Heat Recovery DeHumidifiers (HRDe)

Application Manual

Pre-Cool and Post-Cool, Reheat Arrangement Dehumidification

For Commercial and Institutional Application

ACMV P L

Singapore

Introduction

In order to achieve an acceptable air quality in a commercial building it is important to maintain its air temperatures, relative humidity, air movement, and internal odours that majority of its occupants accept the conditions satisfactorily.

Singapore NEA IAQ guideline states that air conditioned office spaces temperature range 22.5 to 25.5 C, and humidity no more than 70% and air movement of 0.25 m/sec. ASHRAE Standard and AIHA Guideline No. 2 recommend between 30 to 70 % buildings indoor humidity.

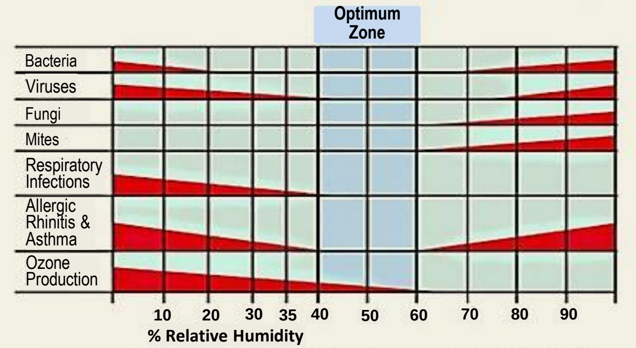
Air Conditioning is the process of controlling the temperature, humidity and ventilation of a occupied space for either comfort or process application.

Dehumidification is the process of reducing water vapour from the air in a condition space. The Air Handling Units and Fan Coil Units in a air conditioning system cool the spaces as well as reducing humidity.

Effect of high humidity at indoor spaces makes occupants feel warm, humid, smelly air and damp. Such environment would promote activity and growth of micro-organisms like mold, fungi, and bacteria that may compromise the health of occupants as well as condition of materials in the space such as wood, paper and paints. High Humidity mostly in consideration on laboratories, hospitals and/or manufacturing processes.

In the graph shown, Fig. - 1, Indirect Health Effect of Relative Humidity in Indoor Environments, from Environmental Health Perspectives, Vol. 65, p358 by Sterling, et.al, 1986, are the possible outcome of humidity on indoor air quality (IAQ). In the graph the highlighted area identified as ‘optimum zone’ of about 50% RH +/- 10%. The larger the bar indicates the intensity of its harmful effect.

Fig. - 1



Indirect Health Effect of Relative Humidity in Indoor Environments
Environmental Health Perspectives, Vol. 65, p358, Sterling, etal. 1986

As indicated above the control range of dry-bulb temperature and humidity has a wide range in office or commercial occupancy. However in process or Institutions like Operating Theaters, Surgery Clinics, laboratories, etc., applications, the control of such temperature and humidity is tighter and critical therefore **Refrigerated Mechanical Dehumidifiers Indirect Cooling** system plays an important role not only in control but in safety and energy consumption. In this article we call the system as HRDe or Heat Recovery DeHumidifier.

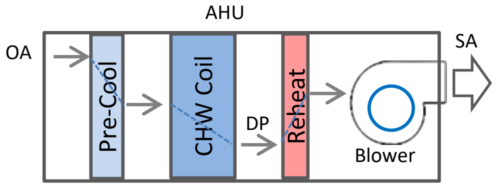
Heat Recovery DeHumidifiers

Controlling relative humidity using Mechanical Refrigeration is most economical method in the Tropics and there are two general arrangements that the system is commonly applied adapting the chilled water supply temperature available.

