THE ENERGY INTENSITY OF LIGHTING USED FOR THE PRODUCTION OF RECREATIONAL CANNABIS IN WASHINGTON STATE AND IMPLICATIONS FOR ENERGY EFFICIENCY

by

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ABSTRACT

The Energy Intensity of Lighting Used for the Production of Recreational Cannabis in Washington State and Implications for Energy Efficiency

Sarah L. Sweet

In November 2012, Washington State voters passed Initiative 502 (Initiative Measure no. 502, 2012), which legalized recreational use of cannabis by adults and created a framework for its production. Due to the need for artificial light and environmental controls, however, commercial cannabis grown indoors suffers from chronically high energy demand. Lighting alone accounts for up to 86% of the total electricity use (Arnold, 2013; Jourabchi, 2014 and Mills, 2012). Based on these numbers, it appears lighting used by indoor cannabis producers would provide the most pertinent data in regards opportunities for energy efficiency. Energy efficiency has significance not only in meeting ever increasing electrical load demands (Northwest Power and Conservation Council, 2015), but also as a requirement of The Energy Independence Act (I-937) which requires the state's largest utilities which provide 81% of the state's electricity to date to attain all "cost effective" energy efficiency (Energy Independence Act, I-937, 2006). To help address energy consumption and potential energy efficiency within this industry, this thesis examines data collected voluntarily from licensed recreational cannabis producers in Washington State regarding their usage of agricultural lighting. The producers surveyed reported using a variety of lighting types other than HIDs and density of fixture placement over cannabis plants. These results contradict existing literature which estimates energy consumption baselines for cannabis production based on the usage of only HID lamps and a standard fixture density. The finding of this thesis show a standard baseline may not be appropriate for the recreational cannabis industry and that approaches to energy efficiency will need to be individualized for each producer. Due to the diversity of the commercial cannabis industry, there will need to be a coordinated effort between policy makers, utilities and cannabis producers to use energy more wisely in this burgeoning industry.

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LIST OF ACRONYMS

aMW- Average Megawatt

CFL- Compact Fluorescent

EE-Energy Efficiency

EUI- Energy Use Intensity

LED- Light Emitting Diode

MH- Metal Halide

NWPCC-Northwest Power and Conservation Council

PAR- Photosynthetically active radiation

PSE-Puget Sound Energy

HID- High Intensity Discharge

HPS-High Pressure Sodium

kWh- Kilowatt hour

THC- Tetrahydrocannabinol

WSIA-Washington Sungrowers Industry Association

WSLCB- Washington State Liquor and Cannabis Board

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CH. 1 INTRODUCTION

1.1 BACKGROUND

In November 2012, voters in Washington State passed Initiative 502 (Initiative Measure no. 502, 2012), which decriminalized recreational use of cannabis (commonly referred to as “marijuana”) by adults and created a framework for commercial cannabis cultivation within Washington State. Use of cannabis for recreational purposes in this context can be understood as the “voluntary ingestion for personal pleasure or satisfaction, unrelated to any medical condition” (Warren, 2015 p. 394). Small-scale legal cultivation of cannabis for medical use had been active prior to I-502, but increased demand from recreational users necessitates larger operations (Washington State Institute for Public Policy, 2015).

Indoor cannabis production has purportedly been the most popular method among cannabis producers for reasons that will be discussed in the next chapter. Large scale or small, indoor cultivation can be complex. Elaborate ventilation and environmental controls to adjust heat and humidity must be installed to create the optimal environment for the cannabis plants. Precise mixes of water and nutrients must also be delivered to each plant at the right time. Finally, agriculturally-appropriate lamps producing the correct spectrums of light must be used for a certain number of hours per day to induce either vegetative growth or flowering (Mills, 2012).

1.2 RESEARCH PROBLEM

The Washington State Liquor and Cannabis Control Board regulates licensing for cannabis growers. At the time of this writing, the Board does include environmental regulations relating to air and water quality in the licensing process, but offers no guidelines or limitations for energy usage associated with cannabis cultivation. The lack of energy guidelines should be concerning, because cultivating cannabis indoors requires massive amounts of electricity, mainly due to the need for specialized lighting and climate control equipment (Mills, 2012). Very little research has been conducted on the actual energy consumption of cannabis production due to its prior history as an illicit activity, which has made data about growers fairly inaccessible (Washington State Institute for Public Policy, 2015). The ambiguity surrounding illicit cannabis operations resulted in a hidden variable for historic electrical load, and has prevented electrical demand driven by these activities from being accurately gauged in forecasts. The commercial cannabis industry may have significant influence on energy demands.

Passed in 2006, I-937 requires the state's 17 largest utilities to obtain at least 15% of their supply portfolio from renewable resources by 2020 (Energy Independence Act, I-937, 2006). These utilities must also pursue "all cost-effective energy conservation;" they must participate in energy conservation programs to decrease demand and lower costs for their customers. The cost of conservation programs must not exceed the price of the energy they offset (Energy Independence Act, I-937, 2006, pp. 2-4). Energy conservation programs offered by each utility differ due to the unique makeup of their power portfolios and the customers they serve. Each service territory also varies and may include a mix of residential, commercial and/or industrial customers, each with distinctive energy needs and conservation opportunities.

Each utility must prepare a biennial Conservation Potential Assessment to identify "achievable opportunities" in conservation (Energy Independence Act, I-937, 2006, pp. 4-5). The assessment takes into account the unique makeup of a utility's customers and their historic electricity usage, which will then be used to make demand projections and identify conservation opportunities. These assessments ultimately set each utility's conservation goal for a two-year period. Failure to meet these goals results in financial penalties for the utility and requires a public report to their customers (Energy Independence Act, I-937, 2006). Of course, demand projections and thus, conservation assessments, never included large-scale cannabis production prior to the passage of I-502 in 2012. The extent of this new energy demand has only recently come to light as the legal commercial cannabis industry grows.

1.3 RESEARCH QUESTION

What is the electrical energy intensity per square foot of cannabis canopy cover attributed to grow lighting for commercial cannabis agriculture in Washington State?

a. What energy efficiency measures for agricultural lighting could be taken in commercial cannabis agriculture in alignment with conservation goals required by Washington State's Energy Independence act (I-937)?

1.4 SIGNIFICANCE OF RESEARCH PROBLEM AND QUESTION

Initiative 502 may have large-scale implications in relation to energy demand as an increasing number of cannabis producers seek to satisfy the needs of a new and growing market. My research seeks to enhance our understanding of energy usage related to cannabis cultivation and how it may fit into the overall state energy plan. Revelations in this area could have implications for future policy changes to I-502 and may also provide utilities with more data on which to base their demand projections, which in turn, may influence energy conservation planning.

The Northwest Power and Conservation Council released the region's Seventh Power Plan, finalized in February 2016, outlining a 20-year regional power plan for Idaho, Montana, Oregon and Washington. Unlike previous plans, the Seventh Power Plan now addresses indoor agriculture, but as of this writing, details on specific electricity load patterns remain in development. Further research in this area will be needed to help develop energy conservation plans and load demand projections. Such plans will be especially important as the debate on cannabis legalization continues to unfold and if more states decriminalize recreational use. By providing a new framework for understanding load demand and energy efficiency within this emerging industry, a more complete picture of cannabis legalization could better inform utility decisions and policy development.

1.5 FOUNDATIONAL WORK

Very little research has focused specifically upon the energy intensity of cannabis production. Three sources in particular provided a foundational basis for this thesis. Evan Mills (2012) authored the only peer-reviewed paper on the topic. In it, he presents a model for calculating high, low and average energy intensity for cannabis production. Mills' model utilizes what he considers "typical [indoor] practices" for cultivation which include heating of irrigation water, high-intensity lighting, extensive climate control for heating and cooling, de-humidification and air cleaning. The resulting framework results in a fairly transferable figure of 13,000 kWh average per year for one "standard production module" consisting of a 4x4x8 cubic foot chamber containing four cannabis plants (Mills, 2012 p. 59).

In the second study, Massoud Jourabchi of the Northwest Power and Conservation Council (NWPCC) postulates lighting alone accounts for up to 80% of total energy consumption (Jourabchi, 2014). Mills' (2012) research also found lighting to be the single largest factor in energy consumption, reporting it to average around 38% of the total electrical energy consumption (p.65). Part of the discrepancy in the numbers can be attributed to the fact that Mills (2012) included in his calculations the preparation of cannabis after harvest, whereas Jourabchi (2014) did not. Mills (2012) also did not interview cannabis growers directly, but rather performed an analysis using data from "horticultural equipment manufacturers, trade media, open literature and interviews with horticultural equipment vendors" (p. 59). Conversely, Jourabchi's (2014) study resulted from interviewing growers directly and generating data based on actual production. Regardless of the discrepancy in methods, both studies found lighting to be the largest proportion of energy usage in cannabis production. A third study, in 2013 by graduate student Jessica Arnold, observed three California cannabis dispensaries and echoed results from Jourabachi (2014) and Mills (2012). Arnold (2013) uncovered results closer to Jourabchi's findings, with lighting accounting for 79% to 86% of total electrical consumption (p.70).

The direction of this thesis has been shaped by consistent observation of lighting as the largest contributor to electrical energy consumption in cannabis production. Because lighting appears to be the most impactful factor in electrical load growth resulting from cannabis production, it also presents the greatest opportunity for energy efficiency. While Arnold (2013) and Mills (2012) focused their research on carbon emissions relating to cannabis production (calculating energy usage as a byproduct of this goal), this thesis concentrates on the electrical energy requirements of agricultural lighting used in cannabis production to better understand this portion of the load demand for the cannabis industry.

1.6 ROADMAP

To understand the potential relationship between cannabis production, energy intensity and the requirements of I-937, the following chapter will begin with a broad overview of cannabis cultivation and distribution patterns, then move into more specific cultivation methods and energy requirements. Energy efficiency measures for indoor agriculture will also be considered. The next section will place the significance of the energy intensity required for cannabis cultivation within the context of I-937. A discussion of the Seventh Power Plan (which lays out energy planning for the entire Pacific Northwest region for the next 20 years) as it relates to indoor agriculture and energy efficiency will be included, as well as a short explanation of the Conservation Potential Assessments required of utilities to set energy conservation goals. Finally, I-502 and impacts associated with its implementation will be discussed, which will transition into the final conclusions of this chapter.

Chapter 3 will introduce the original research conducted for this thesis project in a review of methods used. The sample set for this work consisted of 12 commercial cannabis producers operating in Washington State surveyed specifically for this thesis, along with an additional 17 surveyed by the Northwest Power and Conservation Council (NWPCC) in 2015. Details in the chapter will include research design and data collection as well as an overview of the analyses performed.

Chapter 4 will present the results of this thesis project and reflections related to these results. Analyses will focus on understanding the relationship between energy intensity and lighting used in cannabis production. The first analyses will examine the operation types of each respondent: indoor, outdoor, greenhouse or a combination. Next, reported lighting types used will be explored, along with the daily run time for the lights (photoperiods). The square footage of cannabis canopy served by each lamp (lamp density) will also be investigated, followed by the energy intensity attributed to lighting per square foot of cannabis canopy. Conclusions and recommendations based on the findings will be presented in the final chapter.

2.1 CANNABIS CULTIVATION

Cultivation & Distribution Patterns of Cannabis: Local, Indoor Production

The benefits of indoor cannabis production become apparent when reviewing existing literature. In an anonymous online survey of 6,530 cannabis growers across 11 countries, researchers discovered that growers in the United States preferred indoor cultivation largely because of climate (outdoor crops being at the mercy of the weather), the lack of available land in populated areas for outdoor growing and risk of detection in the case of illegal operations (Potter, 2014 p. 231). Even with legal operations, security raises major concerns. In Washington State, potential cannabis producers must report their security measures as part of I-502's review process to obtain a license for cannabis production (Chapter 314-55 WAC, 2015). As Decorte (2009) points out, conclusions drawn from the comparison of cannabis markets worldwide would be tenuous due to the variations in the cannabis products, legalities in each country and cultivation techniques (p.272). Even so, Potter's (2014) analysis does shed light on the difference in trends of cannabis cultivation between more- and less-densely populated countries. Indoor cannabis cultivation tends to occur more frequently in densely populated areas. For example, respondents in the UK cite a lack of land, and fear of discovery or theft as the main contributing factors for this preference (p. 230).

Another study by Chadillon-Farinacci (2015) analyzes trends in cannabis cultivation between 2001 and 2009 through the review of arrest records tied to the discovery of illegal grow operations in the province of Quebec, Canada. Chadillon-

Farinacci (2015) found that hydroponic cultivation[1] tends to be most popular within large cities. Several factors contribute to this popularity. First, hydroponic methods offer more ability to control the growth cycle of plants due to the ease of administering nutrients and control over light levels, resulting in harvest patterns more easily adjusted to meet market demand (Chadillon-Farinacci, 2015). Second, the ability to control harvest patterns also results in higher overall productivity. Bouchard (2008) found that outdoor soil-based cultivation that would be limited to a natural annual growth cycle had an average yield per plant at 1.9 ounces, but with only one harvest per year. Indoor soil-based cultivation produces 3.38 ounces per plant each year, but over multiple harvests. Indoor hydroponic methods (which as mentioned previously offered the highest level of control over light levels and nutrient loads) yielded the most per plant annually at 3.96 ounces. The high annual yields with hydroponic cultivation can be attributed to the ability to harvest more frequently than both outdoor and outdoor soil-based cultivation. Chadillon-Farinacci (2015) also pointed out that hydroponic methods require greater financial investment than soil-based cultivation, as well as a permanent site for operations and thus a "deeper commitment" on the part of growers (p. 321). As an illegal operation, this could constitute a greater risk; as a legal operation, however, hydroponic methods could be extremely attractive to growers with the financial capital for the initial investment.

Researchers have also found a tendency for cannabis to be distributed closer to the original source than other drugs, with 72.5% having been both grown and distributed on the same continent and 57.5% regionally, making cannabis unique among other

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[1] Hydroponic cultivation refers to the process by which plant roots are suspended in, or continuously misted with nutrient rich solution (El-Ramady et al., 2014).

"plant-based" recreational drugs such as cocaine or heroin (Chadillon-Farinacci, 2015 p. 311). Local cultivation cuts down on the degradation of the tetrahydrocannabinol[2] (THC) during storage since it keeps the product closer to the consumer (Decourte, 2009 p. 272). Cannabis growers have been said to have a "preoccupation with the strength and the quality of the cannabis they grow" (Decorte, 2010 p.274). Through observations during interviews of cannabis growers in Oregon and Washington State, Morris (2015) compared them to the micro-brewers of the Northwest, creating a local product with a sense of pride, a likeness especially appropriate since cannabis belongs to the genus *humulus*, better known as hops (Knight et al. 2010 p. 37).

Market trends and product characteristics leading cannabis to "stay local" result in an interesting side effect: a smaller carbon footprint for transportation. Shorter shipping distances between cannabis producers and ultimate end users translates to less burning of fossil fuels. In turn, this makes THC a "greener" drug, at least in regards to shipping. Local pride and freshness also may greatly encourage the preference of consumers for a local market. At the time I-502 was enacted, however, local production in Washington State had been the *only* option, as no surrounding states had decriminalized recreational cannabis. Even with Oregon decriminalizing recreational cannabis shortly after Washington, transportation of the drug across state lines still constitutes a felony according to Section 812 of Title 21 of the U.S. Code, which classifies marijuana as a Schedule I Controlled substance (United States Code, 2006).

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[2] Tetrahydrocannabinol, or THC, is the main "psychoactive substance" in cannabis that makes it attractive as a recreational drug (Vanhove, 2011 p. 158).

