Cultivation HVACD System Comparison Study

February 2023

ANVIL AGRINOMICS

James E Megerson, PE

AndersonPorterDesign
CANNABIS INDUSTRY ARCHITECTS

Brian D Anderson, AIA

ZARTARIAN ENGINEERING PRECISION AG

Michael Zartarian, M.S.E.E

Introduction / Abstract

Cannabis cultivation at scale is a relatively new application in the Heating, Ventilating, Air Conditioning and Dehumidification (HVACD) industry, and several approaches are regularly used and favored by designers and installation contractors. The authors, collectively, and independently, have designed, installed, and monitored these alternatives and others. The purpose of this study is to objectively compare three different climate control systems for a cannabis flowering room. The inquiry is aimed at answering practical questions such as efficiency, installation cost, performance and maintenance cost. The flowering room under consideration is a standard sized, industrial level (24/7 operation), double-tier, with moving 'archive style' benches. The room is fully indoors - no sunlight is used from the outside. The room design employs 4" insulated metal panels (IMP) on walls and ceiling, with an insulation R value of 20 installed and sealed to meet an infiltration/exfiltration rate of 0.5 ACH @ 50pa (approximately 150 CFM). The electric light is supplied by LED fixtures at an efficacy and density typical for cannabis at the time of this writing.

Two 'VRF' style HVAC systems (ducted and unducted) are included for this comparison because some jurisdictions have explicitly called them out in their cannabis legislation as a high efficiency option. For this study we have included the additional dehumidification equipment these VRF/Mini-split systems need to perform properly in the intended horticulture environment. The third option is an integrated HVACD system specifically designed for handling the sensible, latent, and dehumidification loads in the same horticultural application in a "packaged" arrangement.

All three systems are fully designed including ducting, diffusers, grilles and all hardware and accessories needed for a fully functioning system. There are differences in how these systems are applied properly to a cultivation space and these are highlighted throughout this document. Typical load conditions are established and simulated in an industry standard simulation software package for each and performance compared. A discussion of installation and maintenance costs and procedures are discussed with pros and cons of each approach included to add industry perspective to the performance data.

Cultivation Room Arrangement

We modeled the three systems under the same environmental conditions and room arrangements. The following are the data used in the analysis:

Room size:		35ft x 46ft		Lights on Temp/ humidity	82F / 58% RH
Room area:		1610 sqft		Lights off Temp/ Humidity	72F / 58% RH
Canopy size:		1728 csf		Watering rate:	0.25 gal/ csf/ day
Growing tiers:		Two		Sensible Load:	272,030 Btuh
Lighting Type:		LED		Sensible Credit for Evaporation	108,802 Btuh
Lighting wattage:		45 watts/sqft of canopy		Moisture removal rate:	192 lbs/hr
Room Insulation		R=20		Lights on/off:	12 hrs / 12 hrs

Total operating time is 24 hrs, 7 days per week. Lights on temp and humidity are for week two of flower when lighting and moisture removal rates are at their maximum.

HVACD System Descriptions

Each system was sized and selected based on its ability to provide the cooling and dehumidification necessary to maintain room temperature and humidity setpoints under identical conditions. It is possible that the physical characteristics of the room (e.g. square footage, ceiling height) might change how some of these systems are applied. For example, a larger room may permit dehumidifiers to be located within the space as opposed to ducted. This would have an impact on the installation cost but negligible effect on energy consumption and maintenance cost. Items such as circulation fans and miscellaneous loads were determined to be consistent between the systems and not included in the models.

It should be noted that multiple states have adopted cGMP (current Good Manufacturing Practices) in their cannabis regulations. With cGMP comes the principle of cascading air flow to protect critical areas. This is done by introducing outside air at specific CFM levels to achieve positive pressure in specific rooms. That added air then 'cascades' out through the doors to areas of lower (or negative) pressure. This design feature is very difficult to achieve with Mini Split and VRF systems. It is very easy to do with the integrated HVACD unit.

System 1: Ductless Mini Split System

This system consisted of eight 4 Ton ceiling hung evaporators with matching remote condensing units to handle the sensible load in the space. In addition to the mini-splits, seven standalone dehumidifiers rated at 706 pints per day at 82F and 58% RH take care of the moisture removal. These dehumidifiers remove moisture from the space and convert that energy into sensible heat that is rejected back into the space. For this study each dehumidifier rejects an additional 15,200 btuh of sensible load per dehumidifier into the room (106,400 btuh total) for the ductless split systems to cool. (Refer to Figure 1 & 2)

