# Energy Performance and HVAC System Design Considerations for Indoor Agricultural Facilities

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**Abstract:** ***One of the main cases facing agriculture is the loss of cultivation lands around large cities, because as more land is lost will make it much more difficult to grow enough food to satisfy the increase of human population. Consequently, Indoor agriculture is a growing market. Everybody all around the world, crops developed inside for assortment of reasons. In our study, we will see at a few HVAC considerations &the electrical performances of heat load calculation, ventilation, and cooling (HVAC) systems. Assessment for many cultivated densities when dealing with indoor growing spaces considered. The out-turn showed that using the economizer system minimizes the total power consumption of the air- condition system for high-density building internal agriculture. It demonstrates that taking into account the proper heat transfer between the cooling installations and the environment is of particular importance for determining the appropriate size of the heating equipment. The high latent heat transfer capacity of the installation through evaporation makes it possible to properly size the dehumidification equipment, which is essential in cold season due to the risk of condensation in the shell of the space.***

**Keywords:** Agriculture, Indoor agriculture, HVAC systems, Heat load calculation, Dehumidification equipment

## 1. Introduction

Plants are intricate biological machines that require a wide range of nutrients, minerals and vitamins, as well as water and gases like oxygen and CO2 to grow. Light is an essential factor to produce energy for photosynthesis. In nature, plants are exposed to light and dark periods during their growing season. In the case of indoor plants, they are exposed to "daytime" periods when the sun-replacement lights switched on to allow them to photosynthesize. The lights then switched off to simulate "nighttime" periods. The number, intensity, and temperature of light that is transferred to the plants can vary depending on the species and growing phase.

Because of the amount of light required, the generated heat due to light densities often a lot higher in comparing to needed cooling requirements comfort cooling applications. Some plant varieties thrive in cool environments (65°F or higher), while others thrive in warm environments (80°F or higher). Similarly, plants tend to tolerate higher relatives. Humidity levels typically ranges from 40 to 75 percent.

Keeping your indoor agricultural facility at the right temperature and humidity is critical to achieving maximum crop yield and quality. When designing an indoor heating and cooling system, it is important to consider more than just the size and complexity of your facility. It's also important to consider the effects heat generation from growing plants on airflow dynamics and climate challenges associated with location. In addition, it is important to assess the electrical power consumption of the space in question. In colder atmospheres, direct cooling is considered as a way to reduce energy consumption required by air-condition units. However, due to the outside air flowrate needed to maintain CO2 concentration, free cooling results in higher heating consumption in the winter. In this study, HVAC systems evaluated based on total heat transfer between the plant and the environment for different cultivated densities.

**HVAC design with temperature, humidity and CO2 regulation**

When planning your indoor agricultural facility's HVAC systems, it is important to understand the specific growth needs of your crop. Different crops have different needs in terms of temperature, humidity and airflow, which have a direct impact on their growth and productivity. By customizing your system to meet those needs, you will be able to optimize plant growth, resulting in healthier crops and more productive indoor farming operations. When it comes to indoor agricultural facilities, temperature, humidity and CO2 are all important factors for plant growth. Too high temperatures and too low humidity can be stressful for plants, while too much dry air can slow down their growth. On the other hand, too much CO2 can improve plant growth, but you will need to manage it carefully to avoid any potential problems. By carefully controlling those factors, you are able to create environments that support optimal plant health and development, as well as productivity.

HVAC systems used in indoor agriculture must be manufactured and built to handle heat loads and control operation in any to be much different from that used for human's house cooling. For indoor agriculture, during "daytime" mode, lighting produces a high sensible heat load and a considerable latent heat load from evapotranspiration and a sensible cooling effect from plant transpiration. Therefore, there is a demand to cool and dehumidify the space. In the "nighttime", a small sensible load is present, some latent load is present from evapotranspiration, and sensible cooling is present from transpiration.

Due to these different types of conditions. The air-conditioning system needs to be built to operate in the way

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can handle cooling and dehumidifying when lights switched on dehumidifying. When lights switched off Heat, it is safe to note if plants will add a considerable amount total heat load transfer through the premises structure.

**Determining the Supply Air Parameters**

The quantity of supply air to the indoor growing space and the appropriate supply air state calculated by hourly heat load calculation software to give the total heat load required in the growing area. Sensible heat load gain is directly calculated from light, people, motors, equipment and through building roof, walls and floor. Latent heat load gain comes from evapotranspiration, people, air infiltration to the building and any other source produces moisture.

