Putting Vacants Buildings to Sleep

ABT 212

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Client: Dr. Alan Meier and the Energy Conservation Office

Abstract:

This report was commissioned to investigate the feasibility of a vacancy enabled automatic turndown of energy consuming devices in buildings. The research focused on the topic of vacancy inference, as well as energy savings associated with reducing energy consumption of existing buildings at night. The work consists of 2 field studies to identify energy consuming devices that can be easily turned down, as well as estimates of the potential savings associated with implementing such a strategy. The conclusions of the field studies prove a savings potential of 46% of the overall energy consumption in an office building, and a very conservative savings potential of $37,000 to $148,000 per year in all lecture halls on the UC Davis campus.

The conclusions of the vacancy inference engine feasibility study prove that an array of sensors can be used to infer vacancy to varying levels of certainty. A framework is provided for a vacancy inference engine that will continually output a signal when the building is determined to be vacant. The output will be associated with a statistical confidence level, that can be used to implement different levels of building turn down. The risk analysis showed the importance of the VIE design to reducing economic costs to building owners and occupants. Future work will need to be conducted to create an algorithm that assigns a certainty level to a turndown level. The algorithm will need to be flexible to accommodate the infinitely varied risk and benefit factors present in the worlds building stock.

Introduction:

According to the Campus Energy Education Dashboard at UC Davis, the average energy demand of metered buildings over-night (12am-6am) is as high as 90% of the peak day time demand. For lecture halls and office buildings, the night time demand can be as high as 50% of the day time peak demand. During this time, most buildings on UC Davis Campus are unoccupied. This report was commissioned to investigate the energy end uses of buildings overnight on campus for two buildings, Giedt Hall and the Annual Fund Trailer. The project aims to identify equipment that can be turned into a low power mode, and the energy and cost savings associated with reducing night time energy consumption. The research team also investigated possible means of inferring vacancy in buildings, and a procedure for initiating shut-off for energy consuming devices in buildings at night.

Figure 1: CEED building demand data for Giedt Hall (ceed.ucdavis.edu)

Background:

The UC Davis Energy Conservation Office (ECO) and Alan Meier have partnered up to address the issue of energy consumption in vacant buildings. The goals of the project are to identify the devices in a vacant building that consume energy, and develop methods to reduce this energy usage. Eliminating energy use in vacant buildings is expected to significantly reduce overall energy consumption, based of the statistics regarding the high demand during vacant periods. Furthermore, this strategy provides a simple way to reduce energy demand, while maintaining the same level of service in the building. Much of the important prior work surrounds occupancy detection, and thus the Vacancy Inference Engine portion of the report discusses the prior work that was referenced for the study. SOme risks of the strategy are discussed in detail in the Risk Assessment section of the report.

Device Inventory by Building:

The inventory process for each building involved a general walkthrough in which plug in devices were counted, lighting was inspected and building owners were interviewed or reached through email.

Annual Fund Trailer:

Figure 2: Annual Fund Trailer main room, containing 36 desktops and monitors

Immediately upon entering the building it was evident that the desktop computers would be a big factor. The Annual Fund Trailer, serving as a call center, holds around 40 desktop computers. Talking to the manager, Maile Juranits, we learned that the computers are generally left on continuously on from Sunday night to Thursday night despite the building being unoccupied the majority of that time. The lighting is turned off manually throughout the building at closing time at 10pm and a security system during code is entered by the manager upon closing.The security system is triggered by motion sensors inside the building found in the top wall corners of the main room. Other common office appliances were found including printers, a water heater, as well as a closet that holds IT servers, which are left on 24/7. The HVAC system is fairly new, being installed Summer of 2017 and consists of three rooftop units with programmable thermostats and was originally assumed to turn down upon closing time. Upon further inspection however, the three thermostats all had different schedules as seen in Table 1.

Thermostat	**Day Range**	**Start/Stop**
South	Mon-Fri	12:00-22:00
	Sat-Sun	8:00-13:00
Middle	Mon-Sun	0:00-0:00
North	Mon-Fri	12:00-22:00
	Sat-Sun	8:00-13:00

Table 1: Thermostat schedules for all three rooftop units on Annual Fund Trailer

Despite the hours of operation being 1:00pm to 10:00 pm Sunday to Thursday, all three thermostats are programmed to run during unoccupied hours as well as two thermostats programmed to shut off *during* hours of operation. The building manager claims she has never touched the thermostat scheduling since their installation citing intimidation and fear that she would turn it off and risk discomfort. Despite this,two of the three HVAC units turn off during weekend work hours with no complaints of thermal discomfort. Table 2 lists the inventory of devices found in Annual Fund Trailer.