As illustrated by the previous sections, multiple factors push cannabis growers in the United States towards indoor cultivation. In practice, cultivation trends in known cannabis grow operations also show a tendency toward indoor production (Potter, 2014; Chadillon-Farinacci, 2015). While factors influencing the local production and distribution of cannabis help lower the drug's carbon footprint, indoor cultivation does not. In fact, indoor cultivation tends to be *highly* energy and water intensive (Mills, 2012).

Modern Indoor Cannabis Production

Cannabis sativa L (hereafter simply referred to as "cannabis") contains the highest levels of THC among the cannabis species (Vanhove, 2011 p. 158). The psychoactive effect of THC have been reported to induce relaxation, euphoria, sensory alteration and an elevated or "mellow" mood, making cannabis attractive as a recreational drug (Hart et al., 2001 & Green et al. 2003). The use of cannabis for recreational purposes can be understood as the "voluntary ingestion for personal pleasure or satisfaction, unrelated to any medical condition" (Warren, 2015 p. 394). Growers of the plant have developed techniques that amplify THC concentrations to enhance their psychoactive effects. These techniques include genetic manipulation through cross breeding and the "sinsemilla technique" for cultivation that utilizes only female cannabis plants – their unfertilized flowers contain the highest THC concentrations (Pijlman et. al 2005 p. 178). To control growth cycles through light exposure, indoor cultivation becomes necessary as a way to fully manage the plant's environment. Mills (2012) estimates a cannabis production operation uses one 1,000-watt High Pressure Sodium (HPS) lamp per four plants (pp. 61 & 65). The following outline of the sinsemilla technique exemplifies the energy consumption associated with grow lighting used in indoor cannabis production:

1. **Germination:** Development of the plant's embryo lasts 3-7 days. At the end of this stage, a single rootlet pushes downward and a visible sprout pushes upward (Cervantes, 2006 pp. 2-3).
2. **Seedling growth (about a month):** Rootlets continue to develop. Seedlings need 16-18 hours of light to continue developing properly (Cervantes, 2006 p. 3).
3. **Vegetative state:** "Maintained" by providing plants 18-24 hours of light daily for 4 weeks (Cervantes, 2006 p. 3).
4. **Pre-Flowering:** After 4 weeks of vegetative growth, pre-flowers appear. These flowers signal the sex of the plants. Growers destroy males or remove them to be used as breeding stock, as female cannabis plants produce more cannabinoids and THC (Cervantes, 2006 p.5).
    a. **Mother Plants:** Strong female plants will be selected to become "Mother Plants" that will provide cuttings to produce clones. For them to remain useful in this purpose, they must be kept in the vegetative growth state requiring 18-24 hours of light a day. (Cervantes, 2006 p. 5)
    b. **Clones:** Tips of the mother plant's branches will be clipped off to create a "clone." It takes a clone 10-20 days to develop a root system and then 14 weeks with 18-24 hours of light a day to stay in a vegetative state. Clones provided by the mother plant produce the actual harvested cannabis crop. Thus, keeping a reliable supply of cannabis requires a consistent supply of clones, which in turn depend on the productivity of the mother plants. (Cervantes, 2006 pp. 5-8)

5. **Flowering:** Cannabis plants will be induced to flower by simulating fall-like conditions, e.g., shorter days. Cannabis grown for commercial purposes will be placed on a cycle of 12 hours of darkness and 12 hours of light. (Cervantes, 2006 p. 8). By removing the male cannabis plants earlier in the process, the remaining female clones will be left un-pollinated and their flowers will increase in size for weeks. Shorter light cycles and the absence of pollination results in "cannabinoid-laden resin production" and peaked THC production (Cervantes, 2006 p. 8).

The sinsemilla technique highlights the high level of control developed by cannabis producers. However, environmental control has not been the only motivation for indoor cultivation. As discussed earlier, due to its illegal nature in the United States, cannabis has historically been grown indoors for security and secrecy. Even with legal production, indoor cultivation still has advantages. Growers have full control over environmental factors, the ability to grow year round, and many feel it results in a better final product with higher THC levels (Knight et al. 2010 p. 37; Mills, 2012 p.58; Warren, 2015 p. 401). For example, the ability to block pollination through the removal of male cannabis plants and to manipulate light to simulate the seasonal changes required by the sinsemilla technique can be achieved only through indoor cultivation. In addition, while cannabis would naturally complete its life -cycle over the course of one year (Cervantes, 2006 p.2), the sinsemilla technique shortens the cannabis plant growth cycle to mere months by restarting at the clone stage rather than from the seed. The shortened harvest cycles made possible by indoor cannabis production results in the ability to produce more cannabis per year and a product high in THC (Pijlman et. al 2005 p. 178; Decorate, 2009 p. 271), the ultimate goal for a recreational cannabis grower.

While indoor cultivation offers a high level of regulation for cannabis production, variations among THC levels remain difficult to fully control. In a 2010 study, Knight et al. (2010) found there to be “considerable” variation in THC levels among cannabis plants even within the same crop (p. 41). The authors postulate the cause of such variation may be due to the “narrow window of time in which a flower is in peak condition. They will all mature at slightly different rates and be in different stages of “ripeness” at any given time (Knight, 2010 p.41-42). Despite the lack of uniformity in ripeness, for the sake of logistics, crops will be harvested all at once, leading to variations in THC levels, even among flowers of the same harvest (Knight, 2010 p.42). With the difficulty in obtaining consistently high levels of THC even among the same crop, it becomes apparent why cannabis growers will invest in the energy intensive sinsemilla technique to achieve the best possible THC levels in their plants.

Energy Intensity of Indoor Cannabis Production

Based on surveys collected in 2014 from a small number of licensed recreational cannabis producers in Washington State, electricity demand for recreational cannabis production ranges between 60 and 160 Average Annual Megawatts[3] (Jourabchi, 2014). The producers surveyed also indicated that in their particular operations, lighting accounted for 80% of electricity use (Jourabchi, 2014). Mills (2012) estimates lighting levels associated with indoor cannabis production to be on par with hospital operating

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[3] Average Annual Megawatt, written as aMW, refers to the electricity generated by the continuous production of one megawatt over the course of one year. An average megawatt is equal to 8,760 MW, as there are 8,760 hours in one year (Harrison, 2008).

room usage and also notes it is 500 times greater than the “recommended level for reading” (p.59). As mentioned previously, Mills (2012) created a standard model by analyzing data from horticultural manufactures, vendors and review of literature rather than collecting data directly from cannabis growers. Mills’ (2012) analysis assumed full indoor production and the exclusive use of high intensity discharge lamps (HID) (Fig. 2.1.1). Mills’ (2012) model attempted to provide a general idea of energy requirements for the types of equipment used in cannabis production such as lights, heating units and pumps (p. 59). In the real world, however, cannabis cultivation does not have a standard cultivation method.

The lack of standardization presents challenges in estimating load demand for cannabis production. With no standard method for cultivation, some operations will be much more energy intensive than others. To better estimate future load demand and identify energy conservation and efficiency potential, a broader range of operations need to be analyzed for their methods and corresponding energy consumption patterns.

ELECTRICITY	Energy type	Penetration	Rating (Watts or %)	Number of 4 × 4 × 8-ft production modules served	Input energy per module	Units	Hours/day (leaf phase)	Hours/day (flower phase)	Days/cycle (leaf phase)	Days/cycle (flower phase)	kW/h/cycle	kW/h/year per production module
Light												
Lamps (HPS)	elect	100%	1,000	1	1,000	W		12		60	720	3,369
Ballasts (losses)	elect	100%	13%	1	130	W		12		60	94	438
Lamps (MH)	elect	100%	600	1	600	W	18		18		194	910
Ballast (losses)	elect	100%	0	1	78	W	18		18		25	118
Motorized rail motion	elect	5%	6	1	0.3	W	18	12	18	60	0	1
Controllers	elect	50%	10	10	1	W	24	24	18	60	2	9
Ventilation and moisture control												
Luminare fans (sealed from conditioned space)	elect	100%	454	10	45	W	18	12	18	60	47	222
Main room fans — supply	elect	100%	242	8	30	W	18	12	18	60	31	145
Main room fans — exhaust	elect	100%	242	8	30	W	18	12	18	60	31	145
Circulating fans (18")	elect	100%	130	1	130	W	24	24	18	60	242	1,134
Dehumidification	elect	100%	1,035	4	259	W	24	24	18	60	484	2,267
Controllers	elect	50%	10	10	1	W	24	24	18	60	2	9
Spaceheat or cooling												
Resistance heat or AC [when lights off]		90%	1,850	10	167	W	6	12	18	60	138	645
Carbon dioxide Injected to Increase foliage												
Parasitic electricity	elect	50%	100	10	5	W	18	12	18	60	5	24
AC (see below)	elect	100%										
In-line heater	elect	5%	115	10	0.6	W	18	12	18	60	1	3
Dehumidification (10% adder)	elect	100%	104	0	26	W	18	12	18	60	27	126
Monitor/control	elect	100%	50	10	5	W	24	24	18	60	9	44
Other												
Irrigation water temperature control	elect	50%	300	10	15	W	18	12	18	60	19	89
Recirculating carbon filter [sealed room]	elect	20%	1,438	10	29	W	24	24	18	60	54	252
UV sterilization	Elect	90%	23	10	2.1	W	24	24	18	60	4	18
Irrigation pumping	elect	100%	100	10	10	W	2	2	18	60	2	7
Fumigation	elect	25%	20	10	1	W	24	24	18	60	1	4
Drying												
Dehumidification	elect	75%	1,035	10	78	W		24		7	13	61
Circulating fans	elect	100%	130	5	26	W		24		7	4	20
Heating	elect	75%	1,850	10	139	W		24		7	23	109
Electricity subtotal	elect										2,174	10,171
Air-conditioning				10	420	W					583	2,726
Lighting loads				10		W					259	1,212
Loads that can be remoted	elect	100%	1,277	10		W					239	1,119
Loads that can't be remoted	elect	100%	452	10		W					85	396
CO2-production heat removal	elect	45%	1,118	17		W	18	12	18	60	—	—
Electricity Total	elect				3,225	W					2,756	12,898

Table 2.1.1: Mills' (2012) electrical energy model for cannabis production (p. 65).

Indoor cannabis agriculture has been classified as one of the "most energy intensive industries in the U.S." (Warren, 2015 p. 386). The U.S. Department of Energy places agriculture as a whole second only to mining in the energy intensity required by non-manufacturing industries (Belzer, 2014). According to Mills (2012), all cannabis production accounts for 1% of energy consumption in the United States[4] (p. 58). A Seattle utility reported an estimated 3% expected load growth from recreational cannabis operations alone (Bade, 2015). Consumption rates could even be much higher in certain areas. For example, Humboldt County, California, experienced a 50% increase in electricity consumption after indoor production of cannabis for medical purposes began in 1996 (Mills, 2012 p. 59). Mills (2012) describes the energy consumption of indoor cannabis production:

> Specific energy uses include high-intensity lighting, dehumidification to remove water vapor and avoid mold formation, space heating or cooling during non-illuminated periods and drying, pre-heating of irrigation water, generation of carbon dioxide by burning fossil fuel, and ventilation and air-conditioning to remove waste heat [generated by the lights] (p.59).

Different climates also affect indoor cannabis production since "space-conditioning" needs will vary based on the energy demands required to keep the cultivation space a consistent temperature and humidity (Mills, 2012 p. 59). The concern of "winter peak demand[5]" has also been discussed by Jourabchi (2014), who analyzed the

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[4] Based on official U.S. total cannabis production estimates of 10,000 metric tons annually, one third of which is produced indoors, and Mills' (2012) model of cannabis production including 4x4x8 cubic foot modules for indoor cultivation producing 4-5 pounds of cannabis and consuming 13,000 kWh per module annually (Mills, 2012 pp. 58-59). The resulting calculations come to just under 20 TW/h/year (terawatts per hour per year), or approximately 1% of national electricity consumption (Mills, 2012 p. 59).

[5] "Winter peak demand" refers to the phenomenon where energy consumption rises to meet the heating needs of indoor spaces during the winter months.

load demand of one cannabis producer over 24 hours and noted large variations even from hour to hour, which could be attributed to temperature changes outside throughout the day, requiring more heating or cooling inside to keep a consistent temperature.

Further energy demand for illegally grown cannabis arises from "noise and odor suppression" and the use of diesel generators to avoid plugging into the grid, where energy consumption could be tracked and become conspicuous (Mills, 2012 p.59). Based on the conditions described above, Mills (2012) estimates the energy intensity of cannabis production to be 2000 watts per square meter, similar to computer data centers (p.59). Mills (2012) estimates electrical energy needs to be around 13,000 kWh per year to produce just 4-5 pounds of (final product) cannabis, which equates to the same amount of electricity consumed by 29 refrigerators (Mills, 2012 p. 59). The financial cost of such high energy consumption would seem to be of some concern, but this becomes a moot point for the growers in the face of high profits[6] per pound of harvested cannabis (Morris, 2015).

Energy Efficiency in Indoor Agriculture

Legal production of recreational cannabis on a commercial scale may bring higher electrical demand, but it would also allow for more precise demand projections. BC Hydro in British Columbia, Canada, reported 2,618 cases of "electricity theft" between 2006 and 2010, many associated with cannabis cultivation (Warren, 2015 p. 410). Other

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[6] From January to May 2016, the average wholesale price per pound of cannabis in Washington State ranged from just under $1,600 to $1,800 per pound of cannabis (Cannabis Benchmarks, 2016). At the end of 2015, the average wholesale price per pound of indoor grown cannabis hovered just under $2,000 (Cannabis Benchmarks, 2015).

illegal cannabis growers use diesel generators to provide the electricity needed for their operations. Legal cannabis production, such as that allowed through I-502, eliminates the need for secrecy and provides growers the opportunity to legitimately connect to the grid and avoid the use of generators powered by fossil fuels (Warren, 2015 p. 387). I-502 also allows these operations to be recognized as commercially-operated businesses. Commercial operations normally have the opportunity to participate in utility-funded energy efficiency programs. For cannabis producers, however, the situation becomes complicated.

The assumption that commercial cannabis growers would have access to energy efficiency programs has one underlying problem: federal dollars often fund many of these programs. In Washington State, for example, utility run energy efficiency programs often receive funding from the Bonneville Power Administration, a federal entity. Since Washington State cannabis growers' activities remain illegal on the federal level, utilities may be unable to offer them the benefits of federally-funded energy efficiency programs (Bade, 2015; Morris, 2015). Utility employees themselves have even expressed concerns about working with cannabis growers directly for fear of federal repercussions (Walton, 2014). Technically, as a federal agency, Bonneville Power Administration should not even provide power to a utility that may be used for cannabis production.

Efficiency itself will need to be approached in a specialized way for cannabis production, as some of the normal strategies for lowering energy consumption could prove counterproductive. Reducing illumination levels, for example, could result in lower harvest yields and require more growth cycles to produce the same amount of product. The result could be no change, or even an increase in energy intensity by weight of cannabis (Mills, 2012). Warren (2015) suggests utilities include growers in energy efficiency education programs and work to convert their high-intensity lighting to light emitting diode (LED) bulbs, which provides “three times more light per watt” (p. 411). Unfortunately, Warren’s suggestion proves problematic. Many growers resist the idea of LED conversion because they feel the bulbs do not offer the same light penetration into the cannabis canopy as high-intensity lighting and produce an inferior cannabis product (Morris, 2015). To attract growers, the benefits of LED grow lamps would need to be proven.

