Decoupling of Sensible and Latent Loads for Climate Control of Controlled Environment Agriculture.

Controlled Environment Agriculture (CEA) has gained a strong momentum from the inception of LED lighting for cultivation in the early 2000’s in Japan. An ability to create the environment most conducive to cultivation of specific types of crops has proven to be effective in dramatically increasing yields per area; improving the quality of the product; eliminating needs for pesticides and fungicide due to limiting exposure to pathogens and effective IPM practices; and significantly reducing water consumption. Despite these advantages, the sheer amount of energy required for artificial lighting and HVACD systems has been an impediment to a broader dissemination of the indoor cultivation practices.

Indoor Cultivation Design Criteria.

All plants undergo through daily light and dark cycles as well as a long maturity cycle. Typically a 24 hr day is divided into 12hrs light cycle (lights are on) and 12hrs dark cycle (lights are off). Indoor produce farms do not separate plants by their maturation cycle, but cannabis facilities do. This affects the latent load which adds another complexity layer to the design parameters of indoor cannabis farms.

The design conditions vary depending on the type of the crops, but the most common criteria are 72F-76F / 50%RH-60%RH during the light cycle and 64F-68F / 55%-65% during the dark cycle.

Sensible and Latent Loads Calculations.

Cultivation spaces in indoor grow facilities are designed as a closed system with 100% air recalculations (where OSHA regulations are permitting) and the process of plants’ transpiration adiabatically cools the space. To calculate the actual sensible load, the latent load in Btu/h must be subtracted (credited) from the former.

$$\underline{Qs(actual) = Q\ sensible - Q\ latent}$$

The sources of sensible heat (Qs) are primarily lighting (Qs(lights)), walls conductivity (Qs(conduction)), and plug load (Qs(plug)).

$$\underline{Q\ sensible} = Qs(lights) + Qs(conduction) + Qs(plug)$$

The values of wall conduction and plug loads are negligible compared to the heat rejected from the lighting, and they are often discarded in sensible load calculations.

Latent load (Q latent) is expressed in the total volume of moisture introduced into the space. This information is obtained from the client as a net daily watering rate.

Mechanical Vapour Compression (MVC) Equipment Sizing.

The governing factor in sizing an HVACD system for indoor cultivation is the latent load (Ql) in lbs. It is the volume of moisture that needs to be removed from the processed air. The conditions of the processed air downstream of the evaporating coil are designed at around 44F/98%RH (corresponds to a minimum suction pressure that the system can operate without freezing the coils). The depreciation of specific humidity (delta SH) is used to calculate the minimum airflow volume (CFM) in order to remove the required hourly amount of moisture from the processed air.

$$CFM = Ql / (60 \text{ (min)} \times 0.08 \text{ (lbs/ft3)} \times dSH)$$

Ql - latent load expressed in lbs/hr.
SH1 - air specific humidity before DX (lbs/lbs)
SH2 - air specific humidity after DX (lbs/lbs)

Once the airflow volume is established and the temperature depreciation is known, the compressor capacity can be calculated as

$$Qt = 4.5 \times CFM \times dH$$

H1 - processed air enthalpy upstream of DX (Btu/lbs)
H2 - processed air enthalpy downstream of DX (Btu/lbs)

or alternatively,

$$Qt = 1.08 \times CFM \times dT + Ql \text{ (Btuh)}.$$

HVACD Technologies Employed in Indoor Agriculture Sector.

CEA is relatively new sector and it has primarily relied on Mechanical Vapour Compression technology (DX and Chillers) for indoor climate control.

The largest constituency in COGS of Vertical Farms production is electrical energy of the lighting and the HVACD equipment. As the current energy prices have been on a steadily increased trend, various energy recovery solutions for winter economisation as well as desiccant augmentation for enhanced dehumidification are starting to gain traction in the sector.

DX and Chillers.

