The Future of Dana:

Achieving Net-Zero Building Emissions and Leading by Example

Final Report

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Executive Summary

The ongoing increase in global temperatures due to the increase in greenhouse gas emissions has caused significant damages worldwide. Human activities, such as the burning of fossil fuels, have been the main driving force contributing to climate change. There has been a recent global push for both governments and corporations to rapidly decrease emissions to mitigate the worst effects of climate change. As part of this, the University of Michigan has established the President's Commission on Carbon Neutrality (PCCN) to develop the framework for achieving carbon neutrality by 2030. The School for Environment and Sustainability (SEAS) has played a leading role in the PCCN. The SEAS Facilities Department is developing evidence-based and scalable strategies to improve energy efficiency and find opportunities to integrate more renewable energy into the operation of the Samuel Trask Dana building where SEAS is located. In order to achieve this, this capstone project was created to first generate a model of the Dana building, and associated mechanical and electrical equipment within it, using the Design Builder software. That model was then compared to historical emissions data from the building to verify its accuracy. The model is intended to be used to assess potential energy efficiency measures and savings within the building. This project analyzed emission reduction projects such as window inserts within Dana and solar generation at SEAS properties. In conjunction with this, educational tools were developed to inform students, faculty, and staff within the Dana building on how they can assist with the energy efficiency goals. Lastly, building specific information, such as the various mechanical and electrical systems within the Dana building, was captured in a building manual meant to be easily used by the Facilities Department. With all of these strategies in place, SEAS Facilities hope to make progress towards achieving net-zero building emissions and spearhead this movement for other buildings on campus.

1. Introduction

Global average temperatures have increased approximately 1.1°C over the past century due to climate change.[1] According to the United Nations, human activities have been the predominant driving force of climate change since the Industrial Revolution. These activities include burning fossil fuels and emitting greenhouse gasses such as carbon dioxide and methane through various ways such as building heating through the direct combustion of fossil fuels and cooling using electricity produced by burning fossil fuels. Continuing to burn fossil fuels will result in extreme temperatures, sea level rise, severe droughts, fires, flooding, water scarcity, and more. It will negatively impact biodiversity as well as the global economy. Scientists and government leaders around the world have agreed that, in order to avoid the worst possible impacts of climate change, the global temperature must be limited to 1.5°C above pre-industrial levels.[2] Now, there is a global push from both governments as well as corporations to rapidly reduce CO_2 emissions[3]. According to the U.S. Environmental Protection Agency (EPA), transportation and electricity make up the largest greenhouse gas emissions by economic sector by 29% and 25% respectively.[4] The transportation industry is moving towards many technologies to decarbonize their sector such as electrification. Therefore, one of the best ways to decarbonize is to clean the grid by deploying more renewable energy sources and reducing the dependence on fossil fuel sources such as coal.

The built environment alone is responsible for 36% of energy consumption and 38% of energy related carbon emissions globally.[5] To minimize energy consumption within the built environment, net-zero buildings will play a large role by addressing Scope 1, 2 and 3 emissions. Scope 1 emissions involve direct emissions from a building due to its operation.[6] Scope 2 emissions involve indirect emissions from the electricity, steam, heat, or cooling that a building receives. Lastly, Scope 3 emissions involve all other indirect emissions associated with the building such as commuter travel and purchased goods and services. Reducing emissions in each of these scopes is very important for meeting climate goals.

Historically, the United States has emitted approximately a quarter of the global greenhouse gas emissions[7]. Therefore, the U.S. has a responsibility to significantly reduce their emissions. As part of this, universities throughout the U.S., especially those with long legacies such as the University of Michigan, have a duty to reduce their emissions as well.

The University of Michigan established the President's Commission on Carbon Neutrality (PCCN) back in 2019 to develop the framework for achieving carbon neutrality by 2030. The mission of this commission is to "leverage the resources and expertise of U-M to contribute to a more sustainable and just world by developing a plan for the university to reach net zero (carbon neutral) emissions university-wide".[8] The final report and recommendations were released by the PCCN in 2021 which included the following:

- Reach carbon neutrality for Scope 1 and 2 emissions by 2025 and eliminate Scope 1 emissions entirely by 2040.
- Establish carbon neutrality goals for Scope 3 emissions by 2025 with targets set no later than 2040.

While supporting the University of Michigan's commitment to Carbon Neutrality, the School for Environment and Sustainability (SEAS) facilities sought to develop evidence-based and scalable strategies to improve energy efficiency and find opportunities to integrate more renewable energy resources into the standard operation of the Samuel Trask Dana building on Central Campus, where SEAS is located. With these strategies in place, SEAS Facilities aims to achieve net-zero building emissions and spearhead this movement for other buildings on campus.

By implementing these strategies within the Dana building and by educating the students, staff, and faculty within SEAS about these strategies, there is a potential to have a large ripple effect. There are approximately 500 new SEAS students each school year.[9] If they are educated on the emission reduction strategies that will be implemented where they spend the majority of their time in school, they may be likely to take those learnings to their future careers, where they can be further implemented. The same will be true for other buildings on campus as well. In 2021, U-M's enrollment surpassed 50,000 for the first time, therefore increasing the potential to educate students on emission reduction strategies throughout campus that they can take with them into their future careers.[10]

This project has expanded upon a foundation already established by a previous capstone project, which created a virtual model of the Dana building using spatial modeling software and accounted for the total building energy consumption.[11] This previous project found that Dana's HVAC system accounts for 64% of the total energy usage within the building, 18% of energy usage is allocated to plug loads, and 12% is consumed by lighting. Recommendations from this previous project included shifting all building lighting to LED technology and reducing non-essential plug load consumption in building workspaces. These recommendations reflected an overall 7% reduction in annual energy consumption, which translates to an annual savings of about 110 MWh and 84 metric tonnes of carbon dioxide emissions. Overall, this project continued the initiatives already established by this previous project, with the hope that developments can be extended to the rest of the University community.

2. Project Overview

The overall goal of this project was to identify ways for the Dana building to achieve net zero emissions. This phase of the project continued some of the initiatives from the previous phase of this project, which was conducted by Connor O'Brien, a 2021 Master of Science graduate from SEAS.

2.1. Past Work

The previous phase of this project done by Connor O'Brien involved initiating the development of a building energy model (BEM) of the Dana building within Design Builder and developing a building manual.[12] He was able to construct a 3D model of the building, including each floor within it, by utilizing CAD files for the building's floor plans. Due to timing constraints and the ongoing Covid-19 pandemic, specific structural and mechanical elements were not added to the model. Initial information was collected for a building manual, however more information was needed to be able to fully complete this task.

2.2. Current Project

This phase of the project includes a variety of components. Dana specific structural elements, including the building envelope, as well as mechanical elements, such as HVAC and lighting, were incorporated into the BEM. The goal of doing this was to capture an accurate representation of the Dana building so that various simulations could be run to assess different energy consumption scenarios. This could be a useful tool in determining how future building equipment upgrades might result in energy savings and thus possible emissions reductions. The building manual continued to be developed to host all sorts of important information related to the Dana building including history, emissions data, structural and mechanical systems and components, and the building model. The intent of this manual is to be a source of information on the building for use by Facilities, Engineering, Maintenance, etc.

Additional parts of this project included hourly building emissions calculations and individual emissions reduction projects including solar generation on SEAS properties, window inserts, and education initiatives. The hourly emissions calculations were extremely important for showcasing exactly how much the Dana building has been emitting from its energy consumption (i.e. electricity, chilled water, and steam). This data is needed to showcase the extent to which emissions must be reduced to achieve net zero. Since SEAS owns multiple properties around Ann Arbor, MI, including Saginaw Forest and Newcomb Tract, a solar study was conducted to determine how much solar energy generation could realistically be built within these properties. The idea behind this was to showcase potential hourly emissions savings from this solar generation that the Dana building could then claim.

The project team also studied window inserts in a classroom within Dana that has been known to be colder during the winter. The idea behind these inserts is that they would prevent heat loss through the windows, which would maintain more comfortable temperatures within the classroom and possibly reduce energy consumption from the HVAC systems continually running. Another strategy to reduce energy consumption and thus possibly reduce building emissions was through education initiatives. These included educational slideshows for student orientation and faculty onboarding to make building occupants aware of energy reduction initiatives that they can individually take. Other initiatives included an action template, a collaborative project document, and posters.

This project involved working with the SEAS Facilities Manager, Sucila Fernandes, and a Faculty Advisor, Dr. Parth Vaishnav, as well as a variety of university work groups including Engineering, Maintenance, Building Automation, etc. Each piece of this project is connected and works towards reducing energy consumption and carbon emissions within the Dana building.

3. Dana building History and Renovations

The following sections are excerpts from the 2021 capstone report, The Future of Dana, by Connor O'Brien.

The Samuel Trask Dana building was built between 1901 and 1903 on the Central Campus of the University of Michigan. It has been home to many different departments over the years, but has been home to the School of Natural Resources and Environment (renamed SEAS) since 1973. Between 1998 to 2004, the Dana building underwent significant renovations referred to as the Greening of Dana to both update the building and incorporate sustainable design features within it. The following excerpt from the 2021 capstone report by Connor O'Brien details the heating and cooling upgrades made to the building during this time.

> *Heating and cooling, especially in larger and or aging structures, is one of the most significant energy loads in a building. Prior to the renovation, the building utilized its windows for cooling which can be a very inefficient process since it promotes excessive external air infiltration. To address this, Dana was equipped with a passive Radiant Cooling System. This innovative technological solution utilizes chilled water that is directed and re-circulated through piping in ceiling-mounted panels and passively cools the air throughout the space. Installed on the ceilings of classrooms, laboratories, and offices (except on the 4th floor), the radiant cooling panels require less energy than a traditional air-cooling system while the water pumps consume*

10% less energy than the fans in a forced air system. A detailed analysis of the complete radiant cooling system installation determined that it would reduce overall energy costs by about 30%. A Direct Digital Control ("The Brains") was also installed onto Air Handlers to monitor and maintain the mechanical and electrical systems within the individual workspaces throughout the building.[13]

Additional detail on the history of the Dana building and the Greening of Dana project can be found in Appendix A.

4. Modeling the Dana Building's Energy Use

4.1. Methods & Assumptions

As one deliverable of the project, the team worked to further develop a building energy model for Dana. The model was developed using the Design Builder software. This software allows for the development of a CAD-like 3D geometric representation of the building. Representative data can then be inputted in order to properly account for all aspects of energy related systems. Data is applied in a hierarchical system where components are grouped into zones, zones can be grouped into blocks which then make up the building. Simulations can then be run in order to estimate the energy consumption over a certain time period. Energy simulations are dependent on a heat balance where all relevant aspects of heat gain and loss are accounted for. Weather data and solar simulations are used in conjunction with the building's geometry, orientation, heating envelope, and ventilation. The detailed heating balance allows for temperature estimates which can be used to dictate HVAC simulations. Scheduling can be used to dictate when certain systems are on or off. Analog multipliers can be applied to simulate partially on or off systems.[14]

Figure 1: Dana building Model in Design Builder

The work on this model was a continuation from the prior capstone project from Conner O'Brien. He was able to develop the geometry of the building within the software based on floor plans and direct elevation measurements. Due to unforeseen delays, the rest of the model was unable to be completed.[15] This is where the current team picked up work on the model. Data for the energy related systems was inputted so that the model could accurately simulate the energy usage of the building. This involved inputting data for HVAC, thermal envelope, plug loads, and lighting.

Building Envelope

The first step in this project was to find information on the thermal envelope of the building. Entering the material composition and thicknesses of exterior structures (walls, roof, windows) into the model would allow for the estimation of thermal conductivity, which dictates the heat flux into and out of the building over time. This is important as there are often high gradients between the indoor and outdoor temperature which can determine HVAC requirements. Sourcing much of this data proved to be difficult since most of it had not been previously collected for any reason before, hence the need for documentation in the building manual. The team met with Tim Carroll, from F&O Maintenance Services, who was able to provide estimations for typical window specifications. While there are some discrepancies in window type due to the occasional replacement, for modeling purposes, the windows were consolidated into a general window type which was likely most common. The windows were estimated to have the composition detailed below in Table 1.

Table 1. Window Composition

	Exterior		Interior
Material	Bronze glass	Argon	Clear glass
Thickness	¼"	½"	½"

The air gap was updated to be filled with argon gas at the recommendation of the building manager, Sucila Fernandes.

Over the last two semesters the team had multiple meetings with Susan Monroe, the building architect of many years, where she explained the composition of the remaining building aspects such as the roof, exterior walls, and interior partitions. The interior walls were modeled using the composition shown below in Table 2.

Table 2. Internal Partition Composition

	Exterior		Interior
Material	Gypsum Plasterboard	Fiberglass Batt Insulation	Gypsum Plasterboard
Thickness	⅝"	3 ¾"	⅝"

While there again are likely some discrepancies due to renovations, previous structures, and some variance in uniformity, this was much less important than the exterior envelope for heating purposes. Some assumptions were also made for the exterior walls. Model inputs were based on original building plans, when the Dana building was the medical building shown in Figure 2, which specified the thickness of the exterior materials. The primary materials were brick and stone. Brick was used in the 3rd and 4th floors along with part of the north and south faces of the 1st and 2nd floors. Stone was used on the remainder of the 1st and 2nd floors along with the basement. The thickness of the material does taper off as the height increases, and the composition is shown below in Table 3.

Table 3. External Walls Composition

		Exterior		Interior
Basement, 1st, and 2nd floor stone	Material	Stone	Fiberglass insulation	Gypsum Plasterboard
	Thickness	1'-8"	3 ¾"	⅝"
1st and 2nd floor brick	Material	Brick	Fiberglass insulation	Gypsum Plasterboard
	Thickness	1'-4"	3 ¾"	⅝"
3rd and 4th floor	Material	Brick	Fiberglass insulation	Gypsum Plasterboard
	Thickness	1'	3 ¾"	⅝"

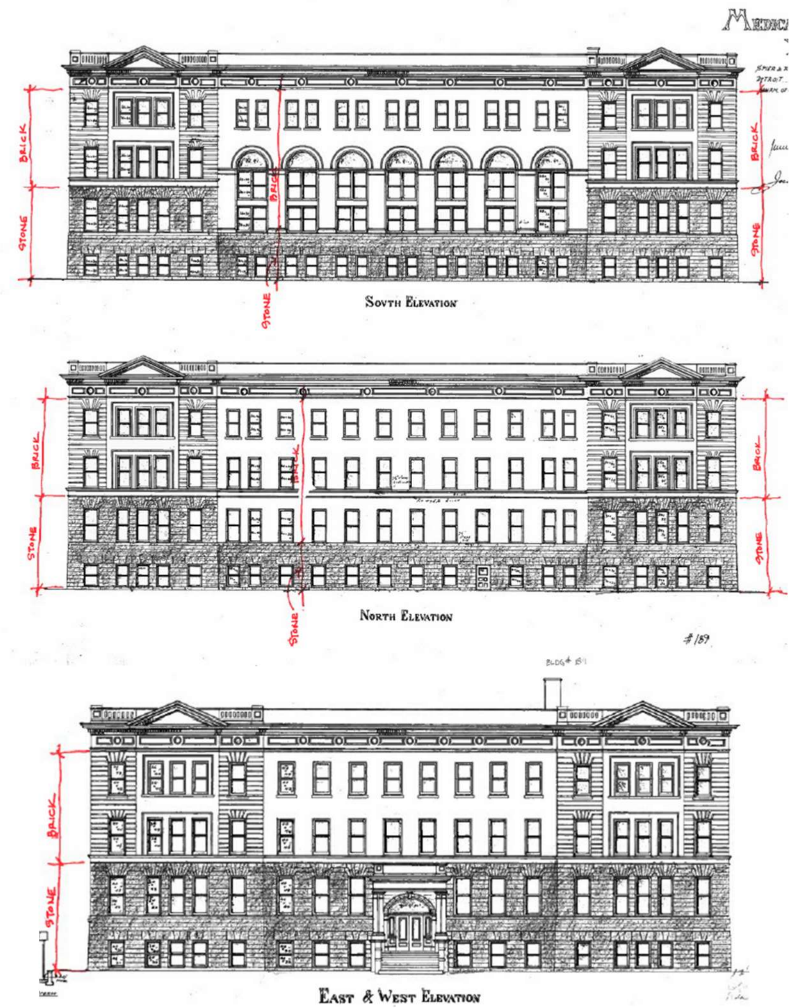

Figure 2: Dana building Exterior Diagrams

The Dana building contains two primary roofing constructions along with a sizable skylight. This information was located in the architectural drawings of the roof provided by Susan Monroe. The first roofing structure is denoted as the EPDM (Ethylene propylene diene terpolymer) roof which makes up the flat portion of the roof around the exterior of the building. This is a black synthetic rubber which can be found commonly on many roofs The construction of this roof is detailed below in Table 4.

Table 4. EPDM Roof Composition

	Exterior				Interior
Material	EPDM	Fiberboard	Polyisocyanurate insulation	Polyethylene vapor barrier	20-gauge metal deck
Thickness	0.06”	¾”	3 ½”	0.15 mm	0.0359”

The Dana building also contains a sloped metal roof on the interior of the EPDM roof. The construction of the metal roof is detailed in Table 5.

Table 5. Metal Roof Composition

	Exterior				Interior
Material	24-gauge steel	Roofing Felt	Plywood	Polyisocyanurate insulation	20-gauge metal deck
Thickness	0.0239”	½”	¾”	3 ½”	0.0359”

Lastly, the skylight was modeled based on the Viracon 1-5/16” VUE1-50 Insulating Laminated glass. The construction is shown in the company detail below in Figure 3. The only change within the model is that the air gap is filled with argon gas. There is also a partial story primarily consisting of a section of windows above 4th floor, denoted the clerestory. This contained a slightly different construction than the rest of the 4th floor, however we were unable to apply this in the model due to the combination of various objects in this zone.

Figure 3: Dana building Skylight Laminated Glass

Electricity

The item modeled within the building was the lighting. Data for this was sourced from a lighting audit done through the Dana building Green Lights project in association with the Energy Conversion Measure Agreement. This audit provided extensive information on the wattage and number of fixtures of linear tubes in each room of the building. Non-linear fixtures were accounted for, however, the wattages for these different fixtures were not yet measured. Therefore, estimations were used based on fixture listings which were assumed to be similar to the listed fixture type and the estimations are shown in Table 6.

The wattages and hours per week of all lights were recorded for each room and added to the model. Schedules were estimated to account for the timing of the lighting usage.

Table 6. Other Lamp Power Estimations

Lamp Type	Wattage Estimate (W)	# of Lamps
Can-pin	5.5	228
Spotlight	12	6
Task	10	2
HID (high intensity discharge)	100	6
PAR (parabolic aluminized reflector)	36	3
Vertical Pin	10	1
Dome	30	468
BR/MR (bulged/multi-faceted reflector)	15.5	32
Fluorescent	40	1

Finally plug loads were estimated using data gathered from Conner O'Brien's previous work. He estimated the time of use for different equipment as well as their wattages and abundance in certain types of rooms as shown in Table 7. This was used to provide the overall kWh per year from plug loads. Since data was not available on a per room basis, a different method was needed than what was previously used in lighting. Design Builder allows for an input of power density which is designated as W/m². Using the total building square footage, the estimated yearly electricity demand for plug loads was converted into power density, which was then inputted into the model. This power density was also distributed over a 40-hour work week schedule to convert power to energy usage. While the Dana building is operational outside of typical work week hours, it is expected that in the early and late hours, usage will be low and on average most equipment operation will still on average be over the typical work week.

Table 7. Estimates for plug loads estimated by Conner O'Brien

Equipment	kWh/week	kWh/year
Monitors	312	16,274
Additional monitors	34.3	1,789
Monitors (sleep)	707	36,851
Hard drives	237	12,383
Laptops	350	18,266
Desk lamps	46.3	2,417
Floor lamps	11.0	573
Heaters	731	38,140
Fans	15.7	821
Speakers	1.98	103
Air purifiers	14.6	764
Fridge (small)	60.7	3,167
Fridge (medium)	50.9	2,654
Fridge (large)	15.5	807
Microwave	4.73	247
Hot pot	319	16,649
Coffee pot	234	12,214
Personal printer	22.6	1,180
Personal printer (in use)	0.460	24.0
TV	3.64	190
Radio	0.261	13.6
Pencil sharpener	0.007	0.365
Toaster	1.54	80.5
Scanner	0.043	2.24
Treadmill	1.50	78.2
Water cooler	20.2	1,051
Electric blanket	0.875	45.6
Total	**3,199**	**166,782**

HVAC

The last component of the building that contributes greatly to the building's energy demand and usage is the HVAC system. Dana's HVAC system consists of 3 air handling units, many fan coil units, 6 exhaust fans, some air conditioning units, a steam system and a chilled water system. Data on the HVAC system was sourced from the building manual, the building management system, building blueprints, and from the physical equipment itself. The building manual and building management system examined which equipment serves each space within the Dana building. The information on the model and manufacturers of each component associated with the HVAC system were found on the physical units themselves. This information was used in an effort to look up efficiency curves to determine more accurate energy usage. However, the equipment manufacturers did not have fan curves, fan coefficients, or motor efficiency available to the public and no manufacturers responded to project team inquiries for useful model information. Due to this, the HVAC equipment in the model used default values, of similar sized equipment, for the efficiencies and fan curves. With these assumptions in mind, the team used Design Builder to track the energy usage and carbon emissions associated with Dana's HVAC system during building operation hours.

4.2. Energy Usage Simulation Results

The results of the Design Builder simulation for the model can be seen in Figure 4 with energy in kWh in the y-axis and time of the year on the x-axis.

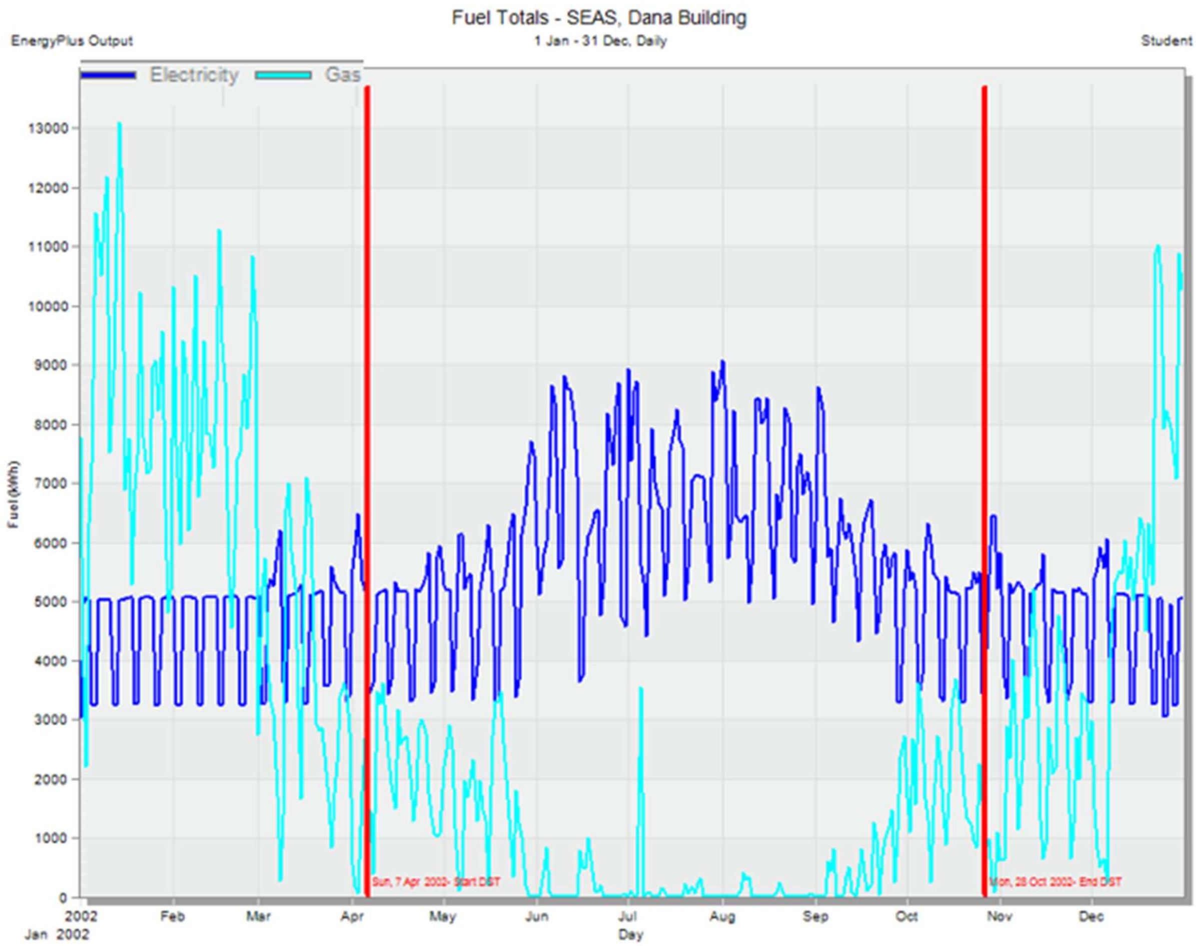

Figure 4: Dana building energy usage over a year. Daily period

Within the model, gas was used as an analog for the heating energy provided from Dana's steam system. The red lines can be ignored as they are just applications of daylight savings time. There is a spike in electricity usage in the summer from air conditioning and a spike in heating energy during the colder months. The summer months required little to no heating in this simulation. The data also shows a cyclic pattern in electricity usage which approximately follows the weekdays and weekend days. It is also important to note that the data does not exhibit variation following the school year. It is expected that energy usage would likely increase during the fall and winter semesters in accordance with the occupancy of the building. In the future, if data on occupancy of this building can be sourced, this should be included in the model to more accurately account for the school-year based usage of the building. In Section 6, this data will be addressed in the context of the known energy usage data. Through this, the accuracy of the model can be analyzed and potential adjustments can be suggested based on the nature of inaccuracies.

