A Comparative Energy Analysis of Liquid and Solid Desiccant Technologies in Indoor Cannabis Cultivation

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ABSTRACT

Liquid Desiccant Air Conditioning and Dehumidification (LDAC) has been emerging in the past 10 to 15 years as an energy-saving alternative design for applications that require high moisture removal and a Cleantech solution that has the potential to provide significant energy savings when applied to more broad markets. Buildings are the primary users of electricity in the U.S., consuming about 75% of the total electricity produced and about 40% of all U.S. primary energy use and associated greenhouse gas (GHG) emissions. A substantial portion of that energy is used for air conditioning and dehumidification. Furthermore, the U.S. Department of Energy (DOE) reports that U.S. buildings account for 35% of the U.S. carbon dioxide emissions that drive the climate crisis.

One specific application that requires significant moisture removal is the indoor cultivation of legal cannabis. It is estimated by the DOE that by the end of this decade, electrical energy usage by indoor cannabis operations will be on par with the electrical energy consumed by either data centers or for the recharging of electrical vehicles. More recent projections indicate cannabis sales are expected to double from 2021 to 2030. As such, more efficient and economical methods of climate control are necessary for more widespread application in cannabis operations to reduce the energy requirements. The added emphasis should be on methods to first reduce the energy required before building the electrical generating infrastructure to support such growing industries. Climate control of indoor cannabis cultivation is one such aspect where energy-efficient air conditioning and dehumidification can contribute to reducing the projected energy usage by end of this decade.

This paper gives an overview of a standalone LDAC system and a hybrid LDAC combined with an air handling unit. This paper will present indoor grow room case studies from a side-by-side installation of a hybrid LDAC unit and Desiccant Wheel (DW) air handling system in two identical cannabis grow rooms. Integration with a Combined Heat and Power (CHP or cogeneration) plant onsite supplying energy for both the technologies will be examined. Further, comparative energy analyses of LDAC, DW technology, and other widely used technologies in the HVAC indoor growing environment will be discussed. This will be the first comprehensive, side-by-side performance and energy analysis of competing desiccant (LDAC and DW) technologies in a controlled, indoor agriculture environment.

INTRODUCTION

Indoor cannabis growing operations are about ten times as energy intensive as a typical office building on a square-foot basis as it has a higher-intensity lighting load as well as a large moisture load from plant transpiration known as evapo-transpiration (Walton, 2019). This requires high-capacity HVAC equipment to create an ideal Indoor Plant Environment (IPE) for plants to grow.

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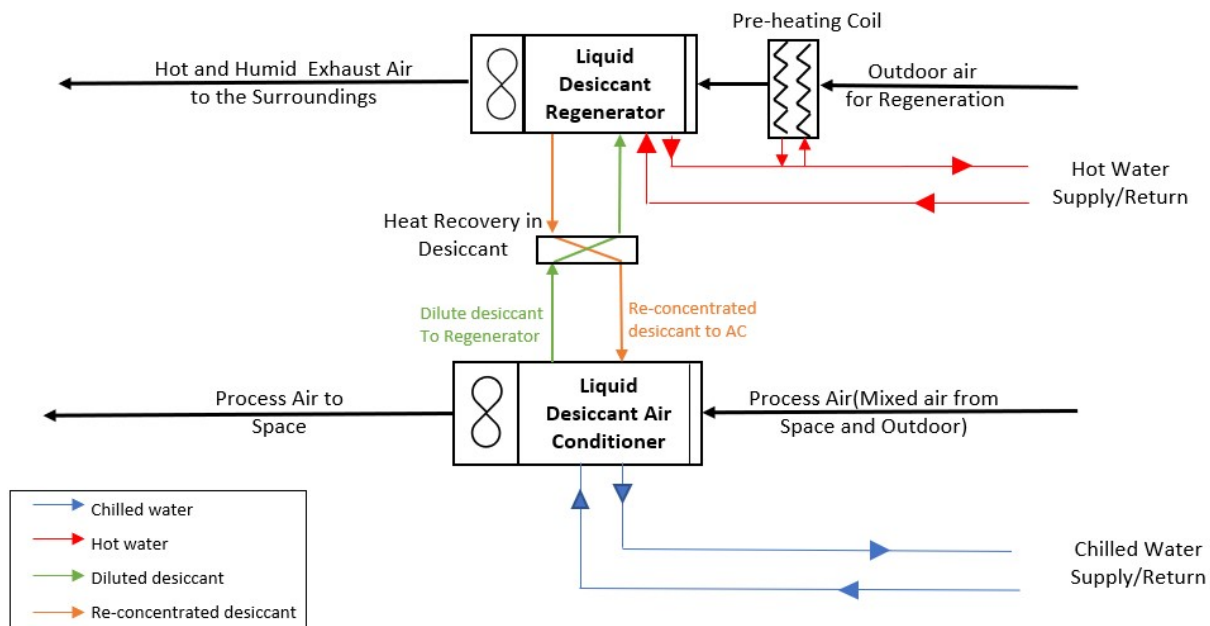
Figure 1 Liquid desiccant system (Mongar, 2018), (Mongar, 2020).

