GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

LOAD MODELING, ANALYSIS AND DESIGN OF A RELIABLE AND COST-EFFECTIVE BUILDING MICROGRID – WITH DISTRIBUTED ENERGY RESOURCES

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Madrid

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Fdo.: Dr. Pankaj Sen Date: 20/06/2019

MODELADO DE CARGAS, ANÁLISIS Y DISEÑO FIABLE Y RENTABLE DEL MICROGRID DE UN EDIFICIO – CON FUENTES DE ENERGÍA DISTRIBUIDAS

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Director: Sen, Pankaj.

Entidad Colaboradora: Colorado School of Mines

RESUMEN DEL PROYECTO

INTRODUCCIÓN

A medida que aumenta la conciencia sobre el cambio climático, el calentamiento global y el consumo responsable de energía en todo el mundo, la eficiencia energética y la conservación de la energía en los campus de educación superior y escuelas (entre todos los edificios comerciales) se ha convertido en una nueva preocupación. Colorado School of Mines (Mines) tiene varios proyectos en curso que buscan reducir el consumo de energía, minimizar las emisiones, reducir la huella de carbono y economizar su perfil energético.

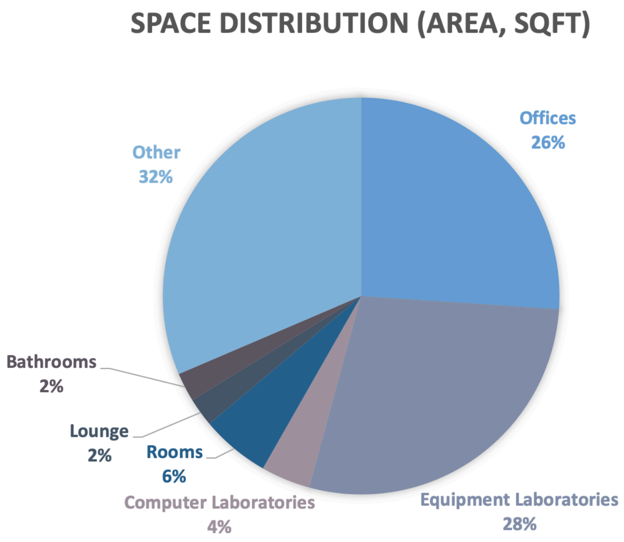
Este interés por el tema en nuestra escuela de intercambio es lo que impulsó a los miembros del grupo de trabajo a participar en uno de esos proyectos. Se va a estudiar el edificio "CoorsTek Center of Applied Science and Engineering" (CoorsTek), para averiguar si se pueden hacer mejoras sobre la eficiencia y la conservación de la energía, mejoras económicas y ambientales y cómo implementarlas. Esto constituirá la primera parte de este proyecto.

Cada miembro trabajará en diferentes aspectos del diseño del edificio, realizará análisis y mejoras de diseño y hará las sugerencias necesarias para las implementaciones. Las ideas y soluciones que resulten de este análisis, ingeniería o diseño de conceptos específicos se abordarán en detalle.

Mi interés especial es el uso de energía verde para mejorar el impacto de nuestra escuela en el medio ambiente y, al mismo tiempo, ser rentable, convirtiéndose en la segunda parte de este estudio.

ESTUDIO

Se realiza un estudio general del edificio para comprender su uso. Se tienen en cuenta las salas, los laboratorios y otros espacios, y se estima su perfil energético típico. El espacio se divide como se muestra en la tabla a continuación.



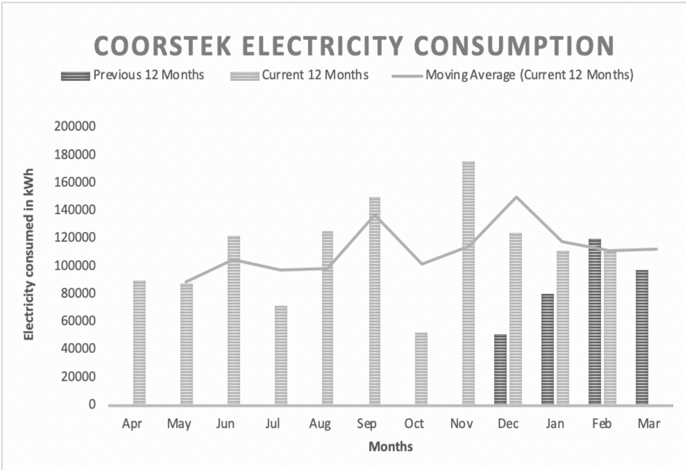
A continuación, se analiza el perfil eléctrico del edificio. Para esto, se utilizan los diagramas eléctricos de una línea de los documentos de construcción. El diagrama de una línea muestra la carga conectada. Sin embargo, los EE. UU. siguen los cálculos de carga estipulados por el código NEC (National Electrical Code NFPA® 70) que permiten cálculos más específicos y precisos de la carga esperada en cada bus para diseñar y dimensionar transformadores y conductores más cercanos al uso real. El National Electrical Code especifica los estándares a seguir para las instalaciones eléctricas.

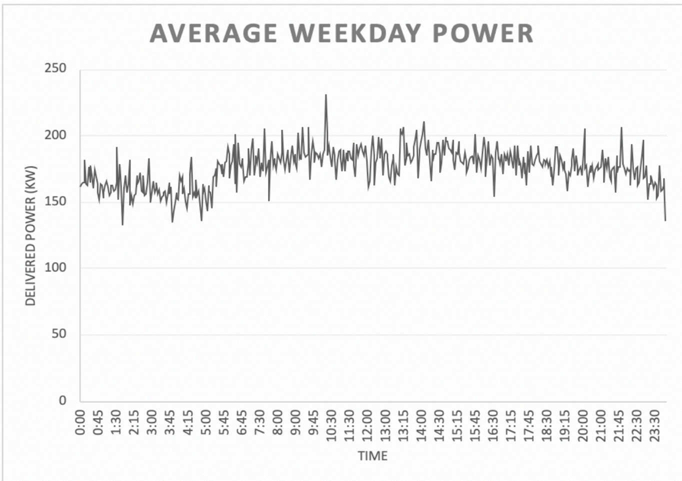
Los factores de demanda de NEC se utilizan para escalar las cargas de acuerdo con su uso. Los factores de demanda se definen como "La relación entre la demanda máxima de un sistema, o parte de un sistema, y la carga total conectada de un sistema o la parte del sistema en cuestión" en el National Electrical Code. Este código permite deducir cargas en función del uso simultáneo de aparatos, enchufes y cargas eléctricas en general. La carga escalada, llamada carga de demanda NEC, se puede calcular en cualquier bus. Esto permite mayores deducciones cuando la carga de NEC se calcula más abajo en el diagrama de líneas. Se estudian las cargas de demanda de NEC y se obtiene toda la carga de demanda de NEC del edificio. En este caso, se realizó un estudio en uno de los paneles principales. Los resultados fueron los siguientes:

Connected Load	**292,040 kVA**
NEC demand load (1)	**242,530 kVA**
NEC demand load (2)	**212,380 kVA**

La carga conectada se compara con la carga de demanda NEC calculada en cada subpanel y luego se suma (1) y la calculada directamente en el panel principal (2). Como podemos ver, las cargas de demanda de NEC permiten que el diseño de cualquier equipo eléctrico necesario sea de menor tamaño y cumpla con los estándares generales de seguridad. Cuanto más general sea el panel de distribución, y cuanto más grande sea la carga conectada, mayor será la reducció hecha a la carga NEC debido a la improbabilidad del uso de todas las cargas juntas. Al dimensionar el equipo, el uso de disyuntores, fusibles, alimentadores e incluso transformadores de menor tamaño pero con un diseño más cercano a la realidad reduce el coste de la instalación.

Además, se estudia el consumo eléctrico del edificio para completar el análisis del perfil eléctrico. Aunque la carga conectada y la carga de demanda NEC son conocidas, el consumo debe considerarse para ver la carga de trabajo real de la instalación. Se utilizan dos programas: EnergyCap para las facturas de electricidad y Niagara para información de medición. La primera figura muestra el consumo de electricidad de EnergyCap, mientras que la segunda muestra la potencia promedio de los días de la semana obtenida de los datos suministrados por Niagara.





La variación promedio es de casi 100 kilovatios por día, con un consumo máximo desde el mediodía hasta las 16 horas, en general. La potencia promedio consumida es de alrededor de 170 kilovatios. Esto significa que todos los meses suman 120000 kWh y, cada año, hasta 1500 MWh. Luego podemos confirmar que estos números coinciden con la factura de electricidad, asumiendo que EnergyCap y Niagara están midiendo los mismos datos y que la empresa de servicios públicos le está cobrando a la escuela la factura correcta.

El impacto ambiental debido a las emisiones de la energía demandada por la empresa de servicios públicos también se contempla a través de los datos obtenidos de EnergyCap.

DISEÑO DEL SISTEMA FOTOVOLTAICO

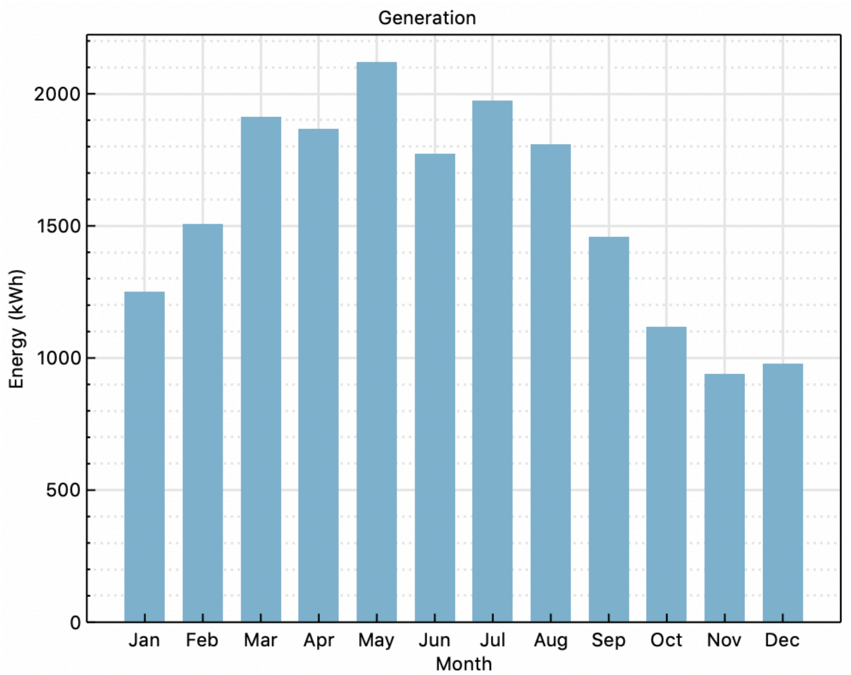
Para reducir la huella de carbono estudiada anteriormente, se estudia la implementación de una fuente de energía renovable. La energía solar fotovoltaica se elige para su implementación en el techo y el sistema es diseñado. Los paneles solares monocristalinos se eligen porque, dado que el espacio en el techo es limitado, estos tipos de paneles solares proporcionarán la máxima potencia para ese espacio. El tipo de montaje será techo plano lastrado y los paneles se orientarán hacia el sur con un ángulo de azimut de 39º. El tamaño del sistema se calcula en términos de espacio de techo, por lo que la capacidad instalada final llega a 37 kW (de forma conservadora). Aunque se evalúa la posibilidad de incluir un sistema de almacenamiento de energía de batería, podemos concluir que no se necesita una batería para almacenar energía, ya que no habrá excedentes de generación y no se desean mejoras los picos. Finalmente, se elige un inversor central como la mejor opción para la conversión de CC a CA, debido a la pequeña escala del sistema y la pequeña posibilidad de desajuste de los paneles.

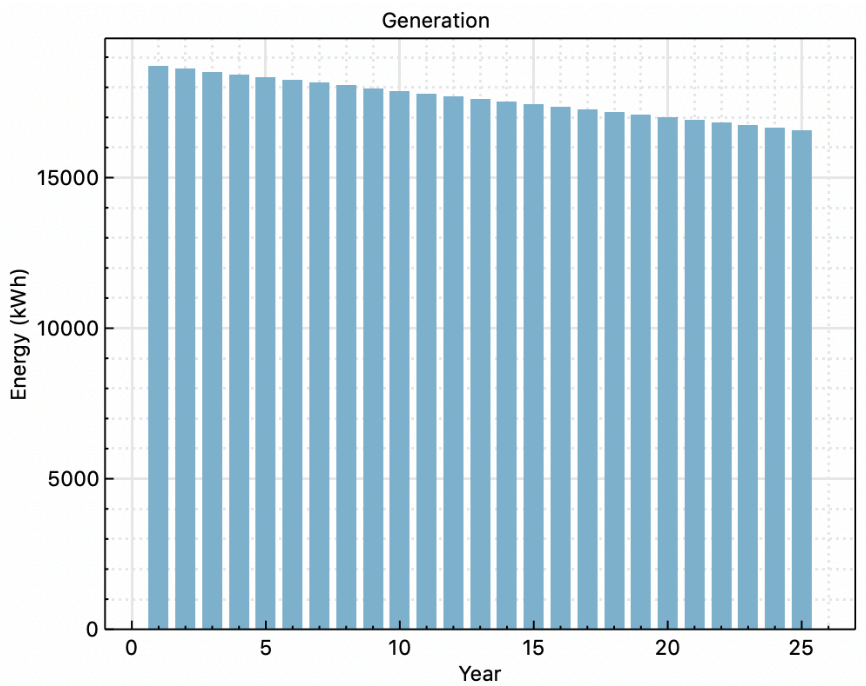
Panel choice	Monocrystalline panels
Mounting	Ballasted flat roof
Size	37 kW (123 panels)
Battery and inverter	No battery, 1 central inverter

Tilt angle	South
Azimuth angle	39º

GENERACIÓN DEL SISTEMAS FOTOVOLTAICO

El resultado más importante para evaluar cuál es el impacto, tanto ambiental como económico, del sistema es la energía que se genera anualmente. Esto se calcula utilizando un software llamado SAM (System Advisor Model), con todas los inputs correspondientes diseñados previamente y datos reales de radiación y clima.

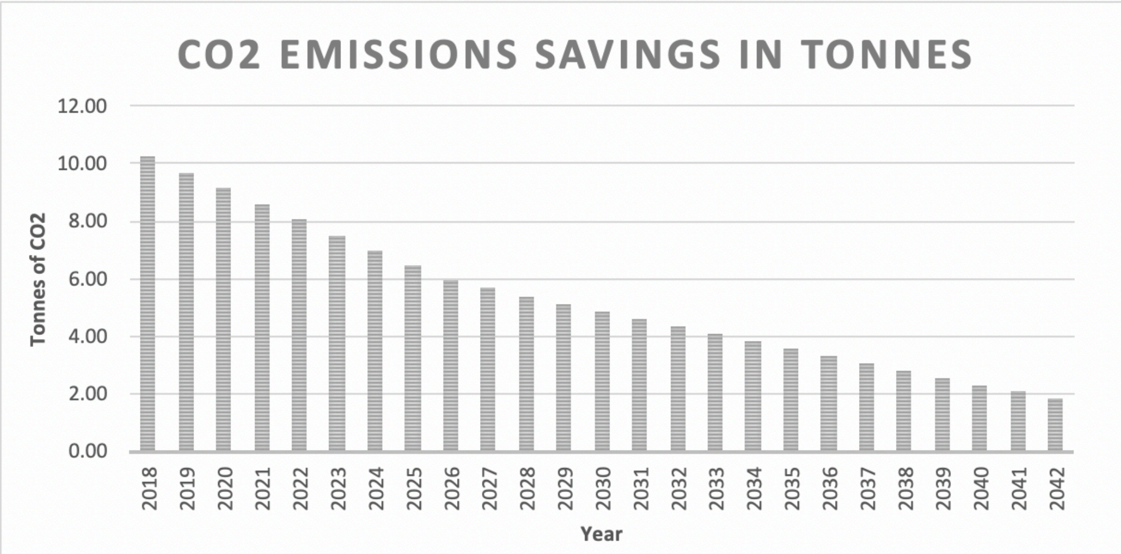




El software utiliza una tasa de degradación del 5% de los paneles. De esta manera, la producción de energía se reduce cada año. La producción mensual sería proporcional a la del primer año y se puede calcular con esa tasa de degradación. Como podemos ver, la generación varía de un mes a otro debido a los datos históricos de irradiación. La generación mensual promedio del primer año es de 1560 kWh. Esto es aproximadamente el 2% del consumo del edificio.

IMPACTO MEDIOAMBIENTAL

Con esta producción de generación y las futuras emisiones de la empresa de servicios públicos, se calcula la reducción de las emisiones y el impacto se muestra a continuación.



La tendencia del ahorro de emisiones es muy clara. Sin embargo, la inclinación de la línea de tendencia es más complicada. Si bien sabemos que el sistema fotovoltaico tiene una tasa de degradación y, por lo tanto, el ahorro de energía disminuye cada año, esta tasa no es tan alta. Lo que más afecta a este gradiente es que la empresa de suministro está reduciendo sus emisiones en el futuro. Esto afecta el ahorro de emisiones porque estamos comparando la energía que generamos con la que de otro modo compraríamos a Xcel Energy, y así, cuanto más limpia se vuelve la flota de generación de la empresa de servicios públicos, menos efecto tiene la introducción de una fuente de energía renovable en el edificio. El porcentaje de ahorro con respecto a la huella de carbono del edificio es del 1,5%. Si bien esto puede no parecer una gran contribución, la expansión de dicho modelo probaría tener un gran impacto en la huella de carbono de Colorado School of Mines.

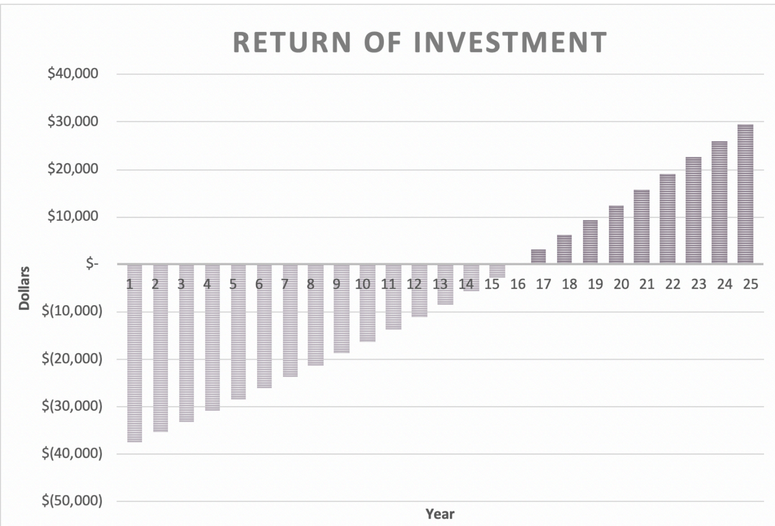
ESTUDIO DE VIABILIDAD ECONÓMICA

Además, se realiza un estudio económico en detalle, que incluye los costos de capital y O&M como gastos y el ahorro en las facturas y el coste de CO_2, que proporciona los resultados finales:

Primero, se muestra un análisis completo del flujo de cajas a 25 años (sin algunos años intermedios).

	1	2	3	4	5	21	22	23	24	25	Total
Savings											
Bill Savings	$ 2,290.47	$ 2,347.39	$ 2,405.72	$ 2,465.50	$ 2,526.77	$ 3,742.23	$ 3,835.23	$ 3,930.53	$ 4,028.21	$ 4,128.31	$ 78,079.71
Cost of CO2	$ 560.76	$ 546.79	$ 531.10	$ 508.20	$ 485.50	$ 224.89	$ 208.62	$ 192.51	$ 173.23	$ 155.79	$ 8,686.22
Total Savings	$ 2,851.23	$ 2,894.18	$ 2,936.83	$ 2,973.70	$ 3,012.27	$ 3,967.12	$ 4,043.85	$ 4,123.05	$ 4,201.43	$ 4,284.10	$ 86,765.92
Expenses											
Capital Investment	$ 40,381.80										$ 40,381.80
O&M		$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 16,800.00
Total Expenses	$ 40,381.80	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 57,181.80
Cash Flow											
Net Savings	$(37,530.57)	$ 2,194.18	$ 2,236.83	$ 2,273.70	$ 2,312.27	$ 3,267.12	$ 3,343.85	$ 3,423.05	$ 3,501.43	$ 3,584.10	
Cash Flow	$(37,530.57)	$(35,336.39)	$(33,099.56)	$(30,825.86)	$(28,513.59)	$ 15,731.70	$ 19,075.55	$ 22,498.59	$ 26,000.03	$ 29,584.12	

En segundo lugar, la siguiente figura muestra el retorno de la inversión y el beneficio total se puede ver en el último año.



El resultado más claro es que el retorno de la inversión comienza el año 16 después de la instalación. Aunque esto parece tarde, todavía hay 9 años en los que la escuela está obteniendo beneficios de este sistema. Como se mencionó anteriormente, podemos ver que, en el primer año, una inversión de capital se registra como gasto y que cada año, con los ahorros que provienen del costo del CO_2 y las facturas de electricidad, hay una ganancia hacia los retornos. La cuenta de ahorros neta final es de $ 30,000. Para un proyecto educativo, con un objetivo ambiental, este número final es satisfactorio.

CONCLUSIONES

En primer lugar, una descripción energética del edificio como la que se realizó como estudio preliminar en el que se basa el proyecto otorga una visión de un proyecto de diseño nuevo y real de un Microgrid. Planos eléctricos y diagramas unifilares de tal complejidad permitieron una comprensión que será útil en cualquier proyecto futuro que se parezca. En segundo lugar, la introducción del concepto de cálculos de carga de NEC amplió lo que habíamos aprendido sobre la carga conectada, y el aprendizaje de las regulaciones que debe seguir cualquier sistema para dimensionamiento y conexiones brinda una valiosa experiencia en el proceso real de diseño y construcción de edificios comerciales y residenciales en el campo de la ingeniería eléctrica. A partir de esto, se extraen conclusiones sobre el diseño y el tamaño de los conductores: las cargas de demanda de NEC permiten diseños más cercanos y seguros que a su vez ahorran dinero. Además, permite una estimación más cercana del uso real de las cargas en cualquier edificio. Finalmente, se realizó el análisis del consumo de energía y energía del edificio. Permite obtener una imagen de lo que es el uso del edificio, así como las curvas de carga diarias y la potencia y energía mensual y anual consumida. Es importante para la escuela verificar que lo que se mostraban en las facturas coincidía con la información del medidor digital y así es.

La segunda parte del proyecto se centró en la mejora de las emisiones y el consumo del edificio. Como ingeniera eléctrica, con conocimientos sobre sistemas de energía y una persona con la necesidad de contribuir a resolver el problema del cambio climático, la investigación realizada sobre energía renovable (y más específicamente, energía fotovoltaica) fue de gran interés para mí y la contribución perfecta a mis estudios. Dentro del proyecto, condujo a la elección más adecuada de un sistema fotovoltaico para la implementación del edificio: un sistema de paneles de 37kW, con un inversor central y sin batería. Se llegó a la conclusión de no agregar un sistema BESS debido a la falta de impacto que tendría el servicio de cambio de energía de la batería.

Con el sistema fotovoltaico diseñado y modelado, se analizó el impacto. La sección más importante fue el impacto ambiental, que resultó ser más pequeño de lo esperado. Sin embargo, da una idea de cómo funciona la energía renovable y de por qué la industria, aunque crece de manera constante, no ha sobrepasado al resto de fuentes de energía.

Por otro lado, el estudio económico demostró ser al menos rentable. El retorno de la inversión se produjo 16 años después de la instalación, lo que dejó 9 años de ingresos limpios para la escuela, sumando $ 30,000.

En general, y para cerrar las conclusiones, este proyecto ha brindado una visión impresionante de cómo funcionan los proyectos de diseño y construcción, así como un enfoque general de todo un sistema eléctrico del edificio y del campus. Además, la oportunidad de mejorar un sistema eléctrico desde el punto de vista ambiental y estudiar más a fondo la generación de energía limpia, ha significado un proceso de aprendizaje en este campo siendo además un estudio exitoso.

LOAD MODELING, ANALYSIS AND DESIGN OF A RELIABLE AND COST-EFFECTIVE MICROGRID – WITH DISTRIBUTED ENERGY RESOURCES

INTRODUCTION

As awareness for climate change, global warming and responsible energy consumption rises worldwide, energy efficiency and energy conservation in campuses of higher education and schools (among all commercial buildings) has become a new concern. Colorado School of Mines (Mines) has several ongoing projects looking into lowering energy consumption, minimizing emissions, reducing carbon footprint and economizing its energy profile.

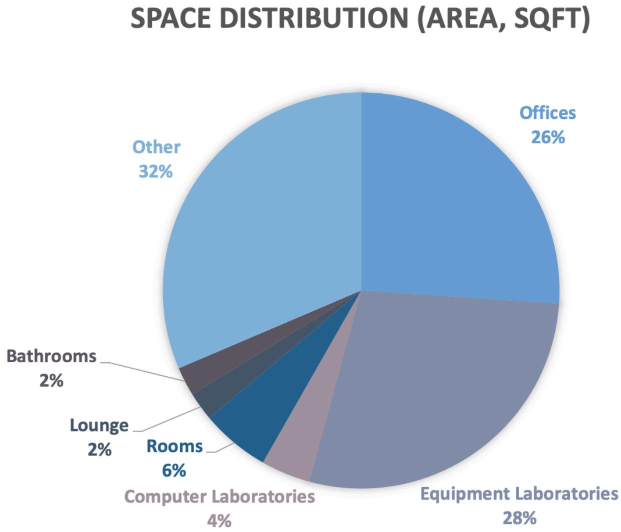
This interest for the subject in our exchange school is what pushed the members of this design team to take part in one such project that we could call our own. The building "CoorsTek Center for Applied Sciences and Engineering" (CoorsTek)is going to be studied, to find out whether energy efficiency and conservation, economic and environmental improvements can be achieved and how to implement that. This will constitute the first part of this project. This will be a base line work, performed by the entire team.

Each member will then work on different aspects of the building design, perform analysis and design improvements and make necessary suggestions for implementations. Ideas and solutions that result from this analysis, engineering or designing specific concepts will be addressed in detail.

My special interest is the use of green energy to improve our school's impact on the environment while being cost effective, this becoming the second part of this study.

STUDY

A general study of the building is conducted to understand the use of it. Rooms, laboratories and other spaces are taken into account, and their typical energy profile estimated. The space is divided as shown in the chart below.



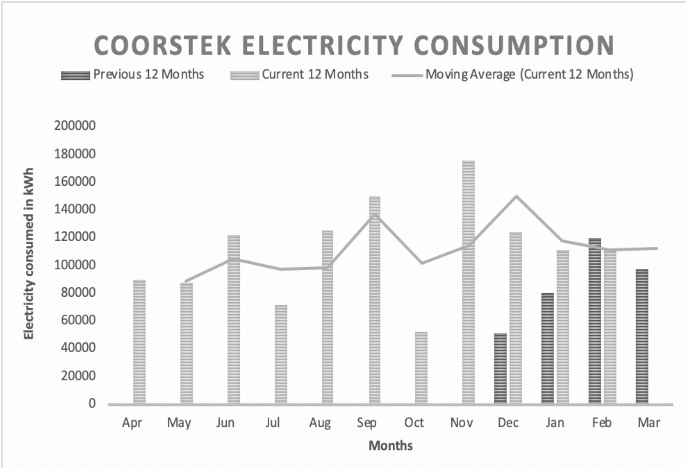
Then, the electrical profile of the building is analyzed. For this, the electrical one-line diagrams of the construction documents are used. The one-line diagram shows the connected load. However, the US follows Load Calculations stipulated by the NEC (National Electrical Code NFPA® 70) that allow for more specific and accurate calculations of the expected load at each bus so as to design and size transformers, feeders and conductors closer to real use. The National Electrical Code specifies the standards to be followed for electrical installations.

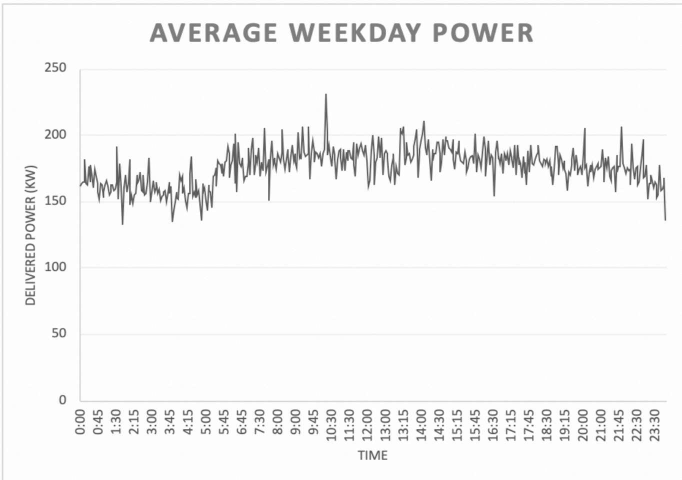
NEC demand factors are used to scale the loads according to their use. The demand factors are defined as "The ratio of the maximum demand of a system, or part of a system, to the total connected load of a system or the part of the system under consideration." in the National Electrical Code. This code permits to deduct loads depending on the simultaneous use of appliances, receptacles and general electrical loads. The scaled load, called NEC demand load, can be calculated at any bus. This allows for bigger deductions when the NEC load is calculated further down the line diagram. NEC demand loads are studied and the whole NEC demand load of the building is obtained. In this case, a study was done on one of the main panelboards. The results were the following:

Connected Load	**292,040 kVA**
NEC demand load (1)	**242,530 kVA**
NEC demand load (2)	**212,380 kVA**

The connected load is compared to the NEC demand load calculated at each sub-panelboard and then added (1) and the one calculated directly at the main panelboard. As we can see, the NEC demand loads allow for the design of any electrical equipment needed to be of smaller size while meeting general safety standards. The more general the distribution board is, and so, the bigger the connected load, the bigger the reduction made to the NEC load due to improbability of use of all loads together. When sizing the equipment, using smaller but more closely designed breakers, fuses, feeders and even transformers reduces the capital cost of the installation.

Furthermore, the electrical consumption of the building is studied to complete the analysis on the electrical profile of the building. Although the connected load and the NEC demand load are known, the consumption has to be considered to see the actual working load of the facility. Two software are used: EnergyCap for electricity bills and Niagara for metering information. The first figure shows the electricity consumption from EnergyCap, while the second shows average weekday power obtained from the data supplied by Niagara.





The average variation is of nearly 100 kilowatts a day with the consumption peaking from noon till 4 pm, generally. The average power consumed is around 170 kilowatts. This means that every month, it sums up to 120000 kWh and, every year, to 1500 MWh. We can then confirm that these numbers match the electricity bill, thus assuming that EnergyCap and Niagara are measuring the same data and that the utility is charging the school the correct bill.

The environmental impact due to the emissions of the energy demanded from the utility is also contemplated through data obtained from EnergyCap.