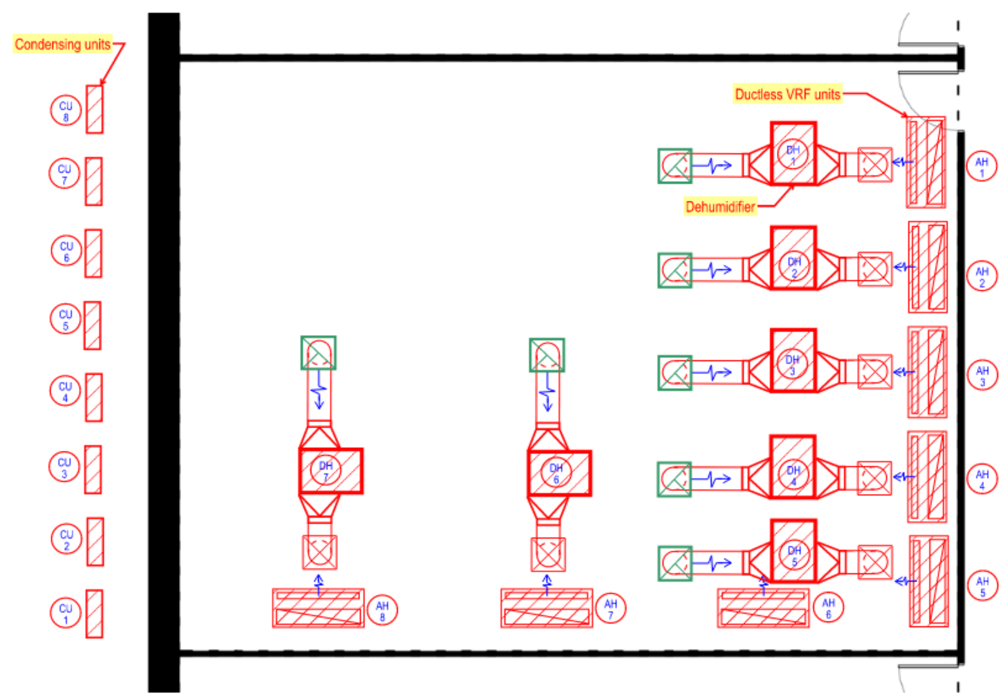

Figure 1 Ductless Mini Split system - Plan View

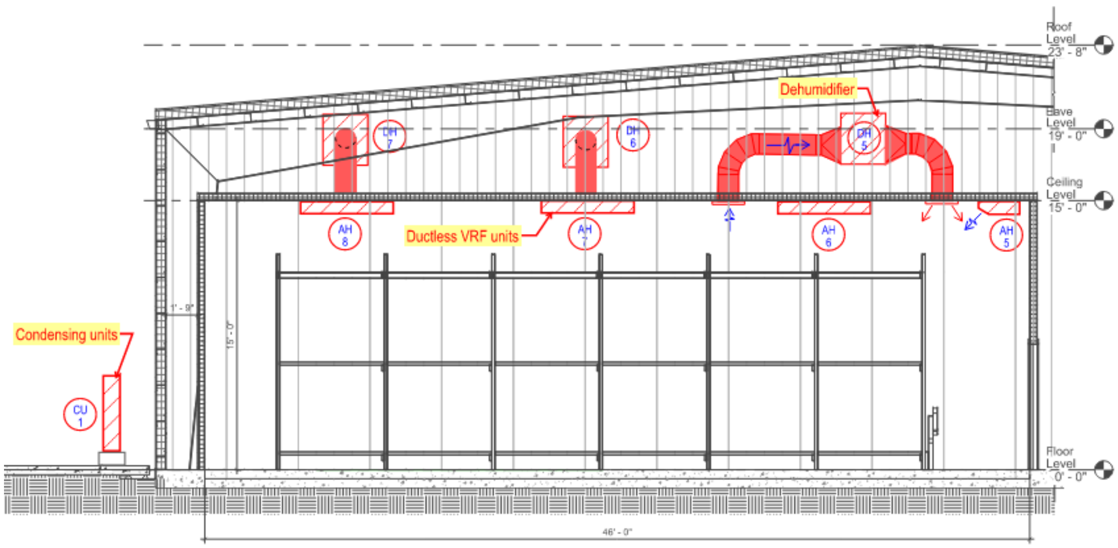

Figure 2 Ductless Mini System - Section View

System 2: VRF Split Systems

This system utilized four 8 Ton fan coil evaporators with matching remote condensing units to handle the sensible load in the space. These units will be located above the ceiling and ducted into the space. In addition to the split systems, seven dehumidifiers rated at 706 pints per day at 82F and 58% RH to take care of the moisture removal rate. As described in System 1, these dehumidifiers reject an additional 15,200 btuh of sensible load per dehumidifier into the room (106,400 btuh total) for the VRF split systems to cool. The dehumidifiers will be side streamed ducted on the return of each fan coil. (Refer to Figure 3 & 4)