Another way to conserve energy would be to increase a cannabis grow operation’s overall production efficiency, not only in equipment but also in cultivation methods and genetic selection of mother plants. Mills (2012) suggests this based on the observation that reduced growth cycles may result in lowered overall energy intensity (Mills, 2012 p.59). Vanhove (2011) discovered that indoor cannabis yield depends most significantly on three factors: plant density, light intensity and variety. While Vanhove (2011) cites genetic pre-disposition as the most important of these three factors, a grower can influence their harvest yield to a certain degree with light. A less densely-packed cannabis canopy, with plants farther apart, allows greater access to light for the whole plant, increasing photosynthesis rates and resulting in greater production overall. Even greater yields can be obtained by increasing light levels (Vanhove, 2011 p. 162).

Manipulating lighting will only go so far, however. First and foremost, genetics determine yield. Vanhove’s (2011) study also found THC concentrations can be *primarily* linked to cannabis variety as opposed to cultivation method, with the highest yielding varieties also producing the highest concentrations of THC (Vanhove, 2011 p.162). Vanhove's (2011) findings contradict popular attitudes among growers and consumers, who have long felt indoor growing methods with high-intensity discharge lamps produce the highest THC levels (Mills, 2012 p. 62-63; Morris, 2015). Vanhove (2011) also agrees the best way for a cannabis producer to increase harvest yield would be to selectively cultivate the genetically-superior plants for this purpose, as seen with the sinsemilla technique. Focusing on the importance of genetics could make the argument for conversion to more energy efficient lighting stronger. A pragmatist would look to maximize profits by lowering overhead, and if genetics play a larger role in yield, more efficient lighting may lower costs without impacting yield.

LEDs in particular have select advantages over high intensity discharge (HID) lamps. LEDs use much less energy than HID lamps, offering the most lumens[7] per watt of any lighting type. LEDs optimized for agriculture can also produce Photosynthetic Active Radiation[8] (PAR) similar to HID lamps, and have a spectral variability the latter does not (Yeh, 2009 & Morrow, 2008). Normally, a combination of red, blue *and* green light spectrums would be used to create the appearance of white light (Yeh, 2009 p. 2176). Plants, however, require only a combination of red and blue light for photosynthesis. LEDs used in agriculture can be set to produce only these two spectrums (Yeh, 2009 & Morrow, 2008). Although LEDs already represent the most efficient lighting type available, those producing only two light spectrums, as opposed to three, consume even *less* electricity than full spectrum white lights (Yeh, 2009 p. 2177 & Morrow, 2008 p. 1948).

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[7] Units of Measure for visible light or brightness (Energy Star, n.d.).

[8] Photosynthetic Active Radiation[8] (PAR) can be understood as the light energy absorbed by vegetation for the process of photosynthesis (Gitelson, Peng, Arkebauer, & Suyker, 2015 p. 101).

Indoor agricultural operations that utilize spectrally-optimized LED lamps have sometimes been dubbed “pinkhouses” due to the pinkish hue emitted from the mixing of red and blue light (Dougcleff, 2013; Meinhold, 2013 & Mitchell, 2014). One such pinkhouse built by Caliber Biotherapeutics in Texas cultivates expensive crops used for drugs and vaccines. The fully indoor and tightly controlled operation limits the crop’s exposure to disease and contamination (Doucleff, 2013). Another pinkhouse in Japan operated by Toshiba uses similar conditions in an attempt to create the “world’s highest-quality lettuce.” Toshiba notes their crop also does not require pesticides, since indoor cultivation allows it to be free of insects (Mitchell, 2014). As commercial cannabis producers cultivate an expensive crop meant for human consumption, limiting pests, disease and contamination would be highly valued. All of the operations mentioned here rely on the energy efficiency and spectral flexibility of LED lamps to make their operations financially viable. Due to the significantly higher energy requirements of HID lamps over LED and the financial costs associated with high electrical energy consumption, the return on investment for the crops in these examples would not be nearly as high if HID lamps had been used (Dougcleff, 2013; Meinhold, 2013 & Mitchell, 2014).

Aside from energy efficiency, LED lamps also offer benefits important to indoor agriculture such as low operating temperatures. LEDs produce much less radiant heat than HID lamps, which allows them to be placed much closer to the plants themselves with lower risk of damaging plant tissues. They can even be placed within the plant canopies, creating better light penetration of the cannabis canopy (Dougcleff, 2013; Morris, 2015 & Morrow, 2008 p. 1948). As mentioned previously, maximum productivity of the entire plant requires good light penetration of the canopy. LEDs also have a considerably longer operating life when compared to incandescent bulbs such as HID lamps (Yeh, 2009 p. 2176 & Morrow, 2008 p. 1949). Despite the higher initial costs often associated with installing an LED system, the longer lifespan of LEDs still creates a high return on initial investment when combined with the reduced energy costs.

With any business, reducing operating costs such as those associated with energy consumption becomes important in the pursuit of maximizing net profit. Based on estimates found in the available literature, lighting used for indoor cannabis production may account for up to 86% of total energy consumption required for such an operation (Arnold, 2013; Mills, 2012 & Jourabchi, 2014). While energy efficiency measures could be targeted at any of the equipment used in cannabis production, due to its high percentage of overall energy consumption, focusing on grow lighting would most likely result in the greatest reduction in electrical energy consumption for these operations. If cannabis producers in Washington State switched to LED systems, not only would they stand a greater chance of increasing their profit, but the electrical load demand within the state could be significantly lowered. The significance of this possibility becomes clear when framed by the importance of energy conservation goals set forth by the Washington State Legislation, which will be discussed in more detail in the next section.

2.2 WASHINGTON STATE ENERGY LEGISLATION & PLANNING

Significance of Energy Conservation

Amid growing concerns relating to anthropogenic climate change, lowering CO_2 emissions has become vital. If the state takes no action, the Washington State Department of Ecology estimates managing the impacts of climate change will cost Washingtonians nearly $10 billion annually by the year 2020 as a result of "increased health costs, storm damage, coastal destruction, rising energy costs, increased wildfires, drought, and other impacts" (Washington State Department of Ecology, 2012, p. 3). In 2015, the U.S. generated 67% of its power from fossil fuels, emitting still more CO_2 into the atmosphere (U.S. Energy Information Administration, 2016). In contrast, Washington State generates just over 70% of its power from hydroelectricity alone and only about 11% from fossil fuels[9] (U.S. Energy Information Administration, State Energy Data System, 2016). Based on these percentages, using electricity more efficiently may not curb CO_2 emissions in Washington State as much as in other areas of the country, but efficiency remains vital for managing load demand.

The Pacific Northwest relies heavily on the acquisition of energy efficiency, cited as the "single largest contributor to meeting the region's future electricity needs" (Northwest Power and Conservation Council, 2016 p. 1-1)[10]. As electrical load demand grows, energy efficiency helps to balance the load by doing more with less, reducing the need for increased generation capacity. Energy efficiency also remains the most

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[9] At time of this writing in 2016.

[10] Includes Washington, Oregon, Idaho & Montana in the context of the Northwest Power and Conservation Council's Seventh Power Plan (Northwest Power and Conservation Council, 2016).

cost-effective method of meeting load demand, costing half of any other resource[11] (Northwest Power and Conservation Council, 2016 p. 1-7). For all the reasons cited above, many utilities have invested in energy efficiency within their service territory for some time. Initiative 937 (the Washington State Energy Independence Act) helps to further drive energy efficiency through conservation (defined as reduced consumption resulting from the increases in the efficiency of energy use, production or distribution) and increased power generation from renewable resources (Energy Independence Act, I-937, 2006).

The Washington State Energy Independence Act: Initiative 937

The Washington State Energy Independence Act (I-937) focuses primarily on the 17 largest utilities in Washington State, which provide 81% of the state's electricity to date (Energy Independence Act, I-937, 2006). Initiative 937 seeks to increase the electricity derived from *new* renewable resources within Washington State to 15% by the year 2020. Under this Act, renewable resources can be defined as water, wind, solar, geothermal, landfill/sewage treatment gas, wave, ocean or tidal power and biodiesel "not derived from crops raised on land cleared from old growth or first-growth forests" (Energy Independence Act, I-937, 2006 pp. 3-4). Because a major portion of electricity generation in Washington state originates from hydroelectric dams (US Energy Information Administration, 2013), additional definitions for "eligible renewable resource" have been included in the Energy Independence Act. Renewable energy must not be from a facility powered by fresh water except in the form of improvements to

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[11] The Northwest Power and Conservation Council considers the acquisition of energy efficiency a "resource" in meeting load demand just they consider the generation capacity of natural gas, wind, solar or geothermal resources (Northwest Power and Conservation Council, 2016).

existing hydroelectric projects resulting in increased electricity generation (Energy Independence Act, I-937, 2006 pp. 2-3).

Initiative 937 also requires qualifying utilities to complete, and make publicly available, biennial conservation potential assessments and set energy conservation goals for the succeeding two years (Energy Independence Act, I-937, 2006 pp. 2-3). Under I-937, "conservation" has been defined as "any reduction in electric power consumption resulting from the increases in the efficiency of energy use, production or distribution" (RCW Chapter 19.285.030, 2006). Conservation methods must also be "cost effective and achievable," meaning they must not cost more than they save (Energy Independence Act, I-937, 2006 pp. 4). Failure to meet conservation goals will result in an administrative penalty of $50 per megawatt hour shortfall (adjusted annually for inflation). Utilities who suffer the penalty will also be required to notify their customers of the size of the financial fine and reasons the penalty was incurred (Energy Independence Act, I-937, 2006 p. 8). The requirements and penalties handed down by I-937 help drive energy conservation and acquisition of renewable resources in Washington. The context in which the goals of I-937 must be met, however, will always be in a state of flux. The energy needs of Washington State, as with that of every region, shift over time. For this reason, the Northwest Power and Conservation Council creates the Pacific Northwest region's energy plan to take into account current and projected conditions.

The Northwest Power and Conservation Council's Seventh Power Plan

In 1980, the U.S. Congress passed the Northwest Power Act, which resulted in the formation of the independent Northwest Power and Conservation Council (NWPCC).

The NWPCC works to create a Pacific Northwest power plan to help ensure the stability of the region's power supply (in its seventh iteration at the time of this writing) that extends to the states of Washington, Oregon, Idaho and Montana. (Northwest Power and Conservation Council, 2015 p. 4). The Northwest Power Act also set a priority for energy efficiency, deeming it an important resource in meeting load demand. Under the NWPCC's power plans, through energy efficiency, utilities in the region have gained the "equivalent of more than 5,900 average megawatts of electricity," tantamount to the power needed for "five cities the size of Seattle" (Northwest Power and Conservation Council, 2015 p. 4). To continue making such impressive efficiency gains, the NWPCC must constantly weigh all potential causes for increases in load demand. Different types of load can necessitate different strategies for conservation; adding insulation to a home, for example, would not reduce electricity consumed by lighting. The NWPCC must also consider how new industries will affect load and what conservation strategies may work for that particular industry. Not surprisingly, load growth related to "indoor agriculture" appeared in the Seventh Power Plan as a response to the legalization of commercial cannabis markets in Washington and Oregon. It had been absent in all prior plans (Northwest Power and Conservation Council, 2016 p. 2-6)

The NWPCC estimates electrical load demand increases of 100-200 megawatts[12] over twenty years due to the legalization of cannabis production in these two states (Northwest Power and Conservation Council, 2016 p. 2-6). As discussed earlier, a minimal amount of data regarding the energy intensity of cannabis production exists. In light of this, the

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[12] In 2014, the average residential home in Washington State consumed about 12MW of electricity for the year (U.S. Energy Information Administration, 2015).

Seventh Power Plan does not offer guidance for reducing the energy consumption of these operations, but rather states the NWPCC will simply monitor and work to forecast future loads and develop "best practice guides" for increasing efficiency in indoor agriculture (Northwest Power and Conservation Council, 2016. p. 17-4). The hedged language regarding cannabis production within the Seventh Power Plan may be due to the fact that, while legal in Oregon and Washington, recreational cannabis production remains illegal in Idaho and Montana, the two other states covered by the Northwest Power and Conservation Council, as well as at the federal level.

2.3 RECREATIONAL CANNABIS LEGISLATION: THE FEDERAL STANCE VS. WASHINGTON STATE

Federal Stance Regarding Recreational Cannabis

Officially, at the time of this writing, the U.S. Federal government still considers cannabis a schedule 1 drug, defined as having "a high potential for abuse" with no "accepted medical use" and "lack of accepted safety for use…under medical supervision" (United States Code, 2006). As of today, close to half of U.S. states have legalized or decriminalized "cannabis-related conduct." The Federal government has responded by removing funding for enforcement of federal laws against those acting within legal grounds according to their state (Warren, 2015 p. 398). Despite this, the U.S. Department of Justice maintains the ability to prosecute anyone participating in the production, consumption or distribution of cannabis. In 2013, in light of state initiatives legalizing marijuana and regulating its production, processing and sale, Deputy Attorney General

James Cole of the U.S. Department of Justice issued a memo to provide further guidance regarding marijuana laws. The memo lists eight priorities for enforcement:

1. Preventing the distribution of marijuana to minors;
2. Preventing revenue from the sale of marijuana from going to criminal enterprises, gangs, and cartels;
3. Preventing the diversion of marijuana from states where it is legal under state law in some form to other states;
4. Preventing state-authorized marijuana activity from being used as a cover or pretext for the trafficking of other illegal drugs or other illegal activity;
5. Preventing violence and the use of firearms in the cultivation and distribution of marijuana;
6. Preventing drugged driving and the exacerbation of other adverse public health consequences associated with marijuana use;
7. Preventing the growing of marijuana on public lands and the attendant public safety and environmental dangers posed by marijuana production on public lands; and
8. Preventing marijuana possession or use on federal property.

(U.S. Department of Justice, 2013)

The U.S. Department of Justice has stated that jurisdictions that have allowed regulation of marijuana activity "must demonstrate the willingness to enforce their laws and regulations in a manner that ensures they do not undermine federal enforcement priorities" (Dept. of Justice, p. 2-3 2013). Essentially, rather than micromanaging marijuana laws, the Federal Government has put enforcement in the hands of states that legalize and regulate marijuana's use and production, with the expectation they will not allow this activity to interfere with federal priorities.

Washington State Cannabis Production

The Washington State Liquor and Cannabis Board[13] issues licenses for cannabis producers, obliging them to remain compliant with the state's Environmental Policy Act. Cannabis producers must obtain environmental permits for water quality, air quality, chemigation and fertigation[14] as well as the handling of solid and hazardous wastes (Washington State Liquor Control Board, 2013 Outdoor, Indoor & Greenhouse Producers guides). Initiative 502 also allows local governments to set even more restrictive zoning and licensing rules (I-502, 2012), including building codes relating to energy. (Washington State Liquor Control Board, 2013 Outdoor, Indoor & Greenhouse Producers guides). Fragmented local regulation provides for some interesting opportunities. For example, Warren (2015) points out that local governments could require cannabis producers to use clean energy technology such as solar panels to meet their energy demands, however, none have done so as of this writing (p. 424).

State energy code, to the contrary, allows an exception for the energy usage of indoor agricultural lights. Normally, according to code, the square footage and type of building dictates the sum of watts that can be used for all connected interior lighting in that space (WAC 51-11 C405.5.1.1- C405.5.1.4 2016). Multiple exceptions exist under the code, including "task lighting for plant growth or maintenance" that allows permissible wattage levels to be exceeded in spaces engaging in indoor agriculture (WAC 51-11 C405.5.1, 2016). The exemption for plant growth means spaces used for cannabis

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[13] Originally the Washington State Liquor Control Board, the name was changed to the Washington State Liquor and Cannabis Board following the passage of I-502.

