Studying a Vacant Building:
Heitman Staff Learning Center at UC Davis

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Client: Dr. Alan Meier and the Energy Conservation Office

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Project Background:

The Heitman Staff Learning Center located at UC Davis is a two-story building used mainly for office space and staff training. Built in 1913, Heitman was originally named the “Hog Barn,” and is a 4,600 square foot wooden frame structure, with its last renovation completed in 2008.

In March of 2020, the COVID-19 global pandemic resulted in a state-wide lockdown, and all nonessential facilities were closed on campus. As of June 2021, Heitman has since been vacant, with employees working remotely. Although there has been next to no one using equipment or appliances inside, electricity and natural gas usage data reveals that a “baseload,” ranging from 0.5 to 1.5 kilo-watt hours (kWh) of electricity, is still being used in the building. In addition, spikes of energy usage are also detected throughout the week within certain time frames.

The client, Dr. Alan Meier (adjunct professor of the Department of Environmental Science and Policy and affiliated with the Energy and Efficiency Institute), requests the team to discover and attribute the causes of these baseloads and energy spikes to specific appliances and building functions. Energy efficiency and conservation strategies and recommendations for Heitman are also needed for both during building vacancy (during the pandemic) and business-as-usual usage (post-pandemic).

While this specific building was chosen for investigation, it is important to acknowledge that building vacancy energy usage is a wide-spread problem around the world, during both pandemic and non-pandemic periods (for example, during weekends and holidays). Analyzing energy consumption leads to insight in where to improve aspects of other buildings, and can reduce electricity wastage, saving resources, money, and emissions.

Scope:

Within 10 weeks, this project aimed to analyze findings from energy audits of the Heitman Staff Learning Center and to uncover the causes behind the baseloads and energy usages during building vacancy periods, as well as make suggestions for improving energy conservation. Single-day data is analyzed to better understand peak usages throughout a 24-hour period, comparing weekdays to weekends. In addition, a week-long period is observed to better visualize the differences between weekdays and weekends. Energy conservation recommendations are made based on both specifics of the building and general common appliances that can be found in other buildings.

Initial Findings:

Wang et al (2010) in a similar study shows that lighting, air conditioning and occupancy rates drive energy consumption. It recommended a study that is extended over a long period and across varying weather conditions. Another study states that Miscellaneous Electric Loads (MEL) account for about 20% of primary energy use in buildings and keeps increasing due to the rise in the use of mobile gadgets and computers (Kamilaris et al, 2014).

Anderson et al (2015) states that there is a wide spread of household energy consumption during vacancy ranging from 27.5% to 31.5%. University buildings are typically used to accommodate people; while a staff learning center is different from a household building, it is meaningful to gain perspective on the ratio of energy consumption during vacancy. The remarkable 31.5% is certainly the ratio we hope to avoid.

Preliminary review of the floor plans show that there are 15 total rooms on the first floor and 3 rooms on the second floor; the rooms on the first floor are mostly offices and the second floor is a mechanical space and networking room.

Energy Audit and Methodology:

Energy audits were performed to inspect the electrical loads within a building. As the pandemic has brought constraints to everyone's everyday life, the same applies for performing the audits. The goal was to have as few in-person indoor site visitations as possible, and thus it was more difficult to gather all necessary information as compared to the non-pandemic era. There are also essential appliances inside Heitman that were not possible to measure the electrical energy consumption of, due to being unable to unplug them or being completely inaccessible. Some examples include being unable to unplug the perpetually-running networking racks, or the inaccessibility of water compressors within the walls for water fountains. Instead, the team made educated guesses based on literature reviews and research to estimate the energy usages of such appliances.

Plug load monitors were used to take the energy ratings of the appliances we were able to unplug and these values were tabulated into different classes as seen in Appendix A. Based on these measurements and that of nameplates of some other appliances, we had five classes of loads in the building.

Site Visits and Energy Audits

After the initial energy audit on April 27th, 2021, the team discovered many appliances throughout the building, some of which are still running, or on standby mode. When initially entering the building, most lights are motion sensed, and thus are never turned on unless someone walks by. Other appliances and devices can be found listed in Appendix A.

Contained upstairs are many building-essential components running inside. There is a networking rack area where computer networking equipment is on and running constantly. In order to regulate the server rack temperature is a wall-mounted air conditioning unit, set to 20°C (68°F).

