Agenda

- Cannabis 101 - Cannabis and the types
- Stages of the indoor cultivation
- Grow considerations
- Design considerations
- Questions
Cannabis 101

- Cannabis is a psychoactive drug from the Cannabis plant used for medical or recreational purposes.
- Cannabis is indigenous to Central Asia and found therapeutic use by 2800 BC Turpan China.
- Spread across the continents with migration.
Major Species of Cannabis

- **Sativa**
  - Tall, but are thinner with more pointed leaves
  - Provides an energetic, cerebral high.
  - Found naturally eastern asia in warmer climates.
Major Species of Cannabis

- Hemp
  - Variety of sativa plant.
  - No psychoactive component.
  - Found in colder climates.
  - Used for food, fiber, building material, paper, clothes and fuel.
Major Species of Cannabis

- Indica
  - Short and wide, with greener colors and round leaves that have marble-like patterns.
  - Provides a heavy, stoned feeling.
  - Found naturally India in colder climates.
Major Species of Cannabis

- **Ruderalis**
  - Small plants, used primarily for making clothes, rope, etc. Provides a heavy, stoned feeling.
  - Low psychoactive component.
  - Found naturally in Russia in colder climates.
Types of Flowers

- **Female**
  - Produce seeds
  - The highest THC level

- **Male**
  - Produce pollens

- **Sensimilla**
  - Most valuable.
  - Seedless.
The Main Psychoactive Chemicals

- **THC** (tetrahydrocannabinol)
  - Primary psychoactive compound
  - Relaxation, philosophical thinking and hunger.
  - Recreational use.
- **CBD** (Cannabidiol) and **CBG** (Cannabigerol)
  - Used for medical purposes such as anxiety, movement disorders, and pain.
  - Also recreational use.
  - Over 1400 compounds can effect the body.
Agenda

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Stages of the Indoor Cultivation

1. Germinating Seeds
   - 1-2 weeks

2. Seedling Stage
   - 2-3 weeks
   - 18-24 hours of sunlight

3. Vegetation
   - 2-8 weeks, depends on strain
   - 4-5 week is recommended
   - 18/6 hours cycle.
Stages of the Indoor Cultivation

4. Flowering
   - 6-8 weeks depending on strain.
   - 12-12 hours of sunlight

5. Cloning
   - Cut off piece from the mother plant and return to the vegetative phase and skip stage 1 and 2.

6. Harvesting
Agenda

- **Cannabis 101** - Cannabis and the types
- **Stages of the indoor cultivation**
  - Grow considerations
  - Design considerations
  - Questions
Grow Considerations

- Growing Mediums
- Irrigation Method and Automation
- Water Filtration and Purification
- Water Recycling
- Greenhouse or Enclosed Indoor Growing
Growing Medium

- Soil or Compost
  - Natural, easy to use, available and inexpensive
  - Nearly all outdoor facilities are in soil
  - The plans are planted directly in ground or slightly raised
Growing Medium

- Soilless Mix (Coco & Perlite)
  - Faster growth
  - Complex scent/taste profile
  - Many controlled environment facilities are in soil or coco
Growing Medium

- Hydroponics
  - Deep water culture
    - Roots are constantly submerged in nutrient and oxygen rich solution
    - Fastest grow possible
Grow Considerations

- Growing Mediums
- Irrigation Method and Automation
- Water Filtration and Purification
- Water Recycling
- Greenhouse or Enclosed Indoor Growing
Irrigation Methods and Automation

- Flood tables or Rolling Benches
  A plant sits on a table with nutrient solution which pumped from a reservoir, then drains back into the reservoir or floor drain.
Irrigation Methods and Automation

- **Drip irrigation**
  - Water is pumped through irrigation tubes and drippers inject nutrient to each plant