[14] Chemigation and fertigation in this context relates to "the application of fertilizers and/or pesticides through an irrigation water system" (Washington State Liquor Control Board, 2013 Outdoor, Indoor & Greenhouse Producers guides).

production have no limitation on energy consumption resulting from agricultural lights.

Summary

Through the reviewing literature relating to the energy intensity of cannabis production, it becomes apparent that many factors push cannabis producers in the United States to grow indoors. Justifications arise from all angles: security, the historically illegal nature of cannabis cultivation, the science of efficient cultivation and the long-held beliefs of growers about the best way to achieve high THC levels. Indoor cannabis cultivation also happens to be extremely energy intensive due to the lights and environmental controls used. Lighting alone appears to account for the largest portion of this energy intensity (Arnold, 2013 & Jourabchi, 2014). These factors and the limited data available on the energy intensity of cannabis production underscore the importance of studying indoor cultivation in terms of its actual energy consumption and energy efficiency potential.

The available literature has guided the direction of this thesis project toward a deeper investigation of agricultural lighting used in indoor cannabis production. In an attempt to advance this pool of knowledge; the following chapters will explore the lighting used by a select number of commercial cannabis producers in Washington State. The subsequent section will outline the methods used for this study, including sampling design, data collection, and overview of analyses preformed. Finally, the results of this study will be presented, followed by recommendations for energy efficiency and future research.

CH. 3 METHODS

3.1 STUDY OBJECTIVES

The main objective of this thesis has been to better understand the energy intensity associated with commercial cannabis in Washington State. In reviewing literature relating to indoor cannabis production, the focus of the research was also guided by a common thread identifying agricultural lighting as the most energy intensive factor during cultivation. The secondary objective of this thesis is discovering potential conservation opportunities in alignment with I-937.

Previous research on the energy intensity of cannabis production was often based on findings from illegal operations or cultivation for medical use (Arnold, 2013; Mills 2012). Mills (2012) based his estimates on trade media, open literature and interviews with suppliers of horticultural equipment but did not work with cannabis producers directly. Arnold (2013) studied medical cannabis producers which obtain licensing per plant, resulting in much smaller operations than recreational producers who can have up to 30,000 square feet of cannabis plant canopy depending on their license (Washington State Liquor and Cannabis Board, 2015). Neither Mills' (2012) or Arnold's (2013) approach adequately addresses large-scale commercial cannabis production. The intention of this study is to address the commercial scale and to examine variations in agricultural lighting practices among these cannabis producers.

3.2 RESEARCH DESIGN & DATA COLLECTION

To gain initial insight into indoor cannabis agriculture, informal interviews were conducted with individuals from the Washington State Department of Commerce and the Northwest Power and Conservation Council (NWPCC). Massoud Jourabchi, Manager of Economic Analysis for the Northwest Power and Conservation Council, provided anonymous survey data collected in 2015 about the energy consumption of 17 commercial cannabis producers in Washington. New surveys created for this thesis were based on Jourabchi's design in an attempt to generate new data compatible with the NWPCC data collected in 2015 and to increase the overall sample size. The surveys were also cleared through The Evergreen State College Human Subjects Review board before data collection began. Content from both surveys can be found in Appendix A.

The survey sampling frame was generated by retrieving data from the Washington State Liquor and Cannabis Board's (WSLCB) map of commercial cannabis producers in Washington State, to add reassurance that producers surveyed would be legal operations (Washington State Liquor Board, 2015). Contacts for producers who had previously participated in the NWPCC survey were removed from the resulting list along with duplicates, as were those without an email address. The final list consisted of 132 Washington State commercial cannabis producers. Due to time, labor, and funding constraints, email became the chosen mode of delivery for participation requests.

Surveys developed for this thesis were distributed to these cannabis producers via the website *SurveyMonkey* (SurveyMonkey Inc., 2016). A link embedded in the email sent to prospective participants provided access to the online survey (See Appendix B). Tools available through the email marketing service *MailChimp* were used in the design and automated distribution of the emails (MailChimp, 2016). The initial distribution of emails occurred on Monday, January 18, 2016. A second, reminder email was distributed on Monday, February 8, 2016. Data collection concluded on February 20, 2016, with a total of 11 responses out of the132 potential participants who had been sent the survey. Survey responses remained anonymous in the hope this would put cannabis producers at ease about revealing their "lighting recipes" – often viewed as a trade secret in this community (Morris, 2015).

3.3 STUDY OVERVIEW

As illustrated by Mills' (2012) research, many different components go into indoor cannabis production including: heating, cooling and ventilation systems; dehumidifiers; irrigation pumps; CO_2 injectors; and, of course, lamps for artificial lighting conducive to agricultural needs (pp. 60 & 65). The analyses conducted for this thesis focused on the use of artificial light in particular. Cervantes (2006) demonstrated how producers use light in cannabis cultivation with a description of the sinsemilla technique as outlined in Chapter 2.

The sinsemilla technique allows cannabis producers to skip the germination and seedling growth stages once quality mother plants have been established, since future crops will be derived from the cuttings of these plants (Cervantes, 2006). The vegetative and flowering stages will then be the only stages of cannabis growth cycled through by established producers. Cannabis producers will keep plants in these two stages, separated due to differing periods of light and darkness or "photoperiods" (Cervantes, 2006 &

Morris, 2015). The areas containing plants in either the vegetative or flowering stage will be referred to as “Vegetative” and “Flowering” rooms respectively. The area square footage of cannabis itself is referred to as the “canopy,” in alignment with the language used by the Washington State Liquor and Cannabis Board in their description of producer licenses (Washington State Liquor Control Board, 2013).

Assumptions used in the analyses of data for this thesis can be found in Appendix C. These analyses have been broken down into five categories for greater ease of reporting:

1. Reported types of cannabis production operations.
2. Lighting types used for both Vegetative and Flowering rooms.
3. Photoperiods used for the Vegetative and Flowering cycles.
4. Light density, or number of lights used per square foot of cannabis canopy.
5. Annual energy intensity per square foot of cannabis canopy.

The first category focused on the type of operation: outdoor or indoor. These samples included 11 responses from surveys collected specifically for this thesis as well as 14 from the 2015 NWPCC data set. The samples collected for this thesis project did not specifically exclude any particular operation type, as data retrieved from the WSLCB website did not identify this information, meaning the sampling frame included all operation types. Conversely, the NWPCC data collection focused specifically on indoor cannabis production, although a number of other operation types had been reported such as outdoor and greenhouse. The mix of multiple operation types reported in a study focused on *indoor* operations makes the operation type important data to consider, because it could mean cannabis producers do not necessarily prefer indoor operations as the literature suggests. Due to the differing nature of data collection for this thesis project and the NWPCC research, these sample sets have been analyzed separately.

The next category of analysis involved examining lighting types used by each survey respondent. First, all lighting types were grouped by the room (either Vegetative or Flowering) as reported by survey respondents. Lights were further organized by basic type, e.g., High Pressure Sodium (HPS) lights with either magnetic or electronic ballasts have been placed into the “HPS” category. Ballasts could not be taken into consideration for this study because too few cannabis producers reported this information. When producers reported using combinations of lighting types, their samples were tallied under multiple lighting types as well as the “combination” category. In this way, an accurate figure as to the proportion of respondents using each lighting type or a combination of types could be determined. Percentages were calculated to help conceptualize which portion of the whole sample set use each lighting type.

In addition to lighting types used, photoperiods were also analyzed. Photoperiods denote the hours per day lights in Vegetative and Flowering rooms run during a crop cycle. After removing responses containing no or ambiguous photoperiod data, 16 samples remained for Vegetative rooms and 14 for Flowering. Surveys developed for this thesis project also asked respondents to provide information on the weeks per year (then converted to days per year for analysis) each photoperiod would be active, thus a portion of the total samples also include this data (n=5 for Vegetative rooms and n=3 for Flowering rooms).

Light density was analyzed by comparing reported square foot of cannabis canopy cover served by each light. Some samples did not directly report this data but did report number of lights used in addition to square foot of canopy cover. From these data, square foot of canopy cover per light could be calculated. Samples with ambiguous data or lacking enough data to calculate lighting densities were also removed from the final sample set. The data was then separated by Vegetative and Flowering rooms and lighting densities calculated.

Calculating the lighting energy intensity per square foot of cannabis canopy was a multi-step process. The first step included removing samples from the data set that did not provide enough data, or contained conflicting/ambiguous information that would not allow for an Energy Use Intensity calculation[15]. In the NWPCC data set, numbers of lamps used by producers were not reported directly but still could be deduced based on the square footage of cannabis canopy served by each lamp and the total square footage of said canopy. The number of lamps used was then multiplied by the reported wattage for each lamp. The resulting number represented the total wattage of lamps used by each respondent in both Vegetative and Flowering rooms. The NWPCC did not collect information regarding the number of days per year reported photoperiods were active. To compensate for this, annual photoperiod lengths have been inferred based on the median days reported in the data collected from the additional cannabis producers surveyed for this thesis. Lastly, a canopy cover EUI could be calculated from kWh per year and total canopy square footage for both Vegetative and Flowering rooms.

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[15] Site energy use intensity or "EUI" is calculated by dividing the total energy consumed by a building in one year by the total square footage of floor area for that building (Energy Star, n.d.).

CH. 4 RESULTS & DISSCUSSION

In 2012, voters in Washington voted to legalize the recreational use of cannabis. With this decision, the state's commercial cannabis industry was established. The available literature has shown that, due to the need for specialized equipment, commercial cannabis production has the potential to be extremely energy intensive. The overarching goal of this thesis project has been to better understand the energy intensity of operations in Washington State. Of the equipment used by cannabis producers, the literature shows a tendency for specialized grow lighting to consume the largest share of energy. For this reason, this thesis has focused on this particular aspect of cannabis production.

To investigate the energy intensity associated with grow lighting used in cannabis production, the data collected for this thesis project has been analyzed in five different ways. First, variations in the use of indoor, outdoor, greenhouse and combinations of such operations were explored to better understand the equipment choices made by each cannabis producer. Next, lighting types used by the respondents were investigated, followed by reported photoperiods. Finally, the density of lights found serving each respondent's canopy cover were identified and an Energy Use Intensity[16] (EUI) based on this density was calculated.

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[16] Site energy use intensity or "EUI" is calculated by dividing the total energy consumed by a building in one year by the total square footage of floor area for that building (Energy Star, n.d.).

4.1 VARIATION IN CANNABIS PRODUCTION OPERATIONS

According to the literature reviewed, whether or not a cannabis production operation utilizes primarily indoor or outdoor cultivation methods can dramatically impact the energy intensity of the operation. The root of this discrepancy lies in the equipment needed for each cultivation method. As discussed previously, indoor cannabis production can be highly energy intensive due to the need for specialized lighting, heating, cooling, dehumidification and other systems. On the other hand, cannabis operations that primarily grow outdoors and follow natural seasonal patterns take advantage of natural light and environmental conditions. The need for the aforementioned equipment (and the accompanying energy intensity) is virtually removed from the equation.

While the sample frame developed for this thesis project did not exclude non-indoor growers due to the inability to filter them out during the development of the survey recipient list, the participation request letter did reference “grow lighting” specifically (Appendix B). That reference may have discouraged participation from non-indoor cannabis producers. While indoor cannabis production operations do represent the largest portion of respondents (28%, n =11) for this project, combinations of production operations together represent the majority (54% in total, n = 11). Combination operations for this sample included cannabis producers growing cannabis in the following settings: outdoor/indoor (27%), greenhouse/outdoor (9%) and greenhouse/outdoor/indoor (18%) (Fig. 4.1.1).

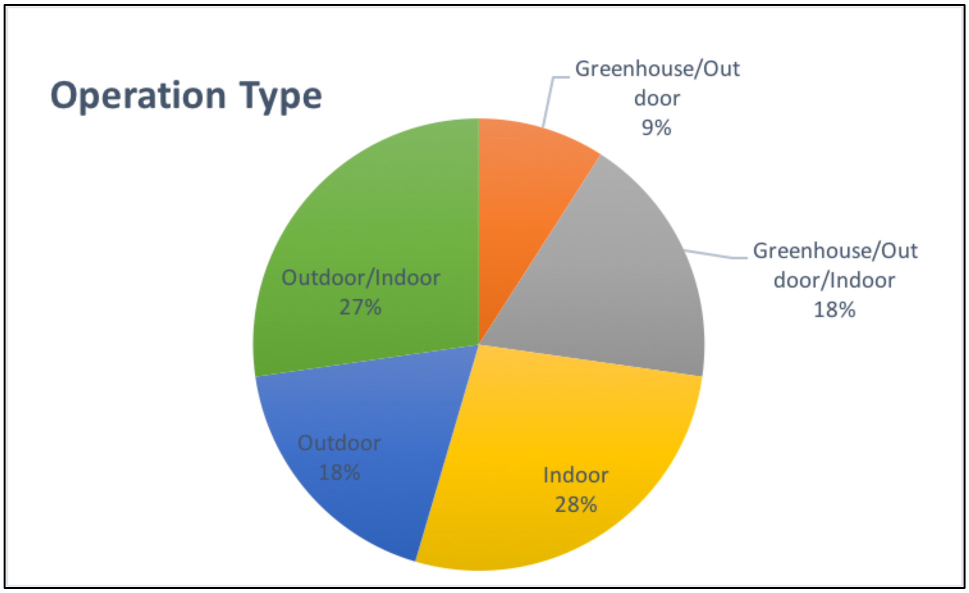

Fig. 4.1.1: Operation types reported by commercial cannabis producer respondents for this project (n=11).

In contrast to the sample frame developed for this thesis project, the frame developed by the NWPCC *did* attempt to focus data collection exclusively on indoor cannabis producers (Jourabchi, 2014). Unsurprisingly, the majority of respondents reported exclusively indoor growing practices (65%, n=14). Respondents reporting growing cannabis in a combination of settings represented 14% (n=14) and were identified as greenhouse/outdoor/indoor (Fig. 4.1.2). Still others reported strictly outdoor and greenhouse growing respectively (Fig. 4.1.2).

The variation in these results is noteworthy because even though both studies focused on indoor cannabis production, outdoor operations and combinations appear in the data. While not a representative sample, these results raise interesting questions. The literature implies indoor growing practices dominate, so why the variation in the results? The legalization of recreational cannabis may influence how the product is grown. Existing literature discusses cannabis production in the context of illicit operations, which by their nature necessitate the need for secrecy to avoid discovery, often leading to indoor production. In Washington, legalization may be opening the door to outdoor cultivation as well as an expansion of indoor production.

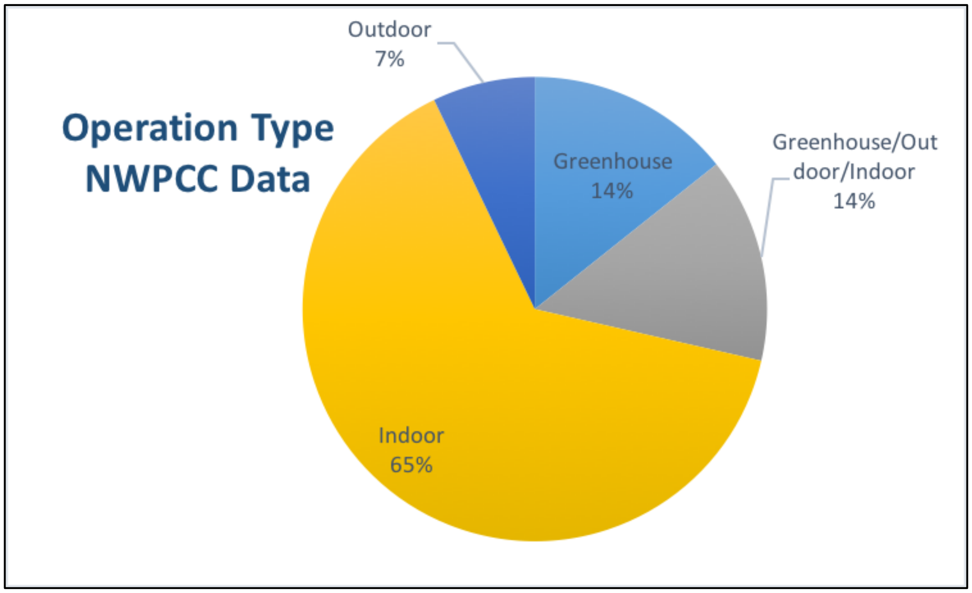

Fig. 4.1.2 Operation types reported by commercial cannabis producers interviewed by the NWPCC in 2015 (n=14).

