

HVAC FOR CANNABIS CULTIVATION

& CONTROLLED ENVIRONMENT AGRICULTURE

BY GRETCHEN SCHIMELPFENIG, PE

Part of RII's Resource Efficiency Best Practices Series



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A report from Resource Innovation Institute

by Gretchen Schimelpfenig, PE

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OVERVIEW

As a cultivator operating in a constantly evolving industry, **you may feel like it is hard to know who to trust.** The horticultural market has changed a lot, technology has advanced, and so have the technical terms used to describe everything. It can be hard to navigate the purchasing process when planning a facility and challenging to understand minimum performance requirements for equipment.

We are here to help. As a non-profit organization, the Resource Innovation Institute establishes industry standards, facilitates best practices, and advocates for effective policies and incentives that drive resource efficiency. Our peer reviewed Best Practices Guides are a way of helping growers like you understand the most resource-efficient technologies and how to use them to boost your bottom line.

The operational changes necessary for an efficient cultivation facility may be detailed, but **they do not have to be a mystery.** Our membership is comprised of subject matter experts with the knowledge to help you build and operate the most high-performance and cost-effective facility for cultivating plant life indoors.

You may be looking for a **source of reliable third-party information**, motivated to reduce overhead for your business, or have goals for a more energy efficient facility. Whatever the reason, when you are considering a decision related to the systems used in your facility, we hope you lay the groundwork with the insights offered in Resource Innovation Institute's Best Practices Guides.



Purpose

Any grower can use a thermostat, but operating heating, ventilation and air conditioning (HVAC) and dehumidification systems for cultivation applications efficiently and effectively can be difficult to navigate.

The purpose of this HVAC Best Practices Guide is to support you, the cultivator, and your design, construction, and operations professionals in:

- Speaking the language relevant to HVAC in horticultural applications
- Assembling an effective design and construction team to ensure desirable outcomes
- Understanding manufacturer's literature to evaluate your purchasing options
- Understanding crucial considerations when selecting HVAC equipment
- Installing and operating successful HVAC solutions in alignment with your business model

Demystifying Terms

As a grower navigating design, construction, and operations decisions, there are often different people telling you contradictory things, many technical terms, and a lot of jargon. You may be struggling with understanding how to take field measurements and why they are important to you, or how to use manufacturer and facility information appropriately.

Throughout this guide, you'll learn more key terms related to heating, cooling, air conditioning, and dehumidification in cultivation facilities, their units of measurement and how they are used, why the terms are important to consider as a cultivator, and how the terms may be commonly misunderstood or misapplied.

The key terms address the topical areas listed below:

- Cultivation
- Energy & Power
- Environmental Conditions
- General HVAC
- Energy Efficiency
- Construction
- Cultivation Key Performance Indicators (KPIs)



Consult our online glossary of key terms to expand your horticultural HVAC vocabulary: <https://resourceinnovation.org/resources/hvac-terms>

To learn about more about the interactive effects between your HVAC and lighting systems, check out our Best Practices on LED Lighting for Cannabis Cultivation & Controlled Environment Agriculture, a companion guide to this one that covers lighting terms and systems used for cultivation environments.





INTRODUCTION TO HVAC FOR INDOOR CULTIVATION

Growing plants indoors introduces biological activities to sealed indoor environments, which involves using HVAC and dehumidification equipment to maintain temperatures in cultivation spaces, manage moisture produced by your plants, and minimize pest, disease, mold, and fungus issues that can be related to your indoor environmental conditions. **Sub-optimal performance of HVAC systems hurts your competitive advantage. Optimizing HVAC systems can reduce energy use and operating costs, while also leading to a better product.**

Capital expenditures for many cultivation operations are in the six to seven figures, and with energy representing 30 to 60% of the operational expense of indoor facilities producing a range of crops, this **variability in energy efficiency represents profit potential**. Various types of business costs like human resources, rent, energy - as well as most other costs - never go down (only up), and so **energy costs**, as well as increased product yield and quality, are major drivers towards profitability.

Increased demand for products and cost compression in cannabis markets have led to new attitudes about efficient and optimized HVAC systems, as growers **consider energy and resource efficiency to rise above the competition by reducing operations and maintenance costs through using high performance systems**. For example, a traditional HVAC and lighting system approach could make up 45% of your operational costs, but a high performance HVAC and lighting system evaluated during design could reduce operating costs to 30%.

HVAC system designers and manufacturers now offer a greater quantity and variety of sophisticated heating, cooling, ventilation and dehumidification options which are much more customizable, durable, and suitable for horticultural facilities than the options designed for human occupancy spaces sitting on the shelf at the box store. They are also better able to maintain optimal conditions for cultivation in your facility, which is crucial for growing successful crops and achieving expected yields. In some

regions, standards and regulations for energy performance have emerged, and cultivators everywhere can benefit from understanding how HVAC equipment and smart controls can be a tool for their facility's compliance and operational success.

While you may understand the need for HVAC efficiency in your facility, you might be unfamiliar with some root causes of HVAC issues and may be experiencing challenges when rectifying them in your cultivation spaces.

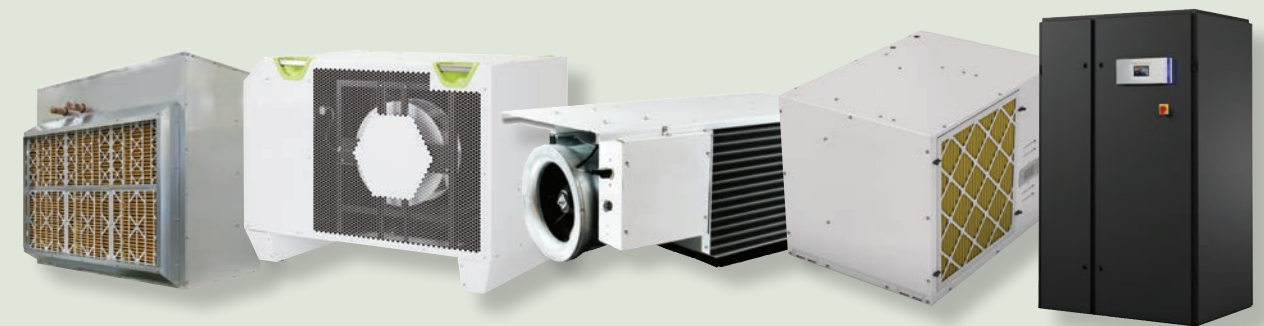
In the following sections, you will learn how indoor environmental conditions affect your plants and support positive business outcomes such as profitability and stable product conditions. Understanding the terms used to describe your indoor grow environment requires a slight learning curve, but is essential if you want to ask informed questions, make informed business decisions, and achieve an energy efficient and properly controlled operation.



To learn more about different types of HVAC systems and equipment, consider entering your facility's information into the Resource Innovation Institute's Cannabis PowerScore tool at <https://cannabispowerscore.org/>, where you can see the various heating, cooling, ventilation, and dehumidification options you could consider for a renovation or new facility.



