Installation Guide
for
R84K Industrial Lighting Systems
for
Horticultural Applications

(Rev C.)

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Robert W. McCullough, PhD

BioPhotonic Systems, LLC

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1. Introduction

This document is intended to guide the installation of R48K lights in a horticultural application. The R48K family of lights is ideally suited for use in environments typical of greenhouses, vertical farms and cannabis cultivation facilities. These environments are characterized by high humidity, standing water, aerosols from water or oil based constituents of the local atmosphere and pathogens such as mold or mildew spores.

The R48K lights consist of a series of linear LED fixtures with a IP67 rating. The glazing on the fixtures is Pyrex glass. This means that the fixtures can be exposed to environments that would destroy conventional air-cooled lights. The R48K lights can be hosed down while operating to clean the glazing or clear pathogens. This operation is not recommended for most air-cooled LED or high-pressure sodium lights.

The architecture of the R48K lights separates the two principal support system requirements of electrical power and cooling to locations exterior to the space being illuminated (Figure 1.). This means that they can be specified for less stringent environmental requirements and the waste heat from these components is not introduced into the grow environment.

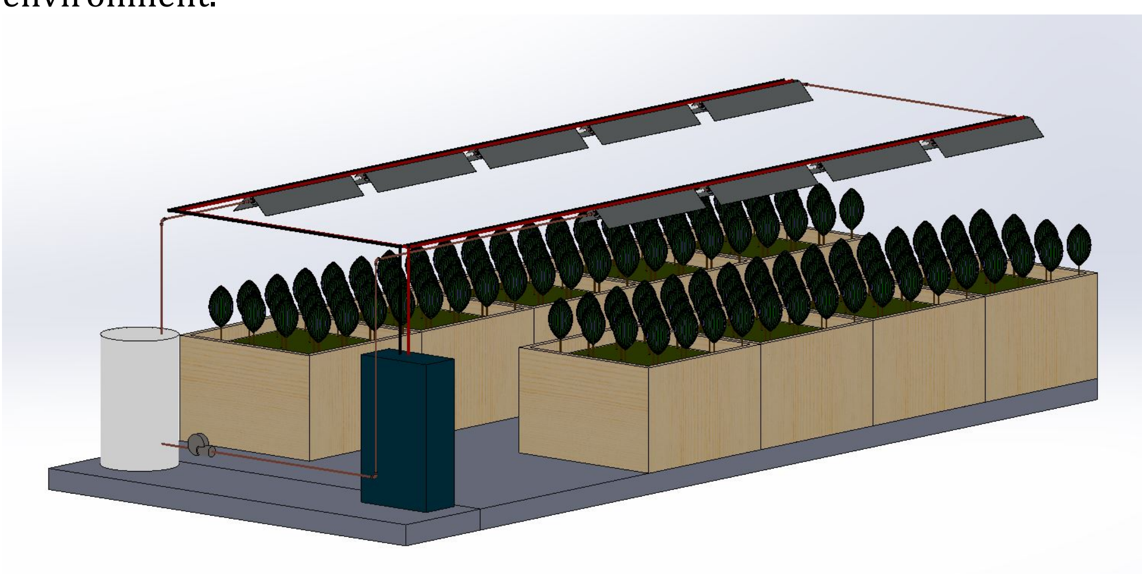


Figure 1. R48K 9kW installation

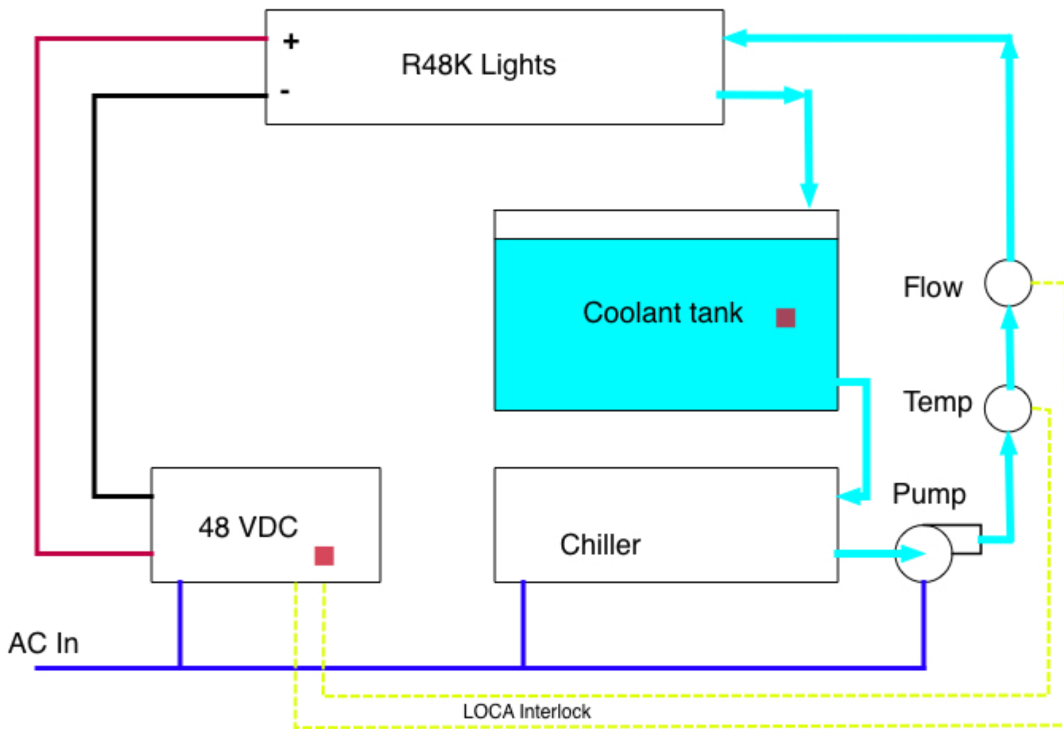


Figure 2. R48K System diagram – Chiller cooling

However the cooling and electrical power support systems must be designed to be compatible with the light installation in terms of power supplied and heat removed. A typical system diagram is shown in Figure 2. indicating power and cooling systems.

In this document we will walk the user through the steps required to configure and install a complete system. The R48K lights are designed for industrial scale operation, not local or amateur grow situations. Typical installations would probably have a minimum of 16 kW of lights serving roughly 250 square feet of grow space for a cannabis cultivation facility environment and 1000 square feet of grow space for a supplemental lighting system for a greenhouse. For practical purposes the largest stand-alone installation on a single power source and will probably be limited to 64 kW of lights serving a cannabis cultivation facility of 1000 square feet.

Because of the inherent scalability of the system, designs of any power level can be configured but will probably consist of multiple 64 kW modules.

We begin this document with a description of the R48K lighting system, is components and their inter-relationships with each other.

This is followed by a discussion of required site preparation design layout where we discuss lighting, cooling and electrical planning.

The next three sections cover specific design requirements for the cooling system, the electrical power system and the lights. System component sizing and performance requirements are discussed and installation guidance given.

Finally the operation of the integrated system is discussed along with programming and safety tips.

In Appendix A, we will go through the design process for a 16kW installation including specification of a typical power and cooling subsystem. Appendix B has the same analysis for a 64 kW system. Appendix C lists power supply manufacturers while Appendix D lists cooling unit vendors. Finally Appendix E discusses heat loads in cultivation facilities and opportunities for synergism using the R48K lighting system.

2. System Description

2.1 R48K lights

The R48K lighting family for horticultural consists of three sizes with power outputs 500, 1000 and 1500 watts. These lights are water-cooled and draw power from a 48 VDC low voltage power bus. Water-cooling allows the light to operate at cooler LED temperatures yielding higher efficiency and longer life for the LEDs. The LED mix is predominantly red with some blue and white in a ratio that was developed by NASA and is currently fairly standard in the industry. Custom LED color mixes are easily accommodated for custom orders.

The lights are housed in an IP67 environmental enclosure that allows efficient coupling of the photons generated by the LEDs to the environment and protects the LEDs and electronics from challenging environments such as those encountered in cannabis cultivation facilities and greenhouses. Water-cooling also allows the excess heat from the lights to be removed from the cannabis cultivation facility in a controlled manner. In addition a cooling system can be configured for dual use purpose to include greenhouse heating/cooling in addition to LED fixture cooling. This option further reduces the facility operating costs through reduced capital costs and lower energy usage.

The low voltage DC bus structure means that only low-voltage wiring need be inside the greenhouse. Actual voltages present inside the greenhouse are limited to 48 volts. The requirement for wiring of dangerous 240/460 VAC fixtures in a wet environment no longer exists.

The IP67 enclosures mean that the lights can be subjected to direct water jets while operating. This is advantageous over all air-cooled units which use forced convection to draw air into an enclosure. Besides being susceptible to moisture, aerosols and insects these enclosures serve as repositories for mold and mildew spores and cannot be easily disinfected.

The R48K lights use a novel optical system to provide uniform illumination over the plant canopy. Levels of 450 +/- 25 µmoles/meter^2/second over a 5 foot wide bed result from hanging the light at a height of 4 feet.

The onboard circuitry protects the LEDs from overheating and over current operation. Multiple cell architecture insures that failure of a single LED does not shut down the whole light.

2.2 Electrical Power supply

The system requires 48 VDC power with reasonable regulation. We recommend power systems from MeanWell, GE or TDK Lambda with rack-mount power supplies designed for the telecom and computer industry that are well regulated, hot swappable and have a good power factor. However any power supply that provides 48VDC with a ripple of 10% or less is acceptable.

The lights can operate at lower voltages than 48 VDC with a corresponding reduction in output. Lower voltage operation also results in greater efficiency and lower cost per photon delivered. This feature can also be used for dimming the lights when power supplies

The lights can be supplied power from a wide variety of sources including batteries, solar, cogeneration, motor generators, etc. Each 1000W light requires about 20 amps to operate so current levels escalate rapidly for large installations. Standard wiring practices used by licensed electricians result in code compliant installations. We recommend electrical installation by licensed electricians familiar with NEC best practices for low voltage installations.

2.3 Cooling System

The cooling system is required to supply approximately 0.5 gallons per minute (gpm) for each R48K-1000 light. Plumbing can be done with 5/8" pex tubing or ½" copper pipe. We recommend using polymer Sharkbite type connectors. These install quickly and are generally leak free. The large flow passage diameter in the lights mean that many lights can be strung in series before the pressure drop through the system exceeds 40 PSI, the maximum pressure we recommend using.

Most installations will consist of several parallel strings overhead of long plant beds, so running a parallel piping system is recommended to keep the pressure drop reasonable. Standard water circulation pumps and plumbing fixtures can be used. We recommend using an inhibited propylene glycol/water mixture to protect the aluminum tubing in the fixtures from corrosion.