- **Hand Watering**
# Irrigation Methods and Automation

<table>
<thead>
<tr>
<th>Irrigation Method</th>
<th>Efficiency</th>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand Watering</td>
<td>Low</td>
<td>● Gives grower “hands on” feel</td>
<td>● Inconsistency of volume per pot and employees</td>
</tr>
<tr>
<td>Drip</td>
<td>High</td>
<td>● Automated</td>
<td>● Potential clogging of dripper</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● Precise volume of water</td>
<td>● Manual inserting/ removal of dripper when moving plants</td>
</tr>
<tr>
<td>Flood tables</td>
<td>High</td>
<td>● Automated</td>
<td>● Large amounts of water used at once</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● Easy and inexpensive to build</td>
<td>● Manual labor to clean</td>
</tr>
</tbody>
</table>
Grow Considerations

- Growing Mediums
- Irrigation Method and Automation
  - Water Filtration and Purification
  - Water Recycling
  - Greenhouse or Enclosed Indoor Growing
Water Filtration and Purification

• Water use in typical indoor cannabis cultivation.
Water Filtration and Purification

• Typical Filtering System
Reverse Osmosis

- Waste of 0.5-5 gallons dirty water to 1 gallon clean water
- RO systems typically produce 75 to 300 gallons per day (GPD)
- Very corrosive to metal piping.
Grow Considerations

- Growing Mediums
- Irrigation Method and Automation
- Water Filtration and Purification
- Water Recycling
- Greenhouse or Enclosed Indoor Growing
Water Recycling

How water is wasted in cannabis cultivation?

- Evaporation from soil
- Disposal of unused irrigation water
- Drained condensation water from the HVAC equipments.
Water Recycling

Water recycling methods

- Excess water which can be captured and piped back to water storage tanks.
- Capturing HVAC condensate and dehumidification water (almost RO quality).
  - Possible to reclaim almost 100% of irrigation water through this method.
  - Recaptured water must be purified again.
Grow Considerations

- Growing Mediums
- Irrigation Method and Automation
- Water Filtration and Purification
- Water Recycling
- Greenhouse or Enclosed Indoor Growing
Greenhouse or Enclosed Indoor Growing?

- **Greenhouse**

  **Pros:**
  - Uses the sun as light source, free light.
  - Year-round grow.

  **Cons:**
  - Outside air constantly introduced.
  - Heat and humidity affected by seasons.
  - Poor odor control.
  - Low level of security.
Greenhouse or Enclosed Indoor Growing

- Indoor

Pros:

- Maximum number of harvests per year.
- No outside air exchange required.
- Consistent climate and light delivery.
- High level of security.

Cons:

- High build-out cost.
- High energy use.
Design Considerations

- Power availability and use
- Cannabis Lighting
- Temperature and Humidity control
- Photosynthesis and Evapotranspiration
- Sensible/Latent load, SHR and VPD
- Typical HVAC systems & Client budget
- CO2
- Odor Control
- Example Load Calculations
Power Availability and Use

- Have you confirmed that power is available?
- What voltage/phase is available?
- Will your budget allow for new power service if the existing electrical capacity is not sufficient?
- What are the back-up power options available?
- Unpredicted energy consumption
Power Availability and consumption
Power Availability and Consumption

According to a 2014 study performed by the Northwest Power and Conservation Council, electricity is generally used in cultivation facility as shown below:

<table>
<thead>
<tr>
<th>Function</th>
<th>Percentage of Total Facility Electricity Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC &amp; Dehumidification</td>
<td>51%</td>
</tr>
<tr>
<td>Lighting</td>
<td>38%</td>
</tr>
<tr>
<td>Space Heating (assuming electric heat)</td>
<td>5%</td>
</tr>
<tr>
<td>Water Handling</td>
<td>3%</td>
</tr>
<tr>
<td>CO2 Injection</td>
<td>2%</td>
</tr>
<tr>
<td>Drying/Curing</td>
<td>1%</td>
</tr>
</tbody>
</table>
Power Availability and Consumption

- Typical Power Requirement for 10,000 sf facility
  - Lights 134 kW
  - AC/Dehumidifier 180 kW
  - Electric Heat 33 kW
  - Recirculation and Exhaust Fans 112 kW
  - Miscellaneous 23 kW
  - Total: 480 kW and 579A
  - 600A connection to 347/600V 3 phase.
5.4 Regulatory Provisions Relating to Intrusion Detection

Guidance: Power Supply

In order to comply with regulations, your security system must include visual recording devices, access control and an intrusion detection system which must operate on a continuous basis. For example, supporting your security system and all components (e.g., sensors, control units and communicators/enunciators, volumetric sensors, glass-break detectors, beam-break sensors) with an **uninterruptible power supply** sufficient for 24/7 continuous operation would effectively maintain the integrity of your security system.