There are many choices to be made when it comes to selecting HVAC equipment designed for growing environments. For every stage of cultivation, there is a high-performance HVAC solution and controls strategy capable of meeting your specific needs.



You may encounter different types of heating, ventilation, air conditioning, and dehumidification systems being used for various cultivation applications. The collage of images above is a small sample of a wide variety of technologies on the market today



HOW PLANTS USE AIR AND MOISTURE

Humans and animals use air to breathe, and we manage moisture in the air using our bodies. Plants also use air and the moisture in it, but have evolved to use it differently, and need specific environmental qualities to effectively grow and produce quality characteristics.

To understand what matters most between plants, air, and moisture, you can approach the topic from the plant's perspective.

DESCRIBING INDOOR ENVIRONMENTAL CONDITIONS

Like humans *perspire* (sweat), plants *transpire* by drawing moisture into the plant through the root system and out through the leaves. Most transpiration occurs through cellular structures called stomata, the pores on plants' leaves that exchange moisture with the air. Grow room air temperature and relative humidity are some of the components of your facility's *indoor environmental conditions* that directly affect your plants and the ability of their stomata to transpire effectively.



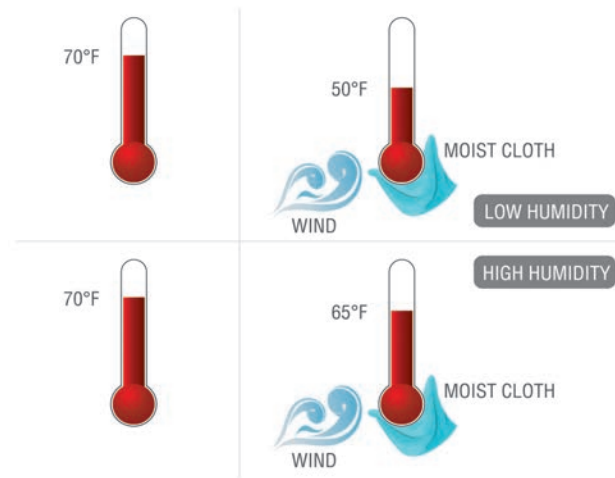
Air Saturation

Air is *saturated* when it holds the maximum amount of water vapor it can at a given temperature. As air gets warmer, it can hold exponentially more water.

Temperature: the Average Kinetic Energy of Air

Temperature must be managed within preferred ranges throughout various growth cycles for your plants' health and growth. Temperature describes the kinetic energy of the air, which is the energy of particles based on their velocity. Warmer air has particles moving at a higher average velocity.

There are two temperatures to be aware of: dry bulb and wet bulb. The units of temperature in North America are degrees Fahrenheit (°F) and Celsius (°C).



? **Dry bulb temperature** is the temperature used by weather reports and displayed by thermostats. **Wet bulb temperature** describes how much moisture is in the air; it is the temperature that a thermometer reads when its bulb is wrapped in a moist cloth. If the difference between the wet bulb and dry bulb temperature is small, the air is very humid and cannot hold much more water.

Dew Point Temperature: The Temperature of Air Saturation

The *dew point temperature* is the temperature at which the air reaches saturation and cannot hold any more moisture. This is when *condensation* occurs, which is when moisture in the air condenses as water droplets on surfaces in your cultivation space.

Evapotranspiration (ET): The Water Vapor Your Plants Emit and Your HVAC Equipment Manages

Evapotranspiration is the sum of plant transpiration and evaporation from water in your cultivation spaces. ET generates an evaporative cooling effect, as your plants actively offset sensible heat loads and reduce the temperature of the space while they introduce substantial water vapor into your grow rooms.



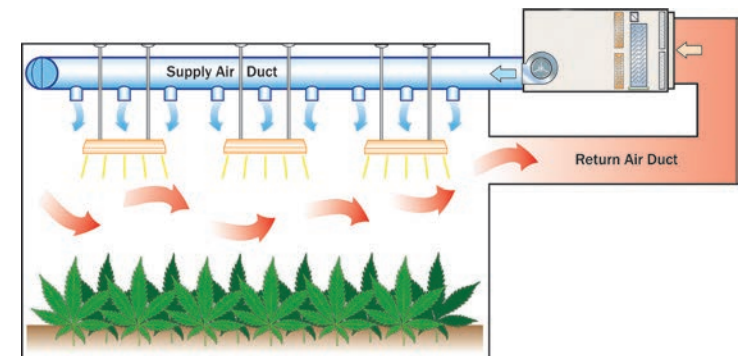
When calculating loads for your heating, cooling, and dehumidification equipment, neglecting the impact of ET can result in improper sizing or misapplication of the equipment you install in your facility.

Relative Humidity (RH): Quantify the Moisture in Air

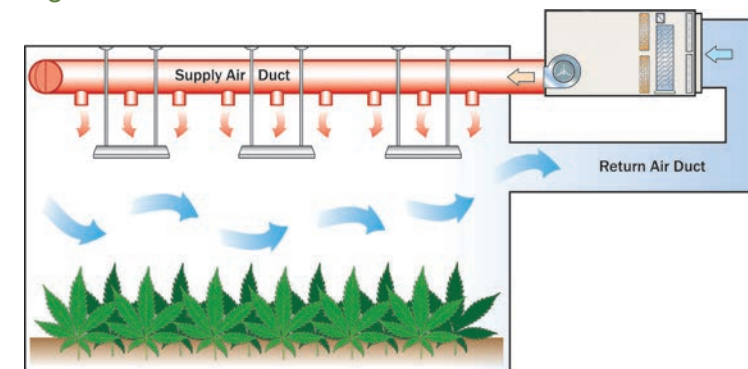
Relative humidity is the amount of water vapor in the air, expressed as a ratio of actual vapor pressure to the saturated vapor pressure, described in percent (%). The amount of water in the air at a given RH is dependent on the temperature of the air. When the wet bulb temperature is equal to the dry bulb temperature, the air is at 100% relative humidity.

Some plants grow better in different RH ranges during their various growth stages; you can use different RH ranges to influence your crops and manipulating RH values can increase yield.

? **Ever wonder why relative humidity spikes after your flower lights turn off?** The air begins to cool soon after the lights go out, but the quantity of water in that air doesn't reduce at the same rate the temperature drops. In this scenario, you have a cooler space with the same amount of moisture in it, which raises your room's RH. A drop of 2 - 5 F can cause a 10-15% spike in RH.