Figure 2: Server Room Racks

Figure 3: Server Room Wall-Mounted AC Unit

A different room holds the water heater and HVAC systems. While the water heater is gas powered, it still requires a certain amount of electricity to run its fans. Space heating uses natural gas, but cooling uses electricity.

While the use of indoor lighting is generally energy efficient, as all are either left off or have motion sensors, the outdoor lighting is set up differently. After dark on May 4th, 2021, it is observed that seven outdoor lights, two of which are LEDs, are on and are not motion sensed. Our team discovered that this is due to safety in the dark.

A second indoor visit on Monday, May 17th, 2021, revealed new discoveries, and served as another opportunity to check over appliances again for clarity of their current states. A fourth HVAC system was found inside next to the first-floor classroom connecting to a vent, which explains the total of four exhaust fans located outside.

The two water fountains on the ground floor did not emit any heat or sounds, and no water came out of the fountains when pressed, so it is safe to assume the water system feeding into the fountains has been shut off.

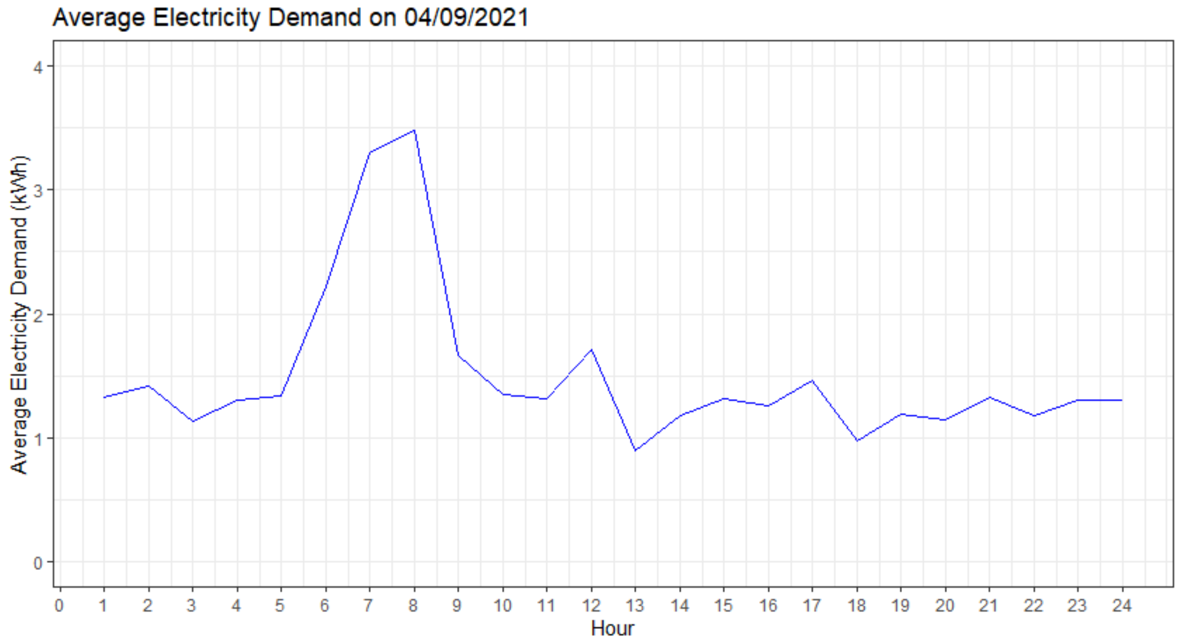
The team gave a closer look at the air conditioning unit in the server rack room on the second-floor, and the nameplate data was recorded. Also on the second floor, the water heater pump was closely inspected, and a schedule as well as an on/off function was documented. As Heitman is not used as a residential unit, hot water is not essential, and thus this system was shut off during the visit.

The HVAC systems were also looked over to count four fans, which use electricity to operate. These fans are used to disperse hot or cool air throughout the building.