5. Energy Consumption & GHG Accounting

5.1. Methods & Assumptions

In order to transition towards a net-zero framework, it is important to quantify the energy use of the Dana building. From the energy consumption, it was possible to estimate the greenhouse gas emissions associated with the energy use in the Dana building. Data was collected from 2015 onwards for electricity and chilled water, but not for steam in which 2016 was the earliest whole year of data available. As a result, the comprehensive comparisons between all utilities start in 2016. However, for individual analyses of each utility, the team decided to include the year 2015 when applicable as the data could still prove valuable for comparisons between years.

This was investigated by acquiring hourly usage for each of the building's utilities. This included electricity, steam and chilled water. The importance of collecting hourly data was to be able to visualize energy consumption trends as they occur throughout the day and how they compare across seasons at a high-resolution scale compared to a daily or yearly scale. It should also be stated that emissions factors can vary throughout the day and capturing these differences can lead to a more accurate estimation of GHG impacts.

The building does not directly use natural gas and does not possess a boiler, as it receives heat in the form of steam from the Central Power Plant. Using energy conversion factors, the team was able to convert hourly utility consumption in units such as kWh, tons of cooling, and steam condensate into megajoules, a standard unit of energy. This was then converted into greenhouse gas emissions using emissions factors that are calculated at the end of every fiscal year by the University of Michigan. This is possible as the East University Chiller Plant and Central Power Plant, which are used for Dana's utility sources, are both University assets. An aspect of the datasets that is worth mentioning is the inconsistency in the operating status of the meters recording usage for each utility. Although occurring very rarely, this manifests in the form of a meter failing to provide a reading for that given hour. A notable example of this is present in the steam usage dataset in which the meter failed to give readings for multiple days in late January 2019.

This particular instance is the most extensive meter failure and almost all other instances are isolated to one-hour or two-hour periods. Overall, hours with meter failures comprise less than 0.001% of hours in the total dataset; affirming that trends drawn from the dataset are not significantly impacted by inconsistencies in meter operating status.

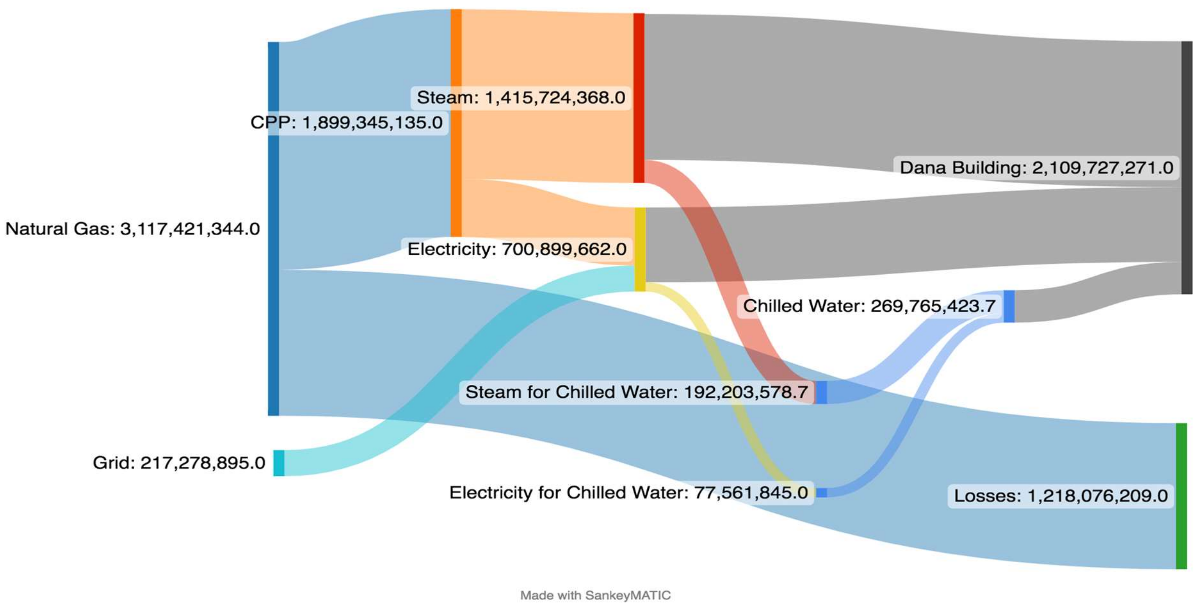

Figure 5: Sankey Diagram of Energy Flows in Dana Building presented in megajoules (MJ). Figures are based on fiscal year 2022 Data. All thermodynamic losses are not captured in the figure.

Chilled Water

The chilled water hourly usage data was derived from meters present in the Dana building. Reliable data was able to be obtained from about mid-2014 to the present. This data is measured as a running total of tons of cooling or refrigeration tons. To understand hourly consumption, the current hour can be subtracted from the previous hour to derive the consumption over that hour. Since the East University Chiller Plant utilizes both steam and electricity to produce chilled water, it was necessary to convert this figure into something more comparable. To act on this, tons of cooling was converted into kilowatts so the East University Chiller Plant's coefficient of performance (COP) could be used to understand how much energy went into creating the chilled water. Based on fiscal year 2022 data for the Chiller Plant, a COP of 2.5 was used which means that for every kilowatt of chilled water the Chiller Plant produced, only 0.4 kilowatts was used. For each unit of chilled water, the energy that goes into producing it is about ~56% steam and 44% electricity. This breakdown between steam and electricity is based on fiscal year 2022 data, however the team assumed that the difference in the breakdowns between fiscal years was negligible and decided to use this allocation for the entire dataset. Once the hourly data could be allocated to either steam or electricity, this number was not only converted into energy consumption in megajoules, but also into greenhouse gas emissions using the aforementioned emissions factors that are calculated at the end of every fiscal year. It should be noted that the team assumed that the electricity used to produce chilled water is produced solely from the Central Power Plant.

Electricity

Hourly use electricity data was able to be retrieved for the Dana building from 2015 to 2022. The hourly numbers were given in kilowatts used for each given hour. The Central Power Plant is not the sole source of electricity that supports the Dana building and a portion is received from the greater grid. For this portion of the electricity, separate emissions factors were calculated for each unit of electricity supplied to Dana, the team assumed that ~68.7% was sourced from the Central Power Plant and ~31.3% was from the grid. Much like the chilled water breakdown between steam and electricity, these figures are based on fiscal year 2022 numbers and the team assumed that this allocation would be applied to the entire dataset. For the electricity that can be attributed to the Central Power Plant, the emissions factors calculated by the University were used to convert the energy consumption into greenhouse gas emissions. As for the electricity that can be attributed to the grid, a web application created by researchers at Carnegie Mellon University was used to estimate the emissions factors in the Midcontinent Independent System Operator (MISO) grid operation area (of which Michigan is a part of).[16] These estimates are based on average hourly emissions for the year of 2018 which were applied to the entire dataset. Once the energy from the grid and the Central Power Plant were converted into greenhouse gas emissions, they were compiled to develop a total impact of Dana's electricity use.

Steam

Steam hourly consumption data was able to be found for the years 2016 to 2022. The steam usage in the building is measured via a cadillac condensate meter which measures steam usage based on the water condensate that accumulated within the meter. Once a certain amount of condensate fills the meter, the device will rotate and drain the condensate and therefore measure the amount of steam used as 'rotations'. Much like the chilled water dataset, the data was presented as a running total of condensate used and the difference between two numbers each from two adjacent hours could be used to find the amount of rotations measured in that period. Due to the nature of this meter, the amount of steam used in a given hour can be hard to understand as the meter only measures a rotation once it has been completely filled and led to rough estimates of how many rotations occurred per hour. To further complicate things, if the number of rotations used in a given year were converted into units of steam, they would not align with the amount of steam actually billed to the Dana building. This means that the amount of steam in the hourly dataset was yielding figures almost double of what was actually being utilized in the building. To work around this, the team decided to use the number of steam rotations in a given hour as a proportion of the amount of steam in a billing period. First, the dataset was divided into monthly billing periods where the number of hourly rotations were summed into a total for that monthly period. The proportion of steam used in a given hour was then derived by dividing the number of rotations in a given hour by this total billing period sum. It was then possible to use this hourly proportion and multiply it by the actual MLB steam total billed to the Dana building for that monthly billing period. This would yield an estimate for the MLBs of steam used in that hour. Once converted to steam, this figure could be converted into energy use as well as greenhouse gas emissions using the emissions factors calculated every fiscal year by the University.

5.2. Analyses & Results

Once the datasets for the utilities of chilled water, steam and electricity were quantified in terms of energy consumption as well as greenhouse gas emissions, an emissions profile was created for the calendar years 2016 to 2022. Overall, there is a general trend downwards for energy consumption as well as greenhouse gas emissions. The peak for energy consumption occurs in 2018 while the peak for emissions occurs in 2017. This difference can most likely be attributed to the emissions factor for steam being less carbon intensive in 2018 than in 2017. There is also a distinct drop in emissions and energy consumption during the years 2020 and 2021 which can almost certainly be attributed to the decreased utilization of the Dana building due to the COVID-19 Pandemic. The energy consumption in 2022 rebounds to 2019 amounts, although greenhouse gas emissions still remain below pre-pandemic levels (See Appendix B, Figures B1 and B2). A comprehensive comparison of each utility in terms of GHG impacts and energy consumption can be found below in Figures 6 and 7, respectively. It can be seen that steam is responsible for the largest share of energy use. However, when examining GHG impacts, electricity use harbors the largest impact.

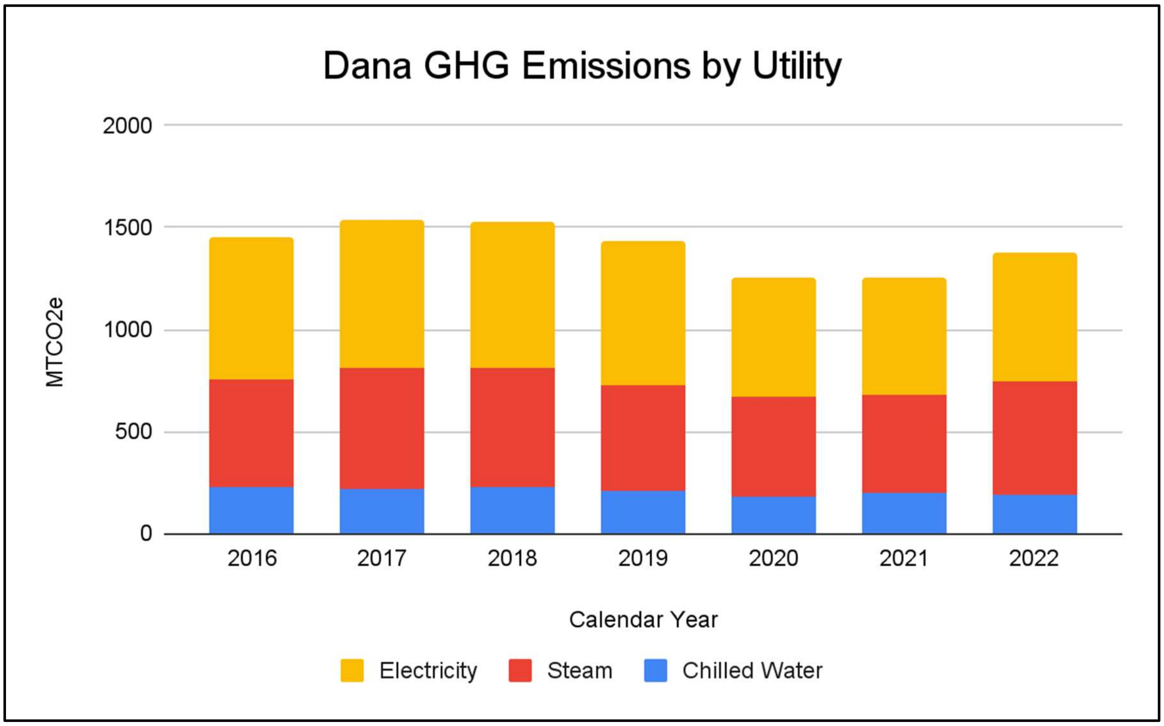

Figure 6: Relative Greenhouse Gas Impacts (metric tons of CO_2 equivalents ($MTCO_2e$)) of Utilities in Dana

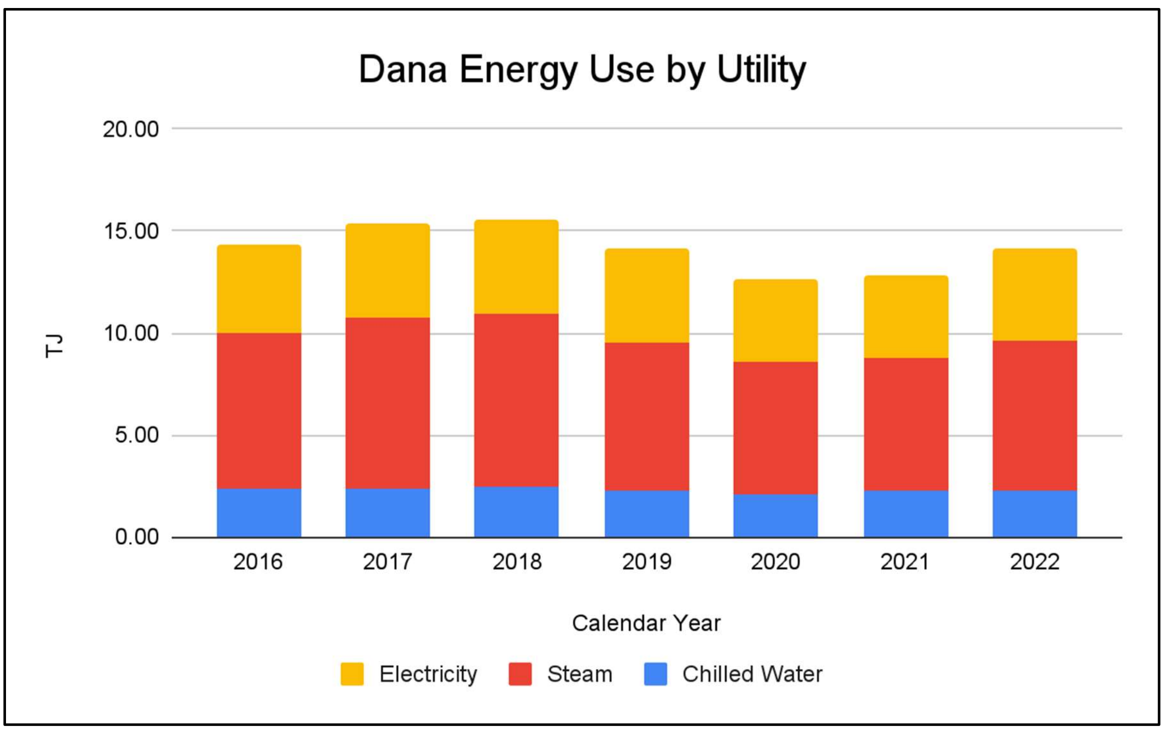

Figure 7: Relative Energy Use Impacts (TJ) of Utilities in Dana

Although steam heavily outweighs the other two utilities in energy consumption, the greenhouse gas impacts between steam and electricity are significantly closer. Given that the electricity derived from the Central Power Plant is much cleaner than the grid (based on the emissions factors), less reliance on the grid for electricity consumption would likely lead to a significant decrease in greenhouse gas emissions. Although it is difficult to increase the capacity of the Central Power Plant, alternative energy generation methods such as increasing the on-site solar PV capacity may help mitigate the carbon footprint of Dana's electricity use. Otherwise, the decarbonization of the Southeast Michigan electricity grid will be necessary for any significant reductions in GHG emissions.

Chilled Water

As stated earlier, chilled water is responsible for the least amount of impacts regarding energy consumption and greenhouse gas emissions among the three utilities. This data follows the trends of the comprehensive data with a general downward trend and a particular low point during the year 2020. The data differs by energy use actually being larger in 2021 than in 2019 which wasn't present in the comprehensive data. Energy consumption and greenhouse gas emissions of chilled water for 2022 were also lower than 2021 levels which wasn't a trend found in the comprehensive data (see Appendix B, Figures B3 and B4).

When breaking down chilled water into its steam and electricity usage, the same trend of steam possessing much higher energy consumption while exhibiting less greenhouse gas emissions was found. An interesting thing to note when comparing the steam and electricity utilized to produce chilled water is that for the years 2020-2022, the greenhouse gas emissions were very similar (see Appendix B, Figures B5 and B6).

Electricity

The energy consumption and greenhouse gas emissions that come from electricity use in Dana do not vary significantly for the years leading up to 2020. As seen previously, these energy consumption drop in the years 2020 and 2021 and rise back to pre-2020 levels in 2022. For greenhouse gas emissions, however, 2022 levels rise significantly from 2021, but don't quite reach previous figures (see Appendix B, Figures B7 and B8).

When looking at the source for Dana's electricity, it makes sense that the Central Power Plant would be the source of the most energy consumption and greenhouse gas emissions due to the fact that over two-thirds of the electricity is sourced from there. What is interesting to note, though, is that greenhouse gas emissions are very similar in 2020 and in the years 2021 and 2022, the grid actually overtakes the Central Power Plant for the larger share of emissions (see Appendix B, Figure B9). This can almost certainly be attributed to the relative 'unclean' state of the grid in Southeast Michigan. Paired with the university's commitment to install 25 MW of solar PV panels on campus, moving away from grid electricity will be instrumental in helping the Dana building reach net-zero carbon emissions. In addition, installing solar PV panels on one of SEAS' properties could help offset the GHG emissions caused by Dana's electricity consumption. This avenue will be explored further in this report.

Steam

The energy consumption and greenhouse gas emissions associated with steam utilization in the Dana building reflect much of the trends found in the comprehensive dataset. Decreasing trends can be found in both energy consumption and greenhouse gas emissions that almost naturally flow into the low points of 2020 and 2021 (see Appendix B, Figures B10 and B11). By 2022, both energy consumption and greenhouse gas impacts return to figures larger than 2019 levels. By targeting cleaner methods to produce steam or relying on alternative methods to heat the Dana building, significant reductions in greenhouse gas emissions can occur which will also help to lessen the impact of chilled water at the same time. Such measures will be necessary in order to transition the Dana building to a net-zero framework.

6. Design Builder and Data Results

After completion of the Dana Building model within the Design Builder platform, a comparative analysis was conducted to determine the model's accuracy with respect to historical building data (for years 2016 through 2022). While this historical data contains several outliers within individually grouped months, the observed trends are as anticipated. Variation within each month is due to year-to-year differences in emissions. Regarding the historical data for electricity consumption, slight modifications were made to accommodate the primary energy associated with chilled water production. Unfortunately, input parameters within the Design Builder software assumes that chilled water generation occurs at-site (i.e., within the Dana Building); however, this is not the case, as chilled water is produced off-site and then transported to the Dana Building. To adjust for this discrepancy, the historical values for the primary energy associated with chilled water production have been calculated and added to the raw data for building consumption patterns, and this adjusted data set was then used for final comparison against the Design Builder outputs. For the historical steam consumption, this data profile mimics expected values, with peaks in the winter months and a decrease over the summer.

When compared with the historical values shown here, the output values from the Design Builder model have some slight discrepancies. For the electricity values estimated by the model, the values for May through October appear to be in line with the values seen in historical data. For the months November through April, however, the model's output appears to be slightly higher than the historical data. This may be due to occupancy and use trends throughout the academic year, and thus would need additional investigation. While the steam consumption output does tend to display a very similar shape to the historical data, there is a slight underestimation by the model. The largest discrepancies here occur during the summer months, which indicates the likelihood that the discrepancy is tethered to the building's HVAC systems. Additional discussions between the project team and the Regional Energy Manager for the University point to the possibility of this discrepancy being accounted for via the building's variable air volume (VAV) systems, which are responsible for reheating cooled air to meet thermostat settings in individual rooms. While the project team recommends further investigation into this possibility and additional adjustments to the Design Builder HVAC systems, preliminary calculations appear to be in agreement with this assessment. Future model adjustments are needed to improve accuracy, which will need to be executed before the model can ultimately be utilized to facilitate iterative building update comparisons. Graphic comparisons between the model output values and the historical data for the two metrics of interest are available in Figures 8 and 9.

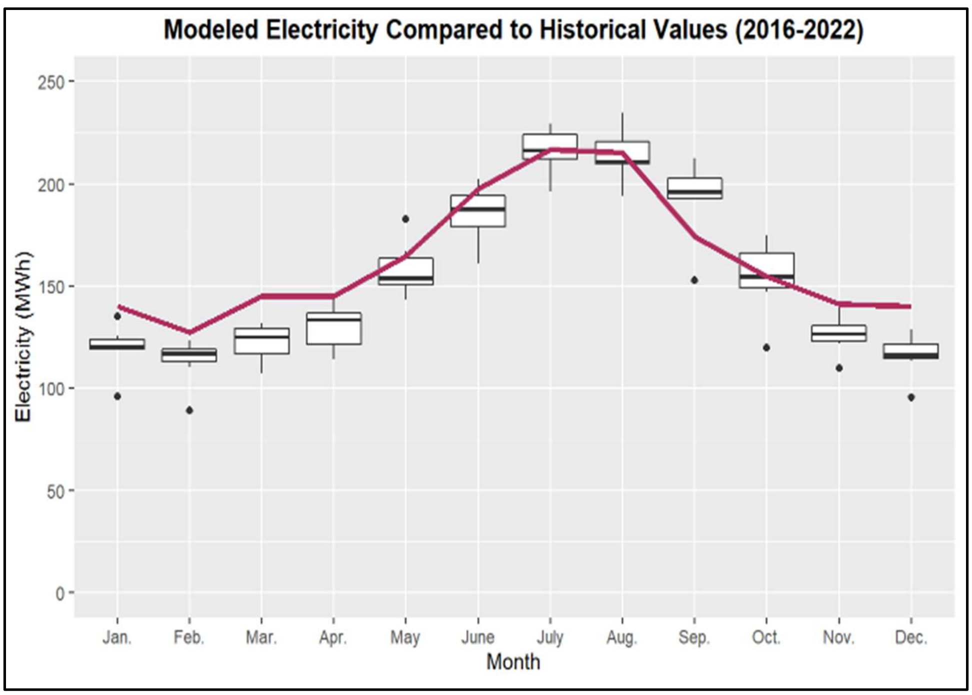

Figure 8: Comparison showing the Design Builder estimated electricity consumption for the Dana Building (represented by the red line) versus the historical electricity data for the last six years (shown as the box-and-whisker distributions).