Another key point made in the existing literature supporting indoor cannabis cultivation regards the efficiency of crop production. Indoor production offers the ability to produce a crop year round. With any business, the push to lower overhead and increase profits require cost-saving measures. Commercial cannabis production would ostensibly be no different. The use of natural light could be viewed as one such cost-saving measure.

Cannabis producers located in regional climates with weather favorable to agriculture could potentially grow their crop outdoors during the appropriate seasons and indoors the remainder of the year. A hybrid system would give them the dual benefit of a year-round crop while still reducing annual total energy consumption. Of course, in some areas this method would be inappropriate due to a lack of suitable agricultural land, resources and climate. As demonstrated by the Washington Sungrowers Industry Association (WSIA)[17], some legal cannabis producers, despite challenges, not only use outdoor cultivation but strongly advocate for it in the legislative arena. While the data regarding indoor vs. outdoor cannabis cultivation collected for this project cannot be considered representative, the findings along with the appearance of an organization such as WSIA points to a need for a more comprehensive survey of cannabis production operation types. Understanding the diversity of operations within Washington State could assist in creating more accurate electrical load demand projections for this industry.

4.2 REPORTED LIGHTING TYPES

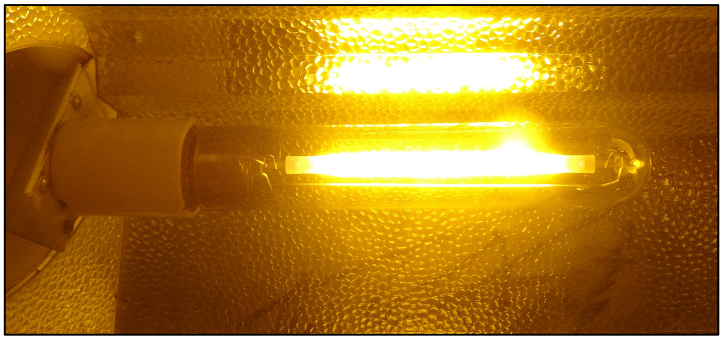

Fig. 4.2.1: High pressure sodium (HPS) is part of the high intensity discharge (HID) family of lighting types. Image credit: Plantlady223 (2015).

When discussing lighting types used for cannabis cultivation, the purpose of the light becomes extremely important. Lighting types reported by respondents between the Vegetative and Flowering rooms differed greatly. A wide variety of lights were reported in Vegetative rooms, which contradicts Mills' model that assumed only HIDs were being used. In fact, high intensity discharge (HID) lamps including high pressure sodium (HPS) and metal halide (MH) and fluorescents including compact fluorescents (CFLs) & T5s

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[17] The WSIA is a group of cannabis producers who lobby policy makers and work with local governments to ensure legislation and zoning requirements support sun grown cannabis (WSIA - Washington Sungrowers Industry Association, 2016).

were actually being used at an equal rate (50% with each type totaled). Fluorescent T-5 lighting held the highest percentage of use in Vegetative rooms at 38% (n=16). Another 12% (combined) reported using CFLs or simply “fluorescent” and 13% reported using LEDs (Fig. 4.2.5).

Fig. 4.2.2: Metal Halide (MH) lamp halfway through warm up. Photo Credit: David H. (2008)

Fig. 4.2.3: Compact Fluorescent (CFL). Image Credit: Sun Ladder (2012)

Fig. 4.2.4: T5 Fluorescent lamp. Photo Credit: Taube (2006)

The high usage of T-5 lighting as well as other fluorescents and LEDs could indicate a willingness to use more efficient lighting types during the vegetative growth cycle. However, a large number of respondents did report the use of HPS lamps (31%) in their Vegetative rooms, showing the popularity of more energy intensive lighting still shows itself in these areas (Fig. 4.2.5). That being said, 25% reported using a combination of lighting types (Fig. 4.2.5), all of which included a HID type lamp supplemented with a fluorescent type which could show a desire to reduce overall energy usage with the use of some energy efficient lighting rather than a full HID system.

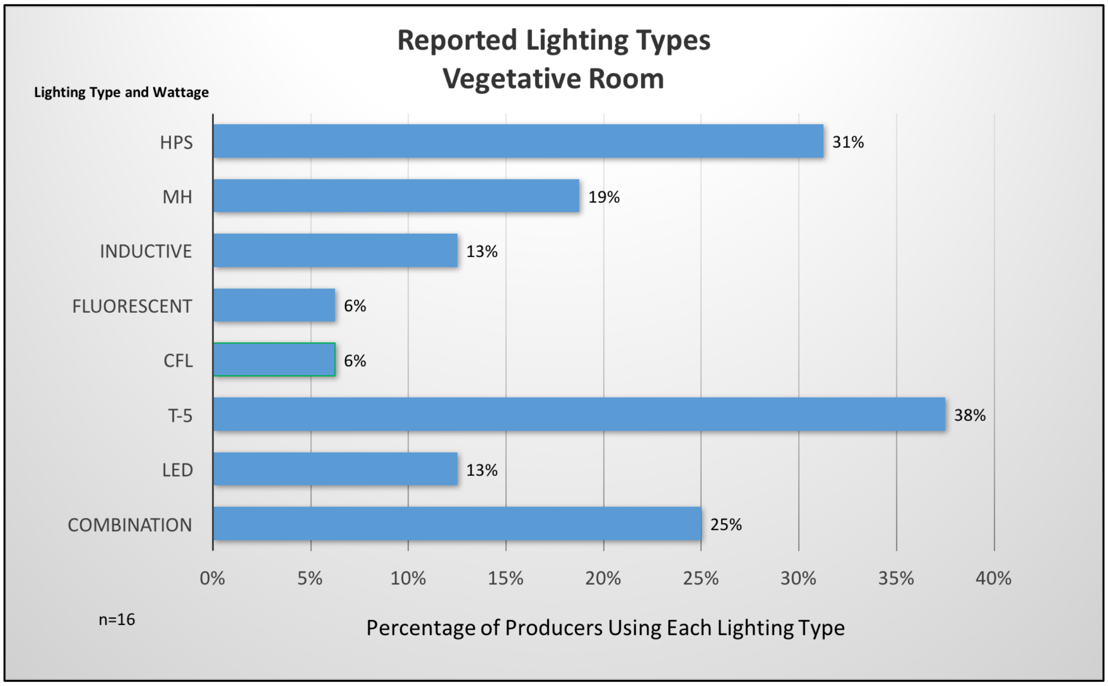

Fig. 4.2.5: Reported lighting types used in sampled Vegetative rooms n=16. Several samples are represented more than once due to the use of multiple lighting types, thus the percentage using a combination of lighting types has also been included.

In contrast to the variety of lighting types used in Vegetative rooms, at 76.92% (n=13) HPS dominated by far as the primary lighting type used in Flowering rooms (Fig. 4.2.6). Such extreme disparity may exist for several reasons. First, the budding flower of the cannabis plant is the final crop and therefore the most valuable part of the plant. The flowering period of the crop cycle can make or break a harvest. The literature reports an overwhelming preference for HID lamp types in the history of cannabis cultivation. These lamps have been the tried and true choice of indoor cannabis producers. Commercial cannabis producers may not be willing to risk their success by experimenting with other lighting types.

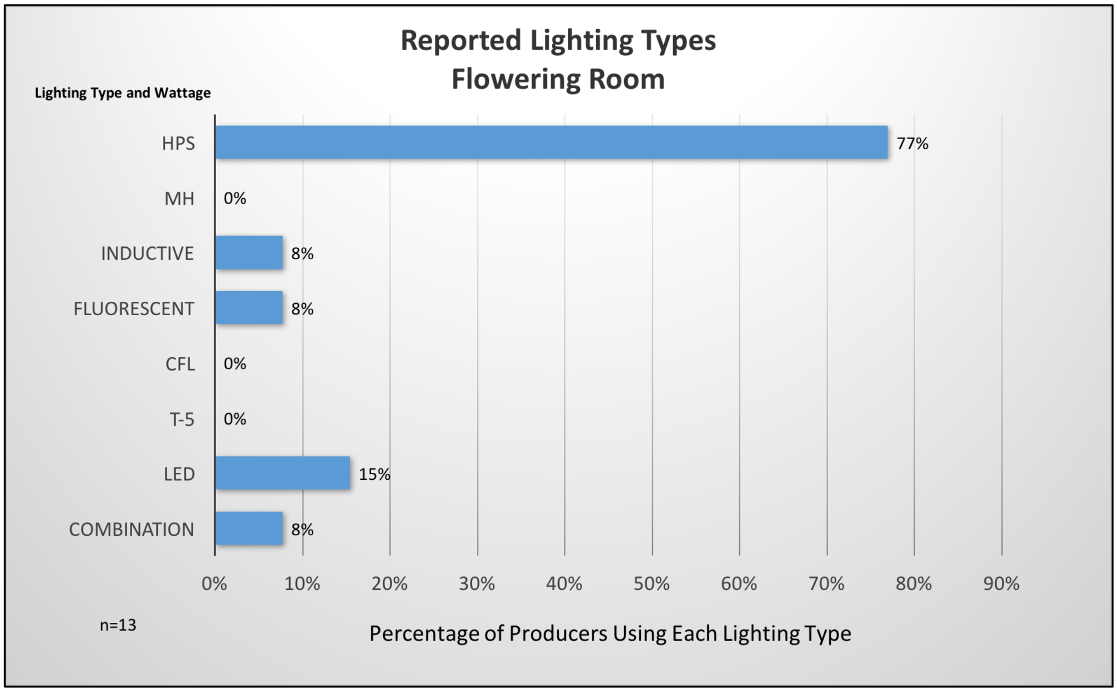

Fig. 4.2.6: Reported lighting types used in sampled Flowering rooms n=13. Several samples are represented more than once due to the use of multiple lighting types, thus the percentage using a combination of lighting types has also been included.

The preference for HID lamps most likely lies in the need for optimal photosynthetically active radiation (PAR) during flowering. Lamps such as HPS and MH offer both optimum PAR and luminous efficacy needed for plant growth (Arnold, 2013 p. 77). While more energy efficient than HID lamps, fluorescents offer less luminous efficacy and PAR than HID lamps (Arnold, p. 55 2013), which may explain their low usage in Flowering rooms. Despite being the most energy-efficient lighting type, LED lights offering comparable PAR to HID lamps have become economically viable for less than a decade (Yeh & Chung, 2009).

At 15%, the reported usage of LED lamps in the data set falls well below that of HPS lamps. However, they do come in second as the highest reported lighting type (Fig.

4.2.6). It would seem some cannabis producers are breaking away from the old standard of HPS in favor of LEDs. Among survey respondents still resistant to the idea of LEDs, three cited the high cost of LED systems as a determining factor and two expressed concern over attempting new strategies that could put their success in jeopardy (n=5). These statements also echo the findings of Morris (2015). It would appear more time may be needed to prove the viability of LEDs, and the technology also needs to reach a lower price point before they will be widely accepted.

4.3 PHOTOPERIODS

Lighting types used by commercial cannabis producers offer only a partial picture of the energy intensity associated with grow lighting. The photoperiods (light and dark periods) will determine how much power each lamp will draw daily. If the yearly cycles are included, an annual kWh consumption can also be calculated. For cannabis production, the photoperiod will depend on the phase of cultivation: Shorter photoperiods are needed to mimic fall and induce flowering. Therefore, Vegetative and Flowering rooms must be analyzed separately.

As outlined in Chapter 2, the vegetative phase generally uses a photoperiod of 16 - 24 hours. In accordance with this, survey respondents for this project as well as the NWPCC study reported a range of hours from 12 - 24, with a median of 18 hours of light per day (n=16, Table 4.3.1). The literature review also shows the flowering phase generally requires 12 hours of light and 12 of darkness, which is in alignment with the photoperiods used by survey respondents, who nearly unanimously reported 12 hours (n=13, Table 4.3.1).

n=16		n=13	
Vegetative Room		Flowering Room	
Photoperiod	Number of Respondents	Photoperiod	Number of Respondents
12 hrs.	1	11 hrs.	1
14 hrs.	1	12 hrs.	12
15 hrs.	1		
17 hrs.	1		
18 hrs.	7		
24 hrs.	5		

Table 4.3. 1: Photoperiods reported by commercial cannabis producers responding to the survey developed for this thesis as well as those interviewed by the NWPCC.

The range in photoperiods reported for Vegetative rooms could result from each cannabis producer's preference for his/her own "lighting recipe." There may be an optimal vegetative photoperiod that may balance high production with energy efficiency by limiting hours of light while not sacrificing final crop yield. Conversely, the near perfect uniformity of Flowering rooms suggests the standard of 12-hours light and 12-hours dark may already be the optimum photoperiod.

4.4 LAMP DENSITY

Energy consumption from one lamp can be calculated by lighting type and photoperiods. However, to understand the energy intensity of lighting for an entire cannabis operation, lamp density must also be considered. In this context, lamp density refers to the square feet of cannabis canopy served by each light and, thus, the density of lamps used for a cannabis producing operation. Because each cannabis producing operation varies in size, observing lamp density rather than total number of lamps will offer more comparative data. Additionally, since Vegetative and Flowering rooms serve different purposes during the cannabis cultivation process, each has been analyzed and presented separately.

Vegetative rooms show a range of densities from 3 sq. ft. of cannabis canopy per light to 50 sq. ft., with a median of 19 sq. ft. per lamp (Fig. 4.4.1, n=8). Of course, the lighting type and wattage used may greatly influence how many square feet of canopy lighting can serve, as some fixtures may offer more coverage than others. Even among respondents utilizing the same lighting types, however, ranges of lamp density can be wide. The square foot of canopy served by each lamp does not appear to be strictly contingent upon the lighting type used for this sample.

