Seal Your Greenhouse to Improve Yield and Quality: An HVACD Systems Approach

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Chances are that if you own or operate a cannabis production company one of the first important decisions you had to make when starting the company was whether to grow indoors or in a greenhouse. There are pros and cons to both options and that debate will likely continue for at least the next decade. However, this paper is not about that debate. This paper is for those of you that chose to grow your crops in a greenhouse, and more specifically, in an "open" greenhouse. Your reasons for choosing an open greenhouse were valid: natural sunlight in lieu of artificial light; costs less to build; and requires less energy to operate. What you might not have considered at that time (at least not in enough detail) are the challenges and risks involved with operating an open greenhouse. The root cause of many of these challenges is climate control… or as you might have learned the hard way, the lack thereof. If you fall into the category of "having learned the hard way," or, if you have learned to cope with the ever-dynamic climate inside of an open greenhouse, but believe it is limiting the quality and consistency of your product, then this paper is for you. You may be wondering if there is a solution that does not include starting over with a new facility. Rest assured, there is: convert your "open" greenhouse into a "sealed" greenhouse. In this paper, we will cover:

- The benefits of sealing your greenhouse
- Why sealing your greenhouse is primarily an HVACD solution
- The key system-design aspects to focus on when sealing your greenhouse

Benefits of Sealing Your Greenhouse

There are many benefits to sealing your greenhouse, but before we focus our attention on those, let's define what we are talking about. An "open" greenhouse relies solely on ambient (i.e., outside) air to control the greenhouse climate. Usually, a "fan and pad wall" is used to cool the greenhouse, while dry ambient air is used to dehumidify. Additionally, one of any number of heating systems is used to raise the temperature in the greenhouse.

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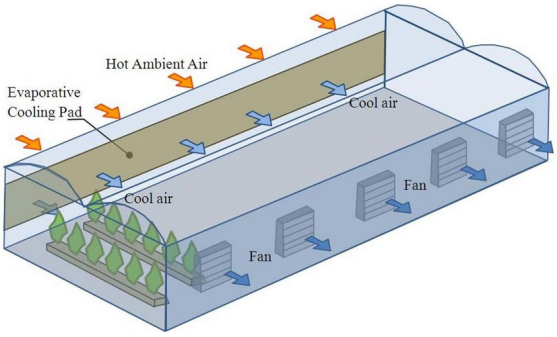

Fan and Pad Wall

Conversely, a "sealed" greenhouse has a sealed, or closed, building envelope and uses advanced Heating-Ventilation-Air Conditioning-Dehumidification (HVACD) systems to treat recirculated air to control the climate inside of the greenhouse.

It is not hard to understand why the climate inside of an open greenhouse is so difficult to control. By relying solely on ambient air to condition the space, you are almost entirely at the mercy of the ambient climate. It is common to experience conditions that vary (+/-) 10°F and (+/- 10%) from the desired temperature and relative humidity setpoints, respectively. Also, it is impossible to leverage supplemental CO2 in an open greenhouse, except for during the winter when ventilation is reduced or eliminated. Furthermore, open greenhouses generally introduce ambient air at a rate of 60 Air Changes per Hour (ACH)… that means you are bringing in enough air to fill the entire greenhouse once per minute; that's a lot of air moving at a very high speed! There is no viable way to distribute that amount of air moving at that speed in any consistent and uniform fashion across the canopy. Lastly, it should go without saying that pest management and odor control are very difficult tasks in an open greenhouse. In summary, in an open greenhouse:

- Temperature and relative humidity can vary widely and regularly
- Leveraging supplemental CO2 is nearly impossible
- The lack of an air distribution system means inconsistent airflow across the canopy
- Odor control is virtually impossible and pest management is not much easier

Those are extremely tough variables to overcome to produce a high quality and consistent product.

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In contrast, sealing your greenhouse would mitigate, or eliminate, every risk noted above for an open greenhouse. Because advanced HVACD systems are used to control the climate in a sealed greenhouse, you can virtually eliminate the wide temperature and relative humidity swings. If designed properly – and that can be a big "if," we'll explain later – you can nearly maintain as tight control over your climate in a sealed greenhouse as you can in an indoor grow facility.