The two General Arrangements are as follows:

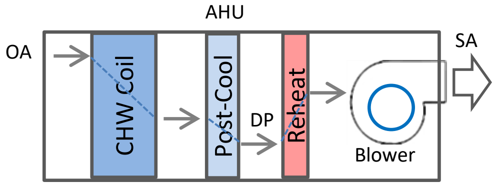
A. Pre-Cooling → Cooling → Reheat

- The Pre-Cool Coil cools the Outside Air (OA) first – Pre-Cooling arrangement is normally applied when the CHW water supply temperature is low enough to cool the air off the CHW coil to the desired dew-point temperature. The Refrigeration system modulates its capacity according to the heat needed to control the desired dew-point temperature supplied to the air conditioned space. The Pre-Cooling + Reheat refrigeration system can either be direct or indirect type.



B. Cooling → Post Cooling → Reheat

- The CHW Coil cools the OA first – Post-Cooling arrangement is applied when the CHW water supply temperature is NOT low enough to cool the air desired off-coil dew-point temperature. The Post-Cool Coil will cool the air to the desired dew-point temperature. The CHW Coil capacity is modulated to control the desired dew-point temperature while the Post Cool Coil operate at constant evaporating temperature to maintain air off-coil dew-point temperature. The Post-Cool + Reheat refrigeration system can either be direct or indirect type.



Note: The same schematic applies when cooling Return Air (RA) instead of Outside Air (OA).

Direct type Cooling system - refrigerant is directly circulated to cool and heat the air circulating in the system.

Indirect Type Cooling System - water is chilled for cooling and heated for reheating the air recirculating in the system.

Important: Note: ASHRAE 15, Safety in Refrigeration prohibits the use of Direct System on Institutions that air conditioned spaces maybe contaminated by refrigerant (and oil) in the event of gas leak.

HRDe Equipment Selection Process

During the HVAC design process, it is the designer responsibility to prepare an accurate estimate of the system heat load based on the type of occupancy of the space to be air conditioned. It is a must that all external and internal loads are accurately accounted for and included in the calculations. If this part is done inaccurately using area method or rule of thumb numbers, the design of the system is no good at all that would lead to over-estimation of the equipment sizes. Definitely the main effect is the increase of the Capital Cost of this particular Air Conditioning System.

- **Heat Load**

  Space Heat Load, Qs = WHG + Qi + Qv + Qm + Qe

  - Wall Heat Gain (WHG) = heat coming from the side walls, roofing at floor due to temperature difference
  - Internal Load (Qi) = Lighting, Occupants, and any other heat generating source in the room
  - Ventilation (Qv) = Ventilation is needed to change the air in circulation and other factors like as required ventilation for occupants or process.
  - Sources of Moisture heat load (Qm) must be accounted for specially in spaces where there is low humidity requirement.
  - Air handling Unit (AHU) heat contribution due to its fan motor drive as well as heat gain into the casing if exposed to higher temperature.
  - Qs is composed of Sensible Heat (SH) and Latent Heat (LH) ; Qs = Σ(SH + LH)
  - Note: Room SH is the basis to calculate Supply Air Flow

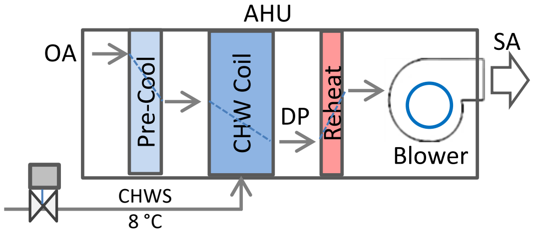
- **Factor of Safety**
  - The more accurate the estimation of Qs would result to optimized Cooling or Heating capacity selection.
  - It is normal practice for designers or engineers to include 'factor of safety' but those safety factors should be more on taking care of the aging of the equipment as part of a system rather than merely for the reason of 'unforeseen' factors. Equipment naturally losses its efficiency overtime therefore it is reasonable to provide in the selection some factor of safety. Over estimating with large Factor of Safety is not desirable.
  - Once the Qs is stablish accurately and with other given major given data conditions (see below), the AHU equipment selection can proceed.
    - CHW Supply Temperature, °C
    - CHW Return Temperature, ° C
    - Space Conditions: DB in °C and % RH

- **Air flow**
  - Supply Air flow is a major parameter that directly affects the sizing of a AHU. If the Qs estimation is too high every unit added is extra and raise the cooling coil, HRDe Pre-Cool and Reheat coils, pumps, casing size and blower horsepower cost up. Although AHU motor drives are quite normal to be specified with variable speed drive nowadays to be able to adjust the right air flow at the site, the oversized effect on the pricing as a whole is irreversible once procurement of equipment is done. Therefore heat load calculation should be done seriously and accurately.