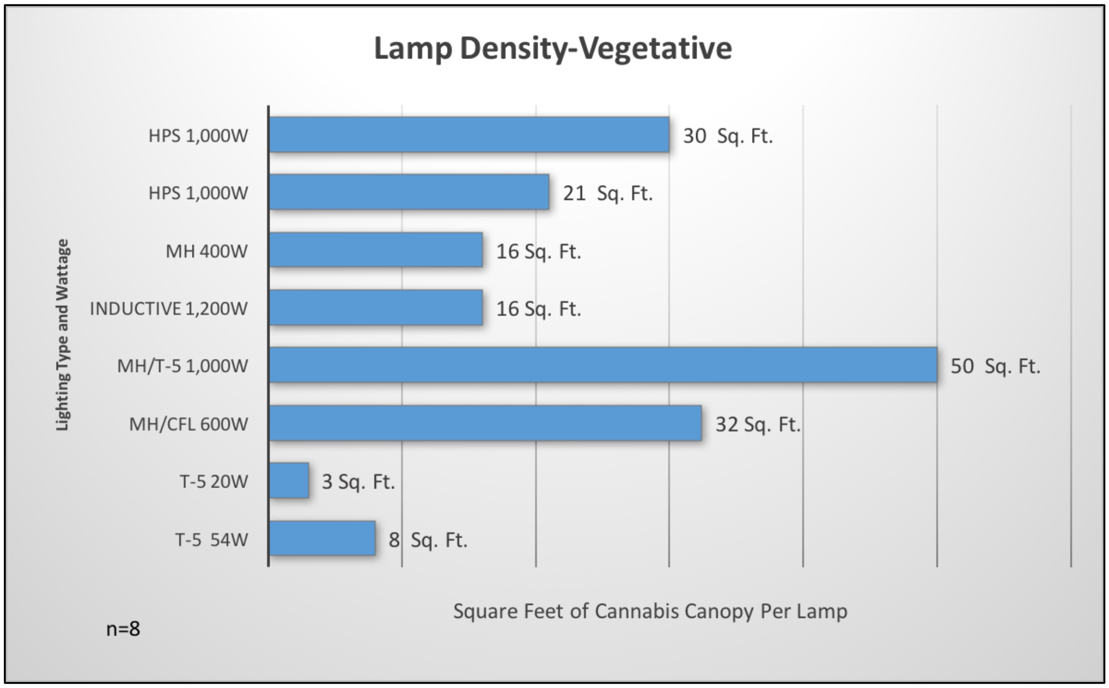

Fig. 4.4.1: Reported square foot of cannabis canopy cover served by each lamp for Vegetative rooms as reported by survey respondents (n=8). Each bar represents an individual producer's response.

The variation in density among lighting types becomes even more apparent in Flowering rooms. Densities for Flowering rooms for this sample range from 5 to 110 square foot of cannabis canopy per lamp, with a median of 26 sq. ft. (Fig 4.4.2 n=8). All but one of the respondents for this sample set reported using HPS lamps. Of the seven using HPS, five reported using exclusively 1000W lamps and included a range of sq. ft. served by each lamp from 16 to 110, with a median of 27 sq. ft. (Fig. 4.4.2). The presence of such variation among lamp density for cannabis Flowering rooms is particularly interesting, as reported photoperiods and lamp types for this space varied so little. Mills's "business as usual" model for cannabis production included the assumption of 16 square feet of canopy per lamp. Within the sample analyzed for this project, however, there does not appear to be such a standard.

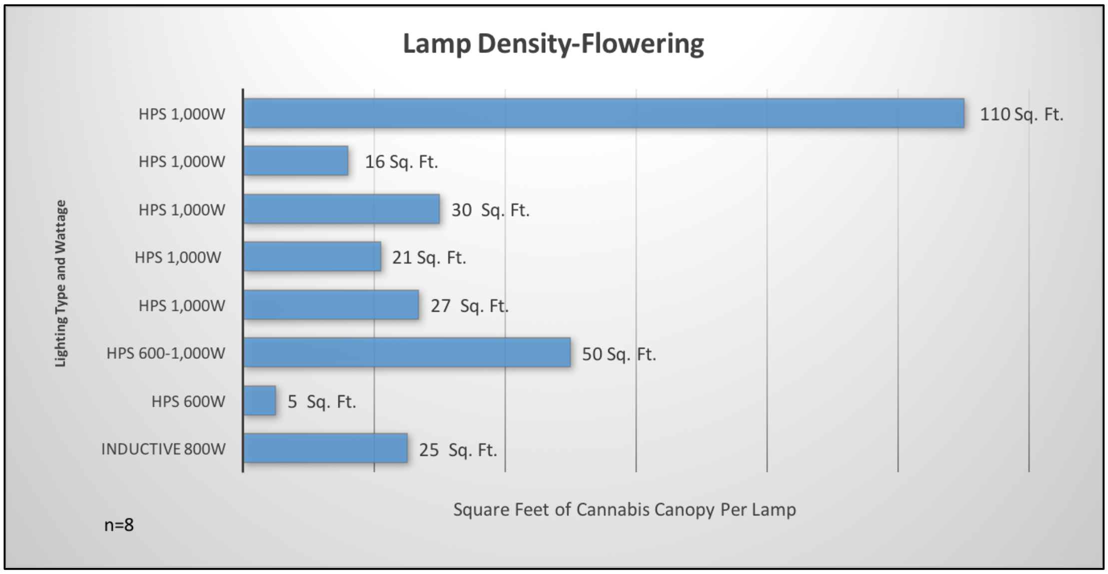

Fig. 4.4.2: Reported square foot of cannabis canopy cover served by each lamp for Flowering rooms as reported by survey respondents (n=8). Each bar represents an individual producer's response.

The variation in canopy square foot per lamp among similar samples in Flowering rooms may indicate confounding factors not examined in this project, such as genetic strain of the cannabis plants grown, distance of lamps from the canopy or the preference of individual producers, Regardless of the causes, the variation in results suggests the assumption of 16 square feet as a standard lamp density does not provide a sufficient baseline. Some producers may be over-lighting their grow rooms, which would present a significant energy-efficiency opportunity. Still others may be under-lighting rooms, which could result in smaller harvests that may indirectly impact energy consumption, since more crop cycles are needed to produce the same results as producers using light more effectively. A balance among crop productivity and efficient placement of lamps to avoid over-lighting a space would need to be discovered.

4.5 ENERGY INTENSITY OF LIGHTING

The combination of lighting wattages, photoperiods and lamp density used by a cannabis producer provide the data needed to calculate the energy intensity that producer's grow lighting. Energy use intensity (EUI) provides the standard for expressing energy usage per square foot per year for most building types (Energy Star, n.d.). Massoud Jourabchi explained during an interview how this type of EUI will not provide an accurate measure of energy use intensity for cultivation, as large portions of these operations may not be devoted strictly to growing (2015). To understand the difference in energy consumption the commercial cannabis industry presents over other industries, the cannabis itself must be the focus.

Attempts during this thesis project to collect the information needed to calculate a traditional EUI for both flowering and vegetative, such as total annual energy consumption, proved unsuccessful. In addition to this, data provided by the NWPCC from their 2015 survey of commercial cannabis producers did not include the square footage for these rooms. In both cases, however, respondents reported the cannabis canopy square footage for each room. Due to the availability of this data and the desire to provide the most applicable understanding of lighting energy use intensity, the EUI for each cannabis producer studied for this project has been calculated by square foot of cannabis canopy rather than building floor area. Because commercial cannabis licenses in Washington State rely on a “tiered” framework of cannabis canopy square foot, an EUI based on this measure may also prove more useful when attempting to project potential peak demand for this industry based on licenses already issued and pending.

As with the previous analysis discussed, the Vegetative and Flowering rooms have been analyzed separately due to their differing functions. Not surprisingly, due to the variation in lamp types and density reported for Vegetative rooms, a wide range of EUIs from 5 kWh to 494 kWh annually per square foot of cannabis canopy exists for this sample (Fig. 4.5.1). The smallest EUI of 5 kWh belonged to an indoor producer using 54W T-5 fluorescent lamps serving 8 sq. ft. of canopy per lamp (Fig. 4.4.1) and using a standard[18] photo period of 18 hours (Fig. 4.3.1). The 54W T-5 lamps represent the lowest wattage lamp within this sample set (Fig. 4.5.1). In line with this pattern, the highest wattage lamp represented for this sample set (1,200W Inductive) also holds the highest EUI at 494 kWh (Fig. 4.5.1) using the same 18-hour photo period (Fig. 4.3.1) but

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[18] Standard in terms of the findings within this thesis.

servicing a larger area of canopy at 16 sq. ft. per lamp (Fig. 4.4.1). When looking at the energy intensity per square foot for each arrangement, it becomes apparent that the T-5 fluorescents consume much less energy overall despite each lamp serving a smaller area of canopy than the 1,200W Inductive lamps. With the variety of lighting types and wattages used within such a small sample size, it can be difficult to decipher patterns from the EUI metrics. However, the importance of lamp density can be seen more clearly within the more homogenous sample set for flowering spaces.

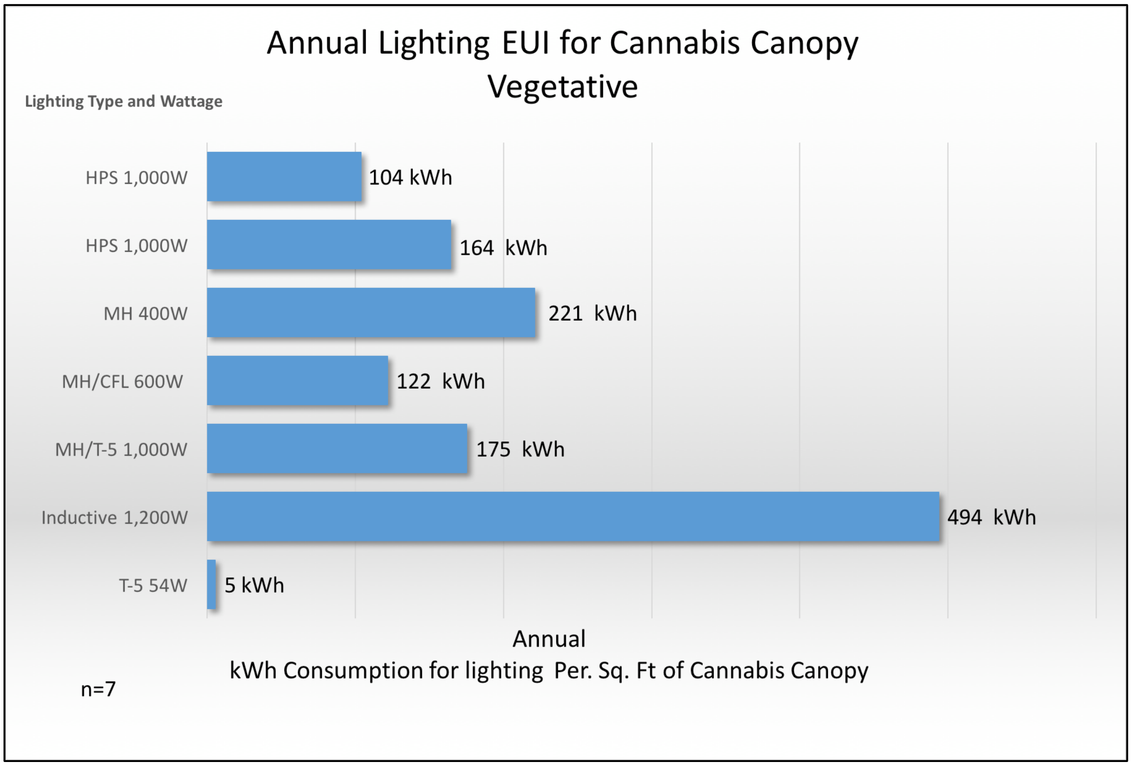

Fig. 4.5.1: Annual lighting energy use intensity per square foot of cannabis canopy cover for Vegetative rooms (n=7).

Of the seven commercial cannabis producers represented within the Flowering room sample set, all but one respondent reported using HPS in their flowering spaces. Of those using HPS, all but one utilize 1,000W lamps (Fig. 4.5.2).

The divergent wattage was 600W and, surprisingly, despite using a lower wattage, this operation also holds the highest EUI score for this sample set at 453 kWh per square foot of canopy cover (Fig. 4.5.2). The remaining five samples used 1,000W HPS and have a range of EUI scores from 35 kWh to 236 kWh (Fig. 4.5.2). The only difference between these samples lies in the density of lamps used for each flowering space. While lamp types and wattages used had an obvious impact on the energy intensity of lighting for any given cannabis producing operation, lamp density appeared to be another important factor due to the large range of densities within this sample.

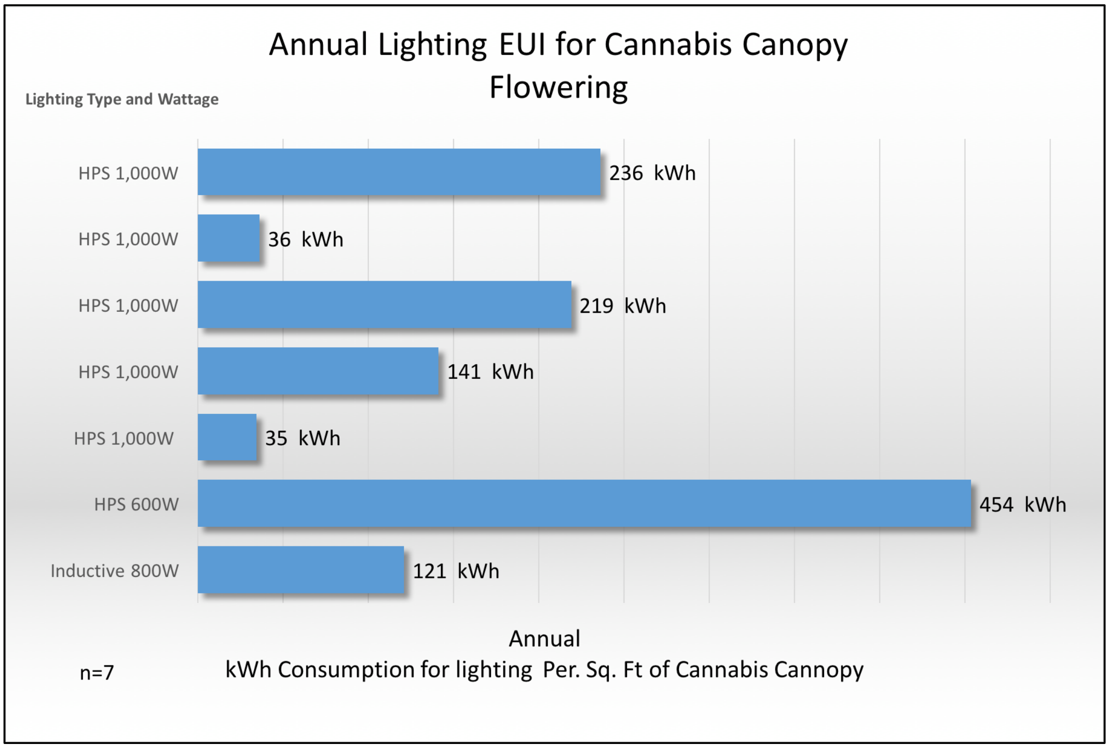

Fig. 4.5.2: Annual lighting energy use intensity per square foot of cannabis canopy cover for Flowering rooms (n=7).

The results of this thesis project represent the best approximation with the available data. In future studies, the available data set could be improved through the data collection process in several ways. First, multiple approaches of survey delivery could potentially increase the response rate and in turn the sample size. Some surveys for this project may have ended up in recipients' junk email or the email addresses may no longer have been in use. Using multiple forms of contact such as traditional mail and phone calls in addition to email may increase the likelihood of reaching more participants. For this thesis, due to time and funding constraints, these additional methods of contact could not be used. Secondly, more direct data collection with the ability to follow up could be utilized to clarify ambiguous information. All data for this project has been self-reported by the cannabis producers to safeguard anonymity, and in some cases unclear or infeasible data was reported and had to be removed from a data set. These steps could help produce larger data sets in the future. However, the findings of this thesis represent an important step in expanding our limited understanding of the energy intensity of agricultural lighting used in cannabis production.

Originally, this research endeavored to create a baseline for energy use intensity of grow lighting for commercial cannabis production in Washington State. The results show that at this early stage in the commercialization of cannabis production, no baseline exits. Contrary to Mills (2012) standardized "business as usual" model for cannabis production, variation in lighting types, wattages and lamp density resulted in wide ranges in lighting EUI. The variation in reported data and resulting EUI scores suggest energy use by commercial cannabis production needs to be explored further to truly understand the energy usage by this industry as well as opportunities for efficiency. The following chapter will discuss suggestions for future research as well as possible avenues for energy efficiency.