#/Item Description	Product No.	Standby Power
Coffee Machine	Mr Coffee BVMC - EHX23	30 W [1]
Printer	HP Lazer Jet P4515x	12 W [2]
GE Turntable Microwave		1.7 W [3]

Closet Server		N/A
38 desktop computers	Optiplex 3010	15.2 W [4]
35 Lighting fixtures	LED CFL 32 W	N/A
1 Alarm System		N/A

Table 2: Device inventory for Annual Fund Trailer

Giedt Hall:

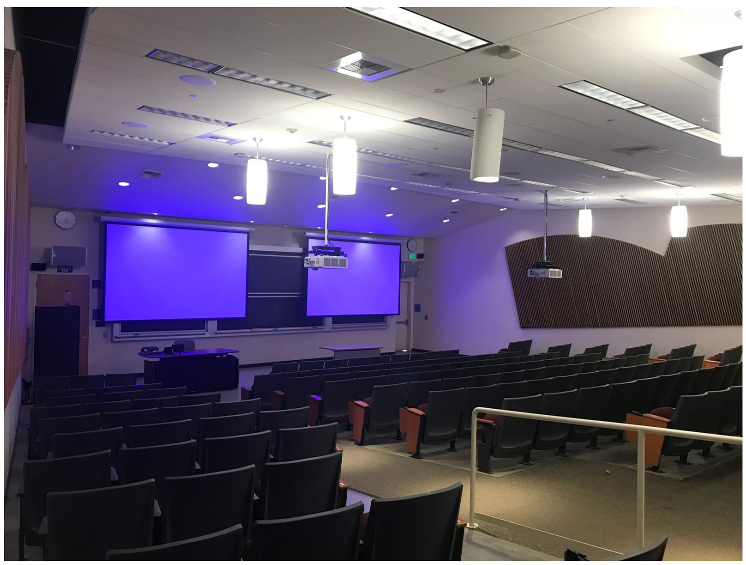

FIgure 3: Giedt Hall lecture room containing two projectors and an AV rack

Serving primarily as a lecture/classroom building, the majority of Giedt Hall's energy usage occurs during lecture hours, when lecture halls are full (assuming students show up), cooling load is the greatest, plugs are occupied for charging of devices such as laptops and AV equipment is fully operational. Giedt Hall's hours of operation are from 8 am to 10pm on weekdays, with weekend events occurring regularly. The initial walkthrough of Giedt Hall occurred around 4 pm, which incidentally happens to be when classes end. This allowed us to enter a few of the classrooms without disturbing lecture. As we looked for energy consuming equipment, the prominent trend we observed was a touchpad at the stacks of AV equipment along with projectors in each room. All rooms were observed to have occupancy sensors with manual light switches. A total of 6 AV racks were found throughout the building with the larger lecture halls containing taller carts of about 6”. A cutsheet of a typical AV rack is seen in Figure 4.