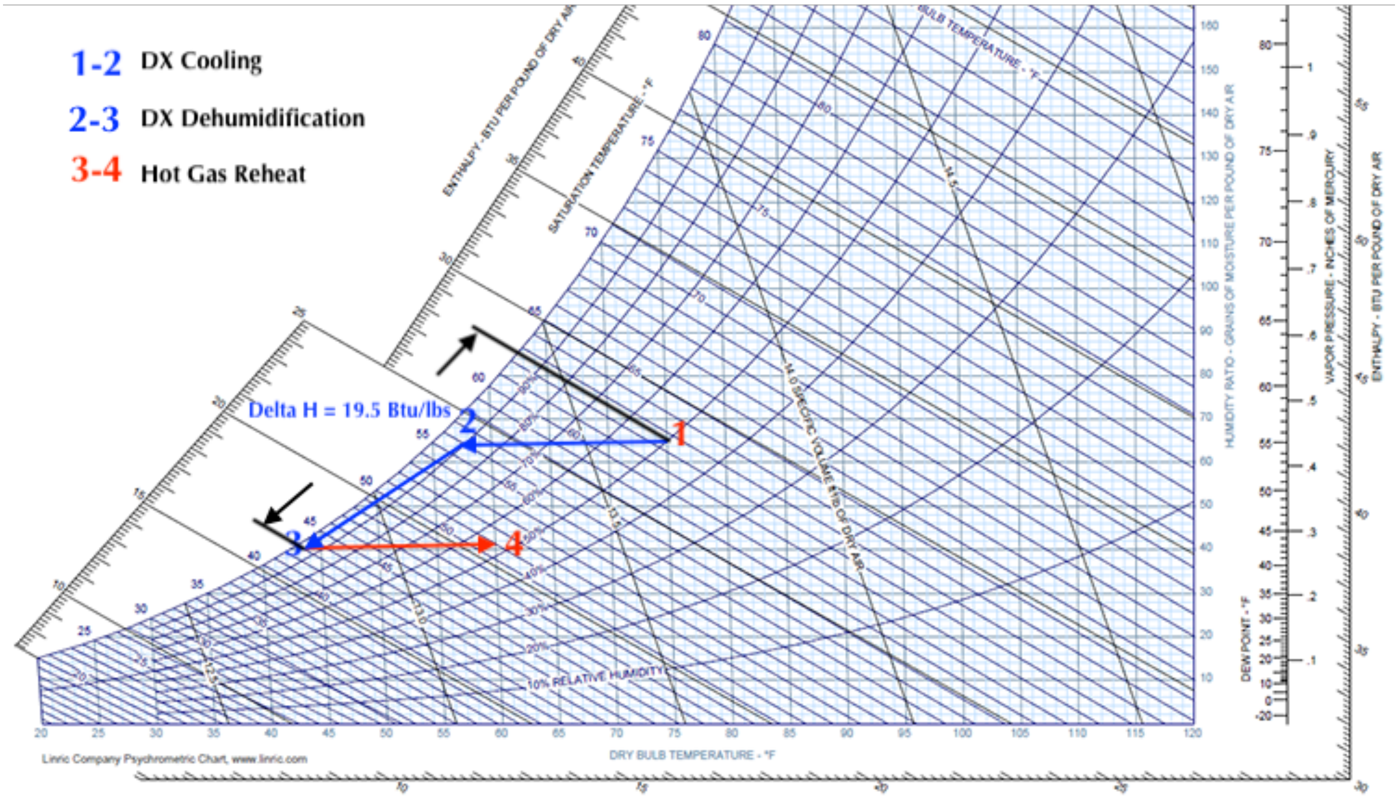
Mechanical Vapour Compression Technology is a standard approach to climate control in indoor farms. However, it’s one of the least effective and efficient methods of dehumidification at low SHR conditions. Since the temperature depreciation required to meet the latent load significantly exceeds the delta T required to meet the sensible load, hot gas reheat is employed to increase the temperature of the supply air. This makes this process of cooling, dehumidification, and the subsequent heating redundant and in-efficient. The Psychrometric Chart #1 illustrates the HVACD processes in a typical cultivation space.

4-pipe chillers exhibit higher degree of performance in dehumidification than DX systems. This technology has an additional energy savings potential in the facilities that have multiple cultivation spaces that operate on an alternate light/dark cycle schedule.

There are technological solutions that improve MVC systems' performance such as heat-pipe technology, plate heat exchangers as winter economisers, Kyoto wheels, indirect evaporative cooling, and others.

<u>Delta Enthalpy (H) of the MVC process for a typical cultivation facility is 19.5 Btu/lbs.</u>

Psychrometric Chart #1



Solid Desiccant Dehumidification.

Rotary Desiccant Wheels have been a common air treatment technology since their invention by Carl Munters over 60 years ago. Most of the industrial purposed wheels are based on silica sorbent that has a capacity of adsorbing moisture from air even at low dew point and low SHR conditions.

