by the project lead design professional about the external construction of walls, windows, shading, roof insulation etc. This is to insure that the structure will pass the requirements of the energy code.

C. HVAC

(1) The careful use of design calculations and the proper selection of equipment is a must in order to achieve the standards set by the Energy Code. How to do this was described in previous chapters.

(2) This will sometimes require more careful selection of equipment, but this is a major responsibility of a professional engineer.

D. Energy Efficiency Code For Building Construction

(1) Some energy codes require that a computer program be used by the design professional. This code can be used for more than one system type in any given building. Copies of the calculations are required when applying for a building permit. Be sure and check with the Building Permit officials as to exactly what they require for print outs.

(2) In most systems, with over a specified amount of HVAC, it is required that a professional engineer sign and seal the energy code, as well as the construction documents. Failure to do so can result in disciplinary action from a State Board of Professional Engineers.

IX Construction and Observation

A. General

(1) After the system has been designed and the plans and specifications are completed, a bid is requested and usually awarded to a Mechanical Contractor.

(2) This involves the engineer in several ways:

(a) The ability and financial capability of the contractor.
(b) Checking of equipment submittals and shop drawings.
(c) Observation during construction.
(d) Generally checking the operation of the system at completion and start up.
(e) Review the system commissioning and test and balance reports and either approve or disapprove.

B. Mechanical Contractor

(1) The mechanical contractor that will be doing the construction should, if not known to the engineer, provide a list of previously completed projects that are similar in size and type. The engineer should randomly check them out by contacting the owner, the design engineer, operating personnel, ask about the completed installation, its operation, ease of use, satisfaction with its operation, and as to the response time during the warranty period.

C. Submittals

(1) The engineer needs to very carefully check the operating characteristics of the proposed equipment. It is the contractors responsibility to verify that the proposed equipment will fit into the designated areas with proper clearances.

(2) The equipment submittals, especially on compressors and air handlers with coils should be "certified for performance" by the manufacturer because they are responsible for the correct performance at design conditions.

(3) Large projects will usually have duct and piping shop drawings indicating the proposed layout. These are provided to the engineer for his review and approval. Check them over and compare them to the engineered documents - sometimes errors are made.

D. Construction

(1) Make sure the overall design professional and the contractor will notify you as to when the mechanical work is being done. The

design engineer should, and with perhaps a junior engineer, inspect the project regularly. Check the duct and piping as well as their insulation, duct size, rough-in locations, hangers etc.. The excuse "we always do it this way" cannot supersede the contract documents. Always write a report on your observations and send it to the overall design professional. If a problem arises, and is resolved, always verify it in writing as to what was done and how. If a return air plenum system is used make sure the plenum is properly sealed and especially at outside walls. Outside air that can be sucked in will seriously effect the air conditioning systems operation.

E. Initial Start Up Operation

(1) At the job completion and when the equipment is being started up, it is wise to be there, as sometimes questions arise that you the design engineer can answer. One should look and listen for noises etc. so that you may point them out to the contractor. Sometimes fans are running backwards and the very cold air that is dropping from a ceiling outlet will clue you that something is not correct. If system commissioning is required most of these items will be addressed; but the design engineer should see the initial operation and results at the projects completion.

X. System Commissioning and Testing & Balancing

A. System Commissioning

(1) System commissioning is a process by a separate contractor to provide technical assistance to the mechanical contractor at start-up and to insure that the operation of the equipment is satisfactory and that the installation is for its intended use.

B. Testing and Balancing

(1) The testing and balancing is also done by a separate contractor that actually adjusts, balances, and tests on the air side, water/refrigerant side, pressures and flow rates of pumps and devices, temperature and humidity in the various spaces, some sound pressure, and electrical data of the HVAC components etc. This is a necessary part of the project and should not be done by the mechanical contractor.

C. General

(1) The reports of system commissioning and test and balancing should be carefully reviewed by the engineer. Check to make sure that the operation of the equipment is in accordance with the design requirements. This will require some calculation but sometimes these reports have errors. If errors are found require them to go back, review, retest, and redo the report to your satisfaction.

(2) Approval of the correct report is a function of the professional engineer and will probably save you future callbacks.

Examination

Mechanical Engineering Overview

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Tallahassee, FL 32301

HVAC - 1

1. The first mechanical HVAC system used this as a refrigerant:

   a. ammonia
   b. air
   c. Freon
   d. water

2. When refrigerant expands through an expansion device the enthalpy :

   a. decreases
   b. increases
   c. remains the same
   d. does all of the above

3. On a PH chart the evaporation of refrigerant occurs between:

   a. the expansion device and the saturated vapor line
   b. the expansion device and the compressor suction
   c. the liquid line and the evaporator condition
   d. the compressor suction and the compressor discharge

4. The compression ratio of a compressor, where "d" is discharge and "s" is suction, is:

   a. psig(d)/psig(s)
   b. psia(d)/psia(s)
   c. psia(d)/psig(s)
   d. psig(d)/psia(s)

5. In mixtures of air and water vapor, the total heat in Btu/lb. closely corresponds to:

   a. the Fwb
   b. the Fdb
   c. the dew point
   d. the specific humidity

6. Large amounts of outside air in HVAC systems usually:

   a. present no problems
   b. cannot be cooled and dehumidified simply
   c. is not solvable
   d. decreases humidity in the space

7. HVAC sytems for 100% outside air can be handled with:

   a. 100% outside air units
   b. energy recovery devices
   c. reheat
   d. all of the above

8. Return air through the lights usually:

   a. reduces first costs and operating costs
   b. has no savings
   c. requires the same amount of supply air CFM
   d. reduces building cooling load

9. Building load calculations:

   a. are the same as they have always been
   b. are by rules of thumb
   c. require a computer
   d. have evolved into more accurate methods

10. The largest internal continuous sensible heat gain in a building is:

   a. people
   b. outside air
   c. lights
   d. windows

11. The type of compressor that does not have varying capacity control availability is a:

   a. scroll
   b. screw
   c. reciprocating
   d. centrifugal

12. When specifying a cooling coil it is necessary to provide only:

   a. ADP
   b. CFM
   c. CFM, entering and leaving air temperatures
   d. total heat

13. The use of dual pumps in parallel is best described as :

   a. less expensive
   b. to insure system operation
   c. a reduction in motor size
   d. none of the above

14. Grey duct tape is:

   a. UL listed
   b. long life
   c. expensive
   d. not a good choice

15. The control of noise in an HVAC system is:

   a. of no importance
   b. of concern to the professional engineer
   c. solved by the contractor
   d. the Architects job

16. A diversity factor can be applied to:

   a. direct expansion systems
   b. chilled water systems with variable internal loads
   c. packaged heat pumps
   d. none of the above

17. Energy code compliance for building construction is:

   a. an alternate requirement
   b. can be guessed at
   c. generally requires an engineers seal and signature
   d. none of the above

18. When observing during construction:

   a. observation should be documented
   b. verbal reporting is acceptable
   c. one should go as infrequently as possible
   d. one should not check out operation at completion

19. System commissioning is:

   a. of no use
   b. to insure proper equipment start-up
   c. provided by the engineer
   d. none of the above

20. Reports of test and balancing should be:

   a. filed
   b. accepted as is
   c. ignored by the mechanical contractor
   d. carefully reviewed by the engineer for corrections and approval.