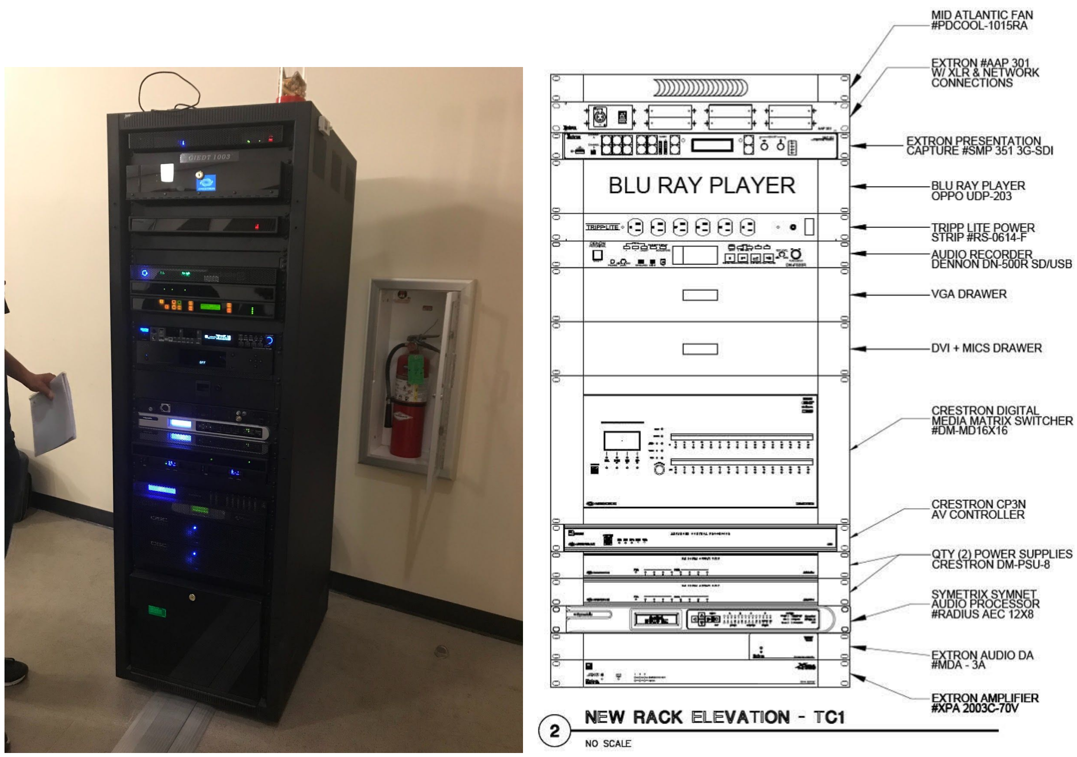

Figure 4: AV rack in Giedt Hall (left) and device breakdown for a typical AV rack from building drawings (right)

Our second walkthrough on May 17 occurred later in the night at about 10 pm accompanied by ECO controls engineer Nico Fauchier-Magnan. At this point the doors were locked and most students had left the building. Each of the rooms we entered had the AV equipment on with a couple rooms We were able to turn off all of the lights in the lecture halls manually which allowed us to better isolate the remaining load. A mechanical room we entered contained a domestic hot water heater as well. The main takeaways from this visit was the high impact that lighting had on the building load. The electrical room contained two lighting control panels that had schedules on both the lecture hall lights and the classroom and lobby. There was a notably high amount of exterior lighting around the building that should also seriously be considered when calculating the sources of the building’s overnight demand.

Demand analysis:

Methods

The goal of the demand analysis was to estimate the potential energy and cost savings associated with implementing a device shut-off strategy. The methodology was different for the Annual Fund Trailer and Giedt Hall, due to a difference in available data.

The Annual Fund Trailer is occupied on a non-traditional schedule, with 29 occupied hours in the week. The device inventory identified two devices which are not scheduled to turn off with the building. The devices are the air conditioner, and a server. Furthermore, there are many plug loads present in the building that contribute to demand, even when the building is vacant.

The Annual Fund Trailer is not monitored via the CEED website, and the analysis was further complicated by the energy metering situation. The energy meter is not a smart meter, but rather a rotary dial meter. The rotary dial meter readings were manually recorded for 2.5 weeks, at random intervals. In order to build a demand profile, the data was reduced to build a weekly profile for each of the 3 weeks during which manual readings were conducted.

The results of the demand characterization were used to estimate the portion of energy used during vacant hours and occupied hours. The model is based off of 8 observations, during which a demand rate was determined for vacant and occupied hours. Because of the sparse nature of the dataset used to build the model, it was necessary to validate the results. In order to test the validity of the model, the modeled 1 week of energy use was compared to the average energy used per week over the observation period. The result showed that the model accuracy is sufficient to provide insight into the potential energy impact of shutting off devices in the Annual Fund Trailer during vacant periods.

$$Energy\ Consumed\ per\ week\ =\ Vacant\ Power * Hours\ Vacant\ + Occupied\ Power * Hours\ Occupied$$

$$Average\ Observed\ Energy\ use\ per\ Week\ =\ (Final\ Energy\ Reading\ -\ Initial\ Energy\ Reading)/\ N\ Weeks$$

$$\%Error\ =\ (|Modeled - Actual|\ /\ Actual\ ) * 100$$

$$Energy\ Savings\ Potential\ = Energy\ use\ while\ vacant\ *\ 52\ (Weeks/Year)$$

Giedt Hall is a lecture hall with 3 large lecture halls, and 2 small classrooms. Giedt hall is monitored via CEED, however the building is not submetered. In an attempt to determine the end use by device type, two energy audits were performed. For the first audit, indoor equipment and plug loads were examined between classes in each classroom. The results of the audit revealed significant amounts of A/V equipment in the building. It was noted that the A/V equipment remains on during the intermission between classes, and so the researchers made an estimate of the number of A/V devices.

An initial analysis revealed that the night time load could be easily attributed to the A/V equipment. After the initial analysis a second energy audit was performed. During the second energy audit, the lights and mechanical equipment were forced off, and the demand was monitored real time via CEED.