PHOTOVOLTAIC SYSTEM DESIGN

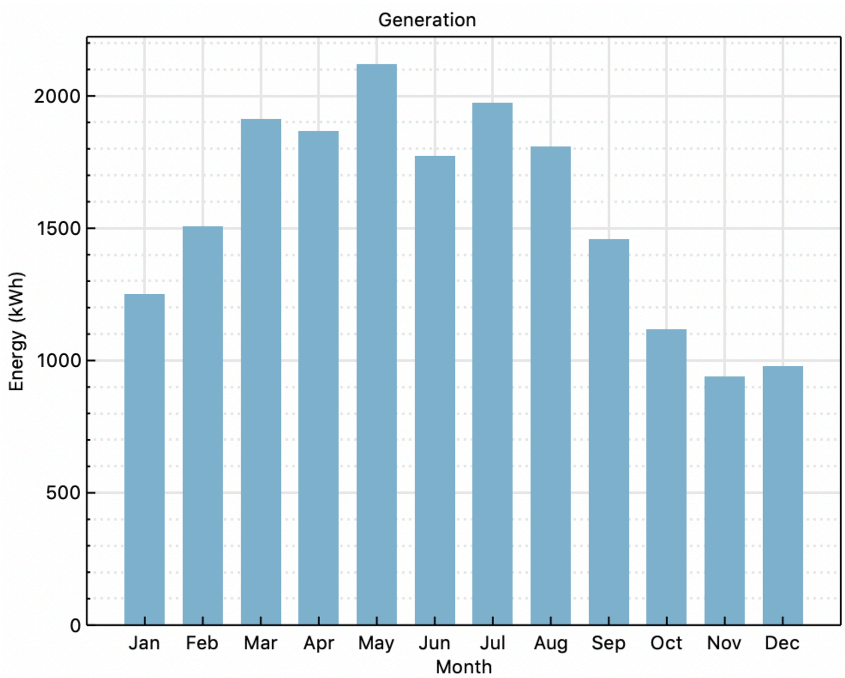
To reduce the carbon footprint studied above, the implementation of a renewable source of energy is studied. Solar photovoltaic energy is chosen for implementation on the roof, and the system is designed. Monocrystalline solar panels are chosen because, since the space on the roof is limited, these types of solar panels will provide the maximum power for that much square footage. The type of mounting will be ballasted flat roof and the panels will be bearing south with an azimuth angle of 39º. The sizing of the system is calculated in terms of roof space, and so the final installed capacity comes up to 37 kW (conservatively). Although the possibility of including a battery energy storage system is evaluated, we can conclude that a battery is not needed to store any power, as there will be no surplus generation and no peak improvements are wanted. Finally, a central inverter is chosen as the best option for DC-to-AC conversion, due to the small scale of the system and the small possibility of mismatch of the panels.

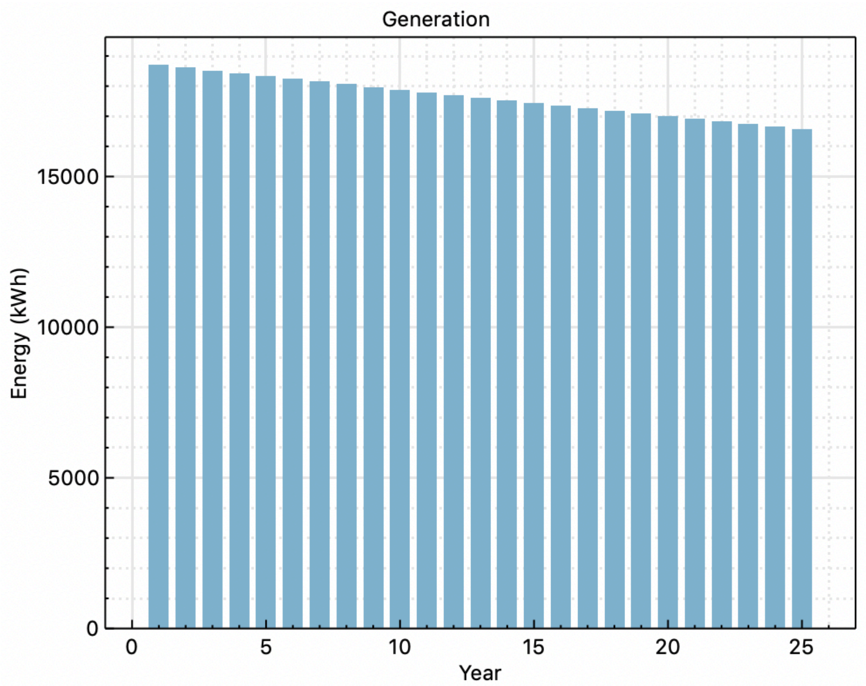
Panel choice	Monocrystalline panels
Mounting	Ballasted flat roof
Size	37 kW (123 panels)
Battery and inverter	No battery, 1 central inverter

Tilt angle	South
Azimuth angle	39º

PV SYSTEM GENERATION

The most important output to evaluate what the impact, both environmental and economic, of the system is the energy generated annually. This is estimated using a software called SAM – System Advisor Model – with all the corresponding inputs designed previously and real irradiation and weather data.

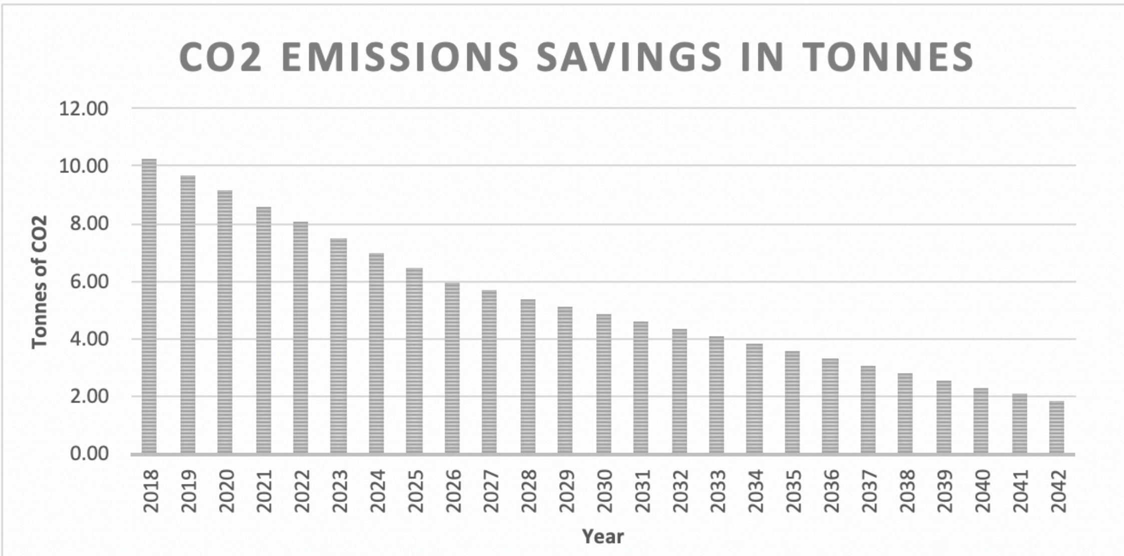




The software uses a 5% degradation rate of panels. This way, the energy production is reduced each year. The monthly production would be proportional to the first year and can be calculated with that degradation rate. As we can see, the generation varies from month to month due to the historic data of irradiation. The average monthly generation of the first year is 1560 kWh. This is about 2% of the building's consumption.

ENVIRONMENTAL IMPACT

With this generation output and the future emissions of the utility, the reduction of emissions is calculated, and the impact is shown below.



The tendency of the emissions savings is very clear. However, the steepness of the trend line is more complicated. While we do know that the PV system has a degradation rate and thus the power savings get lower every year, this rate is not so steep. What affects this gradient the most is that the utility is reducing their emissions into the future. This affects the emissions savings because we are comparing the power we generate with the one that we would otherwise buy from Xcel Energy, and so, the cleaner the utility's generation fleet becomes, the less effect introducing a source of renewable energy into the building has. The percentage of savings with respect to the building's carbon footprint is 1,5 %. Although this may not seem like a big contribution, the expansion of such model would prove to have a big impact on Colorado's School of Mines carbon footprint.

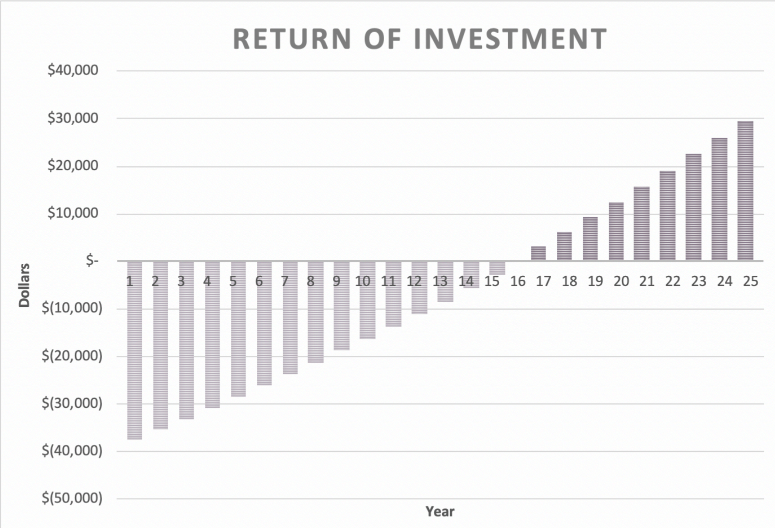
ECONOMIC FEASIBILITY STUDY

Also, an economic study is conducted in detail – it includes capital costs and O&M as expenses and bill savings and cost of CO_2 as savings – providing the final results:

First, a full 25-year cash flow analysis is shown (without some years in between).

	1	2	3	4	5	21	22	23	24	25	Total
Savings											
Bill Savings	$ 2,290.47	$ 2,347.39	$ 2,405.72	$ 2,465.50	$ 2,526.77	$ 3,742.23	$ 3,835.23	$ 3,930.53	$ 4,028.21	$ 4,128.31	$ 78,079.71
Cost of CO2	$ 560.76	$ 546.79	$ 531.10	$ 508.20	$ 485.50	$ 224.89	$ 208.62	$ 192.51	$ 173.23	$ 155.79	$ 8,686.22
Total Savings	$ 2,851.23	$ 2,894.18	$ 2,936.83	$ 2,973.70	$ 3,012.27	$ 3,967.12	$ 4,043.85	$ 4,123.05	$ 4,201.43	$ 4,284.10	$ 86,765.92
Expenses											
Capital Investment	$ 40,381.80										$ 40,381.80
O&M		$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 16,800.00
Total Expenses	$ 40,381.80	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 57,181.80
Cash Flow											
Net Savings	$(37,530.57)	$ 2,194.18	$ 2,236.83	$ 2,273.70	$ 2,312.27	$ 3,267.12	$ 3,343.85	$ 3,423.05	$ 3,501.43	$ 3,584.10	
Cash Flow	$(37,530.57)	$(35,336.39)	$(33,099.56)	$(30,825.86)	$(28,513.59)	$ 15,731.70	$ 19,075.55	$ 22,498.59	$ 26,000.03	$ 29,584.12	

Then, the following figure shows the return of investment and the total profit can be seen on the last year.



The most clear outcome is that the return of investment starts on the 16th year after installation. Although this seems late, there are still 9 years were the school is making a profit of this system. As mentioned before, we can see that the first year, a capital investment is registered as expense and that every year, with the savings that come from the cost of CO_2 and the electricity bills, there is a gain towards the returns. The final net savings account for a total of $30,000. For an educational project, with an environmental aim, this final number is satisfactory.

CONCLUSIONS

Firstly, a building energy profiling like the one performed as a preliminary study on which to base the project gives the perfect insight into a new, real life design of a microgrid. Electrical floor plans and one-line diagrams of such complexity allowed for an understanding that will be of use in any future projects that bear some resemblance. Secondly, the introduction of the concept of NEC load calculations expanded on what we had learnt on connected load, and learning about the regulations that any system has to follow for sizing and connections gives valuable experience on the actual process of design and construction of commercial and residential buildings in the field of electrical engineering. From this, conclusions on the design and sizing of feeders and breakers are drawn: NEC demand loads allow for closer but safe designs that in turn save money. Also, it allows for a closer estimation of the actual use of the loads in any building. Lastly, this analysis of the power and energy consumption of the building was conducted. They allowed the obtaining of a picture of what the use of the building was, as well as the daily load curves and the monthly and annual power and energy consumed. It was important for the school to verify that what the bills were showing matched the digital meter's information and it was so.

The second part of the project focused on the improvement of the building's emissions and consumption. As an electrical engineering, with a huge background in energy systems, and a person with the need to contribute to solving the problem of climate change, the research conducted on renewable energy (and more specifically, PV energy) was of great interest to me and the perfect contribution to my studies. Within the project, it led to the most adequate choice of a PV system for implementation of the building: a 37kW system of panels, with a central inverter and no battery. The conclusion of not adding a BESS system was reached because of the lack of impact the energy shifting service of the battery would have.

From the designed and modeled PV system, the impact was analyzed. The most important section was the environmental impact, which proved to be smaller than expected. However, it gives an insight into how renewable energy works, and into why the industry, although growing steadily, has not taken over all other sources of energy.

On the other hand, the economic study proved to be at least profitable. The return of investment occurred 16 year after the installation which left 9 years of clean income for the school, adding up to $30,000.

Overall, and to close the conclusions, this project has granted an impressive insight into how real-life design and construction projects work, as well as a look onto the bigger picture of a whole building and campus electrical and energy system. Moreover, the chance to environmentally improve an electrical system, and to more deeply study green generation led to a great learning experience in this field and was a successful design study.

ACKNOWLEDGEMENTS

I wish to first thank both of the institutions that have made the fulfillment of this project possible. My home school, Universidad Pontificia de Comillas, for the opportunity to continue my undergraduate studies in the US and my host school, Colorado School of Mines, for so welcomingly giving me the chance to carry out this research, helping in every way possible.

More specifically, I would like to thank Dr. PK Sen, my teacher and project supervisor, for taking the time to guide us throughout the whole project, and for his helpful and sometimes necessary advice and input. Also, many thanks to PE Emily Royal for her interest in our studies and her contribution to our learning experience.

Finally, thanks to Brian Oldfield for access to important data sources and software.

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I. INTRODUCTION

As awareness for climate change, global warming and responsible energy consumption rises worldwide, energy efficiency and energy conservation in campuses of higher education and schools (among all commercial buildings) has become a new concern. Colorado School of Mines (Mines) has several ongoing projects looking into lowering energy consumption, minimizing emissions, reducing carbon footprint and economizing its energy profile.

This interest for the subject in our exchange school is what pushed the members of this design team to take part in one such project that we could call our own. The other two members (form ICAI) and I will be studying one of the newest large buildings (inaugurated in 2017 and still being finished) in our campus, called "CoorsTek Center for Applied Sciences and Engineering" (CoorsTek), to find out whether energy efficiency and conservation, economic and environmental improvements can be achieved and how to implement that. Similar work has been done on other campus facilities but, because of its recent construction, CoorsTek has never been electrically profiled and none of its data has been taken into account yet.

CoorsTek contains classrooms, offices and laboratories, as well as several rest areas and open study rooms for general use of campus students and other members. This makes its energy data vary constantly, and so construction predictions can differ from the actual energy profile. Because of the nature of the building, to be able to change, improve or even just portray this energy profile, an extensive analysis of the physical building, its electrical and natural gas consumption and its occupation must be carried out. This will constitute the first part of this project. This will be a base line work, performed by the entire team.

Each member will then work on different aspects of the building design, perform analysis and design improvements and make necessary suggestions for implementations. Ideas and solutions that result from this analysis, engineering or designing specific concepts will be addressed in detail.

My special interest is the use of green energy to improve our school's impact on the environment while being cost effective, this becoming the second part of this study. On campus, there has been a study conducted by Brian Oldfield, a MS graduate student on the technical and economic feasibility of implementing solar panels and so, with this background, emphasis will be given to the possible use of photovoltaic energy.

II. STATE-OF-THE-ART

The overall energy utilization study of public facilities and on campus is becoming a bigger interest nationwide including at Colorado School of Mines. It is of special interests for students majoring in Mechanical, Electrical and Environmental Engineering. The ME and EE departments have been working closely together to develop a general picture of the school's energy profile. The mechanical area is focusing on reporting heating and cooling by simulation, led by Professor Paulo Tabares. Our project director, Dr. Sen, has been guiding the electrical department on electrical analysis and, just recently, on design and implementation of photovoltaic energy and battery energy storage system (BESS) This last study on PV + BESS has been carried out by Mines graduate student Brian Oldfield for his master's Thesis in Electrical Engineering and is used extensively in our design and analysis process and will be mentioned throughout this paper.

A. MECHANICAL/ELECTRICAL PROFILING WORK AT MINES

Since 2012, Mines has increased its awareness on energy sustainability. Older buildings have been renovated (specially heating and cooling, as well as lighting) to improve building efficiency and increase energy savings. All newly built buildings have to meet the LEED Gold Standard – a green building standard that includes areas from energy and water efficiency to generation of waste and resources – and so design teams have been taking this into account in their study. These teams, focusing on all campus facilities, have also been creating an overall electrical (and mechanical) profile of the building that allows them to see if there is room for improvement in any areas. Open Studio has been used by the ME department to simulate most campus buildings, creating an extensive study of the HVAC systems, water consumption and the natural gas needed for water heating and cooling. In the EE department, focus has been placed on electrical diagrams and simulation of power flow in PowerWorld. All this work is a good base for this project.

B. OPTIMAL PV AND BESS DESIGN FOR THE COLORADO SCHOOL OF MINES

This study takes all of Mines energy consumption, analyses it and looks for a possible solution for reducing its emissions. It focuses on photovoltaic panels and their preferred placement on campus as well as including the optimal azimuth and tilt angles. For this optimization, a software is created in the design that also includes the optimal BESS for these panels. An economical study is also included to determine its feasibility. The main work of the project is the optimization software programmed but the work methodology used and some of the information obtained can be of great relevance.

III. MOTIVATION AND SCOPE

One of the most appealing aspects of this project, for me, is the opportunity it provides to take part in a larger mission that might improve the campus in the near future. Seeing my knowledge and work portrayed in a joint effort towards something that all of us are interested in is part of what motivates me to engage in this work.

With the effects of climate change becoming more obvious in our everyday life, the chance to contribute towards minimizing the greenhouse gas emissions and contamination, however small a contribution it may be, becomes increasingly attractive for an engineer. Furthermore, the challenge of achieving this while obtaining an economic profit, as well as providing a model that can be of educational relevance to the school, makes the project confidently interesting.

Moreover, the general first approach of this work can be implemented in many areas as an electrical engineer. The study of a real-life design and construction of a building with all its intricate workings provides a great base of knowledge for the future of my career as an engineer. It is a learning opportunity that can then be of use, not only to me, but hopefully to others. As well as acquiring better knowledge based on my studies both in ICAI and Colorado School of Mines, the project can provide a wide understanding of new subjects to work upon and learn from that I would have otherwise never contemplated.

Further inspecting the scope of this project, the research that will be conducted of renewable sources of energy, along with emissions and environmental impact, becomes increasingly relevant in the world of energy and electricity. Understanding the technology available, in detail, provides a growth on my studies that will definitely be of great use in the future.

Also, the economic study that the implementation of such sources of energy demands will be of importance in the project. Research on this matter will be crucial, to develop a model that closely adjusts to the costs and payback the actual implementation would have.

IV. CoorsTek Building

A. General description

This 95,000 square foot facility was first opened in September 2017 after nearly four years of construction. The newest addition to the Mines campus was made possible thanks to a $27 million donation from CoorsTek (and the Coors family) and a $14.6 million grant from the State of Colorado. It has become the new home for the Physics Department, whose presence in the building is dominant, and the College of Applied Science and Engineering (1).

Image 1: CoorsTek building from Illinois Street

The building is separated in three levels as well as a basement and a rooftop. Level 1, the most public level, consist of a large open space with full-height glass panels looking out to the campus green Kafadar Commons, where students can work, interact or just hang-out. This level also includes versatile 'Active Learning' classrooms which can hold from course lectures to interactive campus activities.

Image 2: Glass facade from Kafadar Commons

Level 2 and Level 3 contain teaching classrooms and laboratories and graduate student offices on one side, with faculty offices on the other, looking out to the green space below. Throughout the building, study rooms and breakout spaces can be found, making the most out of the space and placed to benefit from the natural light.

The basement is reserved for laboratories with specific requirements, such as moderate lighting and sound or magnetic and vibration isolation. It extends slightly underground from the building to make space for these research spaces and contains the newest technologies of their department.

From the final architectural and construction plans (found in the appendices), a general idea of the space has been obtained, and built upon that, an on-site study of the building has allowed for an accurate description of the facility. The mechanical and electrical rooms were accessed during the building tour to get a notion of the real electrical connections and of the supply of commodities across the whole building. The roof was visited as well, in order to study the available space for the possible implementation of PV in latter part of this project. A full report of the building observation can be found in Appendix A, were all the team members detail an account of the whole tour and the observations.

To understand the space, a division according to its use was made. Six general categories can be made:

Category	*Description*
Offices	Student and faculty offices
Computer Laboratories	Classrooms with access to ten or more computers
Equipment Laboratories	Laboratories with machinery, equipment and energy consuming technology
Lounge	Lounge and Break-Out rooms for the public, students or faculty
Rooms	Rooms for more than 6 people that include Conference Rooms, Classrooms, Active Learning Rooms etc.
Restrooms	All male, female and family restrooms

Table 1: Descriptions of space subdivision categories

These categories were chosen because we can model each group with a general energy consumption profile:

- An office will generally contain one computer (if it is individual), several power outputs and will need the required heating for an occupancy of one person.
- Computer Laboratories will be constantly feeding the installed computers as well as projectors and interactive boards. In turn, the heating required will be much less than that of a normal room but the cooling necessary could be much more in hotter months.
- Equipment Labs, on the other hand, can be more difficult to generalize, as CoorsTek hosts all kinds of different types of machinery, research and testing laboratories that all require very different circumstances, specially the basement labs which are the most demanding.
- The break-out spaces are the simplest, as only furniture will occupy the space, and no permanent computers or machinery will be involved in these rooms.
- Restrooms will not consume much electricity (only lighting) as their use is very intermittent but they will require much ventilation.
- Lastly, the category referred as rooms can be described as big spaces with one or two computers and a projector that can be used as classrooms, conference rooms, meeting or presentation spaces. They will generally hold more people than all the other categories.

Below, a table (Table 2) of the what can be found in each level, divided in the aforementioned categories, is shown. This data has been obtained from the architectural final floor plans of each level.

	Offices	*Equipment Laboratories*	*Computer Laboratories*	*Rooms*	*Lounge*	*Restrooms*
Basement	4	14	0	0	0	3
Level 1	0	2	2	2	2	2
Level 2	24	3	0	1	3	2
Level 3	38	4	0	3	3	2
TOTAL	66	23	2	6	8	9

Table 2: Number of spaces in each floor level according to categories

This data can also be summarized in the square footage per category and level. The square feet of each room are found in the general code plans of the construction plan documents. The following table (Table 3) contains these figures.

	Offices	*Equipment Laboratories*	*Computer Laboratories*	*Rooms*	*Lounge*	*Restrooms*
Basement	1097	7219	0	0	0	594
Level 1	0	1530	3617	2949	960	510
Level 2	10286	9211	0	729	430	510
Level 3	12167	5584	0	1365	700	510
TOTAL	23550	23544	3617	5043	2090	2124

Table 3: Square Feet of categories per floor level

From these two tables, we can get a general notion of the consumption profile of each floor.

The basement will be consuming a great percentage of the building's energy demand, seeing as it contains one of the most square footage of equipment laboratories (and the most demanding and specific) as well as having no natural light which will require extra lighting.

Level 1, the entrance and public level, will be the less consuming, as it doesn't have any equipment labs. The rooms that will require a bigger electrical supply will be the two computer rooms it holds. Also, the floor to ceiling glass façade will provide most of the light to the common areas.

Level 2 holds only three labs but one of them – that is now being built and designed – will occupy 7000 sq. ft., nearly as much as all the laboratories of the basement combined together. However, nearly half of the offices of the facility can also be found in this floor. For now, the offices will consume most of this floor's load, but when the lab is finished it will require more energy.

Level 3 contains more than half of the offices and a few of specialized labs. With less equipment and machinery, it will not need as big a supply as Level 2 or the basement.

While the roof has not been studied yet, as no living space is available, it does consume a significant amount of electricity. It incorporates air scrubbing equipment and ventilation systems as well as two elevator rooms. Since CoorsTek has a lot of clean air requirements (necessary for nearly all specialized laboratories in the basement), most of the ventilation is working daily.

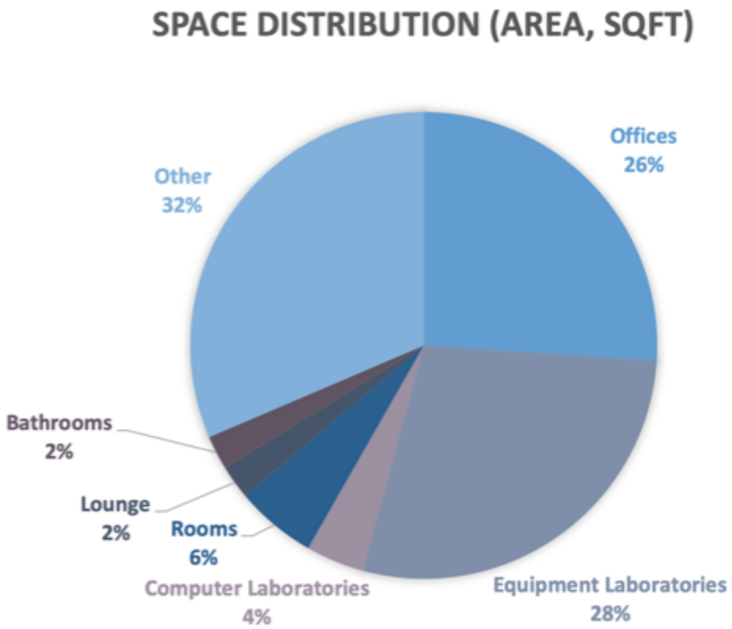


Figure 1: Distribution of the square footage of the building according to aforementioned categories

The graph shown above shows the percentage of square footage occupied by each category throughout the whole building, where the category called others includes open spaces – shown in the picture below – and corridors as well as electrical mechanical and data rooms (they all require simple lighting and heating). As expected, offices and equipment laboratories hold the most square footage. It is then clear that most energy consumption will come from this but from the knowledge we have of the nature of these spaces, we know that the equipment laboratories will conform the biggest load, as the consumption per square footage will be bigger.

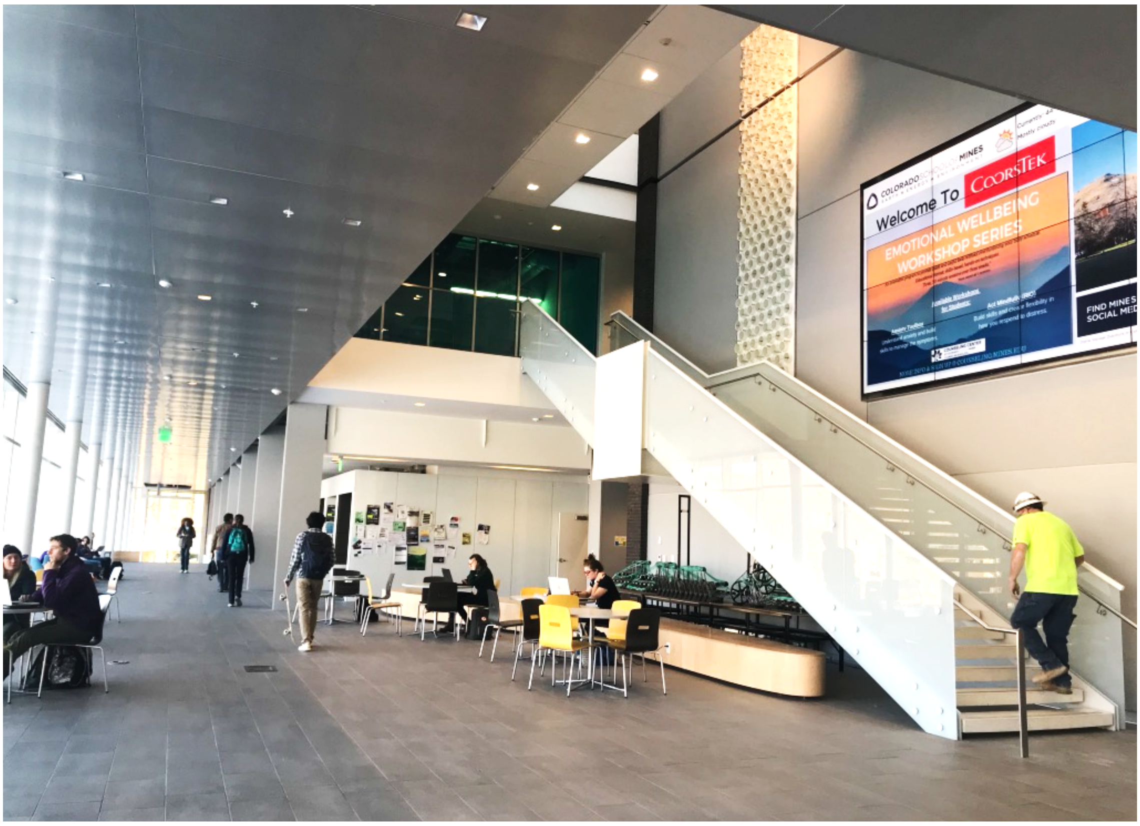


Image 3: Open Space at Level 1 (this space would be included in others)

B. Electrical profile

CoorsTek Center is electrically fed by one of the campus electrical loops of 13.2 kV voltage. This loop is connected to the grid and the electricity is supplied by the Xcel Energy utility (at this same voltage). The building has a 13.2kV – 480Y/277V (called T-3 in the one-line diagram), which then feeds all of the building's electrical loads. The transformers power rating is 2000kVA which is more than sufficient for its peak load.

The one-line diagram of the whole campus shows where the connection of the building underground voltage distribution line lies. The one-line diagram of CoorsTek (E-002A, shown below) shows the T-3 transformer that provides the low distribution voltage to the building.

The power distribution consists of three main boards:

- The main distribution board, which feeds all ordinary loads and panel boards for each level (at 480V or 208/120 V voltage fed by power transformers).
- The emergency distribution board, which feeds the loads that require an emergency source of electricity by law (fire alarm systems, emergency lighting etc.) and that is connected by a switch to the emergency generators located at Marquez Hall (across the street).
- Th stand-by distribution board, feeding all the non-compulsory loads that are fed by the emergency system.

To get more information on the loads of each floor level, the electrical plans of the building are studied. E-004 provides a summary of the loads of each floor, while information on the panelboards and an expansion of the one-line diagram of the building can be found in the construction documents.

