The Future of Dana:
Achieving Net Zero Emissions and Leading by Example

SEAS Practicum Report

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Executive Summary

The School for Environment and Sustainability (SEAS), at the University of Michigan (UM), strives to be a leader in sustainability and environmental initiatives within its buildings, on campus, and in the community. In continuing with this way of thinking, SEAS Facilities has set the goal of achieving complete carbon neutrality across all of its facilities by the year 2025. To move toward this goal, SEAS must first gain a clear understanding of its current energy usage and performance and use this information to identify strategies to increase energy efficiency, reduce consumption, and integrate energy efficient equipment and technologies. This project aims to accomplish this essential first phase and provide SEAS with the necessary, foundational data and knowledge to begin the process of realizing complete carbon neutrality since it only has four years to implement and see results by 2025.

Utilizing existing energy consumption data, I performed an energy audit of the Samuel T. Dana Building, located in the heart of UM's central campus. Through my analyses I determined that the HVAC system accounts for about 64% of the total energy usage in the building while plug load is responsible for 18% and lighting is responsible for 12% of total energy consumption. And that 64% was after deep retrofits and HVAC tune ups were completed. SEAS Facilities Manager Sucila Fernandes had noticed that over the summer, after these upgrades were completed, that the building's energy consumption wasn't dropping so she wanted to know what more could be done. So, with her assistance, I obtained and utilized building modeling software to build a virtual model of the Dana Building that, once completed, will be able to complete a variety of detailed energy simulations on the building. These simulations can help SEAS compare current consumption data to the data provided on the utility bills using the model. It can also identify load rates in the building as well as identify trends outlining specific systems, equipment, and components and simulate replaced or modified equipment in an effort to increase overall efficiency. I also worked with the SEAS Facilities Manager, Dana's Building Engineer, and SEAS Regional Energy Manager to construct a building manual that outlines various information about the Dana Building, how the systems within the building work, how various equipment is scheduled and operated, and how the building uses energy.

It will be essential to ensure that the SEAS facilities understand all this in order to be as efficient as possible before implementing offsetting strategies for carbon neutrality. Furthermore, to optimize decarbonization we must decrease energy consumption as much as possible. With this in mind, I analyzed the impact of retrofitting all of the existing light fixtures in the building to LED lighting technology and determined that this would reduce the energy usage and emissions from lighting by 60%, reducing the building's overall electrical consumption by 7%. I also identified strategies to reduce plug loads in office spaces, which represent about 60% of the total plug load throughout the building, by reducing the amount of non-essential equipment in workspaces. I provided multiple configuration options for typical office equipment with the most stringent providing a total savings of over 110,500 kWh/yr and reducing annual CO_2 emissions by almost 84 metric tons. The ultimate goal of this project is to gather all the necessary foundational data needed to help SEAS begin working towards carbon neutrality as well as to outline specific strategies and tools that will further ensure SEAS reaches their goal.

Introduction

Over the past two years, climate reports from the U.S. and global entities have been released describing the dire situation that the world is facing.[1,2] If we continue business as usual, the consequences include sea-level rise and warming of the planet that will effectively destroy ecosystems and create economic turmoil. These effects highlight the need to reduce CO_2 emissions globally in order to avoid the most detrimental effects of climate change. Recently, there has been a strong push globally by governments, private organizations and nonprofits to reduce CO_2 emissions rapidly.[3,4] One of the most efficient ways to reduce CO_2 emissions is to decarbonize the energy sector,[5] which accounts for 41% of CO_2 emissions globally, according to the International Energy Agency.[6] This can only be achieved through an increased deployment of clean, renewable energy and efforts aimed toward decarbonization. Many organizations have set goals to be carbon neutral through direct purchase of renewable energy, purchase of carbon offsets, or a mixture of both.[7]

Net zero buildings play a very important role in reducing emissions, combating the harmful effects of climate change, and realizing a sustainable future. Since buildings represent around 30% - 40% of total energy usage around the globe, it is essential to find ways to increase efficiency, decrease energy use, and identify alternative energy options for buildings worldwide. The World Green Building Council has proposed the lofty goal that all new buildings must incorporate net zero standards starting in 2030 and that 100% of buildings must operate at net zero by 2050 in order to combat this current climate crisis.[8] To truly reach net zero emissions, buildings must address, mitigate, and offset scope 1, scope 2, and scope 3 emissions; scope 1 emissions consist of direct emissions from a building's operations, scope 2 are the indirect emissions from the generation of the energy that is purchased by the building (electricity, steam, etc.), and scope 3 encompasses any other indirect emissions associated with the buildings operations such as commuter travel emissions.[9] In order to meet these goals to curtail climate change and usher in a sustainable future, strategies to achieve net zero status for the built environment must start being identified and implemented immediately.

In 2019, the University of Michigan (UM) established the President's Commission on Carbon Neutrality (PCCN) to develop a plan for the entire university to achieve carbon neutrality by 2030. The PCCN is composed of many UM faculty, administrators, students, and third-party partners who were all tasked with working together towards achieving this goal of net zero emissions. The PCCN's stated objective is to "contribute to a more sustainable and just world by creating approaches and solutions regarding UM carbon emissions that are sustainable (environmentally, socially, and economically), involve the regional community, and can be scaled and replicated beyond the university".[10] Together, the commission conducted research, identified opportunities, and proposed recommendations to help the university work towards carbon neutrality. In March 2021 the PCCN released its final report and recommendations. The proposed actions outline a pathway for the university to reach carbon neutrality for scope 1 and scope 2 emissions by 2025 or earlier, establish goals and prospective dates for the much more complicated scope 3 emissions by 2025, and to completely eliminate scope 1 emissions by 2040.[11]

The School for Environment and Sustainability (SEAS) intends to pave the way for this transition and the Facilities Department has pledged to realize net zero carbon emissions by 2025. The intended outcome of this SEAS-specific goal is to help pilot innovative ideas, identify comprehensive strategies and recommendations, and provide a clear template for other departments to reach the carbon neutrality goals set forth by UM. SEAS intends to act as a leader and lay the groundwork for the entire university to realize its goal of being a net zero campus. SEAS will be able to utilize the existing knowledge and expertise of its faculty, staff, and students, leverage existing data and projects already aligned with carbon-neutrality topics, and provide the university with a solid foundation from which to proceed. SEAS intends to take a holistic approach by identifying and implementing recommendations to curtail all scope 1, 2, and eventually 3 emissions. My project will focus on gathering all the necessary data and identifying preliminary strategies and recommendations with which SEAS can proceed with achieving its aggressive goal of realizing net zero emissions by 2025.[12]

The ambitious goal of meeting net zero carbon emissions by 2025 represents the next opportunity for SEAS to lead the way for the rest of the university. With its access to skilled and knowledgeable faculty and students, as well as its existing connections and resources within the larger sustainability community, SEAS holds a very advantageous role in the decarbonization movement. Also, its track record of playing a leadership role on campus when it comes to environmental and sustainability initiatives further increases its influence on the rest of the University of Michigan-Ann Arbor campus. SEAS has the opportunity to usher in a new age of leadership at the university; an age characterized by a clean, energy efficient, net zero emission campus. This exemplifies the vast impact that a completely carbon neutral School for Environment and Sustainability can have on the rest of the university and even the community, and this project signifies the first step toward achieving this progressive goal.

Project Overview

In this project I intend to introduce tools and software to aid SEAS in its pursuit of net zero emissions, identify and assess opportunities to increase the overall efficiency of the 118-year-old Samuel Trask Dana Building, and introduce recommendations and strategies for the future. I will 1) identify the different room types, equipment, and systems that are in use in the building, 2) determine the current energy usage within the building, 3) identify what types of improvements SEAS can make to increase efficiencies, and 4) explore new technology and systems options that could further increase efficiency and track/manage overall energy usage within the building. I will then synthesize this data and research to present a clear list of options and strategies that SEAS can utilize as a framework for their future decarbonization endeavors.

It will be essential to ensure that the SEAS facilities are as efficient as possible before implementing strategies for carbon neutrality; to optimize decarbonization we must decrease energy consumption as much as possible. To begin this process, we need to focus on SEAS's primary facility; the Samuel Trask Dana Building, located on UM's central campus. In order to identify strategies to increase efficiency and performance of the building, it is important to understand what systems are currently in use and their current performance levels. From this benchmark it is possible to start to identify opportunities to modify existing practices and technology/equipment to achieve more favorable results. Increasing efficiency and overall building performance will ensure the easiest most effective route for SEAS to pursue its carbon neutrality goals. Through this project, I intend to begin this process and help SEAS Facilities to better understand the building as a whole and realize the most effective, feasible opportunities to increase the efficiency of the Dana Building.

During the course of this project, I worked directly with the SEAS Facilities Manager, Sucila Fernandes and my Faculty Advisor, Michael Craig. Our goal was to develop a better understanding of the systems within the building, its overall operation and performance, and establish feasible strategies that will increase the energy efficiency of the facility while avoiding costly renovations or extensive modifications to the existing structure and mechanical systems. This information and knowledge will provide SEAS with a framework for how to begin pursuing its more extensive goal of realizing complete carbon neutrality. It will also be used to educate the next generation of students how the building works while educating the maintenance staff, who know the building best, about sustainability. Similar to the notion that it takes a village to raise a child, a building functions best when all those involved in its use and operation put forth an effort to improve its overall performance

The Dana Building

Building History

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.[13] 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.[14] The building is located in the University of Michigan's National Register Central Campus Historic District at 430 E University Ave.[13] 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.[15] 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.[15]

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.[15] 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. [13, 16]

The Greening of Dana

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". [17]

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%.[13]

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, 17]

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.[13, 17]

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.[13, 17]

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. [13, 17]

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.[13, 17, 18]

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 and 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.[17]

Literature Review

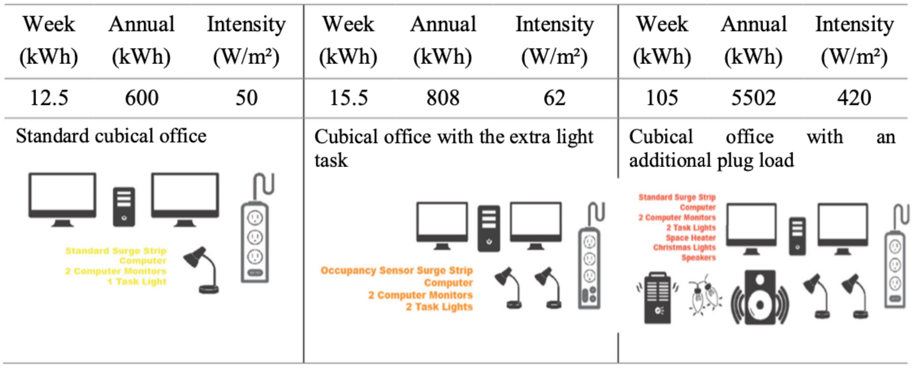
Over the years there have been quite a few case studies looking at the transition to net zero emissions in existing buildings. For the purposes of this project, I decided to primarily focus on literature that focused on this transition in university settings and buildings with similar uses and room types as the Dana Building. Also, to ensure that the information would be relevant to my project, I tried to focus on studies that focused on regions with climate characteristics that are similar to the Ann Arbor area. Since my project is focused on achieving energy efficiency without undertaking extensive renovations or modifications to existing infrastructure and internal systems, I primarily focused on the less invasive energy reduction measures and behavioral use changes highlighted in these articles. Through these resources, I intend to develop a feasible strategy to characterize and evaluate the current energy usage in the building, identify possible energy reduction strategies, and assess the projected impact of these strategies.

The first step outlined in all of the studies was to evaluate the current energy consumption of the building by completing an energy audit. Since it can be difficult to perform an extensive evaluation of energy consumption within existing buildings, Alajmi et al. employed a strategy of separating the audit into a two-scale assessment, evaluating the usage on both a macro and a micro-scale.[19] In this approach, “the first scale starts from an overall look at the building’s site and energy consumption (macro-scale), and the second inside the building and its internal components (micro-scale)”[19]. This process allowed the researchers to obtain a holistic understanding of the building's energy consumption and to bypass the difficulties associated with the lack of existing data. It gives the researcher the opportunity to see the overall usage of the building (macro) then complete a more detailed analysis of what specific systems and components make up that usage, such as plug-loads, lighting, HVAC, etc. (micro). It also allows for the macro-scale assessment to be verified by the findings of the micro-scale assessment.