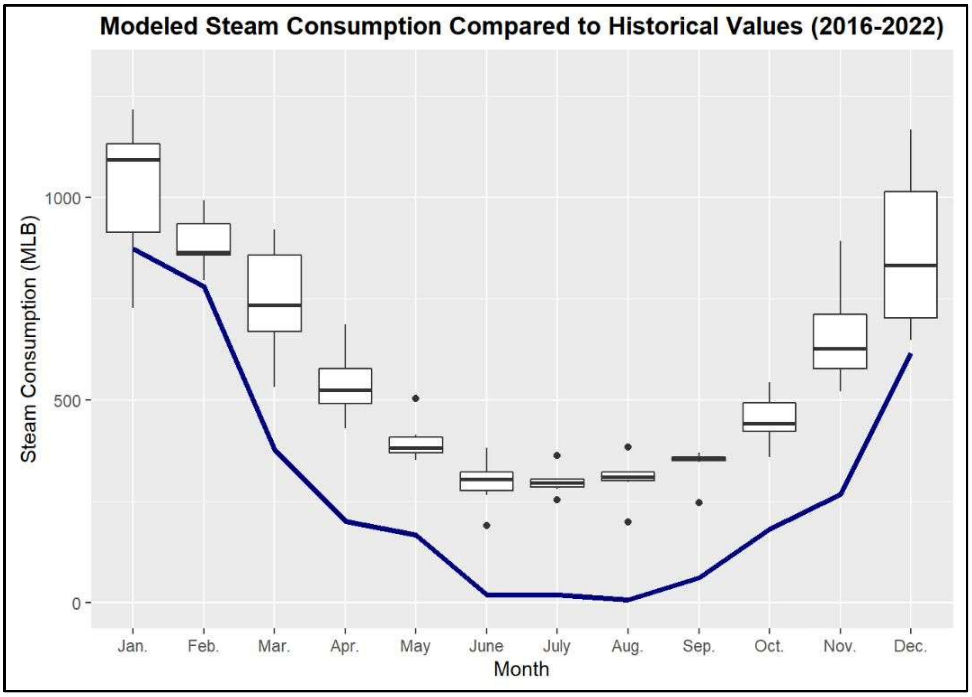

Figure 9: Comparison showing the estimated Design Builder steam consumption for the Dana building (represented by the blue line) versus the historical steam data for the last six years (represented by the box-and-whiskers distributions). Note that VAV systems are known to be absent from the Design Builder model and thus may account for the observed discrepancy.

7. Emissions Reduction Projects

7.1. Solar Energy for SEAS

As this project attempted to address the emissions goals set forth by the PCCN, one of the broader questions requiring investigation was the feasibility of a large-scale emissions reduction initiative. In other words, is there a singular action (or larger group of actions) that SEAS could pursue to dramatically reduce its carbon footprint? Would such a comprehensive strategy be possible? Or would the sum of smaller initiatives need to be executed to reach total decarbonization? This inherent set of questions was the motivation for considering solar energy generation among SEAS' possible future initiatives. And thus, this project assessed the feasibility, costs, and the potential benefits of such initiatives across the SEAS properties within the greater Ann Arbor area.

SEAS Properties Characterizations

To begin with assessing the feasibility of solar, it was first prudent to characterize the individual components of each of the SEAS properties in question. In the immediate vicinity of Ann Arbor, there are four properties of interest for this assessment: the Dana building located on the University's Central Campus, the Newcomb Tract property in Webster Township, the Saginaw Forest property in Scio Township, and the Stinchfield Woods property in Dexter Township. All four properties are actively maintained by SEAS Facilities, with the Dana building being the primary property of interest.

For the Dana building, the most obvious opportunity for on-site solar energy falls to the currently inoperable solar array on the Dana building's roof. Previous reports regarding the building's 33 kW solar array[17] have documented the electrical components of the system,[18,19] and recent assessments performed by NOVA Consultants have provided a path forward to future operability.[20] For the sake of this report, it was assumed that the system is not currently contributing to the energy needs of the Dana building, the cost to upgrade the inverter is equal to the quoted price from NOVA Consultants, and that the system's generation profile after upgrading the inverter will resemble a modeled profile after a 17-year degradation period (i.e., it has been 17 years since the system's installation, so performance degradation has been accounted for). It was also assumed that, because the array is mounted on the roof of the Dana building, generation by the system is not inhibited by shading from surrounding trees or infrastructure.

Perhaps the most promising site available to SEAS, the Newcomb Tract property offers considerable advantages for a large-scale solar installation. According to Michigan's Department of Environment, Great Lakes, and Energy (EGLE), the large meadow space on the northern portion of the property falls outside of floodplain hazards and protected wetlands,[21] so development of the 1.5 acres of land is a distinct possibility. Further, while other academic departments operate individual projects at the site, all utility electricity meters are independent of each other, meaning that SEAS could coordinate with Detroit Edison (DTE) to install separate generation infrastructure without infringing on the operations of these other departments. For this project, the Newcomb Tract property was prioritized for these distinct advantages.

The Saginaw Forest property presented a more challenging opportunity for solar development. The property is home to both Third Sister Lake and the historic SEAS cabin, but EGLE documentation indicates that a large portion of the property falls into restricted wetlands or floodplain hazards.[22] While previous discussions with SEAS Facilities indicate an interest in a potential solar-covered parking lot at the Saginaw Forest Trailhead, this presents other considerations that fall outside the initial scope of this report. A brief investigation here determined that a solar-covered parking lot at the northern edge of West Liberty Road would see a 55% reduction in potential generation hours simply due to shading coverage from trees along the road's southern edge (see Appendix B, Figures B12 and B13). For this reason, combined with the additional costs and environmental impacts associated with clear-cutting a portion of the forest and paving a lot, it is recommended that further investigation into the Saginaw Forest property be pursued independently from this report, and additional consideration be given with a focus on civil engineering, as seen in related projects across the United States.[23,24,25,26]

For the Stinchfield Woods property, there is no large meadow space or elevated structure for a solar installation, as previously documented for the Dana building or the Newcomb Tract property. However, near the on-site SEAS Facilities residence, the original structure for the Peach Mountain Observatory still stands and could be modified to accommodate a roof-mounted system. Specifically, the south-facing façade of the observatory sits at a 41° inclination, as determined by site measurements. This is in relative accordance with the standard tilt of a fixed-axis installation following a site's latitude.[27] After accounting for a 3-feet setback from the crest and edges of the façade, which follows requirements from the 2021 International Fire Code,[28] this leaves an estimated 300 square feet of potential installation space; this is enough space to accommodate a small, fixed-axis, roof-mounted system. Regarding shading concerns at the Stinchfield Woods property, estimates for distances between the façade and the surrounding tree lines were determined using geographic information systems (GIS) methods, which were then compiled into an azimuth-by-altitude shading matrix following basic trigonometric relationships. A table of values for distances between the façade and the tree lines can be found in Figure B14 of Appendix B; and a diagram showing the trigonometric relationships can be found in Figure B15 of Appendix B. While solar generation at the Stinchfield Woods property would be partially limited by the shade from surrounding trees, repurposing an existing structure and supplying on-site solar energy to the SEAS residency nearby were considered priority. Thus, the installation parameters for the Stinchfield Woods site were included in the larger solar analysis.

As a final component of the site characterization process, it was necessary to establish a baseline comparison for energy consumption across all properties. For the sake of simplicity, electricity consumption at all four properties was extracted from the total energy consumption (i.e., without the associated energy of steam or chilled water). Because the electricity demands of the Dana building account for more than 95% of the total electricity consumption across all properties, the average monthly values for electricity demand in Dana were calculated across the last ten years, and then these values were scaled to meet the total electricity demand across all SEAS properties. These average monthly values are shown in Figure 10.

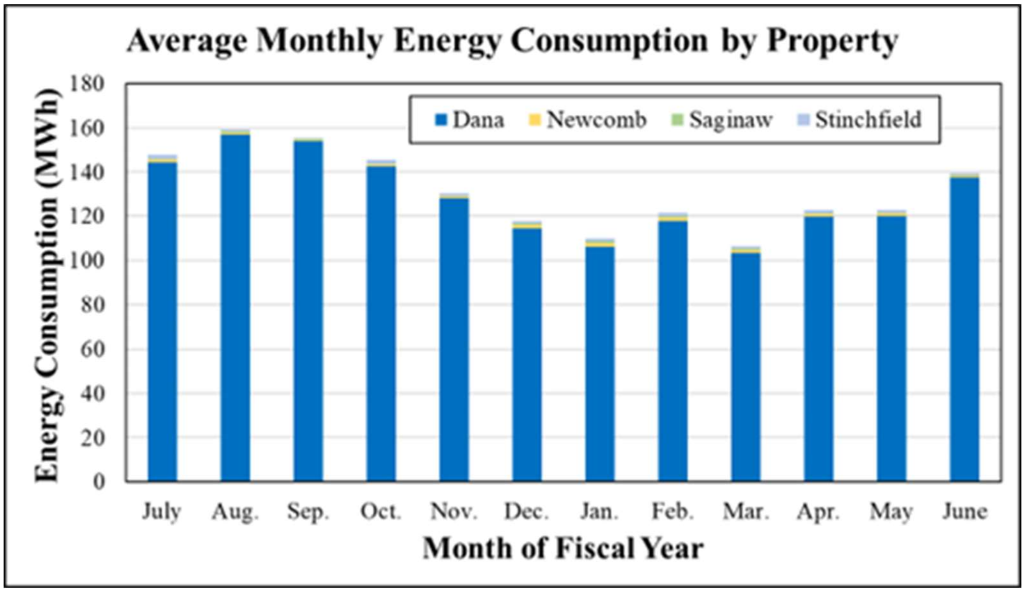

Figure 10: Average monthly energy needs for all SEAS properties, fiscal years 2012 to 2022. As expected, the largest monthly demand profile is allocated to the Dana building.

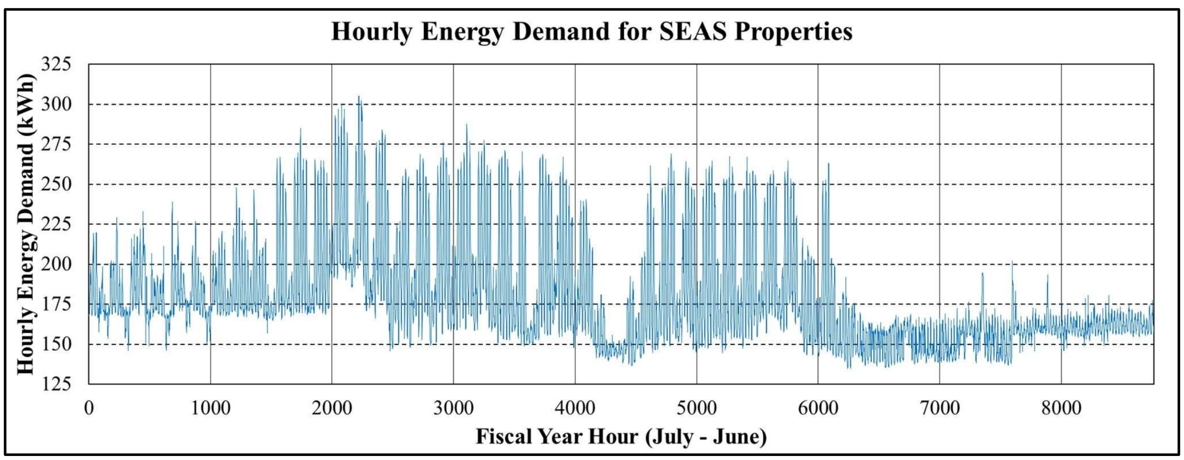

Figure 11: Hour energy demand profile for all SEAS properties. Values for this scaled profile have been based on the hourly data set for the Dana building from FY 2020. Because Dana accounts for more than 95% of electricity consumption across all properties, it is assumed that this profile is a master representative demand profile.

This monthly electricity consumption pattern was then scaled by the hourly demand profile for the Dana building, which produced a sites-wide average hourly profile for expected demand. This is demonstrated by Figure 11. The results of the solar generation modeling were then compared against this average profile for expected energy portfolio, anticipated revenue, and expected emissions reductions.

Methodology

The first step to modeling the solar installations was to determine the input parameters of the systems at the proposed sites. For the Dana building, this was relatively straightforward, with one-line diagrams and layout schematics already available for the existing array. For the Newcomb Tract and Stinchfield Woods properties, several different solar panel modules were selected based on efficiency metrics, and the list for each property was narrowed down to a five-module selection. Using the five modules for each location, the layouts of the sites were mapped using GIS methods, which yielded a total possible number of modules for each installation. Special consideration was given to a ground-mounted system at the Newcomb Tract property, where a ground cover ration (GCR) of 0.4 was assumed, based on the default parameters in the National Renewable Energy Laboratory's (NREL) PVWatts solar calculator. A diagram showing the row spacing calculations based on the assumed GCR is available in Figure B16 in Appendix B, and summary tables for the five modules selected at each site can also be found in Figures B17 and B18 in Appendix B. Layout diagrams for the two sites are shown in Figures 12 and 13.

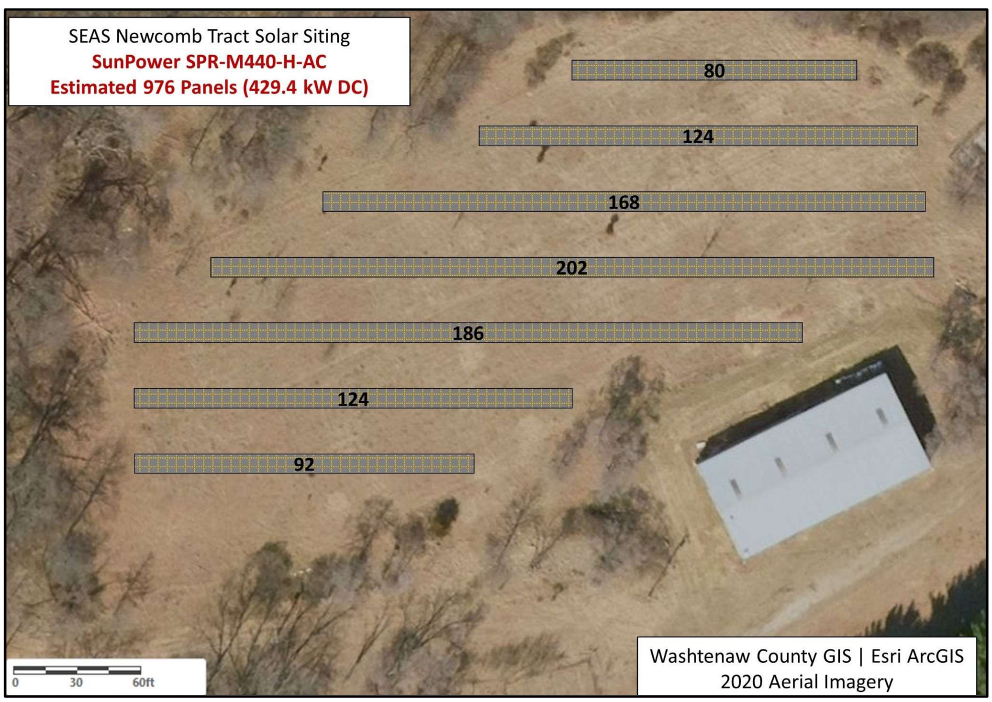

Figure 12: Mock-up aerial image showing the optimized layout of a potential solar installation at the Newcomb Tract property. With the SunPower Maxeon 440W model, the meadow space could accommodate a 429.4 kW DC system for energy generation.

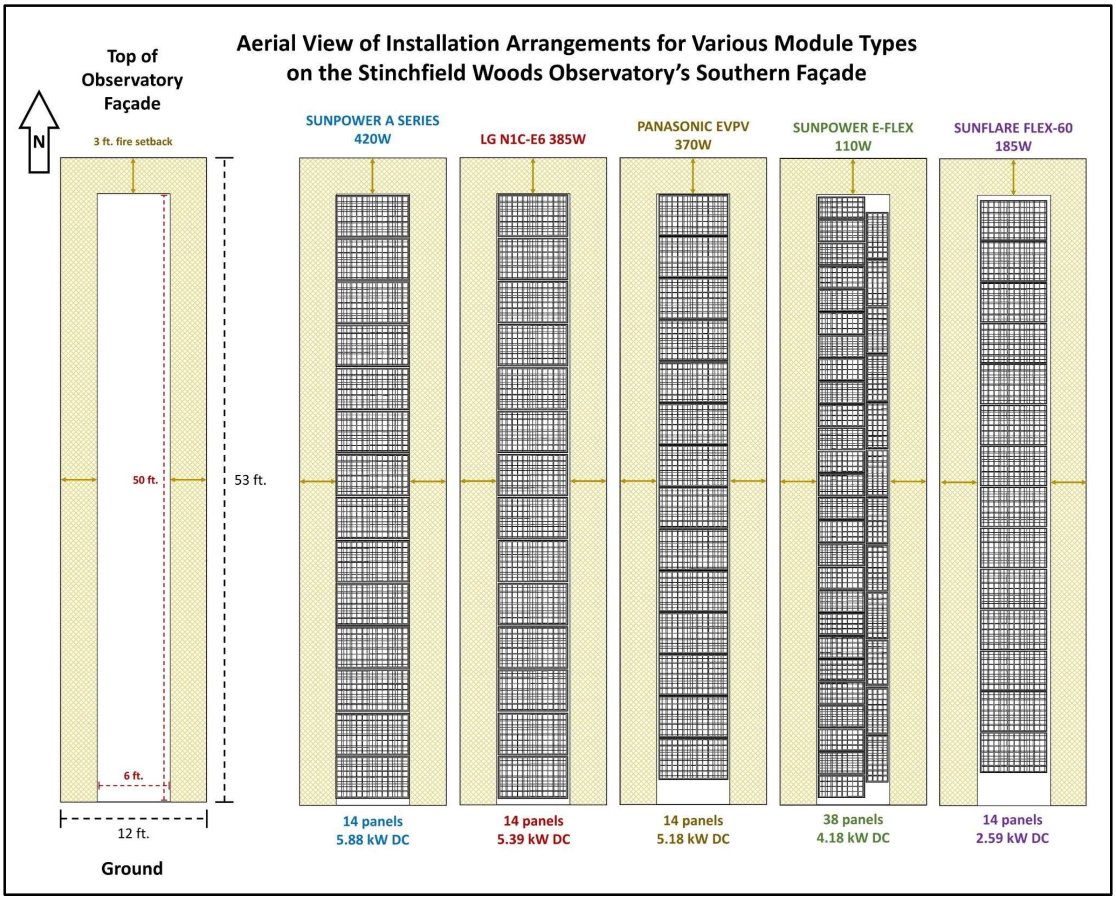

Figure 13: Aerial view showing different panel arrangements on Stinchfield Woods observatory's south-facing facade. Associated total capacity sizes are also reported for each module type, based on the sizing restrictions.

After determining the optimized parameters for all sites, the parameters were input into the System Advisor Model (SAM) software available through NREL. The model was run independently for each site, and the output values for lifetime generation were exported and compiled for further computations.

To assess the economic feasibility of the proposed systems, the capital costs of the systems were estimated using values presented in the Lawrence Berkeley National Laboratory (LBNL) *Tracking the Sun 2022* publication, with costs for Wisconsin installations used as an approximation due to lack of data for Michigan installations.[29] For generation values, it was assumed that available solar energy would first be consumed on-site, and then excess energy would be exported to the grid at a revenue value based on current DTE rate structures.[30] These generation revenues were then summed over each billing cycle, the monthly operations and maintenance costs deducted from the revenue, and a net value for the time period determined. The forecasted net values were then adjusted using the net present value method (NPV), with an applied annual discount rate of 9.9%, which reflects the 20-year annualized rate of return from the University's

Endowment.[31] And with the extension of the Investment Tax Credit to include direct payments towards non-profit and government entities via the Inflation Reduction Act of 2022,[32,33] it was assumed that a 30% investment credit would be received as direct payment in the 18th month after the projects' installations. A full table of values for economic considerations is presented in Figure B19 of Appendix B.

GHG emissions offsets for the SEAS properties were then calculated using the solar generation data output from the SAM software models. For each hour of activity, the solar generation data was compared to the average hourly profile as previously described in this report; each hour's demand data was allocated to the four SEAS properties under investigation, based on their respective contributions within the overall demand profile. Solar generation values were then subtracted from the demand values at each site (e.g., solar generation at the Dana building was subtracted from the Dana demand profile hourly value), and the resulting value was multiplied by the emissions factor for each site based on the respective utility emissions intensity rate. The reported emissions factor for the CPP was obtained as part of the investigation covered in Section 7 of this report, and the DTE emissions factor was determined via a marginal emissions rate approach, using a per kilowatt-hour average emissions for a specific hour of the day based on annual generation values as reported by MISO to the EPA's eGRID program.[34] A table of associated utility emissions rates is available as Figure B20 in Appendix B. The calculated hourly differences were then summed across all sites, which yielded a total SEAS emissions value for that hour, and those values were then compiled to mimic standard billing cycles.

Solar Modeling Results

After executing the models in SAM and compiling the outputs, it was determined that the total electricity produced by the proposed solar installations throughout their lifetimes (i.e., 25 years) would amount to 18.2 GWh, which is equivalent to 11.5 years worth of combined average electricity demand for all the SEAS properties investigated. As Figure 14 demonstrates, the first year of solar generation will yield roughly 2,000 production hours of net-zero or net-negative electricity. However, when summing these net electricity values respective to monthly timeframes, there is not a single month throughout the first year of production that amounts to net-zero or net-negative electricity. This summation is shown in Figure 15, with a comparison to the average SEAS electricity demand shown on a monthly basis.

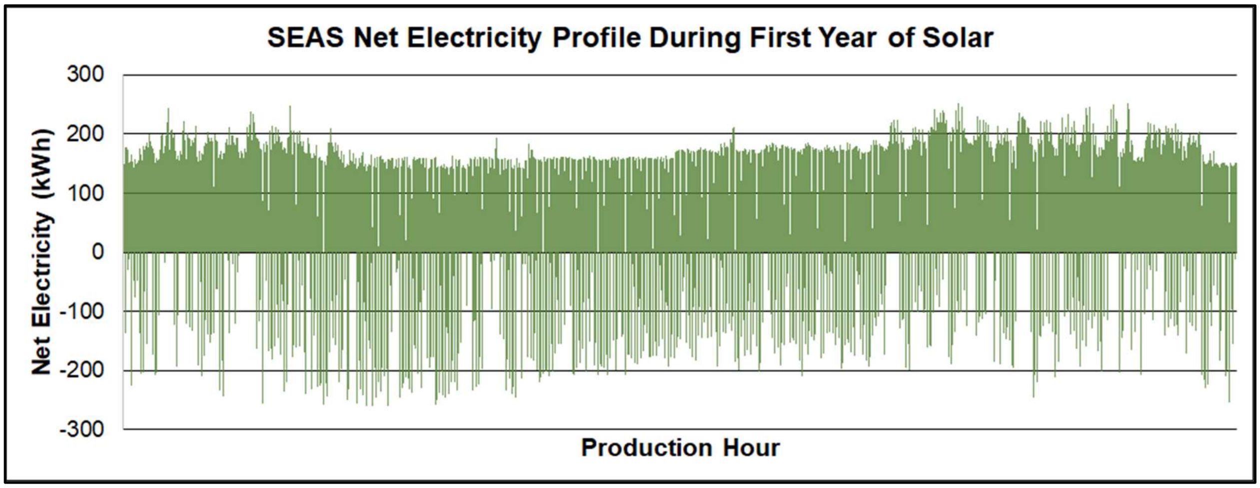

Figure 14: Net electricity profile for all SEAS properties after accounting for estimated solar energy generation. Roughly 2,000 production hours are expected to be net-zero or net-negative, respective to electricity demand.