A typical cooling loop consists of a tank, a pump, filters, valves, flow and temperature sensors and a heat extraction device. The flow and temperature sensors are connected to a loss of coolant alarm system that shuts down the power to the lights in the event that the temperature of the coolant exceeds a preset level (usually 40 °C) or the cessation of flow is detected.

The simplest cooling system configuration is to directly exchange the heat through a heat exchanger to ambient air. So called fan-coil units can be used to transfer heat directly to the ambient air (similar to the fan/radiator system in your automobile). One drawback to these systems is that the lowest temperature to which they can bring the coolant is 10-15 ° C above ambient air. On hot days the lights will run hot.

Liquid to liquid heat exchangers are also available and can be used to transfer heat into bodies of water such as cooling ponds, local streams or swimming pools, which typically exist at lower temperatures than the ambient air in hot environments. This method is very efficient from a heat transfer standpoint and the lights will run cool. If using ground water from a well to dump the heat it is important to insure that the volume of water in the well can dissipate the heat to the surrounding groundwater.

A third cooling option is the use of evaporative cooling devices. Direct systems such as "swamp coolers" are not useful as they cool ambient air at the expense of increased humidity. Instead indirect evaporative coolers (IEC) are used to chill liquids. Think of an automobile radiator that has water sprayed on to it while running. Evaporation cools one side of the heat exchanger that cools the liquid on the other side. These devices work well in hot dry climates and have COPs as large as 20! They are very energy efficient and probably the most efficient method. There are many manufacturers of IEC units. They are limited to the temperature to which they can cool the coolant to 10-15 °C above the *wet-bulb temperature* of the ambient air.

Perhaps the best method is to employ an industrial chiller system. These use mechanical vapor compression cycles similar to air conditioners to extract heat from the coolant and transfer it to ambient air. They are also available as a liquid-to-liquid exchange system. Many manufacturers produce these devices in a wide range of sizes. Large systems are available from established HVAC companies such as Carrier and Trane. Medium size chillers are available from companies like

Advantage and Fluid Chillers, Inc. Small chillers principally used for amateur brewing or wine making are available from companies like EcoPlus or Active Aqua. Rough costs are around $.20 per watt thermal energy exchanged and coefficient of performances (COP) ranging from 3 to 5.5. The COP indicated the watts of thermal energy exchanged per watt of electricity used. In general for most installations, medium size chillers with capacities of 2.5 to 10 tons capacity will be chosen. For small systems of only 2-4 lights the small chillers represent a more cost effective solution. Chillers are available that employ split cycles so that the air cooled condensers can be placed outside the building.

An advantage of chiller systems is that they can control the coolant temperature to a fixed temperature setting for best operation. And they can be conveniently sited in a large facility to serve many rooms economically. Indeed if the chiller has the capacity to produce liquid at temperatures of 5-10 °C they can supply coolant for dehumidifi9er systems as well as cool the lights.

In many current installations HVAC systems are installed on the roof to remove heat from the cannabis cultivation facility air, in which it has been deposited by the local air-cooled lights. These systems are air-to-air and have COP values as low as 2.7 resulting in significantly higher operating costs for the facility.

When LED lights are operated at lower temperatures two effects are observed. First, the output photon flux is increased as much as 10% over nominal operation. Second, the lifetime of the LEDs is dramatically increased. Thus, while chillers may be expensive compared to fan coil heat exchangers, they can have long term benefits.

Note that in all the above examples the heat collected from the lights is just rejected to the ambient environment. Part of the advantage of using water-cooled lights is that the hot water can be put to a variety of uses from heating office space, heating soil, heating the grow room at night or heating a spa. In addition, the inclusion of a water cooling loop in the system involves additional capital costs from the requirements of the auxiliary equipment. However, it is easy to incorporate that cooling system into the environmental control system of the grow room by using it to receive heat from dehumidifying systems etc. This option really enables the use of water-cooled LED lights to construct economic and sustainable grow facilities in which the electrical energy paid for to run the lights can also do double-duty to provide heat for other needs. This would be very difficult with any air-cooled system.

Since the cooling system can perform many functions and can also act as an integrated component to a complete environmental control system, we have presented several system possibilities in Appendix E for the interested reader, with typical designs for a 10 kW light system.

3. Site preparation

We now discuss planning for an installation. As mentioned above, we will describe the design principles for a general installation. Design summaries are provided for 16 kW and 64 kW systems in Appendix A and B respectively.

3.1 Illumination Plan

The first and most important plan is to determine the required light flux for the crop in question. This level varies dramatically between various crops and development stages for the crops. Our lights are designed to deliver substantial fluxes and so are most applicable to the vegetative or flowering stage. The flux level can be changed by changing the distance between the light and the crop canopy as needs change.

The typical light power consumption for the R48K lights is about 250 watts per foot. The lights are typically arranged end-to-end over the beds. The beam width of the linear light is approximately 100 ° where the light is constant over the transverse distance to about +/- 5%.
At a 4 foot height the PPF is approximately 450 μmoles/ meter^2/second uniform over +/- 2.5 feet. At 2 foot height the PPF is approximately 900 μmoles/meter squared/second and the beam is 2.5 feet wide.

There is additional flux out the sides that can be recovered with the use of properly designed reflective walls to increase these levels by 10% to 20%.

3.2 Electrical Plan

Site planning for the electrical system consists of locating the power supply and configuring the wiring distribution system. In most cases a single power supply will be used for each room due to the difficulty of distributing and controlling low voltage DC systems. The large currents mean that the bus may use large amounts of heavy copper wire or even bar stock and that switching for these currents may also require heavy duty switch gear..

The rack mount power supplies that we recommend reside in 19 inch racks. These racks are available with various levels of enclosure technology. In general it is advisable to configure the distribution so that segments of lights can be switched on and off in groups. The MeanWell system we recommend allows groups of lights from 2 kW to 64 kW to be controlled remotely using a single controller module attached to a PC.

Limiting the number of lights on a single string can result in reasonable size wires for the bus which lowers overall system cost.

3.3 Cooling System Plan

In general cannabis cultivation facilities and greenhouses have complicated cooling requirements due to the presence of several time-varying heat loads. These include heating and cooling of the space, cooling of any light induced heat load, solar influx and dehumidification heat load. One of the advantages of using water-cooled lighting is that the total system cooling requirements can be met with a single appropriately sized chiller system. Of course this requires that the facility be comprehensively engineered prior to construction. In this section we will consider a cooling system plan for a system that handles only the load from the lights. An overview of cannabis cultivation facility heat loads and ways to handle them is presented in appendix E for the interested reader.

For the cooling system layout we need to place the tank, pumps, heat transfer device and sensors in a location that is easy to access and monitor. The coolant in the tank gives us a thermal capacitance that allows the system to run for a short time with out any heat exchange. In this case the heat just goes in to elevating the temperature of the tank. This is useful for testing the system with out a chiller or heat exchange element in the loop. A reasonable range to allow the coolant to heat up might be to 50 °C. Starting from room temperature we should allow for 10 minutes of operation at least before reaching this system. In addition provision must be made for locating the loss of coolant (LOC) sensors near the controller and for testing and verifying their operation easily. All components must be compatible with propylene glycol mixtures and the pumps must be sized to deliver the required flow through all the circuit elements: valves, lights, heat exchangers and piping components.

The coolant route should be configured to result in reasonable pressure drops through the loop. Paralleling flow routes may help with this and in addition provide the opportunity to isolate one section of lights for maintenance without having to entire shut the system down or drain it.

3.4 Sizing

The cooling system requirement is to provide cooling fluid to remove the excess heat generated by the fixtures and to deposit that heat in a convenient heat sink, which can include ambient air outside the facility or a water reservoir or stream/river near the facility.

Each R48K-1000 fixture consumes 1000 watts of electricity, generates approximately 400 watts of photons and 600 watts of waste heat. As described above cooling options include heat exchangers, vapor compression chillers or evaporative coolers.

For example a 10 unit installation would require a cooling capacity of 6000 watts thermal or 20,000 BTU/hr. Many cooling systems are rated in tons where a ton of cooling is equal to 12,000 BTU/hr. So in this case a 2 ton system would be more than adequate.

The cooling system will use a closed loop for cooling the lights. Waste heat will be removed from a reservoir of coolant that will provide some capacity for heat storage the system. System pumps must be sized to provide a minimum of 0.25 gallons per minute flow for each light in the string. Strings may be connected in parallel to minimize pressure head requirements.

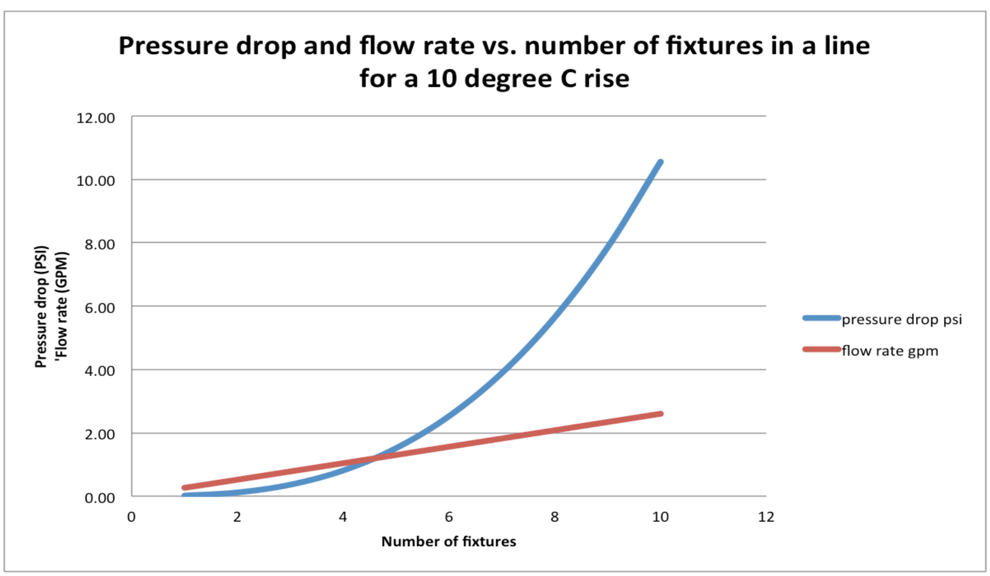


Figure 3. Flow rates and pressure drop for a 10 °C temperature rise.

