HVAC and Lighting Retrofit at the Rifle Range

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Project Background

The Energy Conservation Office (ECO) in UC Davis was approached by PG&E in 2016 to test new energy efficient technology for the upcoming 2019 California Building Code. ECO proposed their own office space, the Rifle Range, for PG&E's tests. The three new systems installed in the space were a variable refrigerant flow (VRF) heat pump, dedicated outdoor air system (DOAS) ventilation, and occupant-sensing overhead LED lights powered through Ethernet. The office space originally used a joint furnace and ventilation package unit and typical fluorescent overhead lighting.

Our client, Joshua Morejohn at the ECO, wanted to understand the energy useage of the building and the cost savings with the new systems in place. In order to meet this objective, a building energy model was built through eQUEST to simulate energy consumption with the old system and with the new retrofit. Additionally, in order to compare the impact on the indoor conditions of the building, a thermal comfort survey was conducted with ECO occupants. For the project, the analysis was done on the VRF system and the LED lights and not on the DOAS.

Equipment

The VRF system used the Samsung DVM S heat pump, the Samsung DVM S Series 360 Cassette fan coils in the open shared areas, and the Samsung DVM S Series Neo Forte Wall-Mounted Unit with Expansion Valve fan coils inside the individual office rooms [Appendix H]. The mounted overhead LED occupant sensing lights were the CREE CR Series with SmartCast PoE Technology [Appendix G].

Methodology

Thermal Comfort Survey

A thermal comfort survey was conducted to gauge the level of satisfaction of those working in the space and to determine if any changes can be made to improve indoor conditions. The survey was distributed to the 16 full-time occupants working in the Rifle Range in May 2017. Created on Qualtrics, a campus surveying tool, the survey included questions asking occupants about the temperature, ventilation, lighting, understanding of thermostat controls, and overall satisfaction. The survey was created referencing previous thermal comfort surveys conducted by the UC Berkeley Center for the Built Environment's Occupant Indoor Environmental Quality (IEQ) Survey[1] and the UC Davis Workplace and Comfort Survey of Ghausi Hall.[2]

Questions in the survey were split into two sections with identical questions asking about occupant comfort before the retrofit (prior to December 2016) and after the retrofit. Questions asked occupants for the frequency that they were too hot or too cold, the amount of airflow and air quality, lighting levels and degree of control over the controls, how often and how well they know how to use the thermostat controls, and overall satisfaction of the space. All the questions and the possible answers are detailed in Appendix A.

Electricity Data Collection

We used data, via ECO's pi system, reporting the natural gas and electricity meter readings on a hourly and daily scale. This pi data source is the same data source that supplies the Campus Energy Education Dashboard (CEED).

Upon investigation, we found that some of the meter data was inaccurate, as seen in Figure 1. To systematically remove inaccurate data, we following the following steps for the electricity data set:

- Removed all data before the meter was established (Aug 8th, '14)
- Added "hourly energy consumption" by finding the difference in the meter readings from one timestamp to the next. Basically, this step calculated the energy use rate in [kWh/h] or power in [kW].
- Removed all time periods with a value error for consumption, mostly from I/O errors (441 points; each point represents an hourly meter reading).
- Removed all time periods that had negative consumption (619 points) as well as the time periods directly after a negative consumption, which reported were inaccurately high consumption (562 points).
- Removed all time periods that had 0 consumption (235 points) as well as the time periods directly after a 0 consumption, which reported consumption for a longer period than 1 hour (47 points). Note that most of the 0 consumption points were consecutive, explaining why there are so many fewer point following a 0 consumption vs reading 0 consumption. This count also suggests the meter stopped sending data at least 47 times in the last 3 years.
- Removed remaining time periods between 6am Sept 14, 2015 and 9am Oct 9th,'15. (26 points) The metering was unreliable during this period (reporting zero consumption for most of the time) giving inaccurately large swings.
- Spot-checked and removed time periods of over 30 kWh/h (415 points) which we considered unreasonably high consumption. This step removed large skips in the meter data.
- Inspected all 1 hour periods reporting between 15 and 30 kWh/h on a case by case basis (~30 cases), removing ones that had neighboring time periods removed in the earlier steps.