Of particular note, the proposed solar array for the Stinchfield Woods property is estimated to generate 7.3 MWh of electricity within the first year of operation. When compared to the 2006 baseline of 8.1 MWh of annual electricity demand for this site, the estimated generation of the proposed system amounts to approximately 90% of the Stinchfield Woods demand profile, meaning that installation of the proposed system would place SEAS Facilities within reach of its net-zero goal for the Stinchfield Woods site. With additional efficiency improvements at the property, this goal is quite possibly attainable.

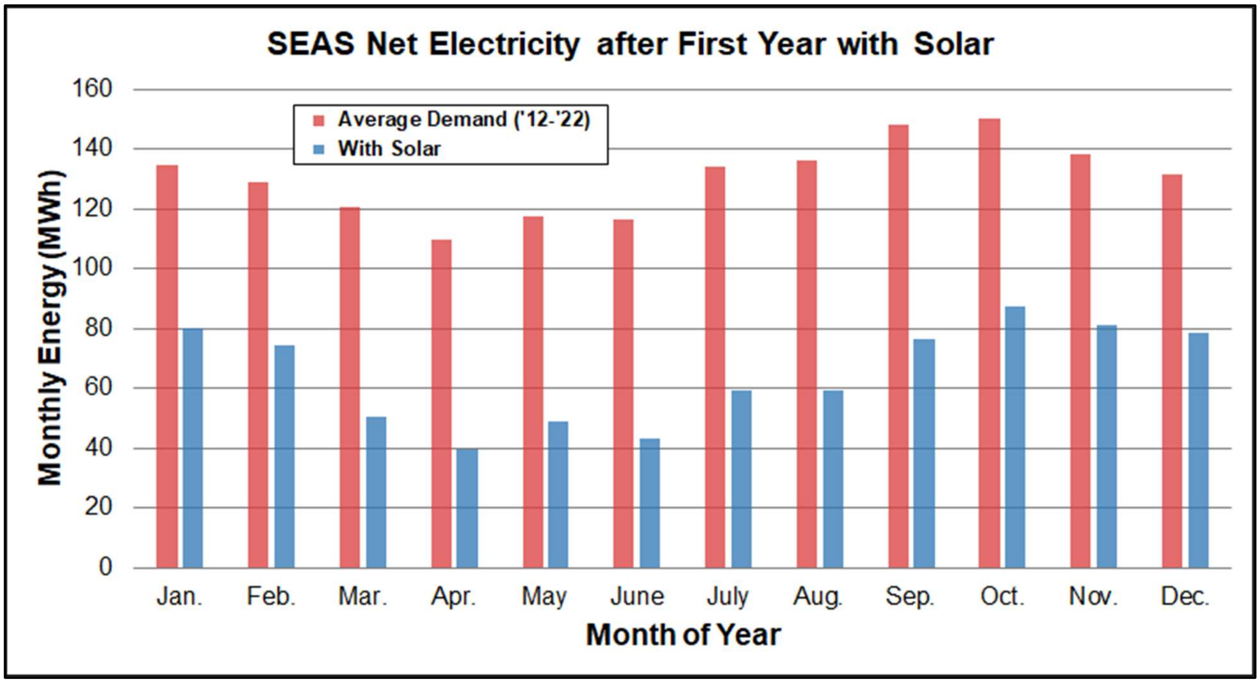

Figure 15: Monthly net electricity profile for all SEAS properties, after accounting for solar generation within the first year of operation.

Using the financial parameters previously described, the capital investment needed to complete all proposed installations was estimated at roughly $740,000, with about 95% of that total cost going to the installation at the Newcomb Tract property. After accounting for revenue from excess generation and operating expenses, it was determined via simple payback strategy that a complete recuperation of capital costs would occur around ten and a half years after installation. After adjusting for an assumed 3% annual inflation, this total recuperation would be expected within the 13th year of operation. This recuperation, however, does not account for the complete discounting of future assets. To capture a better representation of the capital investment's value, an NPV approach was also taken to assess the investment's lifetime performance over 25 years. As previously stated, this method utilized a 9.9% annual discount rate, which was based on the 20-year annualized rate of return for the University's endowment. Thus, with the NPV strategy employed, it was determined that these solar projects would not fully recuperate the capital costs throughout their lifetimes, after accounting for revenue and operating costs; the final system deficit value at the 9.9% discount rate would be roughly $93,000. A graphic representation of these financial projections is available in Figure 16.

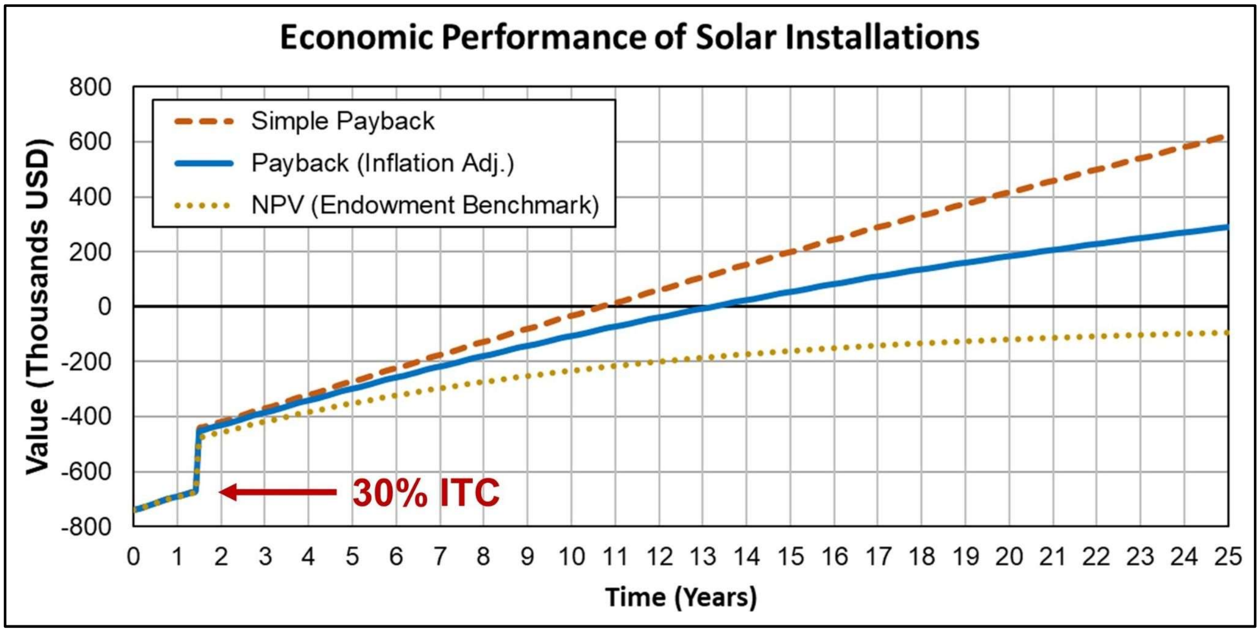

Figure 16: Financial projections for the costs associated with all proposed solar installation projects. The NPV approach utilized a 9.9% discount rate, which is the benchmark chosen for comparison against the University endowment's rate of return. The inflation rate was assumed at 3% annually.

Regarding the potential GHG emissions reductions offered by the proposed solar installations, the outputs from the SAM generation models and the successive calculations determined that the lifetime generation of all proposed solar projects would offset roughly 15,000 metric tons of CO_2 equivalents ($MTCO_2e$) over the next 25 years. In the first year of operation, the solar installations would generate enough energy to offset 646 $MTCO_2e$. By comparison, the total forecasted emissions for all SEAS properties during the first year of operation would be about 911 $MTCO_2e$ – a nearly 55% decrease in GHG emissions from the 2006 baseline values as set forth in the PCCN. When comparing the proposed offsets to the average GHG emissions from the last seven years, this translates into a 42% reduction from more modern levels. A graphical summary of these results is presented in Figure 17. While net-zero emissions status cannot be achieved for the SEAS portfolio during any month within a given year, these reductions do offer a significant step towards meeting the decarbonization goals of the PCCN. Perhaps with additional initiatives in energy efficiency or utility-scale decarbonization, this remaining gap can be whittled down even further.

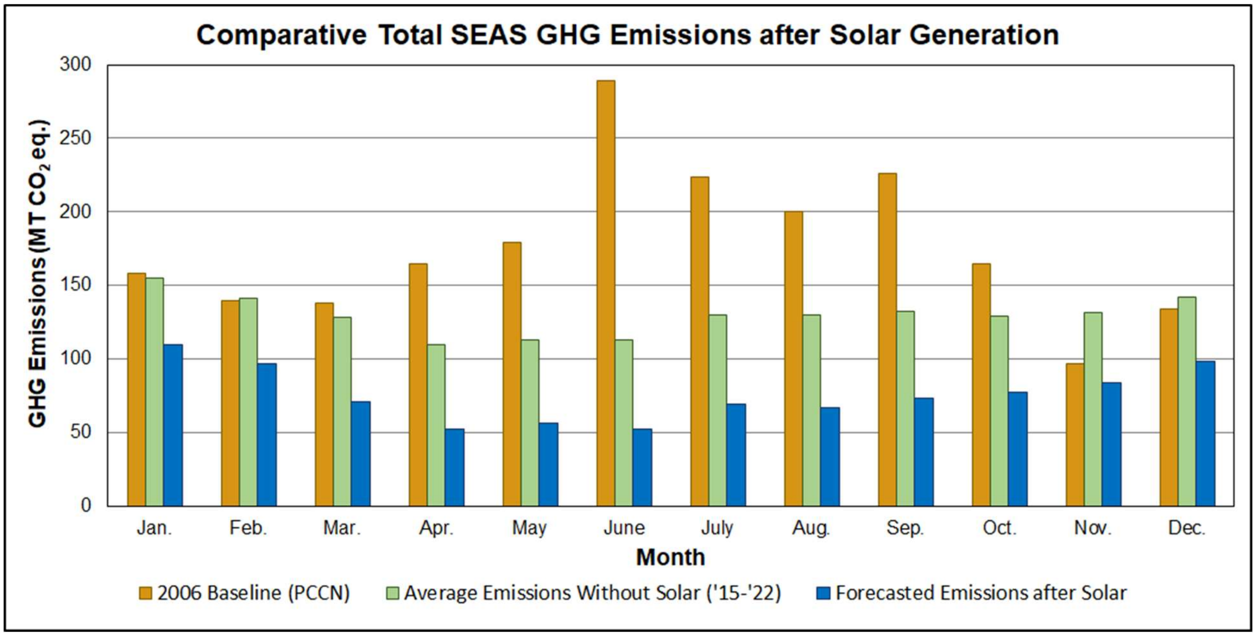

Figure 17: Comparative graph of total GHG emissions for all SEAS properties estimated after accounting for the first year of solar energy generation.

7.2. Window Inserts

Some classrooms in Dana have shown to be too cold for comfort in the wintertime. It is believed that cold air is penetrating through or around the windows in some classrooms, affecting the room temperature. In an attempt to test out this theory, our team set up a study with window inserts and temperature loggers in a room known to have temperature problems, Dana Room 2024.

First, during a normal school week, without window inserts, data was collected, downloaded and analyzed using two HOBO data loggers that record the temperature every minute. These data loggers were strategically placed on two different sides of the room and near the windows. This was so there could be multiple measurements in different locations within the room. Following this data collection period, window inserts were installed. Data was again collected, downloaded and analyzed. This entire study was done once with the window inserts and once without the window inserts. The data collected and observed in the room was compared with corresponding outside air temperatures in Ann Arbor sourced from the NOAA's National Center for Environmental Information database. They provided the dry-bulb outdoor air temperature in Ann Arbor for various times during the study. It was assumed that the Ann Arbor temperature was the same temperature outside of the Dana building. Additional assumptions were that the temperature loggers were precise and that the method of averaging outside air temperatures within these periods was accurate. The difference in these temperatures showcase the potential impact of the window inserts within the classroom. Results from this study are shown in Figure 18.

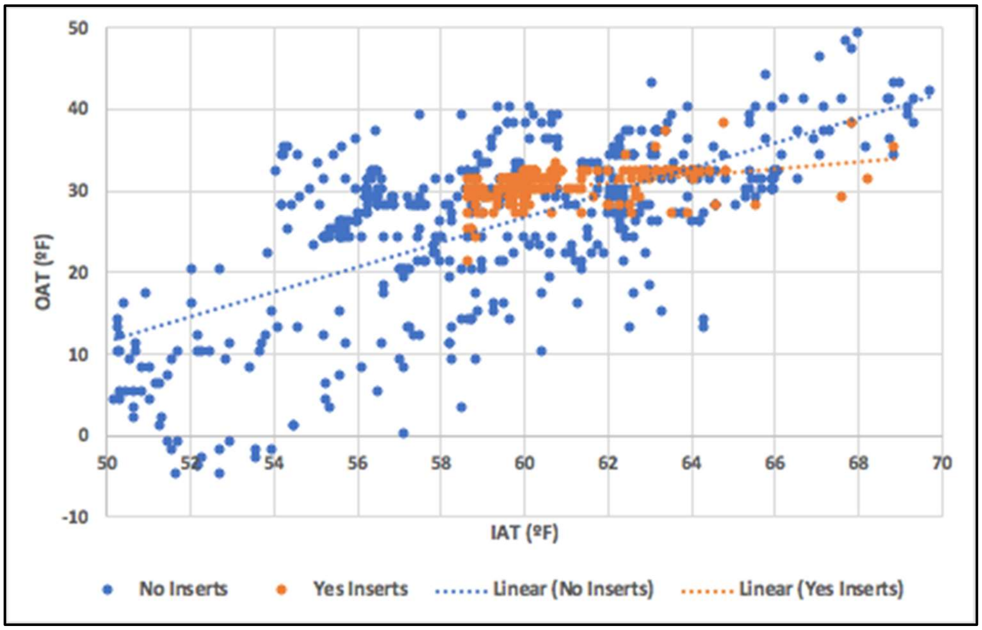

Figure 18: The outdoor air temperature (OAT) as a function of the indoor air temperature (IAT); measured with HOBO data logger at 1-minute intervals in Room 2024 at Dana and compared with data from NOAA, for the window insert observational study.