Arrangement A : Pre-Cool, Reheat

A. Pre-Cool → Cool → Reheat Process (See sketch below for this process):

1. The Pre-Cool and Reheat is part of the mechanical refrigeration equipment to achieve the cooling and heating processes.
2. The Outdoor air (OA) is cooled by Pre-Cool coil then cooled further by CHW Coil. In both process humidity is remove from the air.
3. The CHW coil is use to control the dew point temperature (DP) by modulating the CHWS flow through the control valve,
4. The Reheat Coil is use to raise SA temperature to desired set point.
5. Depending on the amount of sensible heat in the space will determine how much the Reheat Coil should supply into the space.
6. The example below explain the process:



Given data:

- Air Flow = 1000 Li/sec
- Outside Air (OA) : DB = 30 C; RH = 72%
- Pre-Cool : DB = 22C; RH = 98.3%
- CHW Off-Coil : DB = 12C ; RH = 100%
- Supply Air (SA): DB = 23C ; RH = 50%

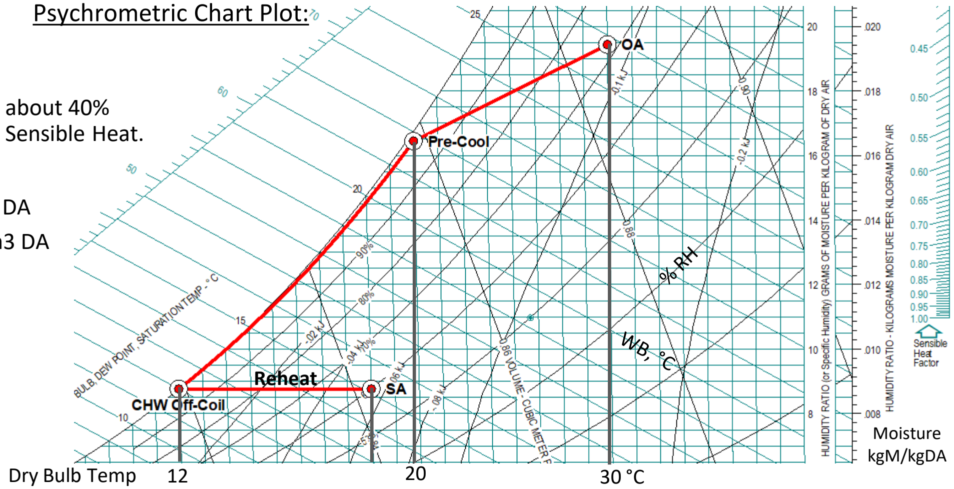
Results from Psychrometric analysis:

- OA to Pre-Cool = 19.1 kW (cooling)
- Pre-Cool to CHW Off Coil = 35.7 kW (cooling)
- CHW Off Coil to SA = 13.5 kW (Heating)
- Note 1: The Pre-Cooling reduce the CHW Coil duty by about 40%
- Note 2: The energy dissipated by the blower motor is Sensible Heat.

Estimated Moisture Removal

- Moisture @ OA = 19.44gm/kg DA; @SA = 8.77 gm/kg DA
- Air density @ OA = 1.1516kg/m3; @SA = 1.1862 kg/m3 DA
- Moisture L/s @ OA = 0.022; @SA = 0.0104
- Moisture Removal to achieve SA RH = 50%
- = Moisture at OA – Moisture at SA
- = 0.022 - 0.0104
- = 0.0116 Li/sec (42 Li/Hr)

Psychrometric Chart Plot:



Arrangement A : Pre-Cool, Reheat

5. Pre-Cool and CHW Coil Capacity

In the Psychrometric sample analysis the AHU cooling capacity required is the sum of Pre-Cool and CHW Coil capacities.