Liquid desiccant air conditioning (LDAC) technology has been gaining attention in the past few years with limited installations in the commercial sector. LDAC has been demonstrated to dehumidify effectively in applications where there is a high moisture load such as indoor agriculture, indoor recreation facilities, the pre-treatment of outdoor air for schools and office buildings, and many other applications. LDAC effectively dehumidifies as it simultaneously cools the air and absorbs moisture without lowering the air temperature down to the dew point to remove moisture and without subsequent reheat. Multiple studies related to LDAC and DW are explored in the review paper (Gao, Sun, Ma, & Ren, 2021). A Combined Heat and Power system (CHP or cogeneration) with a hybrid LDAC system is presented in this study and compared side by side with a solid desiccant wheel system (DW) installed in conjunction with the same CHP system and attached to two identical cannabis flower rooms.

A Combined Heat and Power (CHP) system has a significant energy efficiency advantage by generating electricity and a source of hot and chilled water simultaneously (Chicco & Mancarella, 2007). The thermal efficiency of a CHP system can be higher in winter due to the higher utilization of heat energy (Cao et al., 2021). LDAC and DW systems have an added advantage as the regeneration process utilizes heating all year round.

This paper will discuss and compare the performance of a hybrid LDAC system in an indoor cannabis grow application and a traditional DW system used in the same application on a side-by-side basis. An analytical approach to the energy consumption in terms of operating energy cost is presented for LDAC, a DW system, with and without a CHP system. Direct, continuous full-spectrum energy measurements obtained over several growing cycles using both the LDAC and the DW systems will be presented and compared to the pre-trial analytical analysis in future studies.

TECHNOLOGIES USED

Liquid Desiccant Air Conditioning System

The liquid desiccant air conditioner consists of a conditioner and a regenerator. In the conditioner, multiple stages of media that are wetted out with a chilled desiccant solution. Pumps are used to circulate chilled desiccant to

each stage through a plate heat exchanger, with desiccant on one side and chilled water on the other side at water less than 55 °F (12.8 °C). As the air flows across the media and makes a direct contact with the desiccant, the moisture is absorbed from the air and the heat of the reaction is offset by the chilled desiccant. The difference in the vapor pressure between the chilled desiccant and the entering hot and humid air is the driving force for the dehumidification to occur.

As the desiccant in the conditioner absorbs moisture, it becomes diluted. As system volumes increase, it is transferred to the regenerator for reconcentration. The identically designed, multiple-stage regenerator operates with a low-energy hot water source of 110 °F to 130 °F (43.3 °C to 54.4 °C) to heat the desiccant solution, which allows it to release the moisture absorbed by the conditioner into an exhaust air stream. This is decoupled from the process air being conditioned, often located outside the grow areas, and uses outside air. Pre-heating the outdoor air stream used for regeneration during winter may increase the regeneration effectiveness in the LDAC system. The heated desiccant releases moisture into the exhaust air stream and reconcentrates the desiccant which is then transferred back to the conditioner via a closed-loop piping system (shown in Figure 1). Desiccant solution energy recovery occurs in a dedicated liquid/liquid plate heat exchanger.

To decouple the sensible and latent loads, a chilled water AHU with hot water reheat is installed parallel to the standalone LDAC system to respond to the changing operating conditions in the grow rooms during different growing stages, and day and nighttime scenarios with lights on and off. The heating coil size is small compared to a standalone AHU as the hybrid LDAC can meet higher moisture loads *without* overcooling.