Findings and Data Analysis

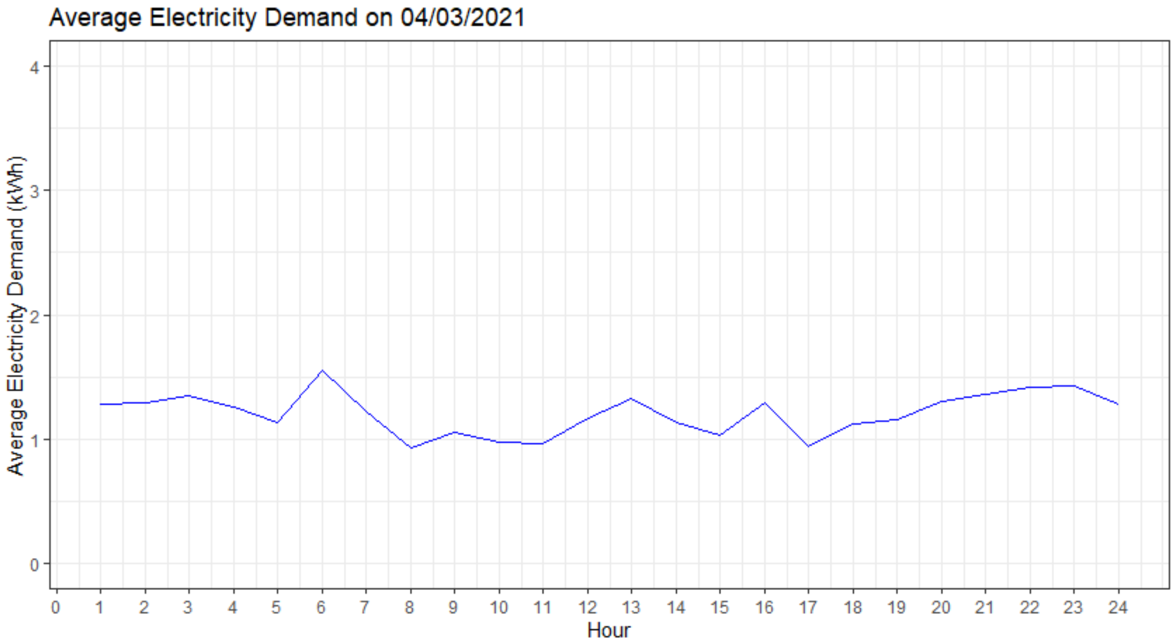
The team was provided vital data points from Leslie Nelson, a graduate student working with the Energy Conservation Office. Given an average electricity use data point in kilowatts every 5 minutes every day for several months in 2020 and 2021, the average use per hour was taken by adding all sampled data points in each hour and dividing by twelve, the total number of points per hour, in order to have kWh as the final units. Using R, we were able to generate graphs of levels detected during the pandemic. We plotted 24-hour periods of specific days in April 2021, separating weekdays from weekends. It is clear that there are several similarities and differences between the two example weekday and weekend plots.

Figure 4: Weekday, During Pandemic - Friday, April 9th, 2021



For weekdays during the pandemic, it can be seen that there is a baseload present throughout the 24-hour period, fluctuating between approximately 1.0kWh and 1.5kWh. From Monday through Friday, it is observed in the data that there are high spikes in electricity use in the early mornings. As shown in Figure 4, this spike occurs from 5AM to 8AM on Friday, April 9th, 2021. From the SWARM Pelican smart thermostat group, our team learned that every weekday morning the schedule is set to “optimum start,” which, in the cooler months, boots up the heating early in the morning to warm up the cooled building from the night before to a more comfortable temperature when occupants arrive at around 8AM in the morning. It was discovered that this system was meant to go off during the vacancy to conserve energy as no one was coming in, but it was left on for most of the duration of the pandemic.