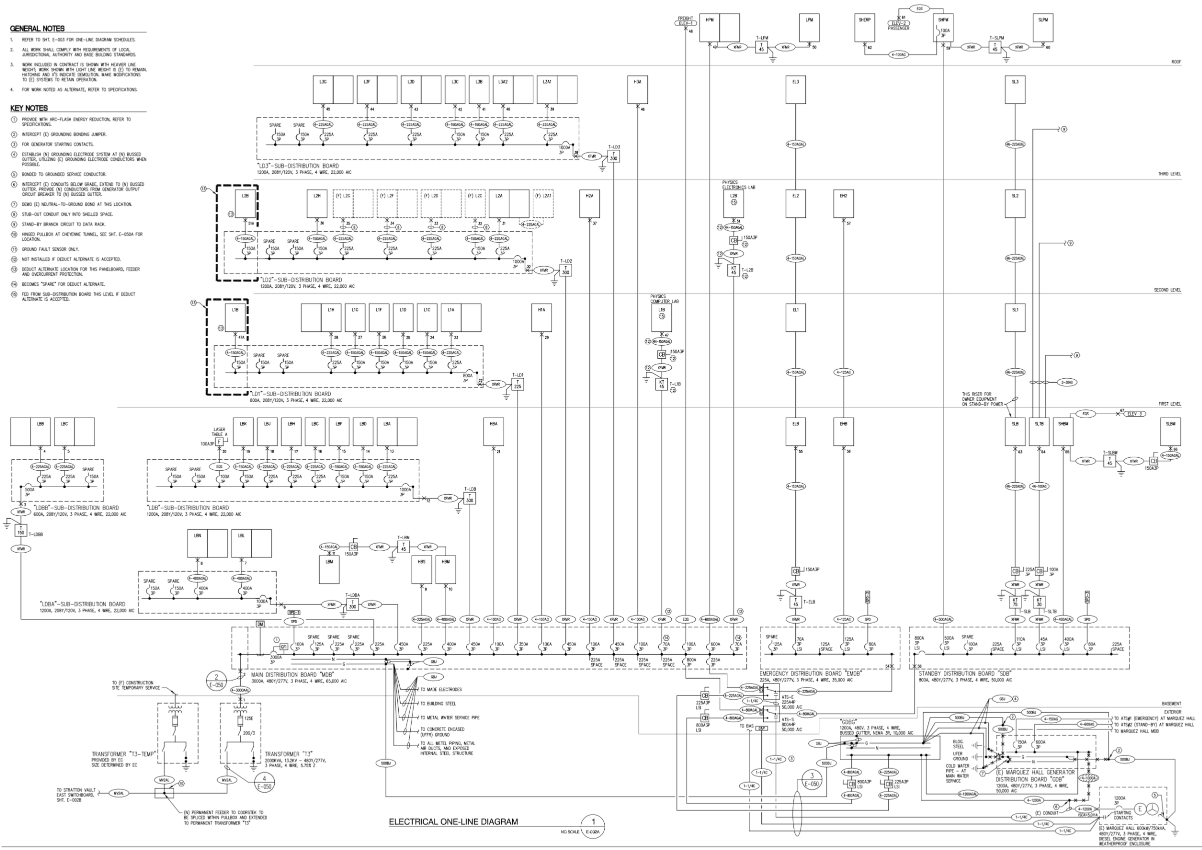


Figure 2: One-line diagram of CoorsTek Center

The one-line diagram shows the connected load. However, the US follows Load Calculations stipulated by the NEC (National Electrical Code NFPA® 70) (2) that allow for more specific and accurate calculations of the expected load at each bus so as to design and size transformers, feeders and conductors closer to real use. The National Electrical Code specifies the standards to be followed for electrical installations. Although it is not a federal law, in most states it is enforced to unify the specification for electrical systems of all types. It covers purpose, rules and scope for any type of installation, and allows for the determination of accurate loads by taking into account the circumstances of the equipment.

NEC demand factors are used to scale the loads according to their use. The demand factors are defined as “The ratio of the maximum demand of a system, or part of a system, to the total connected load of a system or the part of the system under consideration.” in the National Electrical Code. This code permits to deduct loads depending on the simultaneous use of appliances, receptacles and general electrical loads. The scaled load, called NEC demand load, can be calculated at any bus. This allows for bigger deductions when the NEC load is calculated further down the line diagram. To explain this, the load calculation of one of the distribution boards is compared to the calculation of the individual load it feeds and the connected load.

When understanding the load calculations of the building, special attention is taken to comprehend the load factors applied to the connected loads. Appendix B (NEC Sections Describing Load Factors) holds the relevant information regarding the load factors of the loads in question being studied in this building. With that information, the following table is created, summarizing the factors.

Load Type	***NEC Demand Factor***
Continuous Loads	1.25
Largest Motor	1.25
Remaining Motor(s)	1
First 10k RCPT	1
Remaining RCPT	0.5

Table 4: NEC Demand Factor for each load type

The continuous load is always accounted as 125% to design feeders, however, the largest motor to 125% represents the inrush current of starting that or any other of the motors that could be connected as well. Only the first 10kVA of the receptacles are fully taken into consideration due to the improbability of simultaneous use off all receptacles. The rest can be taken into account to 50% of their load.

Non-residential buildings also have to consider kitchen equipment loads. These are electrical cooking equipment, dishwashers, water heaters and other equipment that can be found in lounge areas or office kitchens. As these equipment units won't be used together almost at any time, deductions can also be applied to their corresponding connected loads, according to the following table from the NEC.

Number of Units of Equipment	Demand Factor (%)
1	100
2	100
3	90
4	80
5	70
6 and over	65

Table 5: Demand factor (%) for kitchen equipment depending on the number of connected units

With these load factors and the understanding of the load calculations, the NEC demand load of LD3 distribution board is calculated on an excel sheet. This board does not feed any heating or lighting loads (which would be multiplied by a 1.25 demand factor due to their continuous use) as most of these types of loads are at a 480V voltage and this distribution board is at 208V. One more category is added that hasn't been mentioned before, called equipment. This is for the appliances, equipment and electric loads whose load is known (mostly, lab equipment and tech devices) and so their NEC demand factor would be 1.

Load (VA)	***First 10K RCPT***	***Remaining RCPT***	***Largest Motor***	***Remaining motor(s)***	***Equipment***	***Kitchen***
L3A1	10,000	37,040	2,020		2,500	5,760
L3A2	10,000	14,800	600	480	8,300	4,060
L3B	10,000	3,870			1,920	
L3C	10,000	80			1,920	
L3D	10,000	16,830			37,840	
L3F	10,000	10,170			36,260	
L3G	10,000	17,540			20,050	
Connected Load	10,000	160,330	2,020	1,080	108,790	9,820
Total Connected Load	**292,040**					
NEC Demand Factor	1	0.5	1.25	1	1	1
NEC Demand Load	10000	80165	2525	1080	108790	9820
Total NEC Load	**212,380**					

Table 6: NEC demand load calculations for LD3 distribution load according to NEC code guidelines

The connected load is the sum of all the total loads, while the total NEC Load is the sum of the Demand Loads, which is the individual connected loads multiplied by their corresponding factors. The difference of these two total loads is nearly 80,000 VA.

A similar study is done to these loads except the NEC demand factors are applied to each panel board instead of the total sum of all the panel boards. This is what should be done to design the feeders and circuit breaker of each branch connected to the LD3 distribution board.

Load (VA)	First 10K RCPT	Remaining RCPT	Largest Motor	Remaining motor(s)	Equipment	Kitchen
L3A1	10,000	37,040	2,020		2,500	5,760
D.F	1	0.5	1.25	1	1	1
NEC Load	10,000	18,520	2,525		2,500	5,760
L3A2	10,000	14,800	600	480	8,300	4,060
D.F	1	0.5	1.25	1	1	1
NEC Load	10,000	7,400	750	480	8300	4,060
L3B	10,000	3,870			1,920	
D.F	1	0.5	1.25	1	1	1
NEC Load	10,000	1,935			1,920	
L3C	10,000	80			1,920	
D.F	1	0.5	1.25	1	1	1
NEC Load	10,000	40			1,920	
L3D	10,000	16,830			37,840	
D.F	1	0.5	1.25	1	1	1
NEC Load	10,000	8,415			37,840	
L3F	10,000	10,170			36,260	
D.F	1	0.5	1.25	1	1	1
NEC Load	10,000	5,085			36,260	
L3G	10,000	17,540			20,050	
D.F	1	0.5	1.25	1	1	1
NEC Load	10,000	8,770			20,050	
NEC Demand Load	70000	50165	3275	480	108790	9820
Total NEC Load	**242530**					

Table 7: NEC demand load calculations for each panelboard of the LD3 distribution load according to NEC code guidelines

As we can see, the NEC demand loads allow for the design of any electrical equipment needed to be of smaller size while meeting general safety standards. The more general the distribution board is, the bigger the connected load, and so, the bigger the reduction made to the NEC load due to improbability of use of all loads together. When sizing the equipment, using smaller but more closely designed breakers, fuses, feeders and even transformers reduces the capital cost of the installation.

The most important design is conductor sizing. A minimum conductor size is required for any given load which also takes into account the insulation needed for the current carried to such load. All this ensures the safe installment of any system.

However, conductors and other equipment will almost never be carrying their nominal or full load current. This is why the electrical consumption needs to be studied, to understand what the actual electrical load of the building is.

C. ELECTRICAL CONSUMPTION

The electrical consumption of the building is studied to complete the analysis on the electrical profile of the building. Although the connected load and the NEC demand load are known, the consumption has to be considered to see the actual working load of the facility. The most general data can be extracted from the monthly bills of the facility, found in the bill software called EnergyCap (3). It gathers all the electrical bills of all the buildings of the campus, the consumption in kWh as well as other utilities such as chilled water or steam. Also, it provides data on the carbon footprint of the buildings and the whole campus.

First looking at a general picture, the utilization of electricity of the whole campus is plotted below.

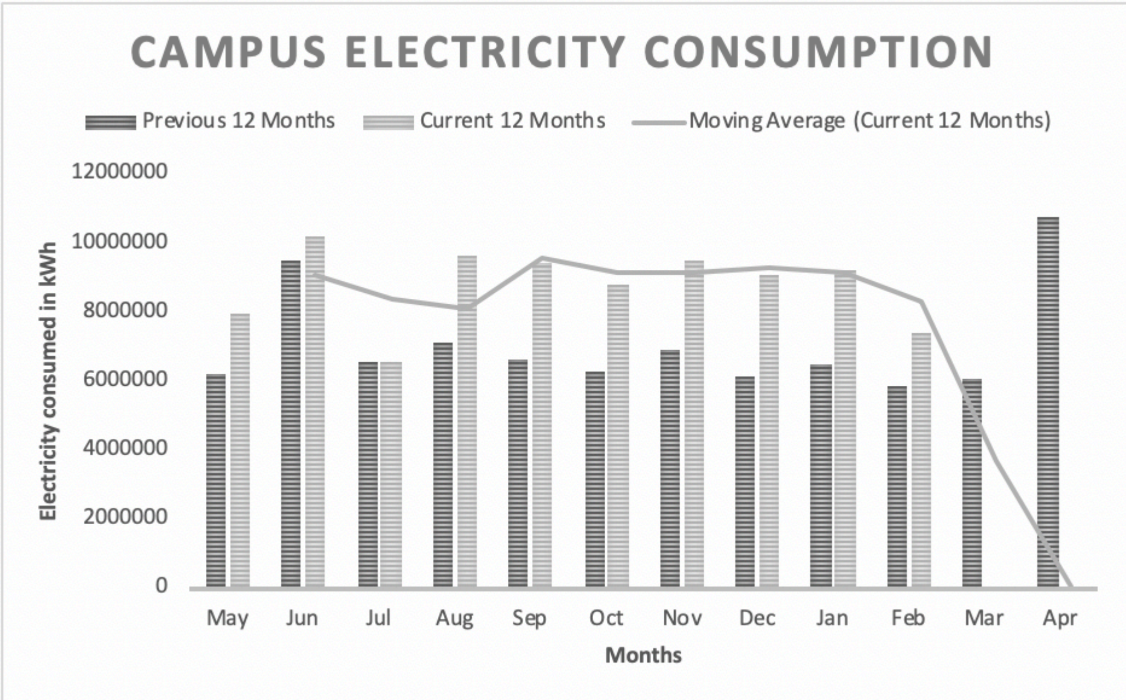


Figure 3: Electricity Consumption of Mines per month (in kWh)

It can be observed that, throughout the year, the electricity use per month remains similar, with a common peak in June because of the hotter weather in Colorado. It can also be seen that the general consumption of electricity of the school is growing, as the current twelve months show a bigger consumption that the previous twelve. This can be attributed to the fast growth of the school, both of the facilities and the number of students and faculty.

Moving on to CoorsTek building, the following figure shows the data of all the months the building has been operating.

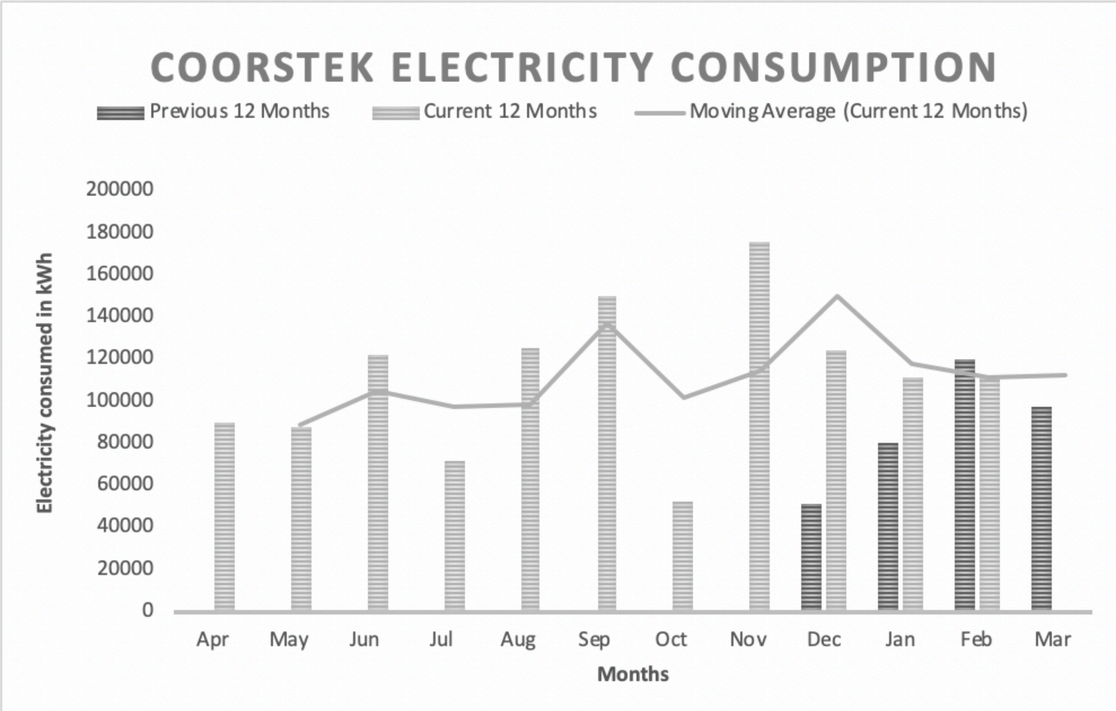


Figure 4: Electricity consumption of CoorsTek per month (in kWh)

While the building was finished in December 2017, when the first set of data is recorded, the building didn't really start-up until November 2018. During that month, a high peak of consumption was recorded, although the consumption stabilized after that to values of about 100000 to 130000 kWh per month. This monthly consumption would mean an average daily energy consumption of 3300 to 4300 kWh and an average power consumption of 130 to 175 kW.

To verify that the bills are reflecting the actual data of the building's energy and power use, it was decided to study the data recorded by the building's meter. Colorado School of Mines uses a real-time data recording software called Niagara where it stores the data from some of the campus' facilities. This data ranges from rooms' and building's temperature; steam, water and air conditioning flow and of course, electrical metering data. Below, a live image of CoorsTek Center's Building Meter is presented.

BldgMeter

Delivered kWH	**250764 kW-hr**	Phase A Volts THD	**5 V**
Peak kW	**260 kW**	Phase B Volts THD	**5 V**
		Phase C Volts THD	**6 V**
Instantaneous kW	**182 kW**	Phase A Amps THD	**60.0 A**
Power Factor	**1**	Phase B Amps THD	**60.0 A**
		Phase C Amps THD	**11.0 A**
Phase A Amps	**216 A**	Neutral Amps THD	**1.0 A**
Phase B Amps	**240 A**		
Phase C Amps	**240 A**	kW Monthly Alarm	**ALARM**

Image 4: CoorsTek's Building Meter Information

The meter, showing instantaneous information, gives the cumulative kWh in the instant the picture was taken. The most important information seen here is the delivered Instantaneous power in kW which in that moment was 182 kW, and the peak that month (so far) which shows 260 kW. This last piece of data is used to calculate peak charges of the bills. It is worth to note that the power factor of the building is exactly 1 at that time.

In particular, for this project, the Energy Consumption (kWh) and the Instantaneous Power (kW) was analyzed. Since, as mentioned before, the building started up in November 2018, the data used was from that month to the present.

As with any meter, the kWh measured are cumulative. Therefore, the data downloaded from the software had to be modified to obtain the daily kWh consumed. With this, the following graph was created, and it can be compared to the daily estimate of energy consumption.

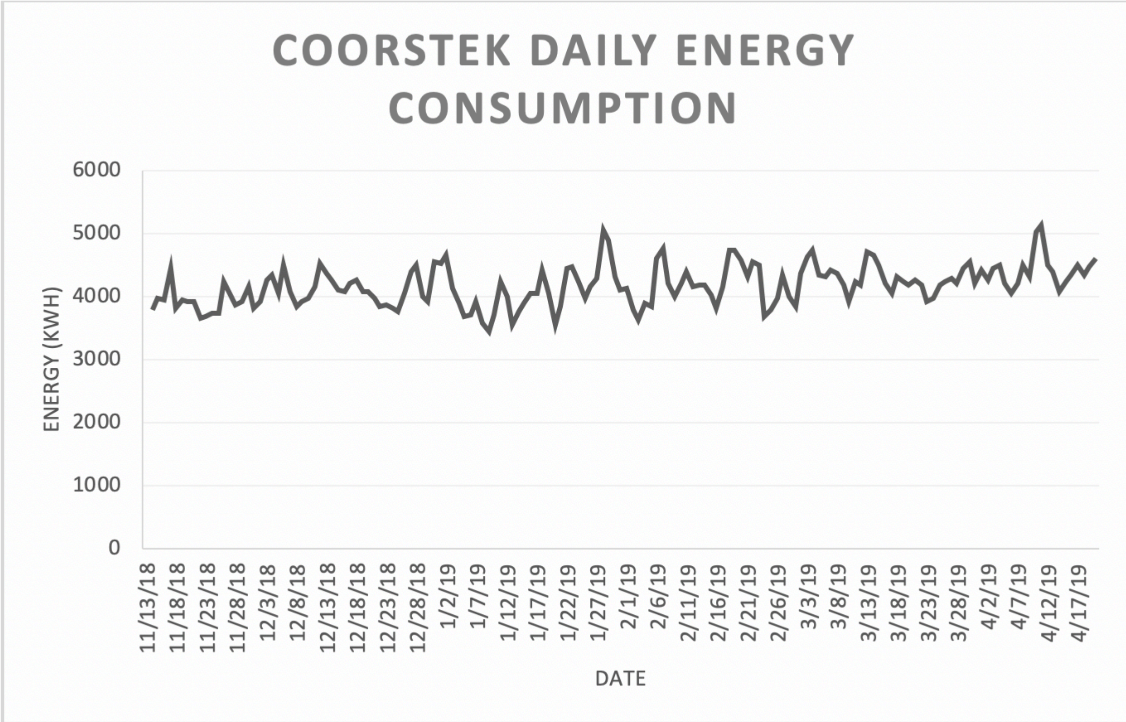


Figure 5: Daily Energy consumption of CoorsTek (in kWh)

The figure shows the energy consumption from November until April. We can see that the average is slightly higher than 4000 kWh a day. The variation is of about 1800 kWh (from 3400 kWh to 5200 kWh) which is in accordance with the approximations calculated with the electricity bill. There is a small upwards tendency in the consumption which can be expected to continue in that manner and even become more considerable.

To compare with the connected load and NEC demand load of the building, the instantaneous power is also analyzed. This data was obtained for 15-minute intervals – the meter takes the average instantaneous power of those 15 minutes and saves that information.

A general picture of this power consumption is seen in the figure below for the same time interval as the energy consumption.

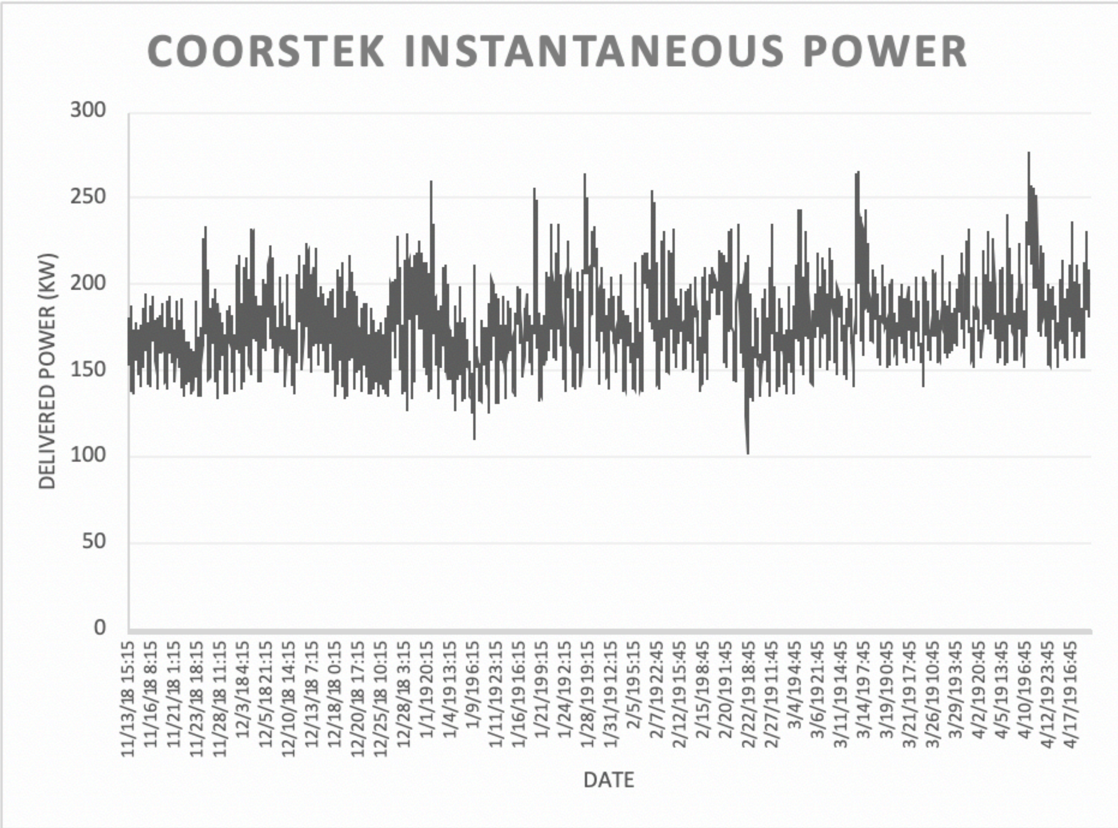


Figure 6: Instantaneous power (every 15 minutes) of CoorsTek in kW

With an average power consumption starting at 165 kW and going up to 190 kW in the month of April, the trend of the power demand of the building is clearly growing. This matches the interpretation of the daily energy consumed and supports it. This clear tendency can be due to the continuous addition of equipment in the laboratories and the growing portfolio of investigations the departments hold. Also, as the building becomes more popular within the student and faculty body, the use of the building grows as well.

To get a more specific idea of the kilowatt demand, focus is drawn on a random month and a random day of that month.

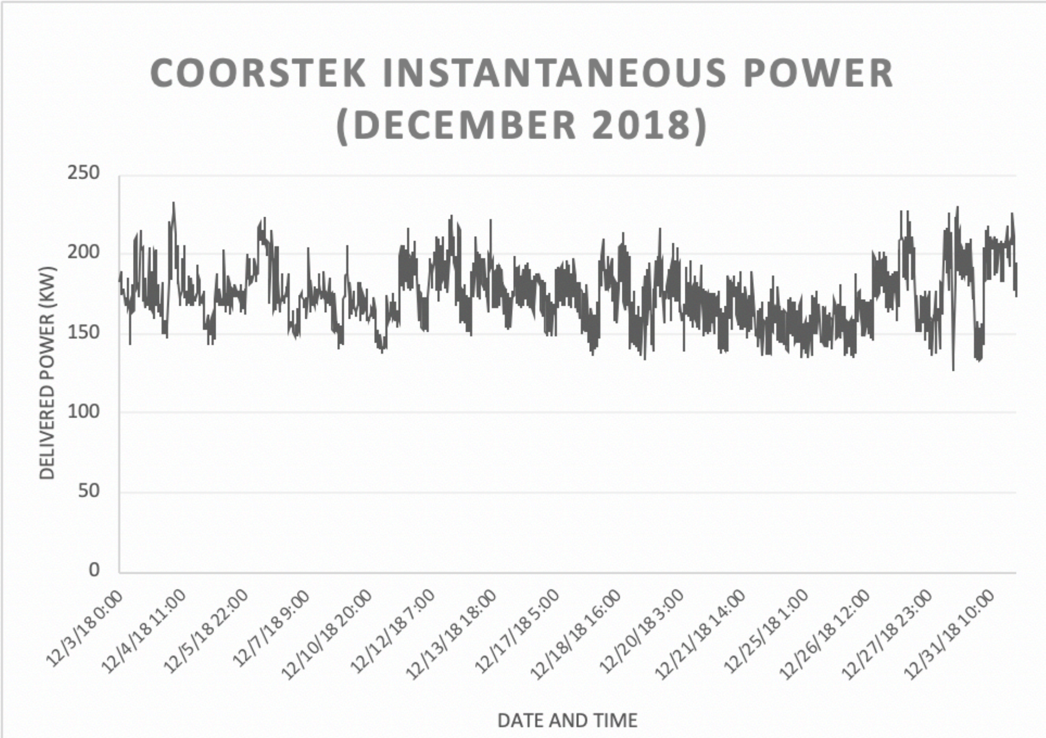


Figure 7: Instantaneous power (every 15 minutes) of CoorsTek in kW in the month of December 2018

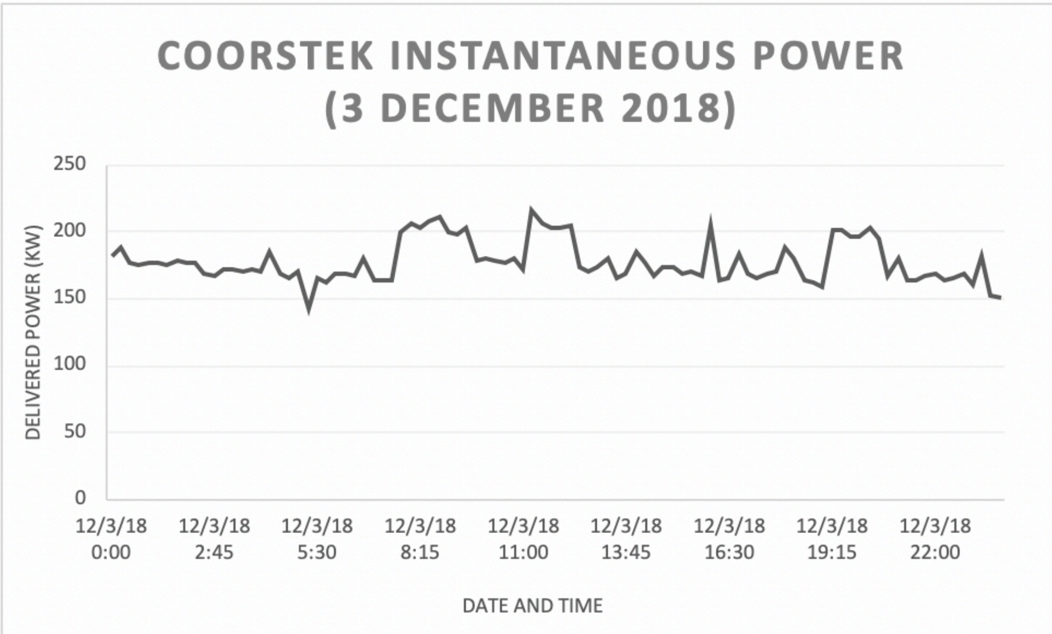


Figure 8: Instantaneous power (every 15 minutes) of CoorsTek in kW on December 3rd, 2018

While daily patterns can be interpreted form the month of December, a day shows only slight peaks during the busiest part of the day. We know that an important load of the building is heating and ventilation, which runs during the whole 24 hours. This makes the daily load curve of the building differ from a household, which would hold clear peaks during the day.

It seems more logical, from the study of a single day, to compute an average day so a clear pattern can be encountered. Also, since the facilities are mostly used during the week and not the weekend, the average is calculated only with weekdays. Next, two figures can be found: the average power of every weekday and the average power during the week.