To discover potential paths to energy efficiency for commercial cannabis production, the current energy intensity of the industry must be addressed. The challenge in finding opportunities for energy efficiency for cannabis production lies in its fledgling nature. A reliable baseline for the energy intensity of commercial-scale cannabis grow operations does not exist at this time. Without an industry baseline, it becomes difficult to understand the potential benefits of industry-wide energy efficiency measures. The goal of this thesis project has been to advance understanding of this industry and, in turn, opportunities for energy efficiency. While the original intent of this project had been to calculate a baseline of energy intensity per-square foot of grow lighting used in cannabis production, the lack of standardization across the industry made that impossible. The findings of this project instead suggest an individualized approach to energy efficiency would need to be taken in cooperation with each cannabis producer. Furthermore, the data collected provides an informative glimpse into the variety of operations now serving Washington State. Future research will be needed to discover optimal methods for producing cannabis that could balance both energy efficiency and production output.

5.1 RECOMMENDATIONS FOR ENERGY EFFICIENCY GAINS IN GROW LIGHTING

Current literature suggests grow lighting accounts for 38% to 86% of the total electrical energy consumption used in the production of cannabis (Arnold, 2013; Jourabchi, 2014 & Mills, 2012). Based on these findings, focusing on the use of agricultural lighting appears to be the most valuable pursuit for energy efficiency in cannabis production and therefore guided the research for this thesis project. The results of this project suggest possible energy efficiency gains in several forms: the use of less artificial light and more natural light, optimized densities for light fixtures in both vegetative and flowering rooms, adjustments in photoperiods, and the implementation of more energy-efficient lighting technology.

First and foremost, the reduction or elimination of artificial agricultural lighting offers the greatest opportunity for decreasing energy consumption. Natural sunlight could be leveraged more widely via greenhouses or outdoor cultivation to supplement or replace artificial light. The formation of organizations such as the Washington Sungrowers Industry Association (WSIA) indicates the use of natural light in cannabis production as an energy conservation method has support in the public arena. Of course, the use of natural sunlight exclusively would limit cannabis producers to seasonal growth cycles, whereas artificial light gives producers the ability to cultivate crops year-round. The most beneficial arrangement would be to balance the use of natural and artificial light. During the longer, brighter seasons, natural light could be used to its fullest potential and supplemented by artificial light when needed in the darker times of the year. Even in areas where lack of access to agriculturally-appropriate land restricts outdoor cultivation, greenhouses or the use of daylighting in buildings could be utilized to reduce the need for artificial light. When circumstances necessitate artificial light, additional steps can be taken to ensure its use in the most efficient way possible.

The first step in using artificial light efficiently would be to use only as many fixtures as necessary. The findings of this thesis showed a wide range of lamp densities being used for cannabis production. Producers using more lamps per square foot of cannabis canopy may be providing more light than needed for optimum production, driving up their energy usage. Conversely, those who do not provide enough light for their cannabis plants to flourish may be lowering their final crop yields. These producers would need to harvest more crop cycles to achieve the same volume of cannabis compared to those who provided adequate light. As suggested previously in the review of literature, this could ultimately *increase* overall energy intensity per pound of product. Therefore, energy conservation would best be achieved by finding the *optimum* light density for cannabis production and not exceeding it. Further research should be undertaken to find this optimum light density, while also taking into account photoperiods which further impact the growth of cannabis.

The operations of survey respondents examined for this thesis reported a range of photoperiods for their vegetative rooms but near uniformity for flowering rooms. The range of photoperiods for vegetative rooms suggests multiple photoperiods work for the vegetative stage of cannabis production. Again, as with light density, some producers may be providing too much light, and others too little. Additional research could help discover whether or not cutting back on photoperiods in vegetative rooms could lower energy usage without hindering final crop output. Discovering the optimum photoperiod for vegetative rooms could help ensure the most efficient use of artificial light in these areas.

Placing lamps farther apart could be another energy reduction method. Increasing the square footage of cannabis canopy served by each lamp or reducing photoperiods represent relatively simple, low-cost or no-cost methods to reduce the energy consumption of lighting for cannabis production. Another step would be to encourage the use of LED lamps, which offer the most light per watt over highly energy-intensive HID lamps. This option, however, would be more difficult for cannabis producers to act on due to up-front cost barriers. At the time of this writing, LED lamps offering optimal PAR for agricultural use do exist in the market, but at a high price. In fact, of the five respondents who answered the survey questions relating to the use of LED lighting, three cited high cost as a barrier to using this lighting type. Arnold (2013) and Morris (2015) also cited cost concerns of LED lighting as a hurdle to implementation among cannabis producers. Cost-cutting measures such as utility energy efficiency rebates for LEDs offering optimal PAR could help reduce the financial burden on cannabis producers and encourage them to move away from the use of HID lamps.

Many utilities in Washington already offer rebates on efficient lighting to capture energy savings as required by I-937. A few, like Puget Sound Energy and Seattle City Light, have started extending these benefits to commercial cannabis producers as well. Some utilities are still not ready to work with cannabis producers due to concerns over conflicts with federal law (Morris, 2015; Radil, 2016 & Walton, 2014). Utilities impacted by I-937 that do not work with cannabis producers could be missing opportunities to claim significant energy savings toward their biennial goal. For example, by helping a cannabis producer pay for a switch from HIDs to LEDs through rebates, a utility could claim the energy saved (measured in kWh) from the switch toward their energy savings goal. Cannabis producers operating within the service territories of utilities not offering energy efficiency programs for cannabis production will miss out on assistance, which could further deter them from the use of expensive LED lamps. Ultimately, in the long term, the federal versus state legal dichotomy over recreational cannabis needs to be resolved before all Washington State utilities can feel comfortable assisting cannabis producers with energy efficiency entirely free from the fear of repercussions.

Utilities that *do* offer energy efficiency assistance to cannabis producers should prepare their strategies for marketing this service carefully and find effective ways to model positive outcomes, as producers may be very concerned about risking their business with a lighting switch. Apprehensive cannabis producers may need to be convinced to try more efficient lighting types in their vegetative rooms first. The vegetative rooms examined for this thesis showed a variety of lighting types, as compared to the nearly exclusive use of HPS in flowering rooms. This suggests other cannabis producers might be more easily convinced to use energy efficient lighting in vegetative rooms. If that process succeeds, a better case may be made to do the same for flowering rooms. Of course, any efforts to encourage cannabis producers to use more efficient agricultural lighting would need to consider the producer's needs and ensure their business would not be negatively impacted in the long term with lower crop yields. Any negative outcomes might damage the attitudes cannabis producers hold toward new efficient lighting types and reinforce the old preference for HID lamps.

Other energy-efficient improvements in agricultural lighting may not come from the lights but from the cannabis plants themselves. One Seattle cannabis producer, Solstice, recently reported experimenting with preserving the DNA of mother plants in petri dishes rather than long-term maintenance of the mother plants to produce cuttings (Radil, 2016). Normally, mother plants would require being kept indoors under lamps, simulating long summer days, to stop the plant from entering the flowering phase. If cannabis producers created the clone starts for each crop from preserved DNA in petri dishes, there would be no need to continually maintain mother plants and thus the energy needed to power their lamps could also be conserved.

While not an energy-efficiency measure, cannabis producers could also install solar panels to help support their energy requirements. For this to be a cost-effective endeavor, however, the time required to recoup the costs of installing such a system ("payback period") through avoided electricity costs would need to be fairly short. What would be considered a reasonable amount of time would differ for every producer due to varying electrical consumption patterns and up-front costs for the required systems.

As mentioned in chapter 2, local regulations could allow certain cities to *require* cannabis producers to supplement their energy needs with the use of clean energy technologies such as solar panels (Warren, 2015 p. 424). Such regulation, however, may result in driving cannabis producers away from these cities to avoid the financial cost and inconvenience of such a requirement. Instead, policy mechanisms such as feed-in tariffs should be used to *encourage* the use of clean energy rather than *enforce.* Feed-in tariffs support clean energy technology by providing financial compensation based on the energy produced. Production-based incentives could also be combined with rebates to make installing a solar system even more attainable for cannabis producers. Although such strategies would not help utilities meet their I-937 conservation goals, it would help them balance the electrical load demand of the commercial cannabis industry.

5.2 SUMMARY OF RECOMMENDATIONS FOR FURTHER STUDY

For any energy efficiency efforts related to cannabis production, further research will need to be conducted to fully comprehend the impacts on energy consumption from such measures on this industry. Variation in the results of this thesis research suggests some cannabis producers may be using less than optimal light densities and photoperiods in their cultivation methods. More research needs to be conducted to find optimal lighting conditions to maximize energy savings within the boundaries of optimizing product yield. Aside from the strategic use of artificial light, the technology of the lamps themselves also represent important areas of research.

Technological development tends to follow a pattern of improved performance and falling costs. The evolution of the LED from small instrument indicator lights to the wide range of uses they provide today indicate lighting technology falls into this pattern as well. Advances in lighting technology will also benefit the fledgling commercial cannabis industry. As energy-efficient agricultural lighting continues to improve and become less expensive, the benefits of such lighting types will begin to strongly outweigh the costs. Specific focus on providing a high PAR in less costly, energy-efficient light will be crucial for the cannabis industry.

Due to the importance of THC to the recreational cannabis market as the source of its psychoactive effects, additional research should also be undertaken to ensure THC levels will not be negatively impacted from the use of LEDs. While Vanhove (2011) suggests genetics play the most important role in THC concentrations, the proper use of light can maximize a strain’s potential. Many in the industry still remain skeptical about the use of LEDs in cannabis production, citing concerns of THC impacts (Arnold, 2013;

Mills, 2012 & Morris, 2015). A well-designed study could put to rest the fears of cannabis growers and answer questions about the relationship between LEDs and THC in a variety of strains of plants.

Current research regarding the use of LEDs in agriculture primarily focuses on food crops such as potatoes and lettuce (Aldos et al, 1996; Bot, 2001; Doucleff, 2013; Meinhold, 2013; Mitchell, 2014; Morrow, 2008; Yeh, 2009). Since legal recreational cannabis production began in Washington State, some LED distributers have conducted case studies on the use of LEDs in cannabis production. One such distributer – Forever Green Indoors – asserts their case studies to be independent, since cannabis producers were not compensated for their participation and THC results have been verified by independent labs (Forever Green Indoors, 2016). To put concerns over negative THC impacts to rest, truly independent and scientifically-rigorous research will need to be conducted on the impact of LEDs on cannabis production.

The experimentation of one cannabis producer, Solstice, with preserving the DNA of mother plants in petri dishes to skip the energy costs of keeping these plants for cuttings also suggests an interesting avenue for future research in cloning. Other research relating to cannabis DNA could focus on continuing to increase harvest yields as the sinsemilla technique has done for generations of cannabis plants. Higher yields would mean fewer harvest cycles would be needed to generate the same volumes of product and, in turn, would lower the energy intensity put into each pound of product. Research on DNA manipulation through genetic selection could also attempt to produce an "energy-efficient" cannabis strain that requires less light to produce the same yield and quality as other strains.

Whether energy efficiency measures taken by the commercial cannabis industry fall into the categories of behavioral, technical or biological, a more comprehensive survey on energy use in cannabis production will be needed. The impacts of such measures will be difficult to predict without a more thorough understanding of how this industry uses energy at all stages of production. Understanding the diversity of commercial cannabis operations would also assist in creating more accurate electrical load demand projections. At this point in time, only one thing can be certain: due to the need for artificial light and environmental controls, commercial cannabis grown indoors suffers from chronically high energy demand. There must be a coordinated effort between policy makers, utilities and cannabis producers to use energy more wisely in this burgeoning industry.

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APPENDIX A- SURVEYS

Questions from the 2015 NWPCC survey from which this thesis' survey design has been based.

Growing method for: (Optional/ name of your business):

Type of facility	Bld. square footage	Total canopy square footage	Type of lights used: e.g. HPS (specify electronic or magnetic ballast), MH, CMH, Double ended HPS, LED, Induction, T-5, T-8, Compact fluorescent)	Square footage of canopy served by each fixture	Number of plants per fixture	Lamp wattage	Photoperiod
Indoor							
Vegetative room							
Flowering room							
Greenhouse							
Vegetative room							
Flowering room							
Outdoors			NA	NA		NA	NA

1. Have you experimented with LED lighting or heard feedback from other growers on LED lighting?

2. Would you consider using LED lighting for any stage of your operation? Why or why not?

   -Have you considered induction lighting strategies? Why or why not?

   -Have you considered double ended HPS or plasma lighting?

3. Questions regarding production:

   -Roughly how many pounds of product do you harvest per crop cycle?

   -What is the average length per crop cycle and how many cycles do you expect each year?

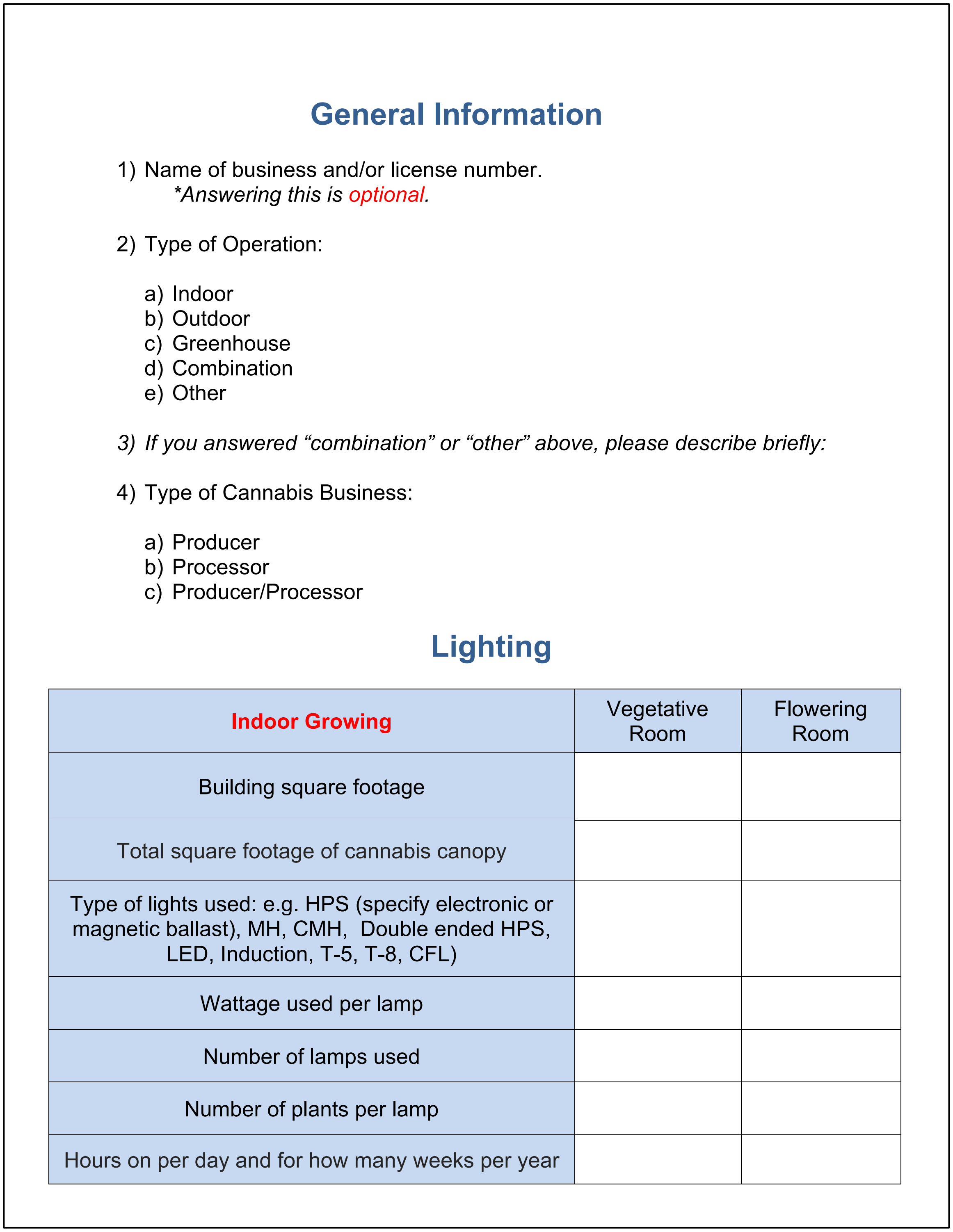
   -Annually, how many pounds of product do you produce?