Climate plays a significant role in determining a building's energy usage, especially when there are significant temperature swings between seasons. In an area like Ann Arbor, where there can be very hot, humid summers as well as very cold, wet winters, it is important to consider how this could impact the energy usage within the building as well as the effectiveness of possible energy reduction measures. Climate Consultant 3.0 is a software that evaluates annual local climate data files for a given region and utilizes that data to suggest specific strategies for building design and operation that are appropriate for that region.[20] A number of studies have utilized this and other, comparable software to provide a comprehensive understanding of specific climate characteristics for the locations of specific buildings to identify relevant energy reduction strategies. This is a very important step to take because the effectiveness and feasibility of certain energy efficiency strategies will differ based on where the building is located and how it interacts with its surrounding environment.

The primary reduction measures that these case studies identified and evaluated focused on plug loads within the buildings, lighting systems, and behavioral use changes. To evaluate the plug loads of workspaces within a building, Alajmi et al. began by classifying the workspaces into the three specific categories based on the equipment located in each space (Figure 1).[19] This allowed the researchers to determine the average plug load of the buildings workspaces and evaluate the overall plug load based on the frequency of each set-up. This data allowed them to calculate the weekly and annual plug load energy and the overall power intensity of the various office spaces. Alajmi et al and Anderson & Wisler both speak to the importance of utilizing energy meters when conducting plug load analysis within buildings. Energy meters help to provide an accurate assessment of the energy consumption for specific equipment over a specified period of time.

This ensures that the results are relevant to that specific space and the equipment that is being utilized within that space.



Week (kWh)	Annual (kWh)	Intensity (W/m²)	Week (kWh)	Annual (kWh)	Intensity (W/m²)	Week (kWh)	Annual (kWh)	Intensity (W/m²)
12.5	600	50	15.5	808	62	105	5502	420
Standard cubical office			Cubical office with the extra light task			Cubical office with an additional plug load		

Figure 1: Workspace classifications and their calculated energy intensity as presented by Alajmi et al.

Lighting systems and technology also present a significant opportunity for reducing the overall energy consumption within a building. Rodrigues et al. observed that through the utilization of LED technologies and improved management of lighting system usage allowed for a decrease in electricity consumption of 30%.[22] Similarly, Alajmi et al. determined that utilizing LEDs instead of the existing fluorescent bulbs decreased the overall lighting power density of the building from 14 to 6 W/m^2, a reduction of nearly 60%.[19] These results demonstrate how lighting technology can have a major impact on the overall energy consumption within a building and how large of an impact changing the installed lighting technologies can have on the total electricity usage.

Finally, behavioral changes regarding how energy is utilized within the building has been shown to result in impactful reductions to overall consumption in many of the case studies I have come across. Anderson & Wisler have concluded that heating and cooling account for the majority of energy consumption in STEM research and teaching buildings located in northern latitudes of the United States (Figure 2).[21] Based on this data it is essential to look at HVAC systems if one is attempting to achieve impactful reductions to overall building energy use, and the best way to address this (apart from major modifications to the HVAC system itself) is to encourage behavioral changes around the use of heating and cooling within the facility. Rodrigues et al. highlights how "occupancy variation, … activity in the building rooms and… the decrease of the HVAC set point temperatures" can all result in energy savings through modified HVAC operation.[22] This shows how it is possible to achieve energy reductions in HVAC systems without actually changing the system's specific components or configurations. The building envelope can also have a major impact on the HVAC system performance. This exemplifies the importance of identifying strategies to increase the insulative properties of windows and doors to decrease the thermal gains and losses of these openings.

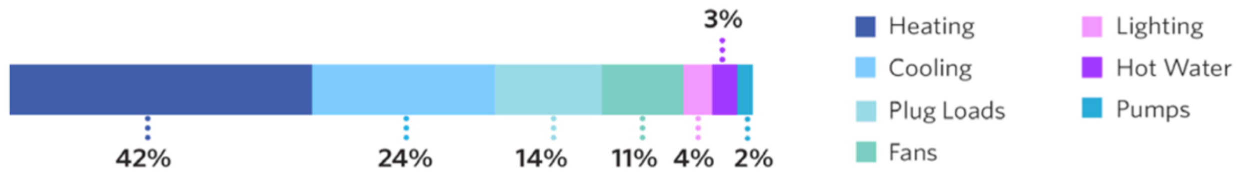


Figure 2: Average energy profile of STEM Buildings in Northern U.S. Latitudes presented by Anderson & Wisler

Alajmi et al. also utilized energy modeling software to "calculate the building's energy consumption components such as HVAC, plug loads, and lighting"[19]. This software also assisted the researchers in identifying possible avenues for increasing energy efficiency and determining how effective these actions might be. The use of energy modeling software helps to provide insights into the effectiveness of specific designs or techniques geared toward reductions in energy consumption and emissions. It allows for various strategies to be tested and evaluated and can also be used to validate findings and assumptions regarding building performance.

Another technique that has been utilized to better understand how buildings operate and consume energy is the use of submetering equipment. Installing energy monitors and data loggers in different spaces or on specific equipment can provide valuable insight into how energy is utilized within a structure and this information can be used to identify opportunities for improved energy management and potentially reducing energy waste. This concept is what drove the University of Pennsylvania to install 400 energy meters within buildings on its campus.[23] The University of California-Berkeley has also implemented energy meters in a building on its campus and, as a result, have been able to identify and address inefficiencies in that building's performance. The university was able to determine that a certain fan was running at a higher speed than it was supposed to, and early intervention helped them to avoid unnecessary energy costs and a possible failure of the equipment.[23] They also identified behavioral trends of students using specific areas of the building during irregular hours (primarily late on Sunday evenings) and modified their ventilation and heating schedules for those areas of the building to account for the increased need at a previously unscheduled time.[23] These are perfect examples of how submetering, especially in an educational setting, can provide a better understanding of how energy is consumed as well as where and when it is needed, allowing an institution to better manage the overall performance of their facilities.

Based on the review of these case studies, there are a few takeaways that were useful to my specific project. First, I utilized the two-scale energy assessment technique outlined by Alajmi et al. This method was useful to me since there was limited data available regarding specific energy consumption rates within the Dana Building. This technique also made it easier for me to obtain a holistic understanding of the building's energy usage by first approaching it from a macro-scale then working my way down to a more specific level within the building itself. Second, these studies outlined the importance of technologies, such as energy modeling software and submetering equipment, and I believe similar technologies could benefit the Dana Building as it looks to optimize building performance and realize carbon neutrality. Third, I employed a similar strategy to Alajmi et al. by characterizing the types of equipment used in workspaces and utilizing that information to identify options to reduce plug loads within different types of spaces within the building. Finally, based on the findings of Rodrigues et al., I completed an analysis on the current lighting system and evaluated the possible impact of switching over to the more energy efficient LED alternative. These case studies provided insightful approaches to tackling the complex process of identifying energy efficiency strategies and evaluating the overall impact of various solutions, and they greatly assisted me as I worked through this project.

Modeling the Building

In order to better understand how the Dana Building and its systems perform the client and I decided to construct a building model using energy modeling software. We began by researching different modeling software options to determine which one would best suit our needs. Since neither of us had any major experience using these types of software, we wanted to ensure that the software we chose was user friendly, comprehensive enough for our needs, and did not require extensive experience or knowledge about engineering and building mechanics. We also had to account for the overall cost of the software to ensure it would fit within our limited budget and had to confirm that it would provide us with all of the information and features we were looking for. After a great deal of research and meetings with software providers, we decided to utilize DesignBuilder's modeling software to complete our model of the building.

DesignBuilder is a software that combines complex 3D modeling capabilities with EnergyPlus simulation software. It allows the user to construct a detailed model of a building and its internal components (materials, lighting, HVAC, plug load, etc.) and then run energy simulations on the model.[24] The energy simulation software that DesignBuilder employs, EnergyPlus, enables the modeler to simulate the overall consumption of a building as well as how the energy is utilized by individual systems including HVAC, plug loads, lighting, etc.[25] With this program, the modeler is able to both understand and characterize the current performance of a building and also test how different technologies, materials, and designs can impact that performance. This process provides a detailed assessment of the building as a whole and insight into opportunities and strategies to increase efficiencies that can ultimately optimize overall performance.

DesignBuilder can be utilized to design brand new buildings or to evaluate existing structures. It allows the user to import existing BIM or CAD files to streamline the modeling process and construct accurate models of buildings with minimal effort. Based on the information available, the model can be as detailed or as simple as the modeler wants. The user can modify building systems and features down to the individual components and materials or utilize the multitude of pre-constructed templates of different system configurations and materials data within the software. These templates can be incorporated into the model if building-specific data is not available to provide an estimate of actual performance and consumption levels. The software also utilizes local weather data to provide simulation results based on the specific location and climate of the building. The software license also includes an extensive online training program, online support, and a database that can be referenced throughout the modeling process.

Once we had completed the process of purchasing the software, I started working through the online training modules. The training consisted of a mixture of instructional videos, individual exercises, hands-on modeling demos, and various readings. The entire training process took about 40 hours to complete and during that time I learned how to construct the model and different types of building geometry and mechanical systems, how to input and modify systems data, how to customize building features and materials, and how to run energy simulations.

After completing the necessary training, I began the process of modeling the Samuel T. Dana Building. The first step that needed to be completed was to obtain CAD files for the building. With the help of my client, the SEAS Facilities Manager, I was able to access floor plans for the five levels of the building and upload them into the software. Once uploaded, I was able to use the modeling tools to construct a 3D model of all the internal geometry of each floor in the building, starting on the ground level and working my way up to the roof. However, one challenge that I was confronted with during this process was the fact that we did not have access to elevation plans for the building. This meant that, even though I could see where doors and windows were located on the floor plans, I had no data confirming how tall these components were or how far off the floor they were. Because of this I completed two site visits to the building so I could take measurements and draw sketches of doors, windows, and other vertical features that were indiscernible from the floorplans. By pairing this individually collected information with the provided CAD files I was able to construct a model that very closely represented both the building layout and the vertical features of the walls.

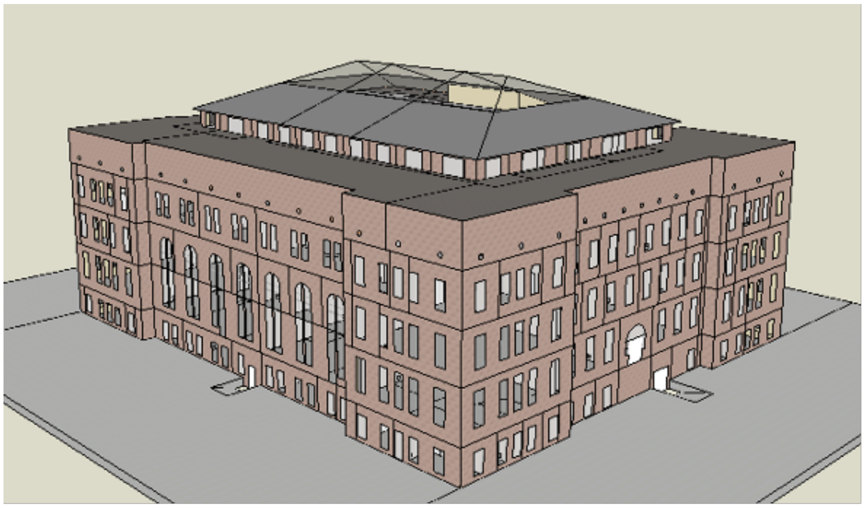


Figure 3: Screenshot of the Dana Building model in DesignBuilder
(see Appendix A for additional screenshots)

Unfortunately, due to timing constraints and unforeseen delays due to the COVID 19 pandemic, I was not able to obtain all of the necessary systems information to begin modeling the internal mechanical systems of the building (HVAC, lighting, plug loads, etc.). Because of this, after consulting with the Facilities Manager and my Faculty Advisor, I decided to place the model on hold and instead focus on continuing to compile all the systems information and data that would be needed to complete the model at a later date. The Facilities Manager and I began scheduling weekly meetings with the Building Engineer and Regional Energy Manager to start gathering this data and incorporating it into an all-inclusive building manual for the Dana Building (described in more detail in the following section) for future reference. At this point the entire building geometry, both interior and exterior, is completely modeled. All that remains to be completed is to begin modeling the internal mechanical systems and inputting the relevant systems data into the software. Once these steps have been completed, SEAS will have access to an accurate, fully functional model of the Dana Building that will be able to simulate the existing consumption and performance of the building and simulate different considerations for opportunities and strategies to increase efficiencies and optimize system operations.