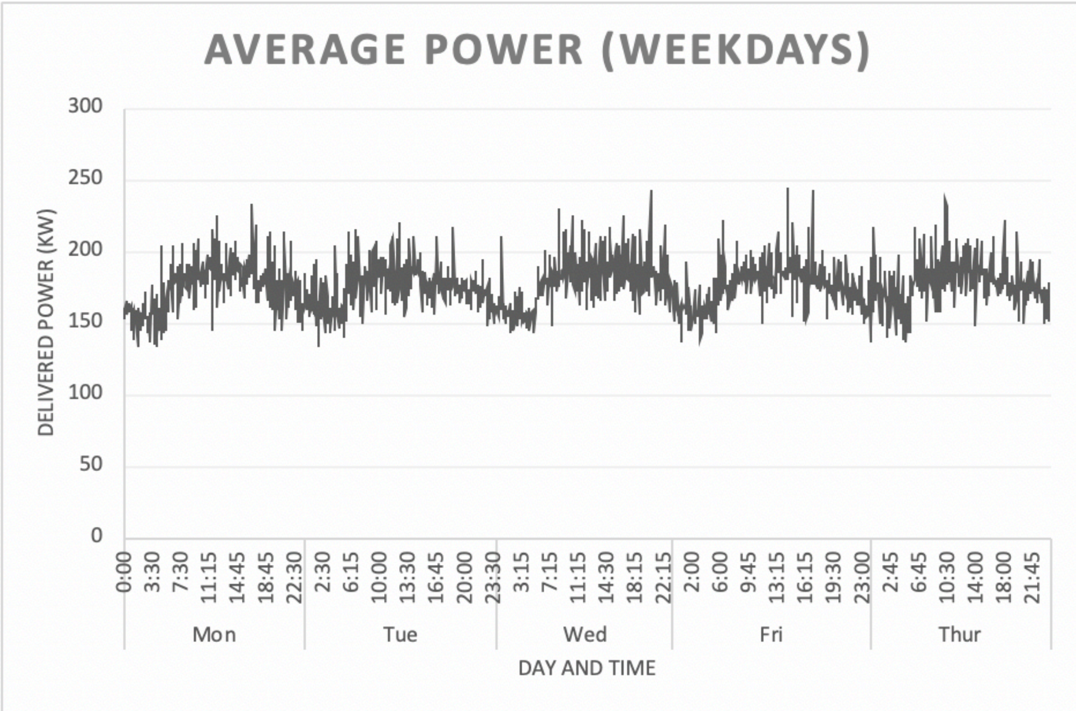


Figure 9: Average instantaneous power (every 15 minutes) of CoorsTek in kW of weekdays

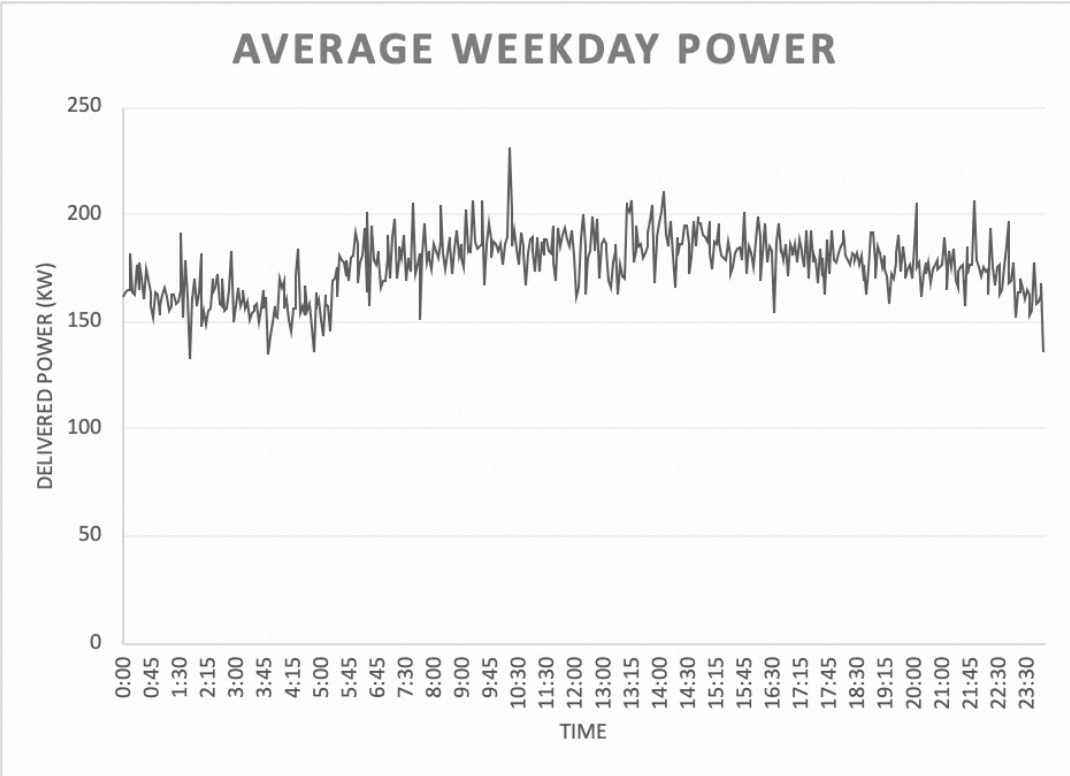


Figure 10: Average instantaneous power (every 15 minutes) of CoorsTek in kW for any weekday

From figure 8, which represents an average load curve for each weekday, a clear pattern can be seen. The power demand rises during the middle of the day, the busiest time frame. However, as mentioned before, because of the nature of the facilities, the consumption is never lower than 120 kilowatts at any time of the day. This represents the minimum consumption of the building. It is also worth to note, that the consumption rises in the times the solar irradiance is at its highest making solar energy relevant to this type of load curve.

The average variation is of nearly 100 kilowatts a day with the consumption peaking from noon till 4 pm, generally. The average power consumed is around 170 kilowatts. This means that every month, it sums up to 120000 kWh and, every year, to 1500 MWh. We can then confirm that these numbers match the electricity bill, thus assuming that EnergyCap and Niagara are measuring the same data and that the utility is charging the school the correct bill.

Moreover, another comparison is made. With the previously analyzed loads and NEC demand loads, we know the whole NEC load of the building is 2,025 kVA. Comparing this to the average mentioned in the previous paragraph, we know the average load percentage is 8,395%. While before, it was concluded that NEC loads were fit for sizing, it is clear that it does not provide an accurate estimation of the instantaneous load.

D. ENVIRONMENTAL IMPACT

Every energy consuming facility connected to the grid (Xcel Energy) will be in turn contributing to the release of environmentally damaging gases to the atmosphere. Even though Xcel Energy's commitment to the reduction of emissions is notable (and growing), in 2017 only 27% of Colorado's power was carbon free. (4) Consequently, Mines campus will indirectly produce a carbon footprint. Some of the campus' buildings also contribute directly to carbon emissions. All of this is accounted for in EnergyCap, where the carbon footprint each year can be accessed.

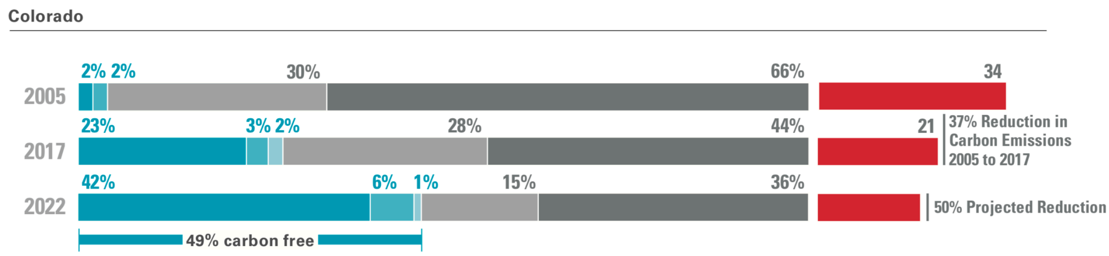


Figure 11: Xcel Energy's energy mix in Colorado and reduction in carbon emissions

All of the Mines carbon footprint mainly comes from carbon dioxide, but nitrate oxide and methane are also released. As mentioned before, as some buildings produce their own greenhouse gases, that is also taken into account as direct emissions. Through EnergyCap, the carbon emissions of the whole campus are obtained. They are expressed in tonnes of CO_2 and follow the same variation as the energy consumption (they are proportional).

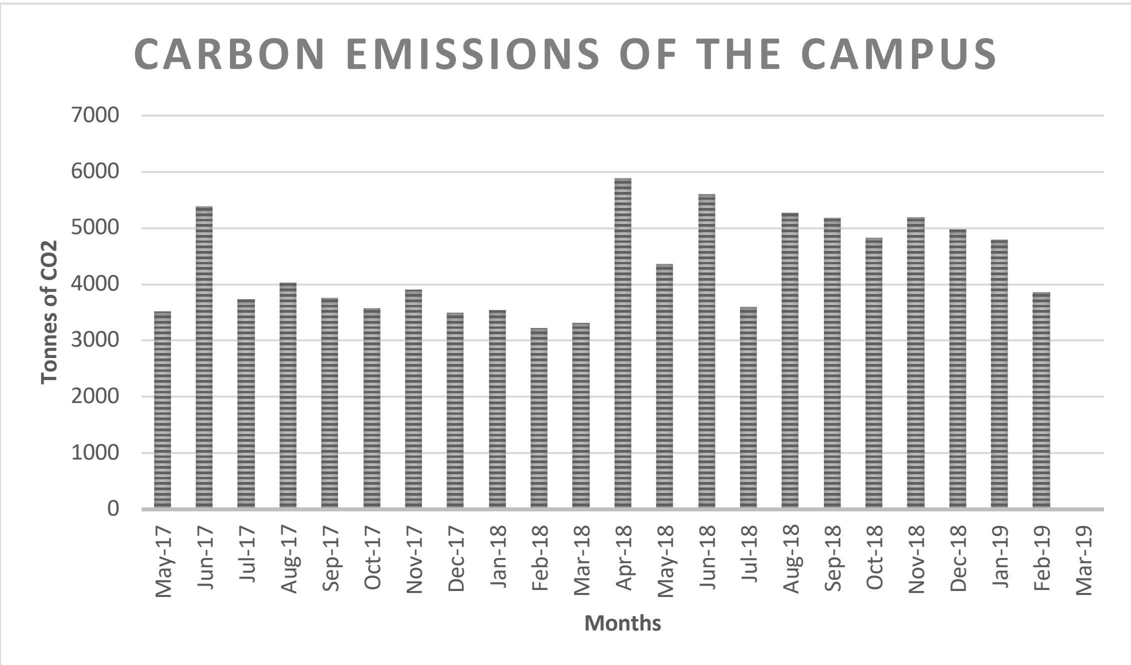


Figure 12: Carbon emissions in tonnes of CO_2 of the whole Mines campus for every month

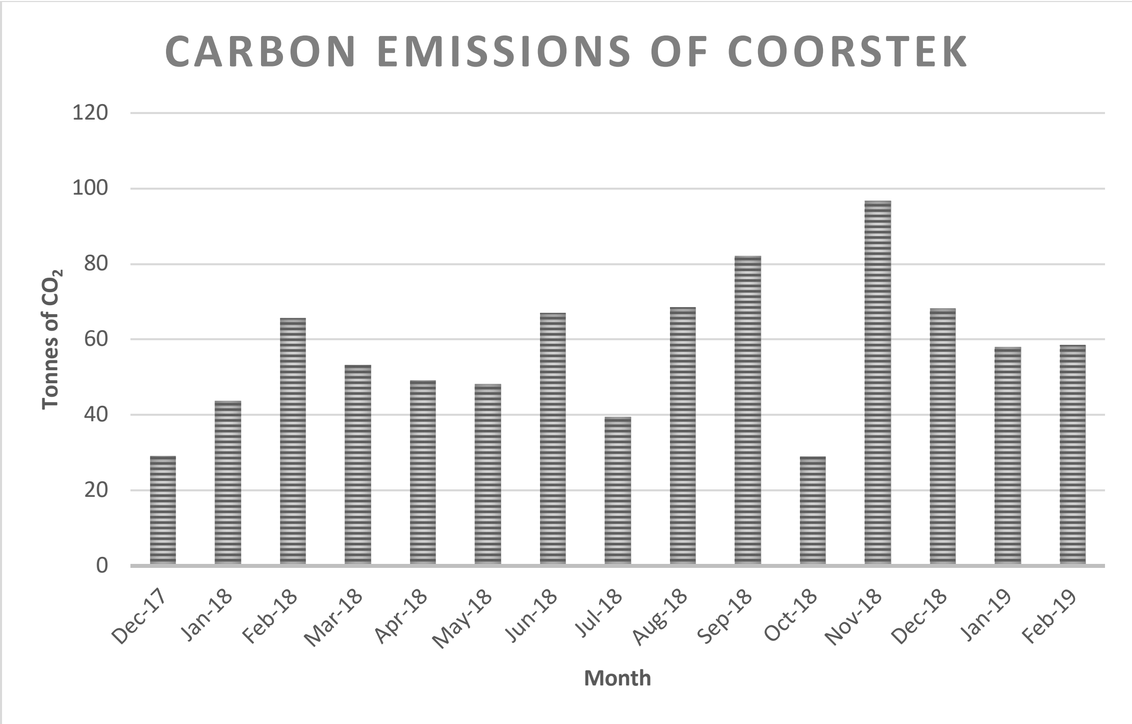


Figure 13: Carbon emissions in tonnes of CO_2 of CoorsTek building for every month

Year	***CoorsTek***	***Mines***	***Percentage***
2018	711,471	54928,23	1,295%
2019	116,502	8653,33	1,346%

Table 8: CO_2 emissions (in tonnes) per year for CoorsTek Center and for Mines

Less than half of the year has been accounted for in 2019 thus the difference in emissions from 2018.

V. POSSIBLE PV IMPLEMENTATION

A. INTRODUCTION

Following the motivation of this project, a solution for the reduction of the annual cost of energy along with an improvement in the building's carbon footprint is researched. The most impacting change in the energy consumption would be the introduction of a form of green energy into the building. This would allow for a reduction of the greenhouse gas emissions that damage the environment, and improvement of the building's green certificate and, hopefully, an investment that will save money in the future.

Renewable energy can come from very different sources, and with the rapid investigation and development in this field, more types of green energy arise every day. The seven most important ones, and that are available commercially are the following (5):

- Bioenergy – Biomass can be burnt to produce steam that generates electricity thanks to a turbine.
- Geothermal Energy – Using the earth's natural heat with a geothermal heat plant.
- Hydroelectric Energy – Commonly called hydropower, it uses dams to create a potential difference that when released can power a plant through turbines.
- Oceanic Energy – mechanical energy from tides and waves can be used to produce electrical energy.
- Solar Energy – It is the most direct use of sunlight. Solar cells, very simply, convert the energy from photons into a potential difference that when connected, generates electricity.
- Wind Energy – The wind can move large wind turbines that generate power.
- Hydrogen – Burning hydrogen produces nearly no pollution when burnt, yet it is difficult to obtain.

The choice of a renewable source for implementation in a campus like Mines is very clear. Since most of the types of energy mentioned above aren't accessible (Geothermal, Hydroelectric, Oceanic) or the small-scale nature of the campus can't hold such cost (Bioenergy, Hydrogen), the only realistic options of green energy are the most conventional ones: Solar and Wind power.

However, wind power requires very special environmental characteristics that are difficult to find in Golden. Since small wind turbines have small efficiencies, they need to be situated in an area that receives very smooth airflow. With the campus being surrounded by buildings, and then mountains. The wind is unpredictable at times, and non-existent at others. Also, when comparing PV and wind in terms of sound and visual pollution, it is clear that a rooftop turbine will bear more impact than solar panels. The visual outcome of an installation of wind turbines on a rooftop can be seen in the image below. (6)

Image 5: Rooftop integrated wind turbines (Copyright: Paul Gipe, WindWorks)

The only reasonable choice of green energy for implementation on a campus rooftop is, then, solar power. For this implementation, photovoltaic energy, its types and the technology available will have to be researched.

B. Research and Panel Type Choice

1. How PV works

Photovoltaic energy is normally obtained from and array of solar (PV) panels. These, in turn, are made from smaller components called solar cells.

The conversion of solar energy to electrical energy in the solar cells can happen thanks to the excitement of electrons by the energy containing photons of sunlight. For this conversion to occur, at least three main physical elements are necessary in any cell (7):

- Absorber: the material, typically a semiconductor, used to absorb the incoming photons into the cell whose electrons become excited.
- Membrane: used to prevent the electrons from going back to their previous state, now-a-days employing layers of n and p conductive materials called np junction.
- Metal conductive plates: collect the electrons and wires that carry the electric energy.

The basic work structure of the cell is the following: Photons from sunlight excite and free the electrons in the semi-conducting material so they flow to the more receptive end of the semiconductor, thus creating a potential difference. Thanks to the protective layer, and the metal conductors connected to a load, this potential difference, or voltage, electricity flows (8).

More in depth, to make the electrons flow, the semi-conducting material's top layer (layer facing the sun) is doped with phosphorus (n-doped) and the rear with boron (p-doped), allowing for effective conduction of these carriers.

2. PV TYPES

To obtain the most benefit out if the implementation of photovoltaic energy onto the building, the main types of commercially available solar panels are studied. Only the ones that could be used are explained below (Cadmium Telluride (CdTe) Solar Cells for example, contain toxic elements that won't be used in a Campus).

First Generation Panels: Crystalline Silicon (c-Si)

They correspond to the original developments of solar power, hence the reference to first generation. This material is, as the name states, the pure element Silicon in its crystalline form. Most photovoltaic technology available in the commercial market uses this material as its semiconductor (compared to other material of similar electric properties), partly because of its abundancy in the earth's crust, partly because of its non-toxic nature. (7)

Two types of cells can be made with crystalline silicon: monocrystalline and polycrystalline. Monocrystalline cells are made with a more complex (and therefore more expensive) than polycrystalline. The former consists of a pure silicon crystal while the latter is melted and recrystallized raw silicon, an easier process than the other one. The microstructure of the silicon used for each panel is what gives them their distinctive appearance: smooth black for the monocrystalline panels and shiny blue for the polycrystalline ones. (9)

Image 6: Monocrystalline vs. polycrystalline solar panels

Second Generation Panels: Thin-Film Solar Panels

This newer technology, as the name implies, is a thinner panel that uses silicon or other semi-conducting materials. They are commonly used in building renewable energy implementations because of their versatility: they can be implemented directly into roofing material or placed on curved surfaces.

Amorphous Silicon Solar Cell (A-Si)

This type of thin film solar panel is the only one being considered for this project, as the rest are still in research or may contain toxic elements that are not the best option for such installation. They are made with silicon, just like the first-generation panels mentioned above, but instead of creating the panel out of a single crystal configuration, a layer of silicon is added on top of a substrate. This substance below is very versatile and it's what allows for the flexibility and integrability of the panels.

Image 7: Thin-film amorphous silicon solar panels on flat roof

Third Generation Panels

This section includes the newest technologies, most of them still in their research or trial phase. Biohybrid cells (uses both organic and inorganic materials) would fall in this category, as well as concentrated solar power. Both of these, and other options of third generation panels, are not optimal for small scale or building use.

To make an informed choice of the type of solar panel that should be implemented in CoorsTek, or in any similar type of facility, a table summarizing the main characteristics and advantages is made. Cost, efficiency and Watts per square feet are the three main decision variables and so, they are shown below for all three types of panels considered. Additional relevant information is portrayed in the last column.

PV Panel Type	*Cost*	*Efficiency*	*W per Sq. Ft.*	*Comments*
Monocrystalline silicon PV panels	Expensive	15-20%	15	Optimized for commercial use, high life-time value
Polycrystalline silicon PV panels	Cheaper	13-16%	11	Sensitive to high temp
Amorphous silicon PV panels	Cheapest	7-13%	7	Flexible but shorter lifespan

Table 9: PV panel type comparison

(10) (11)

Also, to be able to make the right choice, an analysis of the needs, requirements and limitations of CoorsTek's Center roof and building must be done. The next affirmations are written in order of importance of the project.

- To maximize the impact, largest installed capacity is desirable.
- Long life-span to maximize return of investment is necessary.
- Initial investment for such project should not be a limitation for a school with resources like Mines.
- Visual impact should be taken into account but should not be decisive.

From these preferred characteristics, the choice of monocrystalline solar panels can be obtained as a conclusion. Since the space on the roof is limited, these types of solar panels will provide the maximum power for that much square footage. Also, the life span of these panels is slightly longer than polycrystalline or thin film so they will provide a return on the investment for longer and require less changes. Even though the price of monocrystalline panels is higher than the other two, the difference in the initial investment should not be excessive for the resources of the school. In addition, although not as important, the appearance of monocrystalline panels is more discreate than polycrystalline ones, as their surface finish is black and won't be seen from the ground.

C. Electrical feasibility

As with any new electrical equipment, the feasibility of installing such structure must be analyzed. The connections to the existing system, as well as the requirements and limitations it might suppose need to be taken into account.

For a photovoltaic system, it is common to connect it to the service entrance of the building's grid. This allows for fewer restrictions compared to connecting it to a panelboard. Also, it makes the power-flow unidirectional to the load, in this case. Since the facility is newly built, there is no major concerns with any of the equipment inside the building that could be affected by and implementation of such system.

The only electrical limitations the photovoltaic system might encounter are the ones the equipment chosen upon design itself might impose. These could be the inverter (or inverters), the possible use of an energy storage system or a data acquisition metering system.

D. Sizing and design of PV and BESS

In this section, an analysis of the space available and the feasibility of installing the solar panels on the roof will be carried out to find out how much installed capacity can be mounted on it and how. Moreover, the use of battery storage will be studied, along with the additional technical details of a solar panel system installation.

First, the area available must be calculated. To do this, during the field observation, all the empty, flat roof area was recorded. Below, a floor plan of the rooftop has been edited to show those areas. Also, because of the orientation, the primarily shaded areas have also been marked.

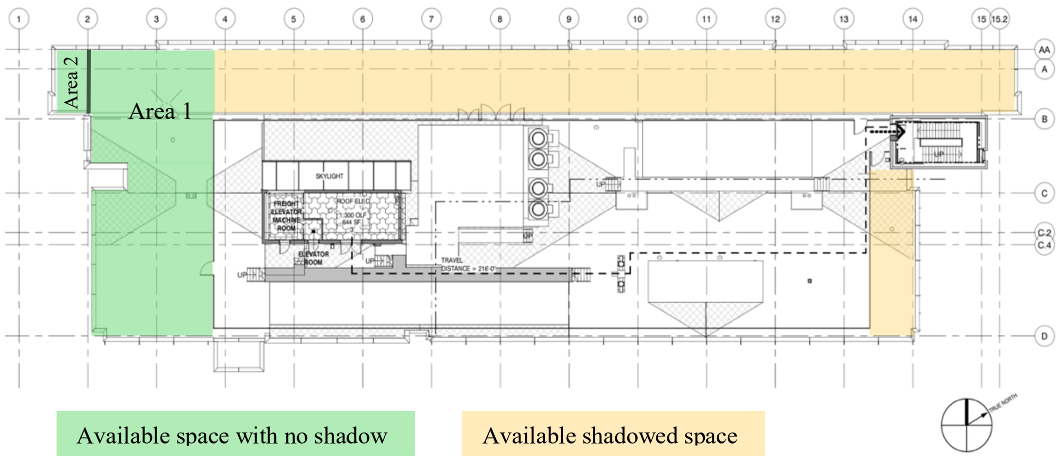


Figure 14: Roof's floor plan showing available areas

The shadowed areas are also considered because, while they might not allow the installation of panels, they can be used to mount the rest of the equipment needed for such system (battery, inverter(s), cables, etc.)

Using the available measurements from the architectural plans shown in the following figure, both green areas shown are calculated to find the total available area that will be exposed to the sun for the most part of the day.

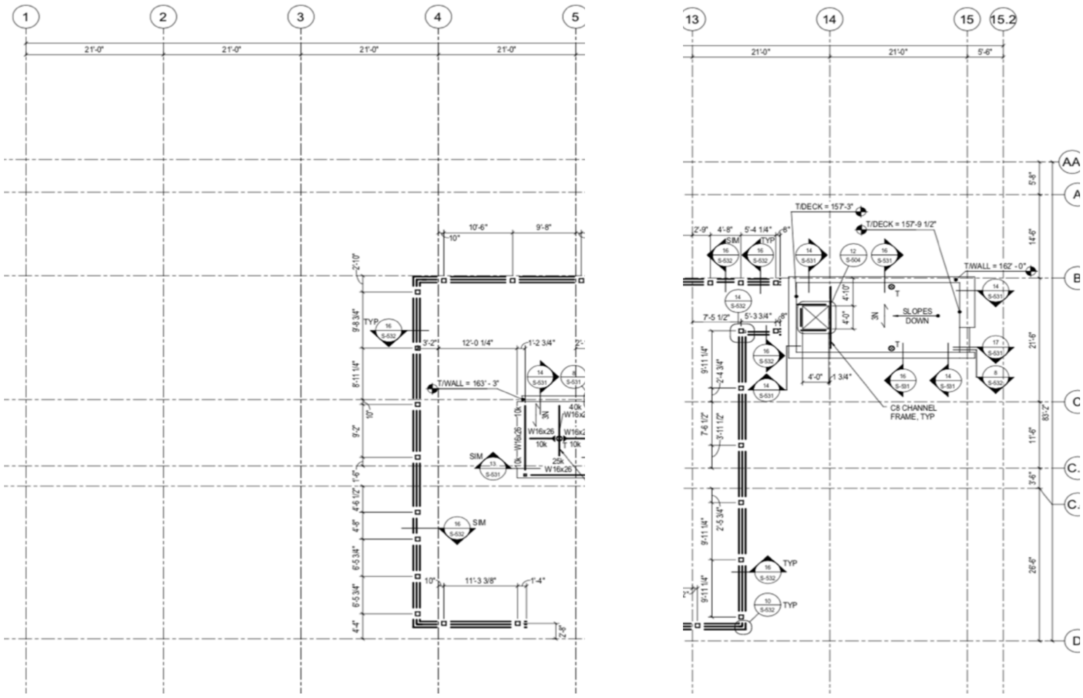


Figure 15: Architectural floor plan showing relevant measurements for the roof

Area 1:

$$A_1 = length * \ width \ = \ (21'x2' - 3'2") * (83'2") \ = \ 38.8333 \ x \ 83.1666 \\ = \ 3229.64 \ square \ feet$$

Area 2:

$$A_2 = l * w = \ (9') * \ (14'6" + 5'8" - 1'10") \ = \ 9 \ x \ 18.3333 \ = \ 165 \ square \ feet$$

Total Area:

$$A_t = 3229.64 \ + \ 165 \ = \ 3394.64 \ square \ feet$$

To get a close estimate of how many kilowatts of installed capacity could be mounted onto the rooftop, the average size of a panel and its capacity are found.

According to Energy Sage, the average size of a commercial solar panel in 2019 is the following:

Solar panel size and weight, residential and commercial panels

FEATURE	RESIDENTIAL PANELS	COMMERCIAL PANELS
# of Solar Cells	60	72
Average Length (inches)	65	78
Average Width (inches)	39	39
Average Depth (inches)	1.5 - 2	1.5 - 2

Residential vs. Commercial Solar Panel Size Comparison

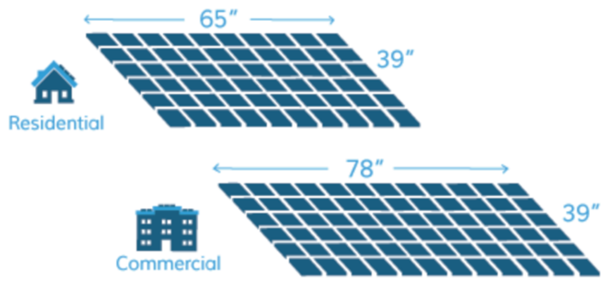


Image 8: Panel size information according to Energy Sage

Since we can consider CoorsTek Center as a non-residential building, we will take as an average size 78"x39".

$$A_{panel} = l * w = (78") * (39") = 6.5' \, x \, 3.25' = 21.125 \, square \, feet$$

With every panel occupying an area of approximately 22 sq. ft. and the space available on the roof:

$$Number \, of \, Panels = \frac{A_t}{A_{panel}} = 3394' / \, 22' = 154 \, panels$$

Assuming 250 to 300-watt panels, this would mean a maximum installed capacity of 46 kilowatts.

However, the shape and orientation of the panels need to be taken into account as this might mean that not all area is fully utilized, and that the capacity could be less. Since the roof being studied for installation is a flat rooftop, the best option (and probably the only one available) is ballasted flat roof solar panel mounting.

Image 9: Ballasted flat roof solar panel mounting

Flat roofs allow more flexibility when designing the PV system. This is because the panels can be mounted in the most optimal orientation (azimuth angle) – usually south – and the tilt angle can be changed to obtain the best performance.

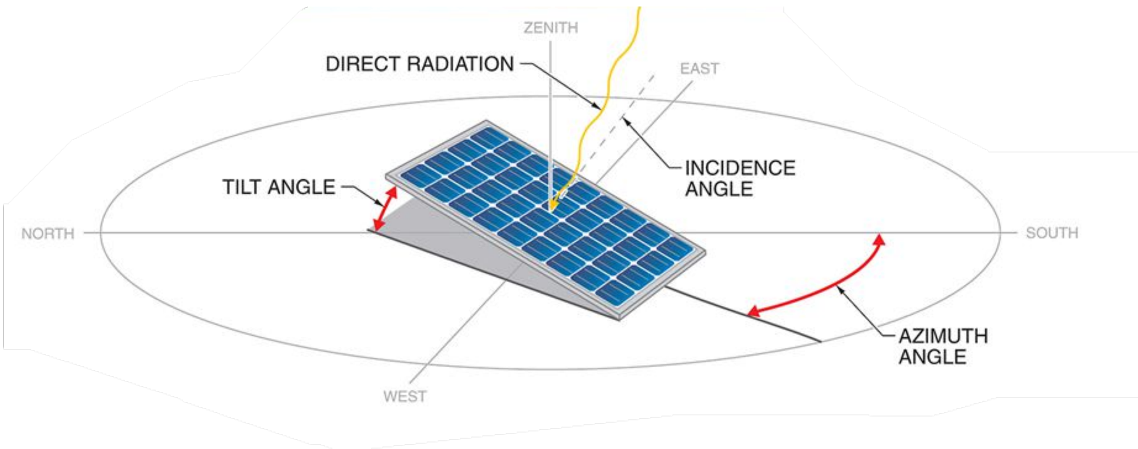


Image 10: Explanatory image of azimuth and tilt angles of an oriented solar panel

To obtain the maximum daily power output, the panel should be installed facing the south – an azimuth angle of 180º with respect to north – and the tilt angle should correspond to the latitude of the location. In this case, the tilt angle would be between 39º and 40º due to the latitude of Golden, Colorado being 39.75. (12)

Because the panels preferably have to be oriented south, the area available will not be fully exploited. To take this into account in the calculation of approximate number of panels and the installed capacity of the installation, this area will be multiplied by a factor of 0.8. This factor also considers that a security margin will be stablished to ensure safety during maintenance.

This modifies the previously calculated capacity in the following way:

$$Installed\ Capacity = \frac{0.8\ x\ A_t}{A_{panel}}\ x\ 330\ W/panel = (0.8\ x\ 3394'/\ 22')\ x\ 300 =\ 37\ kW$$

With this more approximate number, all the design of the installation can be carried out.

First, the possibility of including a battery energy storage system will be evaluated.

While in the aforementioned photovoltaic power installation study of the campus lithium-ion batteries were considered, in this smaller scale, more specific system, their use might not be justified.

The batteries main purpose was to store some of the energy generated during non-peak hours to later use it at the peak consumption time of the campus. This would allow for a reduction of the peak demand value. For the whole campus, it is an important measure to take into account. Part of the electricity bill depends on the demand, measured by the peak demand and charged in terms of that, so lowering the peak would lead to significant savings for the school each month. However, when optimizing the consumption of just one building, shifting or lowering the peak demand would not be noticed in the general electricity peak demand of the campus. Thus, it would be more efficient to allow the PV system to simply feed the building's loads to its maximum extent.

From the previously conducted energy consumption study of the building, the instantaneous power varies from 150 to 200 kilowatts daily in average. The maximum peak recorded by the building meter is 260 kilowatts and it has been observed that the power delivered is never lower than 100 kilowatts. Since the photovoltaic system to be designed would generate a maximum of 37 kilowatts, we know that there will never be excess energy being produced. With this, we can conclude that a battery is not needed to store any power, as there will be no surplus generation and no peak improvements are wanted.