Sealed Greenhouse with Advanced HVACD Equipment

Also, enriching the climate with supplemental CO2 becomes a reality, and because you can control the climate so well, you can maintain optimal conditions for plant uptake of CO2, thereby dramatically improving product quality and consistency. Furthermore, unlike the 60 ACH needed in an open greenhouse, you can lower the airflow to as low as 8 to 10 ACH in a sealed greenhouse. The drop in airflow not only allows you to distribute the air through duct evenly across the entire canopy, but it will also reduce fan energy usage. Lastly, sealing your greenhouse, on its own, is a great way to control odor and pests.

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In conclusion, the comparison can be presented as follows:

	Open Greenhouse	Sealed Greenhouse
Temp. & RH Variability	(+/-) 10°F & 10%	(+/-) 2°F & 2%
Supplemental CO2	Some in winter	Year round
Air Changes per Hour	60 ACH	8 ACH or greater
Air Distribution	No duct; wide variability	Even across canopy, via duct
Odor Control	Virtually impossible	Manageable
Pest Management	Use screens on all openings	Minimal openings to cover

Why Sealing Your Greenhouse is Primarily an HVACD Solution

Sealing your greenhouse sounds like a building envelope solution; just a simple matter of closing any openings in the walls and roof, right? That could not be further from the truth. First and foremost, sealing your greenhouse is an HVACD systems solution that requires an HVACD engineer that understands all aspects of the system on a holistic level, not just a single component or piece of equipment. Beware of the solutions provider that tells you they can "solve your problem if you just buy this piece of equipment." The climate inside of a sealed greenhouse is very complex and dynamic. A simple example of this a storm quickly moving into a sunny area, where dark clouds block the sun and the solar radiation it transmits to inside the greenhouse. In this example, the heat load in the space drops significantly, causing the temperature to drop. When the temperature drops, the relative humidity spikes. Presumably, supplemental lights would turn on in this scenario, causing another variation in the greenhouse climate. A single piece of equipment is not going to completely solve this problem, there must be a controls component to the solution to accompany that equipment. Changing any single variable will have a domino effect on all downstream variables. In summary, the goal for the solutions provider is to balance all variables as best they can, within the constraints of the budget, and in alignment with the owner's goals.

The Key System-Design Aspects to Focus on When Sealing Your Greenhouse

Before we get into the system-design aspects to focus on, there is another aspect of the solution that commands your attention: your budget. As is the case any time you allocate capital for your

business, there will be trade-offs. Here are some notes to consider when evaluating potential trade-offs, and that may help with your decision:

- Do you want/need the solution to cover your risk for 100% of the year? Or is your risk more seasonal? If seasonal, then maybe you should consider only solving the portion of the problem that exists seasonally.
- Was it always your company's business model to produce top-shelf, premium quality flower? Or was mid-grade, or even extraction-grade quality the goal? If so, then maybe you don't need the complete solution, maybe you just need to solve a portion of the total problem.
- Top-notch and meticulous cultivators/operators can solve many problems, or at least mitigate a lot of risk by running a tight operation. Maybe you only focus on the portion of the problem that your cultivator/operator can't mitigate.
- Consider deploying the solution in phases… just make sure your engineer understands what this means, not all engineers can think in phases.

The point is that it doesn't have to be an "all or not" situation. Our job at Harvest Integrated is to deliver the right solution for you, the owner, not to up-sell you a solution that you can do without.

When sealing your greenhouse, the key system-design aspects that you should focus on are:

- Equipment selection
- Airflow and air distribution design
- Controls capabilities
- Testing, balancing, and commissioning

Equipment Selection

You will almost certainly need to add HVACD equipment, exactly what and how much depends on whether you have any existing equipment that can be re-purposed and/or optimized. Without the use of ventilation air (i.e., ambient air), advanced HVACD equipment will be needed to control the climate, otherwise, a sealed greenhouse will simply trap the heat and humidity inside leading to excessive heat and humidity build-up. Selecting your equipment will be the most important and costly decision you will make in this process, so you want to be sure to get this right. Getting this decision right is as much about properly sizing the capacity of the equipment, as it is selecting the

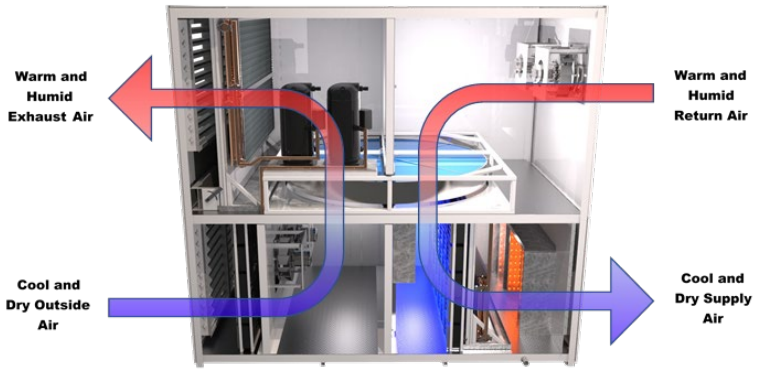
right type of equipment. If your equipment is not sized to handle the load in the greenhouse, then almost nothing else you do will matter, you will not be able to control the climate.