Figure 5: Weekday, During Pandemic - Saturday, April 3rd, 2021



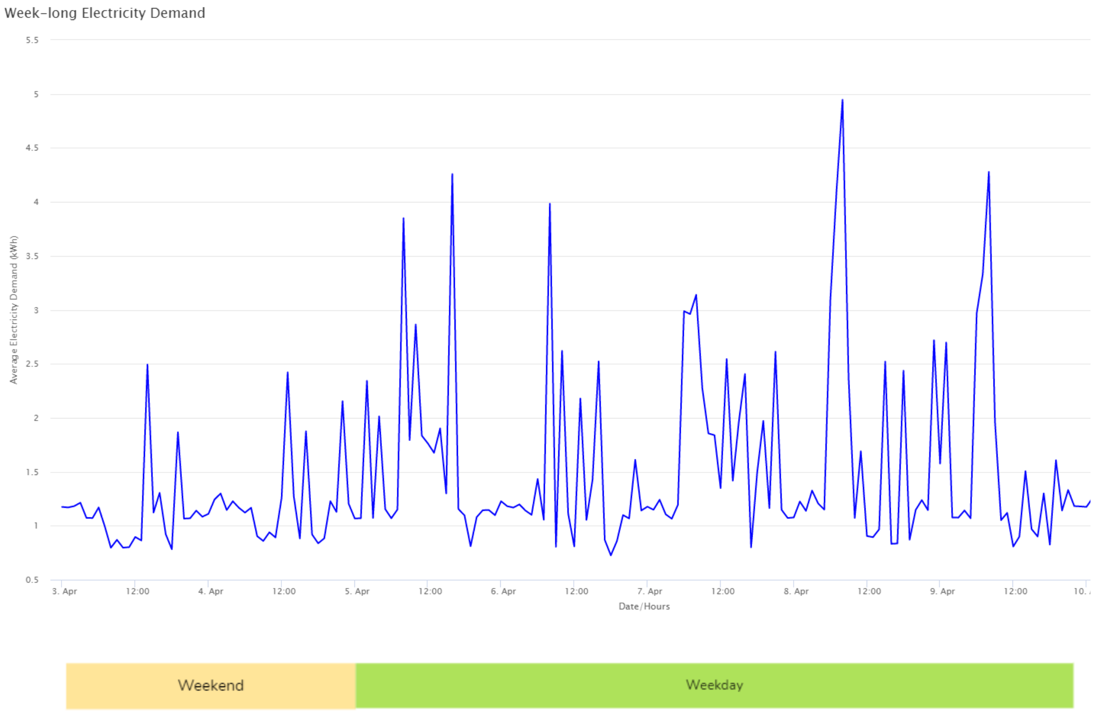
For both weekends and weekdays, the team can infer that certain intermittent loads are using up the energy baseloads and fluctuations seen throughout the day. For example, the schedule for the thermostat is set to be kept off during the weekends, but have it on from 8AM-6PM daily on weekdays (Mondays through Fridays), with the heating set to 70°F and 74° for cooling. This could explain the fluctuations in energy consumption throughout the daylight hours for weekdays, as generally temperature rises in the afternoon.

For weekends, these similar fluctuations could be attributed to loads such as the refrigerator, which runs its system throughout the day, and the networking equipment and the air conditioner in the room which are on perpetually. As there are also other smaller loads inside the building, especially in the office space and classroom such as standby computer monitors, these may add up to account for energy consumption.

During the nighttime, the outdoor lights are left on during all sunset hours, which accounts for approximately 0.4kWh of electricity of the roughly 1.0kWh to 1.35kWh baseload that is seen consistently in Figures 4 and 5 throughout every night of the week.

Compared to weekdays, energy use on weekends during the pandemic is more constant. There are still some fluctuations (slight peaks and drops) throughout the daytime, but the values steady out at night. Figure 6 below displays a week-long, 7 day vacancy data, from April 3rd to April 9th, 2021, to better depict this comparison.

Figure 6: Week-Long Vacancy Energy Usage



From this data, it can be observed that weekends generally use less electricity than during weekdays, with smaller peaks and fluctuations.

After collecting all information through the building energy audits and literature reviews, data sheets were compiled to reflect different categories of energy: Continuous Loads, Intermittent Loads, Continuous Loads - Ratings when not on Standby, Smaller Continuous Loads, and General Lighting - Controlled. Several useful graphics were generated from this data. The description for these loads are Continuous Loads, which are working round the clock irrespective of season; Intermittent Loads, which only come on according to a schedule or the time of the day; Smaller Continuous Loads, such as the emergency light which consume minimal electricity; General Lighting, which are mostly controlled by a switch or motion sensors; and Continuous Loads ratings when not on standby, which does not really affect vacant buildings because most of them are on standby when the building is vacant.

Below in Figure 7, the energy usages of Heitman are divided by time. It shows that intermittent loads consume more than half of the electricity, which include devices such as the refrigerator and the HVAC system. Approximately a third of the energy comes from plug loads, such as projectors, the A/V rack, photocopier, printer, standby computers, etc.