I believe that, once completed, this software will be extremely helpful to SEAS as it looks to reduce its overall consumption and begin working toward carbon neutrality. Based on the training required and the amount of information required, I feel like a dedicated individual could complete the remaining requirements in a couple of months. Having this accurate representation of the building and its systems is a necessary first step when looking for ways to optimize its overall performance. The model would also provide SEAS with a centralized database for all the details about the building, its construction, and system-specific data. As we sought out necessary information for the modeling process, the Facilities Manager and I were confronted again and again with the challenges associated with accessing specific information about the components, materials, and equipment found in the building; acquiring this data usually required reaching out to multiple groups and having countless meetings with various individuals to try and track down what we were searching for. Many times, the reason for this was that institutional knowledge is not documented well in one place and often leaves when those who understand it the most move on to other positions, either within or outside the university. This is a tremendous loss and a significant challenge for new staff trying to not only learn their role but also understand the buildings they need to manage.

This model, once completed, would allow for all of this building-specific information to be located in a single system and easily accessible. Also, by completing and maintaining this model internally, SEAS would be able to have easy access to both the model and all the features of the software. This would allow the school to conduct its own analyses with the software to test new materials, designs, or technologies and determine the resulting impact to the building's performance without having to rely on a third-party energy modeler or design consultant. In addition, it would help SEAS Facilities best understand how systems work and the impacts they have on the occupants/users. Not to mention when emergency repairs are needed, this data will be invaluable. Given the energy simulation potential of this software we have also considered this program to be a valuable tool for a SEAS class that focuses on energy in a real-world application. We have met with students, faculty, and staff who have all expressed an interest in our model and the software it utilizes because it would be a great supplement to their research and work.

In summary, I consider DesignBuilder to be an essential tool for SEAS moving forward and believe that the school should continue to maintain the license for this software and work to complete the model. This could provide an opportunity for an internship or project for one or more students within the school to gain valuable, hands-on experience with energy modeling software and for SEAS to gain valuable insight into the operations of its flagship facility. This would not only contribute to the educational and professional development of the students but would also provide benefits to the school and could even provide a new resource and skill set that the entire university could utilize and benefit from.

Constructing a Building Manual

Another major goal of this project was to obtain a better understanding of how the building was set up and operated and the different types of systems that are in use. To answer these questions, the facilities manager and I began compiling a building manual; a master document which provides specific information and data about the building, its performance and energy usage, the different types of systems and how they work, system configurations and layouts, and how utilities are utilized throughout the building. The primary purpose for establishing this document was to synthesize all of this data, most of which was spread across multiple reports, documents, or available to various third parties outside of SEAS (Building Engineers, Maintenance, Regional Energy Managers, etc.), into a single document that would be available and accessible to SEAS Facilities and maintenance staff.

To tackle this massive task, the client and I utilized both personal research and regular meetings with applicable parties to begin compiling all of the necessary data. We combed through available files and reports to identify system specific data about the heating and cooling systems, major energy consumers in the building including cold rooms, air handlers, exhaust fans, pumps, etc., and information about utilities such as sources, fuel mixes, and how they are received by the building. This process allowed us to begin compiling an extensive list of all the equipment installed within the building, the energy intensity of that equipment, and where and how it was installed. Also, by conducting building walkthroughs, the Facilities Manager was able to take pictures of the equipment and electrical panels throughout the various mechanical spaces in the building to begin constructing a general layout identifying where equipment was located and how it was configured.

Another vital part of this data gathering process consisted of conducting regular meetings with the Building Engineer and the Regional Energy Manager. Through these weekly, 1.5-hour meetings, the client and I were able to gain a better understanding of the internal workings of the building and the various systems that are in operation. Each week we would focus on a specific system within the building (heating steam, heating hot water, cooling, water pumps, radiant panels, etc.) and document how the system worked, review usage and energy data, and access templates and diagrams depicting system configuration and operations. These meetings were extremely helpful because they allowed us to access data and schematics that we would not otherwise have had access to and gave us the opportunity to take advantage of the combined knowledge of our Energy Manager and Building Engineer. This collaborative process, over the course of three months, helped the Facilities Manager and I to obtain clarity into the building’s internal operations and understand how various systems’ performance impacted energy consumption rates.

Though the building manual is still a work in process, the information and data that we have been able to obtain thus far will be very valuable to Facilities and SEAS as a whole going forward. This intimate understanding of how the building operates and how that operation impacts its performance will inform future projects and help SEAS to prioritize modifications and system upgrades in the future. It also gives the Facilities Manager access to a master document where all of the specific information about mechanical systems and equipment can be located to assist her when maintenance issues arise or when there is precise systems data needed for analyses or project development. In order to successfully lead all of SEAS towards a carbon neutral future, all the individuals involved will need to have a detailed understanding of the internal workings of the buildings and how they contribute to the effective operation of the overall facility. This knowledge and familiarity will help them to identify impactful strategies that will be feasible for the property and ensure that all the vital components and systems continue to function successfully.

Methodology & Assumptions

Due to the scope of this project and the current trends on campus and across the country, there will be a few assumptions made regarding building use and the data considered for analysis. As a result of the COVID 19 pandemic, SEAS and the rest of the UM campus has limited in-person classes and events since March of 2020. This means that most of the data regarding energy consumption and building performance from 2020 as well as the beginning of 2021 is not an accurate representation of usual consumption patterns. Though the building is still open and certain systems are still in use (heating, cooling, fans, pumps, etc.), the reduced occupancy does impact how these systems are utilized and greatly impacts other systems that are more dependent on human activity such as plug load and lighting. To account for this, I will primarily be using data from 2019 in order to paint a more realistic picture of the building during standard, business as usual operations.

I started by performing an energy audit of the Dana Building. This helped me to 1) identify current energy usage by source (HVAC, lighting, and plug load), 2) evaluate existing inefficiencies, 3) categorize base load vs non-essential energy usages, and 4) identify possible problem areas. With this information I was able to obtain the necessary baseline data from which I could determine the impacts of the reduction strategies that I analyzed. To collect the necessary data, I worked with the Facilities Manager, Regional Energy Manager and Building Engineer to obtain information about the equipment that is currently in use in the building, accessing historical energy consumption data for the building, and completing a room-by-room audit. This information, paired with the assumptions discussed above, helped me to determine an estimated profile of the building's energy usage and complete a macroscale greenhouse gas inventory of the facility.

For this project I will also be looking at opportunities to increase the efficiency of the lighting systems in Dana and strategies to reduce plug loads in faculty/student office spaces. For the lighting, I utilized existing audits, previous reports, and the information from my site visits to compile a list of all the lighting fixtures and their energy intensity in the building. With this information I was able to calculate the total possible reductions to the existing system through the utilization of more energy efficient LED bulbs. I then completed a cost analysis of this reduction strategy to determine the total cost for the change, the cost-savings, and the projected pay-back period of this change.

For plug load reductions, I completed a similar analysis to Alajmi et al. where I categorized the types of office configurations based on my room audit data then determined what equipment was essential and what was not. From this I worked out different configuration options for office spaces in order to reduce plug load while maintaining necessary equipment in the workspace. This was determined based on the calculated energy intensity of essential equipment as well as other equipment that was identified as part of the room audit. Through this I hoped to show possible reductions that could be obtained by limiting the use of high consuming, non-essential equipment in office spaces such as mini-fridges, microwaves, TVs, etc.

I have also consulted with experts in the fields of electricity, utilities, engineering, and renewable technologies to help me further my knowledge and assist me throughout the course of this project. Through these consultations I was able to acquire a better understanding of the current systems that are utilized throughout Dana and their influence on the building's overall energy consumption. This knowledge was essential for me to identify opportunities to improve efficiency, decrease overall energy usage, and suggest recommendations to reduce overall emissions. These experts were able to help me identify possible opportunities or improvements that could be made to the existing infrastructure and systems that could help me to more efficiently obtain my project goals. These consultations also allowed me to build a comprehensive network of industry experts and professionals who I could turn to if I required additional information or clarification about specific topics or systems. I held weekly meetings with the SEAS Facilities Manager, the Building Engineer for Dana, and the university's Regional Energy Manager to better understand the current performance and operation of the building and to discuss opportunities for improvement. These meetings, along with other meetings with industry experts including local Home Energy Rating System (HERS) raters, energy efficiency specialists, and current/previous students who conducted similar studies on both Dana and other buildings all helped me to better understand the building and become more familiar with common energy reduction strategies.

Analyses & Results

In this section I will discuss the different analyses I completed during this project and present the results and their significance to the overall goal. Over the course of this project, I conducted three analyses: an overview of current energy consumption in the Dana Building, investigating the impact of installing 100% LED lighting in the building, and opportunities to reduce plug loads in faculty and student offices.

Analysis #1: Categorizing Energy Consumption in Dana

All of my research into previous case studies about achieving carbon neutrality in existing buildings and identifying opportunities and strategies to improve energy efficiency started with the same initial process: categorizing the existing energy usage in the building and conducting a GHG inventory. This is an essential step before any additional action can be taken because it allows you to determine a baseline from which you can compare any additional strategies or changes. Understanding how energy is consumed within a building helps the researcher to understand which systems in the building consume the most energy and also helps them to better understand the building as a whole. This process can also help the researcher to obtain large amounts of useful information and data regarding the systems and their performance which can be utilized in future analyses.

Based on the timeframe of this project and the size of the building I decided to limit my focus on categorizing the consumption associated with the HVAC system, lighting, and plug loads in the building. Though there are other systems and equipment that may be consuming energy in the building, through my research I determined these three systems to be the primary consumers and thus chose to focus on them specifically. For the purposes of this analysis, I categorized any additional usage outside of these three sources as “Other”. Below I will discuss the steps I took to gather the necessary data, the process of analyzing the data, and the results of my analysis.

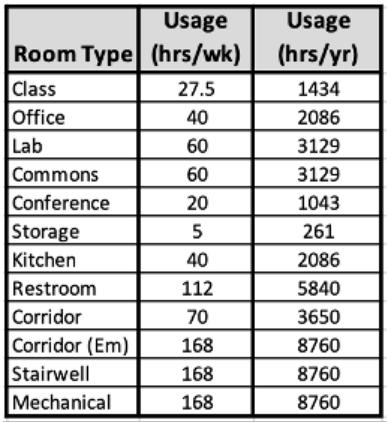
Figure 4: Flow chart depicting general process to calculate consumption and emissions of each system

In order to be able to calculate the estimated GHG emissions for each system, my first step was to determine the appropriate emissions factors to utilize over the course of my analyses. Through meetings with the regional energy manager, I was able to determine that the electricity that the Dana Building consumes comes from two sources: The University of Michigan’s Central Power Plant (CPP) and local utility provider DTE. We were able to confirm that the electricity mix in Dana was 46% DTE and 54% CPP. After obtaining the emission factors for each of the sources of electricity, I was able to calculate the specific emission factor for the Dana Building based on the determined electricity mix (Figure 5).