For a simple calculation, if the Growers have indicated a preference for a 75°F indoor dry-burb temperature. To achieve this, vapor penetration pressure (VPD) at the leaf's surface is calculated to be 75°F room temperature and relative humidity at 100% , which is 2.96 KPa. Additionally, the grower has stated that they prefer the VPD (Vapor Penetration Pressure) of 0,91. By subtracting the suggested VPD value from the leaf's conditions, the desired (VDP) for the surrounding air is estimated to be 2.06 KPa. Therefore, in order to meet the grower's preference of a 75°F outdoor dry-burb and a VPD value of 0,91, the area can be fixed to 75°F with a dry-bulb at 70% relative humidity. These figures represent a humidity ratio of 91.3 grains of moisture per pound of dry air (gr/lb)

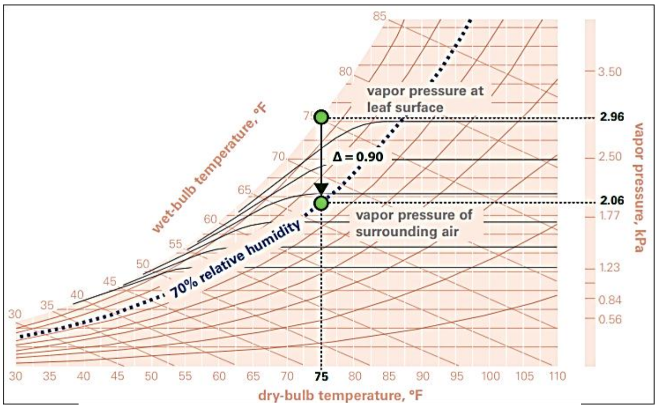


**Figure 1:** Determine vapor pressure difference

From heat load calculation of the building at "daytime" the total heat load gain is 148 MBh. Sensible cooling loads 68MBh and latent loads calculated is 80 MBh . An air-conditioning unit has been selected to provide air quantity of 3700 CFM . From sensible cooling formula, supply air dry-bulb temperature is calculated as follows :

Q Sensible, area = 1.085 x cfm x (DBT area – DBT supply)
68000 Btu/hr = 1.085 x 3700 cfm x (75°F – DBTsupply)
DBTsupply = 58.1°F

From latent cooling formula, supply air humidity is calculated as follows:
Q Latent, area = 0.69 x cfm x (W area – Wsupply)
80000 Btu/hr = 0.69 x 3700 cfm x (91.1 gr/lb – W supply)
W supply = 59.8 gr/lb

Suppose that the air off the evaporator coil is close to saturation. The (DBT) of the air exiting the evaporator coil are estimated to be 53.0 degrees Celsius (59.8 degrees Fahrenheit) and 98 degrees Fahrenheit respectively. These temperatures are colder than the previously calculated DBTsupply. Therefore, the air that has been dehumidified must be heated from 53.0 degrees Fahrenheit to 58.1 degrees Fahrenheit in order to avoid excessive cooling of the space.

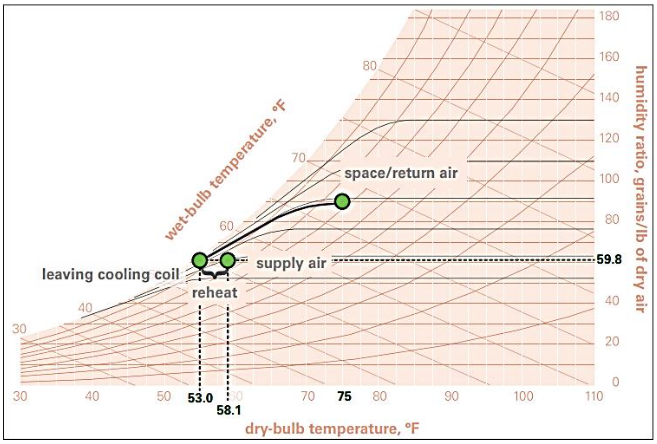


**Figure 2:** Supply air parameters conditions

**HVAC Equipment and Systems Sizing**

HVAC units were sized in accordance with industry to support the indoor environment of the internal agricultural system. In this study two different air-conditioning plants were used. The first one build as a basic and direct cooling unit with (VAV) variable air quantity volume (free cooling). The evaporator coil capacity and electric heating element were sized according to calculated design loads. A safety factor of 1.2 was added to the total calculated design load. The dehumidification system capacity was chosen to meet industry practice. The capacity adjusted until the relative humidity setpoint was reached.