4. Are you currently affected by tiered electricity rates?

	Last month	Last year
Electric bill ($)		
Electric KWH		
Natural Gas bill ($)		
If using generator fuel usage in gallons		

5. Do you currently grow in soil or grow hydroponically?

Survey developed for this thesis. Final surveys administered via “Survey Monkey” through an email link sent to Washington State commercial cannabis growers during data collection.



General Information

1) Name of business and/or license number.
    **Answering this is optional.*

2) Type of Operation:
    a) Indoor
    b) Outdoor
    c) Greenhouse
    d) Combination
    e) Other

3) *If you answered “combination” or “other” above, please describe briefly:*

4) Type of Cannabis Business:
    a) Producer
    b) Processor
    c) Producer/Processor

Lighting

Indoor Growing	Vegetative Room	Flowering Room
Building square footage		
Total square footage of cannabis canopy		
Type of lights used: e.g. HPS (specify electronic or magnetic ballast), MH, CMH, Double ended HPS, LED, Induction, T-5, T-8, CFL)		
Wattage used per lamp		
Number of lamps used		
Number of plants per lamp		
Hours on per day and for how many weeks per year		

Greenhouse Growing	Vegetative Room	Flowering Room
Building square footage		
Total square footage of cannabis canopy		
Type of lights used: e.g. HPS (specify electronic or magnetic ballast), MH, CMH, Double ended HPS, LED, Induction, T-5, T-8, CFL)		
Wattage used per lamp		
Number of lamps used		
Number of plants per lamp		
Hours on per day and for how many weeks per year		

5) Have you experimented with LED lighting or heard feedback from other growers on LED lighting? If so, please explain:

6) Would you consider using LED lighting for any stage of your operation? Why or why not?

7) Have you experimented with, or considered using any other lighting types or strategies? Why or why not?

Energy Usage

Energy Type	Total usage for the past 12 Months
Electric usage in kWh **Found on your electric bill*	
Natural Gas usage in Therms **Found on your Natural Gas Bill*	
If using generator, fuel usage in gallons	

8) How many months of the past 12, has your operation been active in cannabis production?

   a) Have any major changes occurred in your lighting or heating and cooling equipment in the past year? If so, please explain:

Production

9) What is the average length per crop cycle and how many cycles do you expect each year?

   a) **Optional*: Volume of crop (in pounds) produced each crop cycle:

10) Do you currently grow in soil, hydroponically or aquaponically?

Please email this survey by Feb. 15th to:

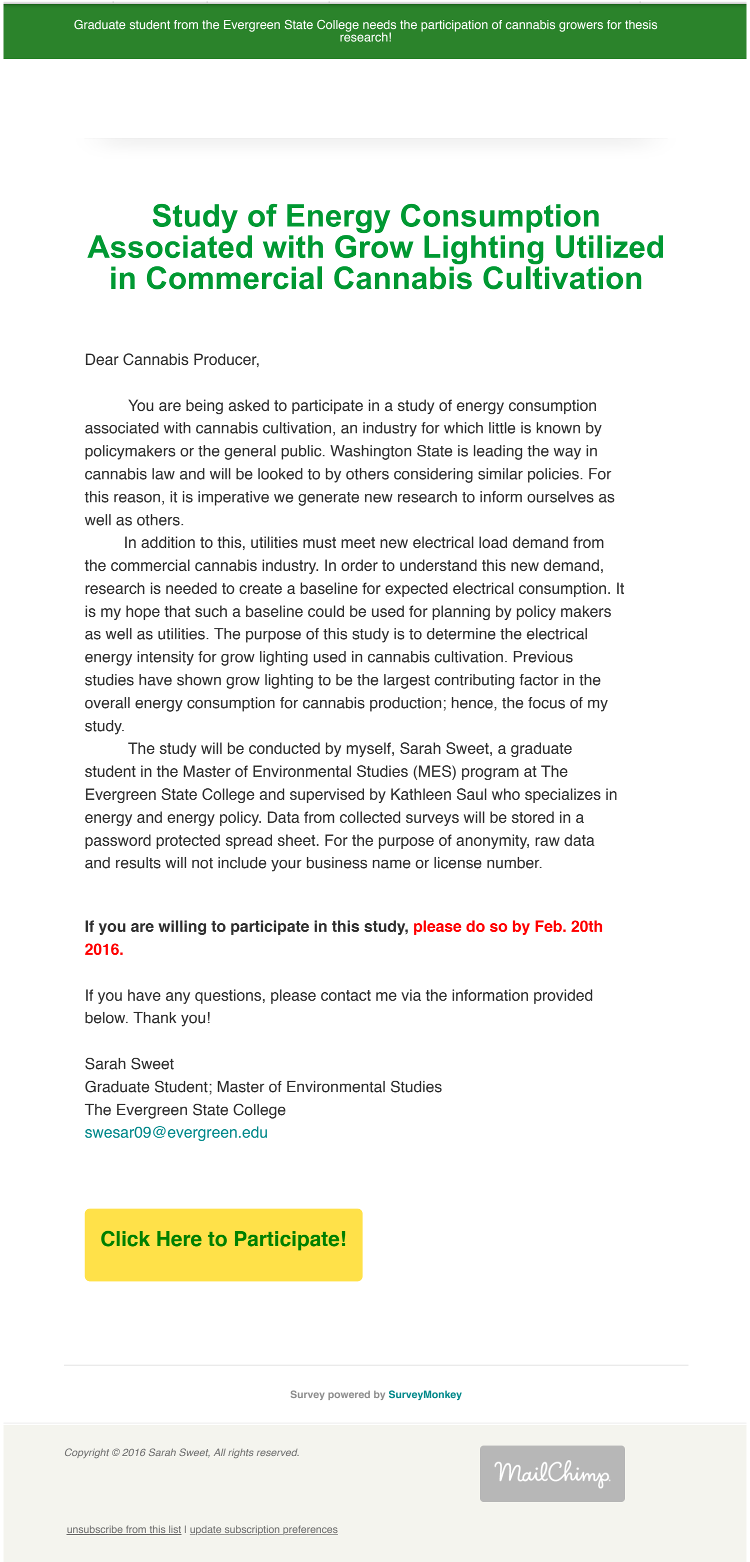
Sarah Sweet
swesar09@evergreen.edu

Please contact me with any questions regarding this survey.

Thank you for your participation!

APPENDIX B-CORRESPONDENCE

Sample participation request email:



Graduate student from the Evergreen State College needs the participation of cannabis growers for thesis research!

Study of Energy Consumption Associated with Grow Lighting Utilized in Commercial Cannabis Cultivation

Dear Cannabis Producer,

You are being asked to participate in a study of energy consumption associated with cannabis cultivation, an industry for which little is known by policymakers or the general public. Washington State is leading the way in cannabis law and will be looked to by others considering similar policies. For this reason, it is imperative we generate new research to inform ourselves as well as others.

In addition to this, utilities must meet new electrical load demand from the commercial cannabis industry. In order to understand this new demand, research is needed to create a baseline for expected electrical consumption. It is my hope that such a baseline could be used for planning by policy makers as well as utilities. The purpose of this study is to determine the electrical energy intensity for grow lighting used in cannabis cultivation. Previous studies have shown grow lighting to be the largest contributing factor in the overall energy consumption for cannabis production; hence, the focus of my study.

The study will be conducted by myself, Sarah Sweet, a graduate student in the Master of Environmental Studies (MES) program at The Evergreen State College and supervised by Kathleen Saul who specializes in energy and energy policy. Data from collected surveys will be stored in a password protected spread sheet. For the purpose of anonymity, raw data and results will not include your business name or license number.

If you are willing to participate in this study, please do so by Feb. 20th 2016.

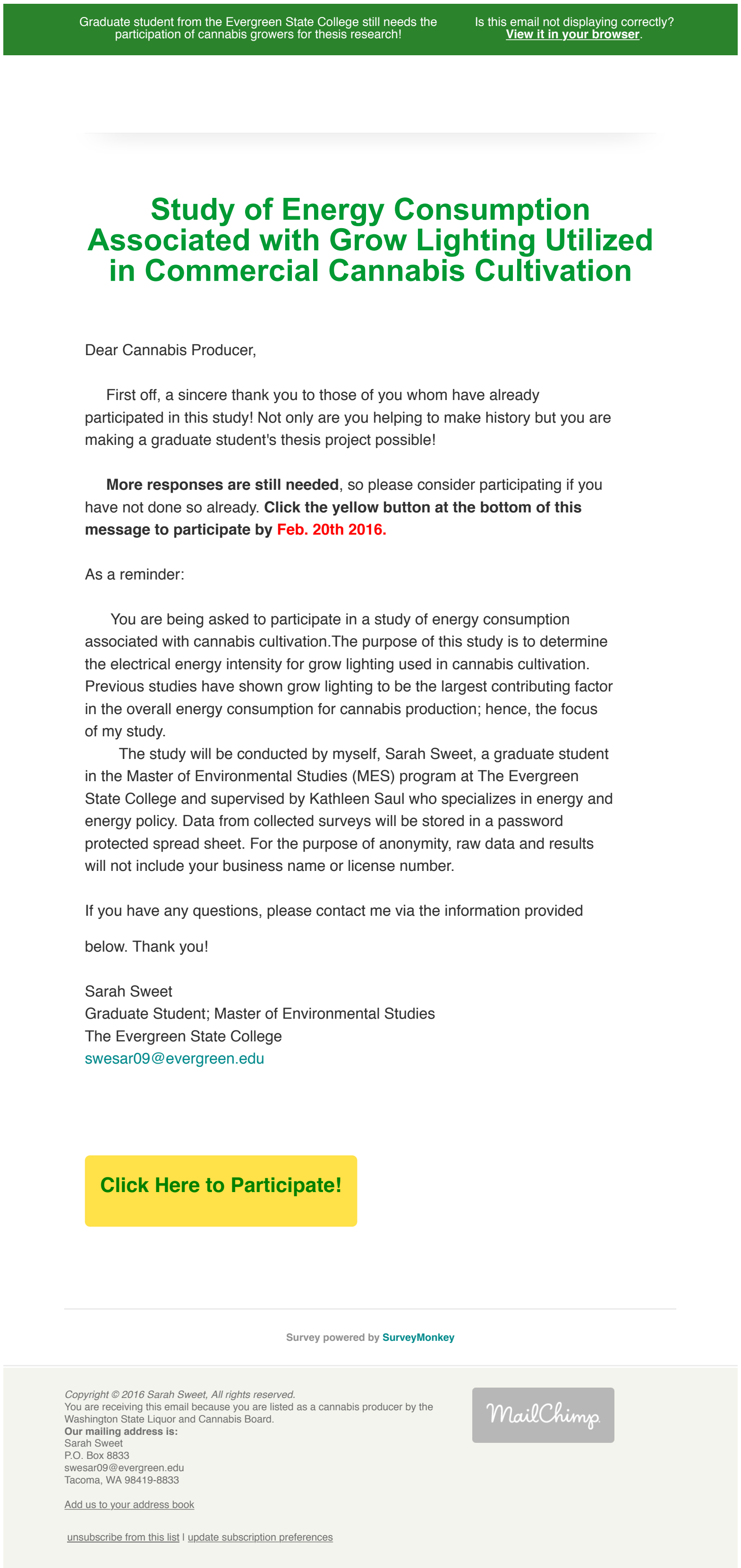
If you have any questions, please contact me via the information provided below. Thank you!

Sarah Sweet
Graduate Student; Master of Environmental Studies
The Evergreen State College
swesar09@evergreen.edu

Click Here to Participate!

Survey powered by SurveyMonkey

Sample participation request reminder email:



Graduate student from the Evergreen State College still needs the participation of cannabis growers for thesis research!

Is this email not displaying correctly?
View it in your browser.

Study of Energy Consumption Associated with Grow Lighting Utilized in Commercial Cannabis Cultivation

Dear Cannabis Producer,

First off, a sincere thank you to those of you whom have already participated in this study! Not only are you helping to make history but you are making a graduate student's thesis project possible!

More responses are still needed, so please consider participating if you have not done so already. **Click the yellow button at the bottom of this message to participate by Feb. 20th 2016.**

As a reminder:

You are being asked to participate in a study of energy consumption associated with cannabis cultivation.The purpose of this study is to determine the electrical energy intensity for grow lighting used in cannabis cultivation. Previous studies have shown grow lighting to be the largest contributing factor in the overall energy consumption for cannabis production; hence, the focus of my study.

The study will be conducted by myself, Sarah Sweet, a graduate student in the Master of Environmental Studies (MES) program at The Evergreen State College and supervised by Kathleen Saul who specializes in energy and energy policy. Data from collected surveys will be stored in a password protected spread sheet. For the purpose of anonymity, raw data and results will not include your business name or license number.

If you have any questions, please contact me via the information provided below. Thank you!

Sarah Sweet
Graduate Student; Master of Environmental Studies
The Evergreen State College
swesar09@evergreen.edu

Click Here to Participate!

Survey powered by **SurveyMonkey**

You are receiving this email because you are listed as a cannabis producer by the Washington State Liquor and Cannabis Board.
Our mailing address is:
Sarah Sweet
P.O. Box 8833
swesar09@evergreen.edu
Tacoma, WA 98419-8833

Add us to your address book

unsubscribe from this list | update subscription preferences

APPENDIX C- ASSUMPTIONS

In some cases, survey responses necessitated interpretations to be made about specific samples. In the following list, “NWPCC” denotes a sample collected from the NWPCC. As the NWPCC collected data from 17 cannabis producers, their samples have been numbered 1-17.

1. NWPCC 14 stated "13X HPS [High Pressure Sodium] Fixtures per room" were used. As no confirmation could be made about their use in the reported green house, it has been assumed to mean the Vegetative and Flower rooms.

2. In cases where the number of lamps had not been reported, but lamps per square foot of canopy had been, the number of lamps were inferred based on the latter metric. The number of lamps used in Vegetative rooms were calculated in this manner for samples NWPCC 6, NWPCC 11, NWPCC 12 and NWPCC 16. For Flowering rooms, number of lamps were calculated for samples NWPCC 5, NWPCC 6, NWPCC 11 and NWPCC All other samples used to calculate energy intensity self-reported numbers of lamps used in each room.

3. Canopy Square footage for the indoor Flowering room for sample NWPCC 11 was also inferred based on the total canopy square footage minus the reported canopy square footage reported for their Vegetative room. Square foot canopy cover per fixture and lighting types were reported for this sample’s Flowering room.

4. Length of photoperiod per year was not reported in the NWPCC data. To calculate annual EUI for canopy cover, the median for samples with reported photoperiods including length of photoperiod per year have been used.