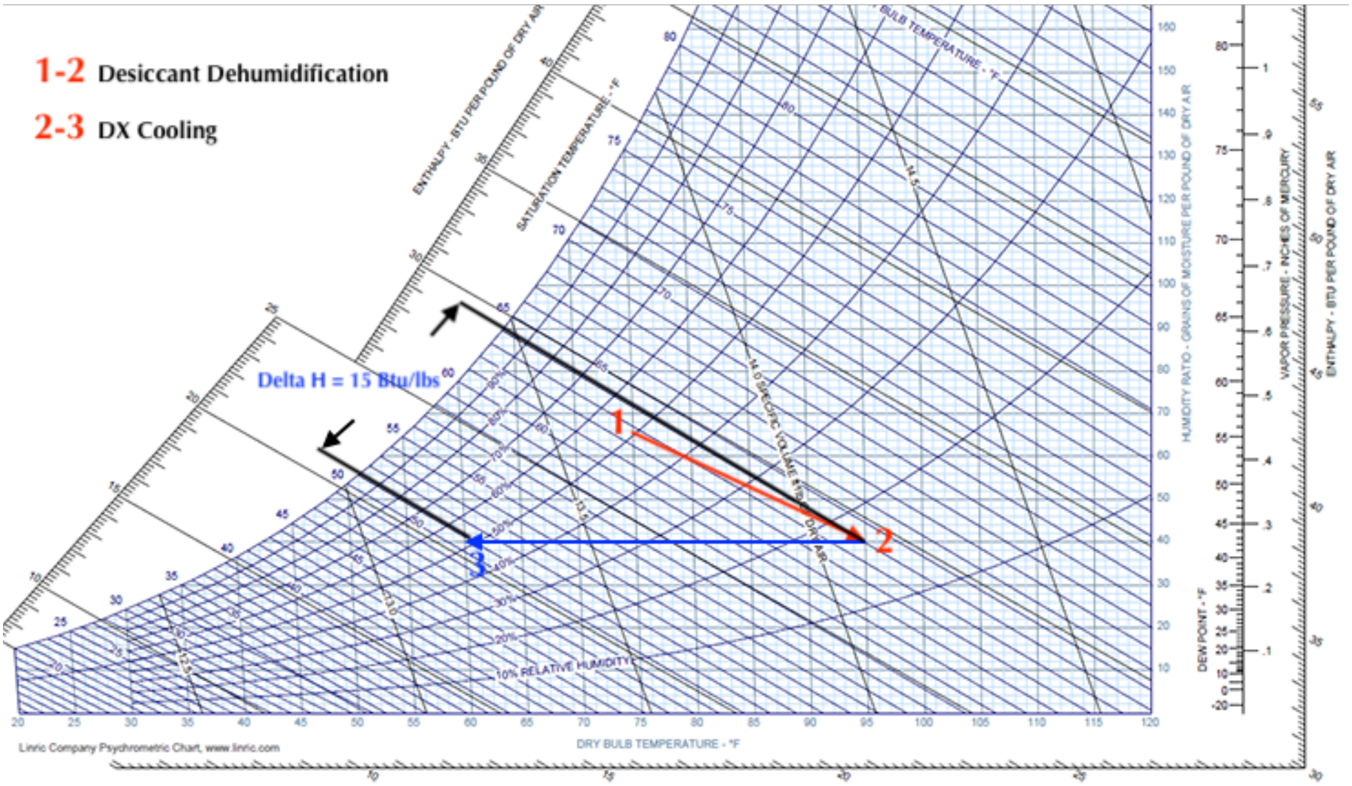
There is an adverse element in desiccant dehumidification as a significant amount of low-grade (140F-160F) thermal energy is required to regenerate the desiccant (evaporate the adsorbed moisture). This downside has proven to be a challenge for the technology to be utilised in facilities that lack a source of natural gas or propane.

The current energy policies have incentivised the efficiency and sustainability of the technological processes, including utilisation of waste heat, a by-product of energy generation, industrial activities, or a geothermal source.

In the Indoor Agriculture sector, the heat rejected by water-cooled lighting can be effectively used for desiccant reactivation. Heat rejected in the condenser of a DX system with desiccant enhanced dehumidification is also traditionally utilised.

Delta Enthalpy (H) of DX cooling and Desiccant dehumidification process for a typical cultivation facility is 15 Btu/lbs.

Psychrometric Chart #2



Desiccant Dehumidification with Indirect Adiabatic pre-cooling and DX cooling.