The results from the study visually show that the outdoor air temperature might have an influence on the indoor air temperature when there are no window inserts present in the room. It is unclear though and needs further investigation with more data for case with the window inserts, at lower outdoor air temperatures specifically. The slope of the distributions does not support that the inserts are a very impactful solution. Factors that may have affected data points include it being sunnier, or warmer, in different parts of Ann Arbor or possibly people in the room affecting accurate room temperature measurements.

```
Asymptotic two-sample Kolmogorov-Smirnov test

data:  Inserts.yes and Inserts.no
D = 0.37246, p-value < 2.2e-16
alternative hypothesis: two-sided
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Figure 19: R Studio statistical results of a two-sample KS-Test for window inserts data. This test was conducted assuming an alpha-significance of 0.05.

R Studio was used for statistical analysis of the window inserts data to help interpret and determine its significance. A two-sample Kolmogorov-Smirnov test was performed to conclude that the samples represent two significantly different population distributions. This means that the data for window inserts and no window inserts are not of the same distribution, further supporting our claim that the inserts may be impactful. Then a D-value of 0.37 means that this is the largest difference between both data sample's cumulative distributions. Results from this test are shown in Figure 19.

7.3. Education Initiatives

Education initiatives began as a way to communicate the above efforts to students, staff, faculty, and visitors. One method of communicating net zero initiatives to incoming students included creating a Google Slides presentation for orientation (Appendix C). This presentation included background information on the history and greening of Dana, as well as a focus on Dana's building systems including: heating and cooling, lighting, plug load, and solar. This was done in conjunction with the building manual and solar siting portions of this project. A focus on Dana's building features were also included in this presentation, which included sustainability initiatives within the restrooms, construction materials, waste management, and green space efforts. Finally, additional ways for students to get involved with SEAS initiatives and learn more about the functions of Dana were included. Similar to the student's presentation, an onboarding presentation for incoming faculty and staff was created. The staff presentation is intended for new hires and as a refresher to faculty and staff at the beginning of academic years. Much like the student presentation, this presentation includes the history of Dana, previous green infrastructure initiatives, recycled & sustainable building materials, and the major building systems. There are a few additions to this presentation, being more tailored to useful building specifics that students may not need to know in detail such as detailed maps of Dana and maps of other SEAS properties. Future additions will include ongoing facilities programs for sustainability such as zero-waste events, an elaboration on building technology and services including: 4help services, standard office equipment, and emergency systems.

One need that showed up in this project was how to implement future sustainability-related project ideas and would they align with net zero goals? An Action Template document was thus created as a guideline for capturing and implementing new ideas (Appendix D). The purpose of this action template is to guide projects in conversation and answer: which categories of sustainability initiatives the proposed project would support (e.g. energy & efficiency, material use, building envelope, natural environment, education, transportation)? which location(s) the project could be applied to? and what metrics are important to be considered with the proposed project? This short-form checklist also has additional questions to prompt thinking about main goals, resources, costs, and considerations with cradle-to-grave resource use, and planning for those in advance.

In addition to this list, a document of proposed projects for future reference was also created. This serves as a main location for ideas and initiatives to carry this project forward and to be utilized for future ENVIRON 391 class projects as well. This list encapsulates potential considerations for future net zero projects by looking into wind, geothermal, carbon sequestration, and Dana-specific, as well as property-specific projects. These ideas were compiled as a starting point to consider energy and consumption-reduction strategies. One such project is the Newcomb solar panel installations which was added on to the team's project this year. Additional projects with the need for Masters of Landscape Architecture (MLA)-student input were created in conjunction with the 2022-23, 3rd year MLA's. For these projects, a multidisciplinary approach can be taken involving other UM schools and departments.

Creating informational posters was the last goal in the education department of this project, where two main topics were posed. The first poster consisting of high-level ideas and project outcomes, utilized for internal (SEAS) distribution; this poster highlights the major topics of this project (building model, manual, energy data, and emission reduction projects) and some key findings within them. The second poster centers around Dana through ways the community can help contribute to lowering resource demand and highlights individual actions one could consider to be mindful of the building's energy and resource use. Some of these contributions include using task lighting rather than overhead lighting if the situation calls for it and wearing additional layers inside the building instead of using additional heat. The goals of the posters are to help garner support and future student interest in building-related sustainability projects while providing helpful information in our efforts.

8. Constructing a Building Manual

In order to implement energy reduction initiatives within a building, it is imperative to have a good understanding of how the various systems within the building operate. This can be difficult at times, especially with old, historic buildings such as Dana, since systems documentation can often be lacking. As part of this capstone project, a building manual was constructed to organize important building information into a single document that can be used by Facilities, Engineering, and Maintenance. The previous capstone project had started collecting data for a building manual but was unable to complete it. Therefore, this project continued the efforts previously started. Important information captured within the building manual included building history, the 'Greening of Dana' project, building energy and emissions data, structural and mechanical systems overviews, and building model information.

The first steps of building the manual involved sifting through and understanding the previous information that had been collected. There was a lot of useful information on the history of the building as well as 'The Greening of Dana' project, so that was quickly added to the official manual. There was also some useful high-level information about where the Dana building receives electricity, steam, and chilled water from - the Central Power Plant and the East University Chiller Plant. Knowing that, the team decided to start by gaining a deeper understanding of the various HVAC (heating and cooling) systems within Dana. To do this, various meetings were held between the project team, Dana Facilities, Building Engineers, and the Building Automation Systems (BAS) group. We discussed and documented the operations of the air handling units (AHUs), the return fans (RFs), exhaust fans (EFs), fan coil units (FCUs), radiant cooling systems, perimeter heat systems, and reheat coils. Once we gained an understanding of how each of these systems worked separate from each other, additional meetings were held to understand how they were all connected to the building's chilled water, steam, and/or hot water loops. These system interconnections appeared to be the least understood concept among all groups, so it was extremely beneficial having these meetings in person where unofficial schematics could be drawn out. These drawings for the chilled water loop and the steam/hot water loop are shown in Figures 20 and 21.

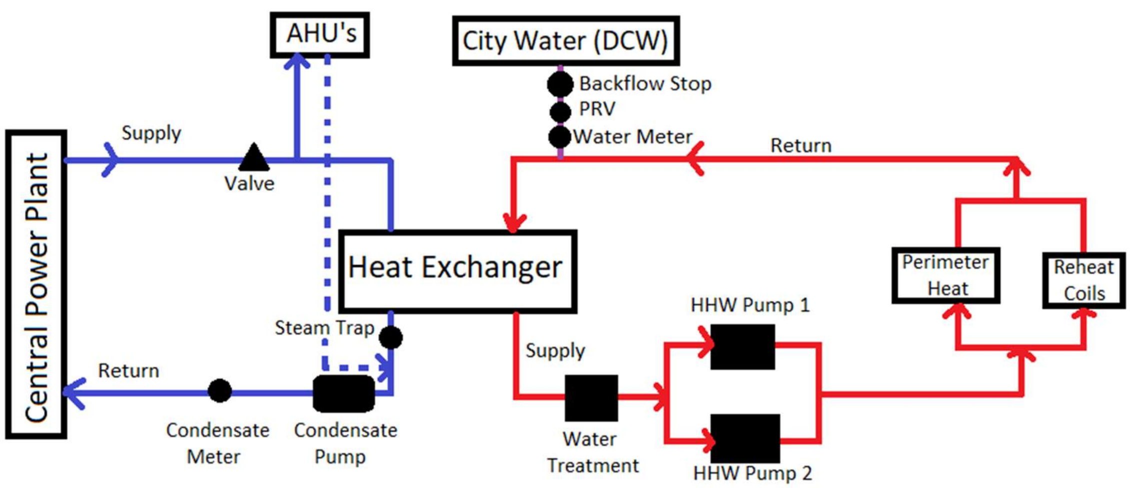


Figure 20: Steam / Hot Water Loops Within the Dana building
(Note: All elements are located inside the Dana building except for the Central Power Plant, condensate meter, and condensate pump)

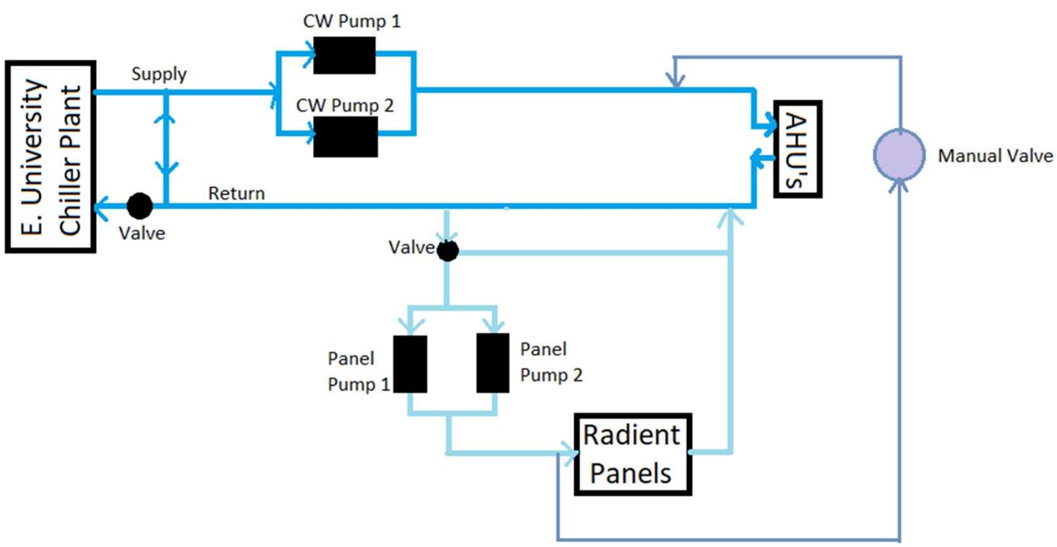


Figure 21: Chilled Water Loop Within the Dana building
(Note: All elements are located inside the Dana Building except for the E. University Chiller Plant)

Understanding the operations and connectedness of the HVAC systems was extremely useful for the team for documentation purposes, however it was also beneficial for all work groups involved with these systems (i.e. Facilities, Engineering, Etc.) to visualize how they all work. This information was also useful for incorporating HVAC into the Design Builder model to better represent the set-up within the Dana building.

Following the HVAC systems, the team continued to meet with Facilities to read through reports and databases to document information on the lighting, sanitary systems, solar panels, drinking water, and other smaller systems. These systems were more straightforward when inputting into the manual since there was more previous documentation on them.

Finally, a section was added to the manual to document the methodology for calculating the Dana building's greenhouse gas emissions from chilled water, steam, and electricity on an hourly basis. The manual provides the necessary information for future groups to continue calculating the building's emissions.

9. Recommendations and Next Steps

9.1. Solar Considerations

It is without doubt that SEAS must actively pursue the net-zero ideal, both to meet the benchmarks as set forth in the PCCN, and to also provide an example for other colleges and institutions across the University of Michigan. While the solar analyses presented here yield a possible annual net electricity reduction of about 50% (when compared to the average energy profile from the last decade) and a possible annual total net emissions reduction of 57% (when compared to the 2006 baseline) for the SEAS properties, additional investigations and investments will be needed to close the final gaps in SEAS' energy portfolio and carbon footprint. And to meet the 2030 net-zero deadline as established by the PCCN, SEAS will need to execute upon these installations within the next couple of years.

Regarding the financial considerations presented in the solar analysis, the total NPV of the proposed solar projects is at a deficit of roughly $93,000, when compared to the anticipated rate of return for the University's Endowment. However, when considering the social costs of carbon-intensive generation strategies, this deficit is absolutely justifiable. In fact, after considering the estimated lifetime displaced GHG emissions of the proposed projects, the NPV deficit would amount to a cost of roughly $6.20 NPV per displaced $MTCO_2e$. This value is considerably lower than the proposed $75 per ton carbon tax discussed by IMF Managing Director Kristalina Georgieva at the most recent COP27 summit.[35] It is also lower than all five of the carbon prices proposed throughout the course of the 117th U.S. Congress: $25 per metric ton by the *America's Clean Future Fund Act*;[36] $15 per metric ton by the *Energy Innovation and Carbon Dividend Act*;[37] $59 per metric ton by the *America Wins Act*;[38] $35 per metric ton by the *MARKET CHOICE Act*;[39] and $54 per metric ton by the *Save Our Future Act*.[40] Because these projects will ultimately yield a positive return on investment after accounting for inflation, and because the University of Michigan seeks to lead in the field of net-zero strategies, the project team concludes that this investment deficit when compared to the Endowment is ultimately worthwhile.

As an additional note regarding funding, this report also stresses the importance of maintaining eligibility for the 30% ITC direct payment, as outlined in the IRA. This includes payment of installation and maintenance workers at the local prevailing wage, and contracting an installation company that meets the apprenticeship requirements – 12.5% of labor hours dedicated to apprenticeships for constructions beginning in 2023, and 15% of labor hours for constructions beginning in 2024 or later.[41] Without the credit contributing to the costs of the systems, the economics of the proposed projects shifts significantly, so these items should be prioritized as SEAS discusses plans for execution on any renewable energy projects that it pursues.

Considering future renewable energy initiatives within the SEAS portfolio, there are three possible pursuits that this project would also like to highlight as potential avenues for further investigation. The first possible future project relates to the Saginaw Forest property and the potential for a dual-use parking lot next to the trailhead, as previously discussed with SEAS Facilities. While complications regarding shading considerations and uncertainties regarding quantification of costs and impacts of clear-cutting the forest space needed to achieve such a project ultimately excluded the site from this report's pursuits, this project idea nonetheless aligns with the larger goals of SEAS. Thus, it is this report's recommendation that such a project be pursued independently by a future Master's project.

The second future project consideration is that of a partnership with DTE for execution of the proposed renewable installations. DTE has previously partnered with the University of Michigan on renewable energy projects,[42] and current projects with local industry leaders means that there is already a precedent for collaboration.[43,44,45] But because DTE ultimately approves or restricts such initiatives, additional investigation into utility cooperation is warranted.

The last future project consideration is that of potential battery systems to optimize net-zero strategies. While this report has ultimately chosen not to include battery systems in its investigations, if SEAS wishes to maximize the number of operating hours where net-zero status can be achieved, then further research will be needed for optimization. This could perhaps also be another subject for a future Master's project.

In all, this report concludes that the solar initiatives outlined are beneficial to the SEAS energy portfolio, considerably reduce the carbon footprint of the SEAS community, and are cost effective for implementing sustainable strategies. Should SEAS wish to continue to lead in sustainability at the University of Michigan, pursuit of the proposed solar projects would be a prudent decision.

9.2. A Case for Window Inserts

Based on the temperature data collected in room 2024 of the Dana building, there is some evidence that cold air may be entering the room through the window areas. This is a case for deeper investigation on the root cause of uncomfortable, low temperatures, in certain classrooms in wintertime. The data is not conclusive enough to claim that the inserts are impactful. If the Dana building does not plan on replacing windows, Facilities should consider auditing the entire building for which rooms experience uncomfortably cold temperatures in the winter months. The window inserts have some influence on the indoor temperature conditions. Installing these inserts would be a short-term fix, until all of the windows in the Dana building have been upgraded, however it could help save money and heating energy during the colder months of the year. More investigation is suggested before considering this a confident, feasible solution.