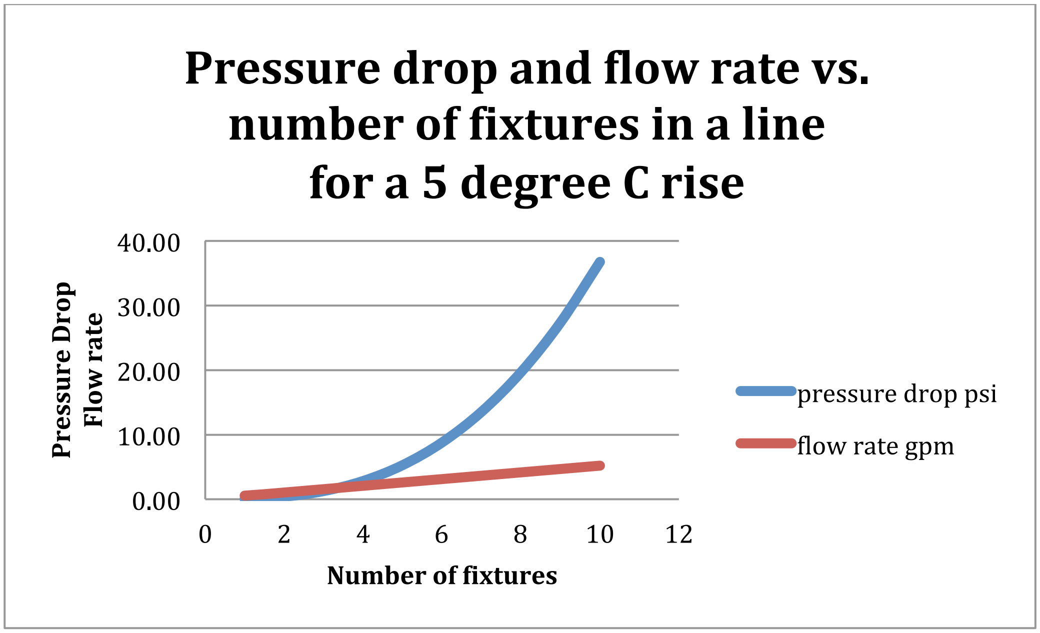


Figure 4. Flow rate and pressure drop for a 5 °C temperature rise.

Figures 3 and 4 above show the flow rates and pressure drops in light strings from 1 to10 units long. A 10 unit string could be connected in a single string with a flow rate of 2.5 GPM and a pressure drop of 10 PSI through the string . Alternatively two parallel strings of five lights each could be provided with 1.4 GPM on each leg for a total of 2.8 GPM and a reduced pressure drop of 1.6 PSI total. HVAC design professionals should be able to configure a system easily sizing the pump to include pressure drops through elbows, tees, heat exchangers, valves, etc. in the loop.

3.5 Safety Interlocks and controls

It is important to monitor and control the temperature of the coolant in the loop. Because aluminum is used in the system internals it is advisable to use an inhibited propylene glycol/water mix. Ethylene glycol is toxic and not recommended for systems designed to grow consumable products. Propylene glycol is safe for food system application.

It is advisable to install a loss-of-coolant detection system that is coupled to the power supply to turn off the power to the lights in the event that a loss of coolant is detected. This system is composed of a flow sensor and a temperature sensor (figure 2.). The system is shut down in the event the flow sensor detects flow below a minimum or the temperature exceeds a predetermined maximum. Coolant temperatures above 70 °C should be avoided.

3.6 System Options

As described above, the cooling system can be based on commercial chiller technology (recommended), evaporative cooling systems or direct heat exchanger systems.

In an industrial chiller system, the water temperature can be controlled directly. These systems use vapor compression cycles and coolant temperatures below ambient can be set. Running the coolant loop for example at 15 °C will result in the LEDs running at a lower temperature and will contribute to a long operating life. Unlike HPS and fluorescent fixtures LEDs can be expected to have operating lives of up to 100,000 hours. Their initial installation costs is higher that HPS or fluorescent fixtures so installing a chiller system is well worth the investment. These systems are available to dump the heat to either ambient air or a body of water.

An evaporative cooling system will have the advantage of lower operating costs. The COP of these systems can be up to 20. However they must be carefully engineered and the water on the evaporative side must be monitored for mineral and scale build up for tower systems. Systems based on ponds or water reservoirs do not need to worry about this. Spray nozzles can improve efficiency. In these systems the heat is generally dumped to ambient air and in all cases the minimum coolant temperature will be approximately 5 °C above the local wet bulb temperature. They are therefore most suited for dry low humidity environments.

The third option is to exchange the heat with a heat exchanger directly with the fluid used to dump the heat. If ambient air is used the minimum coolant temperature will always be 5-10 °C above the ambient. If a water body is used to dump the heat the minimum coolant temperature will always be 5 °C above the water in the sink.

Having control of the waste heat in the R48K system also opens up the possibility of using the heat for other purposes, such as space heating or bed heating. Using the heat for water heating is not advised unless a heat pump is included due to the elevated temperature of the water in this case.

3.7 Installation

Installation by a licensed HVAC technician is recommended. The cooling system will have to undergo inspections by local building code inspectors similar to any HVAC commercial installation.

If parallel flow paths are used, balancing valves and independent temperature sensors for each string are recommended. In addition the system should include a bypass link with shut off valves so that the coolant system can be tested with the lights isolated. This also allows removal of a light from a string without loss of coolant from the system.

The coolant loop must be filled with an inhibited propylene glycol coolant. Never use automotive antifreeze solutions as they may use ethylene glycol which is toxic. In addition all automotive antifreeze mixtures contain silicate corrosion inhibitors with will form a gel on the heat transfer surfaces in the system and inhibit the cooling capacity of the system both internally to the chiller as well as in the R48K light fixtures.

Inhibited propylene glycol is manufactured by:

- Dow Corning – “DowFrost” (800) 258-2436
- Monsanto – “Therminol FS” (800) 459-2665
- Advantage Engineering ‘Thermofluid” (317) 887-0729

4. Electrical System Design

4.1 Sizing

The electrical system requirement is to provide 48 VDC in sufficient power and distribution to safely supply the array of R48K lights. In all instances the electrical installation should be performed by licensed electricians familiar with the National Electrical Code (NEC) requirements and local electrical installation requirements for the local community.

We recommend standard UL approved rack mounted power supplies developed for the telecommunications and computer industry. Systems such as these are well developed and offer features such as being hot swappable and localized computer monitoring and control.

Each R48K-1000 unit requires 20 amps of 48 VDC and is wired in a bus architecture. Bus cable can be specified in decreasing ampacity to account for the linear decrease in current along a bus string. For example a string of 10 R48K-1000 lights will require 200 amps supplied to the bus at the first light on the string but only 100 at the junction of the sixth light on the string. Wire of 000 gauge is required to carry 200 amps but the wire gage can be reduced to 1 gauge for 100 amps.

Wire gauge selection and a wiring plan should be developed by a licensed electrician.

Typical ampacity for electrical wiring according to the NEC is shown in table 1. (Table 310.104(A) 2017 NEC) Note these values are for copper cable capable of withstanding 90 °C operating temperature. Ratings vary with conductor type and insulation type. See section 3 of the NEC to select an appropriate wire gauge for your specific installation.

Wire Gauge	Maximum Current (amps)
4	95
3	115
2	130
1	145
1/0	170
2/0	195
3/0	225

Table 1 - Ampacity for typical electrical wire.

Another option for the DC bus is to use copper bar. This must be housed in an enclosure that protects the buss from accidental shorting and allows for proper thermal dissipation. Again a licensed electrician should be consulted when using this approach and all structures must be compliant with the NEC.

A table of ampacity for copper bus bars is given in table 2 below taken from the ATIS T1 Committee. This rating is for a 30 °C rise above a 40 °C ambient with the bars run with their long axis oriented vertically and laid out in a horizontal plane.

Thickness (in)	Width (in)	Area (cm^2)	Ampacity(Amps)
1/8	½	79.6	154
	¾	119.4	215
	1	159.2	275
	1 ½	238.7	390
	2	318.3	503
1/4	1/2	150.2	238
	1	318.3	409
	1 1/2	477.5	572
	2	636.6	731
	2 1/2	795.8	887
	3	954.9	1040

Table 2 - Ampacity for solid copper bus bar.

4.2 Layout

In general a linear bus co-located with the light string in an overhead cable tray or closed conduit is advisable. Use of UL approved cable or solid conductor bus ways should be installed according to the NEC.

4.3 Installation

The 48VDC bus should be located above the light strings and constructed so that easy access to the light wiring is available. Each light should be connected using standard connectors approved for use with low-voltage high-current applications.

5. Lights

5.1 Mounting options

The R48K-1000 lights come with stainless steel pad eyes for mounting. We recommend that the fixtures be mounted with steel cable assemblies (e.g. cable grippers). This allows easy vertical height adjustment.

In no instance should the aluminum tubes that carry the cooloant be used as structural supports. Their purpose is to carry coolant to the LED arrays. Suspending the lights by them can place undue stress on the light assembly.

5.2 Installation

Installation proceeds by hanging the lights in their strings using wire cable system or other means.

5.3 Connect coolant loops

The lights are next connected using tube connectors. We recommend using SharkBite-style connectors as they can be removed easily and are leak tight.

5.4 Connect Electrical power

The lead wires from the lights are SOOW portable cordage gauge 12/3 and should be led to the 48VDC bus overhead and connected using NEC approved splice devices.

5.5 Test

Power up the coolant pump system and verify the proper operation of the flow sensor in the LOC system. Check for leaks.

Power up the coolant chiller system and monitor the temperature of the coolant to verify proper operation.

Note that the lights have internal over-temperature protection and can be run without coolant (not recommended). In addition the thermal mass of the lights allow the lights to be operated for up to 30 seconds with no coolant present. Also if the coolant flow is present but the cooling system is not removing heat the lights can be operated while monitoring the coolant temperature while it rises. For example a 10 light system with a 10-gallon coolant reservoir will run for about 20 minutes before the temperature reaches 70 °C.

6. **Operation**

Operation of the lighting system basically consists of powering up the cooling system and the power supply. All the systems can be configured from a common supply so that a single switch can control the entire installation. Alternatively the lights and cooling system can be powered on and off for individual strings or areas depending on the required complexity of the system.

Safety interlocks should be tested routinely to assure that they are operating properly.

6.1 Safety interlocks

The two interlocks for the system are the flow sensor and the coolant temperature sensor. The flow sensor monitors flow to the system and depowers the lights in the event of a loss of coolant.

The temperature sensor senses the temperature in the coolant line and depowers the lights if a temperature excursion above what is normal is detected. If chillers are used this control temperature can be set below ambient temperature to give early warning of failure of the chiller system. If ambient air is used to dump the heat, the set temperature must allow for normal excursion in ambient which can cause the coolant temperature to rise to 40 °C or higher.

6.2 Scheduling

Most cannabis cultivation facilities have light schedules. Electrical schedulers can be placed upstream of the electrical supply for the light power. Alternatively if rack mounted power supplies such as the MeanWell RCP series are used, the scheduling can be done with a control computer directly connected to the system power controller through USB or Ethernet.

6.3 Maintenance

Maintenance consists of keeping the lights clean to assure maximum output and minimum pests, monitoring the coolant and power supplies.

The coolant is a propylene glycol solution and should be visibly checked every month for deterioration . The coolant should be changed every six months and a fresh charge installed.