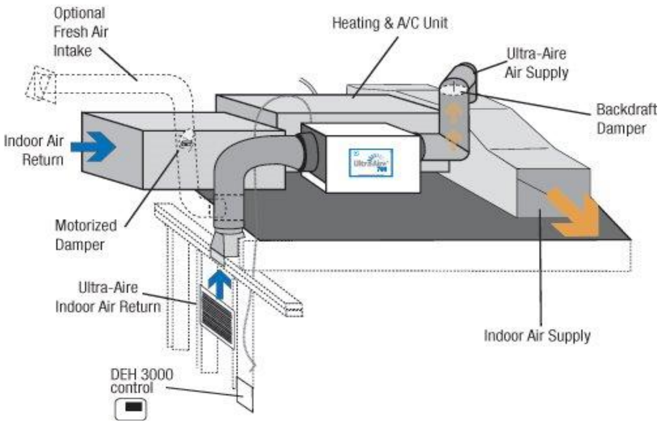


**Figure 3**: Schematic diagram of HVAC

The economizer system is the second system and is shown in Fig. 4. The economizer system is fitted to give free cooling when ambient temperature was suitable and has electric preheating elements.

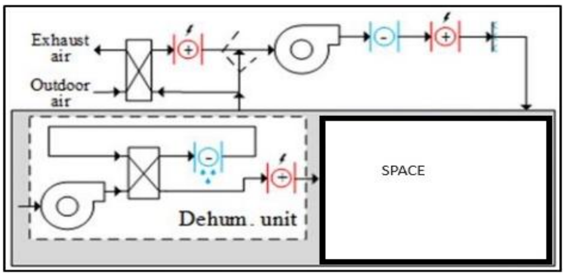


**Figure 4**: Schematic diagram of HVAC plant used with economizer.

**Annual Energy Consumption for Building Peak Load**

One of the biggest challenges in building indoor agriculture faces is high energy costs, so it's important to assess the energy consumption profile of this space. For first A/C system selected (free cooling) is an option that can be used to reduce cooling consumption in colder climates. However, due to the need to maintain a consistent air flowrate in order to maintain a CO2 concentration, this can result in an increase in heating consumption during the colder months which increases energy consumption. Dehumidification systems for a building indoor agriculture airtight system that operates in cold climates require a significant amount of energy consumption. This is to be expected as the system must cool a significant amount of air to a low temperature to remove moisture. This moisture must then be reheated in order to reach the required supply air temperature setpoint.

The yearly power consumption of the economizer unit (second A/C SYSTEM), in which free cooling could be achieved through the utilization of a thermoelectric economizer with temperature control, was significantly lower than the energy consumption of a dehumidification system, as a significant portion of the energy consumption was accounted for by an increase in outdoor air. The heating and cooling consumption was higher due to the supply of outdoor air needed to sustain the CO2 concentration during colder and warmer seasons. The change in heating consumption between medium and high-density building indoor agriculture is attributed to the higher outdoor air flowrate and the effect of plants on the building indoor agriculture load.

In order to show the influence of various cultivated densities on the performance of the systems, a parametrical test was carried out with a time period duration of 0.01 hour. Additionally, a simulation was conducted for a normal climatic year for 3 cultivar densities: low density (CD=0.6), medium density (CD=3) and high density (CD=6).

Figure 5 illustrates highest demand for electricity per end use for closed airtight and economizer systems of various cultivated density. The power demand was determined over a 15- 18-minute integration period, as determined by the electricity provider.

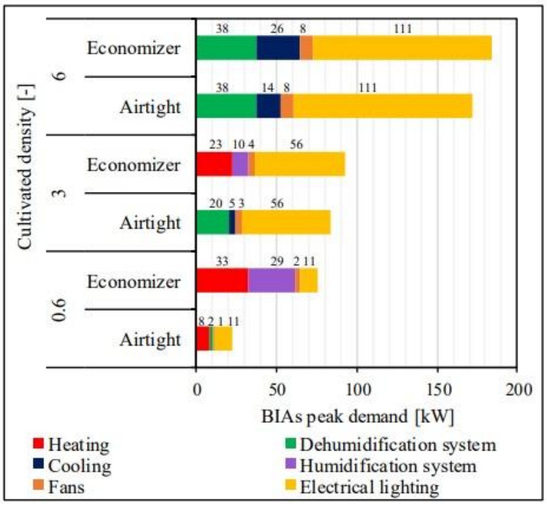


**Figure 5:** Peak Demand Distribution FO Different Cultivation Density

The peak demand of the first A/C system was proportional to the electrical lighting heat gain, while the peak demand of the economizer system was distributed differently due to the use of outside free cooling. Decomposition: lighting heat gain showed high figures with the Combined Decomposition; however, the use of free cooling decreased the cooling load while increasing the heating load requirements due to the high external air flow requirement of the system. Additionally, the highest demand of medium and high density was same for the two systems, with a much lower peak demand for low-density systems than for airtight systems.