Secondly, the conversion of power from DC to AC must be designed. We know that each panel generates direct current power so an inverter must be installed in order to incorporate the generated power onto our building grid. Conventionally, three type of inverter arrangements are encountered commercially:

String Inverter

This technology is the most cost-effective choice. Simply put, for each string of panels attached together, one inverter is used. The string will always produce power limited by the worst panel output, but if all the panels are producing the same amount of energy (all facing the same way, no shading on any) this shouldn't be a problem.

Microinverters

This newer type of inverter works on each panel individually, so the AC output is optimized because no reduction on the power is encountered because of underperformance of other panels. However, due to a greater number of them and their novel nature, the cost is higher than with string inverters and the maintenance more complicated.

Power Optimizers with Central Inverters

This last option is just an addition to string inverters. Power optimizers are added to each panel of the system, to boost their performance and maintain all the power the same (thus canceling the effect of shading)

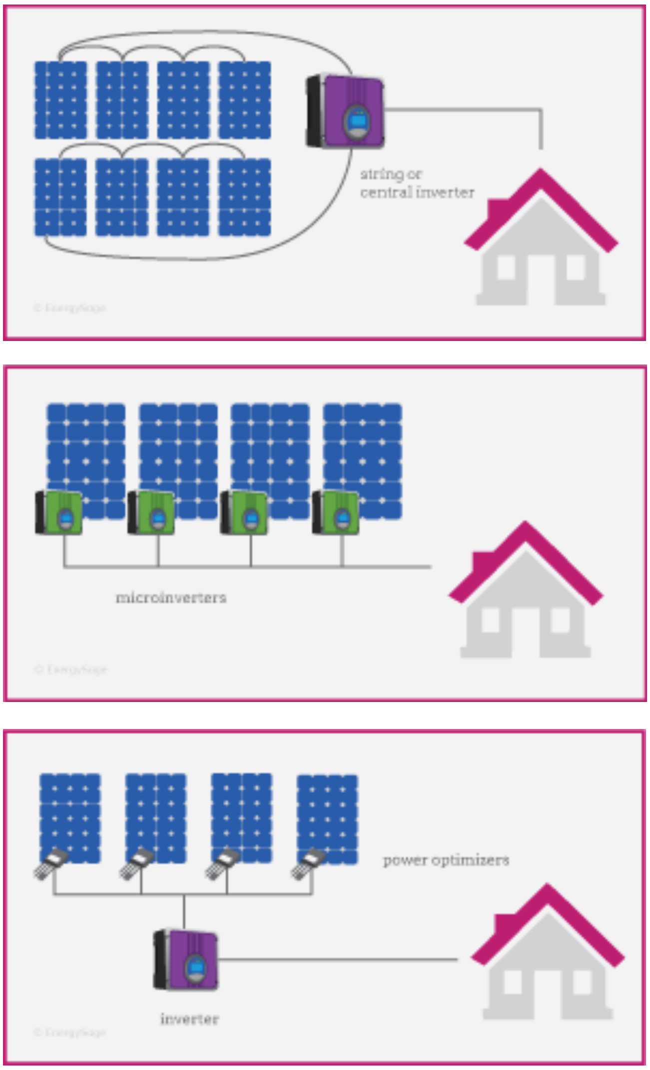


Image 11: Three types of inverter convertion for solar panel arrays

Since the roof of CoorsTek is not shaded by any nearby trees or buildings, and the flat roof allows us to place all the panels facing the same direction, central inverter should not present any problems. The technical difference between the three types of technologies becomes minimal and so the most sensible choice is connecting string inverters, which, with the size of this installation will translate to the implementation of a single, central inverter that will convert all the DC output of every panel to AC.

The last thing to take into consideration is the connection to the building's grid. Although this connection is standard for every installation, it is worth to mention that it will be connected to the most general distribution board of the building, with a bidirectional disconnect switch that will be able to handle the current going either way due to the nature of the system being connected.

VI. Impact of Implementation

The main objective of the implementation of a renewable source of energy was reducing the consumption from the grid which in turn decreases the environmental impact due to the carbon neutral nature of photovoltaic energy. Although this project incurs a small-scale system, making the impact small as well, it serves as a model for future implementations, and the extrapolation of the study to the whole campus could have a more important influence on the carbon footprint of Colorado School of Mines. While the environmental impact, however small, will always be positive, the economic feasibility and impact need to be critically analyzed to conclude if it would be positive as well.

To estimate the reduction of emissions of the building and the future savings, the predicted annual energy generation of the PV system in kWh has to be calculated, as well as the predicted consumption of the building in kWh.

1. Annual Energy Generation

SAM – System Advisor Model – is a techno-economic model created by NREL (the National Renewable Energy Laboratory) that allows the modeling of various types of renewable energy systems (from small to large scale) that facilitates decision making of the systems. For a system like the one designed above, it calculates the performance and financial data into the future. It uses real irradiation data from the NASA lab of the desired location and models, according to this data, with average panels and invertors. With this, the generation has been calculated. (13)

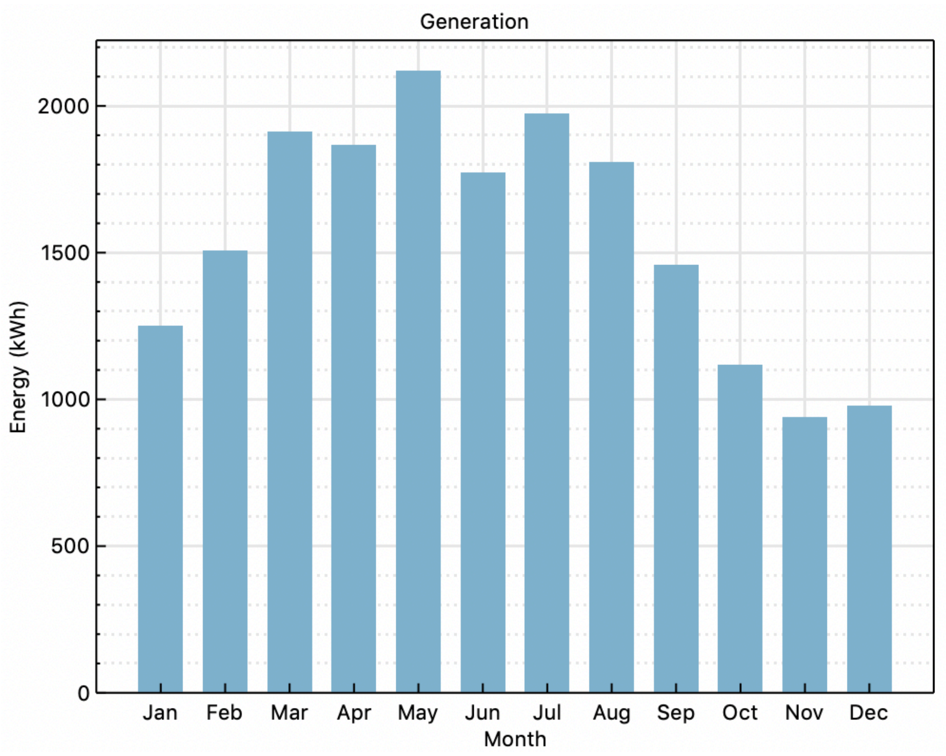


Figure 16: AC Output of the PV system in kWh for every month

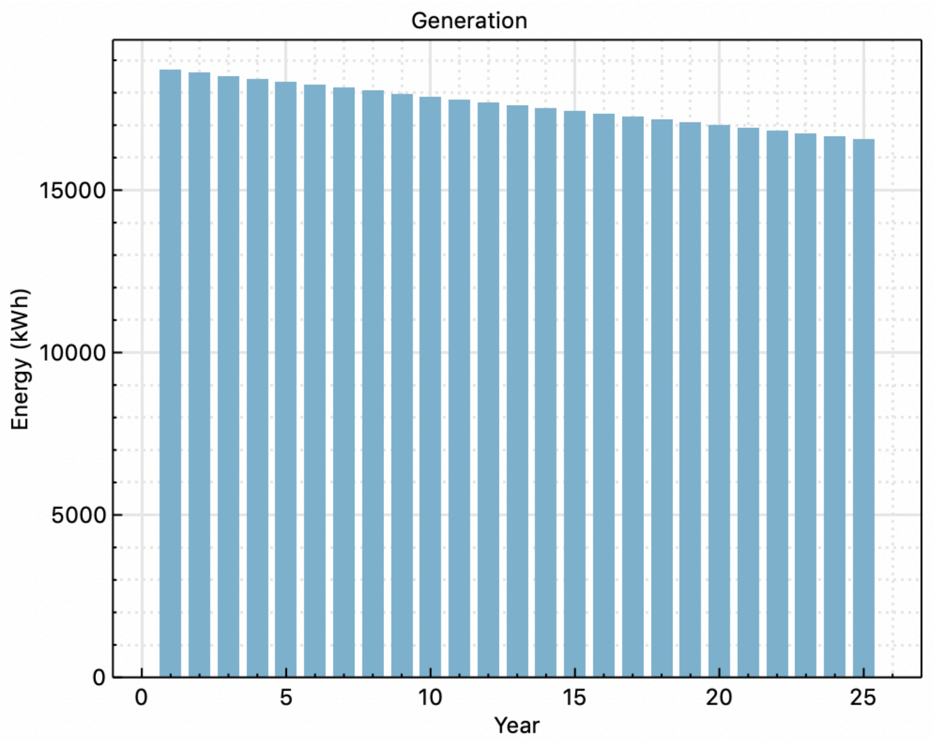


Figure 17: Energy Generated every year by the PV system in kWh

The software uses a 5% degradation rate. This way, the energy production is reduced each year. The monthly production would be proportional to the first year and can be calculated with that degradation rate. As we can see, the generation varies from month to month due to the historic data of irradiation. The average monthly generation of the first year is 1560 kWh. This is about 2% of the building's consumption.

Moreover, as shown below, the average daily power generation is studied for every month of the year. It is easy to see that the energy generation increases due to the higher peak power of the system during sunniest months.

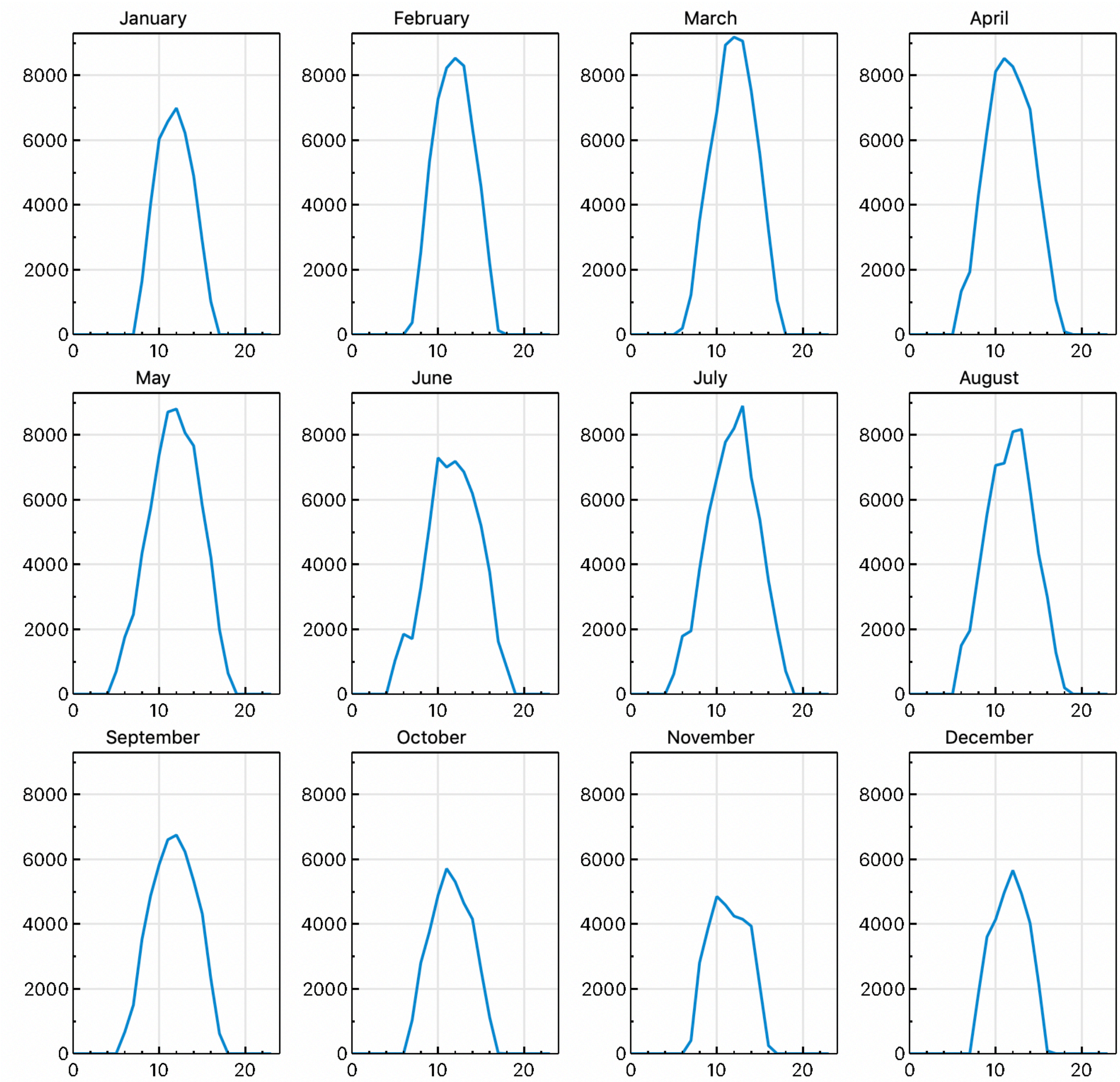


Figure 18: Daily average power output in Watts of the system every month

All this data, monthly and annual, has been introduced into an excel sheet so as to then calculate the corresponding savings and the reduction in emissions.

2. ANNUAL ENERGY CONSUMPTION

To see how much energy would still be demanded from the utility, the annual energy consumption of the whole building will be calculated. Using the historical data analyzed previously in this paper, estimations on future consumption will be made. An increase of 2% will be considered for the first two years and 5% for the third. The final construction of the last big laboratory will be taken into account, as well as the increase in the number of students. However, the consumption will be considered to be stable after the year 2023 since the facilities can only hold and consume so much. Below, the predicted annual energy is portrayed.

Year	Energy (kWh)
2018	1301664.8
2019	1388182.236
2020	1327698.096
2021	1415945.881
2022	1457591.348
2023	1457591.348
2024	1457591.348
2025	1457591.348
2026	1457591.348
2027	1457591.348
2028	1457591.348
2029	1457591.348
2030	1457591.348
2031	1457591.348
2032	1457591.348
2033	1457591.348
2034	1457591.348
2035	1457591.348
2036	1457591.348
2037	1457591.348
2038	1457591.348
2039	1457591.348
2040	1457591.348
2041	1457591.348
2042	1457591.348
2043	1457591.348
2044	1457591.348
2045	1457591.348

Table 10: Annual Energy Consumption (estimated) in kWh

The future consumption is also estimated per month, and but it is shown in the appendices.

A. Environmental impact

With the annual energy demanded from the utility, we can calculate the emissions based on the future percentage of carbon emitting generation. Xcel Energy published a future plan on the decarburization of their generation fleet, promising 100% clean generation by the year 2050. With this plan, the future emissions of the utility each year are estimated.

1. Future emissions of the utility

As stated above, to calculate the environmental impact onto the future, we need to know how much the energy we are demanding from the utility comes from non-carbon-neutral generation. The plan below shows what Xcel Energy has set as a goal for their generation fleet.

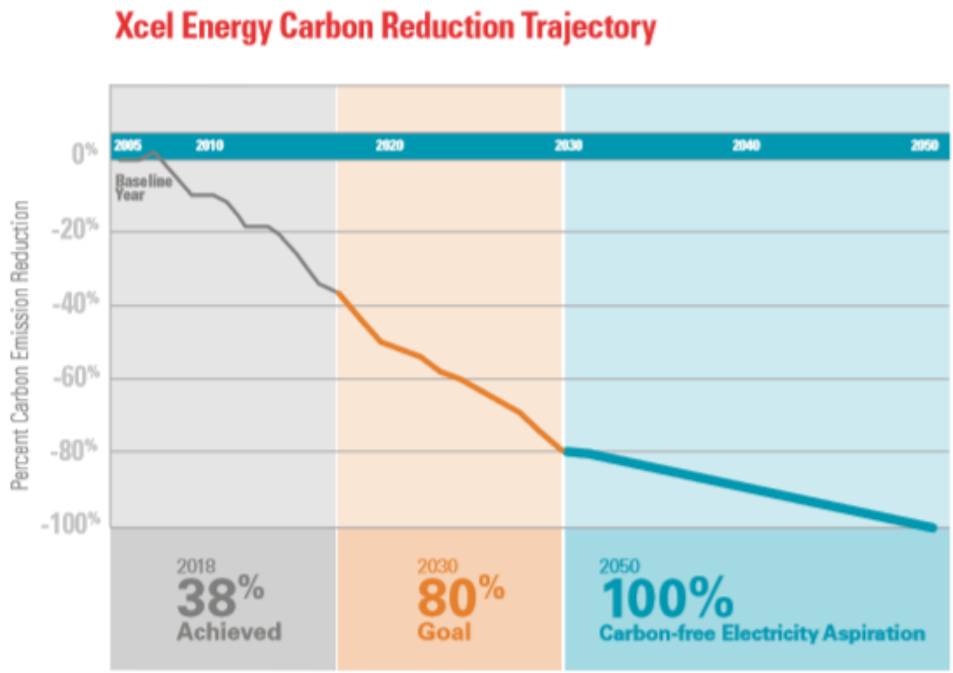


Image 12: Percentage Reduction, Xcel Energy Carbon Reduction Trajectory

Of course, this is only a future estimate, but it is also the promise the utility has made. A more complete estimation, including which type of generation (nuclear, coal, gas…) is reduce each year, can be found on their website. With this and knowing how much emissions each type of generation produces, we can know the carbon footprint of 1 kWh of energy that comes from the utility. (14) This research was conducted by Brian Oldfield and was provided as a source for this project and so his calculations are used. Using the photovoltaic energy generation every year, and the estimations of the future carbon footprint of the utility, the predicted emission reduction is the following:

Year	Tonnes of CO_2/kWh	Energy (kWh)	Tonnes of CO_2
2018	0.0005477	18691.9	10.2376
2019	0.00052062	18598.4	9.6827
2020	0.00049353	18505.4	9.1330
2021	0.00046645	18412.9	8.5887
2022	0.00043936	18320.8	8.0495
2023	0.00041228	18229.2	7.5155
2024	0.00038519	18138.1	6.9866
2025	0.00035811	18047.4	6.4629
2026	0.00033102	17957.2	5.9442
2027	0.00031723	17867.4	5.6681
2028	0.00030344	17778	5.3945
2029	0.00028964	17689.2	5.1236
2030	0.00027585	17600.7	4.8552
2031	0.00026206	17512.7	4.5894
2032	0.00024827	17425.1	4.3261
2033	0.00023447	17338	4.0653
2034	0.00022068	17251.3	3.8070
2035	0.00020689	17165.1	3.5513
2036	0.0001931	17079.2	3.2979
2037	0.0001793	16993.8	3.0470
2038	0.00016551	16908.9	2.7986
2039	0.00015172	16824.3	2.5526
2040	0.00013793	16740.2	2.3089
2041	0.00012413	16656.5	2.0676
2042	0.00011034	16573.2	1.8287
Total			131.8823

Table 11: Carbon footprint reduction calculations, Carbon Emission Savings in Tonnes of CO_2

The table above shows how the emissions were calculated and with which data. With these results, we can plot the savings of CO_2 emissions.

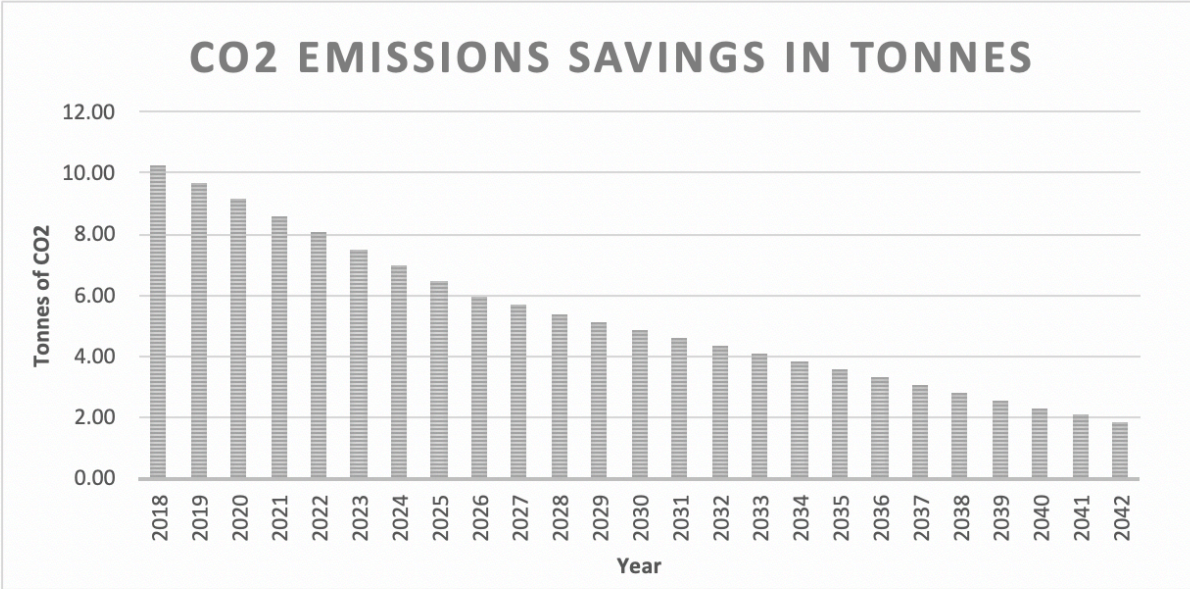


Figure 19: CO_2 Emissions Savings in tonnes

The tendency of the emissions savings is very clear. However, the steepness of the trend line is more complicated. While we do know that the PV system has a degradation rate and thus the power savings get lower every year, this rate is not so steep. What affects this gradient the most is that the utility is reducing their emissions into the future. This affects the emissions savings because we are comparing the power we generate with the one that we would otherwise buy from Xcel Energy, and so, the cleaner the utility's generation fleet becomes, the less effect introducing a source of renewable energy into the building has.

The percentage of savings with respect to the building's carbon footprint is 1,5 %. Although this may not seem like a big contribution, the expansion of such model would prove to have a big impact on Colorado's School of Mines carbon footprint. However, the question of whether the installation of such system is worth such small contribution arises. As always, any contribution is better than none, as this could also become an educational asset for the school. With this question, we need to also answer if it is economically advisable, leading on to the next section.

B. ECONOMIC STUDY

The implementation of a solar photovoltaic system supposes a large investment for the school therefore, an economic study must be carried out to find the profitability of such project. The study will be done to 25 years, as it is the typical life time of solar panels and hence, of the system. To conduct this study, capital expenses, operational expenses and savings every year must be calculated first.

1. CAPITAL COST

The capital expenses of this installation would include the cost of the equipment – modules, inverters and conductors – as well as construction, installation and labor costs. This system is catalogued as commercial PV model, although its small size compared to the average size of such systems has to be taken into account. The NREL (National Renewable Energy Laboratory) publishes a yearly study on the Solar Photovoltaic System Cost. By extrapolating the output data of this paper to the size of the previously designed system, we can get a very approximate global cost that also be broken down into the categories mentioned above.

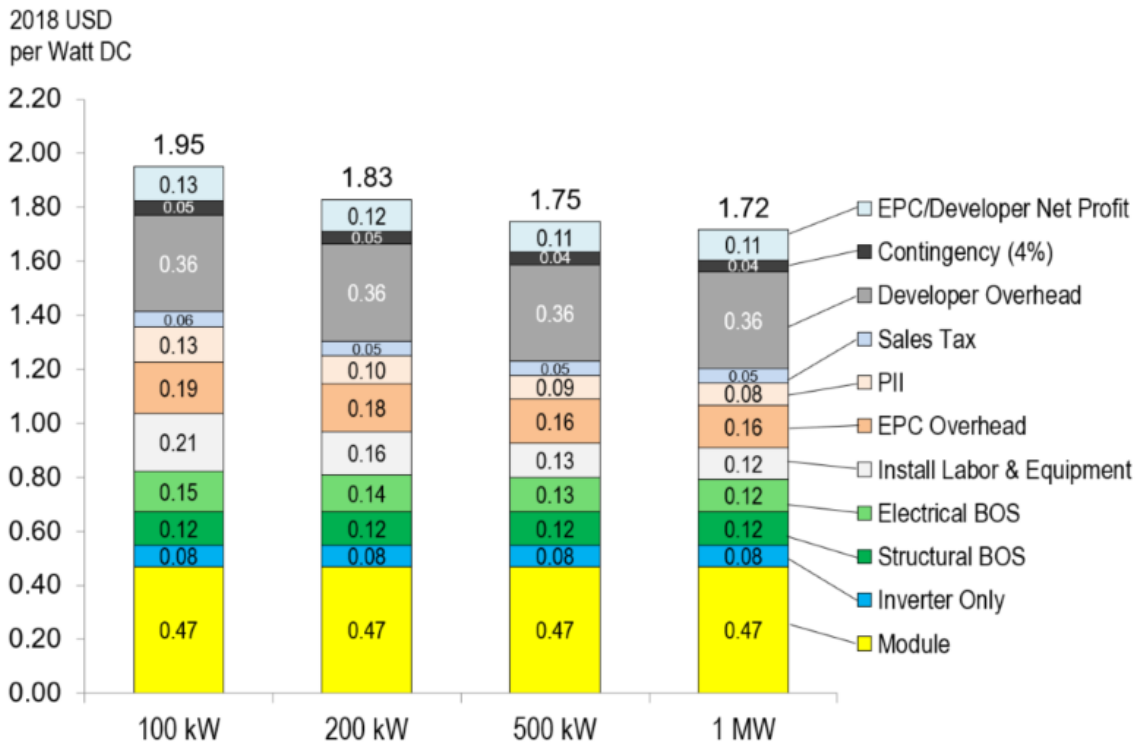
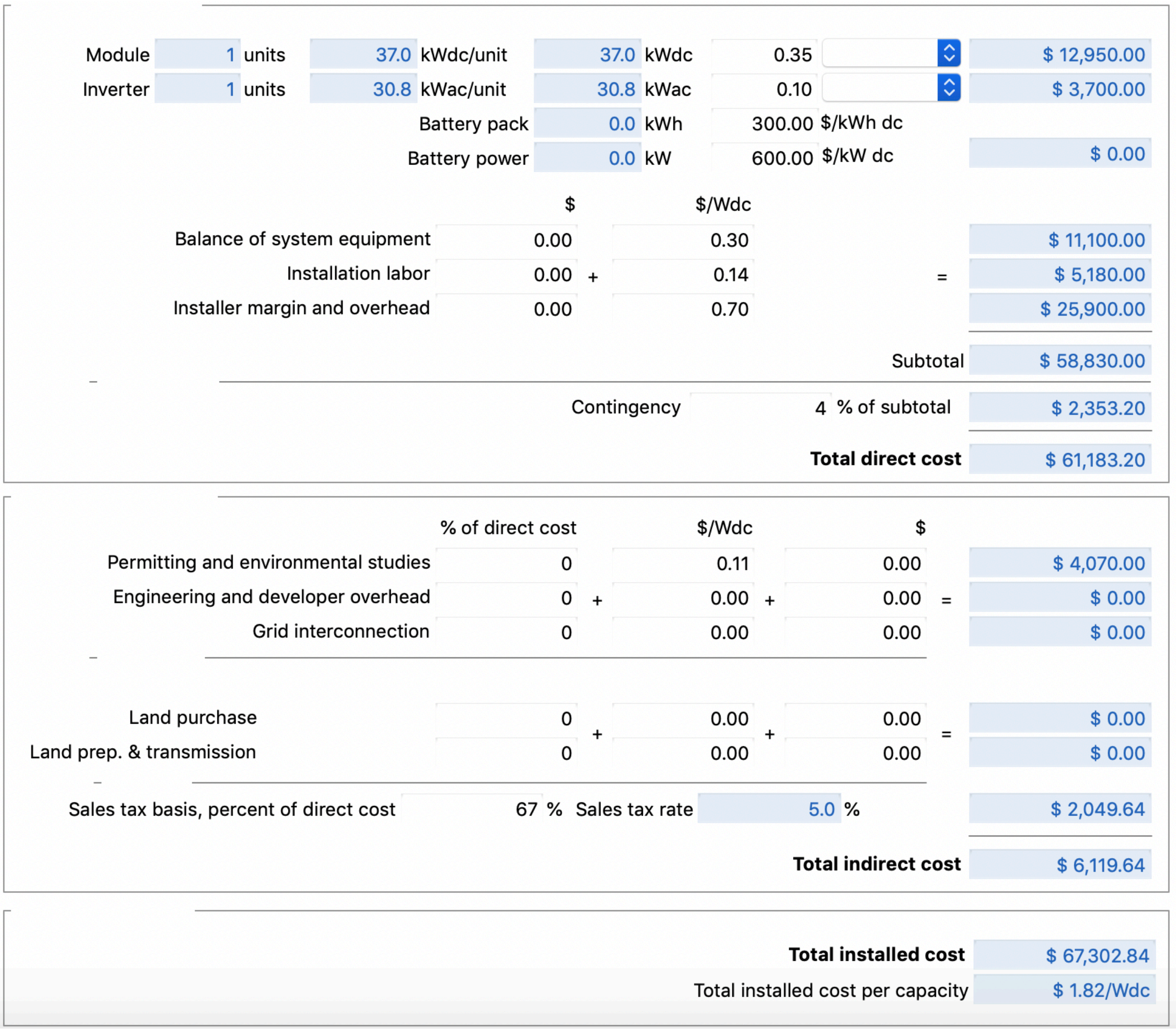


Figure 20: Cost of PV Systems in 2018USD per Watt in the US

The figure above represents the cost in 2018 USD per Watt (DC) of the system. This is a US average, and from the same report we know that the State of Colorado's average is 10 cents of a dollar lower. Extrapolating to our size, 37 kW DC, and taking into account the state's average, **the cost of the system would come to 1.82 USD/Watt DC.** As we can see, the cost of the equipment remains the same for the size, and it is the EPC (Engineering, Procurement and Construction) and Labor that grows (per Watt) as the size decreases. (15)

The software SAM also calculates costs. It follows the same scheme shown above, as it is also from the NREL. Below is a summary of the costs.



