GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

FEASIBILITY OF THE INSTALLATION OF SOLAR PANELS IN THE RESIDENTIAL HOUSING OF THE UNIVERSITY OF MINNESOTA

Autor: Severiano Solana Martínez

Directora: Carley Rice

Madrid

Mayo de 2022

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título Feasibility of the installation of solar panels in the residential housing of the University of Minnesota

en la ETS de Ingeniería - ICAI de la Universidad Pontificia Comillas en el curso académico 2021/2022 es de mi autoría, original e inédito y no ha sido presentado con anterioridad a otros efectos. El Proyecto no es plagio de otro, ni total ni parcialmente y la información que ha sido tomada de otros documentos está debidamente referenciada.

Fdo.: Severiano Solana Martínez Fecha: 22 / 05 / 2022

Autorizada la entrega del proyecto

EL DIRECTOR DEL PROYECTO

Fdo.: Carley Rice Fecha: 22/ 05 / 2022

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Autor: Solana Martínez, Severiano.

Director: Rice, Carley.

Entidad Colaboradora: Sustainability Department of the University of Minnesota.

RESUMEN DEL PROYECTO

La Universidad de Minnesota está desarrollando un plan de sostenibilidad que pretende acabar con las emisiones de CO_2 para el 2050. Un aspecto que no se ha desarrollado tan en profundidad todavía es la instalación de placas solares en los edificios de la universidad. Por ello en este trabajo se estudia este tema, con el principio de saber si sería rentable la instalación de placas solares en términos de gasto eléctrico y contaminación. La Universidad de Minnesota cuenta con una gran cantidad de edificios, por lo que en este trabajo se analizarán 7 residencias de estudiantes que pertenecen al campus con el objetivo también de dar una idea de cuánto podría ahorrar en gastos de electricidad para los estudiantes.

Palabras clave: Universidad de Minnesota, emisiones de CO_2, placas solares, gasto eléctrico

1. Introducción

El gasto económico en los recientes años ha subido considerablemente en Minnesota. Esto junto con los recientes planes de sostenibilidad de la universidad, provocan que la idea de instalar paneles solares en los edificios del campus sea una idea muy positiva. Se analizarán 7 edificios en los que habrá que estudiar la cantidad de tejado disponible (esto incluirá tener en cuenta si hay tuberías, ventanas u otros inconvenientes), la altura y los planes a futuro del edificio. El año pasado estos edificios sumaron un uso total de 11.542.679 kWh. Se deberá estudiar también los distintos tipos de paneles solares que hay en el mercado o que son ofrecidos en Minnesota en cuanto a tamaño y calidad. Para el cálculo de cantidades en la mayoría de los casos se utilizarán valores promedio ya que depende de la Universidad de

Minnesota el tipo de panel a usar finalmente. En cuanto al gasto económico, gracias al Departamento de Sostenibilidad de la universidad, se sabe que el gasto total el año pasado en los 7 edificios fue de 1.336.333,07 $, en este trabajo se proporcionará el ahorro que puede suponer la instalación de paneles. También la reducción de contaminación, ya que en términos de CO_2 las emisiones el año pasado fueron de 9.811.277,15 libras de CO_2. También se analizará si es posible extender este estudio a más edificios de la universidad.

2. Instalación: cifras y costes

En este primer punto, lo primordial será saber la cantidad de espacio disponible de estos edificios, para ello siguiendo los planos proporcionados por la universidad [1], se puede obtener un espacio aproximado de:

EDIFICIO	ZONAS DE TEJADO	APROXIMADO ESPACIO EN m^2
Sanford	E, F*[1], G*, K & L	1405,065
Pioneer	D*,B&D	879,79
Comstock	A, C,D,I,J,K,L,M,P&R	556,675
Centennial	C,D,E,F,G,H*,I,J,K,L,M*, N,O*,R&S	1316,81
Frontier	J & K	640,66
Yudof	C,D,E,F,H&K	411,37
Territorial	A,C,E,H,I,J,L	159,79

Tabla con la indicación de las zonas del tejado disponibles y el espacio total

[1] * No el 100% del espacio en esa zona se podrá usar para paneles debido a que hay irregularidades como tuberías o ventanas, pero sí que se podrá usar alrededor del 50%.

En este espacio disponible se ha tenido ya en cuenta los posibles obstáculos del tejado y una distancia de seguridad desde el lateral del edificio de unos 4,5 metros para los trabajadores que deban subir. En cuanto al cableado eléctrico todos los edificios lo poseen en su interior por lo que no supone un inconveniente. Para el cálculo de la cantidad de paneles se han seleccionado varias cifras estándar, esto es, las placas de unos 1,64 x 1 metros y 350W de potencia, esto proporcionará el número de placas necesario posible de instalación y con ellos cuántos kWh se pueden obtener mediante placas:

EDIFICIO	**Número de paneles 350W**	**kWh de los paneles en un año**
Sanford	432*[2]	1.298.896
Pioneer	539	1.652.574
Comstock	341	1.045.506
Centennial	498*	1.496.564
Frontier	392	1.201.872
Yudof	252	772.632
Territorial	98	300.468

Tabla con la indicación número de paneles a usar y la generación anual

Los dos edificios marcados en verde tienen la capacidad de generar la potencia suficiente que necesitan en un año con placas solares. Como es obvio, durante los meses de invierno no recibirán la cantidad de luz necesaria (la nieve en Minnesota es un factor importante que provoca reflejo de la luz y se genera más de lo que se puede pensar en primera instancia), pero en verano tendrán superávit. La Universidad de Minnesota cuenta con su propio sistema eléctrico en el que están conectados todos los edificios de la universidad y que entonces los excedentes de Sanford y Centennial podrían destinarse a alimentar otros edificios, provocando que él se ahorra una

[2] * Puede mantenerse sólo con energía solar

cantidad total cercana al coste que suponía mantener ambos edificios con sistemas no renovables. Según información proporcionada por el Departamento de Sostenibilidad, el precio aproximado para la instalación es de unos 2,5$/W [2]. Esto supone que la instalación suponga aproximadamente un coste total de 2.217.041,1 $. Esta cantidad puede variar dependiendo del tipo de placa solar elegida finalmente.

3. Rentabilidad

De los cálculos anteriores se desprende que, para la instalación, el costo total va a ser de alrededor de 2,217,041.1 $. En este tema, el tipo de pago o préstamos aplicados cambian otros factores en términos de ahorro en años futuros, pero eso sería una decisión que debe tomar la Universidad de Minnesota. Después de esto, como se mencionó anteriormente en esta parte de la tesis, del Sistema de Reserva Federal (FRS), se puede obtener un incentivo de alrededor del 22% si esto se lleva a cabo en 2023 (de 2020-2022 fue un incentivo del 23% y fue del 30% hasta 2019. Se espera que cambie en 2024, pero no se sabe cómo) [3]. Con esto, una cantidad de alrededor de 487.749$ puede ser crédito fiscal si se pagara el primer año.

Xcel Energy, por ejemplo, paga hasta 0,08$/kWh (incluso puede llegar a 0,13$/kWh), otras empresas utilizan tarifas similares. Con esto, se ahorraría un total de 621.480,96 $ el primer año (hay un total de 7.768.512 kWh solares al año en este proyecto).

Si todo el coste de la instalación se pagara el primer año, esto significaría:

Año 1: se pagan 2.217.041,1 - 487.749 = 1.729.292 $ y se ahorran 621.480,96 $ en la factura eléctrica.

Año 2: 1.729.292 - 621.480,96 = 1.107811,04 $ aún por recuperar y aproximadamente 621.480,96 $ ahorrados en facturas.

El mismo proceso que el año 2 …

No se sabe cómo cambiará el coste de la electricidad, pero si se mantuviera un precio similar al actual, este proyecto sería rentable en unos 4 años si la universidad pagara todo en el primer año. Probablemente no será así, ya que intervienen préstamos y otros tipos de movimientos de dinero, pero esto demuestra que los paneles solares se amortizan rápidamente. También hay otros incentivos, como el crédito a la demanda fotovoltaica, que permite a los sistemas de más de 40 KW CA ahorrar 6,96¢/kWh por la electricidad generada entre las 13 y las 19 horas.

4. Reducción de costes

En información proporcionada por la universidad, es posible saber que el año pasado se gastó 1.336.333,07 $ en luz en los edificios estudiados. A la universidad, mediante su sistema eléctrico, en 2021 se pagó 0,1155 $/kWh. Teniendo por tanto los valores de las secciones anteriores, se puede saber qué porcentaje de la factura eléctrica se puede ahorrar por edificio. En cuanto a los estudiantes, para este trabajo no se pudo obtener que valor del pago semestral de la residencia se atribuye al gasto eléctrico por lo que, mediante los porcentajes de ahorro, se espera que, si la universidad decide llevar a cabo el proyecto, se pueda descontar.

EDIFICIO	AHORRO ($)	PORCENTAJE AHORRADO
Sanford	150,062.32	100%
Pioneer	190,878.1	67,9%
Comstock	121,537.31	63,1%
Centennial	173,195.36	100%
Frontier	139,314.25	82,54%
Yudof	89,456.8	35,53%
Territorial	34,794.36	29,27%

Tabla con las cifras del ahorro económico por edificio

5. Contaminación

Según valores proporcionados por el gobierno [4] se emiten unos 453,6 gramos de CO_2. Aun así, la instalación de placas solares y su fabricación también generan algo de contaminación, pero en mucho menor cantidad, esto sería unos 50 g de CO_2 /kWh [5]. Si comparamos estos dos valores se acaba obteniendo:

EDIFICIO	**emisiones de kg de CO_2 prevenidas con EV**
Sanford	453.849,19
Pioneer	554.527,11
Comstock	350,823.27
Centennial	502,177.4
Frontier	403,292.45
Yudof	259.259.43
Territorial	100,823.11

Tabla con las cifras del ahorro de emisiones de CO_2

6. Expansión

En la Universidad de Minnesota hay más de 100 edificios, muchos de ellos podrían ser candidatos para la instalación de paneles solares, pero estudiar en profundidad cómo son de válidos para ello llevaría una gran cantidad de tiempo. Por ello en este estudio se han proporcionado todos los edificios de menos de 6 plantas (unos 22,5 metros) y que no sean mayores de 30 años (ya que será más fácil que no sean modificados en los próximos años). Con esto se obtuvo un total de 26 edificios. Ya queda en manos de la universidad ver si interesa una expansión o no.

7. Conclusión

En este trabajo se ha estudiado como de posible y rentable es la instalación de paneles solares en 7 edificios en el campus de la Universidad de Minnesota. Junto con el Departamento de Sostenibilidad se ha comprobado que es una operación que podría rentabilizarse rápido y que verdaderamente podría contribuir al desarrollo económico y sostenible de la universidad. La operación costaría unos 2.217.041,1 $ que podría variar según el tipo de panel y la empresa seleccionada finalmente. Además según se ha comprobado, gracias a los incentivos del estado se podría recuperar el dinero en hasta 4-5 años, pero lo más probable es que sea más tarde ya que no se producirá en un solo pago y los tipos de interés pueden cambiar. Otro aspecto estudiado es la contaminación, y se sabe que hasta 2.624.751,96 kg de CO_2 se podrían dejar de emitir a la atmósfera. El objetivo final de este trabajo sería que pudiese expandirse a más áreas del campus, en este sentido habría 26 edificios que por edad y tamaño podrían ser candidatos.

FEASIBILITY OF THE INSTALLATION OF SOLAR PANELS IN THE RESIDENTIAL HOUSING OF THE UNIVERSITY OF MINNESOTA

Author: Solana Martínez, Severiano.

Director: Rice, Carley.

Collaborating Entity: Sustainability Department of the University of Minnesota.

ABSTRACT OF THE PROJECT

The University of Minnesota is developing a sustainability plan that aims to end CO2 emissions by 2050. One aspect that has not been developed in depth yet is the installation of solar panels on university buildings. Therefore, this paper studies this issue, with the principle of knowing whether it would be profitable to install solar panels in terms of electricity costs and pollution. The University of Minnesota has a large number of buildings, so in this paper 7 student residences belonging to the campus will be analyzed with the aim also to give an idea of how much it could save in electricity expenses for the students.

Key words: University of Minnesota, CO_2 emissions, solar panels, electricity expenses

1. Introduction

Economic spending in recent years has risen considerably in Minnesota. This, coupled with the university's recent sustainability plans, makes the idea of installing solar panels on campus buildings a very positive idea. Seven buildings will be analyzed in which the amount of roof space available (this will include consideration of plumbing, windows, or other issues), height, and future plans for the building. Last year these buildings had a total usage of 11.542.679 kWh. The different types of solar panels on the market or offered in Minnesota in terms of size and quality should also be studied. For the calculation of quantities in most cases average values will be used since it depends on the University of Minnesota the type of panel to be finally used.

As for the economic expenditure, thanks to the Sustainability Department of the university, it is known that the total expenditure last year in the 7 buildings was 1.336.333,07 $, in this work will provide the savings that can result from the installation of panels. Also the reduction of pollution, since in terms of CO2 emissions last year were .,811.277,15 pounds of CO2. It will also be analyzed if it is possible to extend this study to more university buildings.

2. Installation numbers and costs

In this first point, the most important thing will be to know the amount of space available in these buildings, following the plans provided by the university [1], you can obtain an approximate space of:

BUILDING	ROOF AREAS	APPROXIMATE SPACE IN m^2
Sanford	E, F*[3], G*, K & L	1405,065
Pioneer	D*,B&D	879,79
Comstock	A, C,D,I,J,K,L,M,P&R	556,675
Centennial	C,D,E,F,G,H*,I,J,K,L,M*, N,O*,R&S	1316,81
Frontier	J & K	640,66
Yudof	C,D,E,F,H&K	411,37
Territorial	A,C,E,H,I,J,L	159,79

Table indicating roof areas and total available space

[3] * No el 100% del espacio en esa zona se podrá usar para paneles debido a que hay irregularidades como tuberías o ventanas, pero sí que se podrá usar alrededor del 50%.

This available space has already taken into account possible obstacles on the roof and a safety distance from the side of the building of about 4.5 meters for workers who have to climb. As for the electrical wiring, all the buildings have it inside, so it is not a problem. For the calculation of the number of panels several standard figures have been selected, that is, the plates of about 1,64 x 1 meters and 350W of power, this will provide the number of panels necessary for installation and with them how many kWh can be obtained by panels:

BUILDING	Number or panels 350W	kWh generated in a year
Sanford	432*[4]	1.298.896
Pioneer	539	1.652.574
Comstock	341	1.045.506
Centennial	498*	1.496.564
Frontier	392	1.201.872
Yudof	252	772.632
Territorial	98	300.468

Table indicating total number of panels and generation

The two buildings marked in green have the capacity to generate enough power in a year with solar panels. Obviously, during the winter months they will not receive the amount of light they need (snow in Minnesota is an important factor that causes light reflection and more light is generated than it may be thought at first), but in the summer they will have a surplus. The University of Minnesota has its own electrical system to which all university buildings are connected and then the surpluses at Sanford and Centennial could be used to power other buildings, saving a total amount close to the cost of maintaining both buildings on non-renewable systems. According to information provided by the Sustainability Department, the approximate price for

[4] * Puede mantenerse sólo con energía solar

the installation is about $2,5/W [2]. This implies that the total cost of the installation is approximately $2.217.041,1. This amount may vary depending on the type of solar panel finally chosen.

3. Profitability

From the previous calculations it is measured that for the installation, the total cost is going to be around 2.217.041,1 $. In this matter, the type of payment or loans applied change other factors in terms of savings in future years, but that would be a decision for the University of Minnesota to make.

After this, as mentioned earlier in this part of the thesis, from the Federal Reserve System (FRS), an incentive can be obtained of around 22% if this takes place in 2023 (from 2020-2022 it was an incentive of 23% and it was of 30% up to 2019. It is expected to change in 2024, but it is unsure how) [13]. With this, an amount of around 487.749$ can be tax credit if it was to be paid the first year.

Xcel Energy for example pays up to $0,08/kWh (it can even go up to 0,13$/kWh), other companies use similar ratings. With this, a total of 621.480,96 $ would be saved the first year (there is a total of 7.768.512 kWh solar per year in this project).

If all the cost of installation was to be paid the first year, that would mean:

Year 1: 2.217.041,1 - 487.749 = 1.729.292 $ are paid and 621,480.96$ are saved in electric bills.

Year 2: 1.729.292 - 621.480,96 = 1.107.811,04$ still to be recovered and approximately 621,480.96 saved in bills.

Same process as year 2 …

It is unsure how the cost of electricity will change, but if it was to maintain a similar pricing as it has today, this project would be profitable in around 4 years if the university was to pay everything in the first year. This will probably not be the case, as loans and other types of money movements are involved, but this shows that solar panels are rapidly paying off. There are also other incentives such as PV Demand Credit that allows the systems with more than 40 KW AC to save 6,96¢/kWh for electricity generated between the hours of 1pm and 7 pm.

4. Reduction of costs

In information provided by the university, it is possible to know that last year $1.336.333,07 was spent on electricity in the buildings studied. To the university, through its electrical system, in 2021 it was paid 0,1155 $/kWh. Having therefore the values of the previous sections, it is possible to know what percentage of the electric bill can be saved per building. As for the students, for this work it was not possible to obtain what value of the semester payment of the residence hall is attributed to the electrical expense so with the savings percentages shown below, it is expected that if the university decides to carry out the project, it can be discounted.