Design Considerations

- Power availability and use
- Cannabis Lighting
- Temperature and Humidity control
- Photosynthesis and Evapotranspiration
- Sensible/Latent load, SHR and VPD
- Typical HVAC systems & Client budget
- CO2
- Odor Control
- Example Load Calculations
Cannabis Lighting

Indoor cultivation facilities typically utilize a combination:

- High Pressure Sodium (HPS)
- Ceramic Metal Halide (CMH)
- Light-Emitting Diode (LED) lamps
<table>
<thead>
<tr>
<th>Light Technology</th>
<th>General Use / Growth Stage</th>
<th>Rated Life - Hours</th>
<th>Intensity* - PPFD - µmole/s*m2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMH</td>
<td>Flower and Vegetation</td>
<td>20,000</td>
<td>800</td>
</tr>
<tr>
<td>HPS (single ended)</td>
<td>Flower and Vegetation</td>
<td>5,000 - 20,000</td>
<td>700 - 900</td>
</tr>
<tr>
<td>HPS (double ended)</td>
<td>Flower and Vegetation</td>
<td>5,000 - 20,000</td>
<td>700 - 900</td>
</tr>
<tr>
<td>LED</td>
<td>All stages of growth</td>
<td>50,000</td>
<td>800 - 1200</td>
</tr>
</tbody>
</table>
Design Considerations

- Power availability and Use
- Cannabis Lighting
- Temperature and Humidity control
- Photosynthesis and Evapotranspiration
- Sensible/Latent load, SHR and VPD
- Typical HVAC systems & Client budget
- CO2
- Odor Control
- Example Load Calculations
Temperature and Humidity

Temperature and humidity control is important in:

- Mother Room
- Cloning Room
- Vegetative Room
- Flower Room
- Drying Room and Curing Room
Temperature and Humidity

Importance of Temperature and Humidity Control:

- Tight environmental control affects the growth, yield, quality, and consistency.
- Avoids disease and mold.
- Avoids damages in building structure by avoiding condensation on surfaces.
- Temperature and the humidity control is affected by lighting, irrigation, building envelope, infiltration, and ventilation.
Design Considerations

- Power availability and Use
- Cannabis Lighting
- Temperature and Humidity control
- Photosynthesis, Evapotranspiration and VPD
- Sensible/Latent load and SHR
- Typical HVAC systems & Client budget
- CO2
- Odor Control
- Example Load Calculations
Photosynthesis:

- When exposed to light, plant converts CO2 and water into chemical energy which is food.
Evapotranspiration:

- Process of evaporating water from leaves (stomata) to surrounding air through plant transpiration during photosynthesis.
Photosynthesis, Evapotranspiration, and VPD

**VPD (Vapor Pressure Deficit):**

- Difference between the pressure exerted by current moisture in the air and pressure at saturation.
- Percentage of water vapor in the air relative to how much vapor the air could hold at that particular temperature (until it reaches saturation).
- VPD is measured in kilopascals (kPa)
Photosynthesis, Evapotranspiration and VPD

![Relative Humidity vs. Temperature and Vapor Pressure Difference (VPD) Chart](chart.png)