The health of the power supplies can be monitored continuously and a replacement supply can be “hot-swapped” in the constellation if trouble is detected. This can all be done easily if the rack mounted power system that we recommend is used.

Appendix A. Design of a 16 kW installation

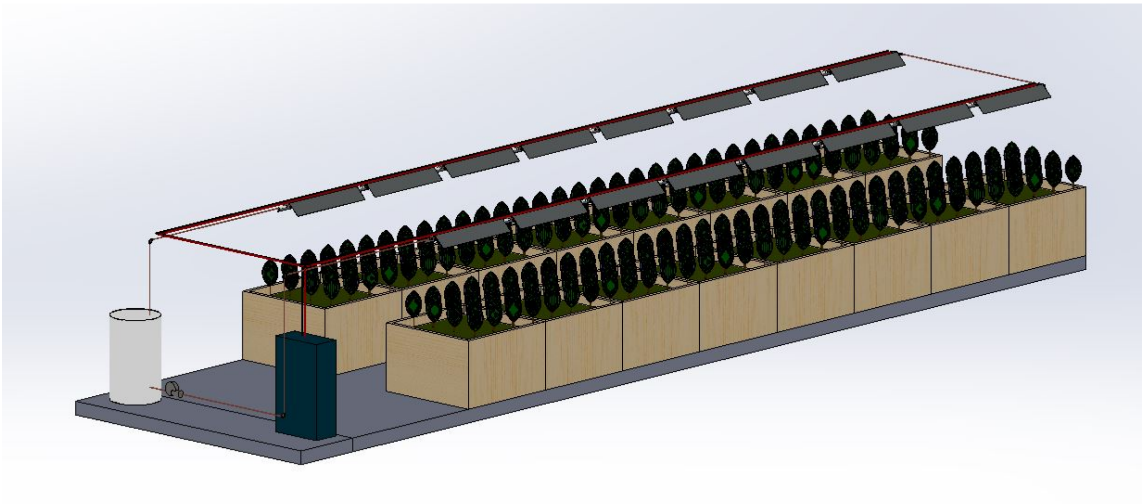


Figure 5. 16 kW system schematic

For this system (Figure 5) we assume that the facility is long and narrow. We specify two beds 32 feet long by 4 feet wide with a 2 feet wide aisle in the middle. This might be a configuration inside a standard 40 foot container that has been converted to be a modular cannabis cultivation facility. We specify a requirement for a PPF of at least 500 μmoles/ $meter^2$/second over the bed width and length. If we suspend the lights at a height of 3.2 feet above the plant canopy we can achieve this. Note that the daily integrated output can be reduced by lowering the voltage or shortening the on time in the grow cycle.

For this straw man system we assume the simplest configuration: all the lights will be controlled together. We place the rack mount power supply in a small room adjacent to the cannabis cultivation facility and run two parallel busses above the two rows of lights.

If the lights are suspended from a structure such as aluminum Unistrut, we can use the Unistrut as a wire tray. We will discuss the sizing of the buss wire in another section.

The rack will need 8 RCP 2000 power supplies which will require three 19' modules this is about 4.5" of rack height. We might specify a rack mountable touch screen PC to be installed in the rack so that all the control and scheduling functions can be centralized in one spot.

This configuration is shown in figure 6

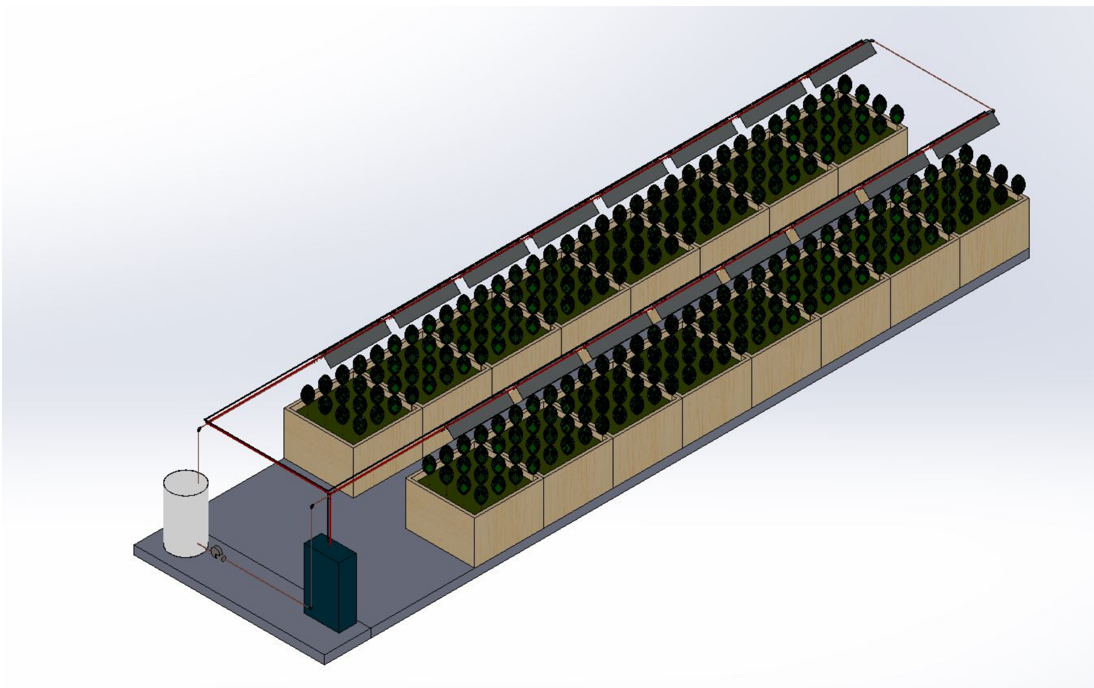


Figure 6. 16 kW system elevated view.

The cost estimate for this system is shown below in table 3.

Table 3. System Summary for a 16 kW R48K System

Lights: 16 ea. R48K-1000 LED grow lights

Power system: MeanWell RCP rack-mounted series
8 ea. RCP-2000 2 kW supplies
1 ea. RKP-1UT-CMU1 controller
2 ea. RKP-1UT rack

Cooling system: 16kW electric = 55,000 BTU/hr. total load
= 4.6 tons of refrigeration
60% of electric load is heat = 2.7 tons minimum

Cooling Tank 80 L.

Advantage M1-5A-RC chiller provides 5 tons
Dimensions: chiller - 40.5” x 35” x 56.5”
condenser - 60” x 45” x 70”

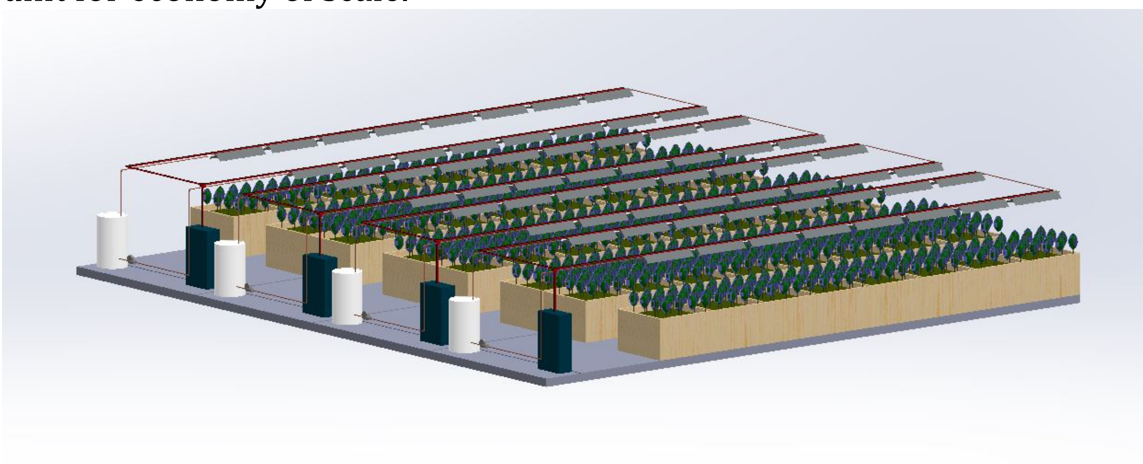
Costs:	16 ea. R48K-1000 @ $1300.00	$20,800.00
	8 ea. RCP-2000 @$364.00	$ 2,912.00
	2 ea. RKP-1UT @ $266.00	$ 532.00
	1 ea. RKP-1UT-CMU1 @ $360.00	$ 360.00
	1 ea. M1-5A-RC	$12,775.00
	Total	$37,379.00

System cost $2.34/ watt or $1.30/micromole/sec.

For a floor area of 100 sq. meters = 320 micromoles/m^2/sec
For a floor area of 30 sq. meters = 1066 micromoles/m^2/sec

Appendix B. Design of a 64 kW system

Here we summarize design parameters for a 64 kW system. We choose an 8 x 8 bed layout with 4' x 4' beds. The lighting and power systems are basically four replicas of the 16 kW system. This allows the independent control of four sets of 16 lights through four RKP-1UT-CMU1 units. We size the chiller to handle the entire load from a single unit for economy of scale.



Fibure 7. 64 kW system illustration

Table 4. System Summary for a 64 kW R48K System

Lights: 64 ea. R48K-1000 LED grow lights

Power system: MeanWell RCP rack-mounted series
32 ea. RCP-2000 2 kW supplies
4 ea. RKP-1UT-CMU1 controller
8 ea. RKP-1UT rack

Cooling system: 64kW electric = 218,000 BTU/hr. total load
= 18 tons of refrigeration
60% of electric load is heat = 11 tons minimum

Coolant Tank 400 L.

Advantage M1D-15A-RC chiller provides 15 tons
Dimensions: chiller - 58" x 35" x 77"
Condenser - 60" x 45" x 125"

Costs:	64 ea. R48K-100 @ $1100.00	$ 70,400.00
	32 ea. RCP-2000 @$330.00	$ 10,560.00
	8 ea. RKP-1UT @ $250.00	$ 2,000.00
	4 ea. RKP-1UT-CMU1 @ $360.00	$ 1,440.00
	1 ea. M1D-15A-RC	$ 22,250.00
	Total	$106,650.00

System cost $1.67/ watt or $0.93/micromole/sec.

For a floor area of 400 sq. meters = 320 micromoles/m^2/sec
For a floor area of 100 sq. meters = 1280 micromoles/m^2/sec

Figure 8. 64 kW system elevated view

Appendix C. Power supply companies.

As mentioned in the main body, any 48 VDC power supply that provides reasonable well regulated voltage at the required currents can be used.

The system is well suited to cogeneration using generators. The circuits in the light fixtures are provided with current limiting controllers that will compensate for brief voltage excursions. However long term excursions above 48 VDC will cause these circuits to overheat and self destruct. This condition is easily detected and will result in a warranty cancellation.