So, what type of equipment should you choose? Keep in mind, depending on your location, you may need to heat the greenhouse more often than you need to cool it, or you may need to introduce humidity into the greenhouse as much as you need to dehumidify it. While cooling and dehumidification are usually the most important, that's not always the case. But let's put heating and humidification aside and focus on cooling and dehumidification, being that those are more of a concern for most of you reading this.

If sized properly, nearly any HVACD equipment will control your sealed greenhouse climate. But will you be able to afford the energy cost to operate "any" piece of equipment, while being profitable? And even if your answer to that question is "yes" for your operation today, will that be the case when the market matures, and the price of cannabis decreases as competition increases? Remember, one of your reasons for choosing to grow in an open greenhouse over an indoor facility is the lower operating cost; can you still maintain that edge if you seal your greenhouse? If you select the right equipment, the answer is yes. The "right" equipment for this application is equipment that can handle the cooling and dehumidification requirement year-round, and can leverage what is known as "economization," or "free cooling;" this is cooling and dehumidification without the use of compressors, thereby drastically lowering energy usage. There are two types of economization:

- *Direct economization:* introduces outside air directly into the space when the ambient conditions can handle the load in the greenhouse.
- *Indirect economization:* uses a heat exchanger to exchange heat, and sometimes humidity, from the greenhouse to the atmosphere when ambient conditions can handle the load in the space.

Considering that you are reading because you want to seal your open greenhouse, direct economization contradicts that goal completely; so indirect economization it is.



Indirect Air-to-Air Economization (Harvest Air®)

There are a handful of indirect economization equipment options to choose from and your engineer can help you evaluate the merits of each. One options you can go with is Harvest Integrated's signature product, Harvest Air®

Airflow and Air Distribution

If selecting the right equipment is your most important and costly decision in this process, then deciding how much air and how to distribute that air throughout the greenhouse is a close 2nd in importance and is your least costly decision to make… in other words, if designed properly, your airflow and air distribution strategy can deliver a lot of "bang for your buck."

There are two metrics to consider when determining the amount of air to supply to the greenhouse:

- The volumetric flow rate, measured in Cubic Feet per Minute (CFM)
- The number of Air Changes per Hour (ACH); the number of times your system treats all the air filling the greenhouse, in one hour

First and foremost, the CFM of supply air will be driven by the heat load your equipment is serving; you must supply enough air for your equipment to handle the cooling and dehumidification requirement. Next, your air distribution design (i.e., duct design) will impact how much air you need to supply to the greenhouse. We'll go deeper on air distribution design shortly, but for now, the key point to remember is you will need much less air when ducting the air close to the canopy, than you will need if you are simply "dumping" the air into the space from a side-wall. Other factors that go into the decision of how much air needs to be supplied are:

- Canopy management – how easily can air flow and mix through the canopy?
- The use of Horizontal Airflow Fans (HAF)
- Room pressurization strategy
- Your preference… that's right, you have a say in this process, too!

As I mentioned at the start of this section, if designed properly your air distribution strategy can deliver a lot of value to your operation. In many respects, the entire reason for sealing your greenhouse is to optimize control of your grow climate to improve the quality, consistency, and yield of your product. Being able to optimize the distribution of your supply air is a key piece to achieving this. There is no single way to design an air distribution system, especially if you are retrofitting an existing facility, as we are discussing in this white paper. With that being the case, at Harvest Integrated, we follow three guiding principles when designing air distribution systems:

1. *Closely couple the supply air to the canopy as much as possible*
   Doing this will allow you to precisely control the canopy climate. This will also allow you to deliver the air at the right temperature and humidity for the plant (although, you'll need to select equipment that will allow for this type of control, it is not a standard). The greater the distance is between the supply air discharge and the canopy, the cooler and drier the supply air will need to be to mix with the heat and humidity in the greenhouse, resulting in the desired temperature and humidity at the canopy.