<table>
<thead>
<tr>
<th>°F</th>
<th>WEAKS 1 to 2</th>
<th>WEEKS 3 to 4</th>
<th>WEEKS 5 to 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>86</td>
<td>83% 82% 80% 79% 78% 77% 76% 75%</td>
<td>74% 73% 72%</td>
<td>72% 69% 68% 67% 66% 65% 64% 63% 62%</td>
</tr>
<tr>
<td>85</td>
<td>82% 81% 79% 78% 77% 76% 75% 74%</td>
<td>73% 72% 71%</td>
<td>70% 68% 67% 66% 65% 64% 63% 62%</td>
</tr>
<tr>
<td>84</td>
<td>81% 80% 79% 78% 77% 76% 75% 74%</td>
<td>72% 71% 70%</td>
<td>69% 67% 66% 65% 64% 63% 62% 61%</td>
</tr>
<tr>
<td>83</td>
<td>81% 79% 78% 77% 76% 75% 74% 73%</td>
<td>71% 70% 69%</td>
<td>68% 66% 65% 64% 63% 62% 61%</td>
</tr>
<tr>
<td>82</td>
<td>80% 79% 78% 77% 76% 75% 74% 73%</td>
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<td>80</td>
<td>79% 77% 76% 74% 73% 71% 70% 69%</td>
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<td>76</td>
<td>76% 74% 72% 71% 69% 67% 66%</td>
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<td>59%</td>
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<tr>
<td>75</td>
<td>75% 73% 71% 70% 68% 66%</td>
<td>65% 63% 61%</td>
<td>58%</td>
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<tr>
<td>74</td>
<td>74% 72% 70% 69% 67% 65%</td>
<td>63% 62% 60%</td>
<td>56%</td>
</tr>
<tr>
<td>73</td>
<td>73% 71% 69% 68% 66%</td>
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<td>55%</td>
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<tr>
<td>72</td>
<td>72% 70% 68% 66% 65%</td>
<td>63% 61% 59%</td>
<td>53%</td>
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<tr>
<td>71</td>
<td>71% 69% 67% 65%</td>
<td>63% 61% 59%</td>
<td>52%</td>
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<tr>
<td>70</td>
<td>70% 68% 66% 64%</td>
<td>62% 60%</td>
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<td>69</td>
<td>69% 67% 65%</td>
<td>63% 61%</td>
<td>50%</td>
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<td>68% 66% 64%</td>
<td>62% 60%</td>
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<td>67</td>
<td>67% 65% 62%</td>
<td>60% 58%</td>
<td>48%</td>
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<td>66</td>
<td>66% 63% 61%</td>
<td>59% 56%</td>
<td>47%</td>
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<td>65</td>
<td>64% 62% 60%</td>
<td>57% 54%</td>
<td>46%</td>
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<td>64</td>
<td>53% 50% 48%</td>
<td>46% 44%</td>
<td>45%</td>
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<td>63</td>
<td>51% 48%</td>
<td>44% 42%</td>
<td>44%</td>
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<tr>
<td>62</td>
<td>49% 47%</td>
<td>44% 42%</td>
<td>44%</td>
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<tr>
<td>61</td>
<td>47% 45%</td>
<td>42% 40%</td>
<td>42%</td>
</tr>
<tr>
<td>60</td>
<td>45% 43%</td>
<td>40% 38%</td>
<td>40%</td>
</tr>
</tbody>
</table>

Growth stage values complements of HIGHTIMES Magazine, Skye Hanke and Harry Resin, March 09, 2017.
<table>
<thead>
<tr>
<th>Stage of Growth</th>
<th>Air Temp</th>
<th>RH</th>
<th>VPD</th>
<th>Watering Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloning</td>
<td>70°F (21.1°C)</td>
<td>80%</td>
<td>0 to 0.2 kPa (0 to 0.06 in Hg)</td>
<td>Saturated soil</td>
</tr>
<tr>
<td>Vegetative</td>
<td>78°F (25.6°C)</td>
<td>70%</td>
<td>0.8 to 1.1 kPa (0.24 to 0.33 in Hg)</td>
<td>Medium as plant is smaller, producing leaves for support</td>
</tr>
<tr>
<td>Early Flowering</td>
<td>75°F (23.9°C)</td>
<td>60%</td>
<td>1.0 to 1.4 kPa (0.30 to 0.41 in Hg)</td>
<td>Maximum to grow full buds</td>
</tr>
<tr>
<td>Late Flowering</td>
<td>75°F (23.9°C)</td>
<td>50%</td>
<td>1.3 to 1.5 kPa (0.39 to 0.44 in Hg)</td>
<td>Medium to start to dry out and preserve terpenes</td>
</tr>
</tbody>
</table>
Design Considerations