Type	Source	Amount	Units
Electricity	DTE	0.975	kg CO_2/kWh
Electricity	CPP	0.572	kg CO_2e/kWh
Electricity	46% DTE + 54% CPP	0.757	kg CO_2e/kWh

Figure 5: Emission factors for electricity providers of Dana and the calculated emission factor based on the electricity mix for the building (highlighted in green)

For the lighting system, I worked with the SEAS Facilities manager and the regional energy manager of the building to access previous Energy Conservation Measure (ECM) reports and audits that were completed in the building. From these documents I began to compile a single master list of all the fixtures that were located within the building as well as the number of bulbs and wattage of each fixture. Once I had established an inventory of the entire lighting system within Dana, I worked with the facilities manager and building faculty to estimate the hours of operation per week for each room type within the building. We decided to utilize a standard 40 hours per week for all faculty and administrative offices, 168 hours per week for all mechanical areas, stairways, and emergency lighting (since these are all required to remain on 24/7 per building code requirements), 112 hours per week for restrooms, 70 hours per week for all non-emergency corridor lighting (based on standard operational hours of the building), 60 hours per week for lab spaces, and 20 hours per week for student office spaces. For classrooms, I reached out to the school registrar to receive a class schedule for an entire academic year at SEAS. From this list I determined the total amount of hours per week each classroom was occupied during both fall and winter semesters then utilized the highest number (27.5 hours per week) for all classroom spaces. I used the highest number because, even though some other classrooms used much less, I wanted to add in a contingency to account for possible study sessions, meetings, or other occupancy that may occur outside of standard class times.

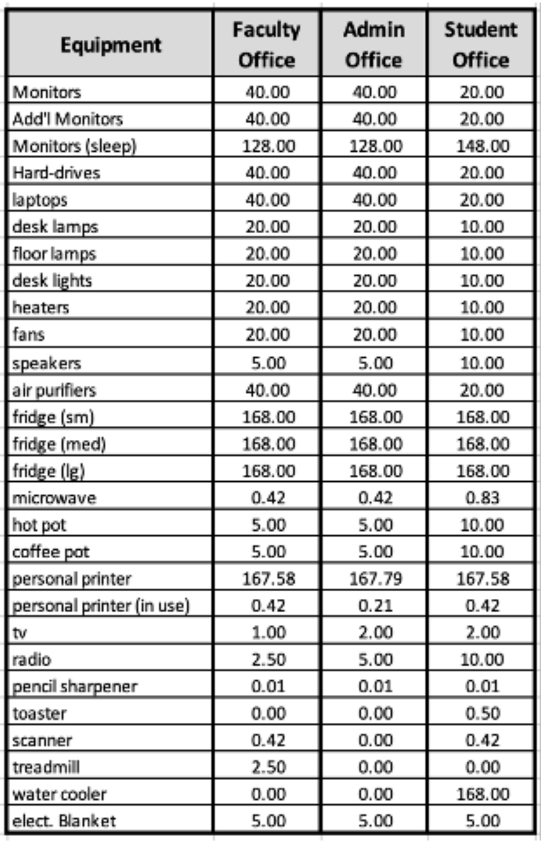


Room Type	Usage (hrs/wk)	Usage (hrs/yr)
Class	27.5	1434
Office	40	2086
Lab	60	3129
Commons	60	3129
Conference	20	1043
Storage	5	261
Kitchen	40	2086
Restroom	112	5840
Corridor	70	3650
Corridor (Em)	168	8760
Stairwell	168	8760
Mechanical	168	8760

Figure 6: Lighting operation hours for each room type

Once I had compiled the full inventory of lighting within the building as well as the estimated weekly operation schedules for the different room types I began calculating the overall consumption per week (Appendix A). From here I converted the results to kilowatt-hours (kWh) per year and calculated the corresponding annual emissions based on the provided emission factors to determine how many metric tons of CO_2 equivalent ($MTCO_2e$) per year were released. Through these calculations I estimated that the lighting in Dana accounted for a total of 183,612.25 kWh/yr and was responsible for emitting 139.08 $MTCO_2e$/yr.

To determine the plug loads within the building I employed a multi-pronged process. The first step was to conduct a room-by-room audit of the office spaces in the building. With the help of the facilities manager, I spent two days on campus auditing 240 of the 340 workstations located in the building (due to timing and COVID restrictions I was not able to audit the remaining rooms). During this audit I noted every piece of electrical equipment that was present at each workstation such as monitors, hard drives, lamps, speakers, mini fridges, coffee pots, etc. Since I was unable to audit the remaining 100 stations, I utilized the existing data from the audit and calculated the probability that a specific piece of equipment would be at a workstation as a percentage (i.e., 36% of faculty stations had a coffee pot, 21% of admin offices had a personal printer, etc.) then applied these percentages to the un-audited spaces to estimate the types of equipment that would be present in these offices (Appendix B). I also audited the kitchen spaces in the building to get the total amount of appliances that were operational in these areas of the building. I then worked with a faculty member to make assumptions regarding how often the equipment would be operational in each type of workspace and used that information to determine the kWh/yr and the resulting annual emissions



Equipment	Faculty Office	Admin Office	Student Office
Monitors	40.00	40.00	20.00
Add'l Monitors	40.00	40.00	20.00
Monitors (sleep)	128.00	128.00	148.00
Hard-drives	40.00	40.00	20.00
laptops	40.00	40.00	20.00
desk lamps	20.00	20.00	10.00
floor lamps	20.00	20.00	10.00
desk lights	20.00	20.00	10.00
heaters	20.00	20.00	10.00
fans	20.00	20.00	10.00
speakers	5.00	5.00	10.00
air purifiers	40.00	40.00	20.00
fridge (sm)	168.00	168.00	168.00
fridge (med)	168.00	168.00	168.00
fridge (lg)	168.00	168.00	168.00
microwave	0.42	0.42	0.83
hot pot	5.00	5.00	10.00
coffee pot	5.00	5.00	10.00
personal printer	167.58	167.79	167.58
personal printer (in use)	0.42	0.21	0.42
tv	1.00	2.00	2.00
radio	2.50	5.00	10.00
pencil sharpener	0.01	0.01	0.01
toaster	0.00	0.00	0.50
scanner	0.42	0.00	0.42
treadmill	2.50	0.00	0.00
water cooler	0.00	0.00	168.00
elect. Blanket	5.00	5.00	5.00

Figure 7: Assumed weekly operation hours of office equipment

Next, with the help of the facilities manager and the IT department, I began compiling the list of equipment that was installed and utilized within the classrooms in Dana. This equipment consisted primarily of projectors (1-3 per room depending on the size), podium computers, and laptops or tablets that professors or lecturers bring in during class. With this equipment data I determined the kWh/yr consumed in each classroom (utilizing the class schedule information obtained from the registrar) and the emissions based on this consumption.

For lab spaces, since I was unable to access these areas due to research security and safety concerns, I determined the plug loads associated with the critical lab equipment that was operated within these spaces. I was able to access documents from the facilities department which provided details regarding the energy intensity and quantities of the equipment in these spaces that I used for this calculation. These documents were originally created to understand what equipment would need to remain operational in the event of a power outage. Since it is critical equipment, it is running 24/7, so I calculated the total kWh/yr and annual emissions for all of this equipment based on this operation schedule. However, since the calculation did not account for additional, non-critical equipment that may be present in these rooms (computers, lamps, other electronics) this number is only a rough estimate and not expected to provide a complete plug load value for all lab spaces in the building.

Also, to account for the plug load associated with occupants in the building using their own electronics such as students charging laptops and phones in common areas, I calculated the estimated plug load for an entire year based on all enrolled students plugging in a device for two hours per week. Though this only provides a rough estimate it allows us to at least account for additional plug loads that are not associated with a specific room type of standard business operations within the building.

I utilized average energy intensity values for the various types of equipment that were identified during the audits and the determined hours of operation to calculate the total kWh/yr and resulting emissions for each workstation type throughout the building as well as all conference rooms, kitchens, classrooms, and study areas. Once I had these totals, I added in the calculated plug loads for the critical lab equipment and common areas to determine the total plug load value. As a result of these calculations, I estimated the total plug load in the Dana Building to be 286,572.54 kWh/yr resulting in 217.07 $MTCO_2e$/yr of emissions.

Determining the consumption of the HVAC system in Dana presented a couple of challenges. First, since there are no energy meters installed in the individual HVAC equipment there was no consumption data that was readily available to me. Second, due to the size of the building, the system is composed of three large air handlers, and multiple smaller air handlers, exhaust fans, and pumps that are equipped with variable-frequency drives (VFDs). These VFDs control the motor speed and torque of the fans based on occupancy and airflow which constantly changes the power consumption of these units. To overcome these challenges, I had multiple meetings with the facilities manager, building engineer, and regional energy manager to strategize how to analyze the consumption of this system.

Working together we compiled a list of all the individual components that make up the HVAC system (air handlers, exhaust fans, pumps, fan coil units, etc.) and obtained the energy intensity ratings of each individual item. We then obtained the programmed schedules for each of these pieces of equipment to determine their hours of operation under normal conditions. We used this information to calculate the projected kWh/yr for each piece of equipment in the overall system. Then, to account for the components equipped with VFDs I obtained annual VFD data sheets from the regional energy manager which showed the percentage of output based on the VFD operation, in 15–30-minute increments, for an entire year. Using these data sheets, I calculated the weighted average of the output to determine an average percentage that each VFD operated at. I then applied this percentage to the previously calculated consumption of these components to obtain a more accurate estimate of the kWh/yr of the equipment with VFDs installed.

Once I had the annual consumption levels for each component calculated, I added them up to determine the total estimated consumption of the entire HVAC system in Dana. From this calculation I was able to estimate that the HVAC system accounted for 1,021,446.14 kWh/yr and a total of 773.73 $MTCO_2e$/yr in emissions. Though these numbers are significantly higher than the calculated consumption values for lighting and plug loads, it seems feasible because HVAC operation is usually the largest consumer in buildings.

After I had calculated the consumption of each system as well as the resulting emissions, I compiled all the totals to see how they related to the total energy consumption of the building. This allowed me to see how much of the total energy consumed by the Dana Building (1,587,120 kWh/yr) each of the sources (lighting, plug load, HVAC) utilized (Figures 8 and 9). This is very useful information to know because it not only provides a baseline understanding of the overall energy usage in the building, but it can also inform where modifications to equipment or systems could be most impactful.

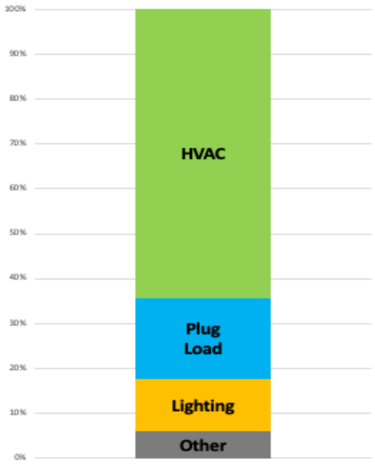


Figure 8: Comparison of energy consumption by source

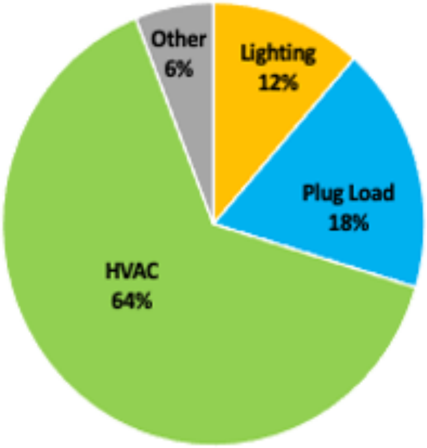


Figure 9: Energy consumption by source in Dana

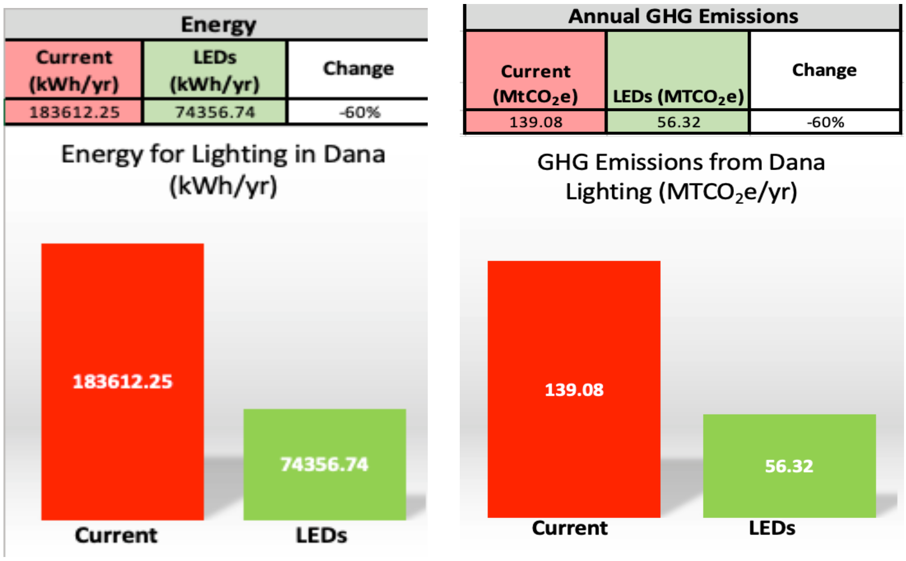
These results seem to be fairly comparable to the average energy profile of STEM buildings in northern latitudes presented by Anderson & Wisler (presented in Figure 2). Their average totals were: 66% for heating and cooling, 14% for plug loads, and 4% for lighting. Lighting does appear to be the outlier; however, I assume this is partially due to the fact that Dana has a large number of offices which are probably not as common in the average STEM building. Also, because Dana does not currently utilize LEDs in most areas of the building, this could also account for such a higher rate of consumption from lighting.