9.3. Dana Consumption Patterns

When examining an avenue to reduce the greenhouse gas emissions that can be attributed to the Dana building, the data seems to suggest that mitigating electricity use would yield the best results. Although steam is responsible for more energy use, electricity carries the most burden when it comes to greenhouse gas emissions. This is due to the fact that the source of the Dana building's electricity is relatively unclean. Electricity derived from the grid accounts for less than a third of the overall electricity utilized by the Dana building, yet is responsible for just under half of the emissions and in most recent years, actually overtakes the Central Power Plant for a larger share of the emissions. As the fuel mix used for the electrical grid is largely out of the university's power to augment, relying less on the grid for electricity would lead to a significant reduction in greenhouse gas emissions attributable to the Dana building. Otherwise, typical energy-saving suggestions such as updating to the most energy efficient models for appliances and lighting as well as employing more strict electricity use habits would likely lead to favorable reductions in greenhouse gas emissions. This method, however, is less certain for significant emissions reductions.

Mitigating the amount of steam used in the Dana building can be another approach to yield greenhouse gas emissions reductions. The issue with this relative to electricity is that steam is primarily used for heating which makes it difficult to directly reduce usage of. It may be possible to reduce steam use by lowering the desired temperature, but it would be difficult to strike a balance between steam use mitigation and personal comfort. Also, this has the potential to backfire as those who feel particularly uncomfortable may replace this lost steam heating with personal heating devices such as electric blankets and space heaters which may increase electricity demand on the Dana building. Expanding the use of window inserts could potentially yield a significant reduction in steam needed to heat the Dana building but would certainly not lead to a net-zero framework. Alternative heating technologies such as geothermal heat pumps could potentially result in significant emissions reductions. Future studies should be conducted to analyze the impact of such technology within the Dana building.

9.4. Design Builder - Future Adjustments

Design Builder is a very high level and detailed software with lots of potential for energy modeling, and more. It is so detailed that it is not as easy to use as advertised. Even with the basic software training, it is difficult for newer users to fully understand all of the software capabilities and intricacies.

Moving forward, to improve the model within Design Builder, it would be important to find the correct inputs for the fan and motor efficiency along with fan curves to measure the systems performance. This would give a more accurate measure of energy use with the HVAC system and better model of airflow through the building. Future project teams should work with the Dana building engineer to verify the building model accuracy and energy output. This would include going through the building automation system (BAS), for Dana, and verifying each space's temperature setpoints and schedule. Being able to confidently check and verify the building's programming increases the confidence of the building model and its output. From the data comparison in Section 9, the focus of the adjustment should be the summer months. Since electricity is significantly overpredicted during this time, it is important to consider how occupancy affects energy system usage during this time given the low occupancy rates in the summer. Future work should consider how occupancy rates could be estimated in order to improve the accuracy of the model. Lastly, an important point of consideration lies within the steam usage during the summer months. It makes sense that the steam usage during this time would be very low as the model predicts. The significance of the steam usage in the summer may highlight some inefficiencies within the building which should be accounted for. The source of any possible inefficiencies should be analyzed to again improve the accuracy of the model.

10. Conclusions

The overall goal of this project was to help the School for Environment and Sustainability identify ways for the Dana building to achieve net zero emissions. As part of this project, a building manual was developed to host a variety of information about the Dana building including history, emissions data, structural and mechanical systems and components information, and the building model data. The manual is intended to be a source of information for any workgroup working with the Dana Building. It proved to be very useful when developing a model of the building within the software Design Builder. Various structural and mechanical elements were inputted into the model such as HVAC, lighting, insulation, etc. The goal of the model was to build an accurate representation of the Dana building so that various energy consumption scenarios could be simulated within it to further identify possible energy savings. Once the model was constructed and run, the results were compared to the actual hourly energy and emissions data associated with the Dana building. While this project team recommends that future iterations of the model include adjustments for occupancy metrics, seasonal usage, and inclusion of the VAV system for steam consumption, the model otherwise captures the building's anticipated performance and is thus a success within this project's scope. As the model evolves, it will be an invaluable decision-making tool for future SEAS initiatives within the Dana Building.

Calculating the hourly energy and emissions data for the Dana building was extremely valuable to the project to show exactly how much the Dana building has been emitting from its energy consumption from electricity, steam and chilled water. Analysis of this data showed that while energy consumption rebounded to 2019 levels in 2022 (post COVID lockdowns), emissions remained below pre-pandemic levels. However, further action will be needed to decrease emissions. This project evaluated adding solar generation to various SEAS properties in order to offset some of the emissions from the Dana building. Based on the proposed solar installations, the first year of operation would result in nearly a 55% decrease in GHG emissions from the PCCN 2006 baseline values as well as a 42% reduction from more modern levels. While total capital investments for the solar installations proposed by this project are estimated at about $740,000, the associated lifetime emissions credits from these installations would offer an implied carbon price much lower than carbon taxes previously proposed by governmental bodies – this is true, even after accounting for a lifetime NPV deficit based on comparative economic performance against the University's endowment. In the opinion of the research team, such a reduced carbon price is a well-justified expense for SEAS, and these solar installations are worth pursuing. A formal solar installation proposal will be provided to the Dean of SEAS, Jonathan Overpeck.

While adding new solar generation to decrease the emissions from the Dana building is beneficial, the project team sought out initiatives to decrease energy consumption within the building. Further studies should be conducted to quantify the energy savings and emissions reductions by utilizing window inserts. Lastly, the project team implemented a variety of educational strategies to improve occupant behavior within the building in regards to energy reduction measures. These strategies include slideshow presentations for student orientation and faculty onboarding as well as the creation of posters showcasing this project's progress on decreasing energy consumption and emissions within Dana. Updated information on Dana's current net zero efforts can be expanded upon within these presentations and posters in the future as further developments and initiatives towards net zero continue.

Overall, reaching net zero within the Dana building continues to be a challenge. It will require operational changes at the University level to truly reach this goal. However, this project has shown that there is still room for additional improvements and energy saving measures within the building. Beyond the Dana building, there are many other similar historic buildings on campus. Lessons learned from this project can be further implemented within those buildings to assist in their energy and emission reductions journey. SEAS has always been a leader in sustainability at the University of Michigan and will continue to be in the years to come.

Appendix A - History of the Dana Building & Greening of Dana[46]

<u>Building History</u>

The Samuel Trask Dana building was built on the original 40 acres of what is now the central campus Diag of the University of Michigan between 1901 and 1903. Originally known as the Medical Building, this Beaux-Arts style building was designed by notable Detroit architects Frederick H. Spier and William G. Rohn, whose portfolios include churches, railroad stations, and the Detroit Chamber of Commerce Building. The building is located in the University of Michigan's National Register Central Campus Historic District at 430 E University Ave. Built by Koch Brothers for a total cost of $167,000, the building, which housed a basement and three stories, measured 175' x 145' with a 75' x 45' interior courtyard. The basement and first floor exterior was composed of dressed fieldstone and the upper stories consisted of pressed and molded brick with intricate arches and cornices. There were originally two entrances, located on the eastern and western sides of the building, which were constructed with decorative Bedford limestone. The interior of the building consisted of brick walls, wooden floors made from Georgia Southern Yellow pine, wooden ceilings, and Louisiana red cypress finishes. It included laboratories, classroom spaces, and offices.

The building was originally home to the departments of Anatomy, Histology, Pathology, Bacteriology, Physiological Chemistry, and Hygiene. By 1955 it housed the offices of the Medical School as well Pathology and Physiological Chemistry laboratories. In 1961, after undergoing a significant $925,700 renovation, the West Medical Building was taken over by the School of Natural Resources and Environment (SNRE) and in 1973 it was renamed the Samuel Trask Dana building, in honor of SNRE's founding dean.

<u>The Greening of Dana</u>

From 1998 to 2004, the Samuel T. Dana building underwent an ambitious renovation. The original goal of the project was to bring the 100-year-old building up to code, expand the facilities within the building, and increase the overall comfort level for the building's occupants. However, through a grassroots effort by students, staff, and faculty pushing for the development of a "greener" building, phase II of the rehabilitation was established: "The Greening of Dana". This phase was implemented by a sustainable design team consisting of green building materials experts William Donough Partners, local architect Quinn Evans, and the engineering firm of Ove Arup and Partners with the goal of integrating sustainable design features and innovative technologies while maintaining the historic integrity that the building was known for. The mission was to promote sustainability, reduce negative health impacts, and showcase ecological themes by designing "a *building where environmental principles are not only taught, but upheld and demonstrated to community".*

The $25 million project sought to conserve energy, water, materials, and make use of environmentally friendly materials wherever possible. By "infilling" the interior courtyard and adding an additional story, they were able to add an additional 20,000 square feet to the building, transforming it from 97,000 square feet to over 117,000 square feet, without expanding its original footprint or dismantling the authentic exterior features. To this addition, a cantilevered atrium ceiling was installed to provide the center of the building with natural daylight and increase the overall passive solar radiation in the structure. The structure also underwent a complete envelope upgrade by installing new insulation and windows. To reduce waste the old windows were donated to Recycle Ann Arbor's Re-Use Center, diverting over 3,000 pounds of materials from the landfill. Throughout this renovation, the Dana building retained 100% of its exterior shell, 50% of its interior structures, and recycled 25% of the overall construction waste. The project also implemented a host of internal mechanical and electrical technologies and features that were estimated to decrease energy consumption by 30% and water consumption by 31%.

Heating and cooling, especially in larger and or aging structures, is one of the most significant energy loads in a building. Prior to the renovation, the building utilized its windows for cooling which can be a very inefficient process since it promotes excessive external air infiltration. To address this, Dana was equipped with a passive Radiant Cooling System. This innovative technological solution utilizes chilled water that is directed and re-circulated through piping in ceiling-mounted panels and passively cools the air throughout the space. Installed on the ceilings of classrooms, laboratories, and offices (except on the 4th floor), the radiant cooling panels require less energy than a traditional air-cooling system while the water pumps consume 10% less energy than the fans in a forced air system. A detailed analysis of the complete radiant cooling system installation determined that it would reduce overall energy costs by about 30%. A Direct Digital Control ("The Brains") was also installed onto Air Handlers to monitor and maintain the mechanical and electrical systems within the individual workspaces throughout the building.

The renovation also instituted several features and techniques to promote water conservation within the building. All of the fixtures in the restrooms were swapped out for low-flow fixtures which use significantly less water than traditional fixtures; The new toilets (28 total) use 1.6 gallons of water per flush as opposed to the 3.5 gallons used by traditional toilets, and dual flush handles provide the opportunity to only use 0.8 gallons per flush for liquids. Along with low-flow technology, the faucets were equipped with sensors to ensure water is not used unnecessarily in the sinks and *waterless urinals (10 total) were installed in all of the men's restrooms and use 0 gallons of water compared to 1 gallon per use of traditional options. Though in concept these toilets work well they learned, through use, that designing the low flush toilets upstream from the urinals worked best to pass the waste through the sanitary system. Composting toilets (3 total) were also installed to provide an alternative for occupants. Composting toilets use 0 gallons of water per use and the entire system in Dana uses 1-3 gallons per day. These toilets collect the waste in the ground floor chamber (as opposed to sending it into the sewer system) where microbes and worms turn it into compost. These toilets are maintained on an as needed basis and have the capacity to handle 40,000 uses per year. The original intent was to have the compost waste applied to the landscape, but Michigan regulatory agencies have not granted approval, stating concerns of pathogens and insufficient temperatures. SEAS Facilities has worked with SEAS students interested in helping the school achieve the goal of land application to complete the full cycle it was intended for, but have yet to be successful.*