BUILDING	SAVINGS ($)	PERCENTAGE SAVED
Sanford	150,062.32	100%
Pioneer	190,878.1	67,9%
Comstock	121,537.31	63,1%
Centennial	173,195.36	100%
Frontier	139,314.25	82,54%
Yudof	89,456.8	35,53%
Territorial	34,794.36	29,27%

Table with total savings in data and percentage

5. Pollution

According to values provided by the government [4] about 453,6 grams of CO2 are emitted for every kWh. But the installation of solar panels and their manufacture also generates some pollution, but in much smaller quantities, this would be about 50 g of CO2 /kWh [5]. If we compare these two values, we end up obtaining:

BUILDING	**emissions prevented in kg de CO_2**
Sanford	453.849,19
Pioneer	554.527,11
Comstock	350,823.27
Centennial	502,177.4
Frontier	403,292.45
Yudof	259.259.43
Territorial	100,823.11

Table with CO_2 prevented emissions

6. Expansion

At the University of Minnesota there are more than 100 buildings, many of them could be candidates for the installation of solar panels, but to study in depth how valid they are for it would take a great amount of time. Therefore, in this study, all buildings less than 6 stories (about 22,5 meters) and not older than 30 years (since it will be easier for them to not be modified in the next few years) were provided. This resulted in a total of 26 buildings. It is now up to the university to see if an expansion is of interest or not.

7. Conclusion

In this work we have studied how possible and profitable is the installation of solar panels on 7 buildings on the campus of the University of Minnesota. Together with the Sustainability Department, it has been proven that it is an operation that could pay off quickly and that could truly contribute to the economic and sustainable development of the university. The operation would cost about $2.217.041,1, which could vary depending on the type of panel and the company finally selected. Moreover, it has been found that thanks to state incentives, the money could be recovered in up to 4-5 years, but it will most likely be later as it will not be in one payment and interest rates may change. Another aspect studied is pollution, and it is known that up to 2.624.751,96 kg of CO_2 could be saved from being emitted into the atmosphere. The ultimate goal of this work would be that it could be expanded to more areas of the campus, in this sense there would be 26 buildings that by age and size could be candidates.

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FEASIBILITY OF THE INSTALLATION OF SOLAR PANELS IN THE RESIDENTIAL HOUSING OF THE UNIVERSITY OF MINNESOTA

By

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Directed Study in

Electrical Engineering

University of Minnesota at

Twin Cities

Advisor: Carley Rice

May 2022

ABSTRACT

The University of Minnesota is developing a realistic and efficient sustainable plan for the next few years. This is why this study will concentrate on helping the university reach its goals sooner by studying the possible installation of solar panels in the housing on campus. Every year renewable energy systems are becoming more affordable and efficient. From them all, solal panels are clearly taking a lead as one of the best options in terms of renewable energy sources. For this study, the possibility of wind energy conversion systems was in the beginning taken into consideration, but the higher prices and less information obtainable, has made solar panels the only renewable energy resource studied in this paper. The main objective of this study is to show how feasible it is to install solar panels in the housing of the University of Minnesota and how it will help reduce costs in light for both the university and its students. It will be studied the profitability of a project like this. Another goal trying to be achieved in this paper is to show how the pollution emissions will drop due to the installation of renewable energy sources. At last, this study will talk about the possibility of this project being applicable to other buildings in the university. This thesis will provide a study on the main Residential Housing Halls on university campus, these are: Sanford Hall, Pioneer Hall, Comstock Hall, Centennial Hall, Territorial Hall, Frontier Hall and Yudof Hall. In the case of Territorial and Centennial there are plans for renovation to convert them into academic buildings, but this study will cover them in case these renovations do not go through or to set the basis for future solar panel installation in the new buildings. More Halls could have been included, but the lack of information in some of them made it difficult to run a full analysis.

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1. INTRODUCTION

This is the first overall view of this study. It will present a general idea of the feasibility of installing solar panels in the residential housing of the University of Minnesota. An overall view of the objectives will be provided in order to see what is expected out of this paper and how it is intended to reach those goals.

1.1. Overview of the scope and issues being studied

Two big concerns existing right now in our society are the constant increase in light costs and the amount of CO_2 emissions that are emitted every year. At first they may not have a lot in common, but they can both be solved, or at least treated, with the installation of solar panels (PV). Solar panels used to look like a big expense, but every year they are becoming cheaper and more efficient and more companies and organizations are starting to make use of them as a way of saving costs in future years. This study will try to show all the benefits that the installation of solar panels in just a few buildings in the University of Minnesota can produce.

The installation of solar panels will also affect the students directly in the monetary aspect as, with an initial investment that nowadays can be paid back in around 10 years, their college expenses will go down for all the students that live on campus. This aspect will be studied later, but it is probably one of the most important ones as it will make the University of Minnesota more affordable and maybe attract more students to attend here and live on campus. One of the main issues that may be taken into consideration when thinking of Minnesota is the lack of light, but in this study it will be shown that even with that the reduction goals are still being achieved.

The University of Minnesota is one of the biggest in size in the Midwest of the United States and so that means that if this study is carried out in the next few years, it could easily be expanded to more buildings in the university. The campus has an approximate 1100 ha and that means plenty of solar panels could be installed all around it.

1.2. Contribution

For this study, it was necessary a great quantity of data from the University of Minnesota. In this data we include tables with electricity used from the buildings being talked about, maps of the campus, documents explaining future plans in terms of buildings from the university, drawings from the housing. This was in great part obtained thanks to the Department of Sustainability and the University of Minnesota website. A great amount of data from the Commerce Department (in collaboration with the university) was also used. This last one includes the amount of solar light that a specific selected location receives throughout the year and the amount of radiation it can get. This has been a crucial tool as it simplifies in a big way the form of analyzing how much electrical power we are going to be able to get from every building. The main objective of this work is to show in a deep and well studied manner how convenient the installation of solar panels in the housing would be for the university and the students. This study also tries to leave a reference for future solar panels plans at the university so that it will not be necessary to work from scratch but from an already worked view. As for a personal reflection, this work has helped me understand and know more about renewable energy and how, if managed well, it can lead to a much better future.

1.3. Outline of the study

In this study, 6 parts are being explained and 2 appendixes are being included:

The first part, the most optimal renewable energy space applicable will be given and also the number of panels to install in the selected buildings during this project and the prices of different companies. It will give numbers in terms of installation, and an analysis of the buildings with their advantages and disadvantages.

For the second part, this part of the project will explain in how many years this project would be profitable dependending on some initial variables such as money initially invested and energy capacity of the renewable energy systems compared to the necessity of the buildings.

The third part will talk about one of the main purposes is to try to reduce the cost of residential housing for students in terms of light expenses. This will give an approximate idea of how the costs for student living will vary during the following years of the installation of the renewable energy systems.

The fourth part will try to explain how this will help reduce the greenhouse gas emissions in the university campus area. This project will give some data on how much the University of Minnesota would be helping in terms of reducing pollution. The help of the Sustainability department will be very important in the study of this section.

In the fifth part, the possibility of installing renewable energy systems to other buildings of the university will be contemplated. This section will look over rather than study the possibilities of this becoming a real option.

In the sixth and last part, a conclusion of all that has been talked about during all these parts will be provided.

Appendix A, the drawings of the Hall-s roofs are provided. This will help in the tables presented in part 2.

Appendix B, information about the permitted greenhouse gas emissions by the Minnesota Pollution Control Agency is provided.

Appendix C, relation of this study with the objectives of sustainable development.

2. INSTALLATION NUMBERS AND COSTS

In order to know how much the installation of solar panels in the housing at the university will cost, it is necessary to know a wide variety of variables beforehand. In this section the total square footage available, the type of buildings dealt with, the different types of panels, are some of these variables that will help conclude with an estimate for installation numbers and costs.

2.1. Study of optimal space and building architecture

For the study of available space in this study, it was necessary an exhaustive observation of the roofs of every building being studied as well as its electrical access and size.
The figures provided in Appendix A of this study help give a general view of the roofs of the buildings being analyzed.

In the following table, it is provided the approximate roof zones available in each building after observation in plans provided by the department of sustainability [1]. This pdf was necessary, not only for the square footage but to observe roof curbs, drains, vent stacks and other elements that may be located on the roofs and difficult the installation. Also, it should also be known that some space will have to be discounted for security for workers (around 15 feet from the border).

Table 1

HOUSING HALLS	ROOF ZONES	APPROXIMATE SQUARE FOOTAGE
Sanford	E, F*[1], G*, K & L	15124
Pioneer	D*,B&D	9470
Comstock	A, C,D,I,J,K,L,M,P&R	5992
Centennial	C,D,E,F,G,H*,I,J,K,L,M*,N, O*,R&S	14174
Frontier	J & K	6896
Yudof	C,D,E,F,H&K	4428
Territorial	A,C,E,H,I,J,L	1720

Table 1. Descriptions of the available roof area and total square footage for each housing hall

This is the maximum space that could support solar panels, but there are other factors too. It should also be observed whether the electrical access runs through the building or on the outside and how tall and accessible the buildings are for installation.
With the information above, a schematic description of each building will try will gather the information necessary to know how optimal the building is:

- *Sanford*: Sanford is a fairly big Hall, with similar height in all its roof. Sanford has an average of 5 floors (62 ft) including ground 0. It was built in 1910, but renovated in 1970, so we can consider it of a decent age. The electrical access runs through the building. Zones F and G of the roof [1] may be considered too high (10 floors ≈123 ft) [2] for solar panel installation as they have around 5 more floors than the main part of the building. Zone I (not included in the square footage because it is probably not possible due to quantity of windows) is angled and so may be difficult to install, but its good location towards receiving light may be a crucial factor. Feasibility of both controversial subjects will be discussed later in the study.

[1] * means that there are roof curbs and drains that may not permit use of 100% of the surface. These roof curbs and drains do not occupy enough space as to not make this "zone" optimal for the installation of solar panels and for so, they are going to be included but not for their 100% of space, but for around 50%.

- *Pioneer*: Pioneer is one of the oldest buildings in this list, built in 1931, but renovated lately. Pioneer is probably one of the buildings with the best accessibility, due to the fact that it is not that tall in most of its body (4 floors high ≈ 49 ft). Its roof also has a great amount of windows and the space is limited, but the amount of light is one of the best in comparison to the rest, so it is worth studying it.The electrical acces goes through the building.
- *Comstock*: Comstock was built in 1940, so as well as pioneer is one of the oldest in the oldest remaining. As well as Pioneer, it is very tall with most of the building being 8 floors tall (≈ 99 ft). This is an inconvenience for installation, but Comstock has a very profitable amount of roof and if the installation cost is not too high, it can be of great profitability to the university in the next few years.The electrical acces goes through the building.
- *Centennial*: Centennial Hall was built in 1950, a few years later than the other buildings in Super Block. As well as the buildings in this area its roof is high with most of it being 6 floors high (≈ 74 ft). It is a similar case to Comstock where the amount of roof available is really big and there are a good amount of zones with no vents. The electrical acces goes through the building.
- *Frontier*: Frontier Hall was built in 1959, making it fairly old, but has had a few renovations in the last years. The building is mostly 4 floors tall in its entirety, which is very convenient for this case. The biggest loss is that it has a very big central space (Zone A), but the huge quantity of vents made it impossible to manage installation. There is still a decent quantity of space in Zones J and K, so it is still a profitable building. The electrical acces goes through the building.
- *Yudof*: Yudof is one of the newest buildings in this list as it was built in 2002, making it a really important building as it will probably stay many years. This building, as well as others, is tall, with around 10 floors, but it counts with a good amount of sunlight and profitable space on the roof. The biggest loss is all Zone A of these buildings as there is a too big amount of roof curbs vent stacks. and The electrical acces goes through the building.
- *Territorial*: Territorial Hall was built in 1958 but was expanded in 1999, making it also fairly new. It has the advantage of being a short building, being almost entirely 4 floors tall. The same as with other buildings, the amount of vent stacks in zone A made it difficult to use the biggest part of the roof, but with the expansion, more profitable zones are available, making the building worth studying. The electrical acces goes through the building.

2.2. Comparison of installation costs

In this second section of the second part it will be studied how much this operation could cost, analyzing the different types of panels and how much money the university should be expecting to spend in this operation.

Having analyzed the square footage of every building. We can start estimating the cost of the installation of the solar panels in this project. For this estimation the Department of Sustainability has helped provide information related to costs [3].

The next graph shows a scheme of all the variables that are to be considered to know the actual cost of installation. As this thesis does not concentrate entirely on installation, this will show what there is to be known.

Figure 1

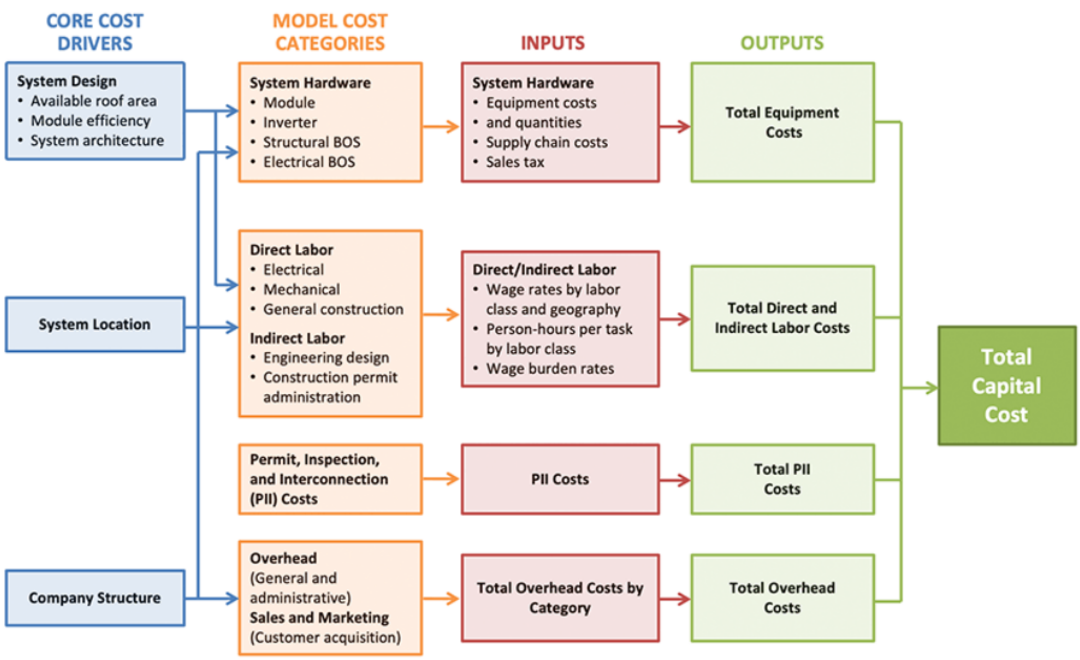


Figure 1. Description of the process of calculation for overall cost of installation of solar panels. Source [3]

In the following graph there is information about the pricing in Arizona, California, Massachusetts and New York. In Minneapolis, the prices can be really similar to Massachusetts and New York, so they will serve as reference for this study [4].

Figure 2

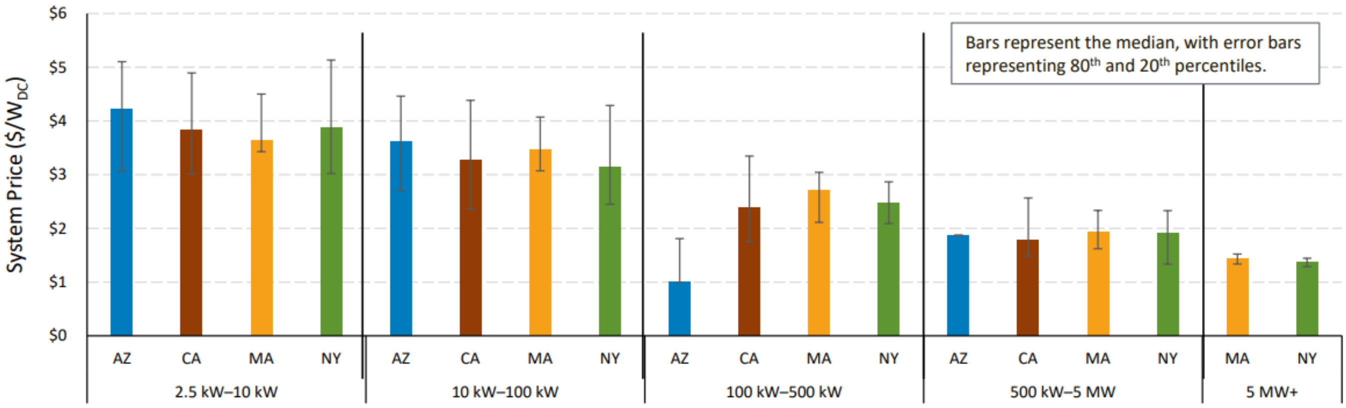


Figure 2. Graphic representation of cost per W of solar power energy in Arizona,California, Massachusetts and New York. Source [4]

In the following graph the different costs depending on what type of project is being handled are shown. It also provides the changes from 2010 to 2020 to have an idea of how the prices have gone down due mainly to advancements in technology and normalization of the use of solar panels[3]. This is an estimate, as there are factors that may change, but for the purpose of this thesis, giving a general idea of feasibility is a good approach.