Analysis #2: Energy Efficient Lighting

The second analysis I completed as part of my project was to look at how switching to 100% LED light bulbs in Dana would impact their overall energy consumption and the resulting emissions for lighting in the building. Utilizing LEDs is an easy way to make large impacts in building energy consumption. The average LED has a life of 50,000 hours compared to an average of 1,000 hours for an incandescent bulb and can use over 75% less energy. The Department of Energy estimated that increased use of LED technology could reduce electricity demands in the U.S. by up to 62 percent, avoid up to 258 million metric tons of CO_2 emissions, and remove the demand of 133 power plants.[17] In short, through the simple act of changing a light bulb, a building can realize incredible increases in overall energy efficiency, vastly reduce their emissions, and save on both energy and bulb replacement costs.

For the purposes of this analysis, I utilized the same lighting inventory list and emission factors that I established in Analysis #1. Also, per the request of the client, I modeled this analysis and the projected wattage and costs associated with the LED replacements based on previous smaller projects where LEDs were installed in the building. SEAS had already installed LEDs in both the Dean's office suite and the Office of Academic Programs (OAP), and for continuity we based the reference data used for this analysis on the data and specs from these previous projects (see Appendix C for breakdown of wattage/cost data used). With the help of the facilities manager and the regional energy manager we made some assumptions regarding labor and installation costs as well: we assumed a labor cost of $75/hour, that three new lighting ballasts could be installed per hour of labor, and that all existing fixtures could be retrofitted with LEDs without requiring the installation of new fixtures. All lamp pricing data was also obtained via reports on previous work orders and were confirmed by the regional energy manager for the building.

For the analysis I first utilized the lighting inventory that was compiled during the previous analysis to act as a baseline for current lighting consumption and emissions levels. I then applied the new wattage for each fixture based on the installation of LED bulbs in the fixture. With these new wattage values, I calculated the anticipated kWh/yr and the resulting emissions for each fixture in the building then totaled up the results. Based on my calculations, I determined that the proposed LEDs would consume 74,356.74 kWh/yr and emit 56.32 MTCO$_2$e/yr. This equates to a savings of 109,255.51 kWh/yr and 82.76 MTCO$_2$e/yr, meaning that Dana would reduce its annual energy consumption and emissions by 60% (Figure 10).



Energy		
Current (kWh/yr)	LEDs (kWh/yr)	Change
183612.25	74356.74	-60%

Annual GHG Emissions		
Current (MtCO$_2$e)	LEDs (MTCO$_2$e)	Change
139.08	56.32	-60%

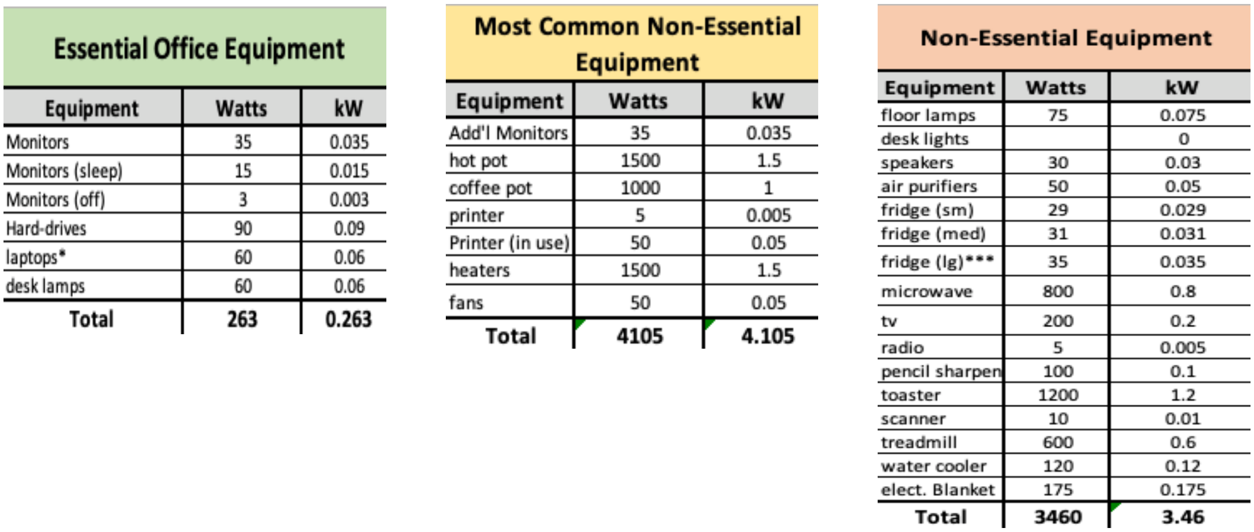
Figure 10: Comparison of energy consumption and GHG emissions for current lighting vs. LEDs

These results show that through the use of LEDs, Dana could dramatically reduce its overall energy consumption and emissions associated with the lighting systems in use within the building. Also, due to the significantly longer lifetime of LED bulbs, the building would see significant savings in the maintenance costs associated with replacing burnt out bulbs. Based on the usage of the different room types in the building, on average an LED bulb would only need to be replaced every 19.6 years versus an incandescent bulb which would need to be replaced every 5 months (see Appendix D for detailed breakdown of bulb lifetimes per room type). In a later section I will explore the cost analysis and the anticipated savings associated with this proposed installation.

Analysis #3: Reduced Plug Loads in Office Spaces

For this analysis I wanted to explore possible strategies to reduce the plug load in faculty, administrative, and student office spaces within the building. From the results in Analysis #1 we determined that plug loads in Dana account for an estimated 18% of the overall energy consumption in the building, and office spaces make up about 60% of that consumption. The intent of this analysis is to distinguish between essential and non-essential equipment that was identified during my room audit of the building and explore different scenarios regarding office setups and the resulting energy and emission reductions.

For the purposes of this analysis, I utilized the same audit data, percentages, and emissions factors from Analysis #1. To be able to easily distinguish between the different office types and their consumption data I calculated the kWh/yr and $MTCO_2e$/yr for each type of office space (faculty, administration, and student) separately then calculated the total of all office types (see Appendix E for complete table). Based on the calculated frequency of equipment present in the offices I separated the equipment into three categories: essential equipment, most common non-essential equipment, and non-essential equipment. For this analysis I defined essential equipment as equipment that was located in nearly every office and is essential to the completion of daily office tasks. Refer to Figure 11 to see the equipment that was included in each category. From this information I explored four different office configurations and their resulting savings to energy consumption and annual emissions. Below I will present each configuration and the resulting savings.



Essential Office Equipment

Equipment	Watts	kW
Monitors	35	0.035
Monitors (sleep)	15	0.015
Monitors (off)	3	0.003
Hard-drives	90	0.09
laptops*	60	0.06
desk lamps	60	0.06
Total	263	0.263

Most Common Non-Essential Equipment

Equipment	Watts	kW
Add'l Monitors	35	0.035
hot pot	1500	1.5
coffee pot	1000	1
printer	5	0.005
Printer (in use)	50	0.05
heaters	1500	1.5
fans	50	0.05
Total	4105	4.105

Non-Essential Equipment

Equipment	Watts	kW
floor lamps	75	0.075
desk lights		0
speakers	30	0.03
air purifiers	50	0.05
fridge (sm)	29	0.029
fridge (med)	31	0.031
fridge (lg)***	35	0.035
microwave	800	0.8
tv	200	0.2
radio	5	0.005
pencil sharpen	100	0.1
toaster	1200	1.2
scanner	10	0.01
treadmill	600	0.6
water cooler	120	0.12
elect. Blanket	175	0.175
Total	3460	3.46

Figure 11: Equipment classifications based on room audit of office spaces in Dana

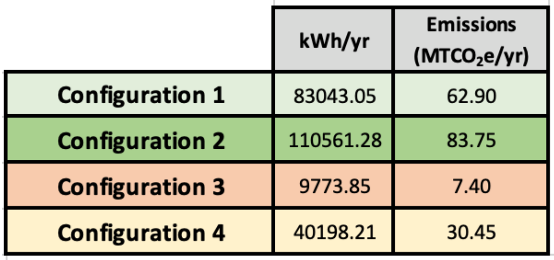
Configuration 1: For this first scenario I explored what would happen if only essential office equipment was used in the offices. I maintained the same usage rates and the same quantity of the essential equipment that is currently in use in office spaces within the building. The results indicated that there would be savings of 83,044.76 kWh/yr and 62.91 $MTCO_2e$/yr with this configuration.

Configuration 2: For this scenario I explored the possible savings associated with a combination of only essential office equipment and users completely turning off monitors when they are out of the office (both after leaving for the day and during weekends). Including just this minor modification to the first scenario resulted in some pretty significant changes to the overall results. Completely turning off the monitors at the end of the day instead of just letting them sleep would increase the total savings to 110,562.98 kWh/yr and 83.75 MTCO$_2$e/yr. That's an additional savings of 27,518.22 kWh/yr and 20.85 MTCO$_2$e/yr just from turning off the monitors!

Configuration 3: In this configuration I analyzed the possible savings associated with limiting office spaces to the items listed on both the Essential Equipment list and the Most Common Non-Essential Equipment list. In this scenario I estimated a savings of 9,775.56 kWh/yr and 7.41 MTCO$_2$e/yr. Though these results are much less than the previous two configurations it still results in an overall annual savings for the building while also allowing for users to maintain access to additional amenities such as coffee pots, space heaters, fans, etc.

Configuration 4: This configuration includes the same equipment as Configuration 3 (Essential Equipment + Most Common Non-Essential Equipment); however, it factors in users completely turning off their monitors and printers when not in use. As we would expect, we do see additional savings in this scenario when compared to the previous example. From this configuration we would see an estimated savings of 40,199.92 kWh/yr and 30.45 MTCO$_2$e/yr. Just like in Configuration 2, we see a significant increase in the overall savings associated with just turning off certain pieces of equipment when they are not in use.

All four of these proposed configurations would help Dana to decrease its overall plug load, though some would result in much more significant savings than others. Similar to the previous lighting analysis there is cost data associated with this analysis that will be discussed in a later section. Overall, we can conclude that there are definite opportunities for the Dana Building to decrease its overall plug load by removing non-essential equipment from office spaces. Many of this non-essential equipment (mini fridges, microwaves, toasters, TVs, etc.) are available to students and staff in shared kitchen and conference areas. Based on this fact, fostering a behavioral change in office users that encourages the utilization of communal/shared spaces for the use of certain amenities and equipment could result in considerable improvements in energy consumption and emission rates for the building.