We strongly recommend rack mounted 48 VDC power supplies. These supplies provide power at roughly $.25/watt and are produced in commodity quantities for the telecommunication and computer server farm community. Two of the major manufacturers of these types of supplies are:

1. MeanWell   http://www.meanwellusa.com/about.aspx

2. TDK Lambda   http://us.tdk-lambda.com/lp/

Other providers include General Electric

We include the first page of the specification sheet for the MeanWell RCP-2000 and the TDK-Lambda HFE2500 here for reference. The other components for the system including rack mounts and controller are available on the web site.

Major distributors for MeanWell include TRC Electronics (http://www.trcelectronics.com) on the east coast and Bravo Electro Components (www.bravoelectro.com) on the west coast.

TDK Lambda is carried by all the major electronics component houses (Avnet, DigiKey, Mouser, etc)

2000W Rack Mountable Front End Rectifier

RCP-2000 series

Dimension						
L	*	W	*	H		
295	*	127	*	41	(1U)	mm
11.6	*	5	*	1.61	(1U)	inch

Features

- Universal AC input / Full range
  (Withstand 300VAC surge input for 5 seconds)
- Built-in active PFC function
- High efficiency up to 92%
- Forced air cooling by built-in DC fan
- Output voltage programmable
- Built-in OR-ing FET, support hot swap (hot plug)
- Active current sharing up to 6000W for one 19″ rack shelf
- Built-in I^2C interface, PMBus protocol
- Protections: Short circuit / Overload / Over voltage / Over temperature
- Optional conformal coating
- 5 years warranty

Certificates

- Safety: UL/EN/IEC 60950-1
- EMC: EN 55022 / 55024

Applications

- Industrial automation
- Distributed power architecture system
- Wireless/telecommunication solution
- Redundant power system
- Electric vehicle charger system
- Constant current source system

Description

RCP-2000 is a 2KW single output rack mountable front end AC/DC power supply with a 1U low profile and a high power density up to 25W/inch^3. This series operates for 90~264VAC input voltage and offers the models with the DC output mostly demanded from the industry. Each model is cooled by the built-in DC fan with fan speed control, working for the temperature up to 70℃. RCP-2000 provides vast design flexibility by equipping various built-in functions such as the PMBus communication protocol, output programming, active current sharing (up to 18000W via three 19″ rack shelves, RKP-1U), remote control, auxiliary power, alarm signal, external control/monitor via the control model RCP-CMU-1, etc.

Model Encoding / Order Information

RCP - 2000 - 24

- 24: Output voltage
- 2000: Output wattage
- RCP: Series name

※ Note 1: 19" rack shelf, RKP-1U, available. Details available on http://www.meanwell.com/
※ Note 2: Control/Monitor unit, RCP-CMU-1, available. Details available on http://www.meanwell.com/

TDK·Lambda

HFE2500 Series

2500W 1U Front End Power Supplies

Features

- ◆ 1U rackmount containing up to 4 units
- ◆ Internal ORing MOSFET & Current Share
- ◆ High Efficiency
- ◆ Up to 9,500W in 1U rack
- ◆ PMBus™(I^2C) and LAN options

Key Market Segments & Applications

Industrial COTS Test COMM Broadcast

(HFE2500-48 model)

Specifications

Model		
Input Voltage Range (2)	VAC	85 - 265VAC, 47 - 63Hz. See model selector for power derating
Input Current (Max) 100/230VAC	A	15 / 12A
Inrush Current	A	<50A
Power Factor Correction	-	Meets EN61000-3-2, PF > 0.98 at full load
Temperature Coefficient	%/°C	<0.02%/°C
Overcurrent Protection	%	105 - 115%
Overvoltage Protection (1)	%	110% (Tracking). Cycle AC to reset or utilize Remote On/Off
Overtemperature Protection (1)	-	Shutdown with automatic reset. Warning signal provided
Hold-up time	ms	>10ms, 115/230VAC Input, 80% loading
Leakage Current	mA	< 0.75 / 1.5mA, 100 / 230VAC, 60Hz
Remote Sense Compensation	-	HFE2500-12: 0.25V / Wire, HFE2500-24: 0.5V / Wire, HFE2500-48: 1V / Wire
Indicators	-	AC OK: Green LED, DC OK / Fail: Green / Red LED
Remote On/Off	-	Unit ON: 0 - 0.6V or short, OFF: 2 - 15V or open circuit
Parallel Operation (1)	-	Yes, single wire current share, 95% accuracy, up to 8 units
AC Fail Signal	-	Open Collector, ON when AC is within 85 - 270VAC
DC Good Signal	-	Open Collector, ON when output is above 85 to 95% of setpoint (tracking)
Remote Adjust (1)	-	By either external 0 - 5V signal or 1k potentiometer
I^2C Interface (1)	-	Isolated from output, Add suffix /S, PMBus compatible
Auxiliary Output	-	11.2 - 12.5V, 0.5A, 240mV ripple and noise
Operating Temperature	°C	-10 to +70°C, derate 2%/°C from 50 to 60°C, 2.5%/°C from 60 to 70°C
Storage Temperature	°C	-30 to +85°C
Humidity (Non condensing)	%RH	Operating: 10 - 90%RH, Storage: 10 - 95%RH
Cooling	-	Two variable speed internal fans, airflow exits across input/output connector (3)
Withstand Voltage	-	I/P to O/P 3kVAC, I/P to GND 2kVAC, O/P to GND: HFE2500-12, -24V 500VAC, HFE2500-48 1.5kVAC
Isolation Resistance	MΩ	>100MΩ at 25°C & 70%RH, Output to Ground 500VDC
Vibration (Basic transportation)	-	Meets IEC60068-2-64
Shock (Basic transportation)	-	Meets IEC60068-2-27
Safety Agency Certifications	-	UL60950-1, EN60950-1, CE Mark
Line Dip	-	Complies with SEMI F47 (200VAC line only)
Conducted and Radiated EMI	-	EN55032 & FCC part 15; Conducted class B, Radiated class A
Immunity	-	IEC61000-4-2 (lv 2,3), -3 (lv 2), -4 (lv 2), -5 (lv 3,4), -6 (lv 2), -8 (lv 4), -11
Size (W x H x D)	in	Power Supply: 4.21 x 1.61 x 12.8”, Rack: 17.5 x 1.72 x 15.8”
Weight	g	Power Supply: 2100g, Rack: 5000g
Warranty	yrs	Three Years

(1) See installation manual for detailed specifications & test methods
(2) Derate linearly 1.3%/V from 100VAC to 85VAC input
(3) Reverse air - contact factory

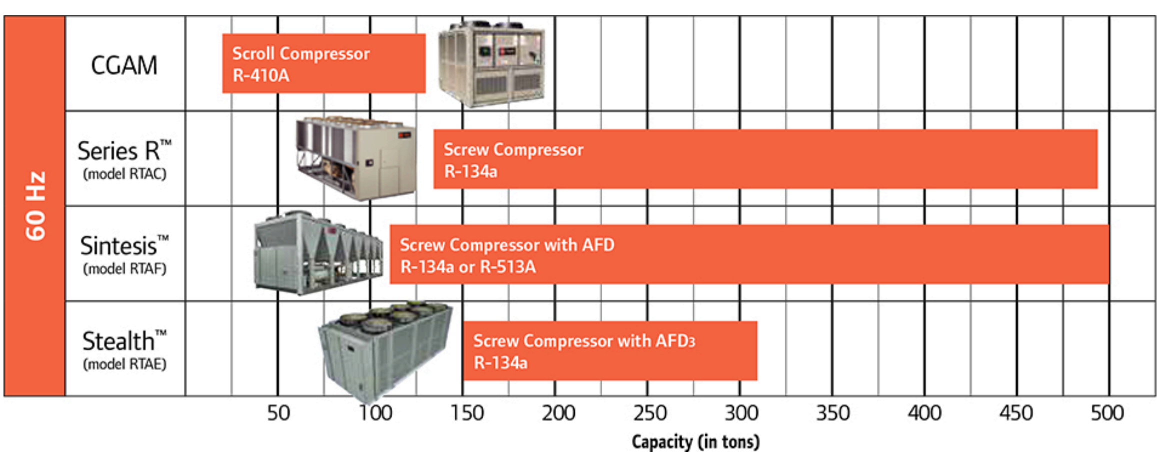
Appendix D. Cooler Companies

The market for water chillers is vertically segmented into three segments: large industrial, medium and small units. The large industrial market is served by a number of companies that manufacture units up to the thousands of tons in capacity. Two companies that manufacture air cooled water chillers up to 500 tons and that also serve the general HVAC markets are Trane and Carrier. The medium size units are typically under 60 tons and are served by a number of smaller companies such as Advantage, Fluid Chillers Inc. Econochill and Cold Shot. The small manufacturers such as EcoPlus, Active Aqua and Chill King make units for home brewing and wine production.

For most installations, chillers from the mid sized companies will be the best b. For large installation of 100,000 square feet and up, a large central chiller from one of the industrial companies is probably the best solution. The architect/engineering firm selected to oversee the installation would specify these units. Small chillers would be applicable to small installations of 4 t6 lights.

Big companies up to 500 tons.

Trane: www.trane.com



Carrier: www.carrier.com

Model	Type	Compressor Type	Refrigerant	Capacity Range, Tons	Capacity Range, kW
AQUASNAP® 30RAP 	Air-cooled	Scroll	R-410A	10 - 150 Std, 11 - 60 with Greenspeed Intelligence	35 - 528 Std, 35 - 200 with Greenspeed Intelligence
AQUASNAP® 30RB 	Air-cooled	Scroll	R-410A	60 - 390 Std, 80 - 390 with Greenspeed Intelligence	210 - 1370 Std, 270 - 1310 with Greenspeed Intelligence
AQUAFORCE® 30XA 	Air-cooled	Screw	R-134a	80 - 500 Std, 140 -350 with Greenspeed Intelligence	265 - 1740 Std, 490 - 1230 with Greenspeed Intelligence