Figure 3

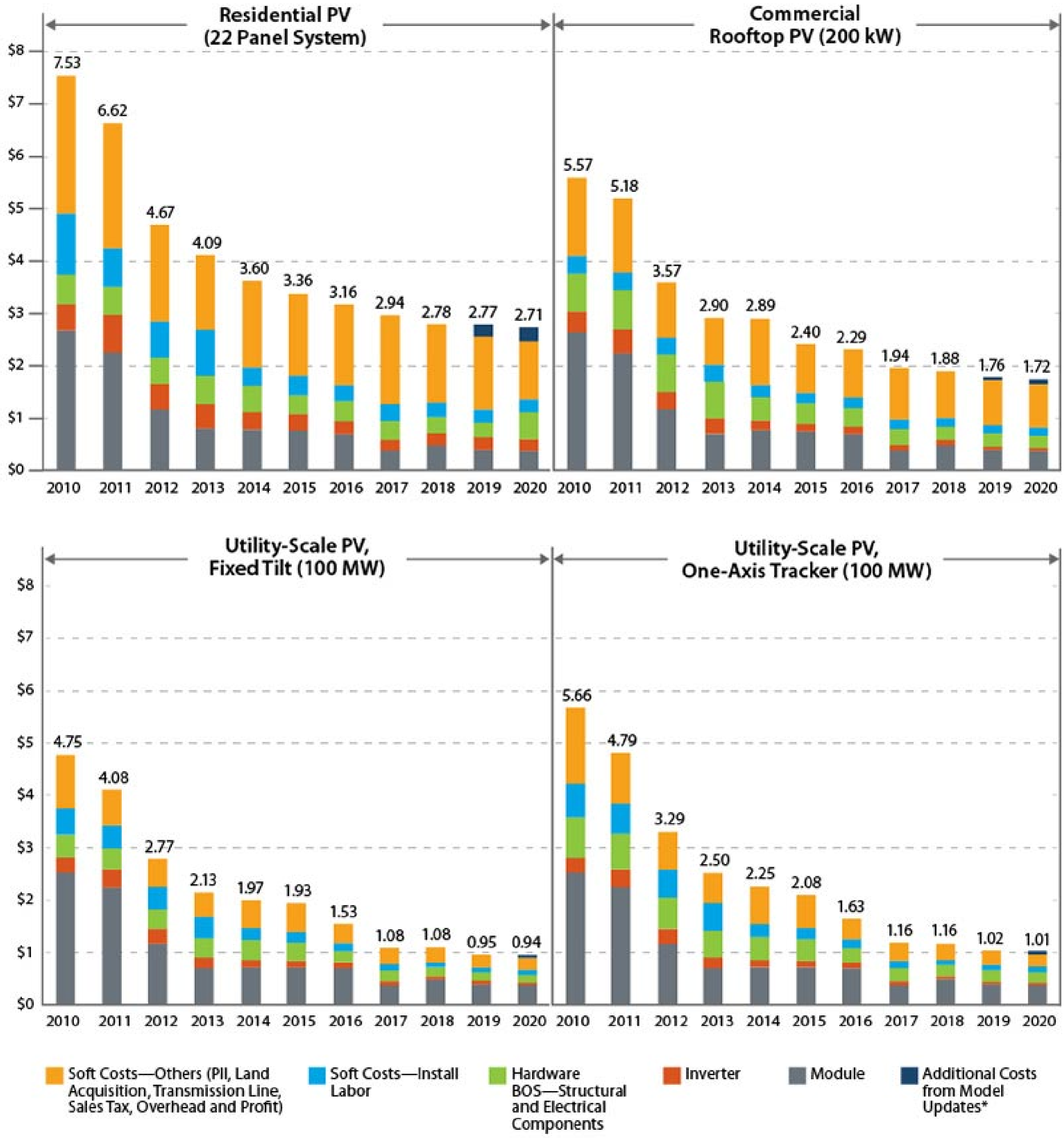


Figure 3. Comparison of installation cost of PV systems in different scales. Source [3]

For the purpose of this study, the roofs being studied are considered between residential and commercial sizes, as the surface studied is still not big enough to be considered great scale. In the following table it can be observed the amount of KWh used per Hall in the last year (Information given by the Department of Sustainability).

Table 2

HOUSING HALLS	APPROXIMATE SQUARE FOOTAGE	kWh used in 2021
Sanford	15124	1,298,896
Pioneer	9470	2,433,675
Comstock	5992	1,656,896
Centennial	14174	1,496,564
Frontier	6896	1,456,141
Yudof	4428	2,174,287
Territorial	1720	1,026,220

Table 2. Table with information regarding the available square footage and kWh used in 2021 by each building. Sources: [1][11]

So, the kW needed in each building are (there are 8760 hours in a year) :

- Sanford: 148.276 kW
- Pioneer: 277.82 kW
- Comstock: 189.14 kW
- Centennial: 170.84 kW
- Frontier: 166.226 kW
- Yudof: 248.206 kW
- Territorial: 117.148 kW

This would basically be the amount of power that would make buildings run entirely with solar power. The biggest issue then is if there is enough space all the necessary for solar panels in the buildings. Normally, the solar panels are rated to produce between 250 - 400W [5] in an hour. For this first calculation, an average size solar panel will be used, that is roughly 5.4 x 3.25 feet.

The next table is going to represent the maximum number of solar panels needed in each of the buildings that are being studied in this thesis (The numbers are approximated to exact values).

Table 3

HOUSING HALLS	APPROXIMATE SQUARE FOOTAGE	Max number of panels
Sanford	15124	861
Pioneer	9470	539
Comstock	5992	341
Centennial	14174	807
Frontier	6896	392
Yudof	4428	252
Territorial	1720	98

Table 3. Table with information available square footage and maximum number of 5.4 x 3.25 ft panels by each building.

Now, knowing how much power is needed in every building, we estimate how much each panel needs to produce in order to know the quality of the panels. In this matter efficiency affects greatly, today solar panels have from 15 - 22% efficiency. To give an average value, 18% efficiency will be used as it is one of the most common in the market.

This would mean that in Minneapolis solar panels are rated to produce between 250 - 400 W an hour, which will then be solar panels of 1.4kW - 2.2 kW approximately. 12 x high efficiency 400W solar panels, such as those from LG or SunPower with a 21.8% conversion efficiency, will provide around 1200W (1.2kW) more total solar capacity than the same number of similar size 300W panels with a lower 17.5% efficiency [6]. In the next table it will be seen how many panels are needed if they rate 300W or 400W. In a year these panels produce 2628kWh and 3504kWh respectively.

Table 4

HOUSING HALLS	kWh used in 2021	Max number of panels (in terms of sf)	Number of panels (2628 kWh)	Number of panels (3504 kWh)
Sanford	1298896	861	494	370
Pioneer	2433675	539	926	694
Comstock	1656896	341	630	473
Centennial	1496564	807	569	427
Frontier	1456141	392	554	415
Yudof	2174287	252	827	620
Territorial	1026220	98	390	293

Table 4. Table regarding kWh used, maximum number of panels in terms of space and number of necessary panels to sustain building rating 300 W and 400 W.

With this it can be seen that with solar panels, as of today, not all the energy in the building can be supported with solar energy, as the buildings studied use a great quantity of electricity and the solar panels are still not enough. It is worth saying that still a great quantity of energy can be saved. *Only the buildings with a big accessible roof surface such as Sanford and Centennial could run with just solar power. This study is doing an average observation on the installation, this means that during winter months when there is not enough light, the buildings would need to use the previous electrical methods. The important observation is that all the buildings in the university run under the same interconnected system for electrical energy, and so, the months when the buildings generate more than they need, this could go to sustain the electrical use of other buildings on campus. That is why in the end, it adds up to approximately the same amount of money that if the building could sustain itself on solar power all year.*

In the next table it will be seen how much energy can be saved, in the case of rating 350W as this study will try to give an average view, but all the specific decisions such as the efficiency will be the university's choice. In this table, if the building can not reach 100% solar, the maximum number of panels is the one in the table. To calculate the kWh it just a simple calculation of 350W*0.001*8760 h.

Table 5

HOUSING HALLS	Number of panels 350W	Solar Energy kWh in a year
Sanford	432*[2]	1,298,896
Pioneer	539	1,652,574
Comstock	341	1,045,506
Centennial	498*	1,496,564
Frontier	392	1,201,872
Yudof	252	772,632
Territorial	98	300,468

Table 5. Table regarding number of 350 W rate panels and the amount of kWh of solar energy generated a year.

With all the information gathered together it can be estimated an average cost of installation. In Figure 2 a more recent pricing can be found, and by looking at the range in Massachussts and New York for installations of around 100KW- 500KW the price is around 2.5 $, which is closer to the residential point of view in Figure 3, as the commercial rooftop is considered to be more than 200KW and only 2 buildings in this study pass that number and not by many square feet.

From solar energy we obtain in kW:

- Sanford: 148.27 kW
- Pioneer: 188.65 kW
- Comstock: 119.35 kW
- Centennial: 170.84 kW
- Frontier: 137.2 kW
- Yudof: 88.2 kW
- Territorial: 34.3 kW

Then, the average cost of installation per building would be found by the simple calculation of the KW*1000 * 2.5$.

[2] * Can be 100% run on solar energy

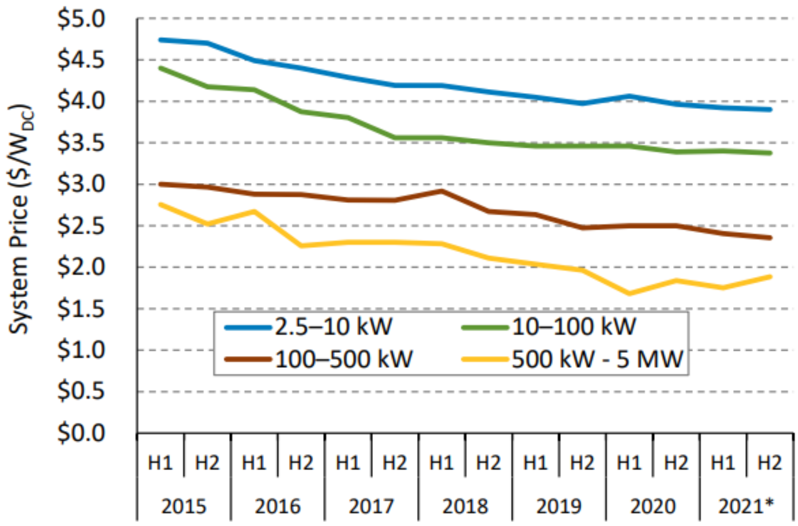
Table 6

HOUSING HALLS	SOLAR KW	AVERAGE COST ($)
Sanford	148.27	370,689.5
Pioneer	188.65	471,625
Comstock	119.35	298,375
Centennial	170.84	427,101.6
Frontier	137.2	343,000
Yudof	88.2	220,500
Territorial	34.3	85,750

Table 6. Table regarding information on total solar kW generated and the average cost of installation of these kW quantities in each building.

It can also be expected for this cost to drop, as in the last few years there has been a slow but constant lowering in the pricing mainly due to financial help by the the government with the reduction of taxes and also due to the new production chains that make installing solar panels a very optimal financial option:

Figure 4



Change in the PV systems installation prices since 2015. Source [4]

Now, it is variables such as the efficiency of the panels, the inclined roofs or different height that come into consideration.

Another factor to take into consideration was the **angled roof** in Sanford. While it may seem that an angled roof may be more expensive, it normally saves around 800$/7KW [7] because it saves the cost of the angled mounts used in flat roofs. It is true that the installation is more difficult and that may affect other areas of the pricing, but that is depending on the company. So, in Sanford Hall the price of installation could be in some way reduced to this factor. It is very beneficial as the angled roof in Sanford has an area of 30,155 sf minus the 15% for security reasons.

One of the most important variables when it comes to solar panels is **efficiency**. Usually in the market, solar panels have an efficiency of 15% - 18% [8]. New technologies are starting to design panels with an efficiency of a little more than 20%. The solar efficiency is measured as: Efficiency(%) = $\frac{Pmax}{Area * 1000W/m^2}$ with Pmax being the maximum power of the power of the panel and Area being the area of the panel. In this matter, the types of solar panels we may find are:

Figure 5

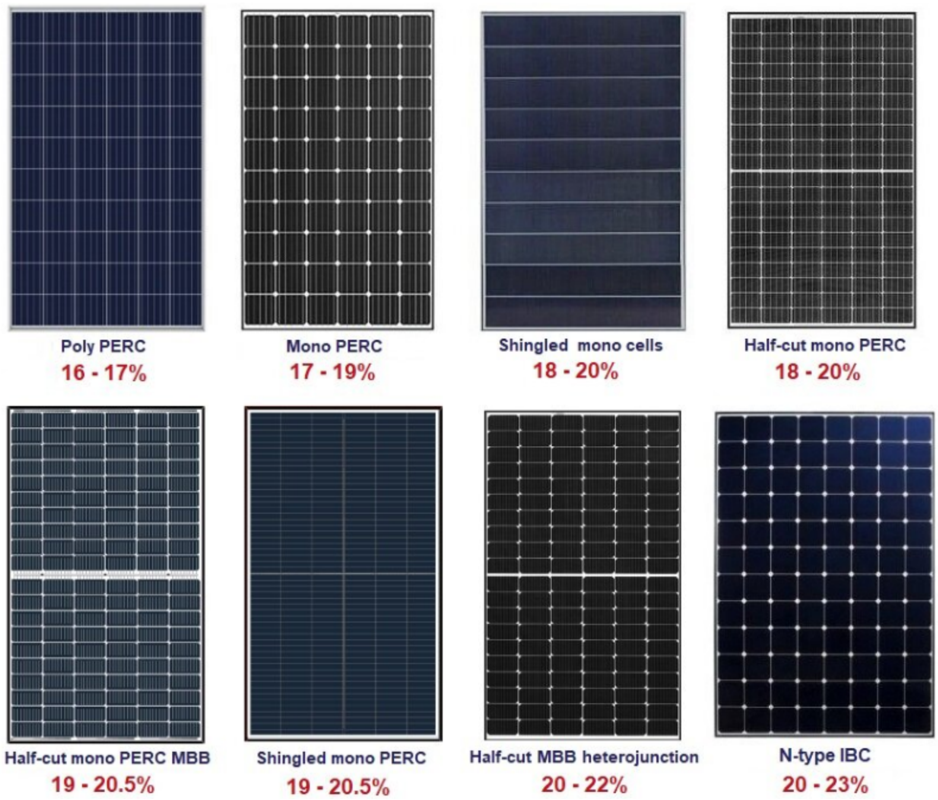


Figure 5. Comparison of efficiency between solar panels. Source [6]

So, the different types that can be found in the market and their efficiency are:

- Polycrystalline - 15 to 18%
- Monocrystalline - 16.5 to 19%
- Polycrystalline PERC - 17 to 19.5%
- Monocrystalline PERC - 17.5 to 20%
- Monocrystalline N-type - 19 to 20.5%
- Monocrystalline N-type HJT - 19 to 21.7%
- Monocrystalline N-type IBC - 20 to 22.8%

The most efficient are the N types, but the most common ones are P types. When it comes to money, panels with 21% and N-type cells are much more expensive, so that is something to take into consideration. On the other hand, these panels normally outperform and outlast the P type panels, so in the long run it is a very good choice. Monocrystalline panels have a lifespan of 25 years or more because of the high purity silicon they have. Polycrystalline has less purity in its panels that is why the efficiency is lower. This makes the manufacturing easier and the prices lower. It also can reach a 25 year life span making it a very optimal choice too.

A panel that has high efficiency and around 400W+ can have a price of around $350 or more while a more average one of 370W will typically cost closer to $185. This means that the comparison is $0.50 per watt to $0.90 per watt. However, big companies such as Sunpower, Panasonic and REC, the more expensive panels deliver higher performance with lower degradation rates and generally come with a longer manufacturer [6].

The Thin Film solar panels are also worthy of mention as they are becoming really popular due to their low cost (in comparison to other panels). They are made by covering a substrate of glass, plastic or metal with a thin layer of this photovoltaic panel. The films are normally flexible and decently light in weight. Their main inconvenience is the lower efficiency which is in the range of 7 - 18% [9]. They also don’t last as long as the types mentioned before because they tend to deteriorate earlier.

For all mentioned this thesis is going to concentrate on monocrystalline and polycrystalline panels for future analysis.
These are the top 10 companies in terms of efficiency as of March 2022:

Figure 6

Manufacturer	Model	Max power (W)	Cell Type	Efficiency
SUNPOWER	Maxeon 6	440W	N-type **IBC**	22.8 %
CanadianSolar	CS6R-MS	440W	N-type **HJT** Half-cut	22.5 %
LG	Neon R	405W	N-type **IBC**	22.3 %
Panasonic	EverVolt H	410W	N-type **HJT** Half-cut	22.2 %
JinKO Solar	Tiger NEO	480W	N-Type TOPcon Half-cut	22.2 %
SPIC	Andromeda 2.0	435W	N-type **IBC** Half-cut	22.1 %
REC Solar	Alpha Pure	405W	N-type **HJT** Half-cut	21.9 %
Trinasolar	Vertex S +	425W	N-Type Mono Half-cut	21.9 %
MEYER BURGER	White	400W	N-type **HJT** Half-cut	21.7%
JA SOLAR	Deep Blue 3.0 light	420W	P-Type Mono Half-cut	21.5 %

Figure 6. Top 10 companies in terms of efficiency of solar panels. Source [6]

As for the difference in height in some of the buildings there does not seem to be an agreement on how that affects the price of installation. In that case, that is a question to be made to the company selected in the end for the installation of the project. It is clear that the higher altitude, the more and better solar radiation is obtained. In terms of installation, as many of the buildings reach up to 10 floors, it should be a common thing to deal with if this project was to be made.

2.3. Conclusion

This is probably the biggest part of this thesis as it requires a great quantity of data and resources. During the evaluation of the 7 Halls being studied, very important information has been extracted. This information regards square footage, number of panels and kWh that could be generated only with solar panels.

In terms of the square footage it was difficult to analyze the roofs as what can be seen from the figures in Appendix A, ventas and roof stacks have to be dealt with. For this project the square footage presented in the tables is composed of all the sections of the roof that have clear open space to make installation possible. There are probably more sections of the roofs that may be capable of supporting solar panels but that would have to be checked by a professional in order to know how much space could be used.

For the final number of solar panels it was necessary a great number of documents, companies websites, data from past years, in order to try to work with average numbers as PV systems is a field in constant development and next year new and better panels will be out in the market.

Using average or at least most common solar panel qualities, it was possible to know that Sanford and Centennial could be run with solar power only. This is only partially true as during the winter months they will probably not obtain all the solar power they need to sustain themselves, but during the summer period they could generate a surplus. Knowing that the buildings on campus are interconnected as the University of Minnesota has its own electrical system, this surplus could go to power nearby buildings. This is why for the purpose of this study, it is said that the money saved by the total power obtained in these buildings could add up to save the entire cost of consumption throughout the year for at least Sanford and Centennial could generate enough solar power to pay their bill costs. Other buildings are also relatively close to achieving this gol, but the lack of available roof in some of them or the high consumption has made it not possible.