2. *Evenly distribute the supply air across or throughout the canopy to avoid wide temperature and humidity gradients*
   Doing this will prevent microclimates from forming in the canopy. This will also improve your ability to control the climate at the canopy and throughout the room.

3. *Separate the supply air discharge openings from the return air openings as much as possible*
   The greater the distance between the supply and return air openings, the greater the temperature difference, or "Delta T," will be between the two. As the Delta T increase, so does the efficiency of your equipment. Conversely, the shorter the distance between the supply and return air openings, the greater the risk of "short-cycling" the air, and subsequently, your equipment. Short-cycling happens when the return air openings pull the supply air back to the unit before that air could do its job of cooling and

dehumidifying the greenhouse. Not only will this cause you to lose control of the greenhouse climate, but this will shorten the life span of the components in your unit, mainly the compressors, and will eventually lead to an unexpected failure of your equipment.

Examples of The Three Principles of Air Distribution Design

There are other factors to consider with your airflow, namely air velocity, filtration, and Indoor Air Quality (IAQ). We won't cover these in this paper, but you should make a note to discuss these with your engineer. However, if you follow the three guiding principles for air distribution design, you will certainly experience much better control over the quality and consistency of your product.

Controls Capabilities

Your control system is the glue that holds all aspects of the solution together, allowing the components to form a complete system. There are many control systems and devices to choose from, without much variation in performance between each. The secret behind nearly all controls offerings on the market is that the system is only as good as the person designing and programming it. Anyone can install sensors and have those sensors communicate with the equipment. However, only someone with the right engineering knowledge and experience will know exactly where to place those sensors; exactly how wide of a temp/humidity differential is needed; and what the correct sequence of operations needs to be to deliver optional performance for your application. Given all of this, the most important features of your controls system are:

- Flexibility of function
- Placement of sensors and devices
- The engineer designing and programming the system

Testing, Balancing, and Commissioning

Last, but certainly not least, is the testing, balancing, and commissioning of your system. This process is all about ensuring that you are getting what you paid for and fine tuning your system for your specific operation. Engineers may argue that each of these is a separate function, but that's an argument of semantics and jargon. From the owner's perspective (your perspective), these three activities make up the single process of making sure your system operates up to your standard, plain and simple. So, let's look at what's involved with each.

Testing is primarily an equipment and controls activity. There are two types of tests that are performed during this phase:

- *Functional Performance Test*
  This is testing of your equipment to ensure that it is working as designed and that fault systems are properly integrating.
- *Integrated Systems Test*
  This is a series of tests that include all systems working together as designed.

Balancing, at least in this context, is primarily an air distribution activity, also referred to as air balancing. Air balancing is a method of ensuring that your air distribution system is delivering the designed airflow requirement, and ultimately, that no microclimates exist. This sounds like a simple process, and if the system is designed and installed properly it is a simple process. It's when elbows and offsets were added to the duct system during installation when this process can become complicated. The thing to remember during construction is that every added elbow or offset increases the static pressure that the fans have to overcome, and the problem is that the fans were designed to overcome a specific level of static pressure. If you see this occurring, bring it to the attention of your contractor and/or engineer, be sure that they have accounted for the additional static pressure, otherwise, you maybe left with a system that can't deliver its designed airflow.

The commissioning process can and usually does include many of the activities described in the testing and balancing sections. Where commissioning goes a step further is that its about fine-tuning your system to your desire. Additionally, the commissioning process includes formal documentation that verifies that the system was installed as designed and operating per the design specifications and requirements.

In summary, I will end this section in the same way I started it: This process is all about ensuring that you got what you paid for and that your system is fine-tuned to your liking. Do not compromise on this process. It is easy to be excited about your newly sealed greenhouse, causing you to skip steps in this process, but do not give into your excitement. Be patient and thorough and require the same from those you hired to manage this process for you. You spent a lot of money doing this, get the most out of it and this process will ensure that happens.

Conclusion

To bring it full circle, your reasons for choosing an open greenhouse were valid. However, your experience has you wondering if there is a better way; a way that will remove barriers that are keeping your business from taking the next step; a way that won't take you back to square-one with your facility. I hope this paper has shown you that sealing your greenhouse is that better way and Harvest Integrated is here for you when you are ready to move forward with deploying it.

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