The four-pipe CHP system supplies hot and cold water to LDAC and AHU. Hot water is circulated to the regenerator, the pre-heating coils used for the regenerator, and the reheat coil in AHU. Chilled water is supplied to both the LDAC system and the AHU. The balance between the AHU and LDAC systems will be automatically adjusted and re-directed based on the room conditions. For example, if humidity conditions are met but additional cooling is required, LDAC operations will be reduced, and AHU operations will be increased.
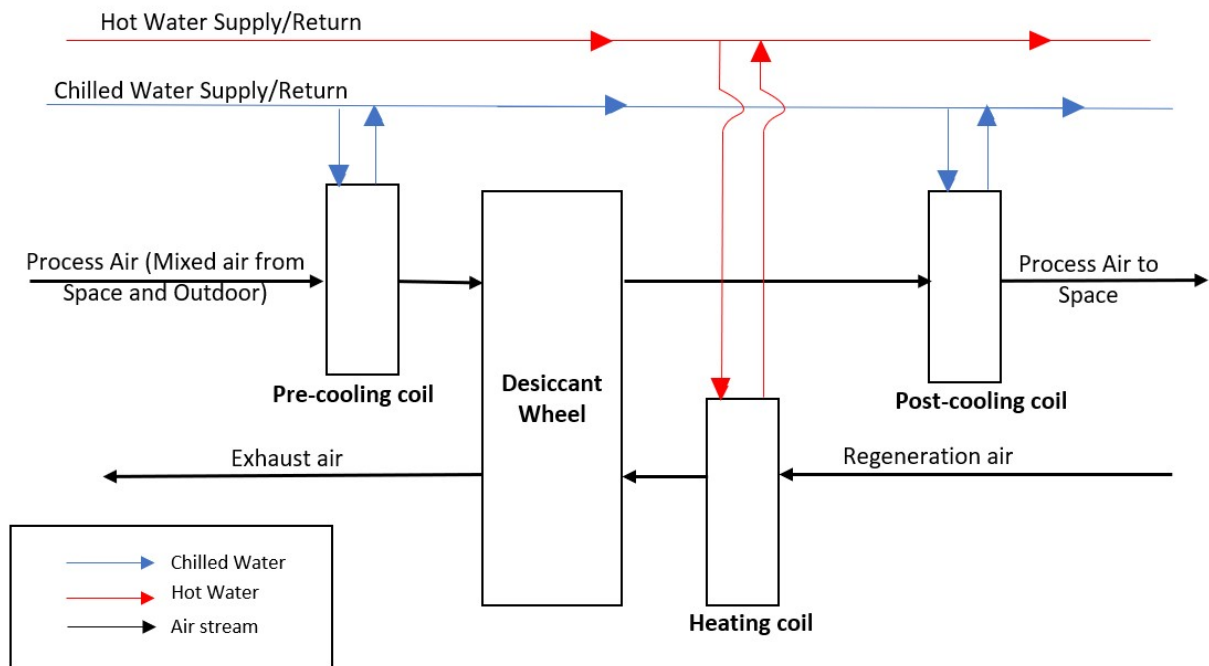

Figure 2 Desiccant Wheel System.

Desiccant Wheel System

The liquid desiccant system will be compared to an air handler that contains an active silica gel desiccant dehumidification rotor for moisture removal, which uses a source of heat to reactivate the wheel. The rotor itself is separated into two airstreams (supply and return), and it moves at a very slow speed as the supply and return air streams pass through the wheel in counterflow directions. This allows the moisture from the supply air side to be adsorbed within the pores of the silica gel desiccant, which is embedded into the corrugated fiberglass media of the rotor. As the wheel rotates to the return air section of the air handler, the moisture within the desiccant pores must be removed from the desiccant wheel by using a heat source to raise the temperature of the air to 170°F or higher so the water vapor can be released back into the air. Solid desiccant wheel systems require far more heat energy for satisfactory regeneration, and for this specific study, the CHP-supplied hot water will be the source of the wheel regeneration energy required. The DW system requires a chilled water pre-cooling coil to cool the air to allow the desiccant wheel to perform, and a chilled water post-cooling coil to offset the heat of reaction in the desiccant wheel to meet the grow room latent and sensible loads.