In the end this study tries to give an overall, but informative view about all that is involved in installing solar panels. In this section, areas such as efficiency is mentioned, but this is a decision that will be made by the University of Minnesota, so one of the goals of this study is to help make the decision easier or at least a little more clear.

3. PROFITABILITY

In this third part of the study, the profitability of the study will be studied. Analysis will be made in order to have a good idea of years and money. After some initial research, it is probably going to take around 10-15 years for this project to pay back. One aspect that favors this project, and all renewable energy ones, is that the price of light keeps rising and so these projects start being profitable sooner. This part comes along with the one described before as it will be necessary to know the costs of installation in order to have an initial investment and be able to study the years it will take to become profitable.

3.1. Accountable variables

Weather, investment, time of action, final type of panel, optimal orientation, these are some of the variables that will be studied as they directly affect the work of the solar panels. This section will not go into a lot of detail in some of them as the study is not centered in them, but at least give an idea of what this project is dealing with in order to be successful.

- **Weather**: It is commonly thought that Minnesota is not a good place for the installation of solar panels but that is not true. During winter Minnapolis is likely to have a good amount of snow days and that improves the amount of light solar panels receive as the snow amplifies the amount of light due to reflection. Also, there are starting to be companies that clean the snow away from your solar panels after snow days.

  Also, in the summer people might be afraid that the strong winds may make the solar panels fly off, but solar panels nowadays are prepared for this type of weather as they can withstand up to 140 mph winds, which is higher than any wind that could be expected in a normal summer.

- **Investment**: One of the most important variables in terms of profitability is the initial investment. From the Federal Reserve System (FRS), an incentive can be obtained of around 22% if this takes place in 2023 (from 2020-2022 it was an incentive of 23% and it was of 30% up to 2019. It is expected to change in 2024, but it is unsure how) [10]. This comes to mean that it is unclear in what way the government will help in terms of taxes. The incentives provided after installing solar panels are also a key factor in the fast growth of this type of renewable energy as these incentives can be around $0.07 - $0.08 /kWh .Also, the total amount calculated before in terms of installation is around 2 million, so it is a decision of the University of Minnesota to try and look to recover that investment in the next 4-5 years or to go with small investment every X years and try to gain profit in the long run.

- **Time**: With time of action what is trying to be said is that it is important to take into consideration the time that is going to be spent installing, what time of the year will that be, how accessible the buildings end up being. That all counts towards the money spent as there could be fluctuations. Also, solar panels normally last around 25 years at a good level so that is something very important to take into account for future renovations in the University of Minnesota.

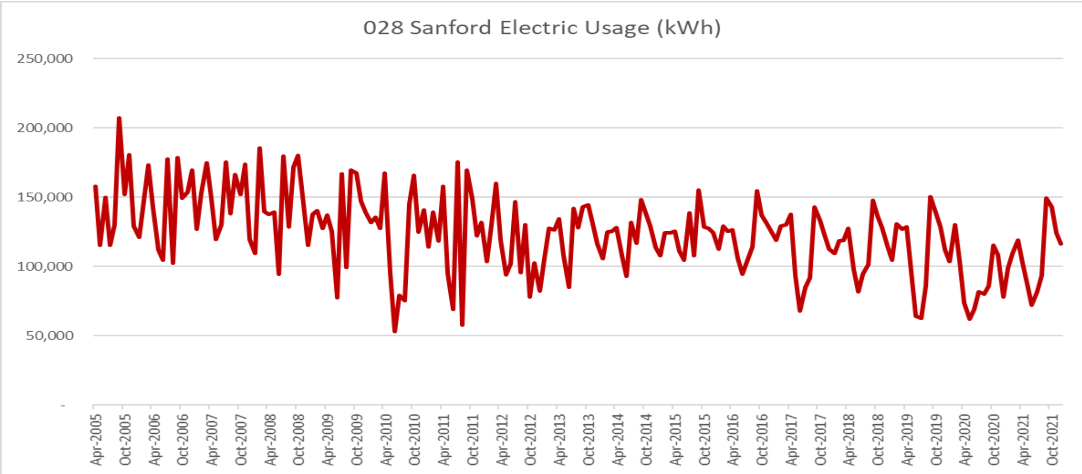
- **Panel configuration**: There are 5 solar panel configurations [12]:
    - Stand-alone (also known as off-grid) without grid power charge function
    - Stand-alone (off-grid) with grid power charge function
    - Grid-tie that feeds all the solar powered electricity to grid
    - Grid-tie that only feeds the surplus solar powered electricity to grid
    - Grid-tie with battery backup

  It is up to the university to choose the most appropriate. Also, as for orientation, in the northern hemisphere, the general rule is to install the solar panels looking south as it is the direction in which they normally receive more sun.

3.2. Numbers in terms of time and money

For this section it is important to know how much money that has been spent every year without solar panels in order to know how much it can be improved from there. In the following graphs and tables there is the information regarding these subjects. Information provided by the Department of Sustainability [11].

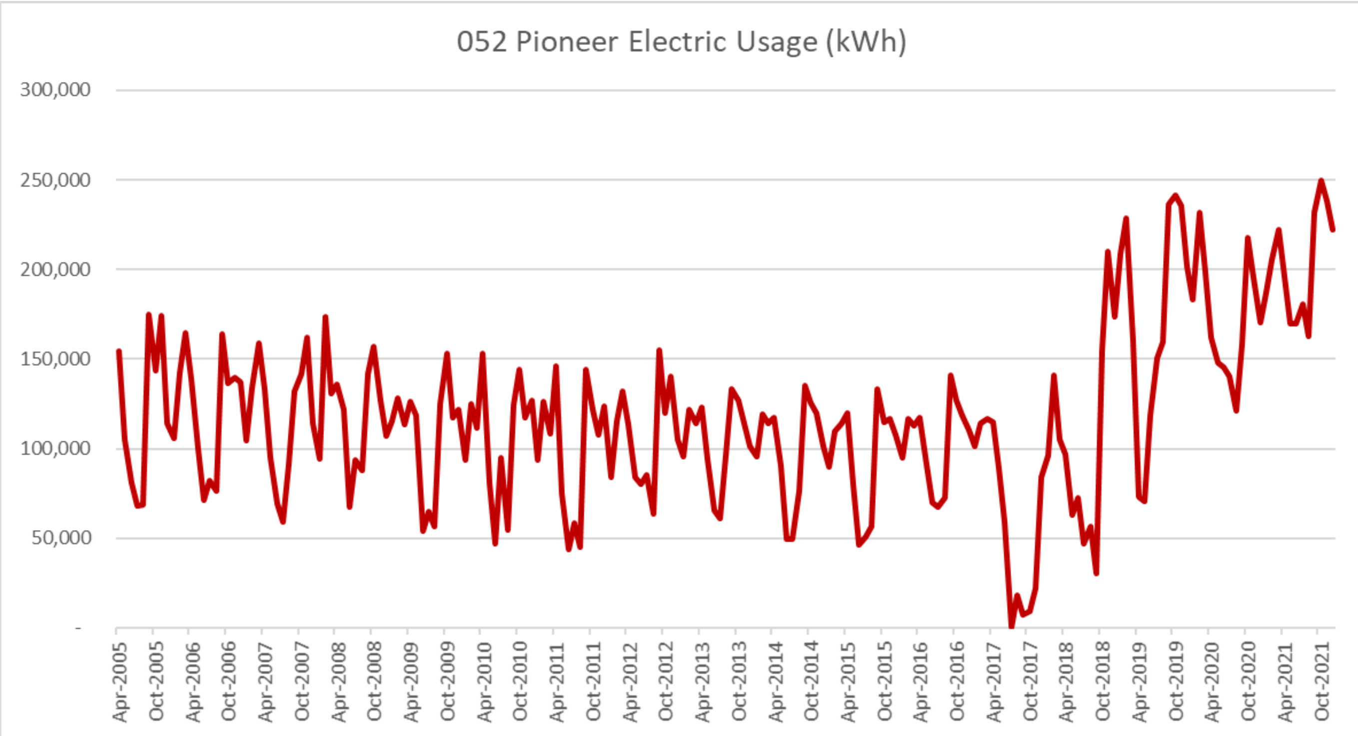
- *Sanford*: (Table 7 : Consumption in kWh a year and its cost; Figure 7 : Monthly consumption in kWh)



Year	Consumption (kWh)	Billed Cost
2006	1.733.320	$129.339,30
2007	1.779.020	$140.126,74
2008	1.727.111	$133.680,16
2009	1.636.448	$130.353,88
2010	1.443.132	$130.378,28
2011	1.500.206	$147.732,65
2012	1.344.994	$133.288,91
2013	1.492.766	$147.933,12
2014	1.463.594	$146.523,68
2015	1.481.215	$162.178,34
2016	1.460.631	$169.271,72
2017	1.366.693	$151.837,85
2018	1.378.262	$151.042,78
2019	1.330.174	$145.418,39
2020	1.093.309	$120.057,15
2021	1.298.896	$150.062,32

With this information about Sanford Hall it can be clearly seen that in the last year the consumption went up considerably due to the end of online classes. It can be expected to keep going up in the following years. It can also be observed the cost in 2021 was one of the highest since 2006 even though it was not one of the years with more consumption due to light prices going up.

- *<u>Pioneer</u>*: (Table 8 : Consumption in kWh a year and its cost; Figure 8 : Monthly consumption in kWh)

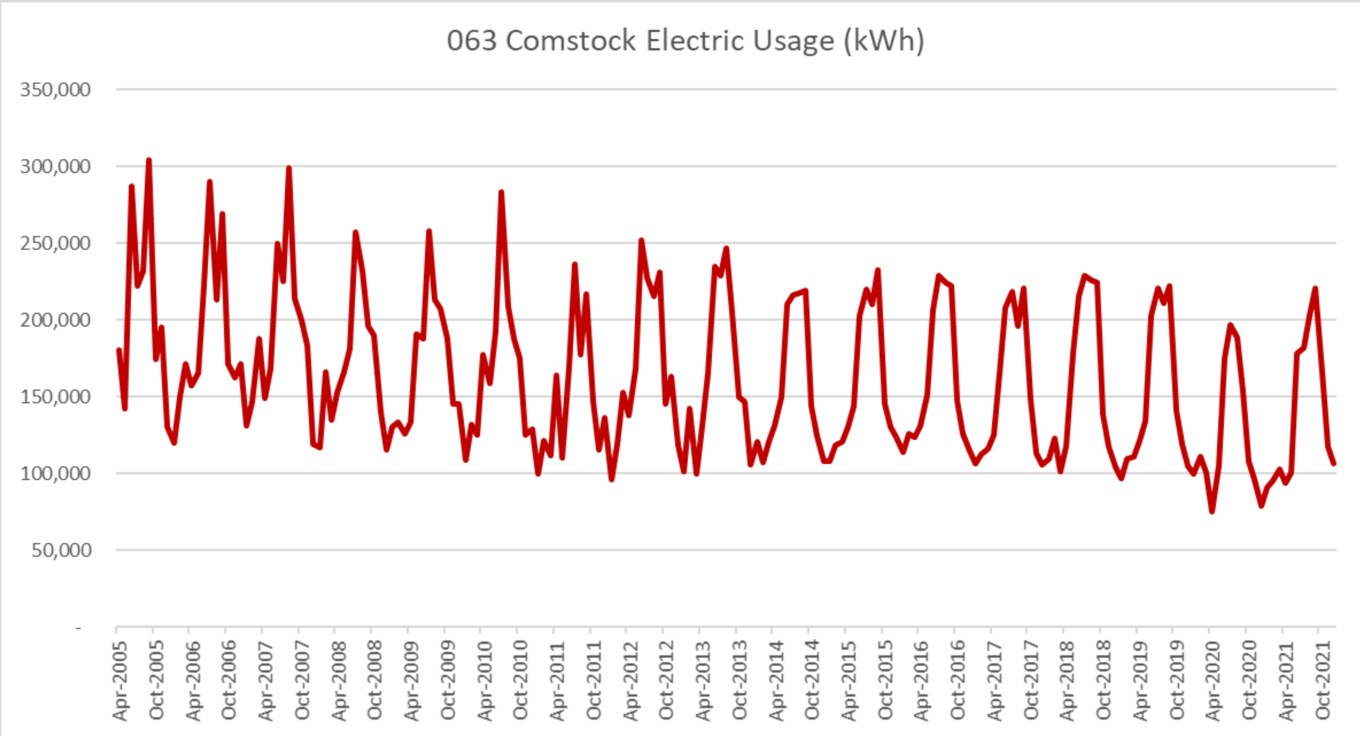


Year	Consumption (kWh)	Billed Cost
2006	1.458.080	$108.012,43
2007	1.393.600	$109.820,41
2008	1.437.920	$111.405,02
2009	1.294.240	$102.732,60
2010	1.272.960	$115.272,01
2011	1.193.600	$117.463,16
2012	1.278.028	$126.652,60
2013	1.246.871	$123.564,92
2014	1.194.193	$119.461,89
2015	1.139.104	$123.894,79
2016	1.238.439	$143.498,17
2017	735.739	$83.684,05
2018	1.247.200	$136.751,02
2019	2.084.411	$227.169,50
2020	2.071.907	$227.417,58
2021	2.433.675	$281.098,01

In this information regarding Pioneer Hall's electric consumption, it is clear that in the last 3 years the consumption has growth enormously, doubling numbers from past years.

This building was renovated in the last years, making it one of the main buildings for freshman students. This obviously derives in a considerable increase in bill costs.

- *Comstock*: (Table 9 : Consumption in kWh a year and its cost; Figure 9 : Monthly consumption in kWh)



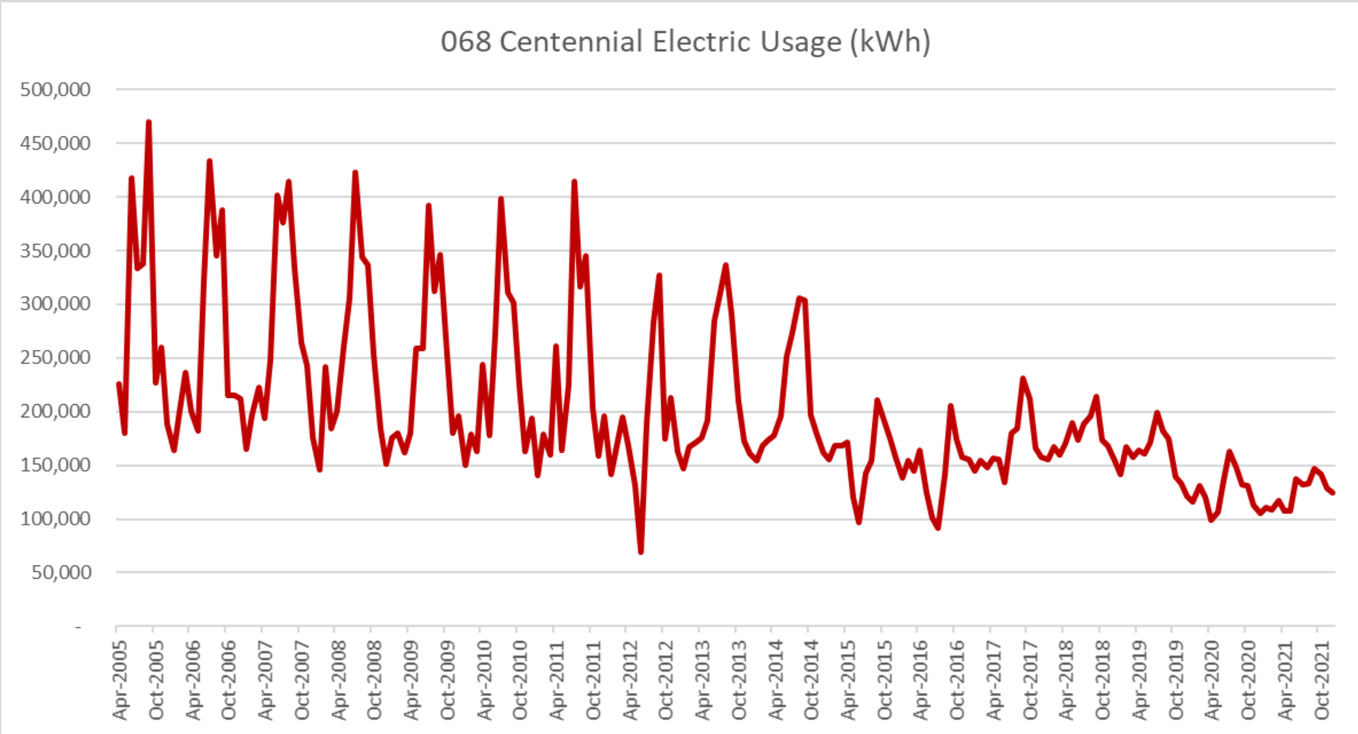
Year	Consumption (kWh)	Billed Cost
2006	2.262.000	$170.150,49
2007	2.273.000	$178.907,90
2008	2.048.000	$158.334,50
2009	2.057.000	$164.491,91
2010	2.003.000	$184.331,00
2011	1.804.000	$177.865,90
2012	2.025.000	$200.677,50
2013	1.958.000	$194.037,80
2014	1.868.053	$187.229,68
2015	1.885.081	$208.347,71
2016	1.914.820	$222.047,86
2017	1.835.649	$202.116,90
2018	1.883.267	$207.089,50
2019	1.794.457	$195.317,86
2020	1.488.539	$164.053,87
2021	1.656.896	$192.609,78

Compared to Pioneer it is clear that Comstock Hall has lost importance, at least that is what it seems from the consumption data that has been dropping in the last years.