Results

The results of the data reduction for the Annual Fund Trailer illustrated a period of 1 kW demand while the building was vacant, and a period of 5.6 kW demand during occupied hours (Figure 1). The results of the model showed that 46% of the energy consumption occurs during vacant hours. The results of the model validation showed that the estimate of weekly energy was within 8% of the observed average weekly energy consumption over the 2.5 week observation period. If the rate of energy use during occupied periods, 46%, is applied to the observed demand level of 328 kWh/week, the result is that 7900 kWh of energy is used during vacant periods per year. Applying the cost of energy on campus of six cents per kWh, the cost of this energy use is estimated to be $471/year.

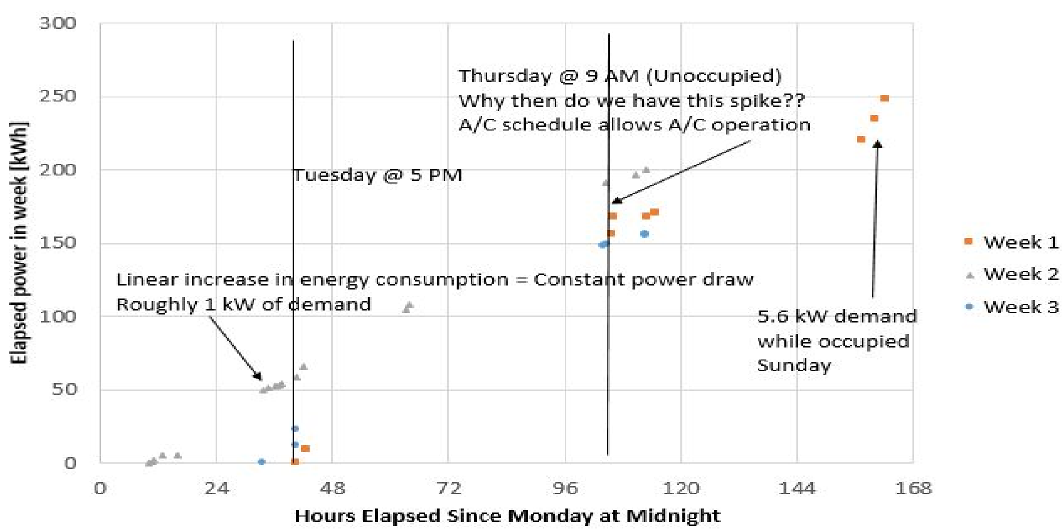

Figure 5: Demand analysis for the Annual Fund Trailer

The initial results for Giedt Hall illustrated the potential for energy and cost savings associated with turning down the A/V devices. The data was illustrated in a histogram from the hours of 12 AM to 4:30 AM. The histogram was constructed assuming that there were 104 shelves of A/V equipment in the building. The histogram presents the rate of energy consumption for each shelf (W).The results clearly indicated that the A/V equipment could feasibly be responsible for all of the night time demand (Figure 2).

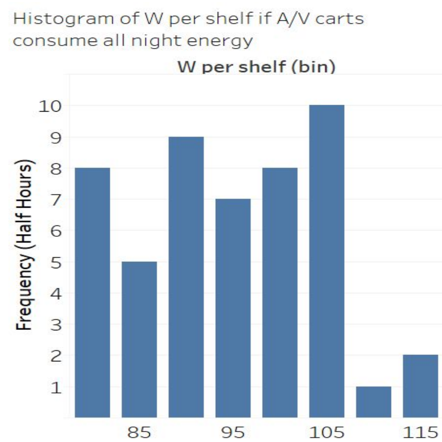

Figure 6: Histogram of hypothetical demand per shelf of A/V equipment

The results of the initial analysis informed the subsequent turn down of Giedt Hall. The demand profile of the day of the Giedt Hall turn down is illustrated with 3 other thursdays from the same month (Figure 3). The turndown occured between the hours of 9 PM and 10 PM, the night of May 17th. The results illustrate that the turn off of lights resulted in a 9 kW drop in demand. The demand drops to 8 kW, which is assumed to be mostly due to the A/V equipment, which was intentionally not turned down at the time.

The demand profiles also illustrate the opportunity for energy savings from tighter light controls. During the turndown the building was unoccupied, and yet the lights were still on at the beginning of the turndown. Furthermore, the data clearly shows that some lights are on throughout many of the vacant hours, for many of the days. A schedule for the lights could be implemented, whereby during vacant hours the lights could be turned off after a short period without occupancy detection. Such a tightening of controls could result in reductions of energy consumption.