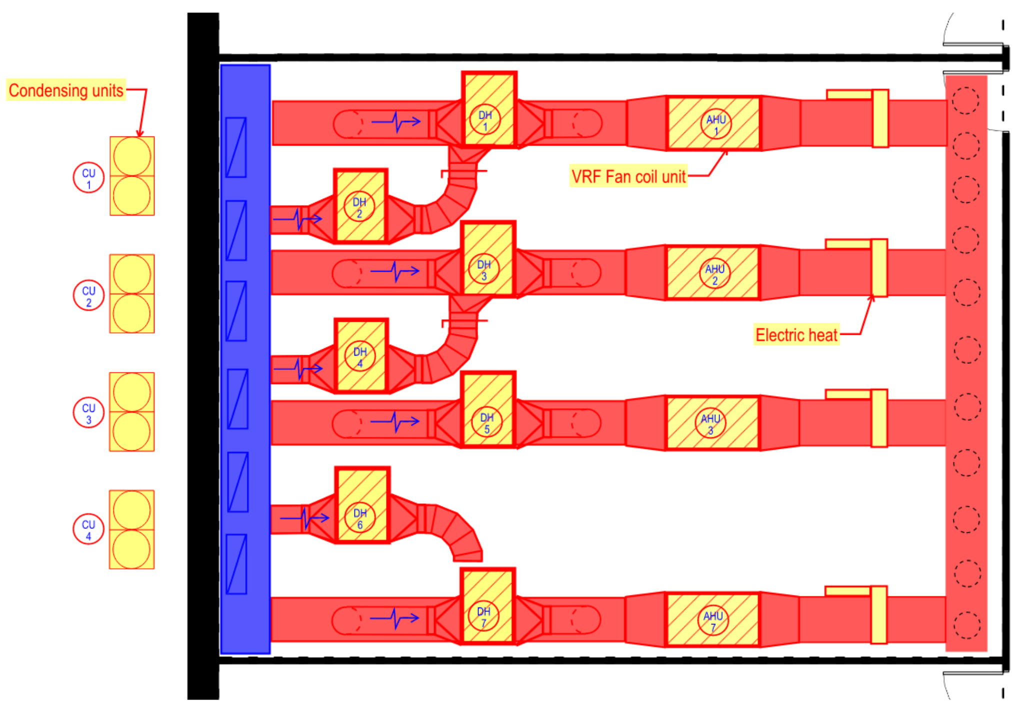

Figure 3 VRF Split System - Plan View

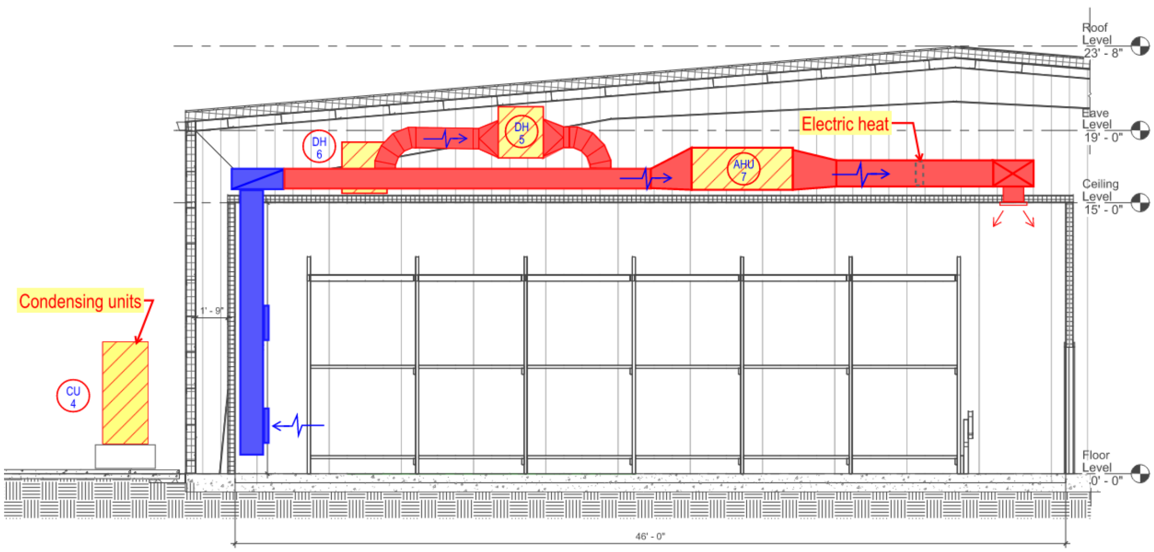

Figure 4 VRF Split System - Section View

System 3: Packaged Purpose Built

This system will utilize two packaged units capable of handling 152.9 Mbtuh of sensible heat and 101 lbs/hr of moisture removal per unit. These units will be placed on the ground and ducted into the space. External ductwork will be insulated with R12 insulation. No additional dehumidifiers are needed as the units are capable of meeting the moisture removal requirements without additional equipment. This equipment reclaims energy from the heat gain of the evaporator and redirects it to a hot gas reheat coil instead of the air cooled condensers when needed. This allows the supply air to the space to be delivered above the dewpoint temperature for the space helping reduce the potential of microclimates and other possible condensation to occur. (Refer to Figure 5 & 6)