GROW PROCESS AND RESEARCH FACILITY

Two identical 2,100 sq. ft. flower rooms at the medical cannabis cultivation and research facility are selected for this side-by-side testing with these two different technologies. The two flower rooms are selected in such a way that they have the same envelope loads, plant counts, and watering rates to aid in the evaluation of both the performance and energy use of the air conditioning technologies. It is critical to maintain the right temperature and humidity in the rooms without which the quality of the plant will be affected. The vapor pressure deficit in the room plays a major role in allowing the plants to transpire effectively and promotes efficient plant growth. As the watering rates change and the lights are either on or off, the sensible and latent loads in the room change respectively (McGowan, 2020).

Each system has hot and cold-water supply lines from the CHP system that are monitored by multiple energy meters and consolidated into continuous, real-time comparative analytics which will be presented in future studies once the grow rooms are operational. The CHP system consists of cogeneration units with backup boilers, and high-efficiency magnetic bearing electric chillers. There are also closed-circuit cooling towers with associated pumping systems installed.

The initial and base capital costs of both the LDAC and DW systems were comparable and within 10% of each other. The installation costs associated with each are not known, but also assumed to be comparable, as each system was tied into the same 4-pipe CHP system. As a result, these two technologies are considered to be of equal cost, and therefore, our focus will be on analyzing the operating costs of each technology.

ANALYTICAL RESULTS

Comparison of LDAC and DW

In this section, the LDAC and DW systems designed for these identical cannabis rooms are used as the basis to perform an analytical comparison of thermal energy usage, electrical energy usage, and operating costs. The peak or worst-case room conditions used for sizing the equipment are considered in this analysis to represent operating costs. See Table 1.

Gross cooling represents the total cooling energy utilized by the technologies. It includes cooling for the heat generated due to the fan, and the heat of reaction in the desiccant dehumidification process. As shown below, the DW system requires 8% more gross cooling to provide the same latent load as the LDAC.

Table 1. Design Conditions

Parameter	Value
Room Temperature, °F (°C)	70.0 (21.2)
Room Relative Humidity, %	45.0%
Sensible cooling load, MBH (kW)	350.0 (102.6)
Latent cooling load, MBH (kW)	197.2 (57.8)
Total cooling load, MBH (kW)	547.2 (160.4)
Room Sensible Heat Ratio, %	64.0%
Cold water supply, °F (°C)	42.0 (5.5)
Hot water supply, °F (°C)	180.0 (82.2)

Cooling energy efficiency (kW/ton) is the amount of electrical energy used by the LDAC system and the AHU to meet both the latent and sensible loads. Components used in estimating the electrical energy include the high-efficiency magnetic bearing central chiller, condenser fan, water circulating pumps, HVAC fans, mag-drive pumps for the liquid desiccant system, and the fan motor for the desiccant wheel. The relatively small amount of power drawn by the control system and sensors is neglected in this analysis.

Table 2. Total Energy and Cost comparison of LDAC and DW HVAC system for Identical Cannabis Flower Room.

Technology	Liquid Desiccant Air Conditioner	Desiccant Wheel System
Design sensible load, MBH (kW)	350.0 (102.6)	350.0 (102.6)
Design latent load, MBH (kW)	197.2 (57.8)	197.2 (57.7)
Sensible Heat Ratio, %	64.0%	64.0%
Net sensible cooling load, MBH (kW)	346.0 (101.4)	350.0 (102.6)
Net latent cooling load, MBH (kW)	198.2 (58.1)	196.7 (57.6)
Net total cooling load, MBH (kW)	544.1 (159.5)	546.7 (160.2)
Gross total cooling load, MBH (kW)	582.8 (170.8)	770.1 (225.7)
Equipment SHR (%)	63.6%	64.0%
Reheat, MBH (kW)	0.0 (0.0)	0.0 (0.0)
Cooling energy efficiency, kW/ton (COP)	0.523 (6.7)	0.491 (7.2)
Electrical energy used, MBH (kW)	86.7 (25.4)	87.7 (25.7)
Cooling cost ($/hr)	$1.96	$2.43
Regeneration, MBH (kW)	110.6 (32.4)	564.7 (165.5)
Regenerator pre-heat, MBH (kW)	48.7 (14.3)	0.0 (0.0)
Gas efficiency	0.8	0.8
Gas energy input, MBH (kW)	199.1 (58.4)	705.9 (206.9)
Heating cost ($/hr)	$2.33	$8.25
Total cost per hour ($/hr)	$4.28	$10.23
FLTH/day	15	15
Total cost per day	$64.27	$160.18