The final portion of the analysis was focused on determining the annual energy and cost savings associated with the turndown. An average baseline of 9 kW was calculated from the electric demand during unoccupied hours between 11 pm and 5 am. An overnight EUI was then calculated for Giedt Hall which was then extrapolated for the total campus square footage of classroom building space. It was assumed that vital equipment in buildings requires around 1 kW of demand. The potential for demand reductions across campus was estimated to be 530 kW, based on the square footage of Giedt Hall and the lecture halls on campus. If the buildings were to minimize demand during during vacancy for 1,000 hours of the year, the annual savings would be 530,000 kWh. The estimate serves as a lower bound of the potential energy savings, however a future estimate should be conducted based on the number of classrooms. Such an estimate would provide an upper estimate of the energy savings. Furthermore, the total hours of vacancy could easily be as high as 4,000 hours, providing 2,120,000 kWh of savings as the upper estimate. Finally, the cost savings associated with the lower estimates ranges from $37,000 to $148,000 per year given the UC Davis Utilities published rate online of $0.699/kWh. The estimates are a lower bound, and the energy and cost savings could very well be significantly higher.

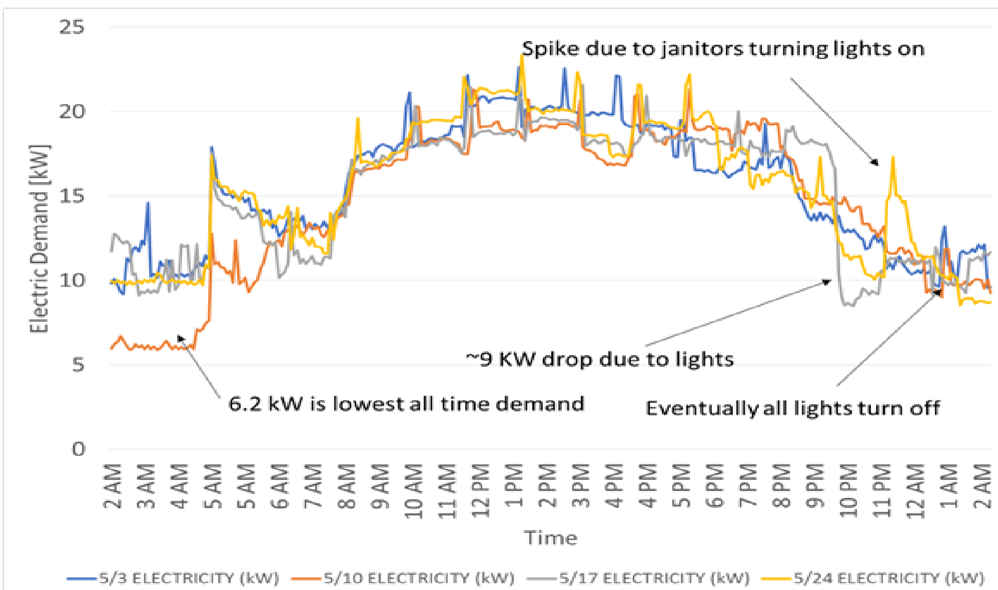

Figure 7: Electric demand for Giedt Hall on 4 consecutive Thursdays. 5/17 shows a steep drop in demand due to manual shutdown of lecture hall lights during our second walkthrough.

Discussion

The results of the field work shows significant opportunities for turndown of energy consuming devices in commercial buildings and lecture halls across campus. The results of the study showed that the energy consumption during vacant hours is around 46% of the overall energy consumption in the Annual Fund Trailer. Further, the turndown of Giedt Hall showed that the potential savings in lecture halls on campus are significant, even for the lowest estimates. The significant potential associated with the strategy warrants further investigation, and discussion with the manufacturers of the A/V equipment. We suggest that future work include a demonstration of the A/V equipment turndown during a 48 hour period of vacancy, in a building with many classrooms. If the data shows significant savings, then the work should be brought to the attention of the A/V equipment manufacturers.

Vacancy Inference Engine:

In order to cost effectively be able to detect vacancy in a building, we need to take advantage of the incumbent infrastructure of sensor networks and building systems with outputs or trending. Our literature review has shown that some systems we could take advantage of with some level of certainty include WiFi connections, a BMS's occupancy sensors, CO2 sensors as well as the security system.