- Pre-Cool = 19.1 kW
- CHW Coil = 35.7 kW
- Total Cooling Capacity = 19.1 +35.7 = 54.8 kW
- It would be a good decision to select the CHW coil capacity equal to 54.8 kW rather than 35.7 kW. This strategy would come handy if during the operation the Pre-Cooling Coil breakdown then the CHW Coil could take care of the total heat load. RH control will not be available unless there is an electric reheat as stand-by.
- However it may not sound a good idea to select HRDe Pre-Cool Coil Capacity equal to the total capacity of 54.8 kW for the same reason that the Pre-Cooling Coil could take over CHW Coil job when it breaks down. The selection could lead to a huge HRDe unit. The designer must take into consideration that the building CHW system reliability is better or is ensured it is better through preventive maintenance than small HRU's and not the other way around. With that in premise it is NOT necessary to consider the HRDe Pre-Cool as stand-by for the CHW Coil. Again if the CHW Coil needs repair for leaks the whole AHU with the HRDe need to be shut-down anyway.

6. Selecting the HRDe Pre-Cool Coil Capacity and Compressor kW

Based on the Reheat capacity of 13.5 kW, this number is also equal to the total heat of rejection (THR) in refrigeration system and expresses as:

- THR = Cooling kW + Compressor kW
- Cooling kW (CkW) is the adjusted Pre-Cool capacity (not the number use in the Psychrometric Chart)
- Compressor kW (PkW) is the power input to the compressor in the refrigeration system.
- Going back to the example, the Pre-Cool = 19.1 and Reheat kW = 13.5, this combination is not a correct basis to select a HRDe to serve the design conditions stated. The Pre-Cool capacity is higher than the Reheat which is not achievable in a refrigeration system.
- To be able to select the correct HRDe capacity a simple calculation and practical assumptions maybe done with the following conditions:
  - OA = 30 °C
  - LAT = 22 °C (Pre-Cool leaving air temperature)
  - Based on the above OA and LAT, the evaporating temperature can be selected as 10 °C. Compressors can operate at higher saturated suction temperatures but for this example 10 °C is practical enough. Condensing temperature range from 40 to 45 °C.
- The typical COP of operating the refrigeration system at 8 to 15 °C range of evaporating temperature is 4 to 6. Use 5 on this case.
- Therefore the HRDe Cooling capacity for this selection can be calculated with the relationship of COP = CkW / PkW or CkW = COP x PkW
- But PkW = Reheat kW – CkW so by equating the two: (Reheat kW – CkW) = (COP/CkW) ; Substituting given numbers; 13.5 – CkW = 5 / CkW ;
- Therefore CkW = (13.5 x 5) / 6 = 11.2 kW; Then PkW = 13.5 – 11.2 = 2.3 kW
- The PkW, Evaporating and Condensing temperatures can be now used to select the appropriate compressor size with given refrigerant type.

Arrangement A : Pre-Cool, Reheat

7. Effect of Oversized HRDe Cooling Capacity

As suggested earlier, selecting the HRDe Cooling capacity equal to the CHW Coil capacity may not be a good idea as the HRDe becomes too big and could lead to requiring a rejection equipment like a condenser (see sketch below).

The following example illustrates the effects of oversizing.