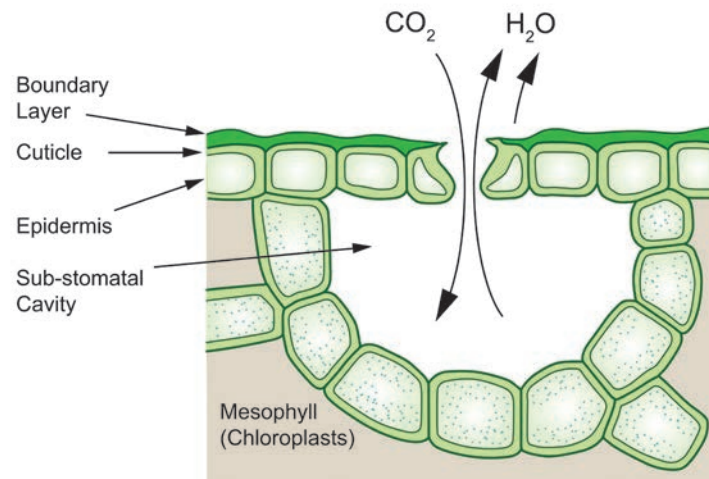


Lights On



Lights Off

The figure above illustrates the two scenarios your plants experience: lights on and lights off. When lights are on, your grow rooms likely need cooling, but when lights are off, evaporative cooling effects from your plants cause your cultivation spaces to need heat.



Think of transpiration in terms of the plant being a drinking straw, where the two ends of the straw are the leaves' stomata and the roots, and the force pulling on the straw is VPD.

Vapor Pressure Differential, or Deficit (VPD): Impacts Effective Evapotranspiration

Vapor pressure differential (VPD) is the pressure difference (or deficit) between the vapor pressure measured at the surface of the leaf and the vapor pressure of the air measured in your grow space. VPD is commonly described using kilopascals (kPa), which is a metric unit that can be translated from pounds per square inch: 1 psi = 6.895 kPa.

An adequate VPD will pull moisture through your plants, drawing water from the plants and into the air in your grow rooms. When the air is dry, VPD is higher and so water within your plants transfers from your plants into the surrounding air quickly; when the air is more humid, VPD is lower and so water within your plants transfers to the air more slowly.

A good range for VPD is 0.8 - 1.2 kPa. As VPD drops below 0.8 kPa, transpiration is inhibited which slows the rate at which water and nutrients flow through your plants, which ultimately slows their growth. A VPD higher than 1.2 kPa can lead to water stress. Target VPDs typically vary by stage of plant growth and the number of hours per day in which your plants are exposed to light, which is known as the *photoperiod*.

Temperature and relative humidity relate to VPD in your cultivation spaces. It is important to give your design team information regarding your target VPD, dry bulb temperature, and RH setpoints in the planning phase. Experienced engineers need two of these three values to accurately size and select your HVAC equipment to meet your requirements.

Powdery Mildew (PM): Avoid it for Healthy Plants

Maintaining good indoor environmental conditions is crucial to plant growth, as your grow room environment impacts plant development along with light source, plant genetics and fertigation. What qualify as 'good' conditions? When your cultivation space's indoor environment is improperly managed, your plants let you know.

Powdery mildew (PM) is one of the most common mold/fungus issues growers encounter and can affect a variety of plant species in addition to cannabis. It can indicate improper management of environmental conditions in your cultivation space, like inadequate air circulation or humidity control, or rapid swings in conditions which cause plant stress. In the worst cases, PM can lead to crop loss.

Proper control of environmental conditions through HVAC is an essential part of avoiding detrimental impacts on your crop from powdery mildew, botrytis, bud rot, and other humidity-related disease issues. These issues can quickly lead to complete crop loss as most legal markets conduct microbial testing that checks for molds and mildews and pesticide/fungicide testing to determine if you used them to combat mold and fungus outbreaks. Authorities do not allow crops to be sold if your flower fails either test.

Correctly sizing your HVAC equipment for your ideal grow room conditions can help you avoid mismanaged environmental conditions in your cultivation spaces, and potentially crop loss. Use sensing devices once you are operating your facility to measure and monitor grow room characteristics like temperature and humidity so you can make informed decisions and make changes when conditions are outside of desired parameters.



Powdery mildew can be a recurrent problem for cannabis grown indoors.



DESCRIBING HVAC LOADS

The equipment you use to heat, cool, ventilate, and dehumidify the air in your cultivation spaces is designed to manage certain *loads*. Loads are energy (heat and humidity) being continuously stored in the air in your rooms.

HVAC equipment can keep your grow rooms within the temperature and relative humidity ranges preferred by your plants.

To describe HVAC loads, you should understand the difference between sensible and latent loads, and the ratio of the two.

Sensible Load: The Heat You Feel

Sensible loads come from the sun heating up your building and lights emitting heat into your grow rooms. In facilities that grow plants, this load is only a part of the total load your HVAC equipment needs to manage. This can also be thought of as the *dry load*. Most conventional HVAC equipment is designed for high sensible loads (75 - 80% sensible load and 20 - 25% latent load).

Latent Load: The Moisture Your Plants Produce

In cultivation facilities, latent loads come mainly from evapotranspiration. This can also be thought of as the *wet load*. Standalone dehumidification systems or HVAC system controls strategies are typically used to address high latent loads.

Heat energy can be described using the British Thermal Unit (Btu), which is a unit commonly used in North America.

A Btu is a small amount of energy and so facility energy is usually described using the kilo-Btu (kBtu) or mega-Btu (MBtu or MMBtu).

Sizing HVAC: Units to Describe Thermal Loads

To effectively size HVAC systems, you must understand whether the fundamental ingredients described above will be satisfied by the capacity of your equipment. Both sensible and latent loads can be measured in Btu per hour (Btu/h), or tons. One ton is equivalent to 12,000 Btu/h. Note that while Btu/h describes Btu per hour, the naming convention looks like Btu-hours.

HVAC loads are usually described using tons or mega-Btu per hour (MBH), which is one thousand Btu per hour.

The sum of the sensible and latent loads determines the total cooling load. Cultivation facilities have very high loads per cubic foot when compared to the average commercial building. Grow environments are also unique because the latent load is often equal to or greater than the sensible load, which is unusual for buildings in which people work or live.

It is important to understand the *peak load* your facility will experience; this is the load your HVAC systems must handle when your facility is demanding the most out of the equipment. To right-size HVAC systems, match equipment capacity closely to peak load.

When your facility is meeting its peak HVAC load, it is probably using its greatest amount of electrical power. Understand electrical power and energy terms to effectively manage energy costs in your facility.

A *watt (W)* is a unit that describes electrical power, and is used to describe the amount of power required to operate a device. Labels on power cords may list maximum rated power, and normal operation may result in lower power draw in your facility. Your electric utility may charge you for the *peak demand* of your facility each month in addition to energy consumed; they charge for demand by the *kilowatt*, which is one thousand watts. *Peak demand* can represent the power draw of your facility at the time of the month when the greatest amount of equipment was turned on or was running at maximum power, or a combination of both.