Lu et al's WiPin system is an end-to-end occupancy inference system which is able to infer room-level occupancy accurately with commodity WiFi infrastructure. Experimental results show that the proposed system outperforms competing systems in accuracy and robustness, reducing errors found in these competing systems by 37%. [1]

Shetty et al's use Internet of Things (IoT) enabled plug meters, as well as PIR sensors to detect the presence of multiple occupants in an office space. The plug meter used is Zigbee enabled which allows it to communicate with a central hub along with the PIR sensor as a form of double verification. This system is very similar to the devices currently installed at the Energy Conservation Office, which are instead Z-Wave enabled and gather data on the plug load of different devices throughout the office. The results of the paper show very high accuracy to ground truth, with a 89-99% for presence detection and a 87-96% rate for absence detection, the latter of which is valuable for our detection of vacancy. [2]

Amato et al integrated building sensors for security purposes. In reference to detecting vacancy, the techniques presented are slightly different than those found for occupancy detection. Some methods proposed include "Background subtraction", an image processing technique, as well as smart meter monitoring. The latter is an interesting concept, since a sudden change in demand during unoccupied hours, especially in plug load, could signify the presence of an individual. Another interesting tool for security purposes included noise sensors, which respond to noise perturbations beyond the average fan or office equipment which could signify an intruder, or for our interests, an occupant. The paper emphasizes that a multipoint verification method is needed to make this sort of wireless sensor network system work effectively. [3]

A higher cost solution could be found in an anonymous occupant counter from a recent startup company named Density. The company has developed a WiFi Enabled foot traffic counter, with a well-documented API, which would allow for real time monitoring of the number of people in a space or building. This sort of technology could possibly be used for vacancy detection easily and allows for some flexibility not necessarily afforded by WiFi connectability or incumbent security systems. Assuming occupants enter a building from a couple of main entrances, this sort of system should be able to accurately determine when a building has become empty all while preserving the anonymity of the occupants, alleviating concerns of occupancy privacy. [4]

Methods

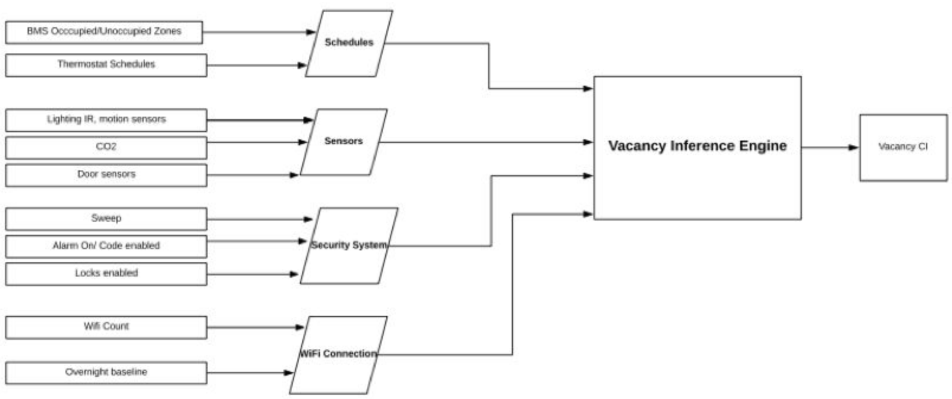

Figure 8: Flow Diagram of inputs and outputs of Vacancy Inference Engine (VIE)

We developed a control program we call the Vacancy Inference Engine (VIE) which will be fed data gathered from the buildings existing infrastructure. The VIE will monitor real time conditions of a building as well as have learning and model predictive control to calculate a vacancy confidence level. This confidence level can then be sent to a building operator or individual systems to initiate demand turndown. We established a hierarchy of inputs for the program in accordance to what is most readily available as well as most indicative of occupancy:

1. Occupied/Unoccupied Schedules

A building with a dedicated building management system (BMS) will have a programmable start and end time for occupied or unoccupied schedules for different zones. These schedules usually dictate the run times of HVAC and lighting systems. Smaller buildings like the Annual Fund Trailer without a BMS do have a thermostat schedule. However, as pointed out previously these schedules may have errors and should be verified before feeding into the program. Table 3 shows the weekly schedule for the two buldings in our analysis.

	M-Th		Fr		Sat		Sun	
	Start	Stop	Start	Stop	Start	Stop	Start	Stop
Giedt	5:00	23:00	5:00	23:00	6:45	23:00	6:45	23:00
AFT	13:00	22:00	Closed	Closed	Closed	Closed	13:00	22:00

Table 3: Occupied/Unoccupied Schedules for Giedt

2. Security System

The security system would need to have some form of manual entry if the building normally conducts sweeps before closing for business or an output from a code-armed security system or lock system, although the latter is normally not indicative of vacancy it could be useful as part of this multi point verification method.