- Select CHW Coil = Total Cooling Capacity = 54.8 kW
- Also Select a HRDe Cooling capacity, CkW = 54.8 kW
- Use COP = 5 for the HRDe refrigeration system.
- Calculated Reheat kW = 1.182 x 54.8 = 64.8 kW, therefore the Compressor Power PkW = 64.8 – 54.8 = 10 kW (about 5X more than 2.3 kW)
- The HRDe selected with cooling capacity of 54.8 kW will always operate unloaded a fifth of its capacity only to use 13.5 kW of heat. The questions is, what if the required Reheat kW is lower than 13.5? Then probably that's when the trouble begin as in actual operating condition there are available sensible heat coming from the room. Note that the 13.5 kW reheat probably is most required during the Qs is lowest therefore it can be expected that when the HRDe is operating at day time the Remote Condenser is working all the time.
- There maybe an argument of why not operate the HRDe 100% and let the CHW Coil unload to meet the demand? This means that the cooling is mainly from HRDE. That's sound acceptable but let us look closely on the situation. If the COP = 5 that is equivalent to around 0.71 kW/TR. This does not include the additional energy from condenser fan and the increase of AHU fan power due to the higher static pressure across the thick Pre-Cooling Coil. Thick coil has tough cleaning issues too that increase maintenance or servicing cost and replacement cost not mentioning installation cost increase.
- For simple comparison use the best HRDe kW/TR of 0.71 and fully operating will use only 13.5 kW as reheat out of the 64.8 kW THR. The extra heat of more than 50 kW is rejected into the atmosphere on this case.
- Now with the CHW Coil supply coming from the building, the chiller system has average efficiency of 0.55 kW/TR or better on part loads. Logically it is more efficient to operate the CHW Coil all the time to meet the cooling demand rather than the HRDe. The owner essentially buying a bigger dehumidifier and pay more for its operation.
- See the Heat Flow in AHU + HRDe System:

Arrangement A : Pre-Cool, Reheat

8. Effect of Factor of Safety on Air Flow and Cost of Equipment

The following example illustrates what oversize air flow means:

- Given: Calculated Qs = 210 kW
- Factor of Safety 10% Applied to AHU capacity = 210 * 1.1 = 231 kW
- Extra capacity = 231 – 210 = 21 kW

Calculate Air Flow using Qs:

- Assuming the Delta-T of the air from Entering and Leaving Air the Cooling coil = 18 K
- SH = SHF x Qs ; (Sensible Heat Factor = 0.7 assumed)
- The air flow, AF = Sensible Heat / (c_p x ρ x ΔT)
- Where: SH = sensible heat = 0.7 x Qs = 210 * 0.7 = 147 kW
- c_p = Specific heat of air at constant pressure = 1.005 kJ/kg-°C
- ρ = air density = 1.202 kg/m^3
- AF = 147 / (1.005 x 1.202 x 18) = 6.76 m^3/s or 6,760 Li/sec
- To calculate Coil Face Area (FA) use Coil Face Velocity (FV) = 2 m/sec; Therefore FA = 6.76 / 2 = 3.38 m^2

Note: The Qs is assumed as the coil Grand Total Heat Load which one of the basis of sizing the AHU.

- Using the 231 kW to calculate AF.
- FA = (231 * 0.7 / (1.005 * 1.202 * 18) / 2 = 3.72 m^2
- Therefore the Owner of the project would buy 0.34 sq meters more per Row for Pre-Cool, CHW and Reheat Coils. That increase would extend to the AHU casing as there would be additional materials needed, fan and motor, refrigeration compressor, its starting components and power cables for the HRDe. The approximate cost of fin-tube cooling or heating coil per sq. meter per row is S$300. CHW Cooling coils average number of rows for this type of application is 6, Pre-Cool Coil is 3 to 4 and Reheat is 1 to 3. There would be about 0.34 x (6 + 3 + 1) = 3.4 m^2 face area additional equivalent to $ 1,020.
- The 10% Factor of Safety commonly applied is acceptable if applied to long hand heat load calculations but when calculations are based on rule of thumb or as per area method oversizing would always likely exceeds 10% of the actual load. It is more prudent to use long hand calculations taking into account of all the parameters of the space to be air conditioned or by using a simulation software like EnergyPlus, Carrier Heat Load Calc Program and other reliable tools available in the market. It is emphasized here though that good input would yield good results or otherwise.