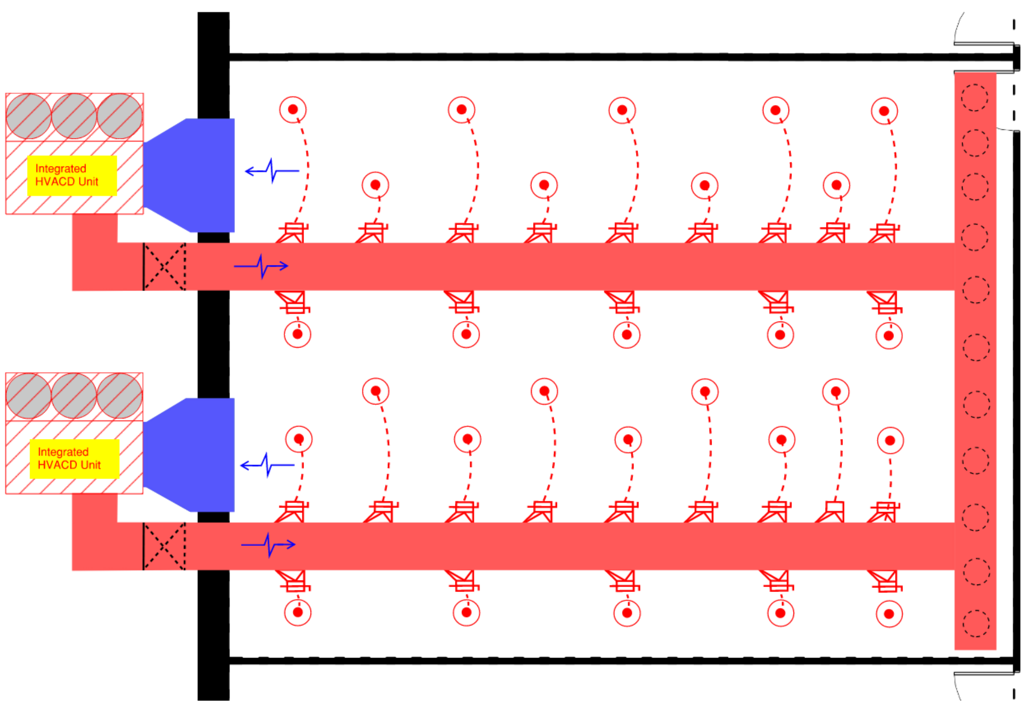

Figure 5 Packaged Purpose built Plan view

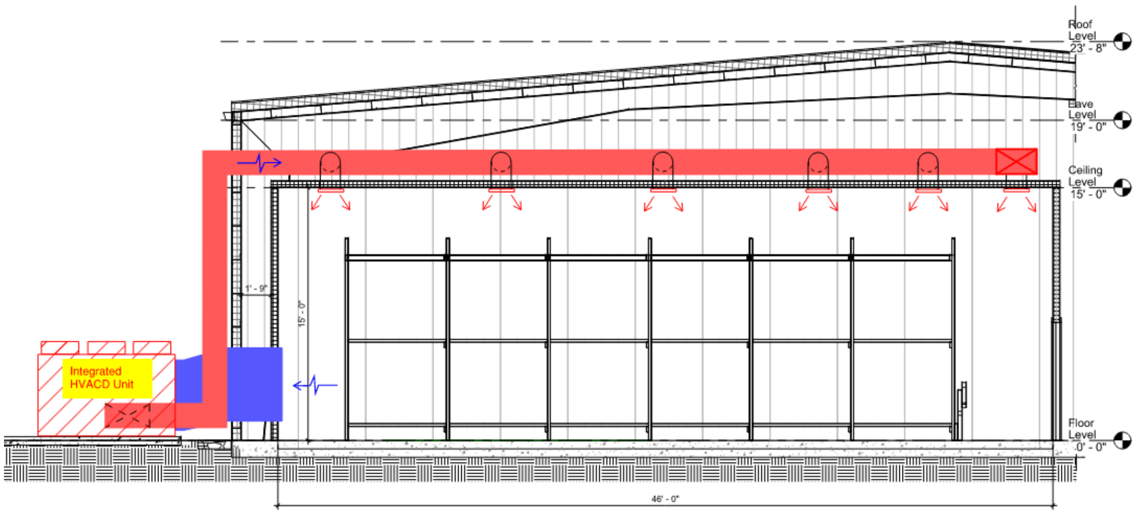

Figure 6 Packaged Purpose Built Section View

Energy Modeling

Carrier HAP Hourly Analysis program Version 5.11 was utilized to simulate the three systems. This was also confirmed using hand calculations. The following are the values used for inputting system efficiency for each component:

Equipment		Efficiency Rating
Ductless Mini Splits		23.5 IEER
VRF Split Systems		22.0 IEER
Dehumidifiers		3.2 liters/kWh or 7.1 lbs/kWh
Purpose Built Packaged Units		18.2 IEER

The following is a table showing the relative energy use of each system for one flower room.

System		Energy Usage kWh/Year
Ductless Mini Splits (including dehumidifiers)		616,758
VRF Split Systems (including dehumidifiers)		626,836
Purpose Built Packaged Units		539,298

The system that uses the most energy is the VRF Split System at 626,836 kWh/year. Overall, the Integrated HVACD System uses the least amount of energy or 14% less than the ductless split system and 16% less than the VRF Split system. Even though the VRF and Mini split equipment is more energy efficient, when combined with the less efficient dehumidifiers to perform moisture removal and increased capacity to handle the added load from the dehumidifiers the overall system energy usage is more.

It should be noted that the values above are kWh used only. We did not include utility cost as this varies greatly depending on region and local utility markets. This was done to represent the energy usage of each system related to each other under identical conditions. There may be equipment in each category that could be more or less energy efficient that should be taken into consideration when choosing a specific piece of equipment.

Opinion of Probable Construction Cost

As part of this evaluation, we obtained construction costs from practicing contractors. The construction cost may vary based on region and local economic conditions and should not be used other than a comparison under the same pricing conditions at the time of this evaluation. The following table shows construction cost per HVACD system evaluated for one Flower room. There may be economies of scale as individual room cost may be lower when spread across the entire project and should only be used as a comparison.

	System 1 Ductless Splits	**System 2 VRF Splits**	**System 3 Integrated HVACD**
Equipment cost	$171,270	$162,718	$159,390
Material	$10,646	$43,086	$25,831
Labor	$39,124	$65,240	$33,477
Subcontractors	$30,000	$30,000	$14,000
Ancillary/Soft Cost	$65,989	$85,146	$56,713
Total HVACD Cost	**$317,029**	**$386,190**	**$289,411**
Cost/ sqft	$194/ sqft	$236/ sqft	$177/sqft

The above costs include electrical for HVACD equipment only and sales tax of 9%. Labor and material costs are from the date of publication.

The biggest contributor to the cost differences is:

1. All systems have a very similar cost of equipment. The higher cost for the ductless splits and the VRF is due to needing dehumidifiers for moisture removal which is not needed for the packaged purpose built system.
2. There is more material and labor associated with System 2 & 3 than that of the Ductless Splits.
3. There is additional material associated with Systems 1 & 2 due to copper refrigerant lines and insulation.
4. System 1 & 2 has more electrical cost due to the number of electrical connections necessary for the additional pieces of equipment.
5. Subcontractor cost includes electrical, hoisting and external duct insulation. The biggest difference in this category is electrical cost.
6. In some instances lower cost for Systems 1 & 2 may be possible if the room is large enough for dehumidifiers to hang in the space in lieu of side stream ducting per the example.

Maintenance and Service Cost

The system designs were submitted to service contractors to estimate annual service cost and the following table is the result of those service estimates. Costs were obtained from a midwest location and may vary depending on the location of the facility.