Module	1 units	37.0 kWdc/unit	37.0 kWdc	0.35		$ 12,950.00
Inverter	1 units	30.8 kWac/unit	30.8 kWac	0.10		$ 3,700.00
		Battery pack	0.0 kWh	300.00 $/kWh dc		
		Battery power	0.0 kW	600.00 $/kW dc		$ 0.00

	$		$/Wdc		
Balance of system equipment	0.00		0.30		$ 11,100.00
Installation labor	0.00	+	0.14	=	$ 5,180.00
Installer margin and overhead	0.00		0.70		$ 25,900.00
				Subtotal	$ 58,830.00
Contingency			4 % of subtotal		$ 2,353.20
				Total direct cost	$ 61,183.20

	% of direct cost		$/Wdc		$		
Permitting and environmental studies	0		0.11		0.00		$ 4,070.00
Engineering and developer overhead	0	+	0.00	+	0.00	=	$ 0.00
Grid interconnection	0		0.00		0.00		$ 0.00
Land purchase	0	+	0.00	+	0.00	=	$ 0.00
Land prep. & transmission	0		0.00		0.00		$ 0.00
Sales tax basis, percent of direct cost	67 %		Sales tax rate 5.0 %				$ 2,049.64
					Total indirect cost		$ 6,119.64

Total installed cost	$ 67,302.84
Total installed cost per capacity	$ 1.82/Wdc

Image 13: Cost Summary of the PV system as calculated by SAM

Using these numbers as a base, the total cost of construction and installation comes to 67 303 USD.

Also, no sales and use taxes will need to be paid for any of the components used for the construction of a solar systems, as the Colorado Department of Revenue exempts taxes in these. (16)

For this capital expense, the Federal tax credit has to be taken into account. It returns 30% of the investment of a PV system in tax credit, which for the school, would be the same as saving 30%. With this, and to simplify, **the capital expense comes to 40 382 USD.**

2. O&M

To properly estimate the income this system could have in the future, the approximate Operation and Maintenance costs must be taken into account. These costs include the cleaning of panels and installation in general, as well as the possible repair and maintenance of the electrical system. The NREL estimates the cost of O&M of solar photovoltaic systems at 22 $/kW for residential and 18 $/kW for commercial, every year. Although the nature of the system is commercial, this cost will be calculated at 19 $/kW, as it is smaller than the average commercial system (17). With this, **the cost of O&M is estimated at 700 $ every year.**

3. Bill savings

This section is very straight forward, since the energy that is not taken from the utility has already been calculated and thus, the money that won't be being paid is easily accounted for. The rate structure Colorado School of Mines is the Primary General Rate Structure of Xcel Energy. It calculates the cost of electricity with three terms: Fixed Charge, Demand Charge and Energy Charge. The Fixed Charge is always the same and it is applied to the bill of the whole campus, so energy savings won't be affecting that term. However, both Demand and Energy Charges are in terms of either the power or the energy consumed and therefore, they will change.

Demand Charge is the rate charged per kW of the peak demand of each month (of a 15-minute interval). If the peak (which is always during the times of the day where irradiation is at its highest) is reduced because some of that power is supplied by the PV system, the monthly demand charge will also be reduced.

Energy Charge is the rate charged per kWh (it changes if it is during on-peak hours or off-peak) and so by reducing the energy demanded from the grid this produces savings. Since on-peak hours are from 9 am to 9 pm, we can assume that energy savings always occur during on-peak hours and so, only that rate will be used.

Below is a summary of these two charges:

	Summer (Jun-Sept)	***Winter (Oct-May)***
Monthly Demand Charge	$ 21	$ 16.41
Monthly Energy Charge	$ 0.04059	$ 0.0478

Table 12: Xcel Energy Utility Charges for the Colorado School of Mines

These charges can be extrapolated into the future with what is known as the rate of escalation of electricity prices which is estimated to be approximately 3%. This means the price of electricity each year will grow by 3% and so, using this estimation of electricity price into the future, the money saved every year on electricity bills is as follows.

With these rates and the peak power and the energy consumption of each month, the bill savings thanks to the PV system are calculated and shown below.

Year	Bill Savings ($)
2018	2290.47083
2019	2347.38903
2020	2405.72165
2021	2465.50383
2022	2526.7716
2023	2589.56187
2024	2653.91249
2025	2719.86221
2026	2981.92968
2027	2656.40568
2028	2927.7084
2029	3000.46196
2030	3075.02344
2031	3151.43777
2032	3229.751
2033	3310.01031
2034	3392.26407
2035	3476.56183
2036	3562.95439
2037	3651.49381
2038	3742.23343
2039	3835.22793
2040	3930.53334
2041	4028.2071
2042	4128.30804

4. COST OF CO2

"EPA and other federal agencies use estimates of the social cost of carbon (SC-CO2) to value the climate impacts of rulemakings. The SC-CO2 is a measure, in dollars, of the long-term damage done by a ton of carbon dioxide (CO2) emissions in a given year. This dollar figure also represents the value of damages avoided for a small emission reduction (i.e., the benefit of a CO2 reduction)." This is what the EPA (The Environmental Protection Agency of the United States) comments on the social cost of CO_2. For this project, the value will be used as the benefit of reducing the emissions and thus, it will be represented as a profit. Below, the cost of CO_2 in dollars per kilowatt is shown for every year. This means that for every kilowatt that has not been demanded from the utility, that is what is saved. (18)

With this, and the generation of the PV System every year, we can calculate the savings of the cost of emissions. This is shown below.

Year	Cost of CO_2 ($/kWh)	Energy (kWh)	Cost of CO_2 Savings ($)
2018	$0.0300	18691.9	560.757
2019	$0.0294	18598.4	546.79296
2020	$0.0287	18505.4	531.10498
2021	$0.0276	18412.9	508.19604
2022	$0.0265	18320.8	485.5012
2023	$0.0253	18229.2	461.19876
2024	$0.0241	18138.1	437.12821
2025	$0.0228	18047.4	411.48072
2026	$0.0214	17957.2	384.28408
2027	$0.0209	17867.4	373.42866
2028	$0.0203	17778	360.8934
2029	$0.0197	17689.2	348.47724
2030	$0.0191	17600.7	336.17337
2031	$0.0185	17512.7	323.98495
2032	$0.0179	17425.1	311.90929
2033	$0.0172	17338	298.2136
2034	$0.0165	17251.3	284.64645
2035	$0.0158	17165.1	271.20858
2036	$0.0150	17079.2	256.188
2037	$0.0141	16993.8	239.61258
2038	$0.0133	16908.9	224.88837
2039	$0.0124	16824.3	208.62132
2040	$0.0115	16740.2	192.5123
2041	$0.0104	16656.5	173.2276
2042	$0.0094	16573.2	155.78808

5. *Economic Profitability Study*

The profitability of this project is fairly relevant: although the main objective of the installation of a solar photovoltaic system is not the economic return of investment, it is important that it at least covers its own cost and would be of interest if some profit was earned. To study this viability, the expenses are compared with the savings each year. On the next page, a 25-year study is shown, portraying the net savings each year as well as the return of investment.

The most clear outcome is that the return of investment starts on the 16th year after installation. Although this seems late, there are still 9 years were the school is making a profit of this system.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Savings													
Bill Savings	$ 2,290.47	$ 2,347.39	$ 2,405.72	$ 2,465.50	$ 2,526.77	$ 2,589.56	$ 2,653.91	$ 2,719.86	$ 2,981.93	$ 2,656.41	$ 2,927.71	$ 3,000.46	$ 3,075.02
Cost of CO2	$ 560.76	$ 546.79	$ 531.10	$ 508.20	$ 485.50	$ 461.20	$ 437.13	$ 411.48	$ 384.28	$ 373.43	$ 360.89	$ 348.48	$ 336.17
Total Savings	$ 2,851.23	$ 2,894.18	$ 2,936.83	$ 2,973.70	$ 3,012.27	$ 3,050.76	$ 3,091.04	$ 3,131.34	$ 3,366.21	$ 3,029.83	$ 3,288.60	$ 3,348.94	$ 3,411.20
Expenses													
Capital Investment	$ 40,381.80												
O&M		$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00
Total Expenses	$ 40,381.80	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00
Cash Flow													
Net Savings	$(37,530.57)	$ 2,194.18	$ 2,236.83	$ 2,273.70	$ 2,312.27	$ 2,350.76	$ 2,391.04	$ 2,431.34	$ 2,666.21	$ 2,329.83	$ 2,588.60	$ 2,648.94	$ 2,711.20
Cash Flow	$(37,530.57)	$(35,336.39)	$(33,099.56)	$(30,825.86)	$(28,513.59)	$(26,162.83)	$(23,771.79)	$(21,340.45)	$(18,674.23)	$(16,344.40)	$(13,755.80)	$(11,106.86)	$ (8,395.66)

	14	15	16	17	18	19	20	21	22	23	24	25	Total
Savings													
Bill Savings	$ 3,151.44	$ 3,229.75	$ 3,310.01	$ 3,392.26	$ 3,476.56	$ 3,562.95	$ 3,651.49	$ 3,742.23	$ 3,835.23	$ 3,930.53	$ 4,028.21	$ 4,128.31	$ 78,079.71
Cost of CO2	$ 323.98	$ 311.91	$ 298.21	$ 284.65	$ 271.21	$ 256.19	$ 239.61	$ 224.89	$ 208.62	$ 192.51	$ 173.23	$ 155.79	$ 8,686.22
Total Savings	$ 3,475.42	$ 3,541.66	$ 3,608.22	$ 3,676.91	$ 3,747.77	$ 3,819.14	$ 3,891.11	$ 3,967.12	$ 4,043.85	$ 4,123.05	$ 4,201.43	$ 4,284.10	$ 86,765.92
Expenses													
Capital Investment													$ 40,381.80
O&M	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 16,800.00
Total Expenses	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 700.00	$ 57,181.80
Cash Flow													
Net Savings	$ 2,775.42	$ 2,841.66	$ 2,908.22	$ 2,976.91	$ 3,047.77	$ 3,119.14	$ 3,191.11	$ 3,267.12	$ 3,343.85	$ 3,423.05	$ 3,501.43	$ 3,584.10	
Cash Flow	$ (5,620.24)	$ (2,778.58)	$ 129.65	$ 3,106.56	$ 6,154.33	$ 9,273.47	$ 12,464.58	$ 15,731.70	$ 19,075.55	$ 22,498.59	$ 26,000.03	$ 29,584.12	

Figure 21: Economic Study showing return of investment and profits

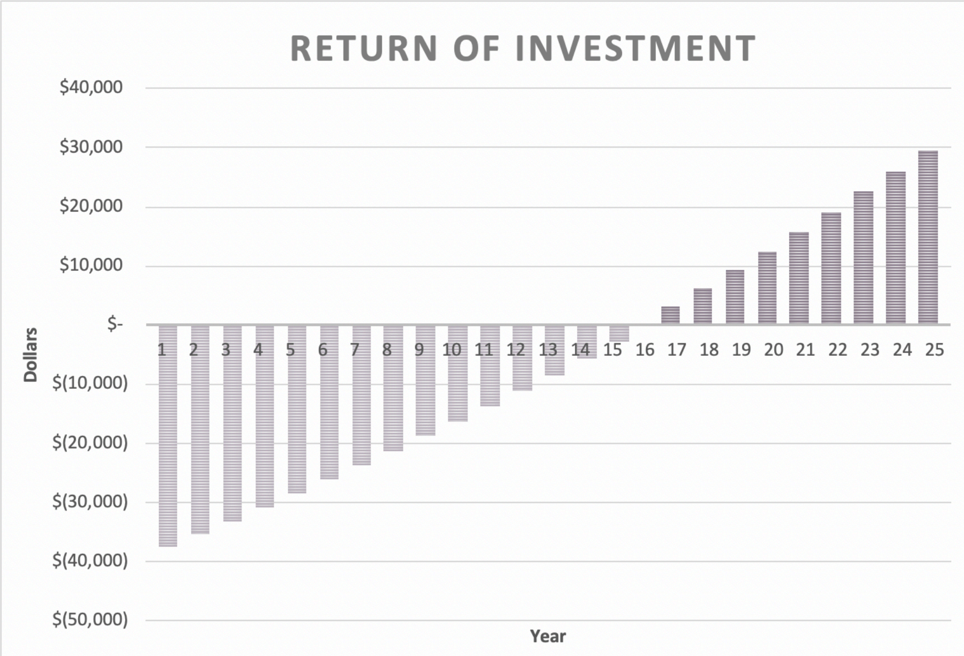


Figure 22: Return of Investment in USD of the PV System

As mentioned before, we can see that the first year, a capital investment is registered as expense and that every year, with the savings that come from the cost of CO_2 and the electricity bills, there is a gain towards the returns. The final net savings account for a total of $30,000. For an educational project, with an environmental aim, this final number is satisfactory.

VII. Conclusions

This project has been slowly shaped into the final study by the small parts that have contributed to the overall learning process it has been. There are clear distinctions between the different sections of the project, and thus, the conclusions and knowledge obtained in each will be evaluated separately.

From the analysis of the building, there are a couple of important points to mention.

Firstly, a building energy profiling like the one performed as a preliminary study on which to base the project gives the perfect insight into a new, real life design of a microgrid. Electrical floor plans and one-line diagrams of such complexity allowed for an understanding that will be of use in any future projects that bear some resemblance. The hands-on application of the knowledge learnt of such one-line diagrams during undergraduate studies, as well as electric protective methods that could then be portrayed onto these systems and help in the understanding of them, helped tie down my whole engineering education.

Secondly, the introduction of the concept of NEC load calculations and NEC demand loads expanded on what we had learnt on connected load, and learning about the regulations that any system has to follow for sizing and connections gives valuable experience on the actual process of design and construction of commercial and residential buildings in the field of electrical engineering. From this, conclusions on the design and sizing of feeders and breakers are drawn NEC demand loads allow for closer but safe designs that in turn save money. Also, it allows for a closer estimation of the actual use of the loads in any building. However, this led to wanting to know what the load of the building really was, leading on to the next section, an analysis of the building's consumption.

Lastly, this analysis of the power and energy consumption of the building was conducted. Useful software for billing information as well as metering information helped obtain all the information. The allowed for the obtaining of a picture of what the use of the building was, as well as the daily load curves and the monthly and annual power and energy consumed. It was important for the school to verify that what the bills were showing matched the digital meter's information and it was so.

All this study of this building is very important when wanting to change something in it. Becoming an expert on the existing infrastructure, as well as the consumption it has and the use it is given, sets the basis for the improvement of it in the most educated way. This leads to the next part of this report.

The second part of the project focused on the improvement of the building's emissions and consumption. To achieve this, the implementation of a source of renewable energy onto the building's grid was contemplated. A small study on the types of renewables available and suitable led to the conclusion that photovoltaic energy was the best choice in a building like CoorsTek. From this, the type of photovoltaic panels, the choice of inverters and the possible addition of a battery were all planned. As an electrical engineering, with a huge background in energy systems, and a person with the need to contribute to solving the problem of climate change, the research conducted on renewable energy (and more specifically, PV energy) was of great interest to me and the perfect contribution to my studies. Within the project, it led to the most adequate choice of a PV system for implementation of the building: a 37kW system of panels, with a central inverter and no battery. The conclusion of not adding a BESS system was reached because of the lack of impact the energy shifting service of the battery would have.

From the designed and modeled PV system, the impact was analyzed. The most important section was the environmental impact, which proved to be smaller than expected. However, it gives an insight into how renewable energy works, and into why the industry, although growing steadily, has not taken over all other sources of energy.

On the other hand, the economic study proved to be at least profitable. The return of investment occurred 16 year after the installation which left 9 years of clean income for the school.

Overall, and to close the conclusions, this project has granted an impressive insight into how real-life design and construction projects work, as well as a look onto the bigger picture of a whole building and campus electrical and energy system. Moreover, the chance to environmentally improve an electrical system, and to more deeply study green generation led to a great learning experience in this field and was a successful design study that although it didn’t present a great contribution in terms of carbon footprint, it was economically viable, and an overall positive asset addition to the school.

VIII. Future Work

As with any research paper, document or project that involves the understanding of a large topic and a bigger picture, there are always paths left unfollowed that could be of great interest.

In this case, and keeping with the individuality of this project, the one thing that, in my opinion, should be further studied is the combination of wind turbines with the PV installation. This method of carbon neutral energy generation is becoming increasingly popular because of its functionality. Photovoltaic generation provides a steady daily supply of clean energy, while the wind turbines are of use during those times where irradiation is low (cloudy days) or non-existent (night-time). The study of this combination would follow a similar structure to the one used in this paper to analyze PV implementation, making it a straight-forward next step.

In addition to this, another phase of this project would naturally be the expansion to a large-scale version that would include other buildings. This work is already being contemplated by the school, and the impact it would have would be much larger and complete. It would include more than just rooftop PV systems, as parking lots and other areas would become available. The implementation of renewable distributed sources of energy throughout the whole campus would allow for other benefits not seen on small scale systems. The most notable one would be the Energy Shifting service, that thanks to the use of battery storage, shifts the peak demand of the school, incurring a lower bill charge for peak demand and the possibility of using the most energy during the times where electricity price is lowest.

With this future perspective, the project takes a more important role and serves as a basis for further investigations and modeling.

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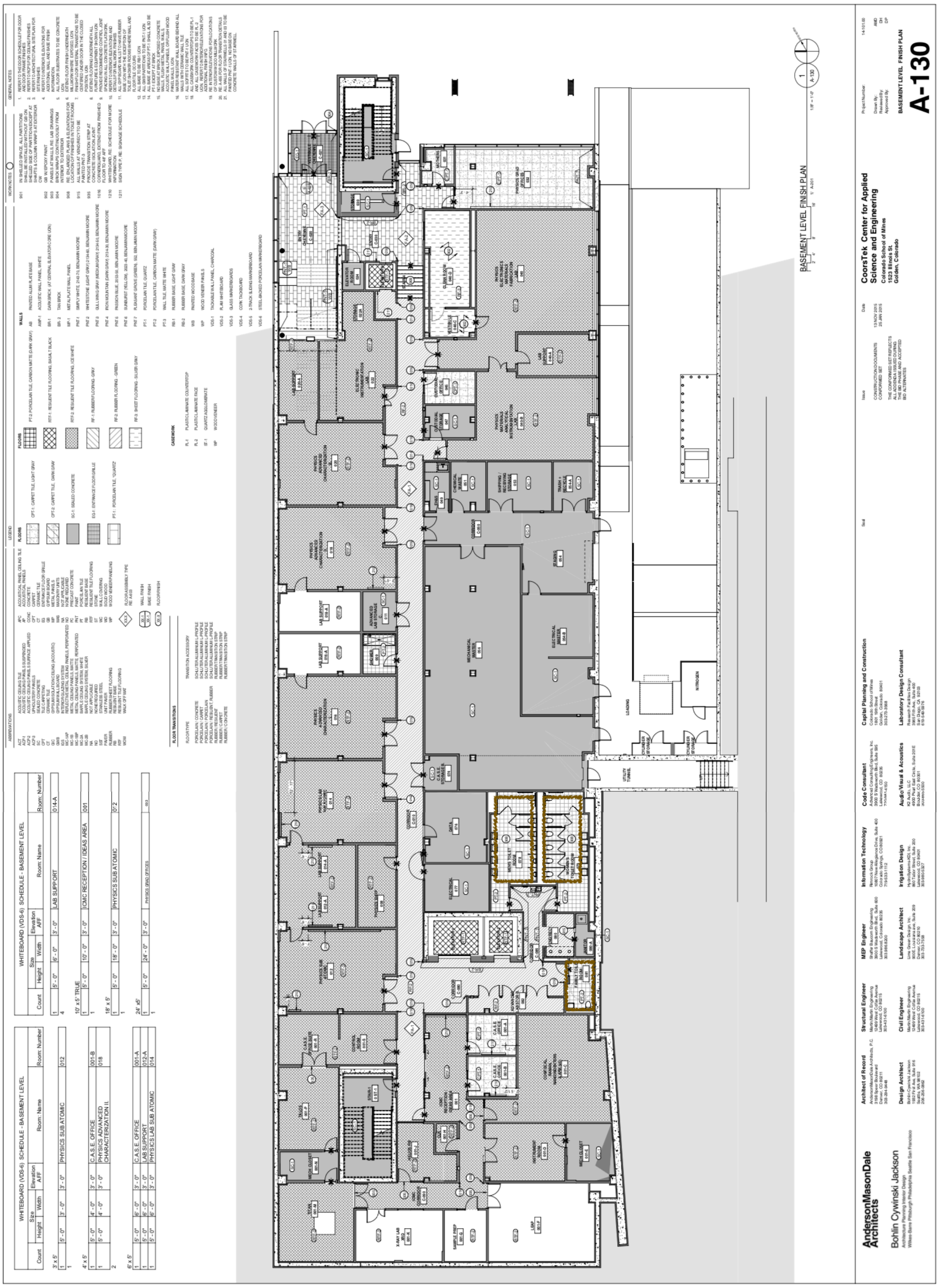
APPENDICES

APPENDIX A: FLOOR PLANS



WHITEBOARD (VDS-6) SCHEDULE - LEVEL 1					
Count	Size: Height	Size: Width	Elevation AFF	Room: Name	Room: Number
6' x 5'					
1	5' - 0"	6' - 0"	3' - 0"	ACTIVE LEARNING STUDIO	130
1	5' - 0"	6' - 0"	3' - 0"	ACTIVE LEARNING STUDIO	130
2					
9' x 5'					
1	5' - 0"	9' - 0"	3' - 0"	PHYSICS ADVANCED LAB II.	155
1	5' - 0"	9' - 0"	3' - 0"	PHYSICS ADVANCED LAB I.	165
2					
12' x 5'					
1	5' - 0"	12' - 0"	3' - 0"	PHYSICS STUDENT LOUNGE	188
1					
16' x 5'					
1	5' - 0"	16' - 0"	3' - 0"	PHYSICS STUDENT LOUNGE	188
1					
20' x 5'					
1	5' - 0"	20' - 0"	3' - 0"	ACTIVE LEARNING STUDIO	140
1	5' - 0"	20' - 0"	3' - 0"	ACTIVE LEARNING STUDIO	150
1	5' - 0"	20' - 0"	3' - 0"	PHYSICS COMPUTER LAB	182
3					

WHITEBOARD (VDS-6) SCHEDULE - LEVEL 1					
Count	Size: Height	Size: Width	Elevation AFF	Room: Name	Room: Number
24' x5'					
1	5' - 0"	24' - 0"	3' - 0"	ACTIVE LEARNING STUDIO	130
1	5' - 0"	24' - 0"	3' - 0"	ACTIVE LEARNING STUDIO	140
1	5' - 0"	24' - 0"	3' - 0"	ACTIVE LEARNING STUDIO	150
1	5' - 0"	24' - 0"	3' - 0"	PHYSICS COMPUTER LAB	182
4					

ABBREVIATIONS

ACT	ACOUSTIC CEILING TILE	APC	ACOUSTICAL PANEL CEILING TILE
ACP-1	ACOUSTIC CEILING PANELS SUSPENDED	AP	ACOUSTICAL PANELS
ACP-2	ACOUSTIC CEILING PANELS SURFACE APPLIED	CONC	CONCRETE
ACP-3	UPHOLSTERY PANELS	CPT	CARPET
SC	SEALED CONCRETE	CT	CERAMIC TILE
CPT	TILE CARPETING	EG	ENTRANCE FLOOR GRILLE
CT	CERAMIC TILE	GB	GYPSUM BOARD
GIC	GYPSUM ISOLATION CEILING (ACOUSTIC)	MP	METAL PANELS
GWB	GYPSUM WALL BOARD	MAS	MASONRY UNITS
IGS	INTERIOR GLAZING SYSTEM	NA	NOT APPLICABLE
MC-1AP	REFLECTIVE METAL CEILING PANELS, PERFORATED	NO	NONE REQUIRED
MC-1B	METAL CEILING PANELS, MATTE	PC	PRECAST CONCRETE
MC-1BP	METAL CEILING PANELS, MATTE, PERFORATED	PNT	PAINT
MC-2A	BAFFLE CEILING SYSTEM, WHITE	PT	PORCELAIN TILE
MC-2B	BAFFLE CEILING SYSTEM, SILVER	RB	RESILIENT BASE
NA	NOT APPLICABLE	RTF	RESILIENT TILE FLOORING
NO	NONE REQUIRED	ST	STONE
SST	STAINLESS STEEL	WC	WALL COVERING
PAVER	UNIT PAVER	WD	SOLID WOOD
RUBBER	RUBBER SHEET FLOORING	WP	WOOD VENEER PANELING
RB	RESILIENT BASE		
RTF	RESILIENT TILE FLOORING		
WOM	WALK OFF MAT		

XX-X FLOOR ASSEMBLY TYPE RE: A-603

XX-1 WALL FINISH

XX-1 BASE FINISH

XX-X FLOOR FINISH

FLOOR TRANSITIONS

FLOOR TYPE	TRANSITION ACCESSORY
PORCELAIN / CONCRETE	SCHLUTER ALUMINUM L-PROFILE
PORCELAIN / CARPET	SCHLUTER ALUMINUM L-PROFILE
PORCELAIN / PORCELAIN	SCHLUTER ALUMINUM L-PROFILE
PORCELAIN / RESILIENT, RUBBER	SCHLUTER ALUMINUM L-PROFILE
RUBBER / RESILIENT	RUBBER TRANSITION STRIP
RUBBER / CARPET	RUBBER TRANSITION STRIP
RUBBER / CONCRETE	RUBBER TRANSITION STRIP

LEGEND

FLOORS

- CPT-1: CARPET TILE, LIGHT GRAY
- CPT-2: CARPET TILE, DARK GRAY
- SC-1: SEALED CONCRETE
- EG-1: ENTRANCE FLOOR GRILLE
- PT-1: PORCELAIN TILE, "QUARTZ"

FLOORS

- PT-2: PORCELAIN TILE, CARBON MATTE (DARK GRAY)
- RTF-1: RESILIENT TILE FLOORING, BASALT BLACK
- RTF-2: RESILIENT TILE FLOORING, ICE WHITE
- RF-1: RUBBER FLOORING- GRAY
- RF-2: RUBBER FLOORING - GREEN
- RF-3: SHEET FLOORING - SILVER GRAY

CASEWORK

PL-1	PLASTIC LAMINATE COUNTERTOP
PL-2	PLASTIC LAMINATE FACE
ST-1	QUARTZ AGGLOMERATE
WP	WOOD VENEER

WALLS

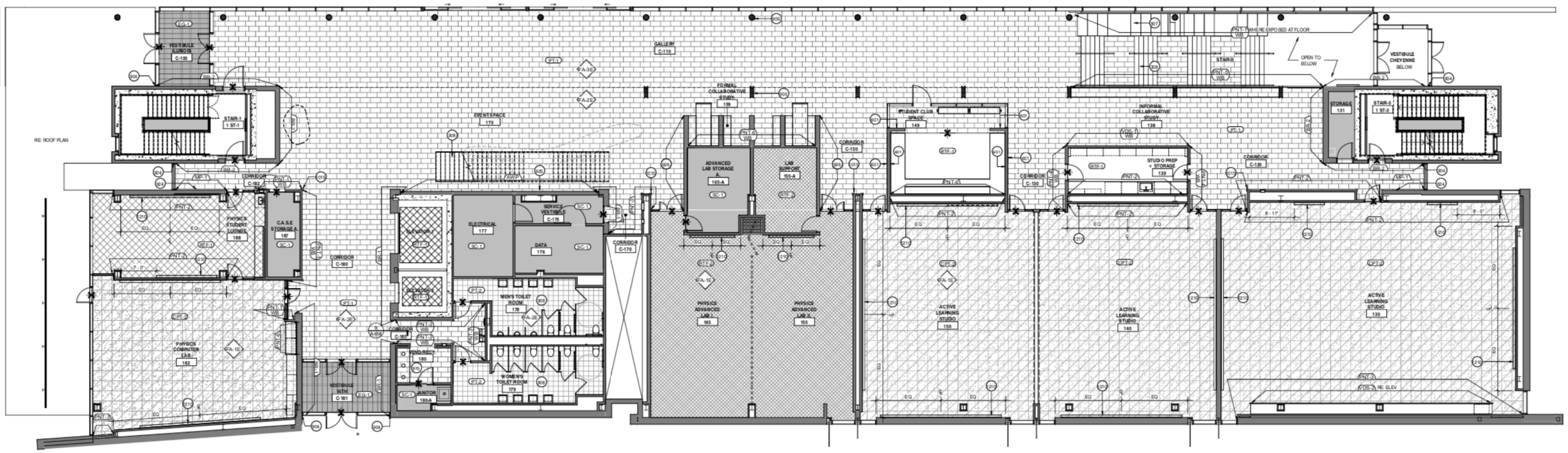
AB	PAINTED ALUM PLATE BASE
AWP-1	ACOUSTIC WALL PANEL, WHITE
BR-1	DARK BRICK (AT CENTRAL ELEVATOR CORE UON)
BR- 2	TAN BRICK
MP-1	METAL PLATE WALL PANEL
PNT-1	SIMPLY WHITE, 2143-70, BENJAMIN MOORE
PNT-2	WHITESTONE (LIGHT GRAY) 2134-60, BENJAMIN MOORE
PNT-3	GULL WING GRAY (MEDIUM GRAY) 2134-50, BENJAMIN MOORE
PNT-4	IRON MOUNTAIN (DARK GRAY) 2134-30, BENJAMIN MOORE
PNT-5	PASSION BLUE, 2063-50, BENJAMIN MOORE
PNT-6	SUNBURST (YELLOW), 2023-40, BENJAMIN MOORE
PNT-7	PLEASANT GROVE (GREEN), 552, BENJAMIN MOORE
PT-1	PORCELAIN TILE, QUARTZ
PT-2	PORCELAIN TILE, CARBON MATTE (DARK GRAY)
PT-3	WALL TILE, MATTE WHITE
RB-1	RUBBER BASE, LIGHT GRAY
RB-2	RUBBER BASE, DARK GRAY
WB	PAINTED WOOD BASE
WP	WOOD VENEER PANELS
VDS-1	TACKABLE WALL PANEL, CHARCOAL
VDS-2	PLAM WHITEBOARD
VDS-3	GLASS MARKERBOARDS
VDS-4	CORK TACKBOARD
VDS-5	2-TRACK SLIDING MARKERBOARD
VDS-6	STEEL-BACKED PORCELAIN MARKERBOARD

WORK NOTES

308	PRECAST CONCRETE TREADS
601	WOOD PANEL(S) WRAP ALL FACES OF WALL, RE: ELEVATIONS. NO BASE AT FLUSH WOOD PANELS.
904	BRICK WRAPS CONTINUOUSLY FROM INTERIOR TO EXTERIOR
905	FIN COLUMNS AT LEVEL 1, GRIDLINE B TO BE WRAPPED IN METAL PANEL, PAINTED WITH SILVER METALLIC PAINT, TYP.
906	PAINT TO MATCH PNT-1, TYP
907	WD-1 BLEACHER STAIRS, RE: ELEVATION AND DETAILS
908	RE: ENLARGED PLANS & ELEVATIONS FOR LOCATION OF FINISHES IN TOILET ROOMS
915	ALL WALLS AT VEND/RECY TO BE PAINTED PNT-3
924	FLUSH METAL PANEL; NO BASE AT METAL PANEL WALL
925	ACOUSTIC WALL PANEL; NO BASE AT THIS LOCATION
926	NO BASE AT WALLS G6 AND G62
1015	CORNERGUARD, EXTEND FROM FINISHED FLOOR TO UNDERSIDE OF CEILING OR TOP OF BAFFLE, UON
1210	WHITEBOARD, RE: SCHEDULE FOR MORE INFORMATION

GENERAL NOTES

1. REFER TO THE DOOR SCHEDULE FOR DOOR AND DOOR FRAME FINISHES
2. REFER TO RCP'S FOR CEILING FINISHES
3. REFER TO ARCHITECTURAL SITE PLAN FOR SITE FINISHES
4. REFER TO INTERIOR ELEVATIONS FOR ADDITIONAL WALL AND BASE FINISH INFORMATION.
5. ALL FLOOR SUBSTRATES TO BE CONCRETE UON
6. EXTEND FLOOR FINISH UNDERNEATH MILLWORK WHERE EXPOSED, UON
7. FINISH FLOOR MATERIAL TRANSITIONS TO BE CENTERED UNDER DOOR IN THE CLOSED POSITION, UON
8. EXTEND FLOORING UNDERNEATH ALL FURNITURE & EQUIPMENT SHOWN UON
9. PROVIDE RECOMMENDED CONTROL JOINT SPACING IN ALL CONCRETE FLATWORK.
10. REFER TO INTERIOR ELEVATIONS AND DETAILS FOR MILLWORK FINISHES
11. ALL GYP BOARD WALLS TO HAVE RUBBER BASE UON WITH THE EXCEPTION OF TOILET/SHOWER ROOMS WHERE WALL AND FLOOR TILE OCCURS
12. ALL BASE TO BE RB-1 UON
13. ALL GWB PARTITIONS TO BE PNT-1 UON
14. ALL BASE AT AREAS OF PT-1 SHALL ALSO BE PT-1 EXCEPT AT BRICK
15. NO BASE AT BRICK, EXPOSED CONCRETE WALLS, FLUSH METAL PANEL WALLS, ACOUSTIC WALL PANELS, OR FLUSH WOOD PANEL WALLS, UON
16. WATER RESISTANT WALL BOARD BEHIND ALL WALLS WITH CERAMIC WALL TILE
17. ALL SOFFITS TO BE PNT-1 UON
18. ALL CASEWORK COUNTERTOPS TO BE PL-1 AND ALL CASEWORK FACES TO BE PL-2 UON. REFER TO INTERIOR ELEVATIONS FOR ADDITIONAL FINISH INFO.
19. RE: INTERIOR ELEVATIONS FOR LOCATIONS OF CUSTOM WOOD MILLWORK
20. RE: A-655 FOR FLOOR TRANSITION DETAILS
21. ALL WALLS OF STAIRWELLS 01 AND 03 TO BE PAINTED PNT-1 UON. NO BASE ON CONCRETE WALLS OF STAIRWELL.