Figure 7: Energy Usage by Usage Time

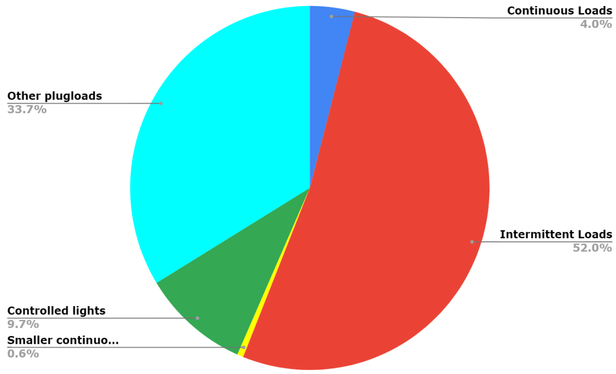
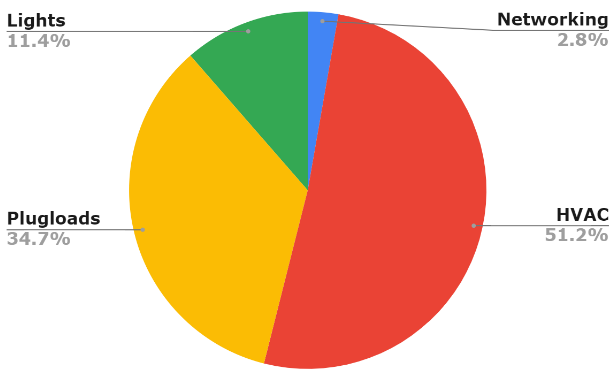


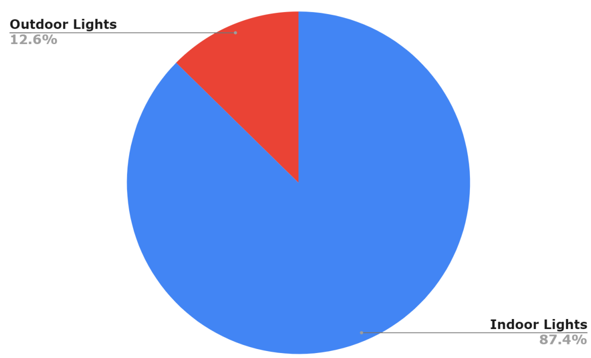
Figure 8 below displays electricity consumption categorized by device or appliance type. The HVAC system uses more than half of the electricity usage within the building, which plug loads consume approximately a third.

Figure 8: Energy Usage by Device/Appliance



When comparing indoor and outdoor lights, almost 90% of the building's lights are indoors; however, most indoor lights are motion sensed or left off during vacancy. Outdoor lighting is turned on nightly, and thus consumes the most energy used for lighting when the building is unoccupied.

Figure 9: Indoor vs. Outdoor Lights



Energy Conservation/Efficiency Tactics, Strategies, and Recommendations:

After several visits to Heitman and a thorough analysis of the energy usage data resulting in attributing certain appliances to consumption, several recommendations can be made in order to conserve energy in the building for both vacant and occupied states of the building.

Thermostat Scheduling and Settings

While a building is vacant, there is little to no need for consistent heating and cooling inside the building. The schedule shows that there is a narrow range for ideal ambient temperature within Heitman (70°F for heating, 74° for cooling). In the future, as the post-pandemic world begins to open up, a suggestion would be to increase the temperature range window to allow for higher and lower temperatures needed to trigger the HVAC system. In a completely vacant building, as with during the pandemic, it is recommended to fully shut off the thermostat system, as its primary use is to keep occupants comfortable while inside. However, it is noted that periodically the HVAC system must be turned on to ventilate the building in order to pump out older, stale air and replace it with new air, as to prevent mold growth and maintain long term building health.

In addition, the "optimum start" program operating within the SWARM Pelican Thermometers system installed in Heitman can be scheduled to turn off during vacancies. If possible, the system could be connected to occupant input data from the TherMOOstat, a UC Davis Energy and Engineering Facilities Management website that allows occupants to indicate their comfort levels within certain buildings. According to this data, the thermostat could gauge whether or not to run optimum start depending on employees. Results from TherMOOstat shows that only 10 responses were received concerning Heitman between Winter 2017 and Spring 2021, out of which 50% of the respondents complained about feeling cold.

Outdoor Lighting

As analyzed in the electricity use data graphs, a measurable portion of nighttime power is used for the seven outdoor lights. These Heitman lights can be shut off as there are surrounding street lights also left on during the night on the bike path adjacent to the building.