- Power availability and Use
- Cannabis Lighting
- Temperature and Humidity control
- Photosynthesis, Evapotranspiration and VPD
- Sensible/Latent load and SHR
- Typical HVAC systems & Client budget
- CO2
- Odor Control
- Example Load Calculations
Sensible/Latent load and SHR

- **Lighting (sensible)**
  - Energy in equals energy out

- **Evapotranspiration (latent)**
  - Equals the difference in the amount of water added through irrigation and the amount of water that goes to drain
    - Penman-Monteith Formula
    - 0.25 to 0.50 gal/plant/day
Design Considerations

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- Odor Control
- Example Load Calculations
Typical HVAC systems & Client Budget

**Cooling Methodology**

- **Mini-Splits**
  - Quick owner installation at relatively low cost
  - Option for very small-scale
  - Low ambient temperature options available
  - Indirect dehumidification capability
  - Limitations with tonnage
  - No precise control for RH
Typical HVAC systems & Client Budget

**Cooling Methodology**

- **Rooftop units**
  - Relatively inexpensive
  - Challenges associated with excessive ductwork, redundancy, low temperature operation
  - Limited Filtration Options
  - Challenges with humidity and CO2 control.
  - Microbial problems due to the cultivation space.
Typical HVAC systems & Client Budget

**Cooling Methodology**

- VRF or VRV
  - Comparatively more expensive to purchase and install
  - Low ambient temperature options available
  - Indirect dehumidification capability
  - Challenges with constant loads during the winter
  - Potential risk of leakage of refrigerant.
Typical HVAC systems & Client Budget

**Cooling Methodology**

- **Chilled Water Systems**
  - Comparatively most expensive to purchase and install
  - Dedicated dehumidification control when coupled with a reheat system
  - A high level of installation flexibility, allowing for changing capacity
  - The ability to design for redundancy as backups
Typical HVAC systems & Client Budget

**Cooling Methodology**

- Custom build Package units
  - Dedicated dehumidification and latent control
  - Lots of filter options.
  - The ability to design for redundancy as backups
  - Low ambient cooling.
  - Hot gas reheat.
Typical HVAC systems & Client Budget

**Dehumidification Methodology**

- **Standalone Dehumidifiers**
  - Small, free-hanging (plug and play)
  - Difficult to integrate with other climate control equipment
- **Reheat**
  - Electric or hot water reheat
  - Hot gas reheat
  - Heat recovery reheat
Design Considerations

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CO2 Enrichment

- CO2 enrichment is used to increase plant growth.
- Target CO2 levels of 1,200 to 1,500 ppm in a production room. Plant growth ceases when the level gets below 200 ppm. A level above 5,000 ppm can be deadly to humans.
- The rate of CO2 uptake is increased when both air temperature and light intensity are increased.
- Used during vegetation, flower and for mother plants for the fast growth.
CO2 Enrichment

Two sources of CO2 used in commercial cannabis production:

- Compressed Liquid CO2
- Combustion Natural Gas (adds more heat and contaminants)
CO2 Enrichment

Figure 1: Overview of a Cryogenic Supply System
Design Considerations

- Power availability and Use
- Cannabis Lighting
- Temperature and Humidity control
- Photosynthesis, Evapotranspiration and VPD
- Sensible/Latent load and SHR
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- CO2
- Odor Control
- Example Load Calculations
Odor Control & Filter requirements

5.5 Regulatory Provision Relating to Air Filtration

To assist in the prevention of the escape of pollen, odours, and other particles, all exhaust air from your cultivation area and other areas within your site where cannabis is present can be filtered through appropriate air filtration systems.

For example, *a high-efficiency particle air filter such as a H13 HEPA filter* can ensure appropriate ventilation and filtration of exhaust air.

Odor Control & Filter requirements

Fresh air side, HEPA filters
Using HEPA in your grow room will ensure that you’re removing harmful particles from the air and creating a safe environment for your crops.
Odor Control & Filter requirements

Exhaust systems remove contaminants and odors from the air. Marijuana plants emit a very strong “skunk like” odor.