FIRST LEVEL FINISH PLAN

1/8" = 1'-0"

1 A-131

AndersonMasonDale Architects

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Research Facilities Design
3965 Fifth Ave, Suite 400
San Diego, CA 92103
619-549-5976

Seal

Issue	Date
CONSTRUCTION DOCUMENTS	13 NOV 2015
CONFORMED SET	25 JAN 2015

THE CONFORMED SET REFLECTS ALL ADDENDA ISSUED DURING THE BID PHASE AND ACCEPTED BID ALTERNATES

CoorsTek Center for Applied Science and Engineering
Colorado School of Mines
1523 Illinois St.
Golden, Colorado

Project Number:	14-101.00
Drawn By:	AMD
Reviewed By:	DH
Approved By:	DP

LEVEL 1 FINISH PLAN

A-131

WHITEBOARD (VDS-6) SCHEDULE - LEVEL 2					
Count	Size: Height	Size: Width	Elevation AFF	Room: Name	Room: Number
6' x 5'					
1	5' - 0"	6' - 0"	3' - 0"	FACULTY OFFICE	201
1	5' - 0"	6' - 0"	3' - 0"	POST-DOC OFFICE	202
1	5' - 0"	6' - 0"	3' - 0"	POST-DOC OFFICE	203
1	5' - 0"	6' - 0"	3' - 0"	POST-DOC OFFICE	204
1	5' - 0"	6' - 0"	3' - 0"	POST-DOC OFFICE	205
1	5' - 0"	6' - 0"	3' - 0"	BREAK OUT	206
1	5' - 0"	6' - 0"	3' - 0"	C.A.S.E. OFFICE INFORMATION SPECIALIST	207
1	5' - 0"	6' - 0"	3' - 0"	C.A.S.E. FINANCIAL OFFICER	213
1	5' - 0"	6' - 0"	3' - 0"	COORS FELLOWS OFFICE	214
1	5' - 0"	6' - 0"	3' - 0"	C.A.S.E. OFFICE	215
1	5' - 0"	6' - 0"	3' - 0"	C.A.S.E. OFFICE	216
1	5' - 0"	6' - 0"	3' - 0"	POST-DOC OFFICE	217
1	5' - 0"	6' - 0"	3' - 0"	POST-DOC OFFICE	218
1	5' - 0"	6' - 0"	3' - 0"	POST-DOC OFFICE	219
1	5' - 0"	6' - 0"	3' - 0"	POST-DOC OFFICE	220

WHITEBOARD (VDS-6) SCHEDULE - LEVEL 2					
Count	Size: Height	Size: Width	Elevation AFF	Room: Name	Room: Number
1	5' - 0"	6' - 0"	3' - 0"	BREAK OUT	221
1	5' - 0"	6' - 0"	3' - 0"	POST-DOC OFFICE	222
1	5' - 0"	6' - 0"	3' - 0"	POST-DOC OFFICE	223
1	5' - 0"	6' - 0"	3' - 0"	POST-DOC OFFICE	224
1	5' - 0"	6' - 0"	3' - 0"	POST-DOC OFFICE	225
1	5' - 0"	6' - 0"	3' - 0"	POST-DOC OFFICE	226
1	5' - 0"	6' - 0"	3' - 0"	POST-DOC OFFICE	227
1	5' - 0"	6' - 0"	3' - 0"	POST-DOC OFFICE	228
23					
20' x 5'					
1	5' - 0"	20' - 0"	3' - 0"	PHYSICS CONFERENCE ROOM	282
1					
32' x 5'					
1	5' - 0"	32' - 0"	3' - 0"	PHYSICS ELECTRONICS LAB	288
1					

ABBREVIATIONS

ACT	ACOUSTIC CEILING TILE	APC	ACOUSTICAL PANEL CEILING TILE
ACP-1	ACOUSTIC CEILING PANELS SUSPENDED	AP	ACOUSTICAL PANELS
ACP-2	ACOUSTIC CEILING PANELS SURFACE APPLIED	CONC	CONCRETE
ACP-3	UPHOLSTERY PANELS	CPT	CARPET
SC	SEALED CONCRETE	CT	CERAMIC TILE
CPT	TILE CARPETING	EG	ENTRANCE FLOOR GRILLE
CT	CERAMIC TILE	GB	GYPSUM BOARD
GIC	GYPSUM ISOLATION CEILING (ACOUSTIC)	MP	METAL PANELS
GWB	GYPSUM WALL BOARD	MAS	MASONRY UNITS
IGS	INTERIOR GLAZING SYSTEM	NA	NOT APPLICABLE
MC-1AP	REFLECTIVE METAL CEILING PANELS, PERFORATED	NO	NONE REQUIRED
MC-1B	METAL CEILING PANELS, MATTE	PC	PRECAST CONCRETE
MC-1BP	METAL CEILING PANELS, MATTE, PERFORATED	PNT	PAINT
MC-2A	BAFFLE CEILING SYSTEM, WHITE	PT	PORCELAIN TILE
MC-2B	BAFFLE CEILING SYSTEM, SILVER	RB	RESILIENT BASE
NA	NOT APPLICABLE	RTF	RESILIENT TILE FLOORING
NO	NONE REQUIRED	ST	STONE
SST	STAINLESS STEEL	WC	WALL COVERING
PAVER	UNIT PAVER	WD	SOLID WOOD
RUBBER	RUBBER SHEET FLOORING	WP	WOOD VENEER PANELING
RB	RESILIENT BASE		
RTF	RESILIENT TILE FLOORING		
WOM	WALK OFF MAT		

XX-X FLOOR ASSEMBLY TYPE RE: A-603

XX-1 WALL FINISH / XX-1 BASE FINISH

XX-X FLOOR FINISH

FLOOR TRANSITIONS

FLOOR TYPE	TRANSITION ACCESSORY
PORCELAIN / CONCRETE	SCHLUTER ALUMINUM L-PROFILE
PORCELAIN / CARPET	SCHLUTER ALUMINUM L-PROFILE
PORCELAIN / PORCELAIN	SCHLUTER ALUMINUM L-PROFILE
PORCELAIN / RESILIENT, RUBBER	SCHLUTER ALUMINUM L-PROFILE
RUBBER / RESILIENT	RUBBER TRANSITION STRIP
RUBBER / CARPET	RUBBER TRANSITION STRIP
RUBBER / CONCRETE	RUBBER TRANSITION STRIP

LEGEND

FLOORS

- CPT-1: CARPET TILE, LIGHT GRAY
- CPT-2: CARPET TILE, DARK GRAY
- SC-1: SEALED CONCRETE
- EG-1: ENTRANCE FLOOR GRILLE
- PT-1: PORCELAIN TILE, "QUARTZ"

FLOORS

- PT-2: PORCELAIN TILE, CARBON MATTE (DARK GRAY)
- RTF-1: RESILIENT TILE FLOORING, BASALT BLACK
- RTF-2: RESILIENT TILE FLOORING, ICE WHITE
- RF-1: RUBBER FLOORING- GRAY
- RF-2: RUBBER FLOORING - GREEN
- RF-3: SHEET FLOORING - SILVER GRAY

CASEWORK

PL-1	PLASTIC LAMINATE COUNTERTOP
PL-2	PLASTIC LAMINATE FACE
ST-1	QUARTZ AGGLOMERATE
WP	WOOD VENEER

WALLS

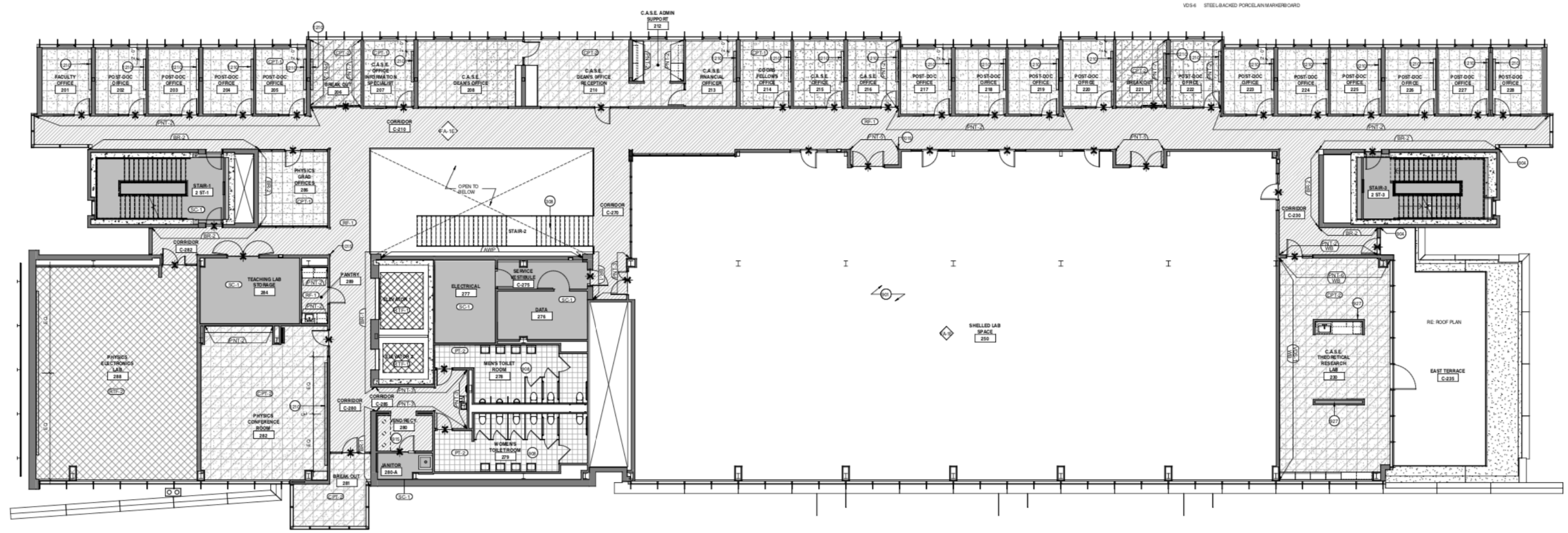
AB	PAINTED ALUM PLATE BASE
AWP-1	ACOUSTIC WALL PANEL, WHITE
BR-1	DARK BRICK (AT CENTRAL ELEVATOR CORE UON)
BR-2	TAN BRICK
MP-1	METAL PLATE WALL PANEL
PNT-1	SIMPLY WHITE, 2143-70, BENJAMIN MOORE
PNT-2	WHITESTONE (LIGHT GRAY) 2134-60, BENJAMIN MOORE
PNT-3	GULL WING GRAY (MEDIUM GRAY) 2134-50, BENJAMIN MOORE
PNT-4	IRON MOUNTAIN (DARK GRAY) 2134-30, BENJAMIN MOORE
PNT-5	PASSION BLUE, 2053-50, BENJAMIN MOORE
PNT-6	SUNBURST (YELLOW), 2023-40, BENJAMIN MOORE
PNT-7	PLEASANT GROVE (GREEN), 552, BENJAMIN MOORE
PT-1	PORCELAIN TILE, QUARTZ
PT-2	PORCELAIN TILE, CARBON MATTE (DARK GRAY)
PT-3	WALL TILE, MATTE WHITE
RB-1	RUBBER BASE, LIGHT GRAY
RB-2	RUBBER BASE, DARK GRAY
WB	PAINTED WOOD BASE
WP	WOOD VENEER PANELS
VDS-1	TACKABLE WALL PANEL, CHARCOAL
VDS-2	PLAM WHITEBOARD
VDS-3	GLASS MARKERBOARDS
VDS-4	CORK TACKBOARD
VDS-5	2-TRACK SLIDING MARKERBOARD
VDS-6	STEEL-BACKED PORCELAIN MARKERBOARD

WORK NOTES

308	PRECAST CONCRETE TREADS
901	IN SHELLED SPACE, ALL PARTITIONS SHALL BE INSTALLED WITHOUT GB ON SHELLED SIDE OF PARTITION EXCEPT AT SHAFTS & COLUMN WRAPS AT EXTERIOR CW
904	BRICK WRAPS CONTINUOUSLY FROM INTERIOR TO EXTERIOR
908	RE: ENLARGED PLANS & ELEVATIONS FOR LOCATION OF FINISHES IN TOILET ROOMS
915	ALL WALLS AT VEND/RECY TO BE PAINTED PNT-3
927	WOOD BASE WRAPS ALL WALLS AT THIS LOCATION
1015	CORNERGUARD, EXTEND FROM FINISHED FLOOR TO UNDERSIDE OF CEILING OR TOP OF BAFFLE, UON
1210	WHITEBOARD, RE: SCHEDULE FOR MORE INFORMATION

GENERAL NOTES

1. REFER TO THE DOOR SCHEDULE FOR DOOR AND DOOR FRAME FINISHES
2. REFER TO RCP'S FOR CEILING FINISHES
3. REFER TO ARCHITECTURAL SITE PLAN FOR SITE FINISHES
4. REFER TO INTERIOR ELEVATIONS FOR ADDITIONAL WALL AND BASE FINISH INFORMATION.
5. ALL FLOOR SUBSTRATES TO BE CONCRETE UON
6. EXTEND FLOOR FINISH UNDERNEATH MILLWORK WHERE EXPOSED, UON
7. FINISH FLOOR MATERIAL TRANSITIONS TO BE CENTERED UNDER DOOR IN THE CLOSED POSITION, UON
8. EXTEND FLOORING UNDERNEATH ALL FURNITURE & EQUIPMENT SHOWN UON
9. PROVIDE RECOMMENDED CONTROL JOINT SPACING IN ALL CONCRETE FLATWORK.
10. REFER TO INTERIOR ELEVATIONS AND DETAILS FOR MILLWORK FINISHES
11. ALL GYP BOARD WALLS TO HAVE RUBBER BASE UON WITH THE EXCEPTION OF TOILET/SHOWER ROOMS WHERE WALL AND FLOOR TILE OCCURS
12. ALL BASE TO BE RB-1 UON
13. ALL GWB PARTITIONS TO BE PNT-1 UON
14. ALL BASE AT AREAS OF PT-1 SHALL ALSO BE PT-1 EXCEPT AT BRICK
15. NO BASE AT BRICK, EXPOSED CONCRETE WALLS, FLUSH METAL PANEL WALLS, ACOUSTIC WALL PANELS, OR FLUSH WOOD PANEL WALLS, UON
16. WATER RESISTANT WALL BOARD BEHIND ALL WALLS WITH CERAMIC WALL TILE
17. ALL SOFFITS TO BE PNT-1 UON
18. ALL CASEWORK COUNTERTOPS TO BE PL-1 AND ALL CASEWORK FACES TO BE PL-2 UON. REFER TO INTERIOR ELEVATIONS FOR ADDITIONAL FINISH INFO.
19. RE: INTERIOR ELEVATIONS FOR LOCATIONS OF CUSTOM WOOD MILLWORK
20. RE: A-655 FOR FLOOR TRANSITION DETAILS
21. ALL WALLS OF STAIRWELLS 01 AND 03 TO BE PAINTED PNT-1 UON. NO BASE ON CONCRETE WALLS OF STAIRWELL.



SECOND LEVEL FINISH PLAN

1 A-132 1/8" = 1'-0"

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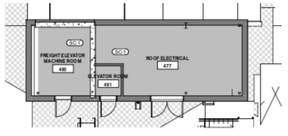
CoorsTek Center for Applied Science and Engineering
Colorado School of Mines
1523 Illinois St.
Golden, Colorado

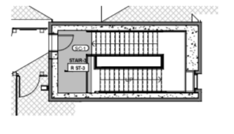
Project Number:	14-101.00
Drawn By:	AMD
Reviewed By:	DH
Approved By:	DP

LEVEL 2 FINISH PLAN

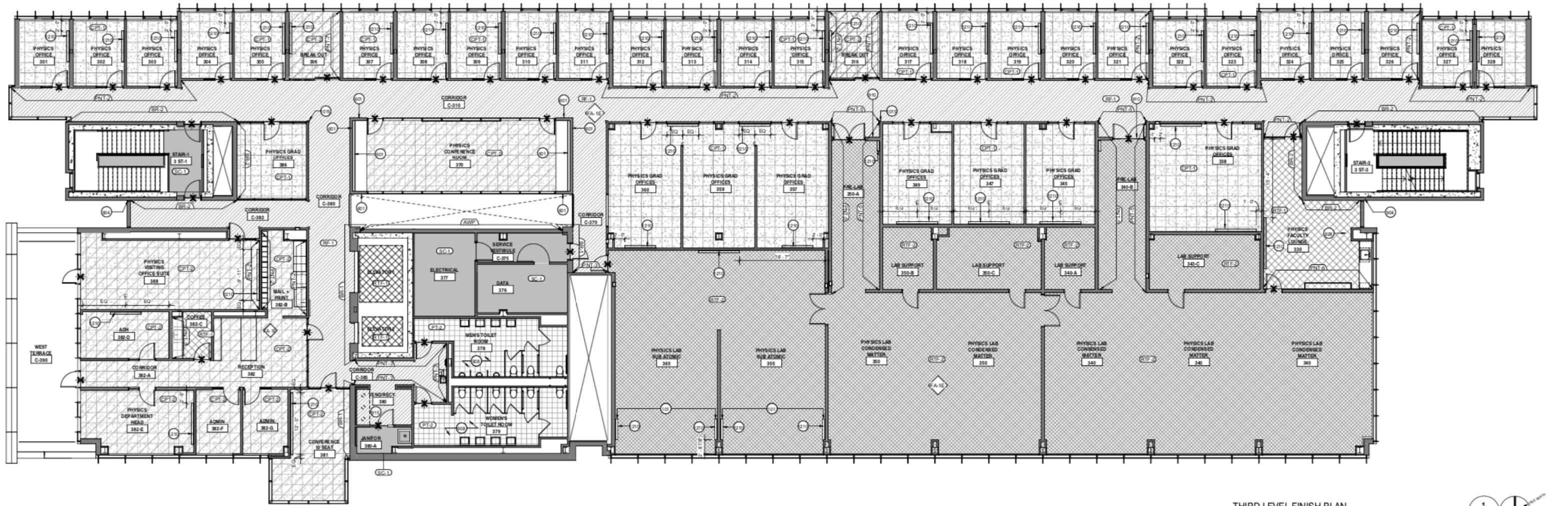
A-132



MECHANICAL ROOF FINISH PLAN - B
3 / A-133 — 1/8" = 1'-0"



MECHANICAL ROOF FINISH PLAN - A
2 / A-133 — 1/8" = 1'-0"



THIRD LEVEL FINISH PLAN
1 / A-133 — 1/8" = 1'-0"

WHITEBOARD (VDS-6) SCHEDULE - LEVEL 3

	Size: Height	Size: Width	Elevation AFF	Room: Name	Room: Number
2' x 5'					
1	5' - 0"	2' - 0"	3' - 0"	PRE-LAB	340-B
1	5' - 0"	2' - 0"	3' - 0"	PRE-LAB	350-A
2					
4' x 5'					
1	5' - 0"	4' - 0"	3' - 0"	PHYSICS LAB SUB ATOMIC	355
1	5' - 0"	4' - 0"	3' - 0"	PHYSICS LAB SUB ATOMIC	355
1	5' - 0"	4' - 0"	3' - 0"	PHYSICS LAB SUB ATOMIC	365
1	5' - 0"	4' - 0"	3' - 0"	PHYSICS LAB SUB ATOMIC	365
4					
6' x 5'					
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	301

WHITEBOARD (VDS-6) SCHEDULE - LEVEL 3

	Size: Height	Size: Width	Elevation AFF	Room: Name	Room: Number
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	302
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	303
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	304
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	305
1	5' - 0"	6' - 0"	3' - 0"	BREAK OUT	306
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	307
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	308
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	309
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	310
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	311
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	312
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	313
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	314
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	315

WHITEBOARD (VDS-6) SCHEDULE - LEVEL 3

	Size: Height	Size: Width	Elevation AFF	Room: Name	Room: Number
1	5' - 0"	6' - 0"	3' - 0"	BREAK OUT	316
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	317
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	318
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	319
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	320
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	321
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	322
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	323
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	324
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	325
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	326
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	327
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS OFFICE	328
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS GRAD OFFICES	357

WHITEBOARD (VDS-6) SCHEDULE - LEVEL 3

	Size: Height	Size: Width	Elevation AFF	Room: Name	Room: Number
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS GRAD OFFICES	359
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS GRAD OFFICES	359
1	5' - 0"	6' - 0"	3' - 0"	PHYSICS GRAD OFFICES	360
1	5' - 0"	6' - 0"	3' - 0"	ADH	382-D
33					
8' x 5'					
1	5' - 0"	8' - 0"	3' - 0"	PHYSICS GRAD OFFICES	338
1	5' - 0"	8' - 0"	3' - 0"	PHYSICS GRAD OFFICES	338
1	5' - 0"	8' - 0"	3' - 0"	PHYSICS GRAD OFFICES	345
1	5' - 0"	8' - 0"	3' - 0"	PHYSICS GRAD OFFICES	347
1	5' - 0"	8' - 0"	3' - 0"	PHYSICS GRAD OFFICES	349
1	5' - 0"	8' - 0"	3' - 0"	PHYSICS LAB SUB ATOMIC	355
1	5' - 0"	8' - 0"	3' - 0"	PHYSICS DEPARTMENT HEAD	382-E
7					

WHITEBOARD (VDS-6) SCHEDULE - LEVEL 3

	Size: Height	Size: Width	Elevation AFF	Room: Name	Room: Number
10' x 5'					
1	5' - 3"	9' - 11"	3' - 0"	PHYSICS FACULTY LOUNGE	330
1	5' - 3"	9' - 11"	3' - 0"	PHYSICS VISITING OFFICE SUITE	388
2					
12' x 5'					
1	5' - 3"	12' - 0"	3' - 0"	CONFERENCE 10 SEAT	381
1					

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CoorsTek Center for Applied Science and Engineering
Colorado School of Mines
1523 Illinois St.
Golden, Colorado

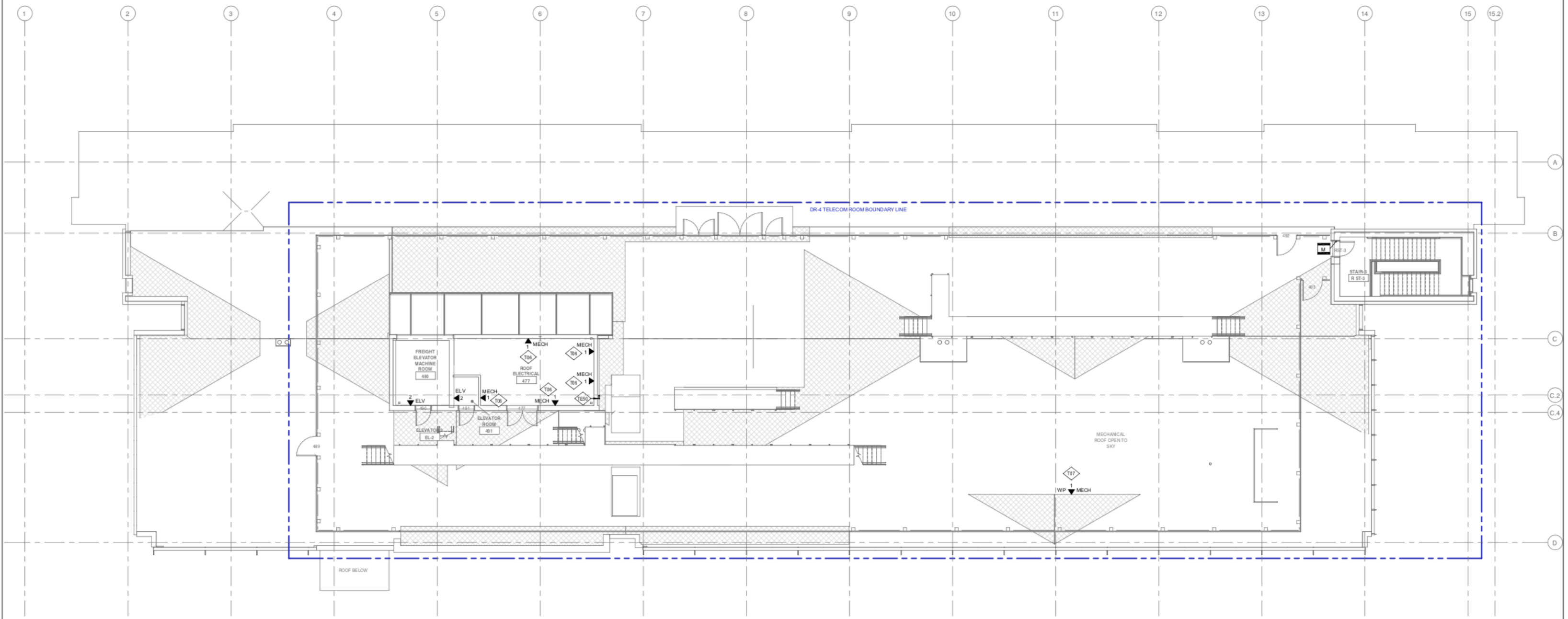
Project Number: 14-101.00
Drawn By: AMD
Reviewed By: DH
Approved By: DP

LEVEL 3 & ROOF FINISH PLANS

A-133

KEYNOTES	
T06	PROVIDE TELECOM OUTLET(S) FOR MECHANICAL CONTROLS/EQUIPMENT IN THIS ROOM. VERIFY FINAL LOCATIONS AND QUANTITY ON SITE WITH MECHANICAL CONTRACTOR AND OWNER PRIOR TO ROUGH-IN.
T07	PROVIDE A WEATHERPROOF TELECOM OUTLET FOR THE ENERGY RECOVERY PENTHOUSE MECHANICAL EQUIPMENT. VERIFY FINAL LOCATIONS AND QUANTITY ON SITE WITH MECHANICAL CONTRACTOR AND OWNER PRIOR TO ROUGH-IN.
TE50	CONDUITS TO ROOF. COORDINATE FINAL LOCATION WITH OWNER PRIOR TO ROUGH-IN, FIRESTOP THE PENETRATION, CAP AND SEAL THE CONDUIT WATERTIGHT AT THE ROOF.