Figure 10: Heitman Outdoor Night Lighting

However, it is important to consider the safety issues at night, as a passerby may need more light to see in the darkness. As such, if these lights cannot be turned off, a suggestion would be to change the outdoor building lights to more energy efficient bulbs. Two are already LEDs, so it could be an option to change the other five bulbs to LEDs, or something else that is more efficient than the current lighting they use.

Server Racks and A/C

As the A/V racks from both the first floor lecture room and the second floor server rack room are operating during vacancy, and they consume an estimated 1.018KWh of energy (taking a ratio of around 68% of total standby energy use of the building), it is suggested to investigate if the server rack operation is necessary during vacancies. If the server rack is not needed to be running all the time, it is highly recommended to turn it off when the building is not in use.

A separate wall-mounted AC unit specifically for the server rack room is left on, and it consumes 0.2KWh of energy. As mentioned earlier, the AC is operating at 20°C; if the server racks are not required to be on during vacancy, this AC unit could be turned off completely. However, if the server racks are designed to be operating all the time, it is suggested to set the AC to 25°C or higher, or at a temperature based on the operation manual of the server racks, in order to save some energy usage.

Overall, Heitman is a relatively energy efficient building, considering that most appliances were off or are on standby mode, the latter of which consumes a smaller amount of energy. The HVAC system, server rack, and outdoor lighting use the most energy during building vacancy, and thus should be addressed first when considering ways to reduce electricity use.

Applicability to Other Buildings/Non-Pandemic Times:

Water Heating and Pump System

As mentioned earlier, in a non-residential building such as Heitman, the use of hot water is mostly used for handwashing, which is more of a comfort rather than a necessity. Thus, the hot water heater and pump was shut off, and other buildings that do not serve as residential housing should consider doing the same. Vacant buildings especially should shut down the water heater and pump.

Figure 11: Water Heater Pump

HVAC Scheduling and Settings

Although there are a variety of types of HVAC and thermostat settings in building spaces, it is important to check vacant buildings for any unnecessary usage of heating or cooling. An adjustment in temperature range, scheduling, or completely shutting down the system can save energy where applicable in all different kinds of buildings, depending on the situation.

Uncertainties and Further Research:

There were some uncertainties when performing the analysis of Heitman's energy usage. For example, there were unmeasurable loads including the server rack, as the team could not unplug the appliance to measure the electricity consumption. In addition, the intensity of the networking equipment energy usage is unknown, as it may fluctuate depending on the number of users. The HVAC scheduling also has its own intermittency levels that are difficult to predict exact values for, as it is dependent on the temperature throughout the day, which can change depending on a variety of factors including season and time of day.

As has been mentioned previously, the two water fountains on the first floor have been shut off during the pandemic, but their status is unclear during weekends of normal operation. Since there are built-in condensers behind the water fountains, which consume energy when running, the water fountains may be suggested to be turned off during weekends and holidays (assuming vacancy).

It is also meaningful to dive into an analysis of six portable foot heaters found in the office space, even when the building has an HVAC system installed. Energy efficiency depends on the scenario: it is still energy efficient if only one to three people are using the heaters at the same time while keeping the heating system on; however, if all six foot heaters are on consistently throughout the workday, this may mean the HVAC system is neither running efficiently or effectively, if occupants are uncomfortable with the heating levels inside the building. As mentioned earlier, the use of the TherMOOstat would be helpful in this investigation.

Analyzing the foot traffic and occupancy levels of Heitman during non-vacancies may also lead to insight in why certain loads are used and discover ways to conserve energy. Additionally, an area of research that may be beneficial to Heitman and other university buildings is the consideration of motion sensors that can be coupled with the Pelican thermostat because if a building is vacant, there should be no reason to heat it up.

Conclusion:

Generally speaking, the Heitman Staff Learning Center is already a relatively efficient building in its energy usage. However, this does not necessarily mean the building conserves energy in places where it can. According to our team's calculations, following our recommendations would result in 3,282 kWh savings per year, roughly 12.7% of yearly electricity usage.

The pandemic caused a massive and sudden shift in where people reside throughout the day, and usages within buildings. As such, nearly all building occupancies have been affected in their daily capacities and time uses. Some suggested actions can be applied to buildings on campus, or other similar buildings elsewhere.

Future investigations can be conducted to discover more inefficiencies or opportunities to conserve more energy in Heitman, such as discovering more accurate energy load measurements for certain devices that have been difficult to gain access to.