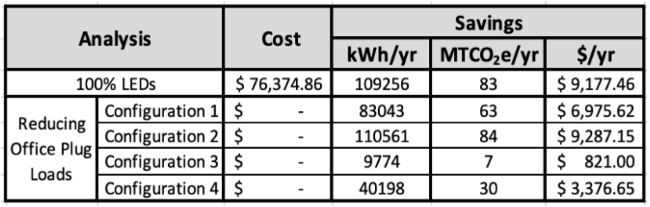
	kWh/yr	Emissions (MTCO$_2$e/yr)
Configuration 1	83043.05	62.90
Configuration 2	110561.28	83.75
Configuration 3	9773.85	7.40
Configuration 4	40198.21	30.45

Figure 12: Comparison of energy and emissions savings of each proposed configuration (ranked by color)

Putting It All Together

Through these analyses we can see how there are opportunities to increase building efficiency and reduce emissions through both technological intervention and behavioral modifications.

Installing LEDs throughout the building would help SEAS to reduce the overall energy consumption and emissions from the lighting systems within Dana by 60%, allowing them to also save money on energy and the maintenance associated with this system. Also, by modifying user's behavior within office spaces, SEAS could also major improvements to efficiency and emissions rates. By limiting the types of equipment in these spaces to essential equipment only they could save over 83,000 kWh/yr and nearly 63 metric tons of CO_2 emissions, and encouraging the simple act of completely powering down monitors (not hard drives) when not is use could increase those savings by another 27,500 kWh/yr and 21 metric tons of emissions! If SEAS implemented 100% LEDs throughout the Dana Building and pursued the most stringent configuration requirements in all of its office spaces, it could reduce its total annual electricity consumption by almost 220,000 kWh, eliminate 167 metric tons of CO_2 emissions, and save nearly $18,500.00 per year in energy costs. That is nearly a 14% reduction in the total electrical consumption and emissions levels of the building. These results demonstrate that there are many ways that SEAS can work towards decreasing energy usage in its facilities and how even minor changes in behavior and individual use can dramatically impact the bottom line.



Analysis		Cost	Savings		
			kWh/yr	$MTCO_2e$/yr	$/yr
100% LEDs		$ 76,374.86	109256	83	$ 9,177.46
Reducing Office Plug Loads	Configuration 1	$ -	83043	63	$ 6,975.62
	Configuration 2	$ -	110561	84	$ 9,287.15
	Configuration 3	$ -	9774	7	$ 821.00
	Configuration 4	$ -	40198	30	$ 3,376.65

Figure 13: Summary of results

Additional Opportunities to Consider

In addition to the strategies analyzed in the previous section, we identified additional opportunities that SEAS should consider in order to further its goal toward achieving carbon neutrality. Due to time constraints, I was unable to conduct detailed analysis on these options to determine their specific impact and benefits, but I still feel they are important to address. Based on my research and consultations with experts I believe that SEAS should look to install submetering equipment within the Dana Building, evaluate the building's envelope, and consider installing window inserts to increase the insulative properties of the existing windows. These additional actions would provide valuable insight into the building's performance and operations in real time and help to further enhance the overall efficiency of its systems.

The use of submetering equipment can help to discern how energy is used throughout a building and help to identify opportunities to optimize the overall energy performance of a building. This process involves the installation of monitors throughout the building, either in specific areas, on electrical panels, or on particular pieces of equipment, to monitor performance and energy usage. These monitors provide real-time consumption data, identify areas of inefficiency or where energy is being wasted, help to recognize opportunities to enhance performance, and can even help to identify maintenance problems before they cause extensive damage.[26] During my research I identified Onset, Buildee, Vitality, and Building OS as companies that provide submetering equipment and/or services that could help SEAS to take advantage of this technology. These installations would allow SEAS to monitor and mitigate consumption rates of specific systems (heating, cooling, lighting, etc.) or room types throughout the building and utilize this knowledge to improve the buildings overall performance. Additionally, SEAS could be one of the first buildings on campus to use this type of equipment and actually have data for how the building functions. And the gathered data would be valuable information to share with classes and projects dealing with energy consumption on campus. SEAS could become the go to institution on campus to learn about establishing focused, real world applications for submetering equipment and data it collects.

Additionally, evaluating a building's envelope and levels of outside air infiltration can result in significant energy savings. According to the U.S. Department of Energy, a building's envelope (walls, windows, roof) accounts for "approximately 30% of the primary energy consumed in residential and commercial buildings"[31]. This makes it easy to see how outside air infiltration can result in increased energy use of the heating and cooling systems and can also account for a great deal of energy waste throughout a building. The National Renewable Energy Laboratory (NREL) established procedures to easily assess a buildings envelope by reviewing architectural drawings to identify the layout and construction of the exterior, completing a visual inspection of the exterior of the building, inspecting windows and doors for drafts, and the use of a thermal imaging camera to identify problem areas around the building.[32] Also through consultations with a local HERS rating expert we discussed the benefits of conducting blower door tests throughout the building. This is a process by which a company utilizes a fan to remove air from a sealed off room and then measures the air pressure within the space to determine the rate of outside air infiltration in the room.[33] This presents another opportunity that would help SEAS to further reduce its consumption and improve the performance of the Dana Building. Assessing the buildings envelope internally, utilizing the procedures outlined by NREL, or via the assistance of a third-party building envelope consultant could help the school to identify specific problem areas throughout the building and determine appropriate strategies to address these areas of concern.

The final strategy that we identified was to look into the possibility of installing window inserts in specific rooms around the building to increase the overall insulative properties of the current windows. Window inserts, such as those offered by companies like Indow Windows, are fitted inserts that are installed within the interior window frame to increase the efficiency of the existing window technology.[34] This technology can result in a "22% reduction in heating, ventilation, and air-conditioning energy use and reduced building envelope leakage by 8.6%"[35]. Throughout my project we have been in touch with representatives from Indow Windows and they have continued to express an interest in helping to supply and install these inserts within the building. I believe that it could be beneficial to identify a couple of rooms within the building (based on orientation within the building, the amount of glazing, internal temperatures, etc.) in which these inserts can be installed and monitor the resulting impact to the space. This could present another useful technology that would allow SEAS to improve the performance and efficiency of the windows and the building envelope without having to make costly renovations to the existing equipment or spaces.

Complimentary Projects

During the course of my project, the Facilities Manager and I collaborated with student groups from the ENVIRON 391 course to identify additional opportunities for SEAS in its pursuit of carbon neutrality. During the Winter 2021 semester we worked with two groups to analyze opportunities for carbon sequestration on off-campus properties owned and managed by SEAS and the impacts of the carbon tax proposed by the PCCN. The following sections provide a general overview of each team's project, the methods they used, and their results/recommendations.

Carbon Sequestration Project

The following summary was composed by students Jackson Klein, Paige Badenhorst, Aric Rasmussen, Geoffrey Batterbee, and Kaitlynn Drako detailing their project which analyzed opportunities for increased carbon sequestration at SEAS properties. For further information please refer to the link to the report in the references section.

> This report provides an analysis and evaluation of the current amount of carbon emitted by the University of Michigan SEAS Facilities and how these carbon emissions can be offset by planting carbon-sequestering trees at offsite properties managed by SEAS.

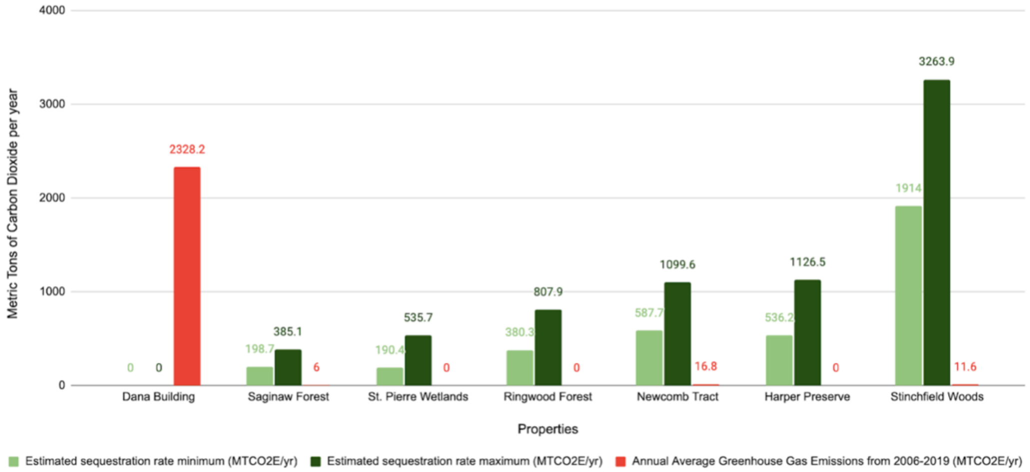


Figure 14: Graph showing the estimated sequestration rates and the annual average greenhouse gas emissions (MTCO2e/yr) from 2006-2019

Methods of analysis include literature-based research on finding tree species that have high sequestration rates, evaluating the amount of carbon each of these trees are able to capture over a period of time, and defining which SEAS field research sites already in decline would be the best candidates for plantings. Since this project revolved around research into tree species, sequestration calculations, and other aspects of land management, data collection methods were mostly through five avenues: academic search engines; data provided in a 2020 SEAS masters project, “Creating a Vision for SEAS Properties”; collaboration with stakeholders working with the project team; local tree nursery catalogues; and the USDA MyTree tool which calculates carbon sequestration rates and other ecological services provided by a tree that the user describes (refer to Appendix H for the specific carbon sequestration rates utilized for our calculations). Additionally, a cost analysis was performed to determine the cost to purchase our chosen tree species for planting. Lastly, a spreadsheet tool was developed that allows users to test different combinations and proportions of species at different sites in order to optimize carbon sequestration capacity, called the “Carbon Calculation Tool” (Appendix I).

Results of the analysis and collaboration with Sucila Fernandes, Paul Bairley, and Gabby Vinyard, showed that Stinchfield Woods, Newcomb Tract, and Saginaw Forest would be the best sites for new plantings. Final tree recommendations include the following species to be used for this project: White Oak, Bur Oak, Sugar Maple, Eastern White Pine, Tulip Poplar, Northern White Cedar, Red Pine, Northern Red Oak, Black Oak, Black Walnut, and Red Maple.

The entirety of these planting recommendations for each of the established 20 areas of decline are highlighted in the Carbon Calculation Tool, which is found in a shared Google Folder with several key stakeholders. These recommendations would initially sequester an additional 57.5 metric tons of CO2 per year (assuming a trunk diameter of 3 inches for each planting) and would require approximately 6410 trees to survive. Specifically, the group recommends a total of 1,135 Eastern White Pines, 68 White Oaks, 234 Sugar Maples, 115 Bur Oaks, 623 Tulip Poplars, 3,319 Red Pines, 82 Northern Red Oaks, 21 Black Oaks, 246 Black Walnuts, and 565 Red Maples. The breakdown of the species recommendations at any given area of decline within a site is easily accessible in the Carbon Calculation Tool. Cold Stream Farm and Porcupine Hollow Farm list tree prices in terms of height rather than trunk diameter, so estimates are slightly different (Cold Stream Farm, n.d.; Porcupine Hollow Farm, n.d.). If all trees were purchased at the minimum height available (from Cold Stream Farm at 6-12”, and the Black Oak from Porcupine Hollow Farm at 4-6”), this recommendation could cost as little as $4304.64; however, trees are also available at other heights, including 1-2’ and 2-3’, which would have higher costs. Transportation costs are more variable relative to the amount purchased and cannot be calculated for each species due to current availability based on growth season, so these fees are not part of that estimate. At some theoretical point in the future where the trunk diameters of each tree have reached 12 inches, 348.2 metric tons of CO2 could be sequestered in a year (this number is purely theoretical, because trees will grow at different rates and circumstances could cause some trees to die before reaching this diameter).