	System 1 Ductless Splits	System 2 VRF Splits	System 3 Packaged Purpose Built
Maintenance cost	$8,500	$6,200	$3,500

Ductless Mini-Splits:

The number of units to maintain and service makes this the higher cost. The maximum capacity on ductless systems is 4 tons. They also provide limited moisture removal so supplemental dehumidifiers are needed. There are substantially more filters that need to be changed. The filters in a mini-split will not filter out the typical contaminants in a flower room. These filters are meant to be cleaned and not replaced.

Mini-splits were developed primarily for the residential and light commercial market and are not built to run 24/7. It should be expected to have higher failure rates especially with fan motors and compressors. Many times these cannot be repaired and replacement is the best option.

VRF Split Systems:

These have less components than the mini-splits because they come in larger capacities (max 8 Tons). However, like the mini-splits they also require supplemental dehumidification. Because these come as a split system they will accept a higher grade filter and are easier to maintain.

VRF Splits were developed primarily for the commercial market and are not built to an industrial standard and designed to run 24/7. It should be expected to have higher failure rates especially with fan motors and compressors. Many times these cannot be repaired and replacement is the best option.

Integrated HVACD System:

These units supply both cooling and dehumidification. They are either repurposed from a dedicated outdoor air unit or made specifically for cannabis cultivation. They are made to run 24/7 and most have variable capacity compressors allowing them to more closely match the load in the space. These units typically can handle the entire sensible load and the moisture removal without the need for additional dehumidifiers. These units will accept a wide variety of different filter types. With fewer moving parts this option is the least for maintenance and service cost.

Space Performance

In this section we compare the integrated HVACD system performance compared to one made of supplemental dehumidifiers and comfort cooling equipment. It should be noted that these examples are from separate operating buildings and may operate differently under different conditions. It is the opinion of the Authors that these results are similar across multiple facilities based on experience with each system type.

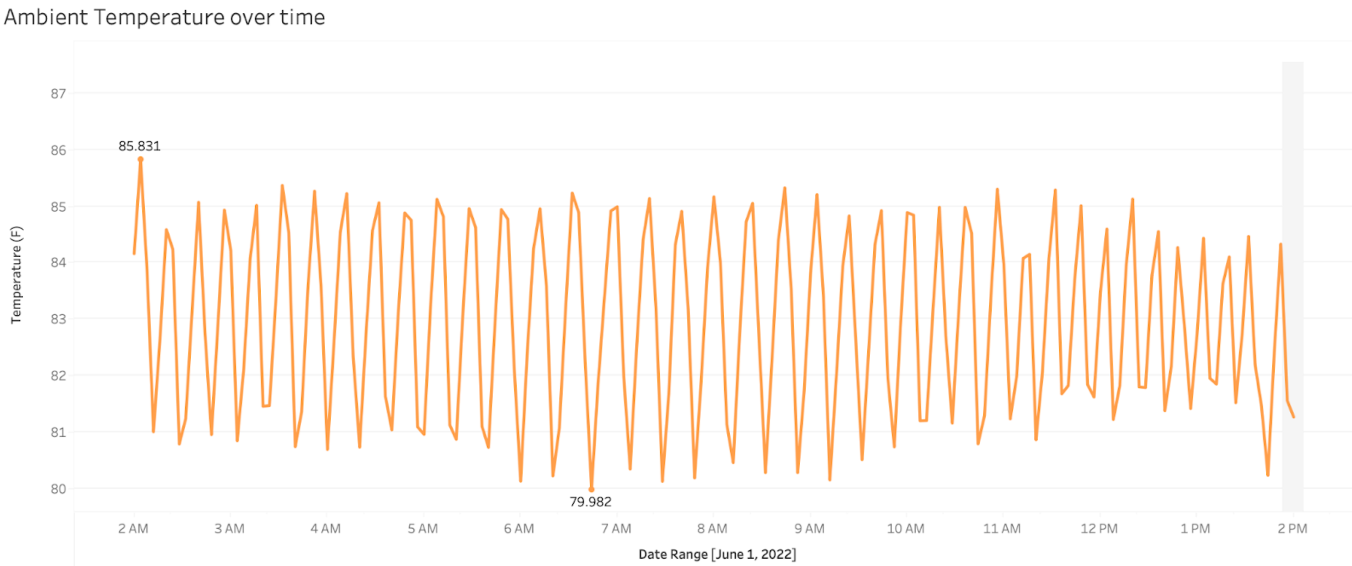

Figure 7: Temperature measurements in a cannabis flowering room during a daytime cycle with comfort cooling + supplemental dehumidifiers