Wattage of equipment determines how much it will cost to operate your equipment, and the load taken by your electrical infrastructure. Running a 100 W fan for an entire day uses 100 W * 24 h = 2,400 watt-hours. In addition to the demand charge introduced above, your electric utility also charges you by the kilowatt-hour, which is one thousand watt-hours; 2,400 Wh = 2.4 kWh.



For the most efficient and effective HVAC system, try to closely match the sensible and latent load of your space.

Pay attention to both the sensible and latent capacities of the system, not just the total capacity.

Oversizing your HVAC equipment can result in *short cycling* (when your equipment cycles on and off quickly), which is hard on your equipment and can affect its life expectancy. Undersizing your HVAC or dehumidification equipment can be detrimental to your operation because your temperature and humidity levels will fall out of specified setpoint ranges, in turn affecting plant health. Cultivators using undersized HVAC equipment often sacrifice light levels to reduce heat rejected into the space in order to maintain environmental control; lower light levels reduce productivity and can impact your crop yield.

Moisture Removal Efficacy (MRE): Describing Effectiveness of Dehumidification Systems

Moisture removal efficacy (MRE) is used to describe the water vapor removed from the air at a specific temperature and humidity, divided by the total energy consumed by a specific piece of dehumidification equipment. MRE describes the efficacy of your dehumidification systems.

Sensible Heat Ratio (SHR): A Tool For Sizing HVAC Equipment

Sensible Heat Ratio (SHR) is the ratio of sensible heat to total heat. Since the latent load of flower rooms within cultivation facilities is generally half of the total load, these spaces generally require systems with low SHR values of 0.5 to 0.6 compared to typical commercial HVAC systems which are manufactured to satisfy SHR values of 0.7 to 0.9.

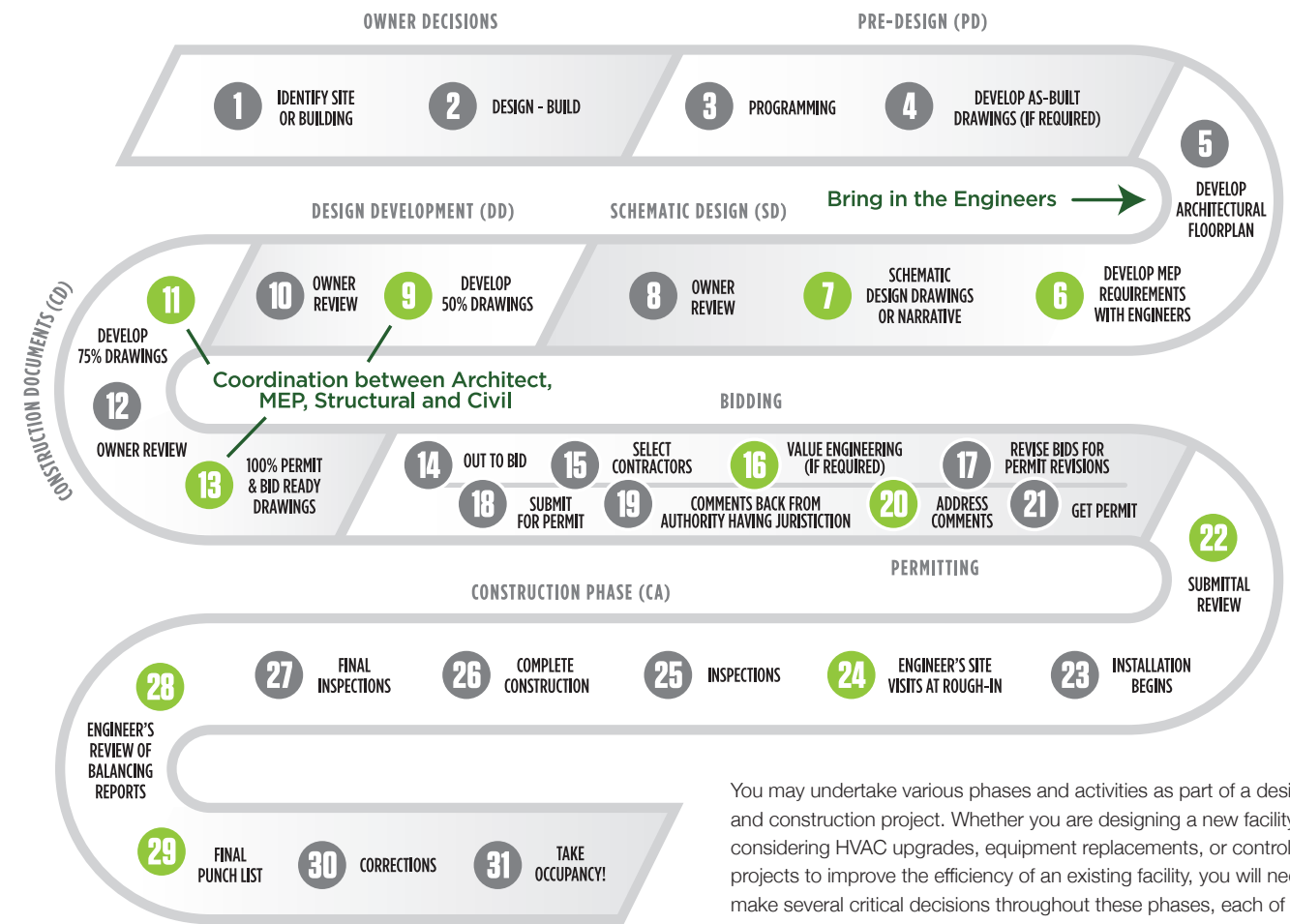
If you use a typical commercial HVAC system, then you might need to add dehumidifiers to take care of the latent load that the central HVAC system can't handle. Standalone dehumidifiers installed in your grow rooms can reject substantial heat into the space through the latent heat of the condensing water vapor, which increases the sensible loads of the room and requires your HVAC system to work harder and more often.

kWh and Btu are two ways of describing energy consumption. While kWh is used to describe electrical energy usage, it can also be converted to Btu using the factor 1 kWh = 3,412.14 Btu = 3.412 kBtu.

To describe the total energy consumption of your facility on a yearly basis, you can add up annual kWh of electricity from the grid and on-site renewable sources and convert them to kBtu (1 kBtu = 1,000 Btu), and then convert the total energy used for heating from fossil fuels to annual kBtu and add the two totals together. *Energy use intensity*, which describes total annual kBtu per square foot, is an important metric for cultivators to monitor to understand how your operational costs are trending over time and against similar facilities.

Capacity: Your HVAC System's Ability to Satisfy Loads

Capacity is the rated heating, cooling, or moisture removal your equipment can handle. For heating and cooling equipment, capacity can be described using kW, Btuh or tons. For dehumidification equipment, capacity can be described using pints (or pounds) per hour.



You may undertake various phases and activities as part of a design and construction project. Whether you are designing a new facility or considering HVAC upgrades, equipment replacements, or controls projects to improve the efficiency of an existing facility, you will need to make several critical decisions throughout these phases, each of which can significantly impact the ultimate performance of the building.