The report also acknowledges the limitations in the group’s research. For instance, trees can take 25-30 years to reach mature growth and sequestration capacity, which is not good for short-term goals or projects seeking to sequester

> maximum carbon in the first few years to meet Carbon Neutrality goals like the PCCN report. Due to constraints as a single semester project, the group did not have the time to evaluate the soils at our three sites in order to determine which trees would thrive, and sequestration estimates are therefore based solely on above-ground vegetation. Moreover, the report also considers that in the middle of the semester, the group discovered that its initial goal, which was to offset the carbon emitted by the Dana building, had already been reached (in terms of comparing above-ground sequestration levels from vegetation to Scope 1 emissions from the SEAS buildings).
>
> The report concluded with recommendations for further research by the university into additional techniques that may further promote sustainable initiatives, such as invasive species management and biochar production. There is also a description of a recommended planting process, and an explanation of the importance of using these recommendations in tandem with continued initiatives to decrease carbon emissions at the University of Michigan.
>
> Overall, the project report highlights the opportunity for replanting at three of the SEAS field research sites which could initially offset 57.5 metric tons of CO2 produced by SEAS per year. This number will only increase with growth over the next 25-30 years. In an effort to reach carbon neutrality within SEAS as laid out in the President's Commission on Carbon Neutrality Report, it is proposed that SEAS consider the final planting recommendations presented from these findings.

Carbon Accounting Project

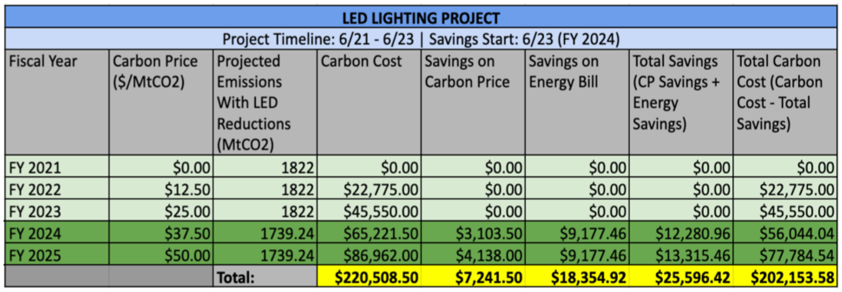
The following summary was composed by students Arynne Wegryn-Jones, Joseph Batdorf, Adam Gawron, Lauren Hanoosh, and Zoe Engle detailing their project which analyzed the impact of the carbon pricing strategies outlined in the PCCNs recommendations to SEAS and its operations. For further information please refer to the link to the report in the references section.

> The Environment 391 Carbon Pricing Project Team was developed to create an easily digestible internal carbon pricing model that could be used not only by the team's sponsor, Sucila Fernandes, but also by other facility managers at the University of Michigan (UM) to understand the impacts of the PCCN Carbon Pricing recommendations on facility's budgets. UM's proposed internal carbon price is a "tax" on carbon emissions, added to business units' annual utility bills. Carbon pricing encourages greenhouse gas (GHG) reduction by taxing annual carbon emissions to reflect their true external costs on society. The project's primary goal was to create an internal carbon pricing model for the Dana Building in accordance with PCCN recommendations that incorporates energy conservation projects to reduce the overall financial burden of the internal carbon price to be imposed on SEAS.

In the pursuit of constructing the model, our project team worked with key stakeholders to collect the necessary data for the project. We worked with our project sponsor, SEAS Facilities Manager Sucila Fernandes, to obtain spreadsheets outlining the annual GHG emissions of the Dana Building since fiscal year 2006, PCCN project team members Larson Lovdal and Jessica Carlin who provided internal carbon pricing models to showcase how the model could be implemented within UM, and Conner O'Brien, a SEAS graduate student, who supplied data for proposed energy reduction projects within the Dana Building. Once all of the necessary data was collected, the project team used empirical analysis to break down the information and gather significant figures essential to complete the project. A spreadsheet was created that modeled carbon price effects for various buildings, and also modeled the effects of energy efficiency projects on carbon pricing for the Dana Building.

The team looked into two projects: 1) replacing all the lights in the Dana Building with LED lights and 2) installing window inserts in all Dana Building windows to enhance their insulative properties. Both of these projects have the potential to significantly reduce the Dana Building's carbon emissions, therefore reducing the carbon price that Dana would have to pay in the future.

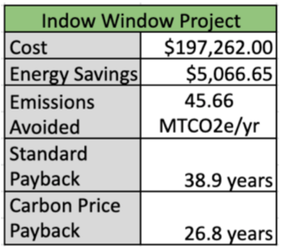
The first project evaluated was an LED lighting project proposed by SEAS graduate student Conner O'Brien. Overall, the installation is estimated to cost $76,374 and for the sake of our analysis we assumed it would take two years to fully implement. Once installed, switching to LED lighting would save the Dana Building $9,177 per year in energy costs and 83 metric tons of CO2 equivalent (MTCO2e) per year, a reduction of 60%. With the target carbon price of $50/MTCO2e, the project saves $4,138 per year on carbon costs. Savings projections for the LED project are shown in Table 1, which assumes that the project begins in June 2021 and finishes in June 2023, being fully done before fiscal year 2024. In total, this equates to yearly savings of $13,315, which would recover the costs of the project in 5.6 years. Additionally, LED lights reduce the maintenance costs of lighting, which reduces the amount of work orders (WOs) needed by the Dana Building. These costs were estimated to be $2,542 per year, bringing the payback period down to 4.9 years when WO savings are included (Appendix J). Through this analysis, the team found that the LED project would be a great start to carbon emissions reduction in the Dana Building because it is relatively inexpensive and has a short payback period - well under the 8-year maximum needed for funding. It also takes minimal construction and can be completed quickly.



LED LIGHTING PROJECT							
Project Timeline: 6/21 - 6/23 | Savings Start: 6/23 (FY 2024)							
Fiscal Year	Carbon Price ($/MtCO2)	Projected Emissions With LED Reductions (MtCO2)	Carbon Cost	Savings on Carbon Price	Savings on Energy Bill	Total Savings (CP Savings + Energy Savings)	Total Carbon Cost (Carbon Cost - Total Savings)
FY 2021	$0.00	1822	$0.00	$0.00	$0.00	$0.00	$0.00
FY 2022	$12.50	1822	$22,775.00	$0.00	$0.00	$0.00	$22,775.00
FY 2023	$25.00	1822	$45,550.00	$0.00	$0.00	$0.00	$45,550.00
FY 2024	$37.50	1739.24	$65,221.50	$3,103.50	$9,177.46	$12,280.96	$56,044.04
FY 2025	$50.00	1739.24	$86,962.00	$4,138.00	$9,177.46	$13,315.46	$77,784.54
		Total:	**$220,508.50**	**$7,241.50**	**$18,354.92**	**$25,596.42**	**$202,153.58**

Table 1: Projected savings from the LED project

The other energy efficiency project evaluated was a window insulation project, which would use window inserts to decrease heat loss through windows in the Dana Building. This project is much more expensive, estimated at $197,000 for the entire building (see Table 2). Additionally, the emissions savings from this project are 50% less than those from the LED project. While this project saves $5,000 per year in energy costs and would save $2,200 per year in carbon costs at the full carbon price, it has a very large payback period. Without the carbon price savings, the payback period is nearly 39 years. With the carbon price savings, the payback period is 26.9 years, which is significantly shorter but still long. One issue with modeling this project is that not all energy savings can be accounted for. The energy savings calculated were based on the reduced heat loss from the windows, but they do not include the reduction in heating, ventilation, and air conditioning (HVAC) operation costs. Unfortunately, the data for these calculations was not available at the time of this project, but the payback period would certainly be much shorter if they were incorporated.



Indow Window Project	
Cost	$197,262.00
Energy Savings	$5,066.65
Emissions Avoided	45.66 MTCO2e/yr
Standard Payback	38.9 years
Carbon Price Payback	26.8 years

Table 2: Pricing details for the window insert project

Based on this analysis, the project team reached three key findings:

1. The internal carbon price will impact business units across the university's three campuses disproportionately based on size; the internal carbon price will have a large financial burden on Dana's utilities budget compared to larger facilities like the Ross Business School
2. Business units need to implement energy efficiency projects as soon as possible in order to lessen the financial burden of the internal carbon price in the long run.
3. Funding of energy efficiency projects will be an area of ambiguity and uncertainty.

The project team concluded that the university can no longer afford to push off GHG reduction initiatives. The easiest way for buildings to reduce carbon emissions quickly is through energy efficiency measures (rather than renewable energy investments, etc.). By avoiding carbon costs through energy efficiency, savings from these projects are even greater, making the payback periods shorter than usual. This contributes further to the mounting incentives for buildings to improve energy efficiency.

With all of the information gathered above, the project team constructed three recommendations:

1. Determine efficiency projects within a business unit
2. Target efficiency projects based on least efficient aspects of a business unit
3. Create new positions to better educate faculty and staff on sustainable initiatives moving forward

Highlighting the finer details of the PCCN to Sucila and other facility managers brings a bigger conversation into focus. Implementing the recommendations in the PCCN is going to require the coordination and support of all university stakeholders affected by the PCCN and more importantly financial transparency to ensure high efficiency and productivity across all business units. The implications of these project findings are a greater financial burden to the Dana Building but in return, will realize higher efficiency buildings that will later save the university money and push them closer towards their goal of being carbon neutral.

Summary/Conclusion

The goal of this project was to help the School for Environment and Sustainability begin its path toward carbon neutrality by categorizing the energy consumption and performance of the Samuel T. Dana Building and identifying strategies to improve energy efficiency and reduce GHG emissions in the building. Through literature reviews of previous case studies, I was able to familiarize myself with strategies that other institutions and buildings employed to achieve carbon neutrality and the process by which they identified those strategies. Throughout this project I relied on the assistance of experts including building engineers, the regional energy manager, faculty members, and the SEAS Facilities Manager to supply me with essential resources and previous reports and to help me better understand the systems employed within the Dana Building. Through these resources and my own individual research, I was able to provide relevant information and identify feasible recommendations that will help SEAS to increase its energy efficiency and reduce emissions.

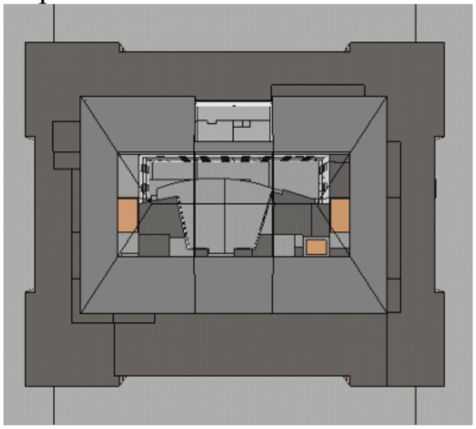
I categorized the energy intensity of the lighting, plug load, and HVAC system within Dana and estimated the energy consumption and resulting emissions of these three sources. This information allows the school to understand the impact that each of these sources has on its overall performance and this knowledge will inform future projects and solutions geared towards increasing system efficiencies and reducing emission levels. I calculated the impact of switching to LED lighting technology within the building and determined that doing so would reduce consumption by over 109,000 kWh/yr and emissions by almost 83 $MTCO_2e$/yr and allow SEAS to save $9,177.46 each year in energy costs. I also identified strategies to reduce plug loads in office spaces throughout the building by reducing the amount of non-essential equipment in workspaces. I provided multiple configuration options with the most stringent providing a total savings of over 110,500 kWh/yr and reducing annual CO_2 emissions by 84 metric tons. I also began the process of establishing an energy model of the Dana Building using the DesignBuilder software and assisted the facilities manager with the initial construction of an all-inclusive building manual which will ultimately detail all of the equipment and inner workings of the building. With these resources and a continued effort to fill in the blanks and finish adding all the necessary data, both the energy model and the building manual will greatly assist SEAS with both general building management and achieving net zero emissions status.

The final step of this progress is to provide an official proposal to the Dean of SEAS, Jonathan Overpeck, outlining the recommendations I have made throughout this report and promoting the continued use of DesignBuilder. Through this proposal I hope to help advance the next chapter in SEAS storied legacy, becoming a completely carbon neutral institution. I believe that the strategies outlined within this report, the technologies that I have presented, and the inherent drive of the SEAS Facilities Manager and key stakeholders will allow SEAS to realize this significant achievement. SEAS has always been a leader in sustainability on campus and within the community and achieving carbon neutrality will only further cement its legacy as an innovative, ground-breaking institution.