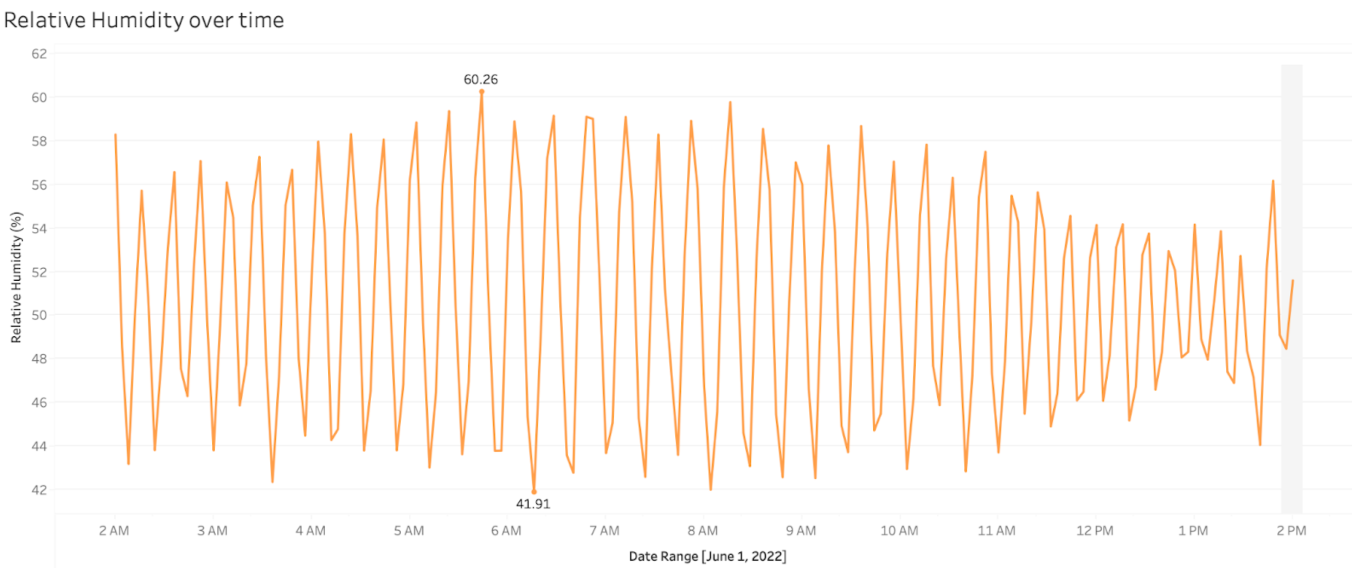

Figure 8: Relative Humidity measurements in a cannabis flowering room with comfort cooling + supplemental dehumidifiers

Figure 7 and 8 above show data collected from a 720 square foot canopy commercial cannabis flowering room. The room is served by four 5-ton split system comfort cooling units and two standalone 320 pint-per-day industry-standard supplemental dehumidifiers.

The temperature stability is +/- 2.5 degrees F, but the system is constantly short cycling and overshooting setpoint. When looking at humidity stability, there is a swing of +/- 10% RH throughout the day consisting of quick transitions. Because the dehumidifiers exhaust heat into the space directly, humidity control and temperature control are mutually exclusive. To change the humidity with the standalone dehumidifiers, heat must be injected into the space, requiring the split system to turn on to transfer this added heat out of the space.

Most importantly, this space in this condition was performing poorly, producing inconsistent plants which were susceptible to disease. This dramatically reduced plant yield and resulted in powdery mildew being present in the crop, leading to failed state testing and additional crop loss and devaluation.

In contrast, Figure 9 and 10 shows a flower room of approximately 3456 sqft being conditioned by a single Integrated HVACD unit. This unit serves all sensible and latent cooling needs; no standalone dehumidifiers are present.

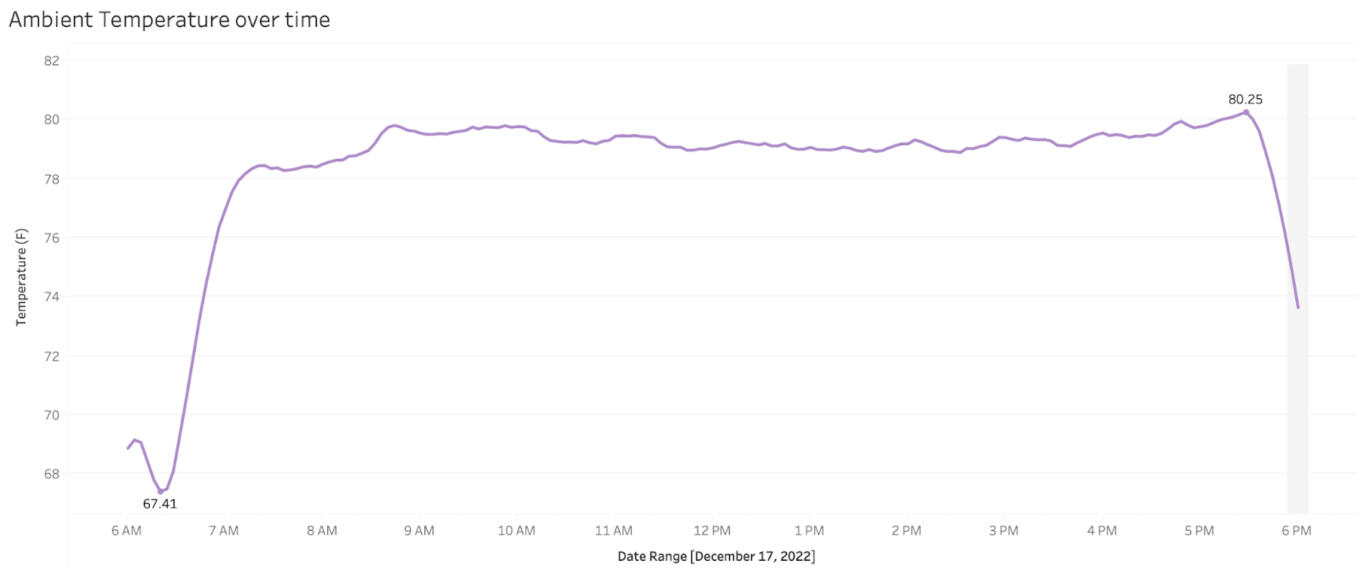

Figure 9: Temperature measurements in a cannabis flowering room during a daytime cycle with a purpose built HVACD system