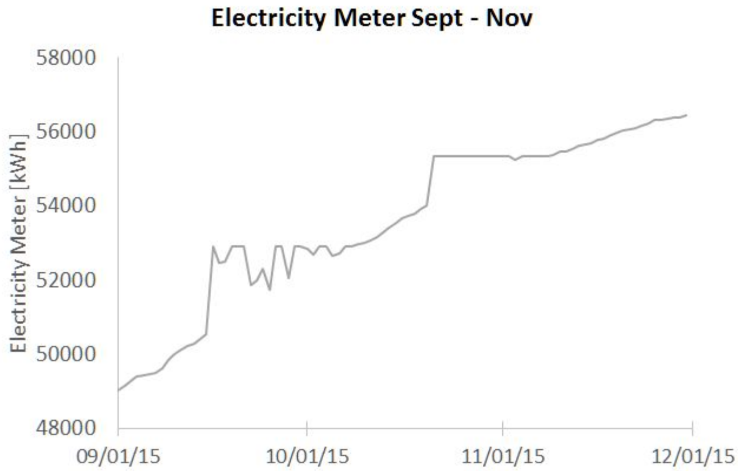

Figure 1. Rifle Range Electricity Meter over a three month time period. Because the Rifle Range does not produce natural gas or electricity, meter readings should strictly increase. This figure show erroneous jumps due to meter glitches.

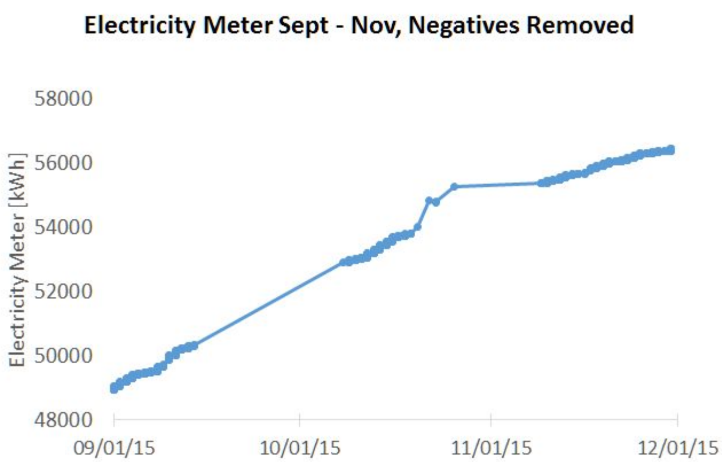

Figure 2. Electricity Meter over the same three month time period. We removed the data showing negative consumption as well as the time periods directly after a negative consumption, which reported inaccurately high consumption.

After cleaning the data of know inaccuracies from jumps in the meter, we then calculated the maximum meter reading of each month. To find the electrical energy used in a month, the month's max meter reading was compared to the previous month's max energy reading. For example, to find the energy use of May 2016, one would take the May meter max (62,889 kWh) and subtract the April meter max (61,781 kWh), leaving 1108 kWh of electricity consumption in May.

Gas Data Collection

The gas meter data had similar quirks as the electricity data, with a few additional issues. The gas meter showed larger meter drops than the electricity data, as seen in Figure 3. Additionally, we found the following peculiarities in the gas data:

- On May 13, 2016, the meter dropped by a factor of 100 and continued as such.
- The unit of the gas meter reported by pi is in ft^3. However, this unit appears to be a factor of 10 too large when comparing the gas use to both the Rifle Range's electricity use and comparing to the gas use of similar buildings on campus, such as Hutchison Child Development Center. We corrected the data by dividing by 10. The gas use reported on the CEED website agrees with this corrected order-of-magnitude.
- The gas meter showed a large jump on between December 18 &19, 2015. Where a normal winter day may cause a rise of 1,000 kBTUs, between those two days the meter jumped approximately 100,000 kBTUs. The jump can be seen on Figure 3.

The natural gas data reported on CEED did not reflect any of above mentioned meter anomalies, suggesting CEED incorporates additional cleaning algorithms. For this reason, we used CEED natural gas data in our analysis rather than the direct pi meter data.