**Total Energy Consumption**

Table 1 compares the total consumption of the HVAC system and the consumption of the electrical lighting system for different cultivation density.

Figure 6 shows the total consumption of HVAC and the total consumption of electrical lighting. The results showed that the lighting accounted for the majority of the consumption, while the HVAC (heating, ventilation, and air conditioning) systems made up a significant portion of the consumption and peak demands (Figure5).

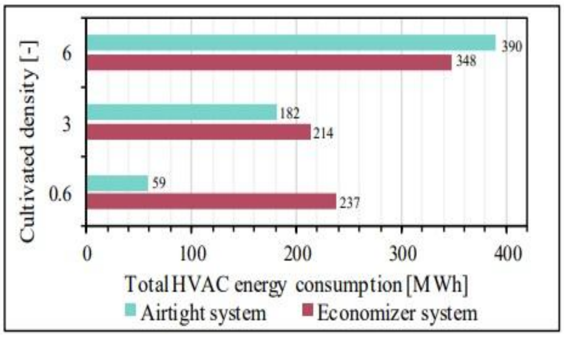


**Figure 6:** Energy consumption for different cultivated density

For building indoor agriculture with lower density, outside air flowrate loss during the cold season was more significant than the lighting heat gain, resulting in a significant sensible and latent heating consumption for that time of season. It explains why the power consumption for the economizer system is higher for a cultivated density CD (0.6) compared to a CD (3). The fixed lighting power is proportional to the number of tiers, resulting in additional lighting heat gain in the case of higher CD. However, using cold outside air cooling to cool the area reduces the power consumption for cooling. In all cases, the power consumption for dehumidification is increased when the cultivated density increases. The condensate from dehumidifying the air can be used to water the plants or for humidification when using the economizer system. This also could be important in designing building indoor agriculture in areas where water efficiency is a priority

**Table 1:** Power consumption for systems at CD= 0.6

| | Cultivated Density CD= 0.6 | | |
|---|---|---|---|
| System | HVAC % | Electrical Lighting % | Total energy consumption (MWh) |
| Free cooling Airtight system | 47 | 53 | 124 |
| Economizer system | 76 | 24 | 302 |

**Table 2:** Power consumption for systems at CD= 3

| | Cultivated Density CD= 0.6 | | |
|---|---|---|---|
| System | HVAC % | Electrical Lighting % | Total energy consumption (MWh) |
| Free cooling Airtight system | 38 | 62 | 507 |
| Economizer system | 40 | 60 | 539 |

**Table 3:** Power consumption for systems at CD= 6

| | Cultivated Density CD= 0.6 | | |
|---|---|---|---|
| System | HVAC % | Electrical Lighting % | Total energy consumption (MWh) |
| Free cooling Airtight system | 36 | 64 | 1041 |
| Economizer system | 34 | 66 | 998 |

## 2. Conclusion

In indoor agriculture HVAC works in the growing zone 24 hours. Seven days a week to control the space conditions (temperature and humidity). It is so important to provide HVAC equipment that will provide the required space condition with the best and lowest power consumption. Study showed Power savings is achieved in operating an HVAC system fitted with an economizer. It is recommended to make further studies to have systems that can handle gaseous transfer between plants and the surrounding environment. Therefore, on focusing on above study with the output results working with professional persons can reach to the needed environmental for indoor plantation with a minimum power use.

## References

[1] ASHRAE.ASHRAE Handbook—HVAC Applications, Chapter 25. 2019.
[2] ASHRAE. (2010). Energy standard for buildings.
[3] ASHRAE. (2011). ASHRAE Handbook - HVAC Applications: Environmental Control for Animals and Plants.
[4] Al-Kodmany, (2018). The vertical farm: A review of developments and implications for the vertical city.
[5] Tei, F., Scaife, A., & Aikman, D. P. (1996). Growth Analysis, Light Interception, and Radiation Use Efficiency.
[6] State of Kuwait Public Authority for Agriculture Affairs and Fish Resources.
[7] Ministry of Electricity & water, State of Kuwait.