Appendix E. Cannabis cultivation facility Heat loads

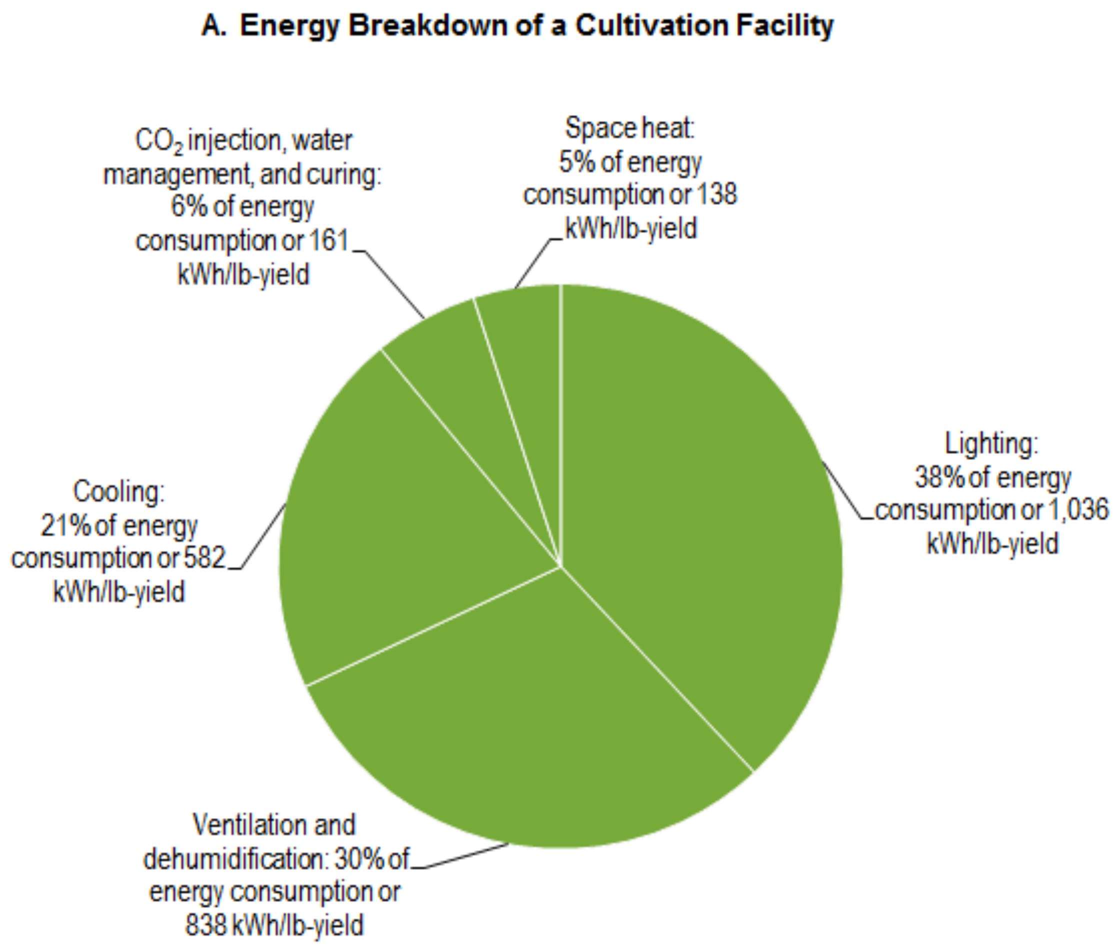
The heat loads for a cannabis cultivation facility consist principally of the grow lights, space conditioning and dehumidification. Figure A below indicates the energy expense of a typical cultivation facility. Note that this figure indicates energy usage in total. The lighting portion represents the electrical costs of operating the grow lights but does not account for the energy required to remove the waste heat. That is included in the cooling portion of the plot. For most lights about 60% of the input electrical energy is dissipated directly as heat in the fixture. The remaining 40% or the electrical energy is used to produce photons for crop growth. Ultimately these photons are converted to heat during the photosynthesis process. In essence then the total lighting power load ends up as heat in the cultivation facility and must be removed. Since the COP of most air to air HVAC systems is about 2.5 this means that the total energy costs for the lighting alone is about 45% of the energy load with a corresponding decrease of 8% of the cooling load for facility alone.

Dehumidification presents a similar situation. The energy costs reported are for operating a vapor compression based dehumidifier system. These systems typically have a reheat cycle that allows the dried air to be returned to the facility at approximately the same temperature as it was extracted at but with lowered humidity. For each pound of water removed then it is necessary to dissipate 1000 BTUs. This is important because the plants transpire most of the water taken up by their root systems so that essentially all of the water used to irrigate the plants ends up in the dehumidifier circuit.

Again the chart only shows the electrical costs of running the dehumidifier system. It does not include the costs of removing the heat from the cycle.

Typical cultivation facilities are constructed treating each system as a separate item. Lights are installed and typically dump their heat into the ambient air. Dehumidification systems are introduced in the same manner. Finally a conventional air to air HVAC is introduced on the roof to remove the heat from the interior air.

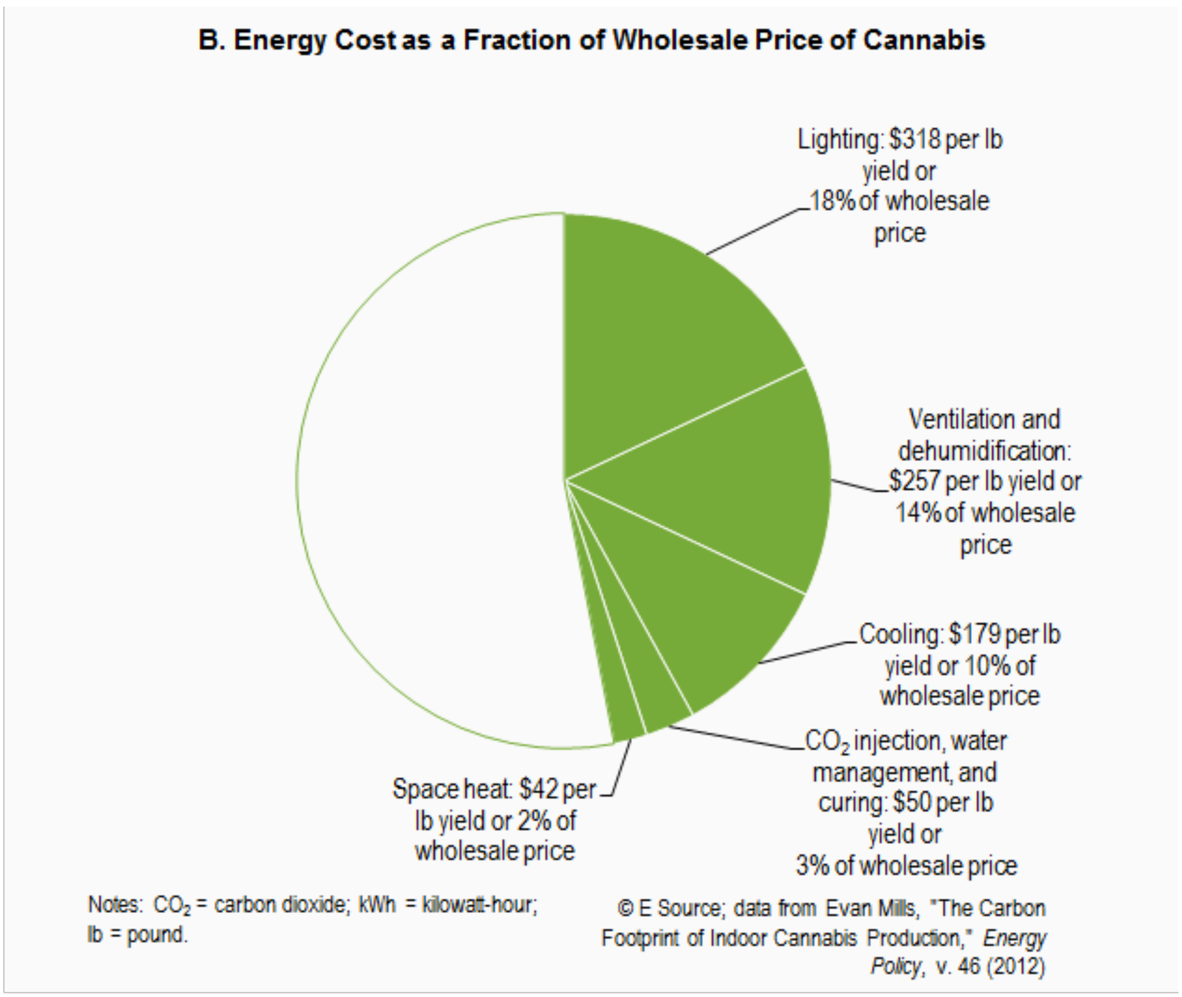
The ambient air inside a cultivation facility is a precious fluid. Its



temperature and humidity need to be precisely controlled for proper plant health. Humidity in particular is important to prevent growth of mold and other crop pests. These parameters need to be controlled throughout the daily cycle, not just when the lights are on. In addition, CO2 is often added to the ambient to improve growth rates and the air is often passed through a disinfecting unit.

So using the ambient air inside the cultivation facility as a heat dump makes very little sense from a systems standpoint. In addition these factors weigh heavily against just ventilating the air to remove the heat.

So how do all these factors hit the bottom line for crop production? Figure B. below shows the cost impact on the wholesale price. Note that the hit for lighting will be approximately constant independent of how efficiently the waste heat is removed. However the dehumidification and cooling costs will be reduced substantially, perhaps as much as 40% by running a central chiller based control system for lighting, cooling and dehumidification. This represents a savings of up to 10% on the wholesale price from just doing a good job at overall system design.



Appendix F. Cooling System Configuration Options

Since one of the main benefits and concerns for these lights is the requirements for the liquid heat removal system, this appendix will spend some time looking at various ways one could configure a cooling system and what the benefits of each configuration are.

The cooling system can be as basic as a pump and a radiator or elaborate enough to use the waste heat and cooling loop to run a highly efficient integrated grow environment. The side benefit of these integrated systems is not only the obvious cost savings in capital expense and operating costs, but the fact that a facility designed to these standards would be a much more sustainable operation having a much lower power appetite, requiring much less water and placing into the environment less unwanted materials, be they fertigation waste dumps or obnoxious odors.

So we will start with the simplest system and work upwards in complexity. A basic choice to be made up front is where the waste heat will be dumped, either into the air or into a water body. The second choice to be made is to what degree of complexity in system configuration we are willing to put up with in order to use some or all of that heat we would normally be dumping to the envirinment.

One thing to be clear about up front is that you are going to have to remove the total electrical power that you put into the room (plus a penalty for what ever energy machines use in the scheme). That is basic physics called "Conservation of Energy". So for example if you have a 10 kW light system roughly 5 kW will show up as thermal heat and 5 kW will show up as humidity in the air (the leaves effectively boil water to stay cool). Of course this ratio will vary with plant mass but in any event you will have to remove some of the power put into the lights in the form of moisture with a dehumidification system.

For a brief discussion of economical ways to control environmental conditions with liquid-cooled lights see "**An Analysis of the Effects of Employing Split-Cycle Dehumidifiers and Water-Cooled Lights on HVAC System Requirements for Indoor Cultivation Facilities**"

I am going to present a few configurations and describe their benefits. The number of possible combinations of system components is large and I will only describe a few. I would encourage designers to look at whatever combination of cooling, dehumidification or HVAC is needed for your application and try a few combinations. It will become rapidly apparent which system will work for your particular situation. Sizing components is simple and there is a lot of professional help to be had for details.