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Appendix A

1. Continuous Loads

S/N	Room	Family	Appliance	Quantity	Rating (W)	Total Rating (W)
1	Lobby	Light	Wall mounted indirect complement 8" long	2	62.00	124.00
2	Classroom	Plugloads	Projector	1	20.00	20.00
3	All rooms	Plugloads	Standby computers	18	3.00	54.00
4	Lobby 2	Plugloads	Water dispenser	1	67.43	67.43
5	Floor 2 - Network room	IT	Brocade FCX624S-HPOE	1	300.00	300.00
6	Floor 2 - Network room	IT	Brocade ICX 7450-48P2	3	106.00	318.00
7	Floor 2 - Network room	IT	APC Smart-UPS 1500	1	400.00	400.00
8	Floor 2 - Network room	HVAC	Air conditioner	1	208.00	208.00
						1,491.43

2. Intermittent Loads

S/N	Room	Family	Appliance	Quantity	Rating (W)	Total Rating (W)
1	Floor 2 - Mechanical Room	HVAC	Fan motor - GF-1	1	559.50	559.50
2	Floor 2 - Mechanical Room	HVAC	Fan motor - GF-2	1	149.20	149.20
3	Floor 2 - Mechanical Room	HVAC	Fan motor - GF-3	1	248.40	248.40
4	Floor 2 - Mechanical Room	HVAC	Fan motor - GF-4	1	373.00	373.00
5	Floor 2 - Mechanical Room	HVAC	Fan motor - GF-1	1	44.80	44.80
6	Floor 2 - Mechanical Room	HVAC	Fan motor - GF-2	1	44.80	44.80

7	Floor 2 - Mechanical Room	HVAC	Fan motor - GF-3	1	44.80	44.80
8	Floor 2 - Mechanical Room	HVAC	Fan motor - GF-4	1	44.80	44.80
9	Outdoor	Compressor - HVAC	Outdoor Condensing Unit motor - ACCU-1	1	3,723.20	3,723.20
10	Outdoor	Compressor - HVAC	Outdoor Condensing Unit motor - ACCU-2	1	2,808.00	2,808.00
11	Outdoor	Compressor - HVAC	Outdoor Condensing Unit motor - ACCU-3	1	3,473.60	3,473.60
12	Outdoor	Compressor - HVAC	Outdoor Condensing Unit motor - ACCU-4	1	3,473.60	3,473.60
13	Outdoor	Compressor - HVAC	Outdoor Condensing Unit motor - ACCU-5	1	2,683.20	2,683.20
14	Outdoor	Condenser - HVAC	Outdoor Condensing Unit motor - ACCU-1	1	270.40	270.40
15	Outdoor	Condenser - HVAC	Outdoor Condensing Unit motor - ACCU-2	1	145.60	145.60
16	Outdoor	Condenser - HVAC	Outdoor Condensing Unit motor - ACCU-3	1	228.80	228.80
17	Outdoor	Condenser - HVAC	Outdoor Condensing Unit motor - ACCU-4	1	228.80	228.80
18	Outdoor	Condenser - HVAC	Outdoor Condensing Unit motor - ACCU-5	1	145.60	145.60
19	Outdoor	Light	wall mounted flourescent area light	7	66.00	462.00
20	Outdoor	Light	remote par36 spot with WP cover	3	18.00	54.00
						19,206.10

3. Continuous Loads - Rating when not on Standby

S/N	Room	Family	Appliance	Quantity	Rating (W)	Total Rating (W)
1	Classroom	Plugloads	Projector	1	708.00	708.00
2	Classroom	Plugloads	Vaccum Cleaner	1	431.20	431.20
3	Classroom	Plugloads	A/V rack	1		0.00
4	Classroom	Plugloads	Camera	1		0.00
5	Office 1	Plugloads	Table Top Space	1	1,153.00	1,153.00