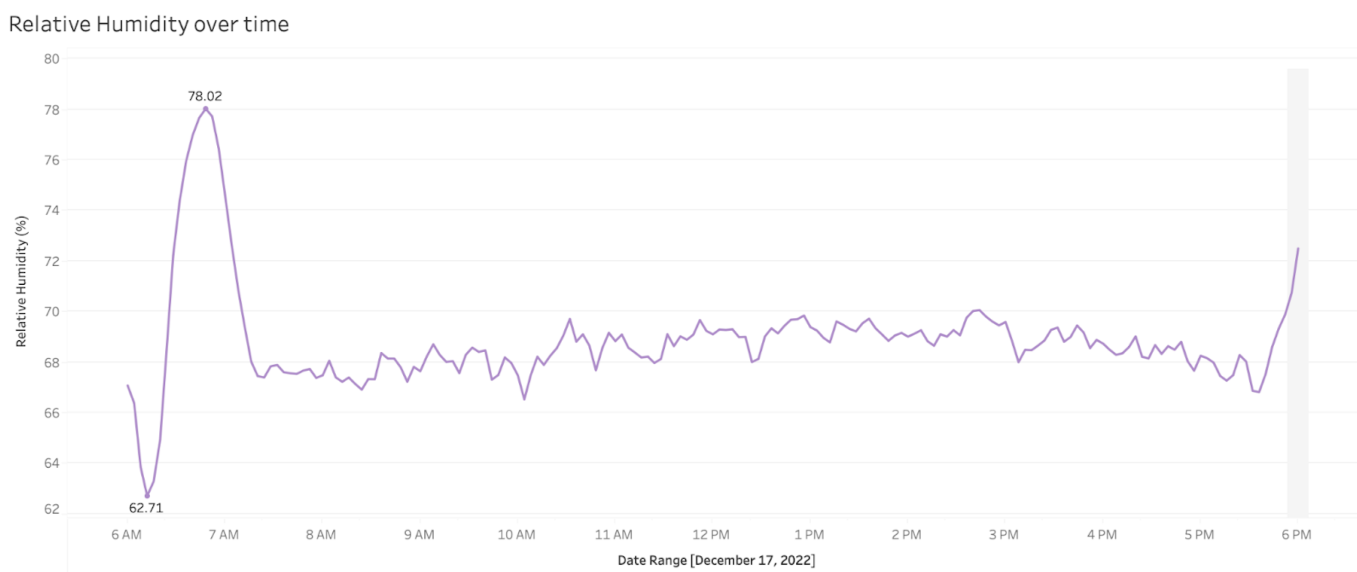

Figure 10: Relative Humidity measurements in a cannabis flowering room with a with a purpose built HVACD system

As can be seen above the temperature and humidity ranges are much tighter and change slowly. Temperature varies by less than +/- 1 degrees fahrenheit, and relative humidity varies by approximately +/-2.5 % once the room reaches equilibrium after lights on/ off. The stability conferred by an integrated HVACD system leads to greatly improved plant performance, health, yield and ultimately facility profitability. Furthermore, with an Integrated HVACD system, there are much fewer pieces of equipment to control and coordinate, leading to much easier control for the operator.

System Differences

The following is a list of potential pros and cons that should be considered when evaluating the merits of any system applied to a cultivation space. This is not meant to be an exhaustive list and there are many items that may only be evident to a trained horticulturist, engineer or other professional familiar with indoor cultivation.

System	Pros	Cons
Mini-split	1. More individual systems that may suggest a higher level of redundancy. 2. Units are readily available for replacement. 3. More readily available service technicians with familiarity of the system. 4. Equipment availability. 5. Owner familiarity. 6. Simplified controls. 7. Reduced amount of ductwork for installation.	1. Not made for 24/7 operation, leading to increased failure rates. 2. Will not accept a MERV rated filter. 3. Requires multiple pieces of equipment to meet room conditions. 4. Requires use of other dehumidification equipment. 5. May require individual condensate pumps.Condensate pumps have high failure rates that could cause the system to shut off. 6. Not good at delivering large volumes of air. 7. Will only deliver 55F air to space. 55F air to the space is not appropriate for grow room applications. 55F air can condense moisture on diffuser surfaces and sometimes on plants. Supply air is best delivered above dew point temperature to the space which is around 66F and above. When these systems are used supplemental air moving devices are needed to mix colder air with warmer air from dehumidifiers. 8. High levels of temperature and humidity inconsistency. 9. Multiple temperature and humidity sensors are required. 10. Lack of sophisticated controls could cause inconsistent room conditions leading to swings in vapor pressure deficit that have a negative impact on plant vitality and product yield. 11. Higher quantity of refrigerant located within the space. 12. HVACD equipment is located above plants where condensate could leak on failure of equipment and make repairs more difficult. 13. It may be easier to replace equipment rather than repair. 14. Difficult to positively pressurize the room.
VRF Split Systems	1. More individual systems that may suggest a higher level of redundancy. 2. More readily available service technicians with familiarity of the system. 3. Units are readily available for replacement. 4. Owner familiarity.	1. Not made for 24/7 operation, leading to increased failure rates. 2. It may be easier to replace equipment rather than repair. 3. Requires multiple pieces of equipment to meet room conditions.