The planting of native plant species in the exterior landscaping also worked to create a more water efficient exterior landscape around the building since it requires no irrigation system. This is very significant because it is estimated that 20-50% of the daily water consumption per person in the United States is used for the irrigation of lawns or gardens. The existing trees on site were also maintained in order to maintain adequate site shading. The use of native plant species is also a primary feature of the greener, more sustainable image that Dana was looking to achieve. Apart from water conservation, the utilization of native plants helps to provide habitats for local insects, birds and small mammals, and allows Dana to showcase examples of specific local ecosystems and species. From the shady, moist area along the south side walkway to the sunny dry area on the northern walkway, Dana is able to present the vast ecosystem diversity of Michigan ranging from shaded woodlands to open prairies.

Another key component of the green rehabilitation of the Dana building was the focused waste reduction throughout the construction process through recycling and reuse initiatives. During the demolition/construction process, sub-contractors were encouraged to separate recyclable materials such as metals, wood products, carpet, paper packaging, etc. that were later collected by Recycle Ann Arbor. Other materials were salvaged, saved, and incorporated back into the building. The 100 year old Southern Yellow Pine beams from the dismantled roof framing were re-milled and utilized as ceiling material, railings, and even furniture for the improved building. The majority of the original doors were refinished and re-installed instead of being replaced, requiring only updated hardware and fixtures. Bricks from the interior courtyard that were removed as part of the demolition were also re-used to fill in wall construction where needed or integrated into walkways *on the exterior of the building. These strategies not only diverted large amounts of waste going to landfills, but also helped to maintain much of the same character and ambiance that the original building was known for.*

The Dana building community also sought to incorporate the use of renewable materials and integrate other sustainable techniques and technologies as much as possible throughout the building. This included the use of thinly sliced bamboo flooring, multiple varieties of biocomposite board (wheat straw, soy flour, waste newspaper, etc.) for cabinets, ceiling tiles, and countertops. Polyethylene derived from recycled materials such as water bottles and various plastic containers was used for countertops in the restrooms and to construct seating and acoustic panels in the main auditorium. The wall and floor tiles located in restrooms and kitchen spaces contain 55% recycled glass, mainly from airplanes, and even the rubber flooring in the entryways is made from recycled tires and postindustrial rubbers. Overall, more than 12% of all of the new materials utilized during the renovation came from rapidly renewable resources. Other sustainable techniques utilized included the use of motion sensors to reduce unnecessary electrical output from the lighting system, white ceilings in the first-floor commons to maximize reflectivity and minimize the use of lighting in the space, LED exit signs, and even a 33kW solar installation of Uni-Solar thin-film and Kyocera multicrystalline PV panels on the roof.

This extensive renovation and the sustainable design strategies and technologies utilized helped the Dana building secure a Gold Leadership in Energy and Environmental Design (LEED) rating from the U.S. Green Building Council (USGBC). This achievement marked the first major academic reconstruction to receive this high of a rating in the entire state of Michigan, as well as one of the first in the entire country. In 2005 Dana was the first building on campus to receive a LEED rating and, since then, 11 buildings on the University of Michigan's Ann Arbor campus have joined Dana in obtaining LEED certification.

Since the "Greening of Dana", as improvements have been needed SEAS has tried to prioritize sustainability in its work. The renovation of the first floor kitchen, which is mostly used by students, included the use of recycled glass countertops, cork flooring and bamboo wall paneling and tables. The renewal of the Academic Suite integrated carpeting composed of recycled plastic from fishing nets, ash wood countertops, tables made from trees that were lost in the Nichols Arboretum due to bug damage, LED lighting, and zero volatile organic compound (VOC) paints. SEAS even increased the amount of glazing on interior doors to establish a more open feel and allow daylighting into the spaces. The Center for Sustainable Systems (CSS) received similar improvements with paint, carpet and lighting but also had additional windows installed in their walls to bring in more daylighting into the interior workspaces. These windows are framed with the ash wood from *the Nichols Arboretum where the bug damage is actually visible and the oak flooring at the entrance was installed using wood from the Art Museum oak tree that had to come down as part of their renovation. The wood is protected with some of the most eco-friendly wood protection of Rubio Monocoat that uses Linseed oil to seal the wood. And, one of the most recent projects that SEAS pursued was the conversion of the Dean's Suite to all LEDs. These past and current actions and improvements exemplify SEAS continued passion for sustainability and the integration of green solutions whenever possible.*

Appendix B - Supplementary Figures, Charts, & Tables

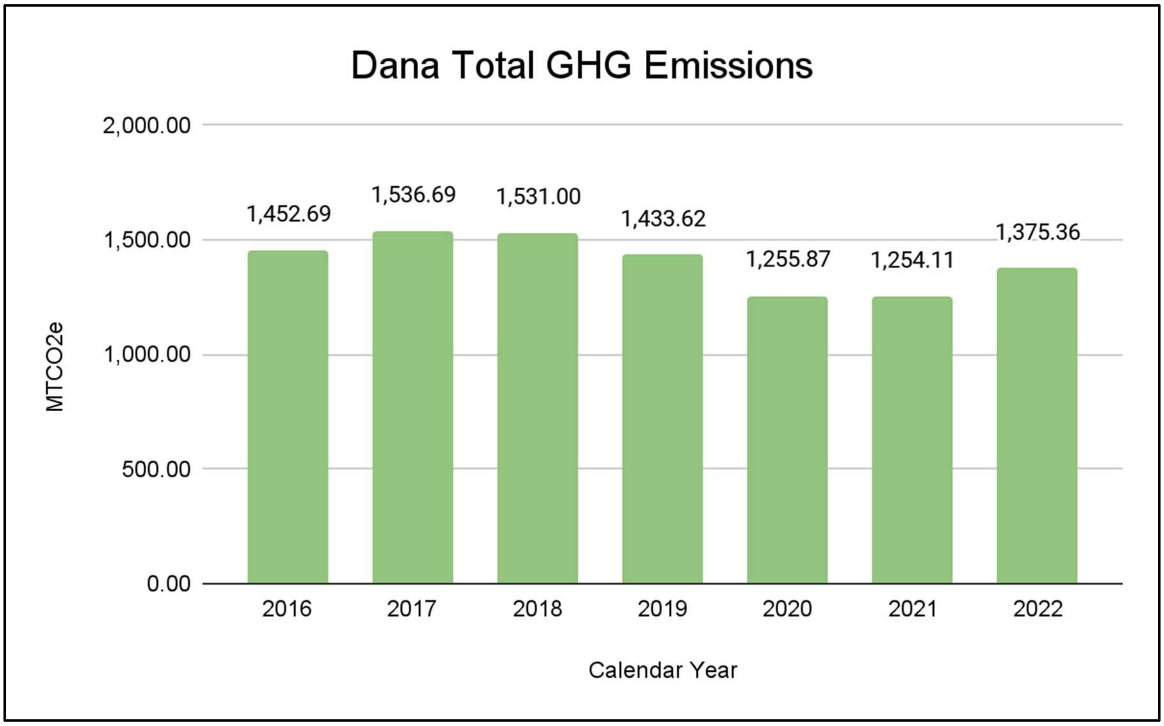


Figure B1: Total Greenhouse Gas Impacts in Dana

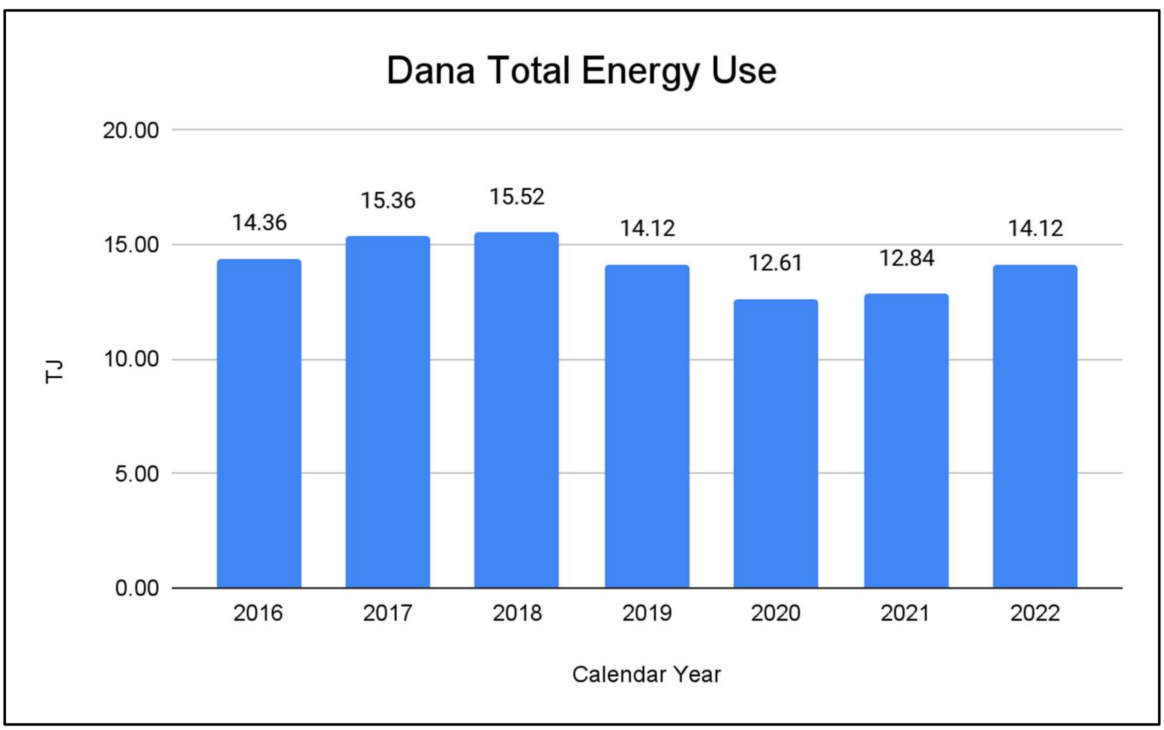


Figure B2: Total Energy Use Impacts in Dana

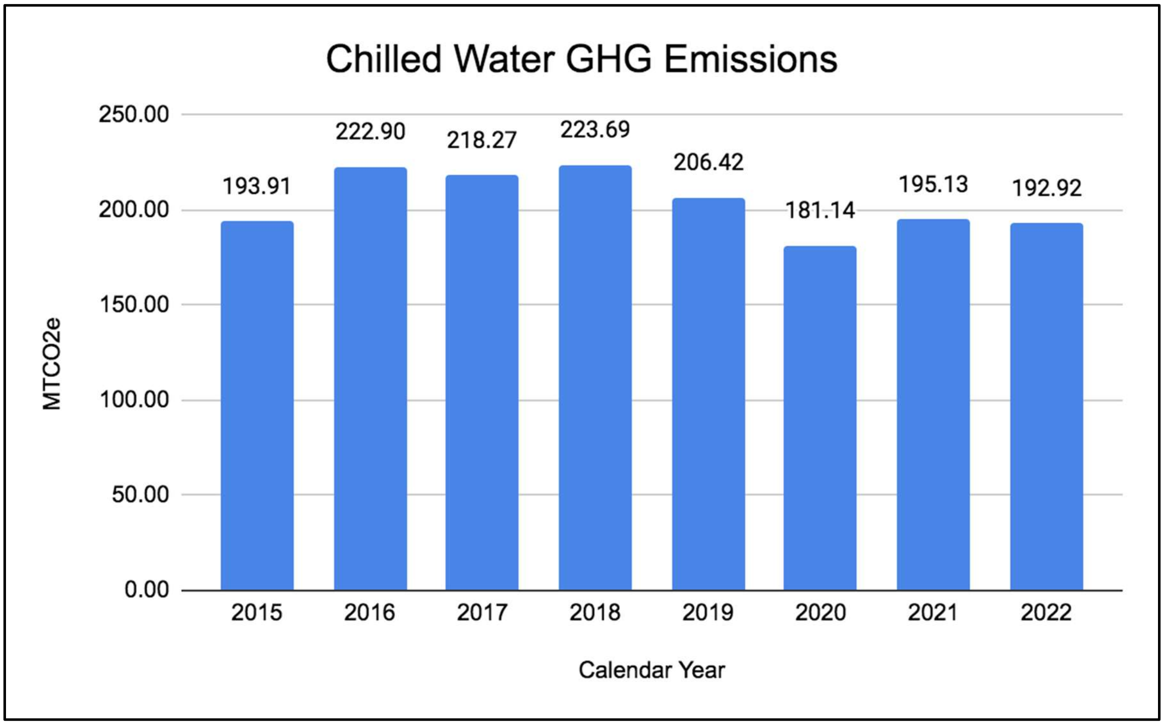


Figure B3: Greenhouse Gas Impact of Chilled Water Use in Dana

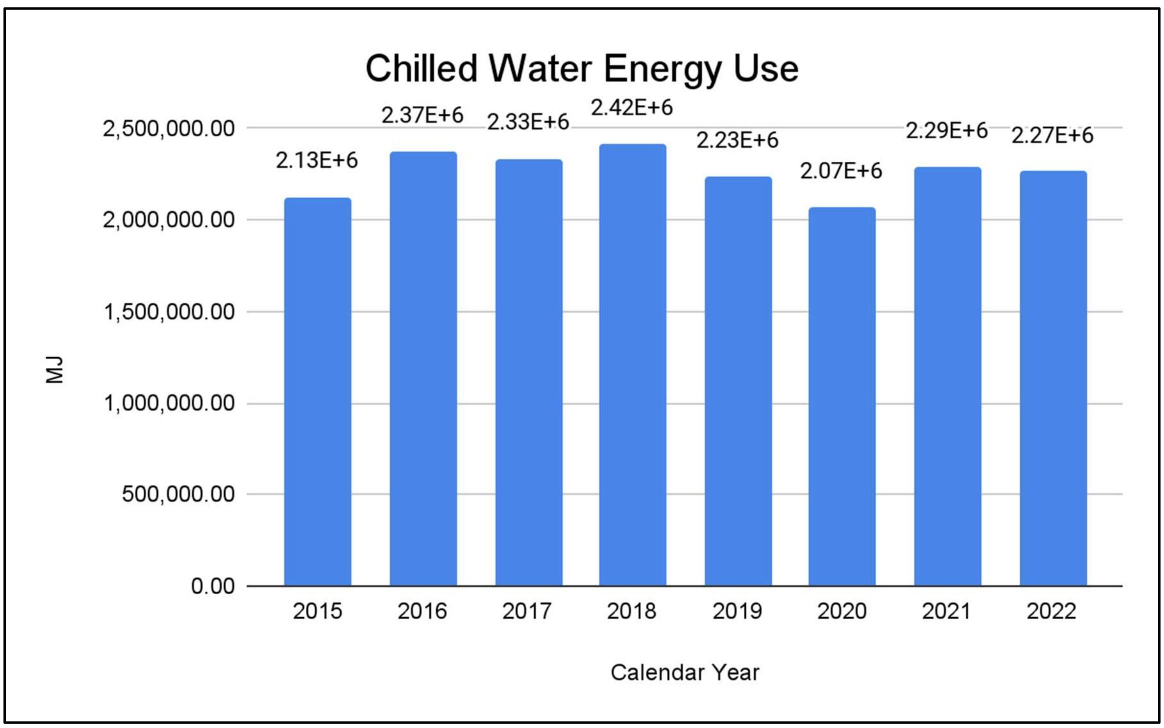


Figure B4: Energy Use Impacts of Chilled Water Use in Dana

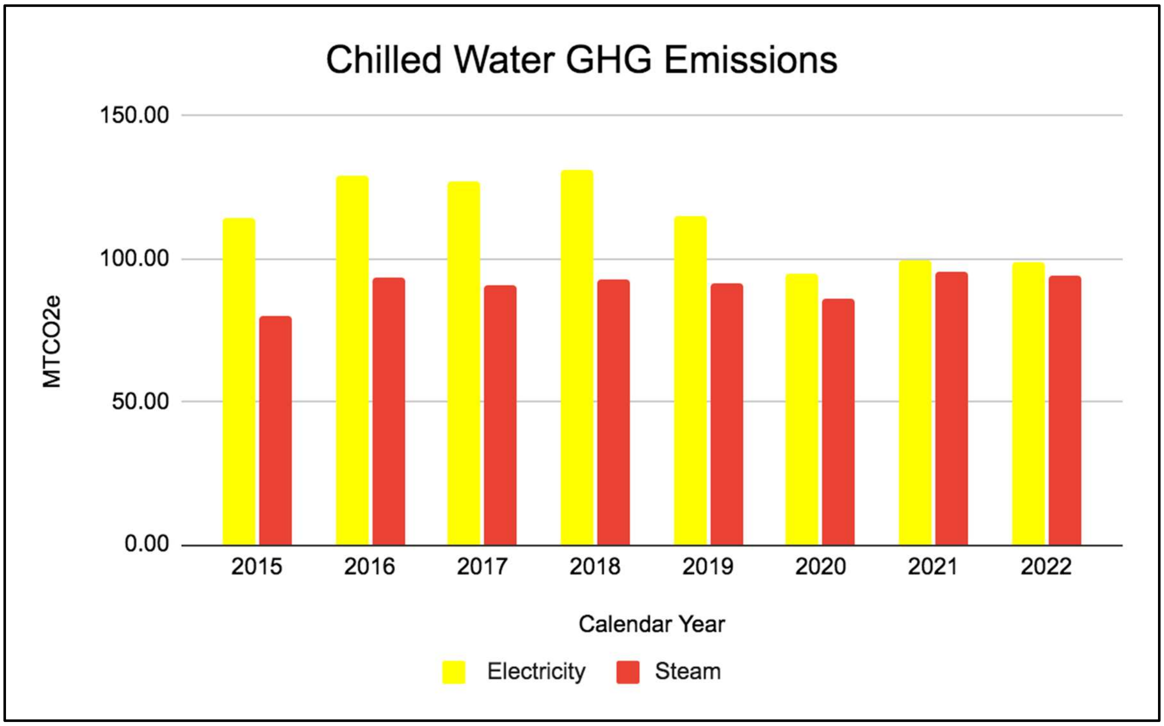


Figure B5: Chilled Water Greenhouse Gas Impacts From Steam & Electricity

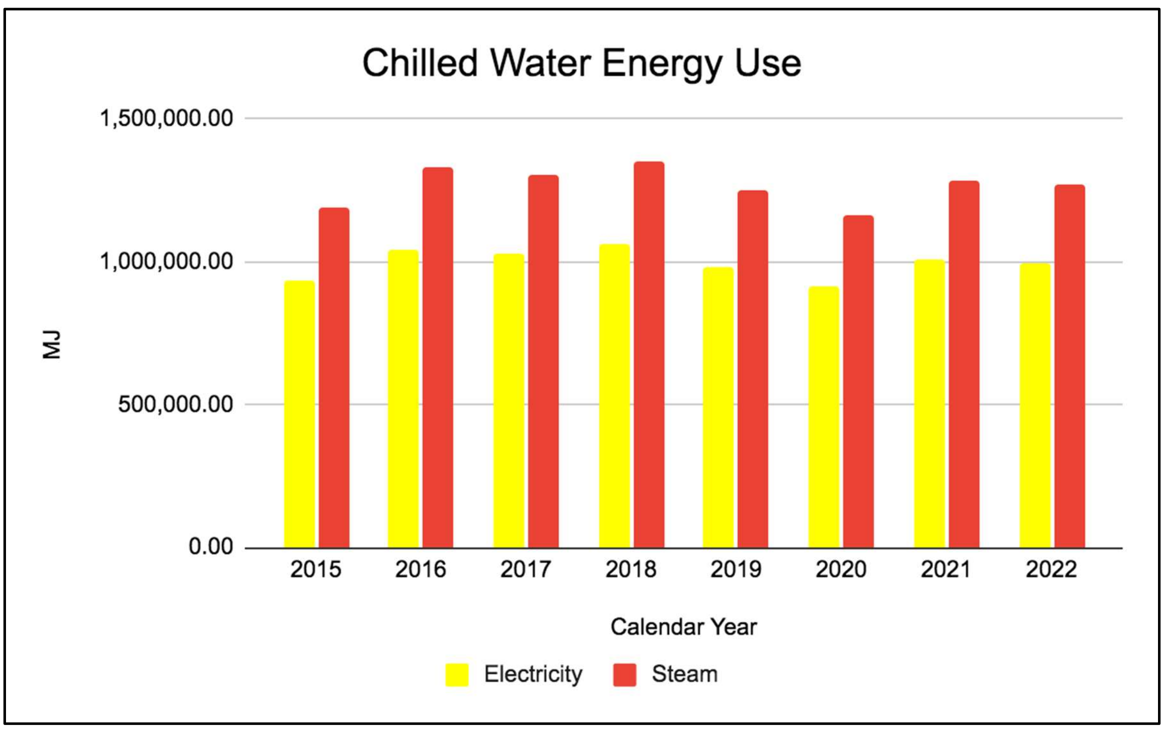


Figure B6: Chilled Water Energy Consumption From Steam & Electricity

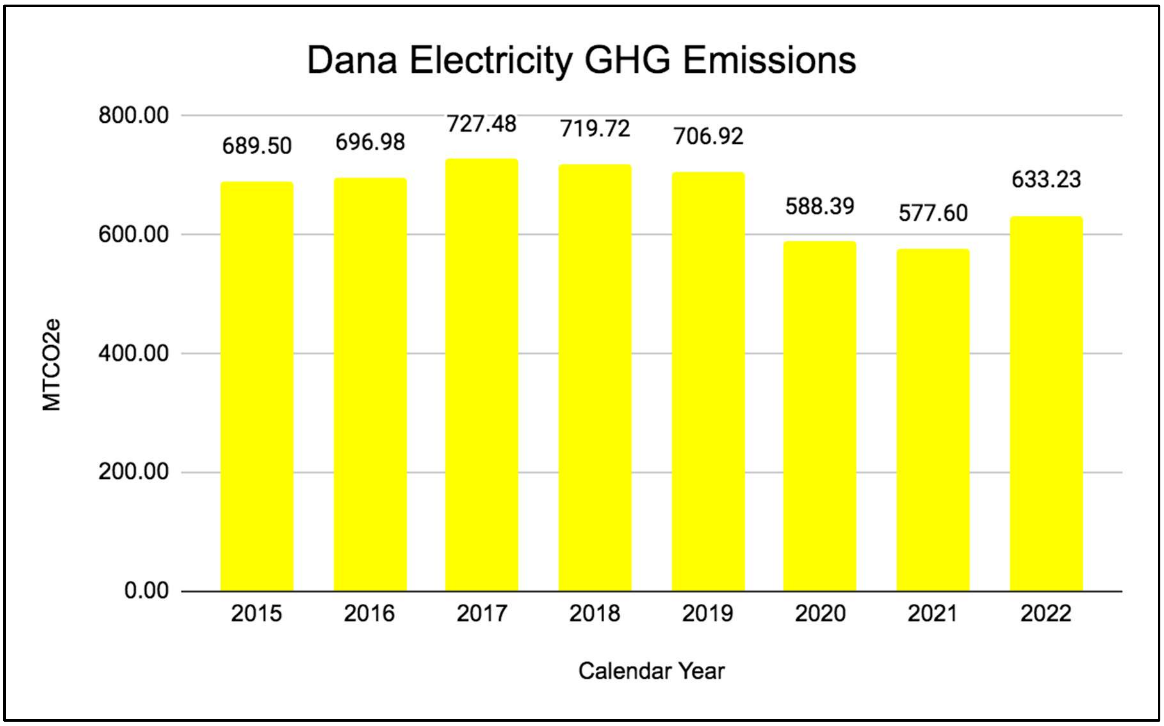


Figure B7: Greenhouse Gas Emissions From Electricity Use in Dana

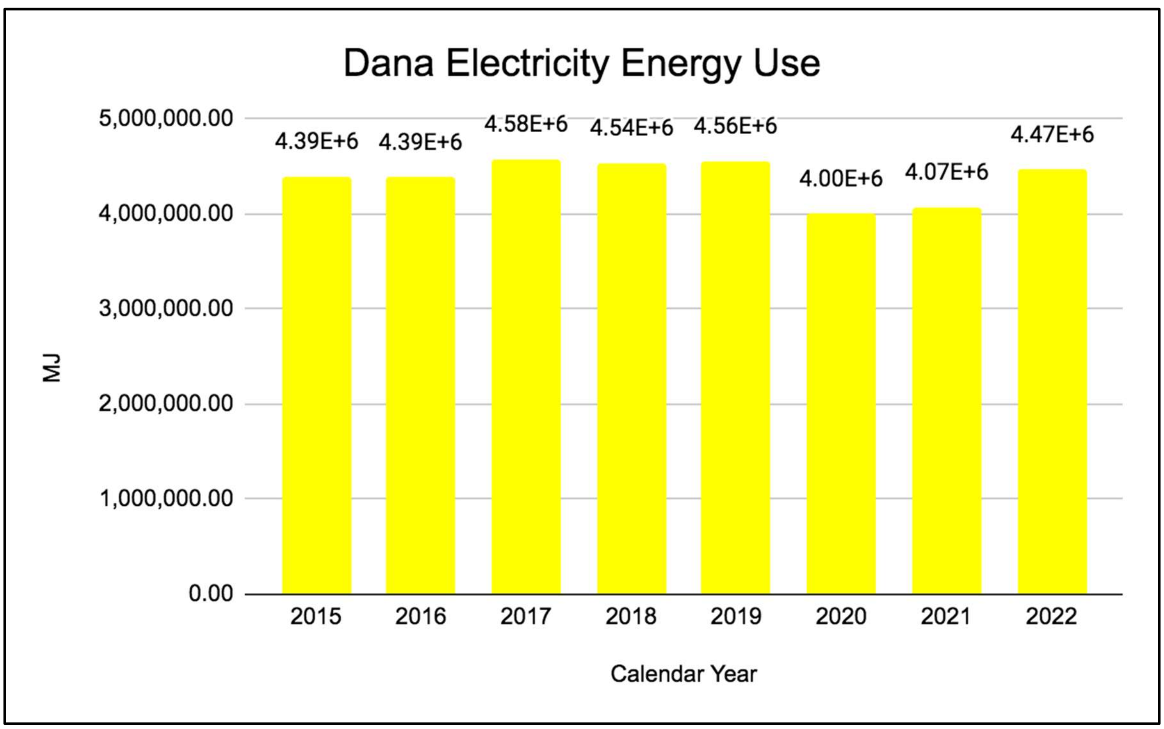


Figure B8: Energy Use Impacts From Electricity Use in Dana

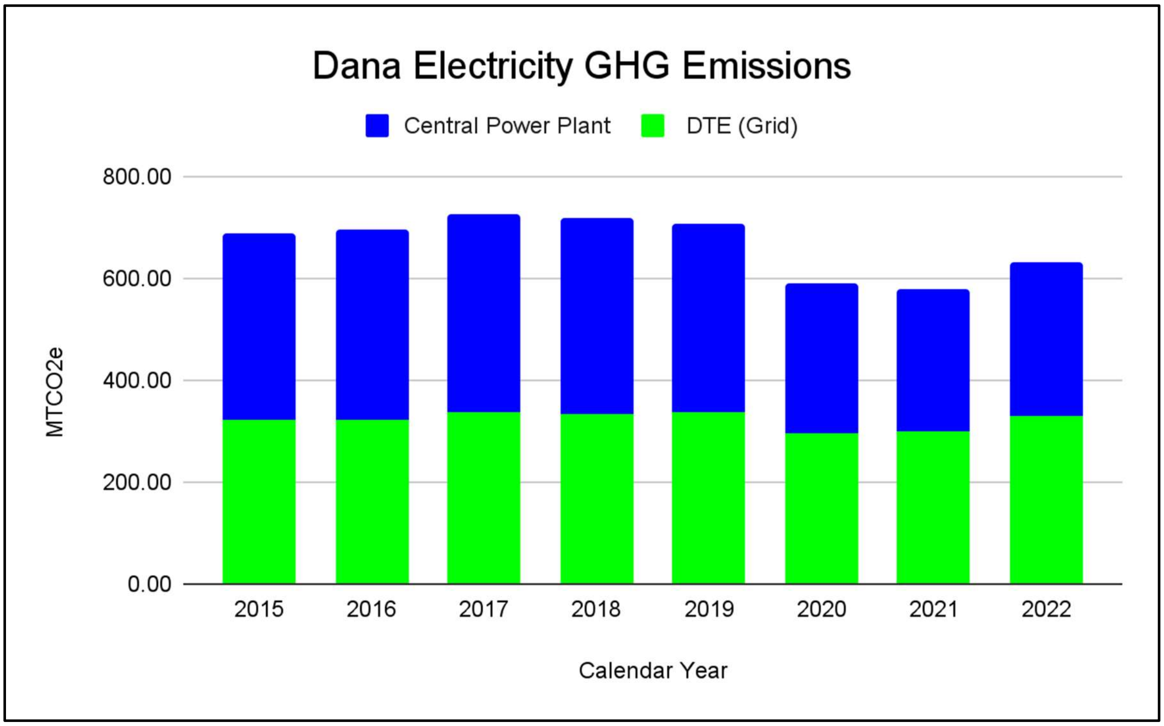


Figure B9: Greenhouse Gas Emissions From Electricity Use in Dana by Source

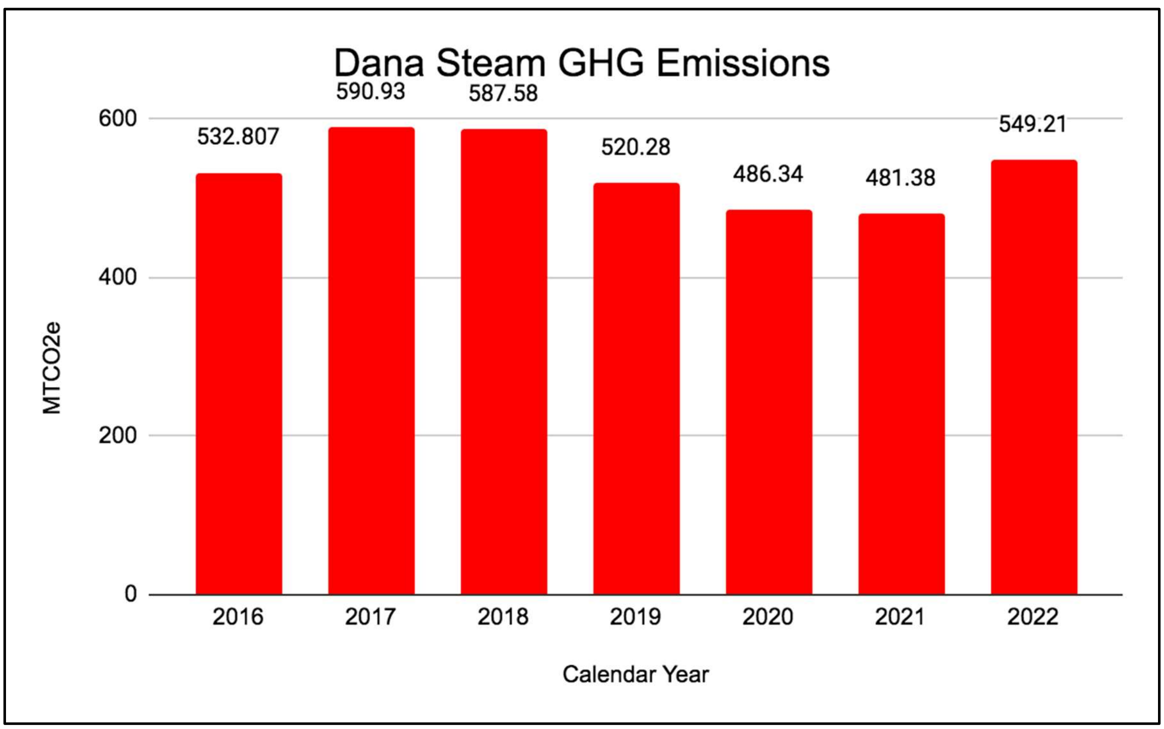


Figure B10: Greenhouse Gas Emissions From Steam Use in Dana

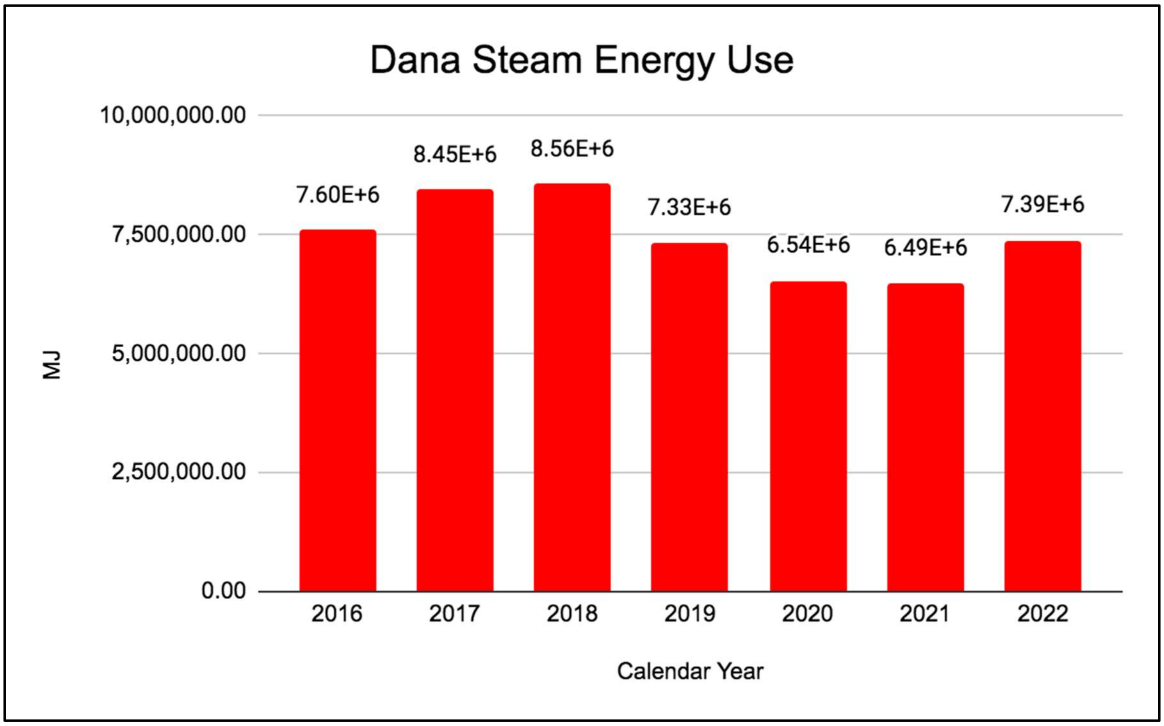


Figure B11: Energy Use Impacts From Steam Use in Dana

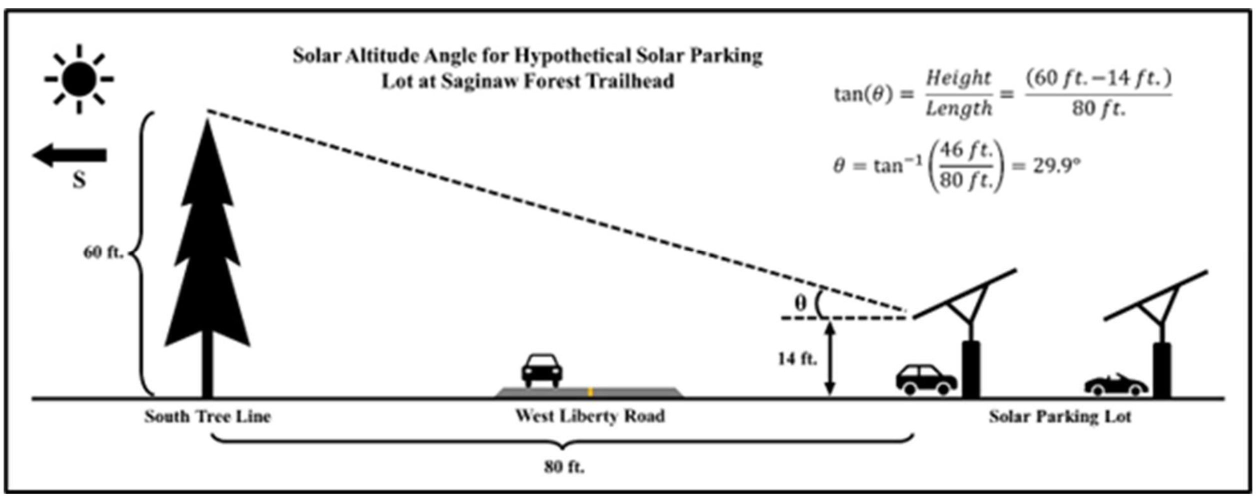


Figure B12: Trigonometric relationships for calculating solar altitude angle needed to avoid shading by southern tree line for a hypothetical solar parking lot at the Saginaw Forest Trailhead. Note that diagram measurements are estimates taken from GIS software and are not presented at scale; additional on-site investigation is needed to confirm values and fully assess property layout characteristics.

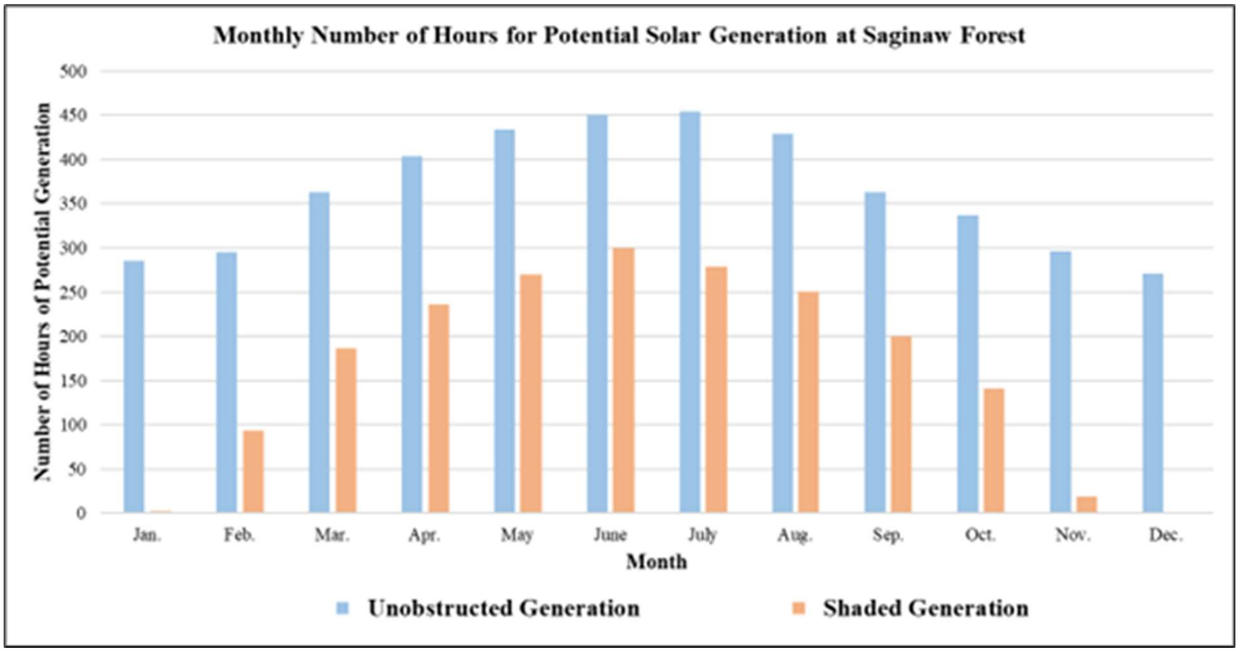


Figure B13: Monthly hours for potential solar generation at Saginaw Forest for a hypothetical solar parking lot using the parameters noted regarding shading restrictions.

Distance Between Installation Site and Tree Line by Azimuth Angle

Azimuth (°)	Distance (ft.)	Azimuth (°)	Distance (ft.)	Azimuth (°)	Distance (ft.)
50	104.5	140	110.6	230	62.2
60	95.8	150	113.7	240	48.4
70	87.8	160	118.4	250	47.5
80	82.8	170	121.9	260	48.9
90 (East)	79.5	180 (South)	153.3	270 (West)	49.2
100	79.2	190	234.8	280	48.5
110	83.4	200	147.3	290	48
120	95.3	210	117.2	300	52.2
130	106.3	220	90.3	310	60.4

Figure B14: Distance estimates between the observatory façade at the Stinchfield Woods property and the surrounding trees, based on calculations from GIS imagery. Note that values for azimuth ranges 0° - 40° and 320° - 360° are absent, per the assumption that these azimuths will have constant shading due to their positions behind the installation site.

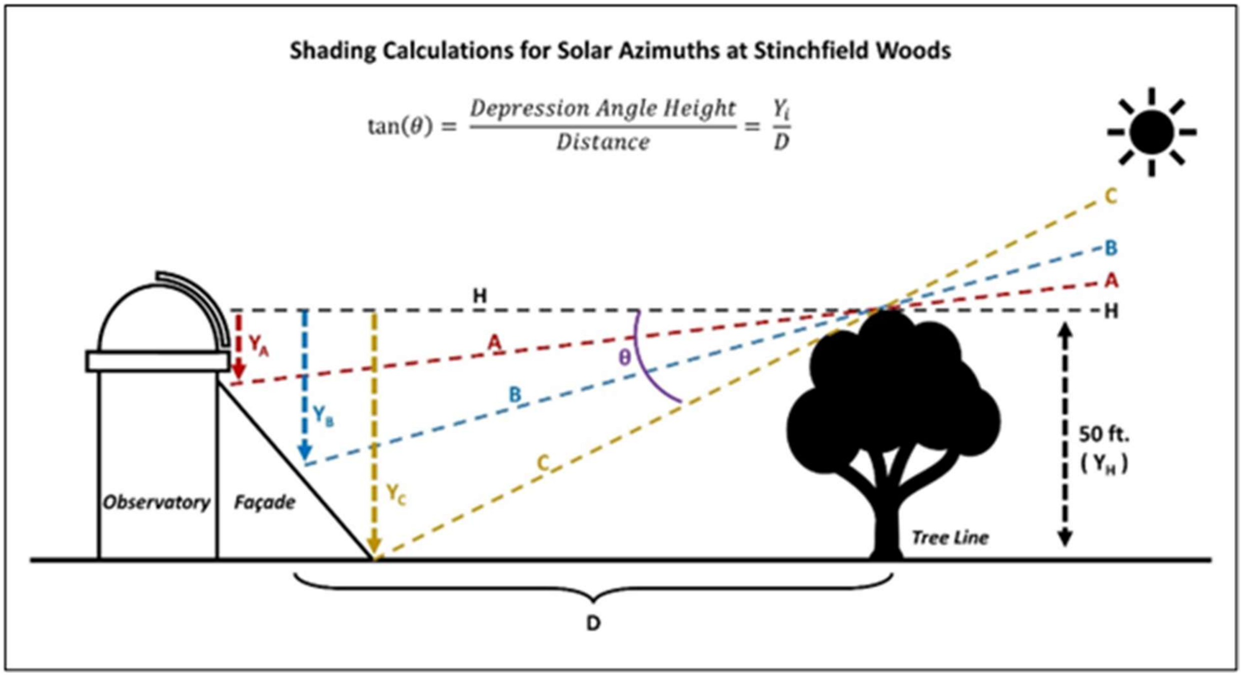
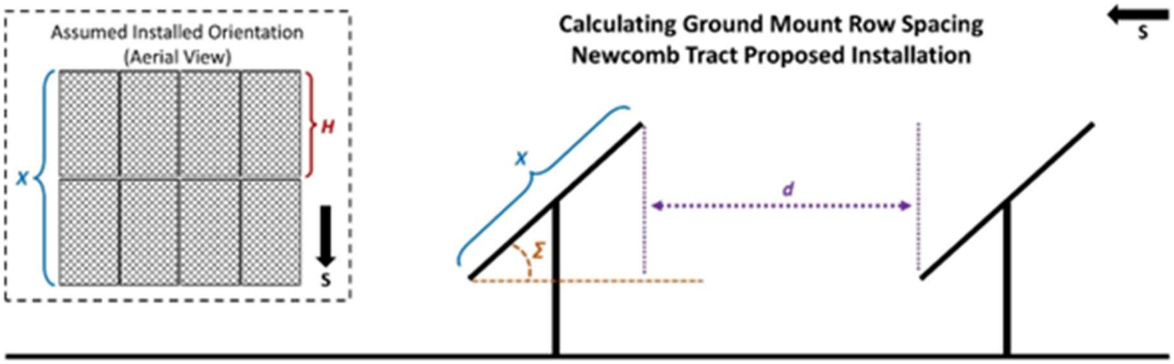


Figure B15: Diagram showing trigonometric relationships for shading calculations regarding specific solar altitudes at a given solar azimuth. The horizontal line for the top of the tree line is indicated by the black dashed line (H), and the associated height of this line (Y_H) is assumed at 50 feet. The topmost point of the solar installation is located at the intersection of the red dashed line (A) and the observatory's façade; the depression height given for this angle (Y_A) depends on the associated distance between the observatory and the tree line (D), which is specific to individual azimuths. Note that line A still represents 100% shading from the surrounding trees. The midpoint of the solar installation is located at the intersection of the blue dashed line (B) and the observatory's façade; the depression height given for this position (Y_B) is dependent upon the associated altitude angle (θ_B). This midpoint represents a 50% shading ratio of the solar installation. The bottom-most point of the solar installation is located at the intersection of the yellow dashed line (C) and the observatory's façade; the depression height given for this position (Y_C) is dependent upon the associated altitude angle (θ_C). This bottom-most point represents 0% shading, as the entire installation is now completely exposed.



$$\text{Distance between Rows } (d) = \frac{\text{Array Height } (X)}{\text{Ground Cover Ratio}} - \text{Array Height } (X) * \cos[\text{Tilt Angle } (\Sigma)]$$

$$d = \frac{2 * H}{GCR} - [(2 * H) * \cos(\Sigma)]$$

Figure B16: Process for calculating spacing between ground mounted solar array rows at the Newcomb Tract site. The distance between rows (d) is a function of the ground cover ratio (GCR), the height of the individual solar module (H), and the tilt angle of the installation.

Module Name	Number of Modules	Total Capacity
Q.Peak Duo XL-G10.2	840	415.8 kW DC
SunPower SPR-M440-H-AC	976	429.4 kW DC
Panasonic EVPV410H	976	400.2 kW DC
LG NeON H LG455N2W-E6	784	356.7 kW DC
Trina Vertex TSM-DEG21C.20	516	343.14 kW DC

Figure B17: Number of modules capable of being installed in the Newcomb Tract meadow space for each type of solar module, as well as rated capacities for the total hypothetical installation.

Module Name	Rated Capacity	Type	Width	Height
SunPower SPR-A420	420 W DC	Mono Si	3.34 ft.	6.02 ft.
LG 385N1C-E6	385 W DC	Mono Si	3.42 ft.	5.80 ft.
Panasonic EVPV370	370 W DC	Mono Si	3.33 ft.	5.65 ft.
SunPower SPR-E-Flex-110	110 W DC	Thin-Film	1.82 ft.	3.82 ft.
SunFlare Flex-60 185	185 W DC	Thin-FIlm	3.25 ft.	5.45 ft.

Figure B18: Short list of panels selected for Stinchfield Woods solar installation on the façade of the decommissioned observatory. Original width and height measurements were reported in millimeters and have been converted to feet here for ease of understanding.

Parameter	Variable	Dana Building	Newcomb Tract	Stinchfield Woods
System Capacity (kW_{DC})	-	33.162	429.669	5.826
Direct Payment ITC (1)	-	30%	30%	30%
Market Costs (2) (per W_{DC} capacity)	-	-	$1.636	$2.547
Capital Cost (3)	V_0	$19,800	$702,940	$14,840
Endowment Discount (4) (% / year)	D	9.9	9.9	9.9
Consumed Solar Energy (5) (kWh)	C_G	Obtained via SAM generation outputs		
Utility Electricity Rate (6) ($ / kWh)	P_G	0.08	0.13	0.13
Excess Generation (7) (kWh)	E_G	Obtained via SAM generation outputs		
Parameter	**Variable**	**Dana Building**	**Newcomb Tract**	**Stinchfield Woods**
Utility Buyback Price (8) ($ / kWh)	B_G	0.08	0.0727	0.0727
Yearly Fixed O&M Rate (9) (per kW_{DC})	-	$19.06	$18.03	$31.12

Figure B19: Table of parameters for hourly economic analysis. Notes regarding specific values or references are given below.

1. Following the passage of the IRA, the ITC has been extended to non-taxable entities, such as governmental bodies and non-profit organizations. This ITC direct payment is assumed to be paid at full value, following apprenticeship and domestic production requirements, as defined by the IRA.[47,48] For modeling purposes, this ITC is not considered to be received until month six of the second year of production (i.e., 18 months).

2. Values for market costs were obtained from averages calculated from the Lawrence Berkeley National Laboratory's (LBNL) *Tracking the Sun 2022* publication[49] and adhere to the ranges produced by modeled market price benchmarks as provided by NREL PV cost analysis.[50] State-specific data was not available for Michigan, so data points were isolated from Wisconsin as a

proxy location. Data points were divided into five categories based on installed system sizes, and average prices were calculated for each category: <20 kW (n = 131), 20-50 kW (n = 209), 50-100 kW (n = 25), 100-200 kW (n =26), and 200-700 kW (n =23). Only data for the 2020 and 2021 years were included, with residential and non-monocrystalline systems excluded. Unfortunately, available data did not have distinctions for tracking or mounting styles. No cost is assigned to the Dana building, as capital investments have already been quoted for the specific inverter upgrades.

3. For the Dana building, refer to the quoted costs produced by NOVA Consultants.[51] For Newcomb and Stinchfield, these values have been calculated using the system capacities and the presented market costs.

4. The discount rate for the University of Michigan's Endowment. This is a fixed value at 9.9% and is based on the 20-year annualized rate of return for the endowment, as reported in the *2022 University Endowment Fund Profile*.[52]

5. These values were obtained via the SAM generation profiles. Consumed solar energy is any energy produced by a solar array and then immediately consumed on-site as part of the location's demand profile. Leftover energy then becomes excess and is exported to the utility.

6. The electricity purchase rate for the Dana building is derived from utility bills provided by SEAS Facilities and is a set value at $0.08 per kWh from the Central Power Plant (CPP). The electricity rates are calculated from the DTE Rate Book for Secondary Educational Institution Rate (schedule D3.2) and rounded up for variability.[53]

7. All excess energy is assumed to be sold back to the utility at the buyback rate.

8. For the Dana building, it is assumed that the buyback rate for excess generation will be a 1-to-1 credit at purchase rate from the CPP. However, due to its large energy demand, it is unlikely that the Dana solar arrays will ever export in excess. For the Newcomb and Stinchfield properties, this rate is obtained from the DTE rate book, Rider No. 18 – Distributed Generation Program for schedule D3.2.[54]

9. Obtained from modeled market price benchmarks for operation and maintenance estimates as provided by NREL PV cost analysis.[55]

Hour of Day	CPP Emissions Factor	DTE Emissions Factor	On-Campus Emissions Factor	Off-Campus Emissions Factor
1	0.359	0.868	0.518	0.868
2	0.359	0.870	0.518	0.870
3	0.359	0.872	0.519	0.872