			heater			
6	Office 1	Plugloads	Underline Shelf Lights	1	26.00	26.00
7	All offices	Plugloads	Computers	18	30.00	540.00
8	Office 2	Plugloads	Table Fan	1	14.08	14.08
9	Office 2	Plugloads	Table Top Space heater	1	1,453.00	1,453.00
10	Office 2	Plugloads	Radio	1	2.05	2.05
11	Office 2	Plugloads	Underline Shelf Lights	1	26.00	26.00
12	Office 3	Plugloads	Underline Shelf Lights	1	26.00	26.00
13	Conference Room	Plugloads	Refridgerator	1	780.00	780.00
14	Conference Room	Plugloads	Microwave	1	1,963.00	1,963.00
15	Conference Room	Plugloads	Coffee Mixer	1	952.70	952.70
16	Lobby 2	Plugloads	Table fan	1	2.64	2.64
17	Open Office 1	Plugloads	Table fan	1	12.08	12.08
18	Open Office 1	Plugloads	Table fan	1	13.56	13.56
19	Open Office 1	Plugloads	Table Top Space heater	1	1,463.00	1,463.00
20	Open Office 1	Plugloads	Underline Shelf Lights	2	26.00	52.00
21	Office 4	Plugloads	Table Fan	1	29.96	29.96
22	Office 4	Plugloads	Underline Shelf Lights	1	26.00	26.00
23	Open Office 2	Plugloads	Table Top space heater	1	240.50	240.50
24	Open Office 2	Plugloads	Table Top space heater	1	1,253.00	1,253.00
25	Open Office 2	Plugloads	Paper Shredder	1	41.99	41.99
26	Work Room	Plugloads	Photocopier + Printer	1	1,249.00	1,249.00
						12,458.76

4. Smaller Continuous Loads

S/N	Room	Family	Appliance	Quantity	Rating (W)	Total Rating (W)
1	Lobby	Light	Emergency Exit Lights	2	1.70	3.40
2	Lobby	Plugloads	Coffee maker - Standby	1	12.95	12.95
3	Conference Room	Plugloads	Refridgerator - Standby	1	80.00	80
4	Conference Room	Plugloads	Microwave - Standby	1	12.00	12.00
5	Conference Room	Plugloads	Coffee Mixer - Standby	1	12.95	12.95
6	Lobby 2	Light	Emergency Exit Lights	2	1.70	3.40
7	Open Office 2	Light	Emergency Lights	2	1.70	3.40
8	Work Room	Plugloads	Photocopier + Printer	1	76.00	76.00
						204.10

5. General Lighting

S/N	Room	Family	Appliance	Quantity	Rating (W)	Total Rating (W)
1	Classroom	Light	2" x 4" parabolic Light	6	186.00	1,116.00
2	Men's Restroom	Light	Wall mounted flourescent	1	124.00	124.00
3	Women's Restroom	Light	Wall mounted flourescent	1	124.00	124.00
4	Office 1	Light	1 x 4 parabolic troffer	1	62.00	62.00
5	Office 2	Light	1 x 4 parabolic troffer	1	62.00	62.00
6	Office 3	Light	1 x 4 parabolic troffer	1	62.00	62.00
7	Conference Room	Light	suspended linear indirect/direct 12" long	1	188.00	188.00
8	Lobby 2	Light	suspended linear indirect/direct 12" long	2	188.00	376.00
9	Open Office 1	Light	wall mounted linear indirect	1	96.00	96.00
10	Open Office 1	Light	wall mounted linear indirect	1	32.00	32.00

11	Open Office 1	Light	surface mounted fluorescent area light	1	22.00	22.00
12	Office 4	Light	1 x 4 parabolic troffer	1	62.00	62.00
13	Open Office 2	Light	suspended linear indirect/direct 8" long	2	124.00	248.00
14	Open Office 2	Light	suspended linear indirect/direct 4" long	3	62.00	186.00
15	Work Room	Light	2' x 4' parabolic tandem wires troffer pair	1	186.00	186.00
16	Janitor's Room	Light	surface wrapround	1	62.00	62.00
17	Storage	Light	surface wrapround	1	62.00	62.00
18	Floor 2 - Mechanical Room	Light	4" 2-lamp strip with wireguard	6	62.00	372.00
19	Floor 2 - Storage	Light	4" 2-lamp strip with wireguard	1	62.00	62.00
20	Floor 2 - Network room	Light	4" 2-lamp strip with wireguard	1	62.00	62.00
						3,566.00

6. Potential Savings

S/N	Equipment	Description	Savings (kW)	Hrs in a day	days	weeks	Total (kWh)
1	Outdoor Light	50% savings by changing bulbs to energy efficient bulbs	0.258	10	365	-	941.7
2	HVAC fan	Putting off the HVAC fans used in heating the building	3	3	5	52	2340
							3281.7