UNDERSTANDING YOUR HVAC OPTIONS

This section is organized to serve every grower at every stage of facility design and construction. Start at the top if you are designing a new facility or a major renovation project, and skip further down to learn about purchasing, installing, and operating HVAC equipment in the field. There are many considerations to take into account, and we are here to help you navigate your choices.

Knowing what choices are important may be difficult to understand. From planning to post-occupancy, the whole project process is important, interconnected, and necessary to achieve a successful outcome. Early decisions in design will waterfall down to construction and occupancy phases, so be thoughtful about how each choice you make may impact your facility's operational costs.



PLANNING YOUR PROJECT

Designing the HVAC equipment in your facility to both successfully serve the needs of your plants and run efficiently requires thoughtful planning before you start construction or a major renovation.

PRE-DESIGN PHASE

Determine Your Setpoints - Temperature and relative humidity setpoints can greatly influence the efficiency of your systems. Establish temperature, RH, and/or VPD targets for your grow rooms when your lights are on and when your lights are off, as well as for the variety of strains that you grow, to accurately estimate your HVAC system's capacity.

Set Goals for Energy Performance - Discuss with your engineers and other team members how you might use energy efficiency to reduce your energy bills. You will need to determine what sort of equipment would be best suited for your facility to meet both the operational goals (i.e., space temperature and humidity targets) and also energy efficiency goals to minimize operational costs.

Decide What You Want - You or the building owner may have some idea of the scope of work your project will entail, but consider developing more detailed *owner's project requirements* (OPR) to quantify what success looks like for your facility. Define your parameters for success: describe the environmental conditions you would like to achieve, include your preferred temperature, RH, and VPD ranges, and elaborate on energy efficiency goals and how you would like the project to accomplish them.

The Owner's Project Requirements (OPR) is the single most important document in developing a design for an existing or new cultivation facility.

An OPR defines the Owner's goals, objectives and performance metrics, and is developed by the owner (not your design team). Creating an OPR should be one of the first items on your to-do list when planning a project, big or small.

Choose Wisely - Select the members of your project team based on their expertise relative to cultivation applications. Consider using qualified and experienced designers, consultants, and contractors in your region to receive local customer support. Request case studies and references to qualify the experience of

your designers, consultants, and contractors.

HVAC equipment for cultivation environments needs to be designed and selected with care. Interactive effects between your plants and the systems you use to manage the macro and micro-level environmental conditions for them, like lighting, and HVAC systems as well as CO2, fertigation, pest management, and condensate collection are something an expert in engineering grow facilities will understand and thoughtfully consider.

Your project team may be big or small, depending on the size and scope of project you are planning for your facility. For new construction or a major renovation project, you should consider having the following members on your team, or at least consider having someone to play these parts:

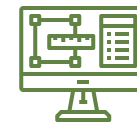
- You, or your Owner's Representative
- Your Architect
- Your Engineer(s)
 - Civil
 - Structural
 - Mechanical (includes Plumbing)
 - Electrical
 - Horticultural Process
- Your Energy Modeler
- Your Construction Manager and/or General Contractor
- Your Subcontractor(s)
 - Mechanical
 - Electrical
 - Plumbing
 - Air & Water Balancing
 - HVAC Controls
- Your Commissioning Agent(s)
 - Building Envelope
 - Mechanical, Electrical, Plumbing & HVAC Controls

Assemble Your Team Early - To improve team coordination and communication, get critical design questions answered as early as possible, ensure code requirements are satisfied, maximize operational efficiency, and lower costs of your project, employ a collaborative *integrated design* approach to effect the greatest changes to your facility's operational efficiency and associated environmental impacts.

An integrated design team works together early and often

throughout a project's planning, design, construction, and occupancy phases to execute a project to its maximum potential. Working collectively from the start allows your team to have a better understanding of the project and interactive elements of their scopes of work. By engaging frequently, issues can be identified and resolved in the design phase rather than later in construction or occupancy phases, when resolution is much more expensive.

Understand Roles - Engage with team members to understand their responsibilities early in the planning process. Document roles and dependencies between roles for effective communication down the road. For the smoothest process, consider assigning a lead designer (generally an Architect, but sometimes an Engineer or a General Contractor) as the main point of contact for all design team members.



OPTIMIZING YOUR FACILITY DESIGN

Before you build or renovate, consider the basis of your facility design so that you can optimize the efficiency and impact of your HVAC decisions.

A basis of design (BOD) is the foundational design document and is developed by your designers to inform you how they intend to achieve the criteria laid out in your OPR, by specifying and describing the heating, ventilation, cooling, and dehumidification systems that can meet your expectations. Ideally this document is a living document that is updated as the design progresses.

In your facility, some criteria you may care about include key performance indicators (KPIs) relevant to profitability, sustainability, and operational efficiency. In the BOD process, help your design team translate the cultivation KPIs to design criteria related to their scope of work. As you may not be able

to do that alone, working with a Horticultural Process Engineer could help you connect the dots.

DESIGN PHASE

Count Your Plants - Understand the number of plants in each cultivation space, as the latent load to be managed by your HVAC equipment is dependent on the moisture given off by your plants, their grow media, and irrigation systems. Consider how the number of plants may fluctuate based on time of year, growth cycle, market forces, and issues with regulations or crop damage.



The number of plants in your grow environment will impact the amount of moisture generated - and HVAC energy used.

Calculate Your Loads - Work with your design team to accurately describe and quantify sensible and latent loads in your facility spaces to properly size the equipment to serve them. Give special attention to latent loads, as the moisture in your facility will drive HVAC sizing decisions.

Consider Peak HVAC Loads - When plants are small, sensible loads may be at their highest. When plants are larger and lights are off, your HVAC equipment may experience peak latent loads. Factor both into your system design to effectively meet all grow room conditions.

Watch Your Water - Determine your *net watering rate per plant*, which is the gross watering rate provided to your rooms less your waste and return water. This directly correlates to the moisture load your HVAC equipment has to manage in your grow space.

Choose Your System Approach - Consider how you want your spaces to be conditioned. Some HVAC and dehumidification system types will be more or less feasible for your climate, and some systems may be more or less expensive to operate depending on your local utilities and their rates. Assess systems' ability to satisfy the requirements laid out in your OPR and BOD.

Set Targets for Indoor Environmental Conditions - Consider how you might use filtration strategies to manage your cultivation environments; this is important to think about long before you set up your systems. Will you be bringing outside air into your facility? How do you want to control for odor and contaminants? What are your contaminants of concern? This will influence the type of filter or air cleaner you select.

Consider whether you will recirculate indoor air or use outside air for ventilation. Decide which will be the most feasible and effective approach for your facility: filters, air cleaners, or activated carbon. Filters may require higher maintenance since they require changeouts. Consider positively pressurizing your grow rooms to prevent intrusion of pests and contaminants. You may find it helpful to add vestibules and air locks to control pressure cascades so that air moves from "clean" to "dirty" areas.