	5. Simplified controls. 6. Reduced amount of ductwork for installation. 7. Will accept a MERV rated filter.	4. Requires use of other dehumidification equipment. 5. Requires ductwork to distribute air. 6. May require individual condensate pumps. 7. Not good at delivering large volumes of air. 8. Will only deliver 55F air to space. 9. High levels of temperature and humidity inconsistency. 10. Needs supplemental air moving devices to mix colder air with warmer air from dehumidifiers. 11. Multiple temperature and humidity sensors are required. 12. Lack of sophisticated controls could cause inconsistent room conditions leading to swings in vapor pressure deficit that have a negative impact on plant vitality and product yield. 13. Higher quantity of refrigerant located within the space. 14. Fan coils and dehumidifiers are located outside of space making access for maintenance more difficult. 15. May require condensate pumps that have a tendency to fail. 16. HVACD equipment is located above plants where condensate could leak on failure of equipment. 17. Difficult to positively pressurize the room.
Integrated HVACD System	1. Multiple units for redundancy. 2. Units are made to run 24/7. 3. Installation is easier and duct routing is simplified. 4. No supplemental dehumidifiers needed. Units provide both cooling and dehumidification. 5. HVACD units are not located inside the building. 6. Easier access to equipment for service and maintenance. Service technicians do not have to gain access in secured areas for service or maintenance. 7. System is more energy efficient than the other alternatives. 8. May be combined easily with a building automation system for monitoring, control and data acquisition. 9. Higher volumes of air delivery which reduces potential microclimates. 10. Ability to positively pressurize the room. 11. Will accept a MERV or HEPA rated filter.	1. Units may have longer available lead times. 2. Units may require a higher level of competence for maintenance and service personnel. 3. Units generally will need to be repaired as opposed to replaced.

Conclusion

It's important when selecting systems for grow room applications that this is done using comprehensive evaluation. All aspects including installation cost, maintenance and operation must be evaluated in order to obtain the true return on investment for the HVACD system used. One of the most important evaluations is how the system will perform in the specific application. With controlled environments for horticulture we are developing systems for plant life support as opposed to comfort cooling. The system must operate properly for the application.

The system comparison shows that the Integrated HVACD system will perform best, cost less, and operate with less energy than the other two systems in the study. This should result in a faster return of investment for the HVACD systems. Importantly for the states administering and monitoring Controlled Environments for Horticulture (CEH) and vertical farms within their jurisdictions, Integrated HVACD systems will be more energy efficient.

About the Authors

James E Megerson, PE, LEED
Anvil Agrinomics
Jmeg@anvil-ag.com
m. 913-226-7077

Anvil Agrinomics, LLC (AnvilAg) is a national mechanical, electrical and plumbing (MEP) engineering design firm located in the heart of the country. We have experience working in several different industries with a focus on controlled environments for indoor agriculture (CEA).

When Anvil Ag was envisioned, founder Jim Megerson set out to create an Engineering firm that was different from the typical design firm. Jim wanted a firm known for being innovative and creative in problem-solving. He wanted to balance construction knowledge and technical engineering prowess. Anvil Ag balances design, construction cost, operations & maintenance to achieve the best return on the owner's HVACD investment; Jim's team delivers the true value of HVACD ownership.

AnvilAg has experience with many building types but focuses on controlled environments for indoor agriculture, namely indoor cultivation, and manufacturing for infused products. They have spent a great deal of time learning and developing expertise with how heating, ventilation, air conditioning, and dehumidification (HVACD) systems provide life support for agricultural products. It is paramount that to design HVACD systems for CEA properly, one must have an equal understanding of horticulture. As we design buildings for people's comfort, we must design indoor agriculture facilities for the plant as an occupant. It is important to know that with Indoor cultivation, the entire building is a system that supports plant life. We are trying to create the perfect outdoor day inside the building 24/7. We can no longer build the systems into the building but the building around the systems.

Mike Zartarian, M.S.E.E
Zartarian Engineering & Precision Ag
z@zartarianengineering.com // www.zartarianengineering.com

Mike grew up in an agricultural-based community and developed a deep respect for the people, plants, animals and systems of small-scale production. He earned his BS and MS in Electrical Engineering from Northeastern University and spent the first portion of his career in product development and research roles in consumer and industrial electronics.

Reconnecting with his agricultural roots, Zartarian Engineering and Precision Ag was founded to bring a plant-centric, systems approach to Controlled Environment Horticulture. Leveraging in-house developed tools, Zartarian Engineering offers robust insights on plant health and system performance, providing clients with the information they need to make data-driven decisions on facility design, commissioning and operations.

As the Principal of Zartarian Engineering and Precision Ag, Mike has contributed his research findings to inform industry best practices for organizations such as RII, DLC, local and state regulatory bodies and USDA. His work has been published in Cannabis Business Times and Greenhouse Grower, and he's participated in many conference conversations on advancing the practice of precision agriculture.

Brian D. Anderson, AIA
Anderson Porter Design
Brian@andersonporter.com // Andersonporter.com
m. 617-515-2648

Brian is a founding partner of Anderson Porter Design, Inc., an international practice focused on design and architecture for the cannabis industry. Anderson Porter Design provides strategy, technology, design, and thought leadership built on 30 years as a general practice in Architecture. Since 2014 they have focused on buildings for plants: Controlled-Environmental Horticulture (CEH), Extraction / Manufacturing and Retail Dispensaries. Brian merges a Harvard master's degree with a RISD education in the craft tradition of making and designing objects with an analytic data-driven process to drive value along the cannabis supply chain. Brian shares his expertise nationally by speaking on energy sustainability in the Cannabis Industry, Facility Design, and interior design for retail.

Brian is a member of SCC, RII, NCIA, ASTM and NFPA and is licensed in 13 states. At the NCIA he founded the Facilities Design Committee and now sits on the Retail committee. With RII he is in the founder's circle as a subject matter expert providing peer review for USDA-sponsored CEH best practice guides. Through the SCC, Brian contributes blog posts and publications with greenhouse growers, cannabis business times, High Profile Magazine, and the Boston Globe. Brian supports the ASTM International's D37.09 sub-committee for cannabis facility sustainability.