Even though this building is consuming less kWh, the fact that the consumption has not dropped considerably in the last 4-5 years is a good signal that Comstock Hall is still a good building to take into consideration.

It is also visible that even with the reduction in consumption, the prices are comparatively really high.

- *Centennial*: (Table 10 : Consumption in kWh a year and its cost; Figure 10 : Monthly consumption in kWh)



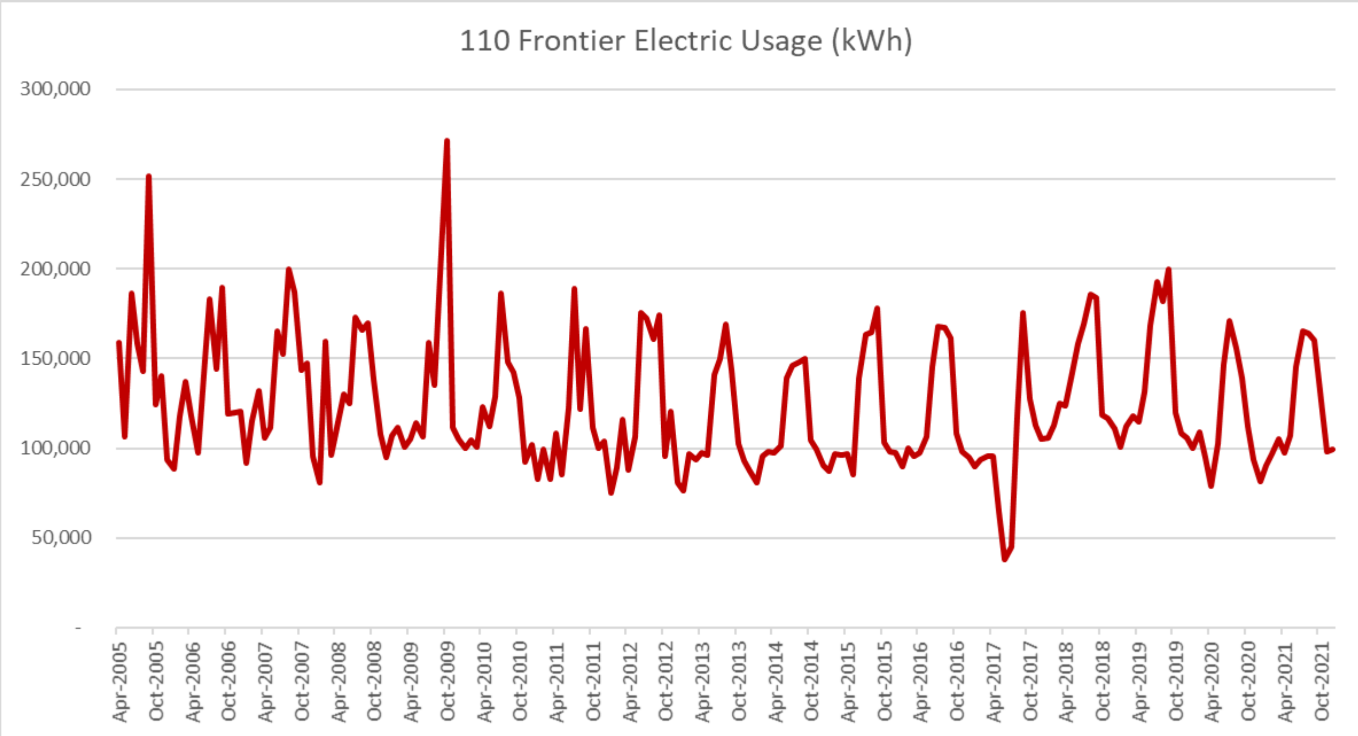
Year	Consumption (kWh)	Billed Cost
2006	3.114.040	$235.262,89
2007	3.236.254	$254.646,14
2008	3.031.560	$234.275,47
2009	2.895.400	$231.775,57
2010	2.778.940	$256.707,84
2011	2.763.140	$273.247,64
2012	2.222.019	$220.202,08
2013	2.617.750	$259.419,02
2014	2.543.891	$254.946,13
2015	1.914.324	$209.344,25
2016	1.753.507	$203.206,93
2017	2.023.981	$223.493,98
2018	2.110.927	$231.488,99
2019	1.912.658	$208.885,35
2020	1.501.461	$165.176,89
2021	1.496.564	$173.195,36

This is one of the most significant cases of reduction in consumption. It is visible that in the last 10 years the consumption has dropped almost to a third of what it used to be.

This is normally due to the fact that in the last years new and more modern residential buildings for students are becoming available making the old ones less attractive.

Even though the consumption has dropped really significantly, the costs the bill is really similar.

- *Frontier*: (Table 11 : Consumption in kWh a year and its cost; Figure 11 : Monthly consumption in kWh)

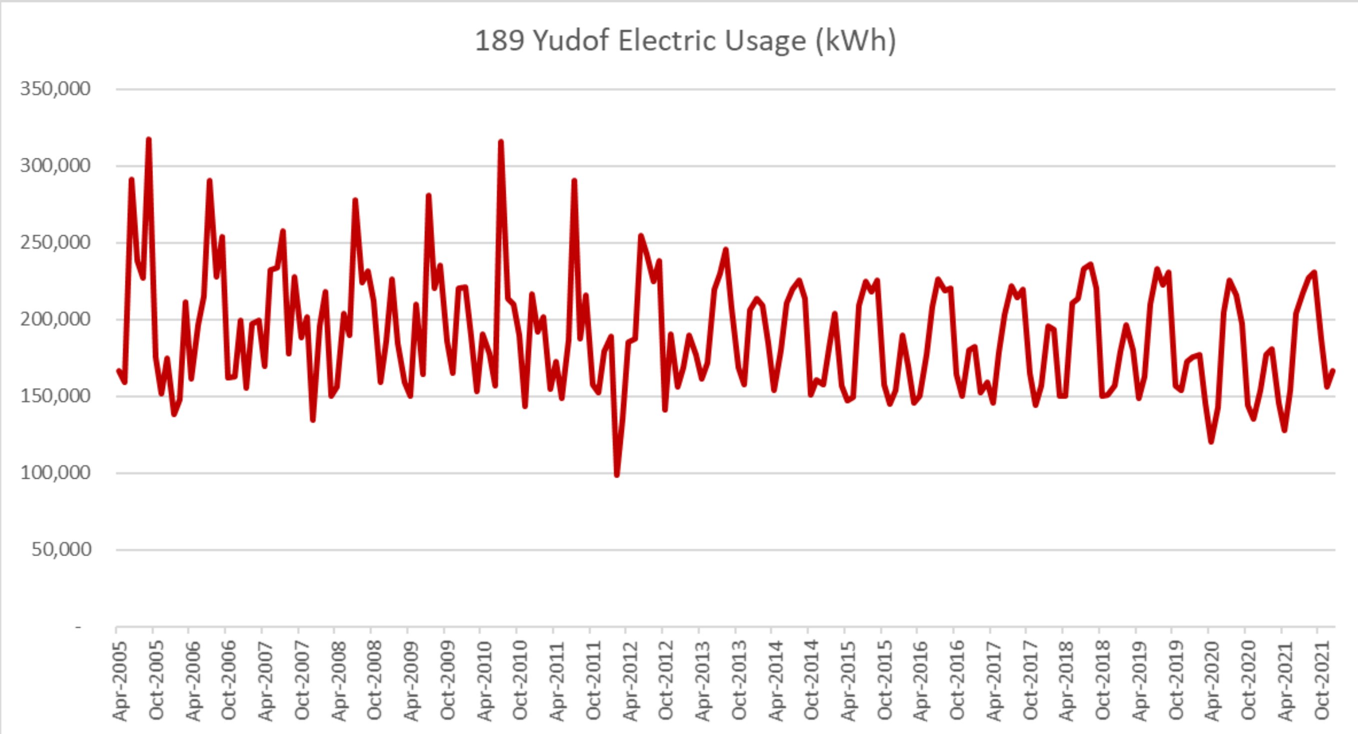


Year	Consumption (kWh)	Billed Cost
2006	1.576.690	$118.394,51
2007	1.647.120	$129.635,13
2008	1.552.780	$120.081,09
2009	1.426.393	$113.845,97
2010	1.468.287	$134.713,57
2011	1.372.184	$135.296,10
2012	1.453.137	$144.005,87
2013	1.346.440	$133.432,21
2014	1.351.924	$135.468,66
2015	1.406.108	$155.411,46
2016	1.432.256	$166.082,48
2017	1.161.532	$128.298,59
2018	1.652.132	$181.410,16
2019	1.653.660	$180.182,82
2020	1.384.379	$152.464,37
2021	1.456.141	$168.787,68

Frontier Hall is probably one the buildings that has kept the consumption more stable. Even through covid the consumption seems the same.

Frontier Hall is one the four buildings of Super Block and the fact that with the renovations in Pioneer is still keeping the same numbers in terms of consumption is something positive for the university.

- *Yudof*: (Table 12 : Consumption in kWh a year and its cost; Figure 12 : Monthly consumption in kWh)

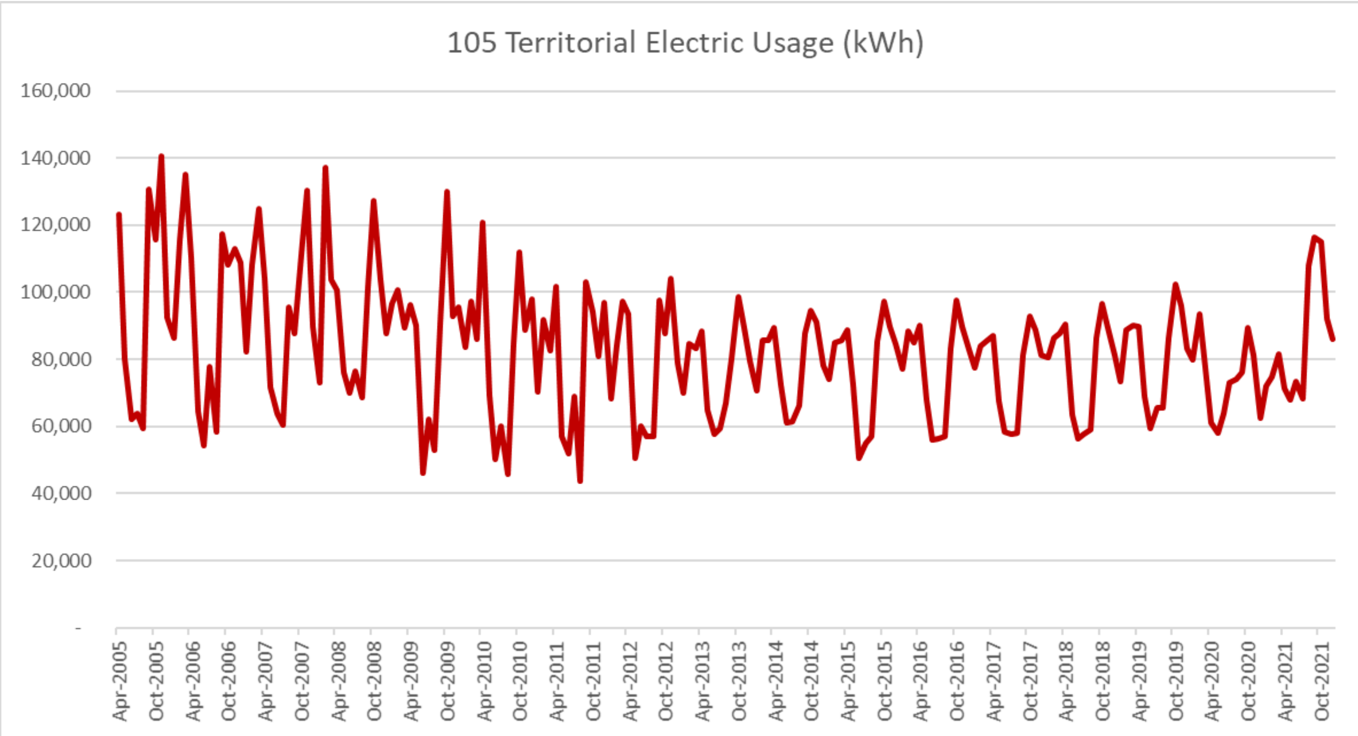


Year	Consumption (kWh)	Billed Cost
2006	2.368.595	$177.027,85
2007	2.375.919	$187.130,35
2008	2.404.769	$186.016,52
2009	2.402.747	$191.653,49
2010	2.377.565	$217.249,37
2011	2.240.356	$220.714,47
2012	2.245.064	$222.485,82
2013	2.305.134	$228.438,77
2014	2.279.933	$228.218,51
2015	2.174.244	$238.516,38
2016	2.202.248	$255.289,27
2017	2.143.658	$236.850,09
2018	2.261.857	$248.054,27
2019	2.247.561	$245.223,27
2020	2.039.133	$224.391,85
2021	2.174.287	$251.743,08

Yudof has also kept a pretty sable consumption for the last 15 years which is something good.

Yudof is also one of the buildings with higher consumption numbers so the installation of solar panels could be very beneficial, even more if we consider the growth in the price of light.

- *Territorial*: (Table 13 : Consumption in kWh a year and its cost; Figure 13 : Monthly consumption in kWh)



Year	Consumption (kWh)	Billed Cost
2006	1.149.250	$85.258,15
2007	1.129.750	$89.014,26
2008	1.125.747	$87.179,38
2009	1.042.950	$82.844,05
2010	995.700	$89.921,19
2011	943.300	$92.875,87
2012	936.704	$92.827,37
2013	922.256	$91.395,57
2014	943.374	$94.406,40
2015	924.867	$100.755,57
2016	930.790	$107.842,26
2017	919.973	$102.121,02
2018	934.678	$102.338,46
2019	968.953	$105.861,27
2020	890.204	$97.814,68
2021	1.026.220	$118.836,84

Territorial is one of the lowest consuming buildings between the one being studied.
This does not change the fact that after covid it had the highest consumption numbers of the last 10 years.
This is something positive for this project as more money can be saved from the bill cost if the consumption keeps going up.

After this analysis of recent consumption and costs of light it is more clear the amount of money that could be saved in future years.

For the calculation of the profitability time Xcel Energy is going to be used as an example of how much could the estimated time be (the University of Minnesota is working with them in other projects). It would go as follows: [10]

From the previous calculations it is measured that for the installation, the total cost is going to be around 2,217,041.1 $. In this matter, the type of payment or loans applied change other factors in terms of savings in future years, but that would be a decision for the University of Minnesota to make.

After this, as mentioned earlier in this part of the thesis, from the Federal Reserve System (FRS), an incentive can be obtained of around 22% if this takes place in 2023 (from 2020-2022 it was an incentive of 23% and it was of 30% up to 2019. It is expected to change in 2024, but it is unsure how) [13]. With this, an amount of around 487,749$ can be tax credit if it was to be paid the first year.

Xcel Energy for example pays up to $0.08/kWh (it can even go up to 0.13$/kWh), other companies use similar ratings. With this, a total of 621,480.96 $ would be saved the first year (there is a total of 7,768,512 kWh solar per year in this project).

If all the cost of installation was to be paid the first year, that would mean:

- **Year 1:** 2,217,041.1 - 487,749 = 1,729,292 $ are paid and 621,480.96$ are saved in electric bills.
- **Year 2:** 1,729,292 - 621,480.96 = 1,107811.04$ still to be recovered and approximately 621,480.96 saved in bills.
- Same process as year 2 …

It is unsure how the cost of electricity will change, but if it was to maintain a similar pricing as it has today, this project would be profitable in around 4 years if the university was to pay everything in the first year. This will probably not be the case, as loans and other types of money movements are involved, but this shows that solar panels are rapidly paying off. There are also other incentives such as PV Demand Credit that allows the systems with more than 40 KW AC to save 6.96¢/kWh for electricity generated between the hours of 1pm and 7 pm.

There is also the fact that all of the university's solar systems are Net Metered. So, anytime the system is generating more power than the building is consuming, the excess energy flows back to the utility and the customer receives credit for the energy generated and not consumed. The University of Minnesota uses a lot of energy, for example the biggest interconnected distributed solar generation is on the West Bank and is 1 megawatt / 1000 kilowatts). This is something to take into consideration as in summer the university would profit in great numbers as the amount of sun is higher and the amount of consumption is lower as there are less students living on campus. This is not a crucial factor in terms of finding profitability numbers but it is worth mentioning it.

3.3. Conclusion

In this third part of the project, profitability is the subject being analyzed. As mentioned in the first section when variables are discussed, elements such as weather, initial investment or the company being selected for installation make a huge difference.

When talking about numbers, for incentives, Xcel Energy was used as their incentive is relatively average with $0.08/kWh. This number varies from around $0.05/kWh to up to $0.12/kWh, just by looking at some of the options on the internet. With these incentives and the government's help with tax discounts, solar panels are becoming a really affordable way of energy. It is worth mentioning that in relation to the tax incentives given by the government, they have dropped from 30% in 2019 to 22% in 2023. It is also true that during this period the price of installation has dropped significantly and so these incentives are in some way less necessary for the customer.

It has been observed in the graphs and tables of this section that the increase in the cost of light is clearly visible as with a similar consumption in kWh a year from the buildings the prices keep growing. This is mainly one of the reasons PV systems are becoming so profitable.

In this part of the study it has been calculated that if the university was to pay the entire cost the first year, after only around 4-5 years (depending on various factors such as change in incentives and costs of light, types of loans and others) the University of Minnesota would start to gain profit. This also depends on the year that this project would start as this is a field in constant development and in 5 years the prices may have changed significantly.

4. REDUCTION OF COSTS

In the fourth part of this study, there will be various analyses concerning the expense the university and the students make in terms of electricity. One of the most important objectives of this study is to be able to reduce expenses in student life for future generations. Each building has different usage quantities so this part of the study will look at each of one separately.