3. Sensor Networks

Depending on the sophistication of the building a variety of sensors are present throughout a building most commonly motion sensors for lighting control. These sensors give a voltage output that could be intercepted as an input for the VIE. These outputs can then be sent on a counter, with a minimum sensor trip count within a time window indicating occupancy/vacancy giving some room for false trips.

Another common sensor type found in high occupancy areas are CO_2 sensors, these sensors are usually used in conjunction with HVAC systems to let in more fresh outside air when CO_2 levels hit a certain ppm level, usually around 800-1000 ppm. The Western Cooling Efficiency Center (WCEC) has CO_2 sensors installed throughout offices, common work areas and conference rooms. As seen in FIgure 9, CO_2 levels are highly correlated with occupancy levels. During the weekdays, the daily profiles show a similar profile to a building's electric demand. However the weekend does settle to a baseline of around 450 ppm. The VIE should be able to monitor individual CO2 levels as well as a whole building average to detect occupancy and determine vacancy. The VIE should also be able to determine its own baseline and see any sudden deviations as an indication of occupancy.

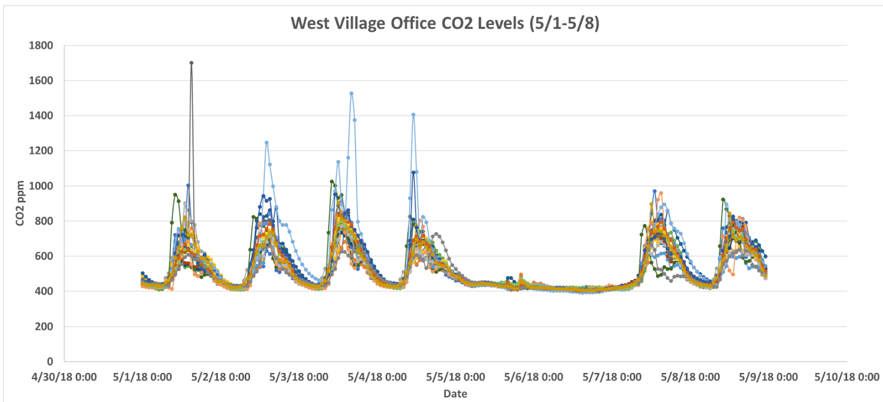

Figure 9: Weeklong CO2 Levels for WCEC offices

4. WiFi Connection Data

Given that WiFi connections may not spatially correlated with a buildings occupancy (ie a student connecting to the WiFi from the outside) as well as prone to errors and noise (ie an occupant leaving his or her wifi enabled device inside a building overnight) this is the lowest tier of information that would feed the VIE. ECO provided wifi connection data for Giedt Hall which we overlaid with electricity demand in Figure 10. There is a noticeable flatline in the WiFi connections (orange trend) over the span of a week during Spring recess. The electric demand (blue trend) however is still going through its diurnal electric demand cycles despite an evident lack of change in WiFi connections. Filtering out the unoccupied hours shows the average baseline of WIFi connections to be around 10 WiFi connections which would mean that the VIE should be able to determine learn and an actionable level of WiFi connectivity.

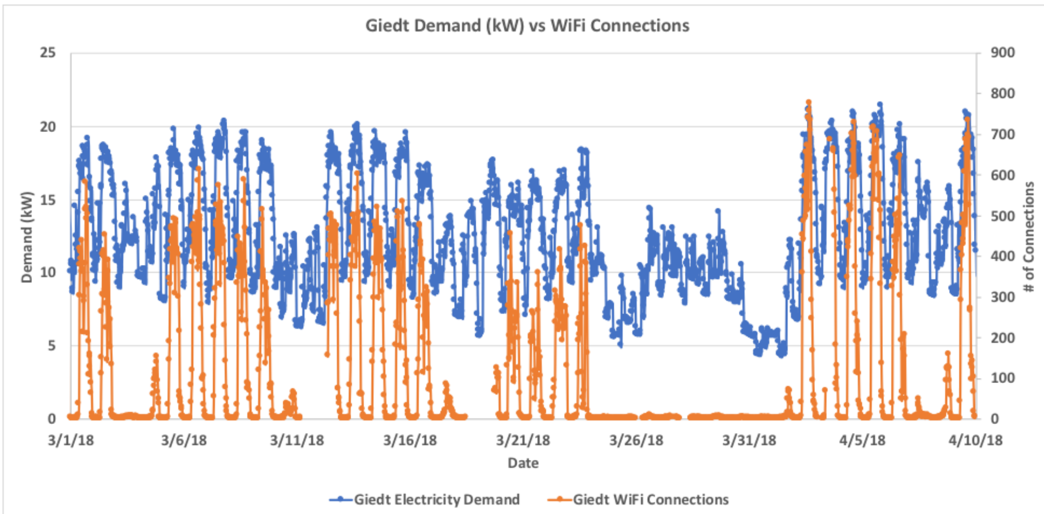

Figure 10: WiFi connections vs building electrical demand for Giedt Hall

Risk Assessment:

Some risks are associated with the strategy, and the future work will need to address these risks. The future possibilities of the strategy include low probability, but high risk implementations, such as complete shutdown while the building is occupied leading to injury or death. Because of the statistical nature of the VIE output, it is impossible to be certain that a building is not occupied. The implementation of a complete shutdown will need to be coordinated by the building managers, and the building occupants, to ensure safety and comfort of the occupants. Some simple designs, such as lights that can be motion activated to light an exit route, could also be incorporated to lower the risk associated with a complete building shutdown.

Furthermore, familiarity with the design, and buy in of the occupants will reduce anxiety associated with the strategy
Some of the less extreme risks include matters of convenience and risk of economic loss. Mitigating these risks is absolutely critical to the successful implementation of the strategy into the market. These risks include cyber security risks around the building systems and the VIE, such as risks of building shutdowns in ransomware style attacks. Some more mundane risks include the risk of inconvenience to the occupants caused by poor implementation of the strategy, which could easily lead to failure to adopt the strategy. Seeing as how labor costs are typically the highest cost to a commercial

organization, even a few instances of systems failing to reboot in the morning could outweigh the cost savings associated with a strategy.

A concrete example of this on campus would be the A/V equipment failing to boot in a single classroom, leading to one cancelled 2 hour lecture. The economic loss to the students in a class of 200 would be $6,250 considering a 16 unit load, and a cost of $5,000 per quarter. In Giedt hall, the savings in a large lecture hall are expected to be no higher than $480 per year (assuming 4,000 vacant hours), which means that a single failed startup in 13 years would technically offset the savings (although the costs would be externalized to the student in our current economic system, so the University may not choose to factor this in. From a societal viewpoint however, this is a real economic loss).

The conclusion of the risk analysis is that the risks absolutely need to be considered and minimized. Even the slightest failure has significant potential to cost society significant economic losses. An ethical approach to the strategy would be to consider all of the costs realized by the building owner, as well as the externalized costs. The assessment should consider the externalized cost of energy as well, since the electric rates effectively subsidize the end user in the current arrangement. The tolerable frequency of failure events can then be calculated to determine the level of statistical certainty of the VIE output needed to trigger each level of shutdown.

Conclusion and Future Work:

The conclusions of the work are that significant opportunity exists, on campus and off campus, to reduce the demand in vacant buildings. It is likely that simple cost effective measures exist such as having devices manufactured to turndown on a schedule, or with input from a vacancy inference engine.The field work demonstrated the opportunity to reduce energy consumption by 46%, saving $471 annually in an office building.

The field experiments also demonstrate that the lower bound of energy savings in all of the lecture halls on campus is between $37,000 and $148,000 depending on the assumed vacancy rate. This estimate is a lower bound, and future work should estimate the upper bound by extrapolating the field results by number of classrooms as opposed to square footage.

A framework for a Vacancy Inference Engine based on sensor inputs was developed and presented. Future work will need to integrate the costs associated with each risk probability, and the savings associated with different levels of building turn down to solve for the acceptable certainty level associated with each level of turn down. Low risk turndowns, such as turndowns of non-essential equipment will be associated with lower required certainty levels, while higher certainty levels will be associated with turndown of all devices.

References for Literature Review:

1. Lu, X., Wen, H., Zou, H., Jiang, H., Xie, L., & Trigoni, N. (2016). Robust occupancy inference with commodity WiFi. *International Conference on Wireless and Mobile Computing, Networking and Communications*. http://doi.org/10.1109/WiMOB.2016.7763228

2. Shetty, S. S., Member, S., Duc, H., Member, C., Gupta, M., Senior, S. K. P., & Ieee, M. (2017). User presence estimation in multi-occupancy rooms using plug-load meters and PIR sensors, 0–5.

3. Amato, G., Barsocchi, P., Falchi, F., Ferro, E., Gennaro, C., Leone, G. R., … Vairo, C. (2018). Towards Multimodal Surveillance for Smart Building Security †. http://doi.org/10.3390/proceedings2020095

4. A very modern solution to a very old problem of counting passengers. (2016). SmartTrail World. Retrieved from https://www.smartrailworld.com/passenger/a-very-modern-solution-to-a-very-old-problem-of-counting-passengers