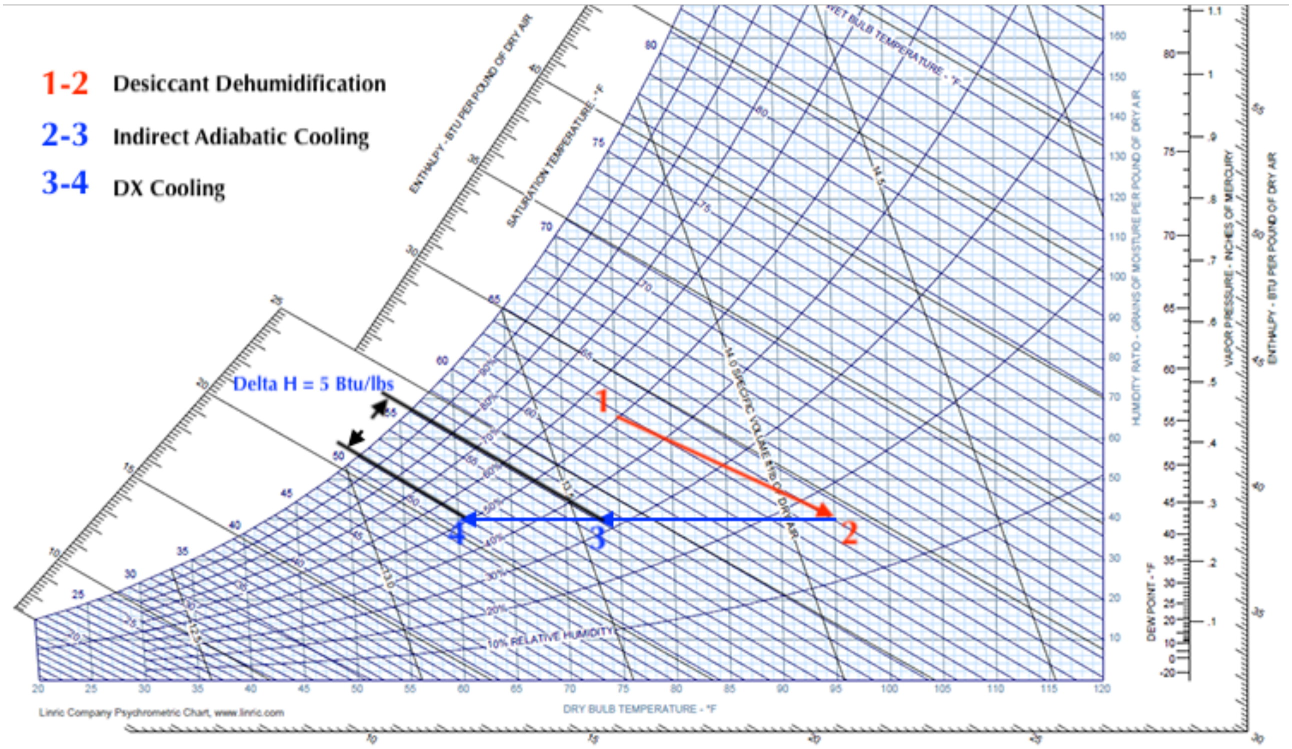
Direct Adiabatic (Evaporative) cooling has been effectively used for greenhouse cooling in regions with predominately low ambient wet bulb temperatures. These systems are inexpensive and efficient in lowering the temperature of the processed by evaporating moisture in the airstream. The process is resulted in increasing the humidity in the space and, therefore, is not suitable for Indoor Ag. Indirect evaporative cooling, on the other hand, has a strong role to play and can effectively lower the temperatures of the airflow to the low 70's in the West and Mid-West of the United States as well as many other regions of the world.

In HVACD systems for indoor cultivation, Indirect Evaporative Cooling is highly effective in reducing the temperature of the processed air downstream of the desiccant, while consuming little energy (pumps operations). When a desiccant dehumidification system is augmented with indirect evaporative cooling, the COP of this process significantly exceeds of the Mechanical Compression Technology (see Psychrometric Chart #3).

The downside of this process is substantial water consumption, which limits a broader dissemination of this technology.

Delta Enthalpy (H) of Desiccant Dehumidification with Indirect Evaporative Cooling and DX post-cooling processes for a typical cultivation facility is 5 Btu/lbs.

Psychrometric Chart #3



Conclusion.

De-coupling sensible and latent loads as a climate control strategy for Indoor Agriculture is not only an effective method, but a cost-viable and low-energy consuming solution for the applications where sources of low grade heat are available. Augmenting these systems with indirect evaporative cooling in low humidity climates or using a geothermal cold source (<70F) further improves the COP of the process by reducing the energy consumption up to 80%.

Complexed solutions with integration of multiple complimentary projects from different industries can benefit energy savings by recovering thermal energy for alternative uses (i.e. CHP plants, Data Centres and Bitcoin Mining operations with immersed cooling, Climate Controlled Greenhouses, Vertical Farms).