The effectiveness of air filters is rated using the MERV scale, which ranges from 1 to 16. The higher the MERV rating, the smaller the particulates the filter can trap. This means that filters with high MERV ratings induce a greater pressure drop across the thicker media, which can result in greater fan power consumption.

Define The Scope of Work - If you are renovating an existing building or upgrading an existing piece of equipment, describe the current conditions. Quantify and qualify the scope of new work by describing your definition of success in terms of indoor environmental conditions and energy efficiency. Your design team can help you write *project specifications* which detail the requirements of every system in the facility that is relevant to your new facility or renovation, at a more granular level than your design drawings can often communicate. Project specifications are the details that support the design documents and can help you avoid pricey change orders down the road by requiring materials specific for indoor cultivation during the bidding phase. Your design team helps you communicate the Scope of Work to your contractors through *Construction Documents (CDs)* which include schedules of equipment, design drawings, details, and specifications.

Sizing your HVAC system around a VPD that is too high (or temperature and humidity rates that are too low) can lead to oversizing HVAC systems, short cycling, and unnecessary energy use which decrease life expectancy.



There are a few ways to describe the efficiency of HVAC equipment, and it is important to understand the terms as you set goals for your facility's energy performance. Many of these efficiency ratings are at 'designated operating conditions,' which means when you install it in your grow rooms, it may not run the same way.

Energy efficiency ratio (EER) is the ratio of net cooling capacity to total rate of electric input under designated operating conditions, measured in Btu per Watt (Btu/W). EER can allow you to compare two different HVAC systems at rated conditions, but does not account for partial load scenarios and does not represent actual field performance, so it does not help you determine the energy use of your facility's equipment.

Moisture removal efficacy (MRE) is the ratio of net moisture removal capacity to total rate of electric input under designated operating conditions measured in pounds per hour per Watt (lb/hr/W) or kilograms per hour per Watt (kg/hr/W).

MRE can allow you to compare two different HVAC systems at rated conditions, but does not help you determine the energy use of your facility's equipment.

Seasonal energy efficiency ratio (SEER) is the ratio of cooling output of equipment during typical cooling-season conditions, divided by the total electric energy input during the same period, measured in Btu per Watt-hour, (Btu/Wh). SEER can allow you to compare two different systems at typical seasonal conditions and partial load scenarios.

Integrated energy efficiency ratio (IEER) is a weighted average of efficiency values for equipment across a cooling season for a diverse set of climates, and so is more representative of actual efficiency, but is still rated at designated operating conditions. IEER does not account for partial load scenarios and does not represent actual field performance.

Note that SEER is used for equipment sized smaller than 5.4 tons while IEER is used for equipment sized larger than 5.4 tons. You might see some equipment using one rating and other equipment using another.

COOLING / DEHUMIDIFICATION MODE	
EAT DB / WB °F	70.0 60.0
SYSTEM TOTAL CAP BTUH	364,092
SYSTEM SENSIBLE BTUH	269,422
THR BTUH	465,196
MOISTURE REMOVAL CAPACITY - LB/HR	89
LEAVING AIR DEWPOINT F	49.2
COMPRESSOR HP	2 - 15 HP
MAX NET SENSIBLE TO SPACE @ 60°F LAT WITH 75°F ZONE	195,300
MRE @ DESIGN DAY	2.0

Understand Sequences of Operation - Your engineers will use the loads, setpoints, and targets for your grow room environmental conditions you developed in the OPR and BOD to create sequences of operation that your HVAC equipment will be programmed with to effectively serve the specific needs of your cultivation facility. Work with them and your controls contractors to understand how different pieces of equipment will be staged on and run to manage heat and moisture in grow rooms so you can identify situations that are outside the normal range of operation.

Consider Energy Recovery - Think about and discuss with your engineers how you might be able to include energy recovery equipment into your design. What is your exhaust air strategy if you are in a climate zone that allows you to use outside air to dehumidify and cool? In those climates, adding a device to recover energy from exhaust air and return the energy to the supply air can save operational costs. Energy recovery systems in dehumidification can reduce your minimum compressor tonnage by 30-50%, at the expense of adding a 5-10% fan energy penalty, resulting in a net HVAC energy consumption reduction. Also consider energy recovery

for chiller operation, whereby the rejected heat from the chiller can be captured and utilized to preheat water which can be utilized for dehumidification via *reheat*.

Understand Opportunities for Free Cooling

For winter time operation, adding a *water side economizer for free cooling* operation to your chiller loop can provide excellent energy savings. Use caution when utilizing *air side economizers* as these are generally an inappropriate solution if you are injecting your cultivation room with CO₂.

Consider How to Dehumidify

Consider the benefits of an investment into centralized or integrated dehumidification systems. While standalone plug-in dehumidifiers are inexpensive, they reject heat back into your cultivation spaces and require your air conditioning systems to work harder and more often. This increases your operational costs and offsets the lower first cost of the standalone units.

Another issue with standalone dehumidifiers arises when your lights are off. Often you rely on your air conditioning to handle a significant amount of the space's latent load when using these types of dehumidifiers. When lights are off and air conditioning is not needed, humidity can spike or be challenging to manage

with only the capacity of your standalone dehumidifier solution.

Centralized or integrated dehumidification systems can offer energy savings as well as finer control of the indoor environmental conditions of your cultivation environment. Units that fully integrate cooling and dehumidification offer dual control of both air conditioning and dehumidification sequences.

Energy recovery is an efficiency strategy that exchanges heat between exhaust and supply air or water streams to recover energy and use it again without introducing outside air into your cultivation rooms.

Energy recovery strategies may be required in your jurisdiction; consult local energy codes to determine their adoption and enforcement of ASHRAE Standard 90.1. Typical energy recovery equipment includes wheels and cores that are made out of materials very effective at conductive heat transfer.



GETTING YOUR BUILDING PERMIT

Before you receive your building permit, your facility's design may be required to satisfy certain performance requirements aligned with local codes. Consider these requirements well ahead of the permitting stage so construction can stay on schedule.

Permitting setbacks can be very impactful to your project. If you install a new HVAC system before receiving permits, you may have to call in an engineer to retroactively design the system to align with code and take *responsible charge*, which allows you to receive your building permit. If your chosen and installed system doesn't meet the energy code or other jurisdictional requirements, you may be required to make significant changes to your newly installed HVAC system in order to get your facility completely permitted.

BIDDING & PERMITTING PHASE

Check the Law

Understand what is required of indoor cultivation facilities in your jurisdiction. Working with a project team that has experience with your local process will ease the learning curve.

Know What They Want

Prevent permitting setbacks from impacting your timeline by checking your design against the code parameters for energy and functional performance. Avoid construction delays by making the energy codes part of your basis of design so you don't waste time evaluating equipment or operations approaches that will be rejected down the line. Energy codes are only one of many jurisdictional requirements that may be enforced.