Arrangement B : Post-Cool, Reheat

B. Cool → Post-Cool → Reheat Process (See sketch below for this process):

1. The Post-Cool and Reheat is part of the mechanical refrigeration equipment to achieve the cooling and heating processes.
2. The Outdoor air (OA) is cooled by CHW Coil coil then cool further by Post-Cool Coil. In both process humidity is remove from the air.
3. Once the air passed through the Post-Cool Coil the air dew point temperature (DP) is maintain by keeping the evaporating temperature constant. The Reheat Coil will raise the off-coil temperature required by the space.
4. Depending on the amount of sensible heat available in the space at any time will determine how much the Reheat Coil should supply into the space to maintain the % RH.
5. The example below explain the process:

Given data:

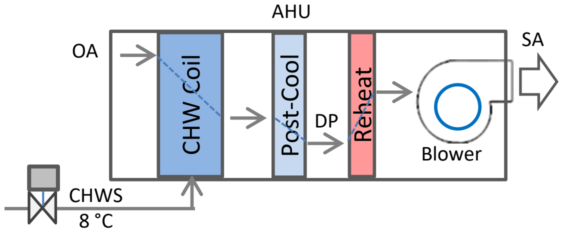
- Outside Air (OA) : DB = 30 C; RH = 72%
- Cool CHW Off Coil: DB = 12C; RH = 100%
- Post-Cool : DB = 9C ; RH = 100%
- Supply Air (SA): DB = 23C ; RH = 40.8% (40%)

Results of Psychrometric analysis:

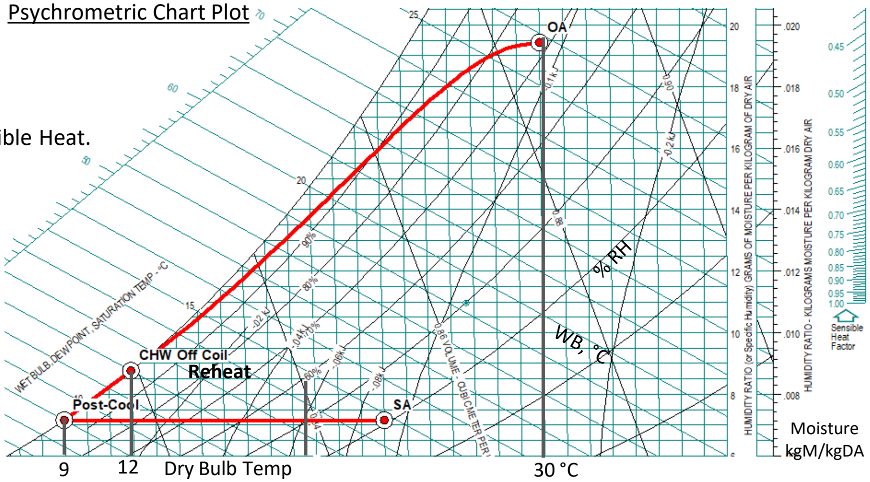
- OA to CHW Off Coil = 54.8 kW (cooling)
- CHW Off Coil to Post-Cool = 8.5 kW (cooling)
- CHW Off Coil to SA = 17.1 kW (Heating)
- Note 1: The CHWS unable to cool down Off-Coil to 9 °C
- Note 2: The energy dissipated by the blower motor is Sensible Heat.

Estimated Moisture Removal

- Moisture @ OA = 19.44gm/kg DA; @SA = 7.16 gm/kg DA
- Air density @ OA = 1.1516kg/m3; @SA = 1.1873 kg/m3 DA
- Moisture L/s @ OA = 0.022; @SA = 0.0085
- Moisture Removal to achieve SA RH = 40%
- = Moisture at OA – Moisture at SA
- = 0.022 - 0.00805
- = 0.0135 Li/sec (49 Li/Hr)



Psychrometric Chart Plot



Arrangement B : Post-Cool, Reheat

5. Post-Cool and CHW Coil Capacity

In the Psychrometric sample analysis the AHU cooling capacity required is the sum of CHW Coil and Post-Cool Coil capacities.