Common methods of odor control:
- Carbon filter in exhaust duct
- Carbon filter in recirculated air
- Ozone generators in exhaust duct
- Ionizers
Design Considerations

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- Typical HVAC systems & Client budget
- CO2
- Odor Control

- Example Load Calculations
Example Growroom Load Calculations HPS Room
### Example Load Calculations

**HPS Room Day/Night Cycle**

<table>
<thead>
<tr>
<th>Room Type</th>
<th>Flower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room Area (sq ft)</td>
<td>2000</td>
</tr>
<tr>
<td>Room Volume (cu ft)</td>
<td>24,000</td>
</tr>
<tr>
<td>Total Light</td>
<td>80</td>
</tr>
<tr>
<td>Total Light (Watts)</td>
<td>84,000</td>
</tr>
<tr>
<td>Total Lights (BTU)</td>
<td>286,692</td>
</tr>
<tr>
<td>Number of the plants</td>
<td>640</td>
</tr>
<tr>
<td>Net Water Use Gallons</td>
<td>160</td>
</tr>
<tr>
<td>Hours of Light</td>
<td>12</td>
</tr>
<tr>
<td>Room Tem. F</td>
<td>75</td>
</tr>
<tr>
<td>Relative Humidity %</td>
<td>60</td>
</tr>
<tr>
<td>Canopy area (sq ft)</td>
<td>1,280</td>
</tr>
<tr>
<td>Ventilation CFM</td>
<td>400</td>
</tr>
<tr>
<td>Room Heat gain (BTU/h)</td>
<td>0</td>
</tr>
<tr>
<td>Room Heat loss (BTU/h)</td>
<td>0</td>
</tr>
</tbody>
</table>
### Example Load Calculations
#### HPS Room Day/Night Cycle

<table>
<thead>
<tr>
<th>Peak Sensible Load Lights on</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting btu/h</td>
<td>286,692</td>
</tr>
<tr>
<td>Room Heat Gain btu/h</td>
<td>0</td>
</tr>
<tr>
<td>Ventilation btu/h</td>
<td>8,680</td>
</tr>
<tr>
<td>Sensible Design Temp</td>
<td>95°F</td>
</tr>
<tr>
<td>Room Temperature</td>
<td>75°F</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peak Latent Load Lights on</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Use (Gallons per day)</td>
<td>160</td>
</tr>
<tr>
<td>Number of plants</td>
<td>640</td>
</tr>
<tr>
<td>Gallons per Plant</td>
<td>0.25</td>
</tr>
<tr>
<td>% Evapotranspiration</td>
<td>75</td>
</tr>
<tr>
<td>Gallons per Hour (12h) EV</td>
<td>10</td>
</tr>
<tr>
<td>Pounds per hour EV</td>
<td>83.3</td>
</tr>
<tr>
<td>Ventilation Load lb/hr</td>
<td>7.1</td>
</tr>
<tr>
<td>Total lb/hr</td>
<td>90.4</td>
</tr>
<tr>
<td>Btu/h</td>
<td>94,910</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peak Loads Lights ON</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensible Cooling (btu/h)</td>
<td>295,372</td>
</tr>
<tr>
<td>Latent Cooling (btu/h)</td>
<td>94,910</td>
</tr>
<tr>
<td>Latent Cooling (lb/hr)</td>
<td>89.5</td>
</tr>
<tr>
<td>Total Cooling (btu/h)</td>
<td>390,282</td>
</tr>
<tr>
<td>SHR</td>
<td>75%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peak Loads Lights OFF</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensible Cooling (btu/h)</td>
<td>923</td>
</tr>
<tr>
<td>Latent Cooling (btu/h)</td>
<td>28,473</td>
</tr>
</tbody>
</table>
Latent load

- **Evapotranspiration (latent)**
  - Equals the difference in the amount of water added through irrigation and the amount of water that goes to drain
    - Penman-Monteith Formula
    - 0.25 to 0.50 gal/plant/day

- **Evaporative Cooling Effect**
  - When water evaporates, it absorbs heat, producing a cooling effect.
Sensible/Latent load and SHR