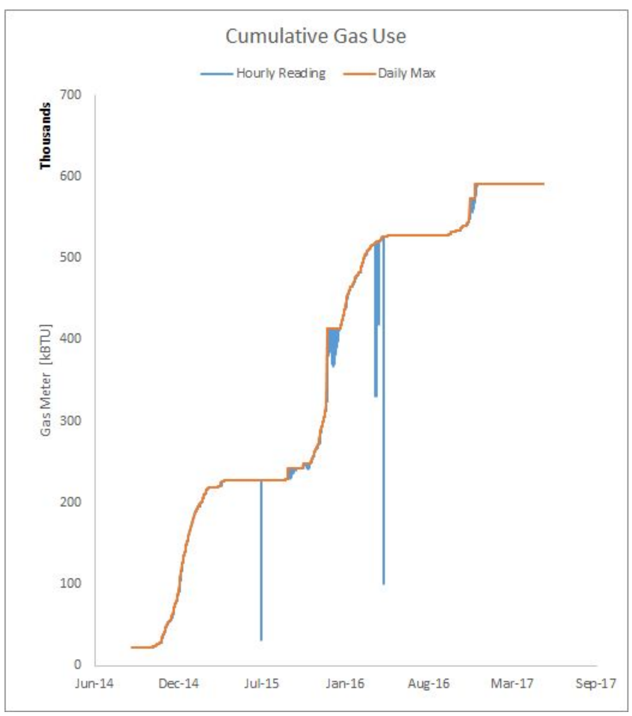

Figure 3. Shows the entire data set of gas meter readings (blue). Although the readings should strictly increase, the graph indicates large drops. By taking the daily maximum meter reading (orange), some the drops are eliminated. Additionally, the figure shows a large upward skip on December 19, 2015.

Data Limitations

Even with the cleaned data, there was still high variation in historical energy use from year to year. Additionally, there are other factors not explicitly included in our analysis. For example, the change in overhead lighting was a non-linear transition over months, and the DOAS was activated on March 23rd, leaving a period of artificially low energy use between ventilation systems.

Simulation

A replica of the Rifle Range building was constructed in the modeling software eQuest 3.65 (build 7173). eQUEST uses the DOE-2 core simulation program which was first developed by James J. Hirsch and Associates (JJH) in collaboration with Lawrence Berkeley National Lab. This software is suited to model building energy for a large diversity of projects both large and small. A key aspect of this software is its simplicity. Coupled with a guide written by JJH, our team was able develop an energy model for this office building in just a few weeks with no prior simulation skills.[3]

To create our model building in eQUEST, we consulted a variety of building schematics from 1958 [Appendix J] - where the building served the army ROTC as an actual shooting range - and from the building's remodel into an office building in 1999 [Appendix I]. Where building information was unavailable from these documents, the CA title 24 code of 1999 minimum standard was used as our guideline.[4] Any information that could not be gathered was untouched in the eQUEST simulation options. A table of simulation input parameters and information source are provided in Appendix E.

In order to separate the plug load from the other electricity load (for the eQuest model), our team performed an onsite energy audit at the Rifle Range. In each room, we counted the number and type of energy-drawing devices such as lamps, fans, computers, kitchen appliances, etc. We would then double check electrical outlets to make sure all of the objects plugged into the electrical source had been counted. If we had not already documented a device type, then we would search for nameplate information, and take a picture of the device. When appropriate, we also inquired with the office workers about their use patterns. Using Microsoft Excel, we then aggregated the equipment counts, multiplied by power consumption, and summed to find the total building plug load. [Appendix C]

To judge the accuracy of the building envelope built in eQUEST we compared the simulation results for gas and electricity to a data set of gas and electricity use during the years 2014-2016. This data was found on the Campus Energy Education Dashboard (CEED) website.[5] We used the average of the data from 2014-2016 years, and we used a slightly cleaned version of this data as discussed above.