CHP heat energy is utilized for regeneration in LDAC and DW as well as pre-heating in the LDAC regeneration process. The DW system requires 80% more energy for regeneration. The reheat required by the room when at design conditions is zero for both the LDAC and DW systems. Note that grow room sizing requires reheat during nighttime or lights-off conditions and at different growing stages, which are considered while sizing the units (McGowan, 2020). The LDAC and DW systems are equipped with a reheat coil for the period when the lights are off (the sensible load is reduced almost entirely, and the evapotranspiration cooling still exists) and other scenarios. Reheat energy analysis including different room load cases is outside of the scope of this first analysis but will also be included in future experimental results throughout a grow cycle.

The total operating energy cost of the DW system is analyzed to be more than double the LDAC system (see Table 2). Total estimated daily costs are $160.18 for the DW system and $64.27 for the LDAC system with CHP, a difference of 60%. Full-load ton hours (FLTH) are considered for a single day period as the grow room load changes over the cycle and year. On-site experimental test results will provide guidance to determine a proper FLTH/yr. value for this cannabis flower room for future studies. Based on the 12-hour lights on and 12-hour lights off cycle, the grow room has maximum cooling and dehumidification requirements during daytime (lights on) but there is still some amount of dehumidification that takes place during the nighttime (lights off). Hence, 15 hours is considered equivalent to FLTH/day for the current study.

CHP electric cost value of $0.077/kWh is considered (*Combined Heat and Power for Cannabis Cultivation*, 2022). Liquid Natural Gas (LNG) will be used in the CHP system to generate electricity and heat energy which is supplied for LDAC and DW systems. The rolling average cost of LNG is $11.36/MMBTU from the U.S. Energy Information Administration database for the year 2022 is considered (U.S. Energy Information Administration, 2022).
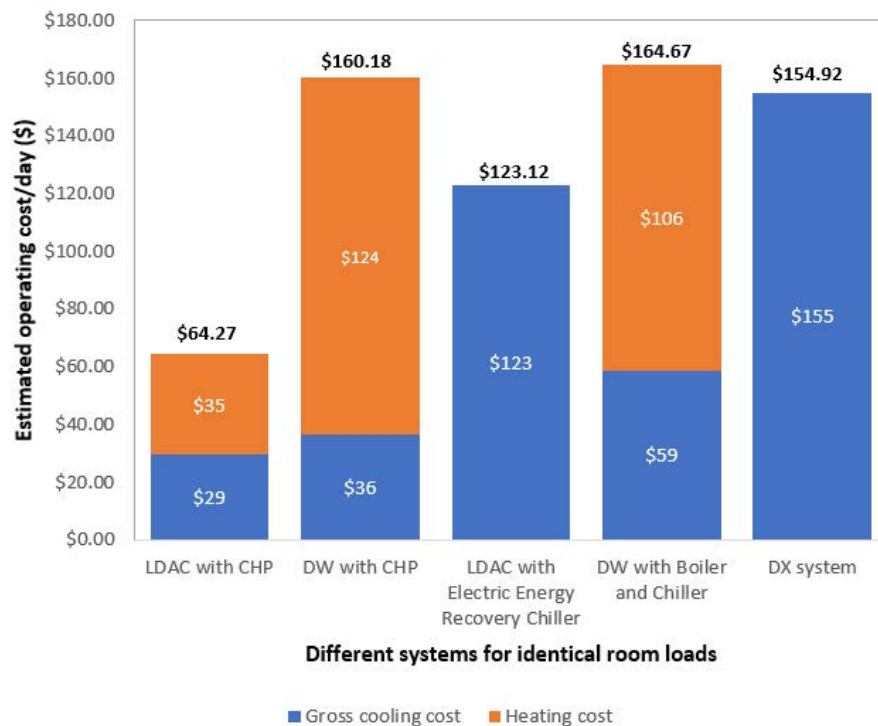
Figure 3 Estimated operating cost per day in Cannabis Flower Room for LDAC and DW systems with and without CHP; standalone DX solution is presented for comparison.

Similar to the operating cost per day presented in Table 2, LDAC and DW operating cost without CHP is estimated and compared to DX (Direct Expansion) type vapor compression system in Figure 3 for the flower room with similar design conditions. The DX system is modeled with free reheat (hot gas reheat). A baseline gas cost of $10.00/MMBTU and a baseline electric cost of $0.12/kWh is considered for the projected cost shown in Figure 3. Note that this value varies by U.S. region and across global markets.