Penman-Monteith Formula

$$\lambda_v E = \frac{\Delta (R_n - G) + \rho_a c_p (\delta e) g_a}{\Delta + \gamma (1 + g_a/g_s)} \iff ET_o = \frac{\Delta (R_n - G) + \rho_a c_p (\delta e) g_a}{(\Delta + \gamma (1 + g_a/g_s)) L_v}$$

$\lambda_v$ = *Latent heat of vaporization*, Energy required per unit mass of water vaporized. (J g$^{-1}$)

$L_v$ = Volumetric latent heat of vaporization. Energy required per water volume vaporized. ($L_v = 2453$ MJ m$^{-3}$)

$E$ = Mass water evapotranspiration rate (g s$^{-1}$ m$^{-2}$)

$ET_o$ = Water volume evapotranspired (mm s$^{-1}$)

$\Delta$ = Rate of change of saturation specific humidity with air temperature. (Pa K$^{-1}$)

$R_n$ = Net irradiance (W m$^{-2}$), the external source of energy flux

$G$ = Ground heat flux (W m$^{-2}$), usually difficult to measure

$c_p$ = *Specific heat* capacity of air (J kg$^{-1}$ K$^{-1}$)

$\rho_a$ = dry air *density* (kg m$^{-3}$)

$\delta e$ = *vapor pressure deficit*, or *specific humidity* (Pa)

$g_a$ = *Conductivity* of air, atmospheric conductance (m s$^{-1}$)

$g_s$ = Conductivity of stoma, *surface conductance* (m s$^{-1}$)

$\gamma$ = *Psychrometric constant* ($\gamma \approx 66$ Pa K$^{-1}$)
## Example Growroom Load Calculations HPS Room Day Cycle

### Peak Latent Load Lights on Penman-Monteith

<table>
<thead>
<tr>
<th>Late stages of Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>EV from PM method full growth (Gallons per day)</td>
</tr>
<tr>
<td>Evaporated Water from surfaces (Gallons per day)</td>
</tr>
<tr>
<td>Total Water Use (Gallons per plant)</td>
</tr>
<tr>
<td>% ET</td>
</tr>
<tr>
<td>Gallons per Hour EV</td>
</tr>
<tr>
<td>Total lb/hr</td>
</tr>
<tr>
<td>Btu/h</td>
</tr>
</tbody>
</table>

### Peak Loads Lights ON

| Sensible Cooling (btu/h) full growth               | 295 372 |
| Sensible Cooling (btu/h) + credit                 | 228 074 |
| Latent Cooling (lb/hr)                             | 67 298 |
| Total Cooling (btu/h)                              | 295 372 |
| SHR                                                | 77% |

### Peak Loads Lights OFF

| Sensible Cooling (btu/h)                           | 923 |
| Latent Cooling (btu/h)                             | 20 189 |
# Example Growroom Load Calculations HPS Room Day Cycle

## Minimum Latent Load Lights on Penman-Monteith

<table>
<thead>
<tr>
<th>Early stage plants</th>
<th>ET initial stage of grow from PM (Gallons per day)</th>
<th>59</th>
</tr>
</thead>
<tbody>
<tr>
<td>% ET</td>
<td></td>
<td>75</td>
</tr>
<tr>
<td>Gallons per Hour EV</td>
<td></td>
<td>3,7</td>
</tr>
<tr>
<td>Total lb/hr</td>
<td></td>
<td>30,1</td>
</tr>
<tr>
<td>Btu/h</td>
<td></td>
<td>32 137</td>
</tr>
</tbody>
</table>

## Peak Loads Lights ON

<table>
<thead>
<tr>
<th></th>
<th>Sensible Cooling (btu/h) full growth</th>
<th>295 372</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sensible Cooling (btu/h) + credit</td>
<td>263 235</td>
</tr>
<tr>
<td></td>
<td>Latent Cooling (lb/hr)</td>
<td>32 137</td>
</tr>
<tr>
<td></td>
<td>Total Cooling (btu/h)</td>
<td>295 372</td>
</tr>
<tr>
<td></td>
<td>SHR</td>
<td>89%</td>
</tr>
</tbody>
</table>

## Peak Loads Lights OFF

|                                | Sensible Cooling (btu/h)            | 923     |
|                                | Latent Cooling (btu/h)              | 9 641   |
Questions