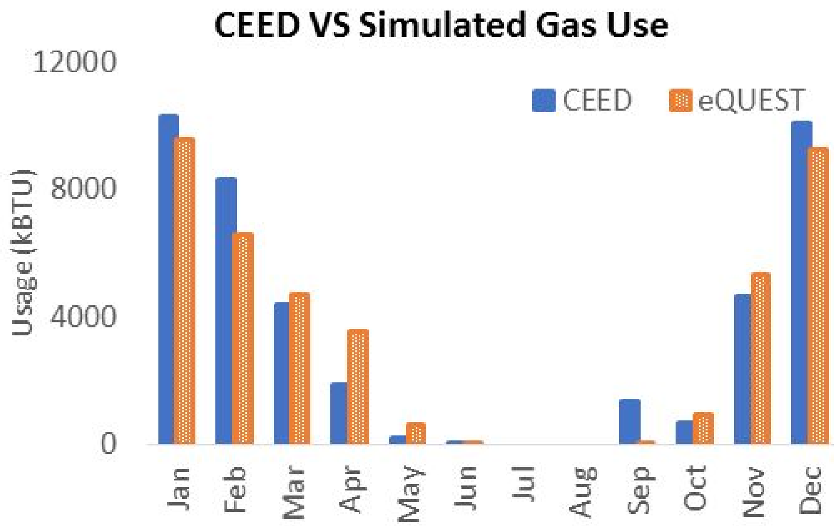

Figure 4. Comparison of the gas use between the eQUEST simulation and measured data from 2014-2016. This comparison shows that the building envelope created in eQUEST is in good agreement with the previous HVAC system. The eQUEST model underestimates the gas use by 3%. These simulation results are our ‘baseline’ case.

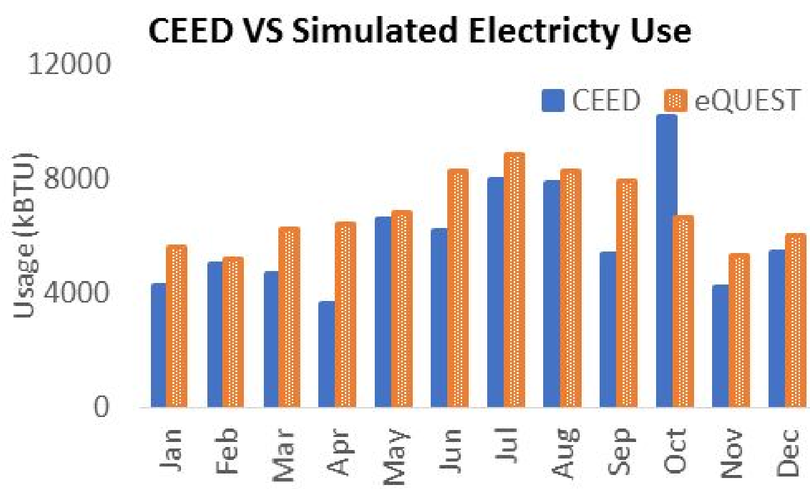

Figure 5. Comparison of the electricity use between the eQUEST simulation and measured data from 2014-2016. This comparison shows that the building envelope created in eQUEST is in good agreement with the previous HVAC system. The eQUEST model over estimates the electricity use by 14%.

Our simulation results of the pre-retrofit building can be seen in Figures 4 and 5, and we see good agreement across the simulated year. For gas use, the annual difference between the CEED data and simulation is 3% where the simulation is underpredicting gas use. The annual electricity prediction is an over estimation of use by 14%. These results are acceptable among building simulations were measured and simulated results often differ by more than 20%.[6,7]

Retrofit Modifications

After validating our building envelope against the CEED data set, we altered the model the account for the HVAC changes that took place in the retrofit during Dec 2016. The major change was the addition of a VRF system and removal of the packaged furnace and AC rooftop system. The VRF system was not a specific option within the eQUEST modeling system, so the VVT system was chosen as being most similar. It is expected that the VRF system would operate more efficiently than the VVT system. This expectation was confirmed by a simulation designed by Zhou et al. that specifically investigated VRF system as compared to VVT systems. They found their simulation for the VRF to use 11% less energy than the VVT system. Their simulation also used the average COP for the VRF system to be 4.5 rather than the 3.2 which eQUEST uses for the VVT system.[8] We estimated the difference using the 11% figured and the improved COP separately and are discussed below.

Lastly, over the Jan 2017 – May 2017 the fluorescent lighting was replaced by high efficiency LED lights. The light system energy intensity was adjusted from 1.0 W/ft^2 to 0.2 W/ft^2 based on the estimation and the LED ballast 27 lights [Appendix F] at 32W each [Appendix G] to reflect the new highly efficient LED lighting fixtures.