4.1. Past and present costs

The following section will try to give an idea of how much a student spends in housing expenses in general, and that will be compared with how much is spent in light costs. There will also be a final table regarding how much could be saved in terms of electrical costs.

Figure 14

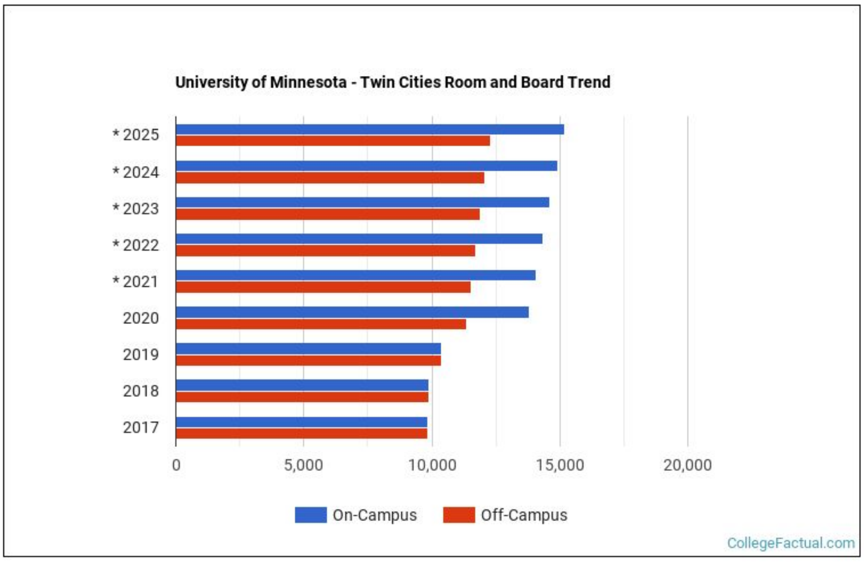


Figure 14. Representation of general student expenses in room and board since 2017 and the expected changes until 2025. Source [14]

Cost of kW consumption for the entire building in the last three years in terms of light and the price students pay a semester [15] (for the price, there is only information available from 2021, so that is the one included):

- *Sanford*:

  Table 14

Year	Bill cost of light ($)	Price/semester
2019	145,418.39	-
2020	120,057.15	-
2021	150,062.32	$3,144 - $3,951

Table 14. Table regarding Bill costs in $ from 2019 to 2021 and the price of Housing living costs per semester in 2021 in Sanford Hall.

- *Pioneer*:

  Table 15

Year	Bill cost of light	Price/semester
2019	227,169.5	-
2020	227,417.58	-
2021	281,098.01	$3,144 - $3,951

Table 15. Table regarding Bill costs in $ from 2019 to 2021 and the price of Housing living costs per semester in 2021 in Pioneer Hall.

- *Comstock*:

  Table 16

Year	Bill cost of light	Price/semester
2019	195,317.86	-
2020	164,053.87	-
2021	192,609.78	$3,144 - $3,951

Table 16. Table regarding Bill costs in $ from 2019 to 2021 and the price of Housing living costs per semester in 2021 in Comstock Hall.

- *Centennial*:

Table 17

Year	Bill cost of light	Price/semester
2019	208,885.35	-
2020	165,176.89	-
2021	173,195.36	$3,144 - $3,951

Table 17. Table regarding Bill costs in $ from 2019 to 2021 and the price of Housing living costs per semester in 2021 in Centennial Hall.

- *Frontier*:

Table 18

Year	Bill cost of light	Price/semester
2019	180,182.82	-
2020	152,464.37	-
2021	168,787.68	$3,144 - $3,951

Table 18. Table regarding Bill costs in $ from 2019 to 2021 and the price of Housing living costs per semester in 2021 in Frontier Hall.

- *Yudof*:

Table 19

Year	Bill cost of light	Price/semester
2019	245,223.27	-
2020	224,391.85	-
2021	251,743.08	$3,724 - $5,773

Table 19. Table regarding Bill costs in $ from 2019 to 2021 and the price of Housing living costs per semester in 2021 in Yudof Hall.

- *Territorial*:

  Table 20

Year	Bill cost of light	Price/semester
2019	105,861.27	-
2020	97,814.68	-
2021	118,836.84	$3,144 - $3,951

Table 20. Table regarding Bill costs in $ from 2019 to 2021 and the price of Housing living costs per semester in 2021 in Territorial Hall.

In the billing cost of the light it is clear how the COVID year affected, but in 2019 and 2021 it is possible to get a good idea of an approximate bill for the years to come. This section helps give an idea of how much a student pays a semester compared to how much the University of Minnesota spends in light. Obviously, the amount students pay includes a wide variety of variables apart from light, but it still helps get an idea. In the next section it will be seen how much money can be saved from the light expenses and in what approximate quantity the student expenses can be reduced.

4.2. Possible improvement

After the analysis made in the first section of this fourth part of the study and with the information with the profitability part, the next step is to know how much money could be saved by the university and the students. In the part of the thesis that talks about installation costs, it is also studied how much kWh a year can be used with only solar energy. In this section that information will be used in order to know how much the electrical bill and the student payments will go down. First, it necessary to know how much the buildings end up paying per kWh last year:

Table 21

HOUSING HALLS	kWh 2021	BILL COST 2021 ($)	$/kWh
Sanford	1,298,896	150,062.32	0,1155
Pioneer	2,433,675	281,098.01	0,1155
Comstock	1,656,896	192,609.78	0,1155
Centennial	1,496,564	173,195.36	0,1155
Frontier	1,456,141	168,787.68	0,1155
Yudof	2,174,287	251,743.08	0,1155
Territorial	1,026,220	118,836.84	0,1155

Table 21. Table collecting kWh and bill cost in 2021 with its corresponding $/kWh.

In the next table, it will be possible to observe a comparison of the kWh that is needed and the generated with solar power to calculate how much money would be spent in electric bills after the installation of solar panels in the housing halls.

Table 22

HOUSING HALLS	Total kWh -Solar Energy kWh in a year	AVERAGE BILL COST ($)
Sanford	0	0
Pioneer	781,101	90,219.91
Comstock	611,390	71,072.47
Centennial	0	0
Frontier	254,269	29,473.43
Yudof	1,401,655	162,286.28
Territorial	725,752	84,042.48

Table 22. Table providing the total kWh not being solar and its corresponding cost.

As it has been discussed before in this study, when it is represented that the bill for Sanford and Centennial is cero, it does not mean that the buildings will run the entire year on solar energy, but that during the summer months it is expected that they generate more than they need and this surplus goes to other buildings as the campus of the University of MInnesota shares the same electrical system between buildings.

So, after this comparison, this is the money being saved in each Hall (comparison made with the last year in records, that is 2021) :

- Sanford: 150,062.32 $
- Pioneer: 190,878.1 $
- Comstock: 121,537.31 $
- Centennial: 173,195.36 $
- Frontier: 139,314.25 $
- Yudof: 89,456.8 $
- Territorial: 34,794.36 $

For this study, it was not possible to know what percentage of what students pay for housing goes to pay electric bills, so, in case this study was taken into reality. The next table will provide the percentage of the electrical bill being saved and that percentage can be applied to the fraction students pay.

Table 23

HOUSING HALLS	MONEY SAVED ($)	PERCENTAGE OF THE ELECTRICAL BILL SAVED
Sanford	150,062.32	100%
Pioneer	190,878.1	67,9%
Comstock	121,537.31	63,1%
Centennial	173,195.36	100%
Frontier	139,314.25	82,54%
Yudof	89,456.8	35,53%
Territorial	34,794.36	29,27%

Table 23. Table representing money saved and what part of the past bill would have been saved.

4.3. Conclusion

One of the main reasons to start this project was the idea of trying to help students reduce student costs. This project aims to help both the University of Minnesota and the students reduce the amount of money paid yearly in terms of light expenses. In this part of the study it has been seen that it is possible to do this.

One of the negative aspects of this section is that it was not possible to know what percentage of the amount students pay goes to light expenses, but it was possible to know in what percentage the electrical bills will drop. With this, it is now only necessary for the university to take that percentage out of the students' costs of living in the section of electricity.

There are a good number of buildings that can reduce in great quantities the cost of electricity such as Sanford, Centennial or Frontier, all over 80%. Although as mentioned before, this study works with average numbers, and so in the months of summer more power will be generated than in winter and so the percentages will change but during summer more buildings apart from the housing halls will be able to operate on solar power due to the interconnected electrical system.

5. POLLUTION

In this fifth part of the study, the theme of pollution is talked about as it is one of the main aspects in which this project could adapt to the University of Minnesota's greenhouse emission reduction plan.

5.1. Past and present greenhouse gas emissions plans

In this first section, the action plan that has been going on since 2011 is the one going to be discussed. Last year the University of Minnesota reduced greenhouse gas emissions by 51% since 2008. In the next two figures it can be observed what the emissions were in 2008 and in what years the university wants to reach emission reduction goals. Both figures come from the action plan document developed by the university and provided by the Department of Sustainability of the University of Minnesota.

Figure 15

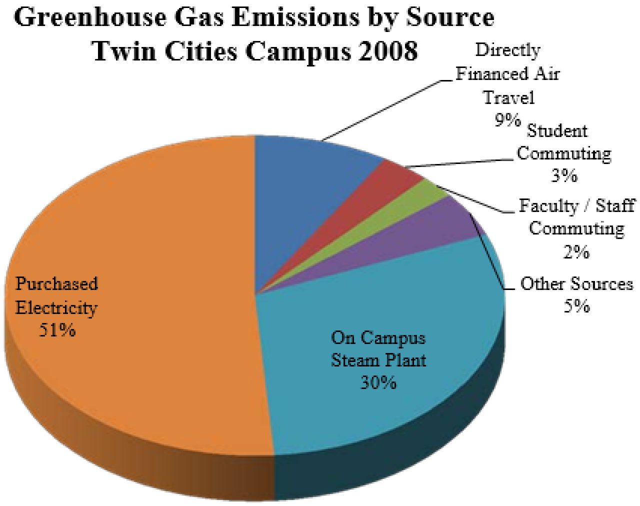
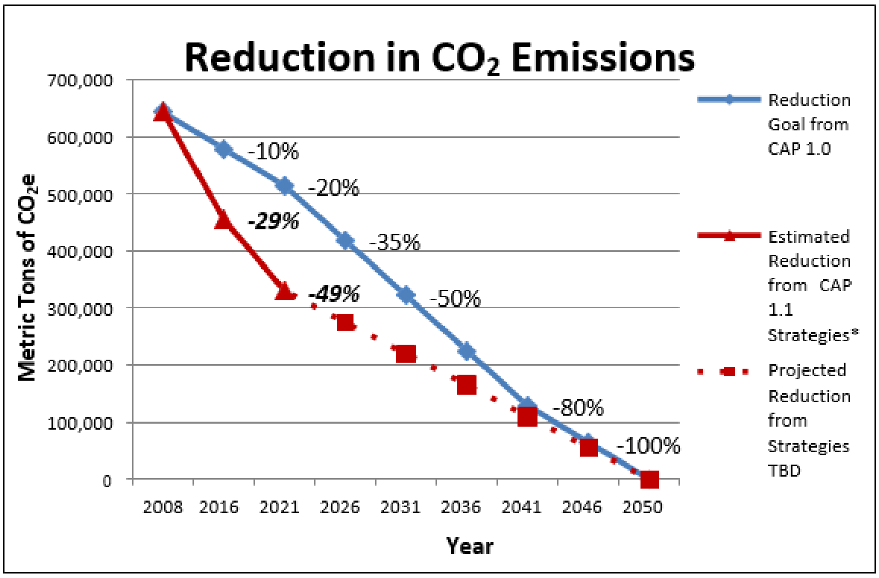


Figure 15. Graphic representation of the greenhouse gas emissions in 2008 by the UMN. Source [16]

Figure 16



*Relative to 2008 baseline, using current energy use and emissions.

Figure 16. Projection of the reduction in CO2 emissions by the UMN. Source [16]

The following information summarizes the CO_2 emission reduction strategy since 2017. The next information has been directly extracted from the action plan document [16]:

Strategies for 2017-2021

Projects from the initial five years will continue to be implemented and add to reductions in the campus' emissions. Continued projects include:

(Est. Savings[3]/Simple Payback[4]/ CO_2 Reduction[5])

Building Recommissioning	**$2,887,000/ 4 /52,400**
Sustainable Building 2030 Guidelines	**$3,837,000/ 15 /57,200**
Laboratory Energy Efficiency Projects	**$3,322,000/ 17 /111,900**
Reduce Campus Size (additional 500,000 GSF)	**$7,000,000 / 9 /22,000**
Renewable Energy Pilot Projects	**To Be Determined**

[3] Estimated annual operating costs (in dollars) avoided or saved by 2021.
[4] Period of time, in years, that it will take for the net annual financial savings to pay back the upfront costs required to implement the strategy. Some of the strategies listed involve several projects with different paybacks. In these cases, the highest payback period is listed.
[5] Estimated annual metric tons of CO_2 equivalents reduced by 2021.

In addition, new projects are proposed for implementation between 2017 and 2021, including:

Combined Heat and Power Plant **TBD – In Design/TBD /65,000**

The University will build a 14MW Combined Heat and Power (CHP) plant to augment the University's Southeast Steam Plant. The CHP will generate electricity and use the excess heat produced to create steam for the campus' heating and cooling needs, increasing efficiency and reducing waste during the energy generation process.

Window Replacement **$409,000/ 27 /4,600**

Single pane windows will be replaced with double paned windows on approximately 100,000 square feet to improve the building envelope and reduce heating loss.

Projected CO_2 Reduction by 2021……………….313,100 tons CO_2/year

Figure 17

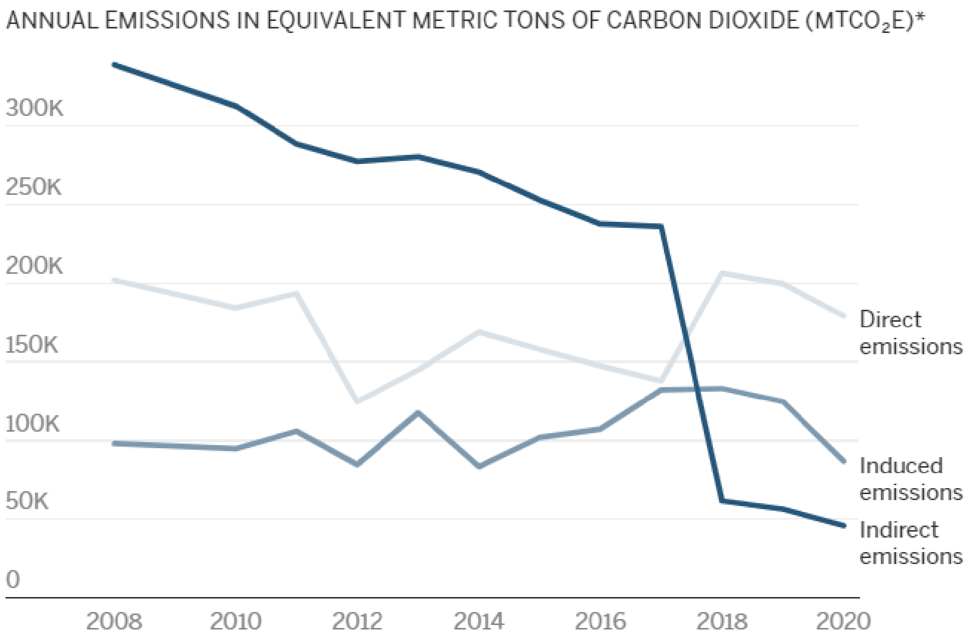


Figure 17. Annual emissions of CO2 in the last years by the UMN. Source [17]

Strategies for 2022 and Beyond

The technologies and policies that will enable a carbon neutral future are constantly and rapidly evolving. Given this, it is difficult to project what specific strategies will be part of the University's solution after 2021 for achieving carbon neutrality. The University expects to revise this plan every two years to account for this shifting landscape and to begin the process of identifying strategies for the years following 2021.

5.2. Improvements with this study

This study aims to help the University of Minnesota in a wide variety of fields including pollution. In previous sections of this thesis, information regarding the number of panels and square footage that would be used. This information will now be studied in terms of how much it can help the university in its aim of reducing greenhouse gas emissions. The permitted air pollution emissions (from the Minnesota Pollution Control Agency) for the University of Minnesota are included in the Appendix B of this study to give additional information on this topic.

According to the U.S Energy Information Administration : "In 2020, total U.S. electricity generation by the electric power industry of 4.01 trillion kilowatthours (kWh) from all energy sources resulted in the emission of 1.55 billion metric tons—1.71 billion short tons—of carbon dioxide (CO_2). This equaled about 0.85 pounds of CO_2 emissions per kWh."[18]

Here is a table with the main sources of energy and its contribution to the emission of greenhouse gasses (picture obtained from the U.S Energy Information Administration website):

Table 24

U.S. electric utility and independent power electricity generation and resulting CO_2 emissions by fuel in 2020

	Electricity generation	CO_2 emissions		
	million kWh	million metric tons	million short tons	pounds per kWh
Coal	757,763	767	845	2.23
Natural gas	1,402,438	576	635	0.91
Petroleum	13,665	13	15	2.13

Electricity generation is net electricity generation.
Includes electricity-only power plants. Combined heat and power plants are excluded because some of their CO_2 emissions are from fuel consumption for heating purposes.

Table 24. Table with main sources of energy and their corresponding greenhouse gas emissions. Source [18]

Using the fact that about 0.85 pounds of CO_2 were emitted into the atmosphere for every kWh, it is possible to calculate how much of this would be avoided with the kWh obtained from solar power.

From past sections of this study it was obtained the approximate kWh obtainable from solar panels, which are:

Table 25

HOUSING HALLS	Solar Power kWh in a year
Sanford	1,298,896
Pioneer	1,652,574
Comstock	1,045,506
Centennial	1,496,564
Frontier	1,201,872
Yudof	772,632
Territorial	300,468

Table 25. Review of the kWh in 2021 used per building.