Reheat is part of some air handling units' dehumidification cycle and can allow for precise control over the supply air conditions. The use of new energy to reheat air in your facility may not be allowed by the local code; instead code may require recovered energy such as hot gas reheat. Understanding the difference between reheat with new heat and reheat with recovered heat will prevent lost time and increased construction costs.

Reheat, measured in Btu per hour (Btuh), is heat applied to air through a reheat coil after it has been cooled through a cooling coil. The cooling coil decreases the relative humidity of the air by bringing the air temperature down to the saturation point, which allows the moisture in the air to condense from the cool air. After removing the desired amount of moisture, the air is often too cold and introducing back into the space without reheating would cause over-cooling of your grow spaces. To avoid this, the air is passed through the reheat coil which raises the air temperature and decreases the relative humidity to the desired supply air temperature and humidity setpoint. Overall,

this is a very effective way of controlling temperature and humidity closely within a space.

Reheat with recovered heat, using recovered waste energy such as heat rejected from a compressor, is a more energy efficient strategy and reduces the total energy usage of your facility.

Reheat with new heat is a less energy efficient strategy that increases total energy usage of your facility. Systems using new heat have reheat coils served by hot water, electric resistance, or steam, and use new energy.



PURCHASING EQUIPMENT FOR YOUR FACILITY

Once you understand the vocabulary used to describe the indoor environment your plants need and the metrics of performance for HVAC systems, you will need to apply them to make informed decisions when selecting equipment for your facility.

MATERIALS PURCHASING PHASE

Compare Apples to Apples

Compare HVAC technology using metrics like rated capacity and input power to understand what size and type of HVAC equipment is capable of satisfying the needs of your plants.

Find the Right Fit

Review minimum performance metrics to sort and eliminate equipment by intended use, efficiency ratings, and warranty terms. Many growers have experienced the pain of rooftop units freezing up in the winter; recognize that most rooftop units are only designed to provide cooling down to ambient temperatures of roughly 32 °F. Many units have optional factory-installed low-ambient kits that allow for cooling during much colder outdoor conditions. There are also kits that can be retrofitted onto most existing rooftop units in the field.

Verify Quality

Look for independent verification of quality claims made by HVAC

equipment manufacturers. For best results, confirm that the equipment is rated by a third party such as AHRI. It is important to compare the performance of the equipment relative to your operating conditions. The conditions that the equipment is rated at (typically rated in accordance with AHRI 340/360) may not match your cultivation conditions.

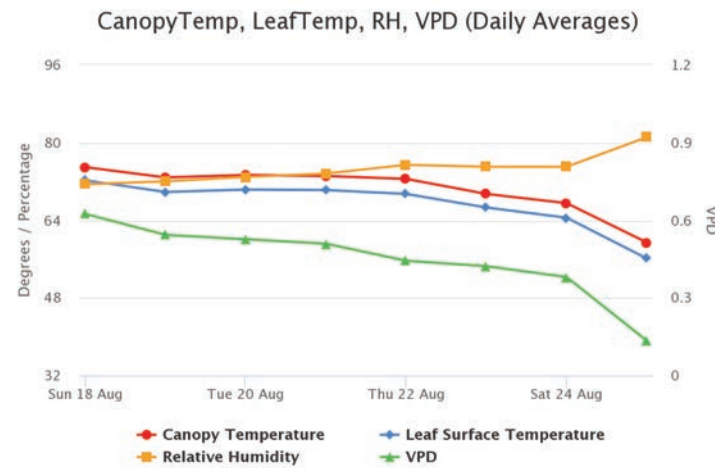
Also review the UL1995 safety test reports produced by certified laboratories like CSA, Intertek, and TUV. Code officials may enforce special requirements upon facilities operating equipment not rated by national testing labs. A list of nationally-recognized testing labs (NRTL) is published by the Occupational Safety and Health Administration (OSHA) at <https://www.osha.gov/dts/otpca/nrtl/nrtllist.html>.

Validate How Your Equipment Will Run

Work with your engineer, commissioning agent and mechanical and controls contractors to understand how the sequence of operation in your design drawings is going to be executed by the equipment being installed. If you have a *building automation system* that controls your HVAC equipment, choose what points

are important for you to monitor, which ones should be trended, and for how long they will be stored.

Building automation systems can control systems in your facility to provide accurately and finely tuned indoor environments. Points measured and recorded by your control system refer to the prescribed and actual measured parameters like temperature, power, and relative humidity in your facility, and are important to *trend* over time so you can visualize your facility's historical operation.



The purpose of the commissioning process is to confirm that the final construction and installation and programming of equipment meets the original design intent and owner's project requirements for the facility. Ideally, the documentation of these objectives would be produced by members of your project team such as your designers, contractors, and commissioning agents.

- Ensure that Contractors have provided operations and maintenance (O&M) manuals for engineered systems in the building.
- Suggest preventative maintenance plans.

Get Construction Support - Engage with your engineer during the construction phase to follow through with design goals. Consider having a commissioning agent on your team to functionally test equipment with your controls contractor, and think about inviting a facilities or operations staff member to participate or operations staff member participate in the commissioning process.

An abridged version of the commissioning process is outlined below. Check out resources provided by the Building Commissioning Association and the California Energy Commission to learn more about best practices recommendations and to get guidance for completing commissioning activities in your facility.

- Review OPR created by owner/operators.
- Assist design team with creating BOD.
- Develop commissioning plans.
- Perform design review of drawings.
- Identify issues with building system designs and offer suggested adjustments.
- Review equipment submittals.
- Create pre-functional checklists and functional performance tests.
- Witness and record all functional tests.
- Create staff training agendas.
- Produce final commissioning reports.

Check Your Lists - Review start-up checklists provided by manufacturers, balancing reports provided by contractors, and pre-functional checklists and functional performance tests developed for your project by your engineers, contractors, and commissioning agents to ensure they can assure you that equipment is performing as designed. Check with your engineering team or horticultural process engineer if you have any questions about whether reported equipment performance aligns with your facility design.

Read the Reports - Your contractors and consultants should provide final reports to summarize the testing they performed to validate the equipment can satisfy your design parameters. Ensure you request these documents and read them completely to follow up on issues identified within, as it is much more expensive to resolve problems once your building is occupied and operational.



INSTALLING HVAC EQUIPMENT IN YOUR FACILITY

Before you grow, there are several strategies you can use to ensure your HVAC equipment will provide the indoor environment your plants need. These strategies can be employed throughout the phases of the construction process.

CONSTRUCTION PHASE

To determine when and how to use these strategies in your project, make sure you know the timing and scope of phases of construction.

Start-Up: Once equipment arrives on site and is connected to power, the start-up phase can begin. When HVAC equipment is turned on for the first time, a start-up checklist must be completed by your installing contractor to receive the warranty from the manufacturer.