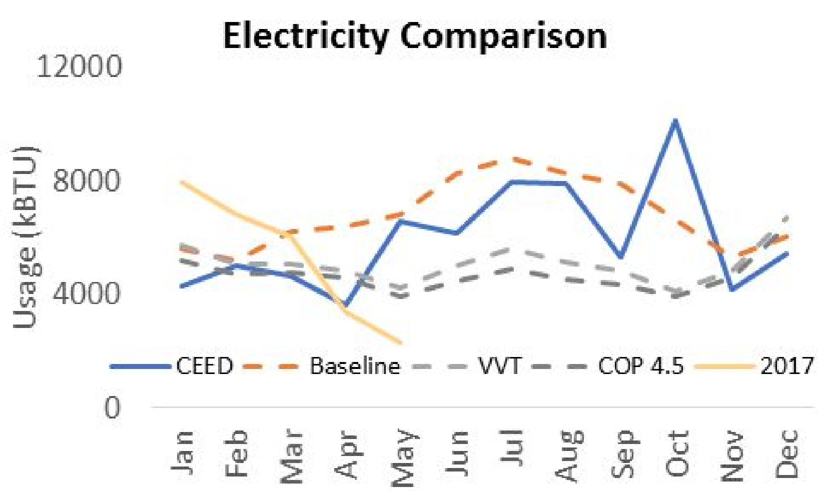

Figure 6. This comparison between simulations shows that the VVT and COP 4.5 simulation use less electricity overall when compared to the previous building's baseline simulation 'baseline' or the 2014-2016 average 'CEED'. The 2017 data show that in the cooling season the simulation underestimates the expected energy use, but over estimates the energy use as the heating season begins in May. It is expected the Summer months will see an increase in electricity use, but it is expected to stay lower than the electricity use pre-retrofit.

Figure 6 shows the VVT system without the COP change, and with the increased COP 4.5. The simulation results show that the building will use more electricity in the winter months, which is necessary since the furnace was removed. When comparing the measured 2017 data with the simulation we can see that the COP 4.5 is not capturing the full amount of electricity needed in the Jan – Mar months. In May, as we move into the heating months, we see an overestimation in the simulation. If this trend is maintained, we might expect the annual electricity usage to match well with the measured data, even if the month to month agreement is poor.

Results and Discussion

The thermal comfort survey results showed occupants were more satisfied with the new retrofit system compared to the old HVAC system. The results indicated that it is too cold for occupants, so we adjusted the minimum cooling temperature on the thermostat from 67 to 70 degrees Fahrenheit. The satisfaction for airflow was high, and the lighting levels had a wide distribution of responses since the lights were not completely operational at the time of the survey distribution, thus neither were modified. More detailed results can be found in [Appendix B]. Although occupants had a good understanding of using the thermostat according to survey responses, we received inquiries on how to operate the thermostat controls. In response to the questions, a tailored thermostat guide was created from editing the manufacturer's user manual. It was simplified and edited to provide clear directions on how to use applicable settings for the installed system. The guide will be distributed to all the building occupants [Appendix C].

Our final analysis was to use information from our simulations to determine the change in expected annual cost, annual carbon emissions, and the energy use intensity (EUI). Using energy cost data from the UC Davis utilities website we were able to calculate the cost of gas and electricity cost for the measured and simulated results.[9] Referring to the UC Davis Sustainability Report on electricity sources, the campus uses 60% carbon free electricity and 40% from non-renewable sources.[10,11] Assuming the non-renewable is on average the same carbon intensity as natural gas produced electricity, we can arrive at a carbon estimate for both gas and electricity use. Lastly, the EUI will help us understand total energy demand of the building by combining electricity and gas. The table below summarizes our results.

Summary	Baseline	CEED	COP4.5	Savings
Annual Cost	$1,803	$1,628	$1,014	$615
Carbon [ton/year]	6.07	5.98	1.20	4.78
EUI [kBTU/ft^2]	36.41	33.72	16.77	16.95

Recommendations and Future Work

The comfort survey will be made available to the client to conduct future surveys during different seasons to ensure the HVAC system is providing adequate service to the building occupants. We would also recommend investing the source of the meter reporting anomalies and eliminating or correcting the anomalies for the portfolio of campus meters. Possible future analysis could be to separate the savings of the three install technologies. In contrast to teasing apart the savings, we would recommend further study into integrating the conditioning, ventilation, and lighting systems, such as using outside air to pre-cool the space when possible. The data files for these simulations will be made available to the client in case they wish to make refinements to improve the accuracy as future data are collected. The final cost and carbon analysis excel files will also be given to the client so these may be updated as more data become available.

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