- CHW Coil = 54.8 kW
- Post-Cool = 8.5 kW
- Total Cooling Capacity = 54.8 + 8.5 = 63.3 kW
- It would be a good decision to select the CHW coil capacity equal to 63.3 kW rather than 54.8 kW. This strategy would come handy if during the operation the Post-Cooling Coil breaks down then the CHW Coil would take care of the total heat load. RH control will not be controllable even there is an electric reheat as stand-by. This is because the DP is not achievable with the CHWS temperature of 8 deg C.
- The same situation as the Pre-Cooling arrangement, selecting HRDe Pre-Cool Coil Capacity equal to CHW Coil capacity would lead to a big HRDe unit. The designer must take into consideration that the building CHW system reliability is better or is ensured it is better through preventive maintenance than small HRU's. With that in premise it is NOT necessary to consider the HRDe Post-Cool as stand-by for the CHW Coil. Again if the CHW Coil needs repair for leaks the whole AHU with the HRDe need to be shut-down anyway.

6. Selecting the HRDe Post-Cool Coil Capacity and Compressor kW

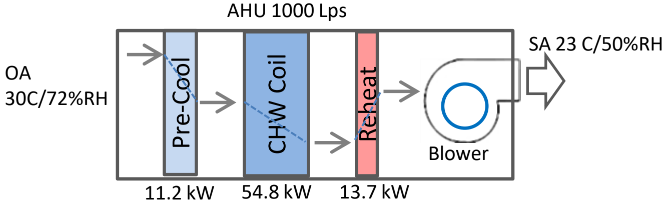
The Reheat capacity is equal to THR = 17.1 kW and expressed as:

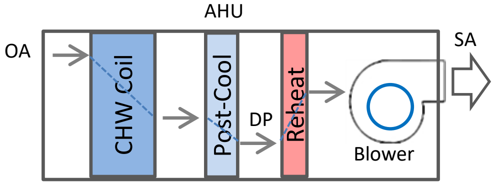
- Reheat kW = THR = Cooling kW + Compressor kW
- Cooling kW (CkW) must be sized to cool the air flow lower than 12 °C down to 9 °C DP and check if it balance with the calculated Reheat of 17.1 kW. For this example the evaporating temperature for the post cool should be around 5 °C, 4 K difference from 9 °C DP.
- Compressor kW (PkW) is the power input to the compressor in the refrigeration system.
- Going back to the example, the Post-Cool = 8.5 and Reheat kW = 17.1, this combination can be verified using a Compressor selection program if 8.5 kW cooling can produce 17.1 kW THR at 5 °C evaporating temperature and varying the condenser temperature. However the COP for this range is around 4 and can be used to estimate the CkW and PkW.
- Use COP = 4
- The HRDe Cooling capacity for this selection can be calculated with the relationship of THR = CkW + PkW and COP = CkW/PkW ; PkW = CkW/COP
- PkW = 8.5 / 4 = 2.12 kW ; Therefore THR = 8.5 + 2.12 = 10.2 kW (6.9 kW less than the required Reheat of 17.1 kW)
- Using the THR and COP data, PkW = 17.1/ (COP +1) = 17.1 / 5 = 3.42 kW; Therefore CkW = 17.1 – 3.42 = 13.7 kW
- By comparison using a Compressor selection program, the required CkW and PkW can also estimated
- The Compressor selection program use on this example showed that to produce 17.1 kW heat the evaporating capacity needed is 13.8 kW at 5 °C evaporating and 40 °C condensing. The compressor PkW = 3.29 kW and the COP = 4.2.
- The data generated from the Compressor Selection Program is considered as more accurate.

Summary

Pre-Cool, Cool and Reheat Process

- Either Pre-Cool or Post-Cool arrangement to produce heat to control humidity saves energy.
- CHW system is considered reliable and maintenance is well established
- It is a great advantage if the heat load is calculated accurately.
- Selection of HRDe capacity equal to the AHU CHW Coil cooling capacity is not desirable as it does not only increase capital cost but also increase maintenance, service and power consumption.
- It is important to give a close consideration when to apply a Direct and Indirect System.





Note: The same schematic applies when cooling Return Air (RA)