Balancing: Once HVAC equipment is up and running, the balancing phase can commence. In this phase, air and water flow rates are verified and adjusted to meet design documents. Balancing reports are critical to verify the system is set-up correctly to achieve the required flow rates. Without this balance, the HVAC units cannot meet their required performance. If your systems' flow rates are not correct, they cannot function as designed.

Configuration or Programming: Your mechanical and electrical contractors start up equipment (sometimes with the assistance of the factory representative that provided the equipment), your balancing contractors adjusts air and water flow rates, and then your controls contractors configure the sequence of operations to program your systems to function as designed. Many pieces of equipment have integrated controls and a controls contractor may not be necessary. Some controls contractors create configuration reports to describe the steps taken to configure equipment, and these can be used to inform commissioning activities.

Commissioning: Ideally commissioning activities will span both design and construction phases, and pre-functional checks may occur before, during, or after start-up, balancing, and configuration activities. Once programming is complete, functional performance testing of HVAC systems and their associated controls allows your commissioning agents to run equipment through its paces to ensure it responds as designed. Commissioning allows for facilities to better achieve energy performance goals by addressing modifications to controls sequences earlier, which can save you money in the long run, especially when commissioning activities are performed by a third party consultant.



OPERATING HVAC EQUIPMENT IN YOUR FACILITY

Once you are ready to grow in your new or renovated space, keep an open mind as you operate new equipment and document changes you make as you adjust your growing approach.

OCCUPANCY PHASE

Re-commission Your Equipment - Continue to verify that installed equipment is operating according to your design documents. You can use mounted or handheld sensors to field verify the performance of your systems and calibration of thermostats after the project team is gone. Some growers use thermal cameras or infrared thermometers to measure canopy temperature, as well as handheld hygrometers for spot measurements of grow room temperature and relative humidity. Mounted sensors are similar to the sensors used to control your equipment, but with a nicer interface for you to monitor.

Ask for Guidance - Talk with growers that have similar HVAC systems to yours and benefit from their experience to move quickly up the learning curve. This is where the Resource Innovation Institute can help. Attend Efficient Yields, our grower education events, and workshops led by RII subject matter experts to learn from our industry network of manufacturers, designers, and installers. Join our grower network to connect with other cultivators and get your questions answered.

Make One Change At A Time - Alter parameters like temperature and relative humidity individually and incrementally and document what changes you made and when, and for how long with both notes and pictures. By understanding the

changes you make and their interactive effects, you can make more informed observations on what impact your adjustments are having on your plants before making multiple changes at once. Regularly record adjusted factors to benchmark your operation as you make changes. Record data over time to establish trends.



Adopt a ‘tweak and peek’ approach to observe how your plants respond to changes including new HVAC equipment or setpoints, controls, and growing approaches.

There are limits to adjusting HVAC equipment. Work with your engineer and contractor to understand what setpoints you can adjust as you ‘get to know’ your new HVAC systems. Do not press buttons on packaged displays that you do not understand, as you may adjust equipment programming without intending to change something. Skip taking apart manufactured controls to make adjustments installed at the factory, as you will void your warranty.

While a worthwhile endeavor, know that there are HVAC challenges with converting from HID to LED lighting. A retrofit to LED light fixtures will cut the heat load by about 1/3.

Unless the HVAC system was intended for a varying load, your equipment will have to cycle more rapidly, which could lead to temperature and humidity swings in the space. Cycling is hard on your HVAC equipment, and reduces its useful life. Ideally the heat load of the new LED fixtures could be matched fairly closely to the heat load of the old HID fixtures, which may be possible if you are moving to vertical indoor cultivation. Otherwise, you may have to make HVAC system

Revisit Your Temperature and Relative Humidity Setpoints

- If you grow with LED light fixtures, you may understand that LED lights give off less waste heat. For that reason, consider keeping your grow room at a warmer temperature than your rooms when you were using HID lights. Your relative humidity settings for cultivation spaces may need to change, as the dynamics of the heating of the canopy change with the reduction in heat. Your plants’ transpiration pattern is different, especially when your lights turn off and on, due to the absence of the infrared radiation (IR) that is produced by HID lights.

Monitor Airflow - Monitor and manage airflow effectively to break through the boundary layer of the plant without causing undue plant stress. Assess if field-measured airflows align with readings from your final balancing report and design drawings. Install more sensors to monitor more of your cultivation spaces and establish more accurate trends.

Control for Indoor Environmental Conditions - If you are looking into changing out filters, assess the MERV rating and pressure drop associated with the various filter choices to understand if they are appropriate for your operation. Higher MERV filters will require more fan power energy and may require more frequent changeouts or maintenance to meet energy consumption goals. Also, a dirty filter can greatly affect the effectiveness of an HVAC system, so change filters at the proper intervals as recommended by the manufacturer in your O&M manuals.

Continue Optimizing and Maintaining Your Equipment - Dial in your HVAC controls strategy with your controls contractor to fine-tune your new systems to operate more efficiently or address issues that were not resolved in construction. Re-read your final commissioning report to prioritize remaining issues and follow up with your engineers and controls contractors if you are unsure about the best path to resolution. HVAC equipment in indoor cultivation facilities experiences high loading and long run times. To ensure reliable and efficient performance, regular preventative maintenance should be performed by a qualified contractor.

To learn more about considerations for operating HVAC equipment when cultivating with LED lighting, and many more tips for operating lighting equipment efficiently in your facility, check out our LED Lighting Best Practices Guide.



MEASURING YOUR FACILITY’S OPERATIONAL EFFICIENCY

You may be using a variety of metrics to track the success of your business; different companies track this differently, but all of your methods should include tracking efficiency.

How do you measure the efficiency of your operation?

You may have heard quite a few metrics before, like pounds per light fixture, pounds per plant, or grams per watt, but none of these are accurate measures of your operational efficiency.

Cultivators limited by licensing size may measure their facility space efficiency, grams of dried flower produced per square foot, which informs them of the total production output possible in a given area. However, this does not tell a grower about their energy use.



Facility energy efficiency is the ratio of production of dried flower in grams to whole building energy consumption in thousands of Btu (kBtu) per square foot of facility area per cycle. This metric reflects true facility efficiency more accurately than facility electrical efficiency, measured in grams per kWh per square foot per cycle, or grams per watt of equipment.

Refer to our Cannabis PowerScore to learn more about how the Resource Innovation Institute can help you measure and track the efficiency of your facility.

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The Resource Innovation Institute (RII) is a non-profit organization whose mission is to advance resource efficiency to cultivate a better agricultural future. RII provides best practices guidance on resource efficient cultivation technologies and techniques via peer-reviewed reports and curated events. RII's performance benchmarking service, the Cannabis PowerScore, enables cultivators to gain insights about how to reduce energy expenses and improve their competitive position. Resource Innovation Institute is funded by foundations, governments, utilities and industry leaders. For more information, go to ResourceInnovation.org.