If the value of 0.85 lb CO_2 / kWh the amount of reduced emissions would be:

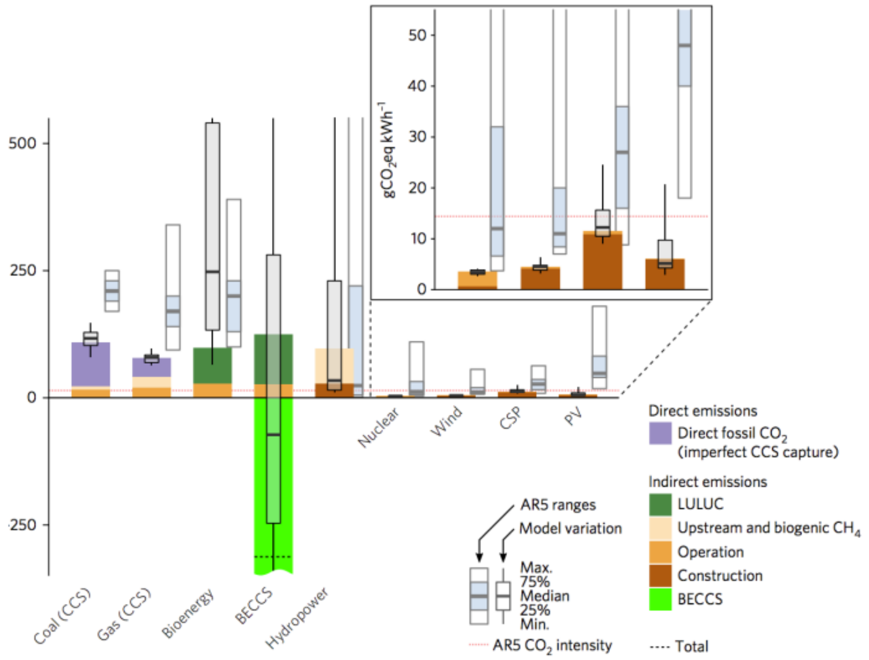
Table 26

HOUSING HALLS	Solar Energy kWh in a year	Avoided emissions of Lb of CO_2 from non-PV sources
Sanford	1,298,896	1,104,061.6
Pioneer	1,652,574	1,404,687.9
Comstock	1,045,506	888,680.1
Centennial	1,496,564	1,272,079.4
Frontier	1,201,872	1,021,591.2
Yudof	772,632	656,737.2
Territorial	300,468	255,397.8

Table 26. Comparison between how much solar energy could be generated and the avoided emissions of CO2.

This all contributes to a total of 6,603,235.2 lb CO_2 reduction in a year. To this it will be necessary to subtract the carbon footprint PV systems generate. This number will be considerably lower, but there is still some greenhouse gas emissions due to power generation from solar panels. In the next figure there is a representation of what the government is hoping for the emissions to be around 2050 from renewable and not renewable energy sources.

Figure 18



Lifecycle direct and indirect greenhouse emissions associated with generating a unit of electricity from different fuels, in a 2C world in 2050 (coloured bars). The colours break down these emissions by source. For comparison, the light blue ranges show the range of results published in the latest Intergovernmental Panel on Climate Change assessment, AR5. Source: Pehl et al.

Figure 18. Projected emissions by source of generation in 2050. Source [19]

The carbon footprint of PV systems right now is around 50 g CO_2 /kWh [20]. These emissions occur during the construction phase of the solar panels, as later they do not pollute. The next table will provide the emissions made by solar panels to compare it to what it saves in terms of CO_2 compared to non-renewable energy sources. To be able to compare it with the above tables in this section of the thesis, pounds of CO_2 will be used. With this, it will calculated that around 50 * 0.00220462 = 0.110231 lb CO_2 /kWh is emitted.

Table 27

HOUSING HALLS	Solar Power kWh in a year	emissions of Lb of CO_2 from PV sources
Sanford	1,298,896	143,178.605
Pioneer	1,652,574	182,164.885
Comstock	1,045,506	115,247.172
Centennial	1,496,564	164,967.746
Frontier	1,201,872	132,483.552
Yudof	772,632	85,167.998
Territorial	300,468	33,120.888

Table 27. Emissions of CO2 by PV systems and the kWh generated by this source.

And now, if the data is compared to what is saved from non-renewable sources, the actual amount of pounds of CO_2 is:

Table 28

HOUSING HALLS	emissions of Lb of CO_2 avoided with PV
Sanford	960,882.995
Pioneer	1,222,523.015
Comstock	773,432.9281
Centennial	1,107,111.654
Frontier	889,107.6476
Yudof	571,569.202
Territorial	222,276.9119

Table 28. Total emissions of CO2 avoided between solar energy and non- renewable sources.

Due to the lack of information about emissions of other gasses, this study will only talk about CO_2 as they serve as a good reference and they are one of the most taken into account when developing a renewable project.

5.3. Conclusion

In this part of the project one of the most important and controversial aspects in the generation of energy was analyzed and that is pollution.
In Appendix B, it is possible to see all the limitations in terms of air pollution by pollutants set by the Minnesota Pollution Control Agency.

For the numerical analysis of this part of the study, this thesis talked about CO_2 emissions as it is one of the most representative and it is the most available when it comes to collecting data. The energy generation emits a wide variety of air pollutants, but even with just evaluating CO_2 emissions this study can provide a good idea of how beneficial PV systems are. In this section it can be observed that buildings such as Pioneer and Centennial could save up to over a million pounds of CO_2 a year.

One of the aims of this study is to collaborate in the Climate Plans the University of Minnesota has for the future and after analyzing the data it is clear it can be of great help. The next section of the thesis will talk about possible expansion, as this study only talks about 7 buildings but there are more than a hundred on campus. Solar panels and renewable energy is a field that the university can work on in the next few years as it is clear it contributes greatly in the reduction of air pollutants.

6. POSSIBLE EXPANSION OF THE PROJECT

In this last part of the thesis, the possibility of expanding this project to other buildings will be briefly studied. The University of Minnesota has more than a hundred buildings between the east and west bank campuses. This gives the opportunity to make a real difference in terms of energy savings.

6.1. Feasibility of plan expansion

In this first section of the last part of the thesis, this study will look at feasibility. In this study 7 buildings are being analyzed. This means that not all the housing buildings are being included. This is mainly because the project would have become too big for this study to approach it correctly.

For this section, this study will look at what qualities a building should have to be eligible. This main qualities are:

- *Height*: It would be optimal for the building to be around 3 - 6 floors high as it is more convenient for installation and accessibility purposes.

- *Age*: It is preferable to find buildings no more than 30 years old, as it is important in terms of roof quality. Also, new buildings will not suffer renovations in the next few years.

- *Electrical access*: It is very necessary that the building's electrical access runs through the inside of the building so as to not have electrical issues connecting the solar panels to the grid.

- *Roof space*: One of the most important aspects is to find buildings that have an optimal roof to install solar panels. The less roof drains, vent stacks and windows the building has, the better.

For this section of the study, the data obtained from the EMPORIS website will be used. Emporis is a provider of building data (link in the bibliography).[2]

There is information about 135 buildings on campus. Looking at the information from these buildings it can be possible to obtain the ones in the height and age range.

- In terms of **height** there are a total of 109 buildings under 6 floors (this is around 74 ft tall)
- In terms of **age** a total 26 out of the 109 are available.

This buildings are (year of building in parenthesis):

- *6 floor buildings (74 ft)*
    - ❖ Nils Hasselmo Hall (1996); Molecular & Cellular Biology Building (2002); Winston and Maxine Wallin Medical Biosciences Building (2009)
- *5 floor buildings (62 ft)*
    - ❖ Carlson School of Management (1998); Lions Research Building (1992); Middlebrook Hall East (2001); Bruininks Hall (2010); Center for Nanostructure Applications (2013); Microbiology Research Facility (2015); Cancer & Cardiovascular Research Building (2013); Land O'Lakes Center for Excellence (2018); Health Sciences Education Center (2020);
- *4 floor buildings (49 ft)*
    - ❖ Weisman Art Museum (1993); Elmer L. Andersen Library (2000); Hanson Hall (2008); Roy Wilkins Hall (1996); Ten Mann Concert Hall (1993); Larson Football Performance Center (2018)
- *3 floor buildings (37 ft)*
    - ❖ Barbara Barker Center for Dance (1999); University Recreation Center (1993)
- *2 floor buildings (25 ft)*
    - ❖ Center for Magnetic Resonance Imaging Research (1998); Regis Center for Art East Building (2003); Regis Center for Art West Building (2003); University Boathouse (2007); Landcare Building (2010)

This section of the study will not go more into detail about these buildings as it would require a study the size of this one to analyze each one of the 26 buildings listed above in terms of characteristics regarding electrical access and roof analysis. This study is providing what could be 26 new buildings to add to the list of buildings run with renewable energy as they appear to be potential candidates in terms of height and age. A similar study to this thesis would need to take place to evaluate if it is possible to install solar panels in these buildings.

6.2. Conclusion

In this section of the thesis, the aim was to give a small introduction to possible future work in the field of PV systems. In this thesis, due to the size of the research it concentrated in 7 buildings out of the very many on campus. If this project was taken into action and the results were as positive as they seem on numbers it would make sense to try and expand it. In order to expand, the buildings should have appropriate qualities. These qualities have been described in this section and the buildings on campus filtered through these qualities.

After the evaluation in terms of height and age, there seems to be around 26 buildings that could be potential candidates in the installation of solar panels. This is surely not the final number as there are many other variables to take into account as mentioned all throughout this thesis. With this section of the thesis what is trying to be accomplished is to give the initial start for a future expansion. As it has been seen, evaluating a building takes time and data and that is why this section does not go deeper.

PV systems are an innovative and ecofriendly way of saving costs and help in terms of pollution so it makes sense that in the following years the University of Minnesota starts growing in this field.

7. CONCLUDING REMARKS

This final part of the thesis will try to resume all that has been analyzed in past sections. This thesis has dealt with a really innovative aspect of renewable energy that can be very beneficial in a wide variety of fields such as economic, pollution or even future development and studies at the University of Minnesota. The Department of Sustainability has been helping alongside the project providing valuable information that has been summarized in this thesis. The main objective of this study is that it helps the University of Minnesota if they decide to install solar panels in buildings on campus in the future. This study may not have all that is needed, but it provides a very dense general idea of all that involves PV systems in terms of numbers. It was also explained at the very beginning of the thesis that even though there are plans for renovations in Territorial Hall and Centennial Hall, this study has analyzed them in case they maintain the same outside structure or if if the future renovation plans do not go through. If they were to be totally renovated, this study has at least provided more diversity in the analysis.

7.1. Summary of the results

This study has tried to provide a wide view of what to expect if a project of this size was to take place in the University of Minnesota in the next few years. It has analyzed it in different fields. The first one was the economic cost of installation. In this section it was first necessary to know how much space was available in the roofs of the 7 Halls being studied, these have been: Sanford Hall, Pioneer Hall, Comstock Hall, Centennial Hall, Frontier Hall, Yudof Hall and Territorial Hall. This first step of analyzing the roof provided that approximate square footage available. There was a lot more space than what has been said in this study, but it could not be used for installation as many buildings had various sections with many vent stacks and roof drains. Sanford and Centennial had the most usable space with more than 10,000 square footage each. The lowest was Territorial with approximately 1720 square footage available.

It was later necessary to know how many panels and how many kWh could be gained from that available space. Analyzing panels with a rate of 350 W (as it is a very average amount), it was possible to see that both Sanford and Centennial could make enough energy in a year to sustain themselves. In this matter as it has been described before, this study is doing an average observation on the installation, this means that during winter months when there is not enough light, the buildings would need to use the previous electrical methods. The important observation is that all the buildings in the university run under the same interconnected system for electrical energy, and so, the months when the buildings generate more than they need, this could go to sustain the electrical use of other buildings on campus. That is why in the end, it adds up to approximately the same amount of money that if the building could sustain itself on solar power all year.

When proceeding to analyze the cost, it was difficult to know an approximate exact number, but in documents provided by the Department of Sustainability, it was given that it was an approximate of \$2.5/W in Massachusetts and New York that are states with similar costs. This provided that an approximate cost of installation, if following the values used, would be of around 2,217,041.1 \$. This could vary as it was described later depending on the final efficiency of the panels (choice to be made by the University of Minnesota) and variables such angled roofs and different heights in the buildings may vary the price of installation, but that is also an aspect that varies according to the company selected for installation.

After obtaining an approximate amount this study worked on profitability. This is something that can vary greatly, in great part depending on the initial investment. This is due to the incentives provided by the government, as the Federal Reserve System (FRS), an incentive can be obtained of around 22% if this takes place in 2023 (from 2020-2022 it was an incentive of 23% and it was of 30% up to 2019. It is expected to change in 2024, but it is unsure how) and the incentives provided after installing solar panels are also a key factor in the fast growth of this type of renewable energy as these incentives can be around \$0.07 - \$0.08 /kWh, but they are in constant change and could vary in the next years. With the numbers as they are right now, if all the investment necessary was to be made the first year, the university could recover this money in less than 5 years as the quantity of solar energy made and the incentives are significant.

The next section is mainly focused on students as this study could help reduce the cost of housing in terms of light costs in years to come. It would obviously also help the University of Minnesota in terms of reducing electrical costs too, but also attract more students for a cheaper living situation than other universities. The 7 buildings being analyzed have the same student housing costs except for Yudof, but it is still around the high 3000\$ - 4000\$. After analyzing the solar energy obtained from the panels and what it saves in terms of electricity it was directly calculated how much money could be saved from the bill cost. For this study, the 2021 bill cost, but this number will grow in the following years as the price of light has grown a considerable amount in a very short time. (This can be seen in the profitability section in the graphics. It is very clear visually how the consumption in some buildings has dropped, but the cost of light is still the same or even higher). After the entire analysis it was obtained that in percentage, Sanford Hall, Centennial Hall and Frontier Hall could reduce in more than 80% their annual light expense, and all the buildings except Yudof and Territorial (the ones with smallest available space for installation of solar panels) could cover more than 60%.

Another very important aspect covered in this study was pollution. The permitted air pollution emissions (from the Minnesota Pollution Control Agency) for the University of Minnesota are included in the Appendix B of this study to give additional information on this topic. In terms of pollution, this thesis has concentrated on talking about the air pollution caused by carbon dioxide CO_2. Using an average value of 0.85 pounds of CO_2 emitted into the atmosphere per kWh by non- renewable sources of energy and with 0.110231 pounds of CO_2 being emitted by the fabrication and installation process of solar panels, it was possible to obtain how much is saved in emissions which is around 5,746,904.354 pounds of CO_2 a year that are not emitted into the air by the installation of solar panels. This could really help the University of Minnesota in its efforts to reduce greenhouse gas emissions as the objective is to have no CO_2 emissions by 2050.

Finally, in the last section of this thesis, it was discussed the possibility of expanding the project to other buildings. This was done through filtering mainly in terms of age and height. For this filtering process the maximum height was established at 6 floors (around 74 ft) and the building had to be constructed in the last 30 years. With this, a total of 26 buildings were available. After this, the next step would be to go through all the steps that have been described throughout this study, so this section did not go into deeper details, but it achieved its goal of trying to provide the university of a good number of possible candidates and the instructions that follow afterwards for analyzing the quality of the building in terms of solar panel installation.