So lets look at the simplest system dumping the heat from the lights to ambient air or water:

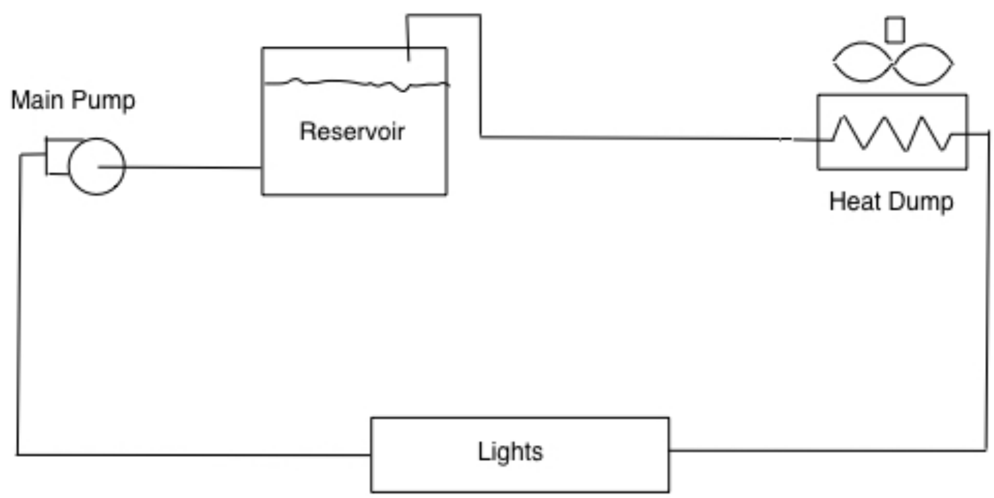


Figure 1. Basic cooling system with air dump.

Figure 1 shows a simple system with a pump circulating coolant through the lights to a fan-coil (think radiator), cooled by a fan. For this case the difference in temperature between the coolant and ambient air is 5-10 °C. This means if the ambient temperature is 40 °C, the lights will see coolant at 50 °C. The lights can handle temperatures much higher than this, but running them cooler generates more photons per watt and also extends the life of the LEDs.

Fan-coils come in many sizes. A common product that works well is made for the wood fired hoe heating market. An example is shown in Fig 1a. This unit is rated for 100,000 BTU/hr for the heating market. In this application the water temperature is about 80 deg C and the air temperature is about 25 deg C. for a temperature difference of 55 deg C. For our application the temperature difference between the coolant and air will be about 13 deg C. Since the heat transfer is proportional to the temperature difference we have to de-rate thecapacity by the ratio of the temperature ratios or about a 4:1 ratio yielding a net capacity for the heat exchanger of 25,000 BTU/hr.


Figure 1a. Typical fan coil

Just to clarify some terms here lets review the units that describe HVAC technology. The SI unit for power is the watt. In the English system it is BTU/hr. where a BTU is defined as the amount of energy required to raise one pound of water by 1 deg F. 1000 watts = 3414 BTU/hr.

In air conditioning, the unit is the Ton. This is a reference to the old days where refrigeration was done with ice and a Ton was the amount of refrigeration available if a ton of ice were melted in a 24 hour period. Since ice has a heat of fusion of 144 Btu/lb and a ton is 2000 pounds that equates to 12,000 BTU/hr. or about 3.5 kW.

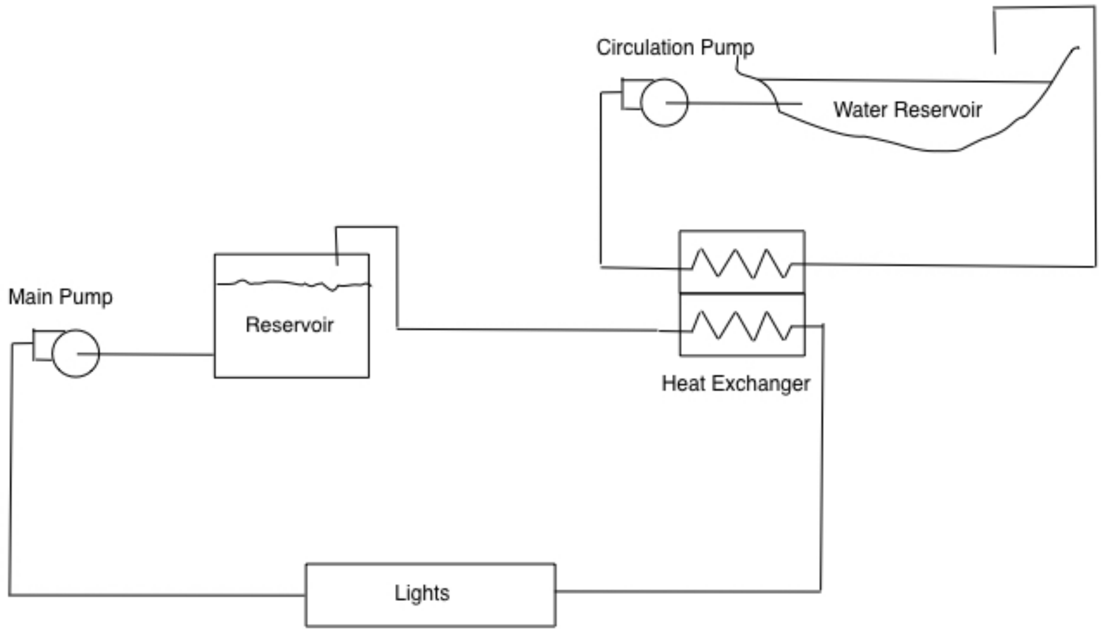


Figure 2. Basic cooling system with water dump.

Figure 2 shows a simple system with the coolant heat is dumped into a local water body such as a pond, lake, stream or swimming pool. The system looks similar to the first one except that a heat exchanger has been added to keep the glycol solution separate from the cooling water. Liquid to liquid heat exchangers are available in many forms but the simple flat plate heat exchanger is well suited to this applicaton. A typical plate heat exchanger is shown if figure 2a for reference. These units are much more compact than fan-coils.

This requires a pump and some plumbing in addition to the heat exchanger but the benefits are large. This is because the temperature of the heat dump stays constant and for wells taping into ground water, the temperature can be as low as 10 °C. This means that the lights will see 20 °C coolant which will mean higher light output and much longer life. Ponds and lakes rarely get above 20 °C

Figure 2a Typical plate type liquid heat exchanger

So the lights will run with 30 °C coolant if this water is used as the heat dump.

Even swimming pools, which are kept between 20 and 25 °C, would be beneficial. And the energy paid for in the grow room would be used for pool heating! (Evaporative cooling loss from the pool surface increases dramatically with pool temperature so the pool temperature will only slightly increase. There is some irony in that we are condensing water vapor in the grow room and then using that energy to evaporate pool water to balance the heat flux)

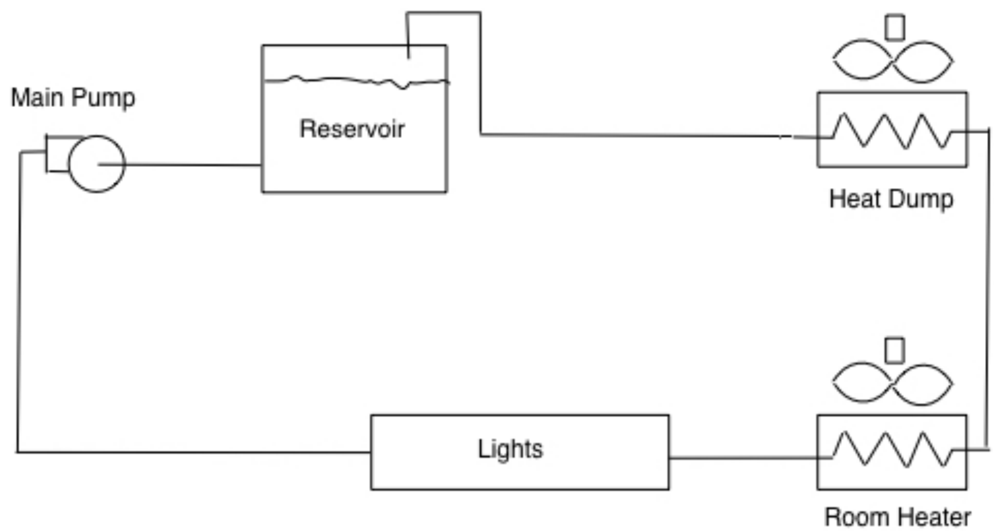


Figure 3. Basic cooling system with room heater.

Figure 3 shows a simple system in which some of the heat in the coolant loop is recovered and used for heating. (Air heating is shown but a little imagination will produce similar systems used to heat water). This system works best with the air-cooled system described above due to the higher temperatures of coolant in the loop. Heat could be used to heat offices, grow rooms, hot water heaters and more. The lights are happy to operate at elevated temperatures – they just put out fewer photons and will not live as long.

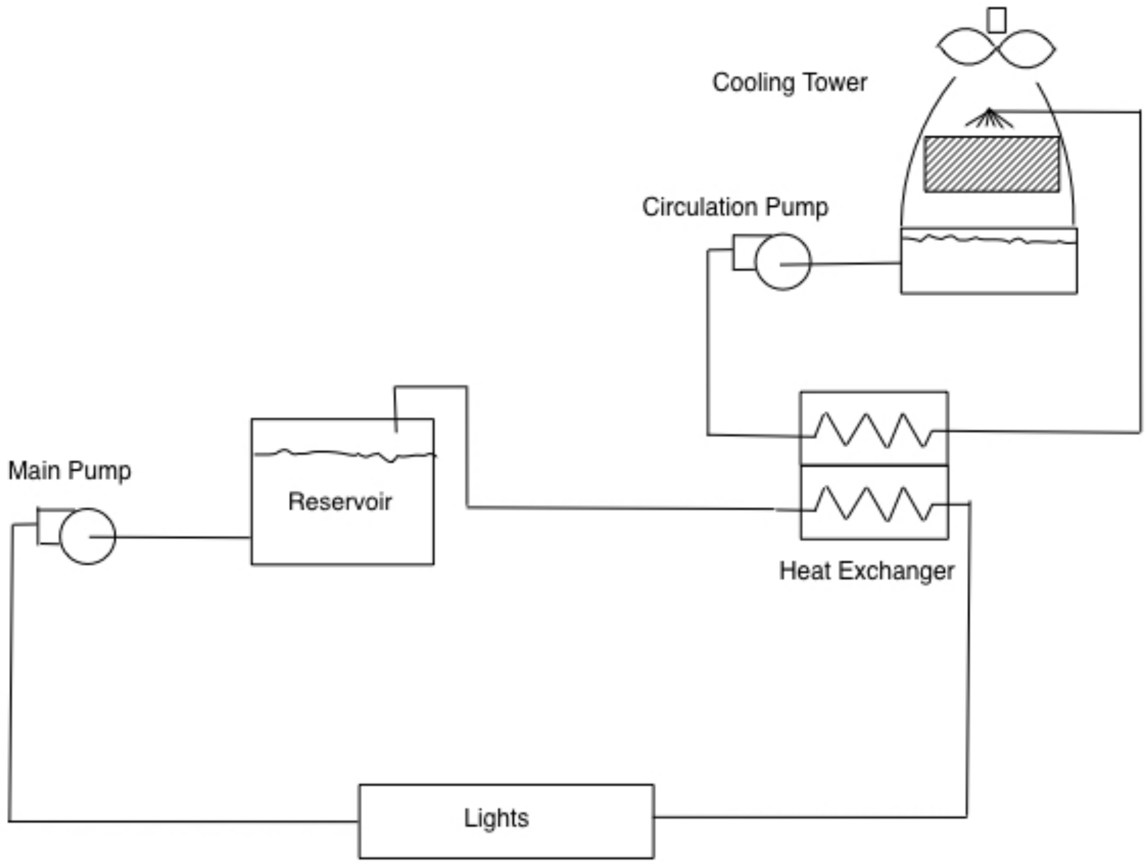


Figure 4. Basic cooling system using a cooling tower.