GENERAL NOTES	
A	REFER TO THE GENERAL NOTES SECTION LOCATED ON THE BEGINNING SHEETS OF THE T-SERIES CONSTRUCTION DRAWINGS FOR ADDITIONAL INFORMATION RELATED TO THIS SHEET.
B	ALL CONTRACTORS SHALL CLOSELY REVIEW AND COORDINATE WITH THE LABORATORY SHEETS (LF, LP AND LE-SERIES) PRIOR TO BEGINNING ANY WORK IN RELATED SPACES.
C	FOR ALL LAB SPACES THE ELECTRICAL CONTRACTOR SHALL REFER TO THE LABORATORY ELECTRICAL SHEETS (LE-SERIES), IN PARTICULAR THE LABORATORY ELECTRICAL DETAIL SHEETS FOR ADDITIONAL ROUGH-IN DETAILS AND REQUIREMENTS RELATED TO THE INSTALLATION OF TELECOM OUTLETS.
D	THE TELECOM CONTRACTOR SHALL REFER TO THE AV CONSTRUCTION DOCUMENTS (TA-SERIES) FOR COORDINATION OF ALL TELECOM OUTLET/CABLING REQUIREMENTS INCLUDING, BUT NOT LIMITED TO TELECOM OUTLET(S), TELECOM CABLING AND CONNECTIONS, MOUNTING LOCATIONS AND INSTALLATION DETAILS.
E	AT EACH CEILING TELECOM OUTLET WITH A SUBSCRIPT "TP" THE ELECTRICAL CONTRACTOR SHALL PROVIDE A TELECOM OUTLET ABOVE THE ACCESSIBLE CEILING FOR THE TELECOM CONNECTION TO THE TOUCH PANEL SHOWN ON THE TA-SERIES CONSTRUCTION DOCUMENTS. PROVIDE A BLANK COVER AND VISIBLY LABEL THE COVER WITH: "NETWORK CONNECTION FOR TOUCH PANEL DEVICE". THE TELECOM CONTRACTOR SHALL TERMINATE THE CABLE IN A SURFACE MOUNT HOUSING (BISCUIT) WITHIN THE BACKBOX. THE TELECOM CONTRACTOR SHALL PROVIDE A PATCH CORD TO THE AV CONTRACTOR FOR THEM TO INSTALL FROM THE TELECOM OUTLET ABOVE THE ACCESSIBLE CEILING TO THE TOUCH PANEL.
F	WAP TELECOM OUTLET LOCATIONS ARE PROVIDED BY MINES CCIT DEPARTMENT. VERIFY ALL FINAL LOCATIONS WITH OWNER PRIOR TO INSTALLATION OF TELECOM OUTLET. THE TELECOM CONTRACTOR SHALL PROVIDE A 2-PORT BISCUIT (SURFACE MOUNT HOUSING - NO BACK BOX) ABOVE THE ACCESSIBLE CEILING WITH A MINIMUM OF A 10-FOOT COIL OF CABLING AT THE LOCATION SHOWN. THE CONTRACTOR SHALL INSTALL OWNER FURNISHED WAP EQUIPMENT.
G	ALL TECHNOLOGY CABLING FOR TELECOM OUTLETS AND TECHNOLOGY EQUIPMENT SHOWN ON A SPECIFIC FLOOR PLAN SHALL BE ROUTED TO AND TERMINATED IN THE ASSOCIATED DATA ROOM (DR) LOCATED ON THAT LEVEL/FLOOR. IF THE ROUTING REQUIRES THAT THE CABLE IS ROUTED ON THE LEVEL/FLOOR ABOVE OR BELOW THE REFERENCE LEVEL/FLOOR THEN THE CABLE SHALL BE ROUTED BACK TO THE REFERENCE LEVEL/FLOOR AT THE NEAREST OPPURTUNITY SUCH AS A WALL OR CHASE.
H	THE ELECTRICAL CONTRACTOR SHALL REFER TO THE AV/IT/ELECTRICAL FLOOR BOX DETAILS IN THE ELECTRICAL CONSTRUCTION DRAWINGS FOR "IT CONDUIT" QUANTITY AND SIZE REQUIREMENTS. THE ELECTRICAL CONTRACTOR SHALL REFER TO THE GENERAL COMMON WORK / ELECTRICAL NOTES ON SHEET T-001 "IT CONDUIT" INSTALLATION REQUIREMENTS.



1 T-104 MECHANICAL ROOF LEVEL TECHNOLOGY PLAN

1/8" = 1'-0"

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Project Number:	14-101.00
Drawn By:	RIMROCK
Reviewed By:	RIMROCK
Approved By:	RIMROCK

MECHANICAL ROOF LEVEL TECHNOLOGY PLAN

T-104

APPENDIX B: NEC SECTIONS DESCRIBING LOAD FACTORS [1]

Continuous Load. A load where the maximum current is expected to continue for 3 hours or more. Where a branch circuit supplies continuous loads or any combination of continuous and noncontinuous loads, the minimum branch-circuit conductor size shall have an allowable ampacity not less than the noncontinuous load plus 125 percent of the continuous load.

Receptacle Outlets. Except as covered in 220.14(J) and (K), receptacle outlets shall be calculated at not less than 180 volt-amperes for each single or for each multiple receptacle on one yoke. A single piece of equipment consisting of a multiple receptacle comprised of four or more receptacles shall be calculated at not less than 90 volt-amperes per receptacle. This provision shall not be applicable to the receptacle outlets specified in 210.11(C)(1) and (C)(2).

Several Motors or a Motor(s) and Other Load(s). Conductors supplying several motors, or a motor(s) and other load(s), shall have an ampacity not less than the sum of each of the following:

(1) 125 percent of the full-load current rating of the highest rated motor, as determined by 430.6(A)

(3) 100 percent of the noncontinuous non-motor load

(2) Sum of the full-load current ratings of all the other motors in the group, as determined by 430.6(A)

(4) 125 percent of the continuous non-motor load.

Exception No. 1: Where one or more of the motors of the group are used for short-time, intermittent, periodic, or varying duty, the ampere rating of such motors to be used in the summation shall be determined in accordance with 430.22(E). For the highest rated motor, the greater of either the ampere rating from 430.22(E) or the largest continuous duty motor full-load current multiplied by 1.25 shall be used in the summation.

Kitchen Equipment — Other Than Dwelling Unit(s). It shall be permissible to calculate the load for commercial electric cooking equipment, dishwasher booster heaters, water heaters, and other kitchen equipment in accordance with Table 220.56. These demand factors shall be applied to all equipment that has either thermostatic control or intermittent use as kitchen equipment. These demand factors shall not apply to space-heating, ventilating, or air-conditioning equipment.

However, in no case shall the feeder or service calculated load be less than the sum of the largest two kitchen equipment loads.

[1] All paragraphs have been extracted from different sections of the NFPA® 70 (NEC, National Electrical Code) 2014 Edition.

Table 220.56 Demand Factors for Kitchen Equipment — Other Than Dwelling Unit(s)

Number of Units of Equipment	Demand Factor (%)
1	100
2	100
3	90
4	80
5	70
6 and over	65

Noncoincident Loads. Where it is unlikely that two or more noncoincident loads will be in use simultaneously, it shall be permissible to use only the largest load(s) that will be used at one time for calculating the total load of a feeder or service.

APPENDIX C: COORSTEK ELECTRICITY CONSUMPTION

Month	Previous 12 Months	Current 12 Months
Apr		90,000.00
May		87,889.80
Jun		122,263.80
Jul		72,265.80
Aug		125,284.20
Sep		150,000.00
Oct		52,968.00
Nov		176,472.00
Dec	51,323.40	124,662.00
Jan	80,000.00	111,312.00
Feb	120,000.00	112,464.00
Mar	97,201.20	

APPENDIX D: COORSTEK INSTANTANEOUS POWER

Timestamp		11/13/18 19:45	169.8	11/14/18 1:00	138	11/14/18 6:15	156.6
	Instantaneous_kW	11/13/18 20:00	153.6	11/14/18 1:15	139.2	11/14/18 6:30	157.2
(kW)		11/13/18 20:15	154.8	11/14/18 1:30	139.2	11/14/18 6:45	160.2
11/13/18 15:15	166.8	11/13/18 20:30	160.2	11/14/18 1:45	137.4	11/14/18 7:00	168.6
11/13/18 15:30	163.2	11/13/18 20:45	158.4	11/14/18 2:00	138.6	11/14/18 7:15	162
11/13/18 15:45	181.2	11/13/18 21:00	166.2	11/14/18 2:15	137.4	11/14/18 7:30	151.2
11/13/18 16:00	164.4	11/13/18 21:15	156	11/14/18 2:30	155.4	11/14/18 7:45	153.6
11/13/18 16:15	164.4	11/13/18 21:30	157.8	11/14/18 2:45	139.8	11/14/18 8:00	154.2
11/13/18 16:30	162.6	11/13/18 21:45	169.2	11/14/18 3:00	145.8	11/14/18 8:15	154.2
11/13/18 16:45	159	11/13/18 22:00	158.4	11/14/18 3:15	136.2	11/14/18 8:30	148.2
11/13/18 17:00	163.2	11/13/18 22:15	188.4	11/14/18 3:30	139.2	11/14/18 8:45	150
11/13/18 17:15	167.4	11/13/18 22:30	156	11/14/18 3:45	142.8	11/14/18 9:00	159.6
11/13/18 17:30	174	11/13/18 22:45	163.8	11/14/18 4:00	141	11/14/18 9:15	152.4
11/13/18 17:45	160.2	11/13/18 23:00	154.2	11/14/18 4:15	140.4	11/14/18 9:30	154.8
11/13/18 18:00	175.8	11/13/18 23:15	144	11/14/18 4:30	139.2	11/14/18 9:45	160.2
11/13/18 18:15	173.4	11/13/18 23:30	162.6	11/14/18 4:45	154.2	11/14/18 10:00	159
11/13/18 18:30	165.6	11/13/18 23:45	152.4	11/14/18 5:00	141.6	11/14/18 10:15	159.6
11/13/18 18:45	157.8	11/14/18 0:00	152.4	11/14/18 5:15	139.8	11/14/18 10:30	160.2
11/13/18 19:00	160.2	11/14/18 0:15	145.8	11/14/18 5:30	159	11/14/18 10:45	167.4
11/13/18 19:15	159	11/14/18 0:30	145.8	11/14/18 5:45	155.4	11/14/18 11:00	156.6
11/13/18 19:30	156.6	11/14/18 0:45	154.2	11/14/18 6:00	174	11/14/18 11:15	162

11/14/18 11:30	166.8	11/15/18 10:15	167.4	11/16/18 9:00	161.4	11/19/18 7:45	174
11/14/18 11:45	156.6	11/15/18 10:30	180	11/16/18 9:15	165.6	11/19/18 8:00	166.2
11/14/18 12:00	159	11/15/18 10:45	166.2	11/16/18 9:30	182.4	11/19/18 8:15	168.6
11/14/18 12:15	162.6	11/15/18 11:00	170.4	11/16/18 9:45	167.4	11/19/18 8:30	163.8
11/14/18 12:30	157.2	11/15/18 11:15	186	11/16/18 10:00	178.8	11/19/18 8:45	166.2
11/14/18 12:45	160.2	11/15/18 11:30	174	11/16/18 10:15	173.4	11/19/18 9:00	177
11/14/18 13:00	160.8	11/15/18 11:45	175.2	11/16/18 10:30	169.2	11/19/18 9:15	171
11/14/18 13:15	156	11/15/18 12:00	172.8	11/16/18 10:45	186.6	11/19/18 9:30	175.2
11/14/18 13:30	157.8	11/15/18 12:15	165	11/16/18 11:00	174	11/19/18 9:45	171
11/14/18 13:45	157.8	11/15/18 12:30	167.4	11/16/18 11:15	181.2	11/19/18 10:00	167.4
11/14/18 14:00	176.4	11/15/18 12:45	170.4	11/16/18 11:30	177.6	11/19/18 10:15	166.2
11/14/18 14:15	173.4	11/15/18 13:00	168.6	11/16/18 11:45	178.8	11/19/18 10:30	168.6
11/14/18 14:30	177.6	11/15/18 13:15	179.4	11/16/18 12:00	177.6	11/19/18 10:45	178.8
11/14/18 14:45	159.6	11/15/18 13:30	184.8	11/16/18 12:15	178.8	11/19/18 11:00	166.2
11/14/18 15:00	163.8	11/15/18 13:45	167.4	11/16/18 12:30	193.2	11/19/18 11:15	163.8
11/14/18 15:15	160.8	11/15/18 14:00	169.2	11/16/18 12:45	183	11/19/18 11:30	169.2
11/14/18 15:30	160.8	11/15/18 14:15	176.4	11/16/18 13:00	175.2	11/19/18 11:45	163.2
11/14/18 15:45	171	11/15/18 14:30	168.6	11/16/18 13:15	172.8	11/19/18 12:00	183
11/14/18 16:00	165	11/15/18 14:45	164.4	11/16/18 13:30	174	11/19/18 12:15	171.6
11/14/18 16:15	161.4	11/15/18 15:00	186	11/16/18 13:45	174.6	11/19/18 12:30	164.4
11/14/18 16:30	162.6	11/15/18 15:15	175.2	11/16/18 14:00	174.6	11/19/18 12:45	171.6
11/14/18 16:45	163.8	11/15/18 15:30	171	11/16/18 14:15	175.8	11/19/18 13:00	170.4
11/14/18 17:00	168	11/15/18 15:45	169.8	11/16/18 14:30	191.4	11/19/18 13:15	166.8
11/14/18 17:15	159.6	11/15/18 16:00	168	11/16/18 14:45	183.6	11/19/18 13:30	164.4
11/14/18 17:30	156.6	11/15/18 16:15	194.4	11/16/18 15:00	174	11/19/18 13:45	175.8
11/14/18 17:45	160.8	11/15/18 16:30	178.8	11/16/18 15:15	175.8	11/19/18 14:00	183
11/14/18 18:00	162	11/15/18 16:45	171.6	11/16/18 15:30	186	11/19/18 14:15	175.2
11/14/18 18:15	169.8	11/15/18 17:00	189.6	11/16/18 15:45	171.6	11/19/18 14:30	187.2
11/14/18 18:30	147.6	11/15/18 17:15	175.8	11/16/18 16:00	178.8	11/19/18 14:45	173.4
11/14/18 18:45	156	11/15/18 17:30	167.4	11/16/18 16:15	170.4	11/19/18 15:00	170.4
11/14/18 19:00	156.6	11/15/18 17:45	172.2	11/16/18 16:30	164.4	11/19/18 15:15	189
11/14/18 19:15	159	11/15/18 18:00	174	11/16/18 16:45	162.6	11/19/18 15:30	183
11/14/18 19:30	174	11/15/18 18:15	180	11/16/18 17:00	162	11/19/18 15:45	175.8
11/14/18 19:45	157.2	11/15/18 18:30	171	11/16/18 17:15	175.2	11/19/18 16:00	174
11/14/18 20:00	166.8	11/15/18 18:45	172.8	11/16/18 17:30	162	11/19/18 16:15	175.2
11/14/18 20:15	156	11/15/18 19:00	164.4	11/16/18 17:45	164.4	11/19/18 16:30	183.6
11/14/18 20:30	162	11/15/18 19:15	161.4	11/16/18 18:00	163.2	11/19/18 16:45	168.6
11/14/18 20:45	156.6	11/15/18 19:30	178.2	11/16/18 18:15	168	11/19/18 17:00	171
11/14/18 21:00	158.4	11/15/18 19:45	163.2	11/16/18 18:30	170.4	11/19/18 17:15	169.2
11/14/18 21:15	166.2	11/15/18 20:00	162	11/16/18 18:45	157.8	11/19/18 17:30	169.2
11/14/18 21:30	159	11/15/18 20:15	165	11/16/18 19:00	158.4	11/19/18 17:45	175.2
11/14/18 21:45	169.2	11/15/18 20:30	162	11/16/18 19:15	159.6	11/19/18 18:00	165
11/14/18 22:00	159.6	11/15/18 20:45	174.6	11/16/18 19:30	160.8	11/19/18 18:15	166.8
11/14/18 22:15	167.4	11/15/18 21:00	162.6	11/16/18 19:45	169.8	11/19/18 18:30	167.4
11/14/18 22:30	164.4	11/15/18 21:15	178.8	11/16/18 20:00	156.6	11/19/18 18:45	164.4
11/14/18 22:45	155.4	11/15/18 21:30	160.2	11/16/18 20:15	158.4	11/19/18 19:00	166.8
11/14/18 23:00	156.6	11/15/18 21:45	163.8	11/16/18 20:30	160.2	11/19/18 19:15	160.8
11/14/18 23:15	162	11/15/18 22:00	162.6	11/16/18 20:45	162	11/19/18 19:30	162.6
11/14/18 23:30	174	11/15/18 22:15	160.8	11/16/18 21:00	159.6	11/19/18 19:45	158.4
11/14/18 23:45	166.8	11/15/18 22:30	163.2	11/16/18 21:15	160.2	11/19/18 20:00	159.6
11/15/18 0:00	163.8	11/15/18 22:45	162.6	11/16/18 21:30	180	11/19/18 20:15	164.4
11/15/18 0:15	155.4	11/15/18 23:00	160.2	11/16/18 21:45	159	11/19/18 20:30	164.4
11/15/18 0:30	160.8	11/15/18 23:15	150	11/16/18 22:00	171.6	11/19/18 20:45	163.8
11/15/18 0:45	163.8	11/15/18 23:30	148.2	11/16/18 22:15	159	11/19/18 21:00	161.4
11/15/18 1:00	159	11/15/18 23:45	160.2	11/16/18 22:30	155.4	11/19/18 21:15	161.4
11/15/18 1:15	164.4	11/16/18 0:00	149.4	11/16/18 22:45	156	11/19/18 21:30	175.2
11/15/18 1:30	150	11/16/18 0:15	150.6	11/16/18 23:00	147	11/19/18 21:45	160.8
11/15/18 1:45	155.4	11/16/18 0:30	148.2	11/16/18 23:15	157.2	11/19/18 22:00	174
11/15/18 2:00	153	11/16/18 0:45	149.4	11/16/18 23:30	146.4	11/19/18 22:15	167.4
11/15/18 2:15	149.4	11/16/18 1:00	161.4	11/16/18 23:45	145.8	11/19/18 22:30	160.8
11/15/18 2:30	142.2	11/16/18 1:15	145.8	11/19/18 0:00	145.8	11/19/18 22:45	163.2
11/15/18 2:45	148.2	11/16/18 1:30	147	11/19/18 0:15	148.2	11/19/18 23:00	151.2
11/15/18 3:00	154.8	11/16/18 1:45	143.4	11/19/18 0:30	150	11/19/18 23:15	157.8
11/15/18 3:15	148.2	11/16/18 2:00	142.8	11/19/18 0:45	157.2	11/19/18 23:30	145.8
11/15/18 3:30	149.4	11/16/18 2:15	143.4	11/19/18 1:00	144.6	11/19/18 23:45	147
11/15/18 3:45	172.2	11/16/18 2:30	141.6	11/19/18 1:15	144	11/20/18 0:00	167.4
11/15/18 4:00	159.6	11/16/18 2:45	157.8	11/19/18 1:30	152.4	11/20/18 0:15	146.4
11/15/18 4:15	157.2	11/16/18 3:00	141	11/19/18 1:45	144.6	11/20/18 0:30	160.2
11/15/18 4:30	147.6	11/16/18 3:15	147.6	11/19/18 2:00	143.4	11/20/18 0:45	148.8
11/15/18 4:45	154.2	11/16/18 3:30	141	11/19/18 2:15	142.2	11/20/18 1:00	146.4
11/15/18 5:00	145.8	11/16/18 3:45	141	11/19/18 2:30	141.6	11/20/18 1:15	142.8
11/15/18 5:15	140.4	11/16/18 4:00	148.8	11/19/18 2:45	150	11/20/18 1:30	144
11/15/18 5:30	176.4	11/16/18 4:15	145.8	11/19/18 3:00	142.2	11/20/18 1:45	151.8
11/15/18 5:45	157.8	11/16/18 4:30	142.2	11/19/18 3:15	142.8	11/20/18 2:00	144
11/15/18 6:00	168.6	11/16/18 4:45	143.4	11/19/18 3:30	139.8	11/20/18 2:15	144.6
11/15/18 6:15	154.8	11/16/18 5:00	152.4	11/19/18 3:45	139.8	11/20/18 2:30	141
11/15/18 6:30	156.6	11/16/18 5:15	140.4	11/19/18 4:00	150.6	11/20/18 2:45	139.2
11/15/18 6:45	159.6	11/16/18 5:30	161.4	11/19/18 4:15	141.6	11/20/18 3:00	156
11/15/18 7:00	157.8	11/16/18 5:45	170.4	11/19/18 4:30	142.2	11/20/18 3:15	141
11/15/18 7:15	157.2	11/16/18 6:00	165	11/19/18 4:45	152.4	11/20/18 3:30	144.6
11/15/18 7:30	154.2	11/16/18 6:15	163.8	11/19/18 5:00	145.2	11/20/18 3:45	140.4
11/15/18 7:45	162.6	11/16/18 6:30	163.8	11/19/18 5:15	154.2	11/20/18 4:00	141.6
11/15/18 8:00	157.8	11/16/18 6:45	188.4	11/19/18 5:30	180.6	11/20/18 4:15	140.4
11/15/18 8:15	151.2	11/16/18 7:00	174	11/19/18 5:45	170.4	11/20/18 4:30	141.6
11/15/18 8:30	157.2	11/16/18 7:15	163.8	11/19/18 6:00	170.4	11/20/18 4:45	152.4
11/15/18 8:45	156.6	11/16/18 7:30	163.8	11/19/18 6:15	168	11/20/18 5:00	145.8
11/15/18 9:00	156.6	11/16/18 7:45	165.6	11/19/18 6:30	175.2	11/20/18 5:15	144
11/15/18 9:15	157.8	11/16/18 8:00	168	11/19/18 6:45	166.8	11/20/18 5:30	180.6
11/15/18 9:30	171	11/16/18 8:15	180.6	11/19/18 7:00	166.8	11/20/18 5:45	165
11/15/18 9:45	160.2	11/16/18 8:30	165	11/19/18 7:15	159.6	11/20/18 6:00	170.4
11/15/18 10:00	175.2	11/16/18 8:45	176.4	11/19/18 7:30	160.8	11/20/18 6:15	168

11/20/18 6:30	168.6	11/20/18 15:00	186.6	11/20/18 23:30	147	11/21/18 8:00	165
11/20/18 6:45	170.4	11/20/18 15:15	171	11/20/18 23:45	160.8	11/21/18 8:15	162
11/20/18 7:00	166.8	11/20/18 15:30	175.2	11/21/18 0:00	143.4	11/21/18 8:30	164.4
11/20/18 7:15	170.4	11/20/18 15:45	174.6	11/21/18 0:15	155.4	11/21/18 8:45	162.6
11/20/18 7:30	163.2	11/20/18 16:00	171	11/21/18 0:30	150	11/21/18 9:00	175.8
11/20/18 7:45	163.8	11/20/18 16:15	163.2	11/21/18 0:45	148.2	11/21/18 9:15	183.6
11/20/18 8:00	190.8	11/20/18 16:30	162.6	11/21/18 1:00	145.2	11/21/18 9:30	170.4
11/20/18 8:15	160.8	11/20/18 16:45	180.6	11/21/18 1:15	147.6	11/21/18 9:45	165.6
11/20/18 8:30	166.2	11/20/18 17:00	160.2	11/21/18 1:30	154.2	11/21/18 10:00	171.6
11/20/18 8:45	166.8	11/20/18 17:15	169.8	11/21/18 1:45	159.6	11/21/18 10:15	165
11/20/18 9:00	160.2	11/20/18 17:30	166.8	11/21/18 2:00	144.6	11/21/18 10:30	163.2
11/20/18 9:15	175.2	11/20/18 17:45	157.8	11/21/18 2:15	142.8	11/21/18 10:45	164.4
11/20/18 9:30	166.2	11/20/18 18:00	166.2	11/21/18 2:30	144	11/21/18 11:00	174
11/20/18 9:45	170.4	11/20/18 18:15	168	11/21/18 2:45	157.2	11/21/18 11:15	162
11/20/18 10:00	174.6	11/20/18 18:30	164.4	11/21/18 3:00	148.2	11/21/18 11:30	157.8
11/20/18 10:15	175.2	11/20/18 18:45	172.8	11/21/18 3:15	150.6	11/21/18 11:45	171.6
11/20/18 10:30	184.2	11/20/18 19:00	158.4	11/21/18 3:30	174.6	11/21/18 12:00	162.6
11/20/18 10:45	172.2	11/20/18 19:15	162.6	11/21/18 3:45	163.8	11/21/18 12:15	160.8
11/20/18 11:00	175.2	11/20/18 19:30	157.8	11/21/18 4:00	160.2	11/21/18 12:30	174.6
11/20/18 11:15	169.8	11/20/18 19:45	159.6	11/21/18 4:15	165	11/21/18 12:45	162
11/20/18 11:30	174.6	11/20/18 20:00	157.2	11/21/18 4:30	166.8	11/21/18 13:00	180
11/20/18 11:45	193.8	11/20/18 20:15	156.6	11/21/18 4:45	162	11/21/18 13:15	160.2
11/20/18 12:00	174.6	11/20/18 20:30	171.6	11/21/18 5:00	146.4	11/21/18 13:30	174.6
11/20/18 12:15	177.6	11/20/18 20:45	163.2	11/21/18 5:15	144	11/21/18 13:45	167.4
11/20/18 12:30	165.6	11/20/18 21:00	163.2	11/21/18 5:30	169.2	11/21/18 14:00	159.6
11/20/18 12:45	164.4	11/20/18 21:15	154.2	11/21/18 5:45	169.2	11/21/18 14:15	159.6
11/20/18 13:00	165.6	11/20/18 21:30	158.4	11/21/18 6:00	178.8	11/21/18 14:30	157.2
11/20/18 13:15	165.6	11/20/18 21:45	173.4	11/21/18 6:15	169.8	11/21/18 14:45	151.2
11/20/18 13:30	168.6	11/20/18 22:00	158.4	11/21/18 6:30	171.6	11/21/18 15:00	165.6
11/20/18 13:45	184.2	11/20/18 22:15	159.6	11/21/18 6:45	163.2	11/21/18 15:15	156
11/20/18 14:00	168.6	11/20/18 22:30	162	11/21/18 7:00	165	11/21/18 15:30	154.8
11/20/18 14:15	176.4	11/20/18 22:45	161.4	11/21/18 7:15	190.8	11/21/18 15:45	152.4
11/20/18 14:30	168	11/20/18 23:00	154.8	11/21/18 7:30	172.8	11/21/18 16:00	156.6
11/20/18 14:45	163.8	11/20/18 23:15	147.6	11/21/18 7:45	178.2		

APPENDIX E: EXCEL CALCULATIONS SHOWING GENERATION OF PV SYSTEM

Year	Month	Energy (kWh)	Peak kW	Demand Charge	Energy Charge	Total Savings
2018	1	1249.68	6.147057658	100.8732162	59.734704	160.6079202
2018	2	1506.74	7.741101643	127.031478	72.022172	199.05365
2018	3	1912.6	8.315431935	136.4562381	91.42228	227.8785181
2018	4	1866.2	7.9079326	129.769174	89.20436	218.973534
2018	5	2117.71	8.12993929	133.4123038	101.226538	234.6388418
2018	6	1770.17	6.90957398	145.1010536	71.8512003	216.9522539
2018	7	1972.05	7.650836361	160.6675636	80.0455095	240.7130731
2018	8	1808.8	7.352722181	154.4071658	73.419192	227.8263578
2018	9	1458.08	6.154978907	129.254557	59.1834672	188.4380242
2018	10	1117.1	4.942262303	81.1025244	53.39738	134.4999044
2018	11	936.923	4.357332447	71.50382545	44.7849194	116.2887448
2018	12	975.854	4.750407387	77.95418522	46.6458212	124.6000064
2019	1	1243.4316	6.11632237	100.3688501	59.43603048	159.8048806
2019	2	1499.2063	7.702396135	126.3963206	71.66206114	198.0583817
2019	3	1903.037	8.273854776	135.7739569	90.9651686	226.7391255
2019	4	1856.869	7.868392937	129.1203281	88.7583382	217.8786663
2019	5	2107.12145	8.089289594	132.7452422	100.7204053	233.4656475
2019	6	1761.31915	6.87502611	144.3755483	71.4919443	215.8674926
2019	7	1962.18975	7.612582179	159.8642258	79.64528195	239.5095077
2019	8	1799.756	7.31595857	153.63513	73.05209604	226.687226
2019	9	1450.7896	6.124204012	128.6082843	58.88754986	187.4958341
2019	10	1111.5145	4.917550992	80.69701177	53.1303931	133.8274049
2019	11	932.238385	4.335545784	71.14630632	44.5609948	115.7073011
2019	12	970.97473	4.72665535	77.5644143	46.41259209	123.9770064
2020	1	1237.214442	6.085740758	99.86700584	59.13885033	159.0058562
2020	2	1491.710269	7.663884154	125.764339	71.30375083	197.0680898
2020	3	1893.521815	8.232485502	135.0950871	90.51034276	225.6054298
2020	4	1847.584655	7.829050972	128.4747265	88.31454651	216.789273
2020	5	2096.585843	8.048843146	132.081516	100.2168033	232.2983193
2020	6	1752.512554	6.84065098	143.6536706	71.13448458	214.7881551
2020	7	1952.378801	7.574519269	159.0649046	79.24705554	238.3119602
2020	8	1790.75722	7.279378777	152.8669543	72.68683556	225.5537899
2020	9	1443.535652	6.093582992	127.9652428	58.59311211	186.5583549
2020	10	1105.956928	4.892963237	80.29352672	52.86474113	133.1582678
2020	11	927.5771931	4.313868056	70.79057479	44.33818983	115.1287646
2020	12	966.1198564	4.703022073	77.17659222	46.18052913	123.3571214
2021	1	1231.02837	6.055312054	99.36767081	58.84315608	158.2108269
2021	2	1484.251717	7.625564733	125.1355173	70.94723208	196.0827494
2021	3	1884.054206	8.191323074	134.4196117	90.05779104	224.4774027
2021	4	1838.346732	7.789905717	127.8323528	87.87297378	215.7053266
2021	5	2086.102914	8.00859893	131.4211084	99.71571927	231.1368277
2021	6	1743.749991	6.806447725	142.9354022	70.77881215	213.7142144
2021	7	1942.616907	7.536646672	158.2695801	78.85082027	237.1204004
2021	8	1781.803434	7.242981883	152.1026195	72.32340138	224.4260209
2021	9	1436.317974	6.063115077	127.3254166	58.30014655	185.6255632
2021	10	1100.427143	4.868498421	79.89205908	52.60041743	132.4924765
2021	11	922.9393071	4.292298715	70.43662192	44.11649888	114.5531208
2021	12	961.2892571	4.679506963	76.79070926	45.94962649	122.7403358
2022	1	1224.873228	6.025035494	98.87083245	58.5489403	157.4197727
2022	2	1476.830459	7.58743691	124.5098397	70.59249592	195.1023356
2022	3	1874.633935	8.150366459	133.7475136	89.60750209	223.3550157
2022	4	1829.154998	7.750956189	127.1931911	87.43360891	214.6268
2022	5	2075.672399	7.968555936	130.7640029	99.21714067	229.9811436
2022	6	1735.031242	6.772415486	142.2207252	70.42491809	212.6456433
2022	7	1932.903823	7.498963439	157.4782322	78.45656616	235.9347984
2022	8	1772.894417	7.206766974	151.3421064	71.96178438	223.3038908
2022	9	1429.136384	6.032799502	126.6887895	58.00864582	184.6974354
2022	10	1094.925007	4.844155928	79.49259879	52.33741534	131.8300141
2022	11	918.3246106	4.270837222	70.08443881	43.89591639	113.9803552
2022	12	956.4828108	4.656109428	76.40675572	45.71987836	122.1266341
2023	1	1218.748862	5.994910316	98.37647829	58.25619559	156.6326739

2023	2	1469.446306	7.549499725	123.8872905	70.23953344	194.1268239
2023	3	1865.260765	8.109614627	133.078776	89.15946458	222.2382406
2023	4	1820.009223	7.712201408	126.5572251	86.99644086	213.553666
2023	5	2065.294037	7.928713156	130.1101829	98.72105497	228.8312379
2023	6	1726.356085	6.738553409	141.5096216	70.0727935	211.5824151
2023	7	1923.239304	7.461468622	156.6908411	78.06428333	234.7551244
2023	8	1764.029945	7.170733139	150.5853959	71.60197545	222.1873714
2023	9	1421.990702	6.002635504	126.0553456	57.71860259	183.7739482