4	0.359	0.873	0.519	0.873
5	0.359	0.872	0.519	0.872
6	0.359	0.867	0.518	0.867
7	0.359	0.860	0.515	0.860
8	0.359	0.854	0.514	0.854
9	0.359	0.849	0.512	0.849
10	0.359	0.846	0.511	0.846
11	0.359	0.843	0.510	0.843
12	0.359	0.840	0.509	0.840
13	0.359	0.838	0.509	0.838
14	0.359	0.837	0.508	0.837
15	0.359	0.837	0.508	0.837
16	0.359	0.836	0.508	0.836
17	0.359	0.836	0.508	0.836
18	0.359	0.836	0.508	0.836
19	0.359	0.836	0.508	0.836
20	0.359	0.838	0.509	0.838
21	0.359	0.840	0.509	0.840
22	0.359	0.846	0.511	0.846
23	0.359	0.854	0.514	0.854
24	0.359	0.861	0.516	0.861

Figure B20: Reported emission factors for utility generation associated with the SEAS properties. Note that on-campus utility generation is a combination of both utilities, with roughly 69% electricity provided by CPP and 31% electricity provided by DTE; off-campus utility generation is synonymous with the emissions factors for DTE. All emission factors are given in units of kilograms of CO_2 equivalents per kilowatt-hour.

Appendix C- Orientation Slideshow

The Dana Building

An Introduction for Students, Staff, and Faculty

Questions, Answers, and Need-to-Know Info

Developed By: Sarah Avery and Brandon Smith in conjunction with SEAS Facilities

Welcome to Dana!

1. Building Background
2. Building Systems
3. Building Features
4. SEAS Field Properties
5. How can you contribute?
6. Contact Information

Building Background

Background: Dana's History

1901-1903

Our Building was constructed to be the West Medical Building

1961

Became home to the School of Natural Resources. Later renamed Natural Resources Building

1973

Renamed the Samuel Trask Dana Building

In honour of the former dean within the school of Forestry and Conservation

1977

Major Renovations!

3 main goals in mind:

1. Updates to modern building codes
2. Increase office and classroom space
3. Increase comfort and health of occupants

Background: Renovations & Upgrades

1998-2004

"The Greening of Dana"

To model environmental sensitivity, energy, water, and material-resources conservation from cradle-to-grave was instituted for the remodel.

Lighting

Fixtures are changed over to fluorescent lamps, motion sensors, and LED exit signs added. Skylight was kept in the center atrium to maintain natural lighting in more spaces.

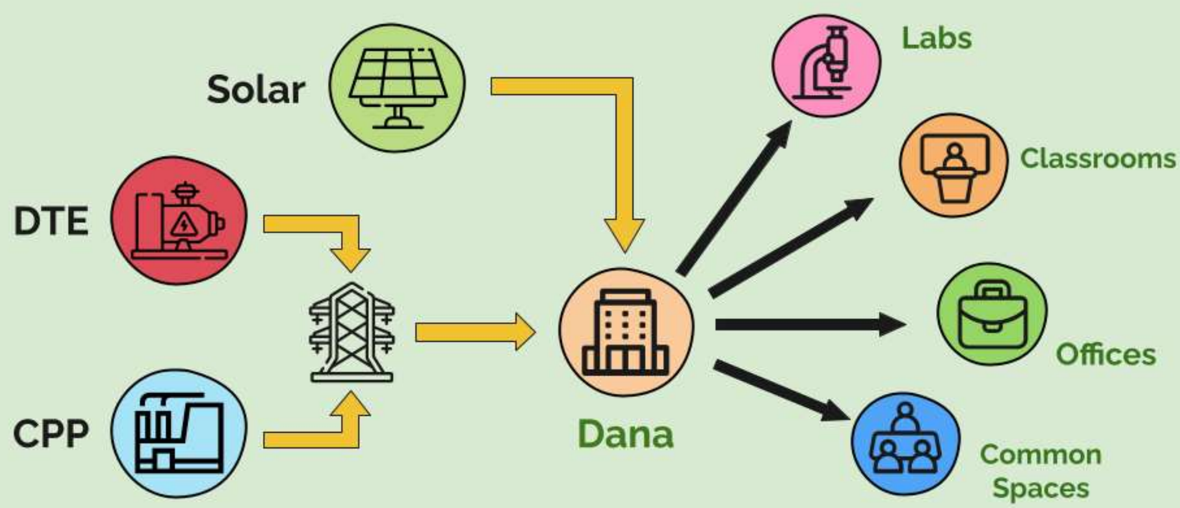
Walls and Windows

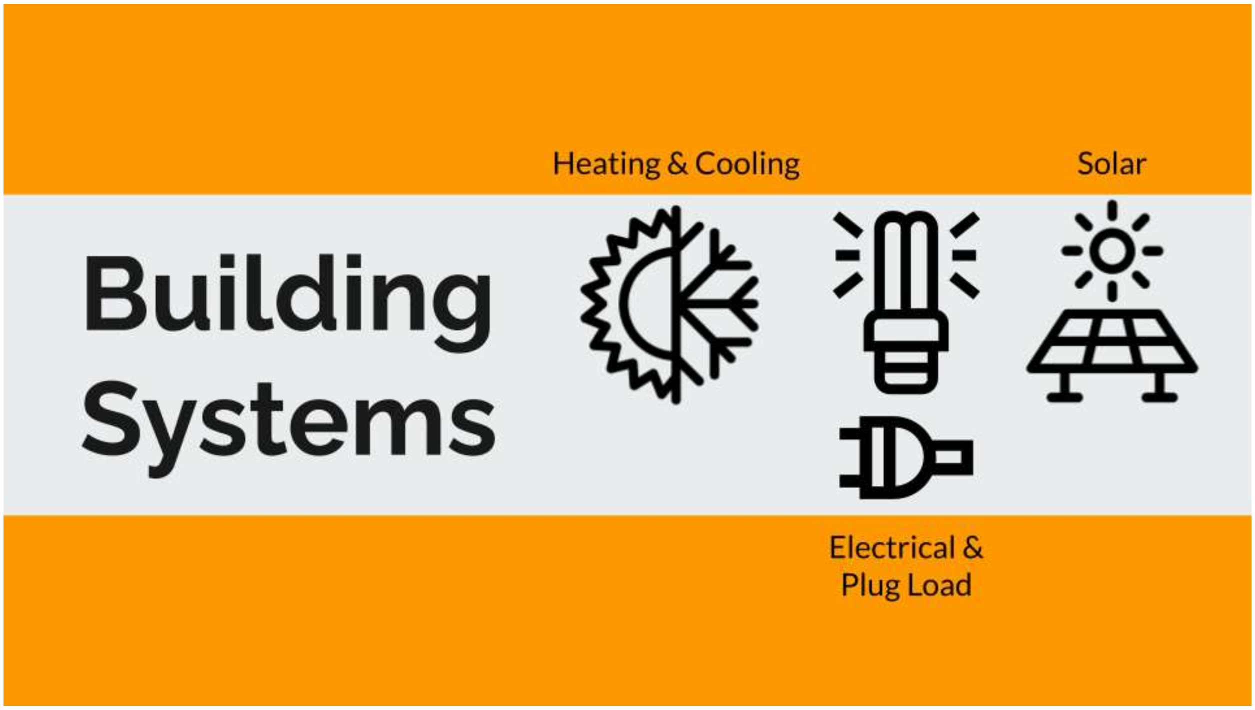
Fiberglass insulation and drywall sheets are added to the exterior walls of the building. Windows get removed, repaired, and some replaced to be operational.

Occupants Impact

Adding recycling, waste initiatives, energy and water conservation within the building was essential.

Background: Dana's Energy Sources




Heating & Cooling
Solar
Building
Systems
Electrical &
Plug Load


Heating &
Cooling Systems

Heating Systems: Steam & Heating Hot Water

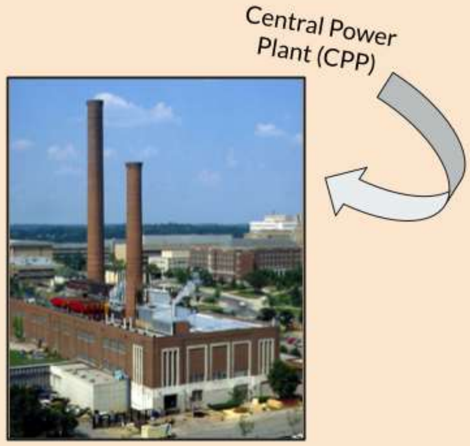
What appliance produces steam? A boiler!

How does it work?

- ➔ Steam from CPP comes to Dana through steam tunnels
- ➔ Steam then disperses through Dana's pipes to machines and building systems

Why do we use it?

- ➔ Steam from CPP is relatively close in proximity to Dana and is available for use to support more efficient heating



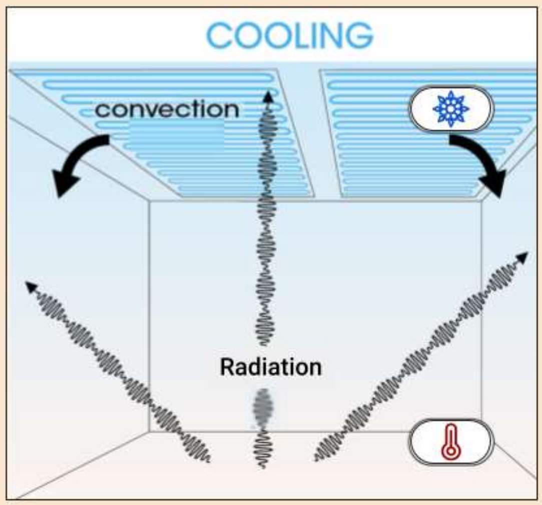
Cooling: Radiant Panels

How do they work?

- ➔ Panels absorb heat from rooms into copper pipes circulating chilled water
- ➔ Water is carried back to central distribution point for re-chilling

Why do we use them?

- ➔ Radiant panels are highly efficient and a lower cost than conventional cooling



Dana's Solar Arrays

Solar: Panel Types

There are 3 main types of solar panels:

What type(s) of solar panels does Dana have?

Monocrystalline

- 24.4% efficiency
- Moderate cost
- Longest lifespan
- Pure silicon

Polycrystalline (Multicrystalline)

- 19.9% efficiency
- Least expensive
- Moderate lifespan

Thin-Film

- 18.9% efficiency
- Most expensive
- Shortest lifespan
- Variety of materials

Solar: Quick Facts

295 Panels installed in 2005

- 88 polycrystalline Kyocera 120W
- 75 thin-film Uni-Solar 62W
- 132 thin-film Uni-Solar 136W

33 kW DC rated power

Improvements in-progress:

- Inverter replacement
- Rewiring faulty strings
- Monitoring system upgrade

Helped Dana achieve LEED certification!

Electrical & Plug Loads

Electrical: Lighting

Why do we use Fluorescents and LEDs?

- ➔ Fluorescent lamps are more energy efficient and longer-lasting than incandescent bulbs.
- ➔ Use of motion sensors to reduce overall consumption
- ➔ Several spaces within Dana already have LED lighting: Dean's Office, Student Center & Center for Sustainable Systems

Did you know?

Our LED exit signs consume less than 5 watts of power and last 25 years!

Improvements in-progress:

- ➔ Replace all office and hallway bulbs in Dana with LEDs!

What type(s) of lighting is Dana currently using?

A mixture of all three

	LEDs	CFLs	INCANDESCENT
ENERGY EFFICIENCY	Best	Good	Average
TYPICAL LIFESPAN	25,000 hrs	8,000 hrs	1,200 hrs
YEARLY COST	$1.34/yr	$1.73/yr	$3.05/yr

Electrical: Plug Loads

Plug loads account for the largest portion of electricity consumption within the Dana Building.

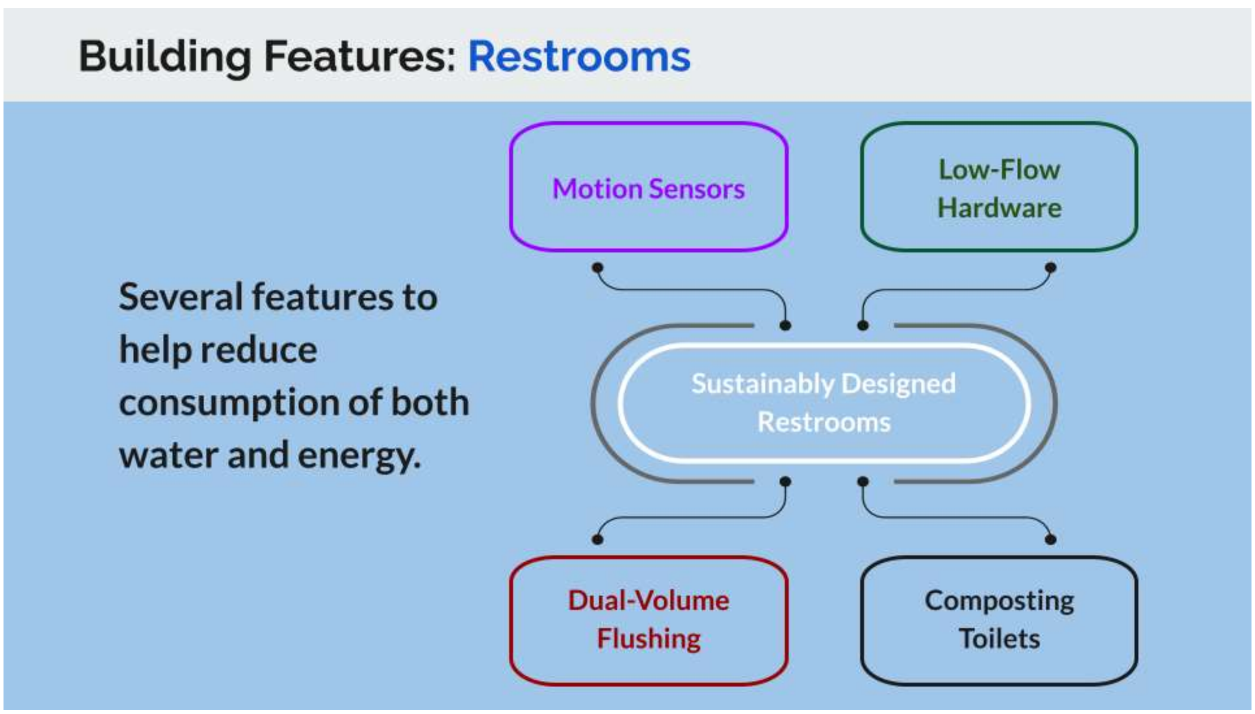
Plug loads includes:

- ➔ Academic and lab equipment
- ➔ Overhead Lighting
- ➔ Personal equipment (laptop and phone charging, desk lights, etc.)
- ➔ Mechanical Equipment- HVAC

What can you do to help reduce plug load use within Dana?

- ➔ Turn off lights when you leave a room, especially at night.
- ➔ Ensure projectors, TVs, podiums, and other presentation equipment have been powered off or put to sleep.
- ➔ Use natural lighting, when possible.
- ➔ Consider using task lighting instead of full-room lighting.
- ➔ Generally, unplug equipment when not in use.


Building Features
Restrooms
Materials
Waste
Green Space


Building Features: Restrooms
Several features to help reduce consumption of both water and energy.
Motion Sensors
Low-Flow Hardware
Sustainably Designed Restrooms
Dual-Volume Flushing
Composting Toilets

Building Features: Restrooms

Motion Sensors

- ➔ Sensors to control lighting reduce energy consumption
- ➔ Sensors on faucets to reduce water consumption and improve on/off accuracy

sensor

Pressing the button on the light switch will turn on/off the lights manually.

It's a good habit to turn off lights when no one else is in the room!

How much can you expect to save?

Room Type	Occupancy Sensor Lighting Energy Savings[2]
Breakroom	29%
Classroom	40-46%
Conference Room	45%
Corridor	30-80%
Office, Private	13-50%
Office, Open	10%
Restroom	30-90%
Storage Area	45-80%
Warehouse	35-54%

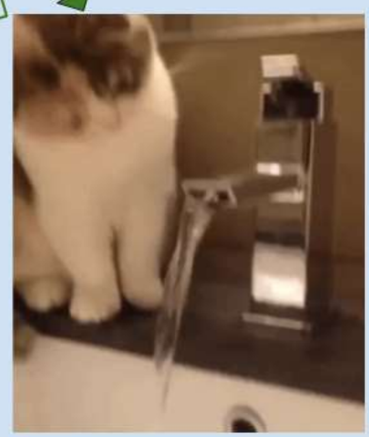
Federal Energy Management Program. 2019. *Wireless Sensors for Lighting Energy Savings.* U.S. Dept. of Energy.

Building Features: Restrooms

Low-Flow Hardware

Low-flow hardware makes this situation more eco-friendly

- ➔ Low-flow sinks and waterless urinals installed during *Greening of Dana*
- ➔ Low flow hardware:
  - Limits water waste
  - Decreases germs
  - Uses less energy
- ➔ 10 waterless urinals installed as well



Building Features: Restrooms

Dual-Volume Flushing

These signs posted by each toilet are as simple as lift the handle towards the ceiling for #1, push the handle towards the floor for #2.

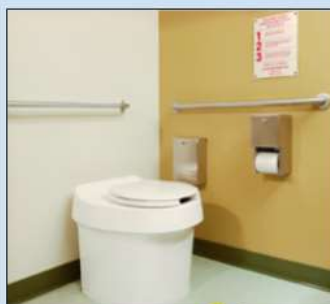
- ➔ Dual flushing uses less water than traditional toilets
- ➔ Handle design is larger and not located on the tank like traditional toilets for easier accessibility

500 gallons of water saved for every 1,000 reduced flushes.

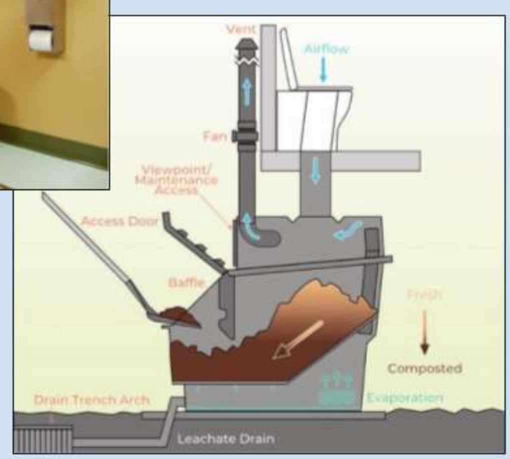
Building Features: Restrooms

Composting Toilets

- ➔ 3 composting toilets in Dana are located on the 1st, 2nd, 3rd floors
- ➔ Uses 0 gallons of water per use
- ➔ System uses 3 gallons of water per service period (monthly)
- ➔ Capacity to handle 40,000 uses/year



Clivus Multrum Composting Toilets



Building Features: Composting Toilets

Composting Toilets

- 3 composting toilets in the building- 1st, 2nd, 3rd floors
- Uses 0 gallons of water per use
- System uses 1-3 gallons of water per day
- Capacity to handle 40,000 uses/year

Important Reminders:

- The composting toilets are designed for human waste and toilet paper. NOTHING ELSE. (Please place compostable materials, e.g. plates and cups, into compost bins in the hallways.)
- The composting system relies on proper airflow. Please be sure to lower the seat cover after use!
- Fruit flies (unfortunately) happen but we do try to keep their numbers down. They won't harm you. Please do not remove fly-catchers from the restrooms.
- If you see issues, be sure to report them ASAP!

Building Features: Sustainable Materials

Dana has proudly used materials that focus on energy conservation or recycling of unconventional waste products:

Wool Carpeting
From recycled fishing nets

GreenGuard Gypsum Drywall
To reduce chemical emissions

Ceiling Tiles
From shredded wheat and/or compressed sunflower seeds

Restroom Tiling
From recycled glass tiles

Restroom Stall Dividers
From recycled airplane plastics

Other Recycled Materials
Furniture, wood, stone, etc.

Recycling materials during remodeling has contributed to Dana's certification as a LEED Gold building.

Building Features: Waste Management

3 Types of Waste Receptacles in Dana

COMPOST

RECYCLING

LANDFILL

If you must dispose of something, focus on composting and recycling!

Tips for reducing your waste production:

- **Utilize reusable materials** (water bottles, lunch pails, utensils, coffee mugs, etc.)
- **Focus on food waste** - only purchase / bring to Dana what you will eat or drink
- **Find alternatives to single-use products** (e.g., brew a small pot of coffee instead of a K-Cup, bring a closed dish of ketchup from home instead of a ketchup packet)
- **Prioritize Existing Resources.** (e.g., Don't request extra sugar packets, salad dressings, stir sticks, or other single use items when ordering catering.)

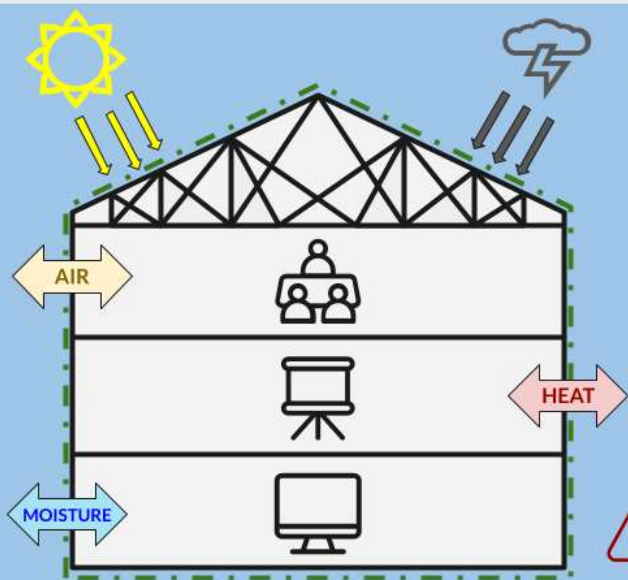
Building Features: Waste Management

Composting Items

Recycling Items

Did you know? Dana was the first campus building to coordinate compost pickup. Since then, it has spread campus-wide. Don't be afraid to start something new!

Building Features: Envelope



What is the building envelope?

➔ Barrier that separates the interior of the building from exterior forces, temperatures, and precipitation.

➔ Composed of brickwork, wood, insulation, windows, doors, etc.

➔ Critical for energy conservation, shelter from the elements, air flow, natural lighting, etc.

The Dana Building has had many renovations and upgrades throughout the years. But it's still an old building, so maintaining the envelope can be a challenge.

Building Features: Envelope

What can YOU do to maintain the envelope?

➢ **Please, do not open the windows!**
This imbalances Dana's heating and cooling systems.

➢ **Do not prop open the exterior doors!**
Like the windows, this imbalances Dana's heating and cooling systems.

➢ **Dress with the weather and the building in mind.**
It gets cold in Michigan, and some rooms get more sunlight during different parts of the day. Be prepared to be comfortable by bringing in an extra sweater or layering an outfit.

➢ **Thermostats are available for you to adjust temps in your spaces.**
For shared spaces, please keep others in mind with your settings.

➢ **Consider other strategies** to manage room temperatures:

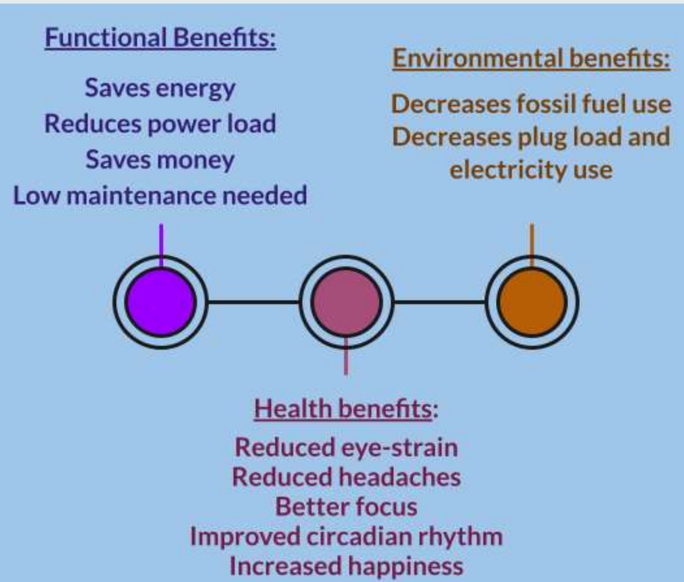
- Close the blinds to reduce heat from sunlight
- Open hallway doors to circulate air
- Turn off unnecessary electronics, especially when not in use

Improvements in progress:

➔ Installing Indow-Window inserts to improve envelope insulation in the winter

Building Features: Green Spaces

Natural lighting in the common area provides: environmental, health, and functional benefits!



Building Features: Green Spaces

Native Gardens at Dana

- ➔ 2010- 2011 SNRE (now SEAS) and MLA Landscape project to showcase native plants and grasses to the area
- ➔ Location: East side of Dana. Initially split into a forest ecosystem (South half) and prairie ecosystem (North half)
- ➔ No irrigation installed
- ➔ Current challenge: how do we balance garden aesthetics with environmental conservation?

Research Areas

Utilize the SEAS Properties!

Research
Hundreds of publications surrounding the field sites

Career Opportunities
Students: Interested in becoming a SEAS Caretaker?
(Living arrangements and a stipend included)

Engagement
Coordinate events or community involvement
Volunteer to assist with Facilities

Leisure
Take a jog. Walk a dog. Enjoy the outdoors.

How to contribute to SEAS Facilities initiatives?

- ★ Report any issues immediately to seas-facilities@umich.edu
- ★ Become a Planet Blue Ambassador
- ★ Work towards earning your Sustainability Honors Cord
- ★ Masters student? Interested in Net zero? Apply for the Dana Building Net Zero Masters Project
- ★ Get involved with the waste management or composting crew
- ★ Contribute with the native gardens
- ★ Run for SEAS student government Sustainability Chair- contact here
- ★ Organize your own projects and recruit other SEAS Students

SCHOOL FOR ENVIRONMENT AND SUSTAINABILITY
UNIVERSITY OF MICHIGAN

Thoughts, issues, or questions?

Contact: **Sucila Fernandes**
SEAS Facilities Manager

seas-facilities@umich.edu

See something? Say something!

Scan me!

Fill out this Google Form for improvement ideas, feedback, or to just get involved!

Appendix D - Action Template

Purpose of this document: Decision making matrix

Select the following categories to which this project contributes:

_______ Energy & Efficiency

___ Electricity ___ Solar ___ HVAC

_______ Material Usage

___ Waste ___ Recycling ___ Compost ___ Water

_______ Building Envelope / Infrastructure

___ Windows ___ Insulation ___ Doors

_______ Natural Environment

___ Green Spaces ___ Bio-Remediation

___ Daylighting (glazing in doors or ceiling tile converted)

_______ Education & Engagement

___ Students ___ Faculty ___ Staff ___ Public

_______ Transportation

___ Scope 3 ___ Facilities Vehicles

Properties this potential project applies to:

_______ DANA Building _______ Stinchfield Woods _______ Newcomb Tract

_______ Saginaw Forest _______ St. Pierre Wetland _______ Harper Preserve

_______ Ringwood Forest

Metrics to utilize / consider with this project?

_____ Greenhouse Gas Emissions _____ Biodiversity

_____ Carbon Capture / Sequestration _____ Avoided Energy

_____ Human Performance / Engagement _____ Reduced Material Consumption

_____ Retention _____ Satisfaction

Describe the project. What are the major parameters / scope? Who is responsible for execution?

What is the estimated time frame of this project?

What are the main **goals** and **deliverables**?

What **resources** do you have access to and can allocate to the main deliverables and goals?

What additional resources and contacts may be needed, and how do you plan to obtain them?

How do you plan to measure success? Does this tie into the metrics selected above?

What are the costs associated with this project? How is funding being secured?

After implementation what continued efforts and resources are going to be allocated to sustain the project? How will this project continue (i.e. who will be working on it next, where will they find additional funding, how and where will project check-ins be handled)?

Does the project need to be reevaluated / reassessed after a certain amount of time? How long should that time frame be? Who should be involved in that re-evaluation?

How can physical resources be minimalized, and for those that are needed, what is the plan to recycle materials after their use? (i.e. thinking of cradle to grave considerations, how will any materials be sustainably recycled or utilized after initial use)?

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