Figure 4 shows a simple system that dumps its heat to the air with the help of a cooling tower. In this system we require and additional pump loop to separate the glycol from the cooling tower water. This system is limited to reducing the temperature to 10 °C above the wet bulb temperature, often from 5 to 15 °C, giving a coolant temperature for the LEDs of 15-25 °C! Of course the cooling tower must be supplied with make up water as we (once again) evaporate water to remove heat using the heat removed from condensing water.

Figure 4a - Typical Cooling tower

Cooling towers are industrial units and the smallest units come in capacity levels of 5 tons and up. This would correspond to an installation with

18 kW of lights or more. A picture of a 5-ton cooling tower is shown in figure 4a.

One possible way to achieve the benefit of evaporative cooling without the need for a cooling tower is to mount misting spray heads upstream of the fan-coil in the very first system shown. This water will hit the fins on the fan coil and be evaporated by the airstream. The spray will be most effective at high ambient temperature (when it will be most needed) and can be controlled with solenoid valve triggered by high ambient temperature or high coolant temperature.

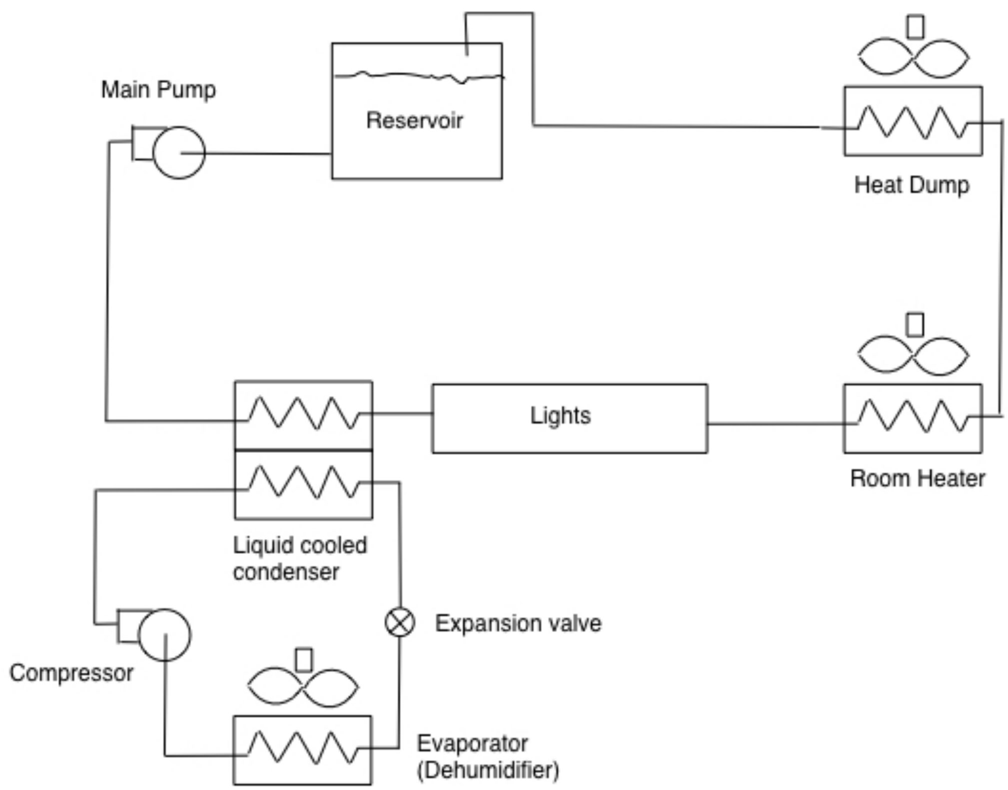


Figure 5. Standard integrated system

Figure 5 shows the first level of an integrated system in which we remove not only the direct heat from the lights but also the heat that ended up in moisture in the air. In this system we have added a dehumidifier driven by a direct vapor-compression system. This looks like a conventional refrigeration system but 1) on the evaporator side, the evaporation temperature is set to a level a few degrees than the desired wet bulb temperature and the fan speed is set on low to allow the air to cool to the dew point while passing through the coil and 2) on the condenser side the heat is dumped into the coolant loop to be dumped into the air ultimately.

A typical water-cooled condenser unit is shown in figure 5a. These units are available with a variety of refrigerants and capacities. Most are designed for low temperature operation and when using them in dehumidification it is important to choose one that operates at medium or high temperatures.

Figure 5a - Water-cooled condenser

Atypical evaporator unit for this type of application is shown in figure 5b. These units appear similar to plain fan coils but have a collection pan and drain for collecti9ng condensate. In addition the liquid side of the heat exchanger is often arranged with several parallel paths and provision for an expansion valve to be mounted in the unit.

Figure 5b - Typical evaporator

Also shown in the system of Figure 5. Is a room heater which could be placed in the grow environment. Unlike most dehumidifiers which dump their waste heat into the grow room (to be later removed by yet another vapor compression cycle (the AC) this system dumps the waste heat into the coolant loop. This means that the air exiting the dehumidifier is at the dew point and must be reheated to be in equilibrium with the ambient room temperature. This energy requirement is only a small portion of the heat being dumped and can be reclaimed with a small fan coil. The dehumidifier gets an air conditioning credit! This means that there is no need for a separate air conditioner! *Note that this only works with water-cooled lights.* Air cooled lights dump their heat into the grow room and it must be removed through AC.

Note also that the system shown in figure 5 will work with any type of heat dump discussed previously: water as in figure 3 or a cooling tower as in figure 4.

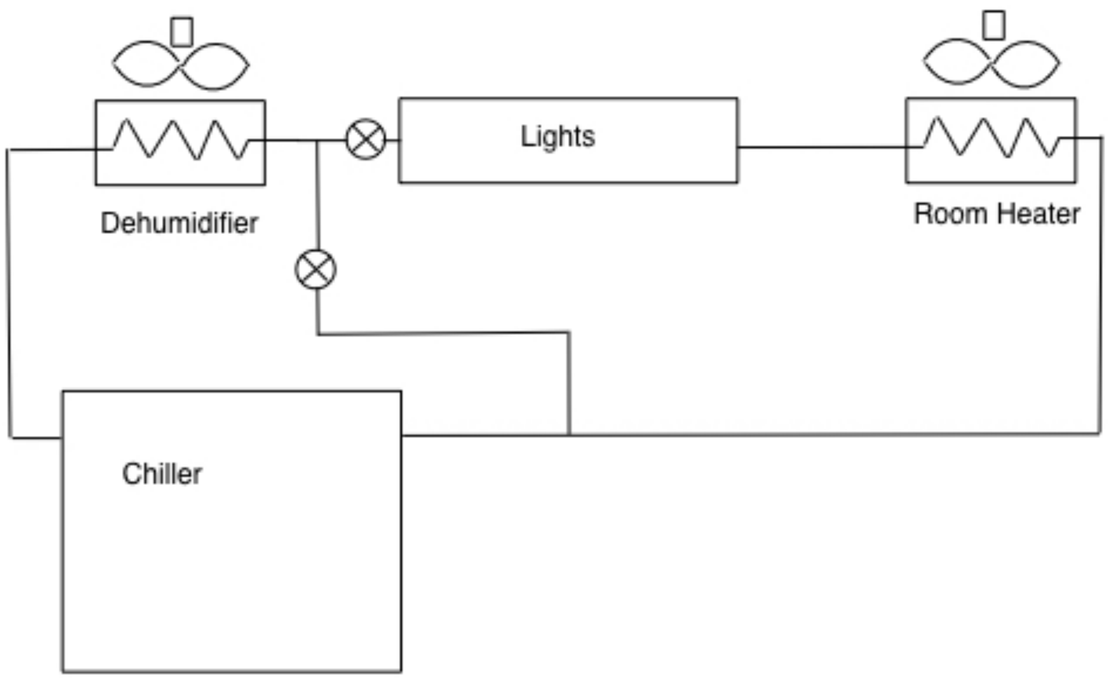


Figure 6. Integrated system using a liquid chiller.

In figure 6 we see a system that does not have a vapor-compression device in the cooling loop but rather uses a liquid chiller to circulate chilled glycol solution through the coolant loop. The temperature of the coolant in the chiller loop is set low enough to condense water vapor in the dehumidifier. That would probably be around 5-10 °C. By adjusting the flow rate through the lights we can make the coolant temperature at the exit of the light circuit high enough to drive a room heater. In this case most of the chiller flow leaving the dehumidifier returns to the chiller. Since the chiller extracts all the heat there in no need for a heat exchanger in the loop. However, the need to dump the heat ultimately remains and the chillers are basically large vapor-compression devices dumping their output to either air or liquid.

The advantage of this system configuration is that chillers are an industrial commodity and are available in sizes up to several hundred tons of capacity. This means that, for a large grow operation, a bank of chillers cooling a common reservoir can handle the total cooling load. This system has the advantage of redundancy and the capacity can be over specified by 10-20% to allow operation of the full system with the loss of one unit and partial cooling with 2 units out.

Figure 6a - 5 Ton Chiller

A typical chiller is shown in figure 6a.
This unit is a 5-ton capacity unit. In general large chillers sell for around $1000 per ton, but units less that 10 tons sell for closer to $2000/ton. These units contain a coolant reservoir, pump, full controls and a vapor-compression refrigeration unit.

Now it is apparent that there is an endless set of systems assembled from these basic components. Two things to remember are: 1. The lights will dump heat into a cooling fluid over a wide range of temperatures and 2. A dehumidifier system will have a substantial air conditioning credit due to the large amount of energy circulating within the system from moisture in the air generated by the plants absorbing the light energy.