The DW technology operating cost is calculated to be $164.67 per day without CHP and $160.18 per day with CHP. The operating energy cost estimate of the DX system is $154.92 per day for identical room design conditions. The LDAC system with CHP is nearly 60% less at $64.27 per day compared to the DW system with CHP. The LDAC system with an electric energy recovery chiller has an estimated $123.12 per day operating cost, which is nearly 25% lower compared to DW without CHP. Studying the real operating energy cost once the grow rooms start operating will give a much more comprehensive perspective on the energy analysis compared to the analytical data based on the design conditions.

CONCLUSION AND FUTURE WORK

The operating cost of a cannabis flower room based on the design conditions and from analytical data has shown higher operating energy costs for desiccant wheel (DW) systems with ($160.18 per day) and without CHP ($164.67 per day) when compared to liquid desiccant air conditioning system (LDAC) and DX. The liquid desiccant system when compared to the DW system with CHP has a 60% lower operating cost per day ($64.27 per day) and a 25% lower operating cost ($123.12 per day) without CHP.

Taking into account various room load scenarios with the number of plants and the light intensity, a standalone DX may not be suitable without supplementary dehumidification requirements to avoid excess reheat. The desiccant systems often do not require running at full capacity during various stages of plant growth. The analysis presented in this paper will be a helpful tool to observe the extent to which the designed HVAC system is utilized during real-time operations of the cannabis flower rooms. This can give insights into the selection of the HVAC system and the operating energy costs in the ever-growing indoor cannabis market. Once the site is fully operational, direct measurements of energy use of the LDAC and DW installed on site will give more insight into their overall operational cost for each day and throughout a full growth cycle.

The data shows that LDAC paired with CHP offers the highest energy savings and can work directly to solve the energy challenges faced by indoor cannabis cultivation industry. The LDAC system also requires less CHP capacity, which will allow for future expansion without additional investment, or a reduction of the initial CHP capacity. It will also reduce the overall energy consumption which directly correlates to reducing the carbon footprint, as well as reducing greenhouse gas emissions.

ACKNOWLEDGMENTS

REFERENCES

Andrew Mongar. (2018). Air conditioning method using a staged process using a liquid desiccant (U.S. Patent 9,982,901).U.S. Patent and Trademark Office. https://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&p=1&u=/netahtml/PTO/srchnum.html&r=1&f=G&l=50&d=PALL&s1=9 982901.PN.

Andrew Mongar. (2020). Air conditioning method using a staged process using a liquid desiccant (U.S. Patent 10,823,436). U.S. Patent and Trademark Office. https://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&p=1&u=/netahtml/PTO/srchnum.html&r=1&f=G&l=50&d=PALL&s1=1 0823436.PN.

Cao, Y., Dhahad, H. A., Togun, H., Abdollahi Haghghi, M., Anqi, A. E., Farouk, N., & Rosen, M. A. (2021). Seasonal design and multi-objective optimization of a novel biogas-fueled cogeneration application. *International Journal of Hydrogen Energy*, *46*(42), 21822–21843. https://doi.org/10.1016/j.ijhydene.2021.04.044

Chicco, G., & Mancarella, P. (2007). Trigeneration primary energy saving evaluation for energy planning and policy development. *Energy Policy*, *35*(12), 6132–6144. https://doi.org/10.1016/j.enpol.2007.07.016

Gao, D. C., Sun, Y. J., Ma, Z., & Ren, H. (2021). A review on integration and design of desiccant air-conditioning systems for overall performance improvements. *Renewable and Sustainable Energy Reviews*, *141*(February). https://doi.org/10.1016/j.rser.2021.110809

McGowan, M. K. (2020). Load calculations for cannabis grow facilities. *ASHRAE Journal*, *62*(4), 83–87.

Walton, R. (2019, May 1). *Marijuana prices have collapsed, forcing growers to focus on energy efficiency*. Utility Dive. https://www.utilitydive.com/news/marijuana-prices-have-collapsed-forcing-growers-to-focus-on-energy-efficie/553287/

Combined Heat and Power for Cannabis Cultivation. (2022, April 21). Greater Philadelphia Chapter Association of Energy Engineers. https://gpaee.org/meetinginfo.php?id=138&ts=1650643238