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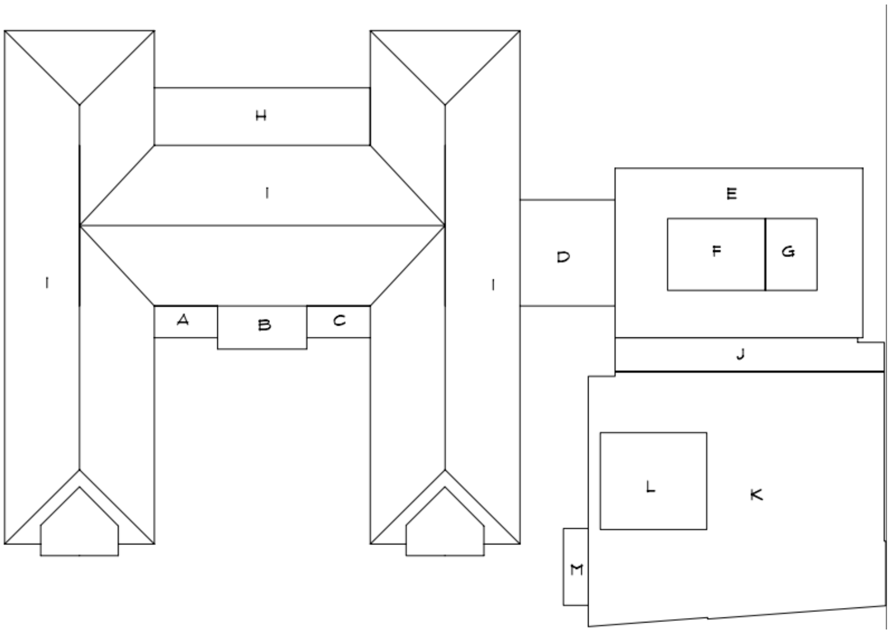
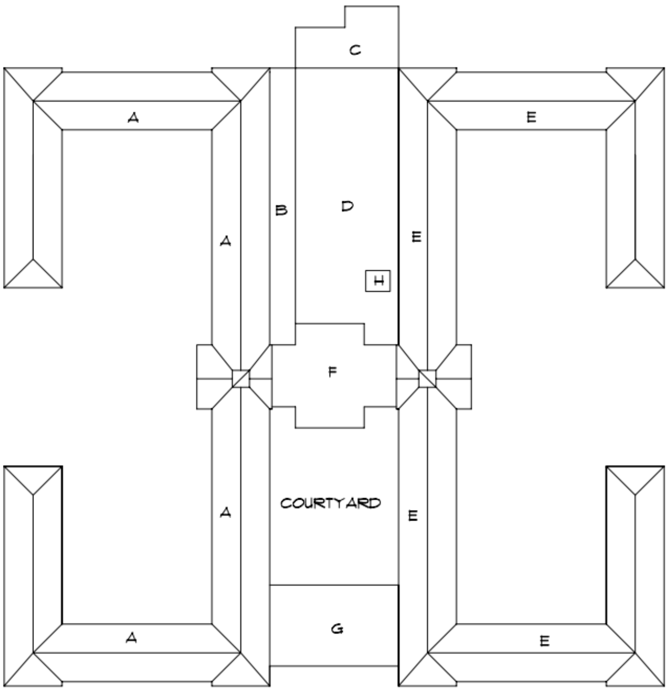
ROOF AREAS

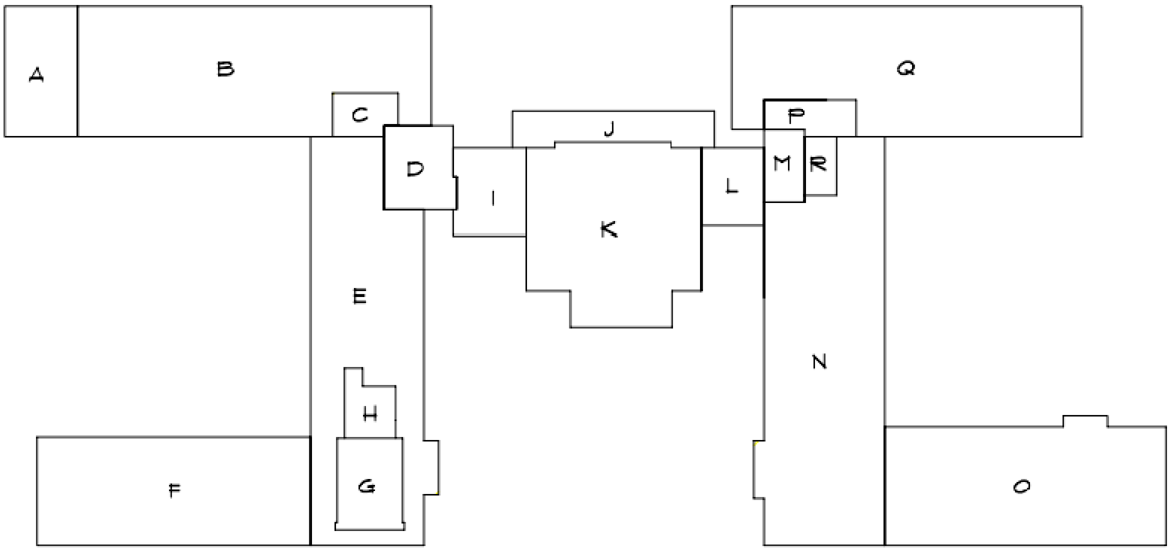
Sanford



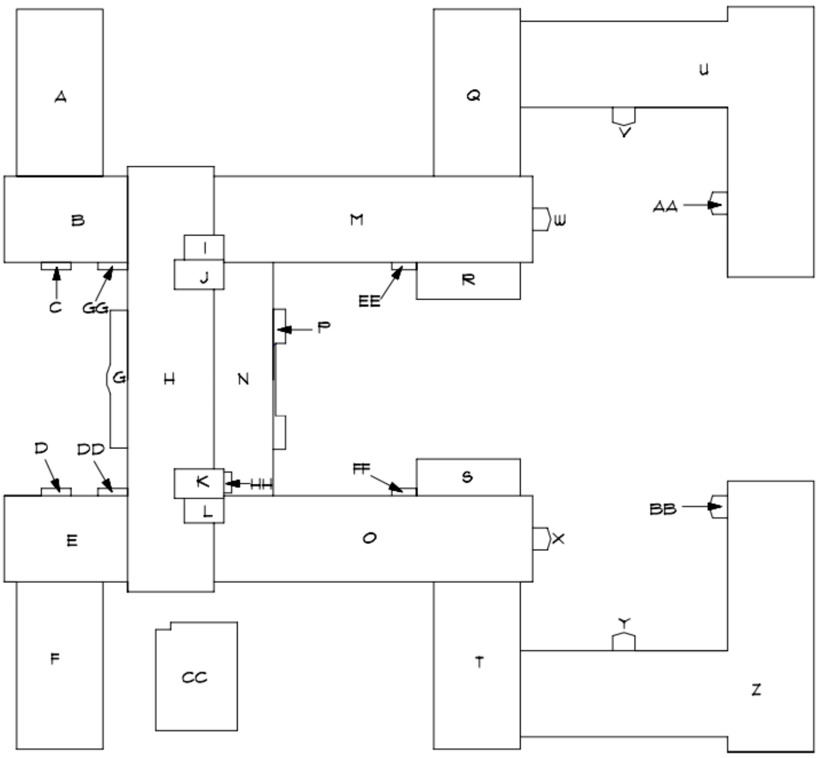
pioneer



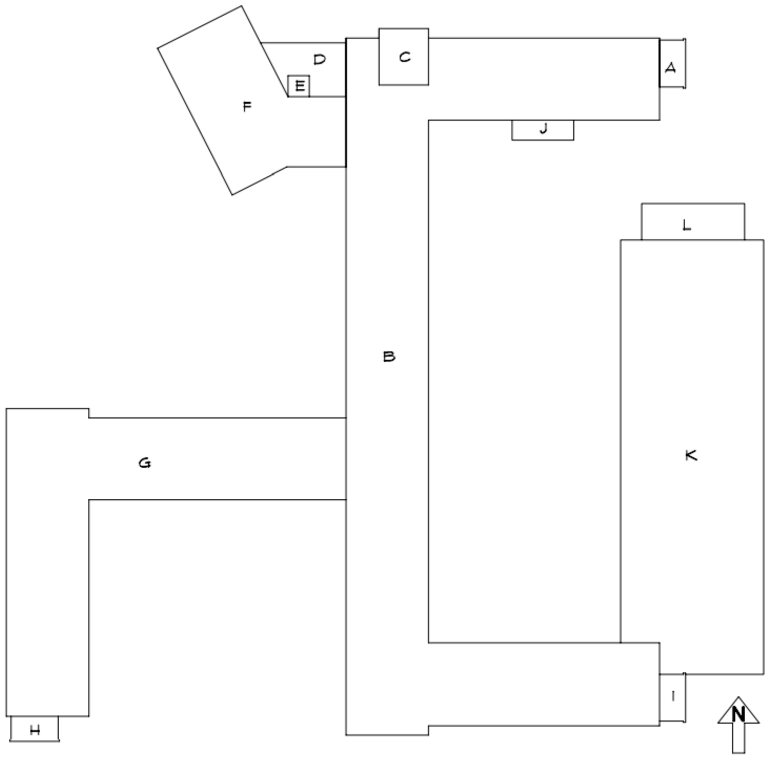
comstock



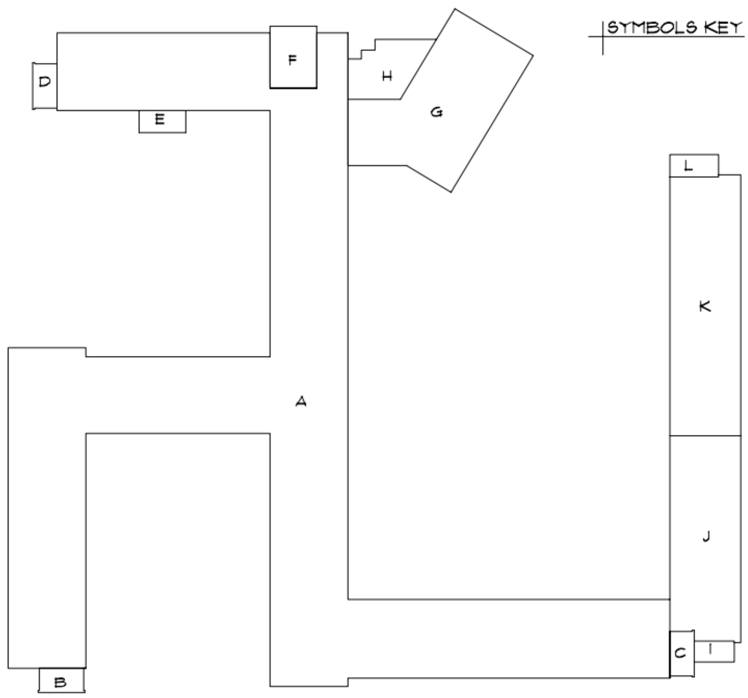
centennial



territorial



frontier



yudof

POLLUTION LIMITS

Facility name	Facility ID	Year	Pollutant	Emissions (Lbs)	Emissions (Tons)
University of MN - Twin Cities	05301050	2020	1,1-Dichloroethane	3.19e-03	1.60e-06
			1,1,1-Trichloroethane	2.70e-02	1.35e-05
			1,1,2-Trichloroethane	4.30e-03	2.15e-06
			1,1,2,2-Tetrachloroethane	5.41e-03	2.71e-06
			1,2-Dibromoethane	7.61e-03	3.81e-06
			1,2-Dichloroethane	5.72e-02	2.86e-05
			1,2,3,4,6,7,8-Heptachlorodibenzodioxin	6.51e-07	3.25e-10
			1,2,3,4,6,7,8-Heptachlorodibenzofuran	1.04e-06	5.20e-10
			1,2,3,4,7,8-Hexachlorodibenzodioxin	9.13e-08	4.57e-11
			1,2,3,4,7,8-Hexachlorodibenzofuran	3.25e-07	1.63e-10
			1,2,3,4,7,8,9-Heptachlorodibenzofuran	3.02e-07	1.51e-10
			1,2,3,6,7,8-Hexachlorodibenzodioxin	7.47e-08	3.73e-11
			1,2,3,6,7,8-Hexachlorodibenzofuran	8.17e-08	4.09e-11
			1,2,3,7,8-Pentachlordibenzofuran	5.75e-08	2.87e-11
			1,2,3,7,8-Pentachlorodibenzodioxin	4.43e-08	2.22e-11
			1,2,3,7,8,9-Hexachlorodibenzodioxin	9.37e-08	4.69e-11
			1,2,3,7,8,9-Hexachlorodibenzofuran	1.02e-07	5.11e-11
			1,2,4-Trimethylbenzene	1.93e-03	9.67e-07
			1,3-Butadiene	1.09e+00	5.47e-04
			1,3-Dichloropropene	3.57e-03	1.79e-06
			1,3,5-Trimethylbenzene	4.57e-03	2.29e-06
			2-Chloroacetophenone	9.45e-03	4.73e-06
			2-Methylnaphthalene	3.33e-02	1.67e-05
			2,2,4-Trimethylpentane	3.38e-02	1.69e-05
			2,3,4,6,7,8-Hexachlorodibenzofuran	1.61e-07	8.07e-11
			2,3,4,7,8-Pentachlordibenzofuran	2.27e-07	1.14e-10
			2,3,7,8-Tetrachlorodibenzo-P-Dioxin	4.78e-08	2.39e-11

			2,3,7,8-Tetrachlorodibenzo furan	3.16e-07	1.58e-10
			2,4-Dinitrotoluene	3.78e-04	1.89e-07
			3-Methylcholanthrene	1.48e-03	7.40e-07
			5-Methylchrysene	2.97e-05	1.49e-08
			Acenaphthene	1.69e-02	8.45e-06
			Acenaphthylene	5.27e-02	2.63e-05
			Acetaldehyde	8.35e+01	4.18e-02
			Acetophenone	2.03e-02	1.01e-05
			Acrolein	1.38e+01	6.91e-03
			Aldehyde	6.84e+02	3.42e-01
			Ammonia	1.37e+04	6.87e+00
			Anthracene	2.14e-02	1.07e-05
			Antimony	2.43e-02	1.22e-05
			Arsenic	7.84e-01	3.92e-04
			Benz(A)Anthracene	1.80e-02	9.02e-06
			Benzene	3.56e+01	1.78e-02
			Benzo(A)Pyrene	2.94e-03	1.47e-06
			Benzo(B)Fluoranthene	2.47e-03	1.24e-06
			Benzo(E)Pyrene	5.62e-05	2.81e-08
			Benzo(G,H,I)Perylene	5.86e-03	2.93e-06
			Benzo(K)Fluoranthene	2.99e-03	1.50e-06
			Benzofluoranthenes	1.49e-04	7.43e-08
			Benzyl Chloride	9.45e-01	4.73e-04
			Beryllium	8.77e-02	4.39e-05
			Biphenyl	3.10e-02	1.55e-05
			Bromoform	5.27e-02	2.63e-05
			Bromomethane	2.16e-01	1.08e-04
			Cadmium	1.04e+00	5.20e-04
			Carbon Disulfide	1.76e-01	8.78e-05
			Carbon Monoxide	1.60e+05	7.99e+01
			Carbon Tetrachloride	5.01e-03	2.50e-06
			Chlorobenzene	3.38e-02	1.69e-05
			Chloroethane	5.70e-02	2.85e-05
			Chloroform	8.35e-02	4.18e-05
			Chromium (III)	1.52e+00	7.59e-04
			Chromium (VI)	1.11e-01	5.56e-05
			Chrysene	5.23e-03	2.61e-06
			CO2-equivalent	3.74e+08	1.87e+05
			Cobalt	2.04e-01	1.02e-04

			Copper	7.98e-01	3.99e-04
			Cumene	7.16e-03	3.58e-06
			Cyanide	3.38e+00	1.69e-03
			Dibenzo(A,H)Anthracene	6.68e-03	3.34e-06
			Dichlorobenzenes	1.44e+00	7.21e-04
			Dimethyl Sulfate	6.48e-02	3.24e-05
			Dimethylbenz(A)Anthracene	1.32e-02	6.58e-06
			Dioctyl Phthalate (Dehp)	9.86e-02	4.93e-05
			Ethylbenzene	5.93e+01	2.96e-02
			Fluoranthene	7.92e-02	3.96e-05
			Fluorene	2.91e-01	1.45e-04
			Formaldehyde	1.42e+03	7.11e-01
			Hydrochloric Acid	1.62e+03	8.10e-01
			Hydrogen Fluoride	2.03e+02	1.01e-01
			Indeno(1,2,3-C,D)Pyrene	5.23e-03	2.61e-06
			Isophorone	7.83e-01	3.92e-04
			Lead	3.31e+00	1.65e-03
			Manganese	8.73e+00	4.37e-03
			Mercury	1.84e-01	9.21e-05
			Methanol	3.38e-01	1.69e-04
			Methyl Chloride	7.16e-01	3.58e-04
			Methyl Ethyl Ketone	5.27e-01	2.63e-04
			Methyl Hydrazine	2.30e-01	1.15e-04
			Methyl Methacrylate	2.70e-02	1.35e-05
			Methyl Tert Butyl Ether	4.73e-02	2.36e-05
			Methylene Chloride	3.94e-01	1.97e-04
			N-Hexane	2.16e+03	1.08e+00
			Naphthalene	4.02e+00	2.01e-03
			Nickel	2.15e+00	1.08e-03
			Nitrogen Oxides	1.59e+05	7.96e+01
			Octachlordibenzofurans, All Isomers	7.59e-07	3.79e-10
			Octachlorodibenzodioxins, All Isomers	1.74e-06	8.70e-10
			PAH/POM	1.71e-01	8.55e-05
			Phenanthrene	3.13e-01	1.56e-04

			Phenol	2.48e-02	1.24e-05
			PM Primary	1.27e+04	6.37e+00
			PM2.5 Primary	1.24e+04	6.19e+00
			PM10 Primary	1.27e+04	6.34e+00
			Propionaldehyde	5.13e-01	2.57e-04
			Propylene	2.52e+01	1.26e-02
			Propylene Dichloride	3.64e-03	1.82e-06
			Propylene Oxide	5.36e+01	2.68e-02
			Pyrene	5.14e-02	2.57e-05
			Selenium	1.92e+00	9.58e-04
			Styrene	3.70e-02	1.85e-05
			Sulfur Dioxide	1.10e+04	5.52e+00
			Tetrachloroethylene	5.84e-02	2.92e-05
			Toluene	2.49e+02	1.24e-01
			Vanadium	1.89e+00	9.46e-04
			Vinyl Acetate	1.03e-02	5.13e-06
			Vinyl Chloride	2.02e-03	1.01e-06
			Volatile Organic Compounds	1.39e+04	6.95e+00
			Xylenes (Mixed Isomers)	1.21e+02	6.06e-02
			Zinc	2.39e+01	1.20e-02

SUSTAINABLE DEVELOPMENT GOALS

In this thesis it will also be explained how this study is related with the Sustainable Development Goals (SDGs) proposed by UNICEF to make the global community work together to fight against poverty, improve living standard and protect the environment. There are 17 goals in this list, but this study can help specially in 3 of them, these are:

- *Number 7: CLEAN ENERGY.* This study talks about the possibility of installing solar panels and one of its goals is to reduce pollution. Solar energy is one the cleanest renewable energies and it is also the one that step by step is becoming one of the most important ones. It is described how the pollution can be reduced on campus and the numbers speak for themselves.

- *Number 11: SUSTAINABLE CITIES AND COMMUNITIES.* As it is described earlier in the project, the University of Minnesota has its own electrical system that connects all the buildings. As it is explained in the expansion part of this thesis, the installation of solar panels could be done in more than just the 7 buildings on campus. The ultimate aim would be to install solar panels and other renewable energy systems such as wind systems in so many buildings in the university that it could just make enough energy to run all buildings on campus.

- *Number 13. PROTECT THE PLANET.* Throughout this study it has been tried to show how beneficial the installation of solar panels would be not only in the economic part but also in the pollution aspect. Greenhouse gas emissions are a big threat to the world and that is why one of the aspects being studied in the thesis is how many kg of CO_2 can be prevented from going into the atmosphere.