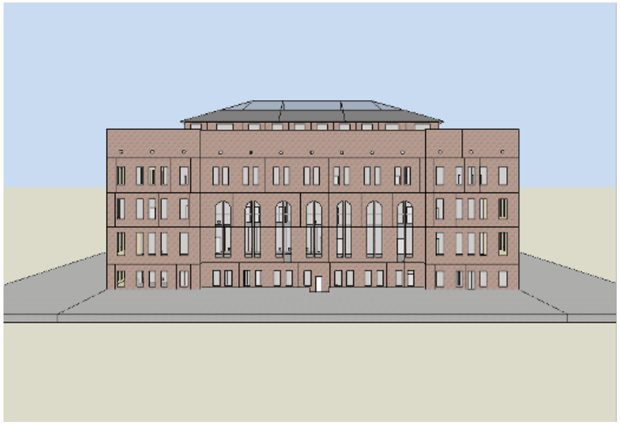
Appendices

Appendix A: Additional pictures of the building model:

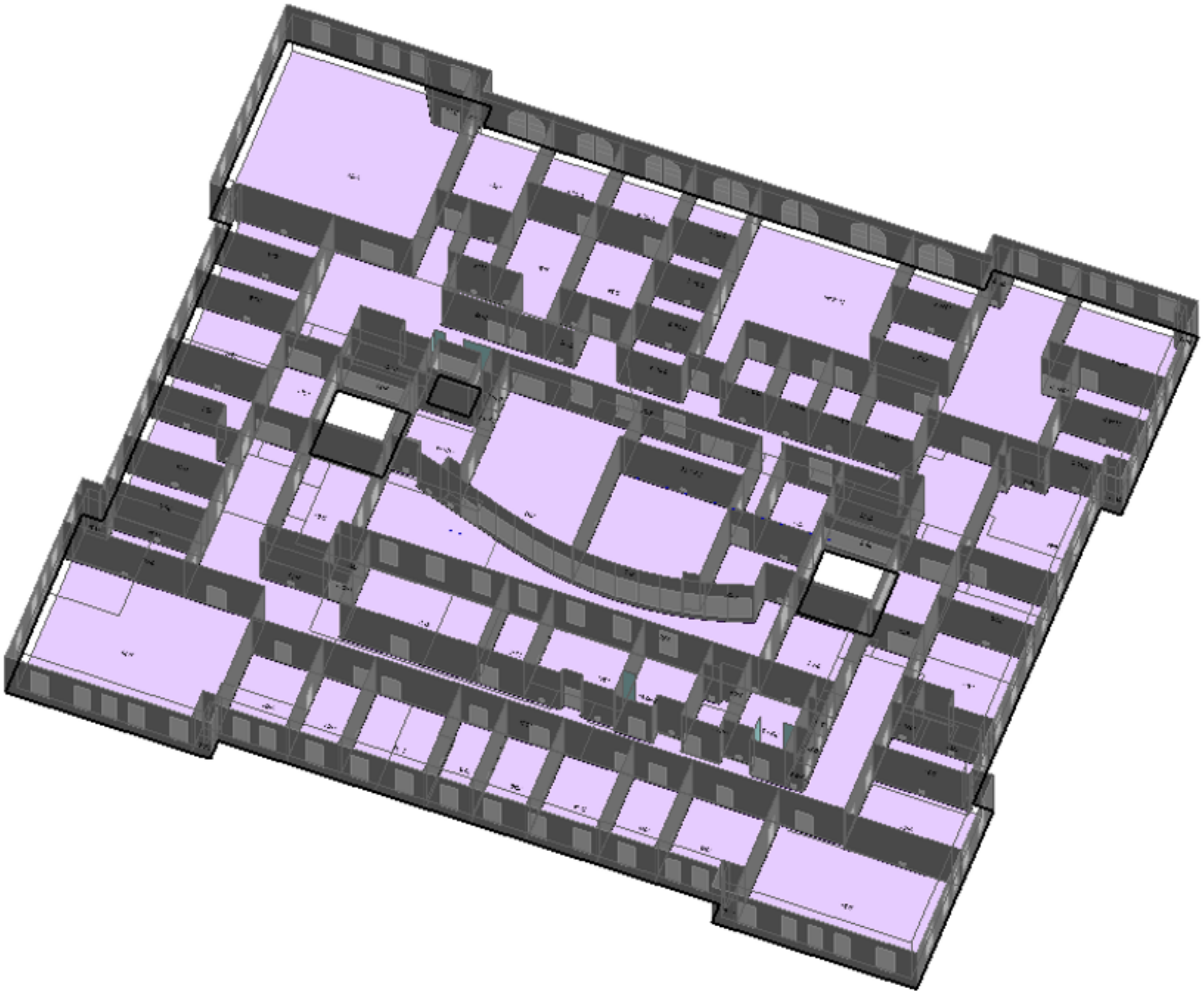
Top View:



Side View (south):



Example of the interior view of a single floor (2nd floor):



Appendix B: A segment of the lighting inventory sheet utilized to calculate the total consumption and emissions of light fixtures in the building

Floor	Room No.	Room Type	Fixture Code	Fixture Quantity	Lamps/ Fixture	Lamp Quantity	Usage (Hrs/Wk)	Watts / Fixture	kWh/Yr	Annual Emissions ($kgCO_2e$)
1	1003	MACHINE	4F2LT8	1	2	2	168	60	525.60	398.134
1	1006	CLASS	4F1LT8	11	1	11	7	30	120.45	91.239
1	1024	CLASS	4F1LT8	14	1	14	16	30	350.40	265.423
1	1028	CLASS	4F2LT8	4	2	8	27.5	60	344.14	260.683
1	1028	CLASS	4F1LT8	16	1	16	27.5	30	688.29	521.366
1	1040	CLASS	4F2LT8	4	2	8	18	60	225.26	170.629
1	1040	CLASS	4F2LT8	21	1	21	18	60	1182.60	895.802
1	1044E	ELECTRIC	4F1LT8	0	0	0	5	30	0.00	0.000
1	1046	CLASS	4F2LT8	14	2	28	8	60	350.40	265.423
1	1064	CONFER	4F1LT8	3	1	3	20	30	93.86	71.095
1	1067	STORAGE	4F1LT8	1	2	2	5	30	7.82	5.925
1	1068	OFFICE	4F1LT8	3	1	3	40	30	187.71	142.191
1	1315	COMMONS	4F1LT8	22	1	22	60	30	2064.86	1564.098
1	1315	COMMONS	*Cans	14	2	28	60	60	2628.00	1990.670
1	1315	COMMONS	8PAR20	36	1	36	60	8	901.03	682.515
1	1315	COMMONS	*LL	6	1	6	60	60	1126.29	853.144
1	1315	COMMONS	CPFL52	2	2	4	60	52	325.37	246.464
1	1501	CORRIDOR	4F1LT8	4	1	4	168	30	1051.20	796.268
1	1504	OFFICE	4F4LT8	4	3	12	40	46	383.77	290.701
1	1504A	OFFICE	4F3LT8	2	3	6	40	34.5	143.91	109.013
1	1505	STORAGE	4F2LT8	1	2	2	5	23	6.00	4.542
1	1520	OFFICE	4F2LT8	16	3	48	40	23	767.54	581.402
1	1520A	OFFICE	4F3LT8	2	3	6	40	34.5	143.91	109.013
1	1520C	OFFICE	4F3LT8	2	3	6	40	34.5	143.91	109.013
1	1520D	OFFICE	4F3LT8	2	3	6	40	34.5	143.91	109.013
1	1527	OFFICE	4F3LT8	1	3	3	40	34.5	71.96	54.506
1	1529	STORAGE	4F2LT8	1	2	2	5	23	6.00	4.542
1	1532	CONFER	4F2LT8	4	3	12	20	23	95.94	72.675
1	1535	COPY/MAIL	4F3LT8	6	3	18	40	34.5	431.74	327.039
1	1536	OFFICE	4F3LT8	2	3	6	40	34.5	143.91	109.013
1	1538	OFFICE	4F2LT8	2	3	6	40	23	95.94	72.675
1	1539	COPY/MAIL	4F2LT8	2	3	6	40	23	95.94	72.675
1	1540	OFFICE	4F2LT8	2	3	6	40	23	95.94	72.675
1	1543	KITCHEN	4F2LT8	4	2	8	40	23	191.89	145.351
1	1544	OFFICE	4F2LT8	4	3	12	40	23	191.89	145.351
1	1545W	RESTROOM	4F1LT8	3	1	3	112	30	525.60	398.134
1	1550	OFFICE	4F2LT8	4	3	12	40	60	500.57	379.175
1	1551M	RESTROOM	4F1LT8	3	1	3	112	30	525.60	398.134
1	1556	CLASS	4F2LT8	16	2	32	20	60	1001.14	758.351
1	1568	STORAGE	4F2LT8	6	2	12	5	60	93.86	71.095
1	1572	OFFICE	4F2LT8	2	2	4	40	60	250.29	189.588
1	1573	STORAGE	4F2LT8	1	2	2	5	60	15.64	11.849
1	1574J	STORAGE	4F2LT8	1	2	2	5	60	15.64	11.849
1	1575	CORRIDOR	4F1LT8	4	1	4	168	30	1051.20	796.268
1	1576	OFFICE	4F2LT8	2	3	6	40	60	250.29	189.588
1	1F03	STAIRS	4F1LT8	4	1	4	168	30	1051.20	796.268
1	1F04	STAIRS	4F1LT8	4	1	4	168	30	1051.20	796.268
1	1S01	STAIRS	4F1LT8	2	1	2	168	30	525.60	398.134
1	1S02	STAIRS	4F1LT8	2	1	2	168	30	525.60	398.134
1		CORRIDOR	CPFL52	13	2	26	70	52	2467.40	1869.018
1		CORRIDOR (EM)	CPFL52	13	2	26	168	52	5921.76	4485.643
2	2003	STORAGE	4F2LT8	1	2	2	5	60	15.64	11.849
2	2004	OFFICE	4F2LT8	4	3	12	40	60	500.57	379.175
2	2006	OFFICE	4F2LT8	2	3	6	40	60	250.29	189.588
2	2008	OFFICE	4F3LT8	2	3	6	40	80	333.71	252.784
2	2024	CLASS	4F2LT8	17	2	34	24.5	60	1303.05	987.041
2	2026	CONFER	4F3LT8	3	3	9	20	80	250.29	189.588
2	2026	CONFER	4F1LT8	2	1	2	20	30	62.57	47.397
2	2028	KITCHEN	4F2LT8	2	2	4	40	60	250.29	189.588
2	2030	STORAGE	4F2LT8	1	2	2	5	60	15.64	11.849
2	2032	OFFICE	4F2LT8	6	3	18	40	60	750.86	568.763
2	2032A	OFFICE	4F3LT8	2	3	6	40	80	333.71	252.784

Appendix C: Percentages (determined by room audit) utilized to estimate frequency of different types of equipment present in un-audited workstations

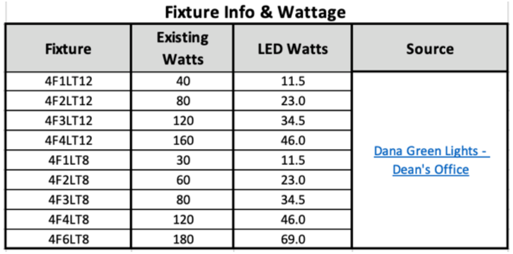
Percentages

Equipment	Faculty Office	Admin Office	Student Office	Facilities
Monitors	100%	100%	85%	50%
Add'l Monitors	11%	36%	0%	0%
Hard-drives	27%	14%	36%	50%
laptops*	73%	86%	49%	0%
desk lamps	36%	14%	5%	0%
floor lamps	5%	7%	0%	0%
desk lights	7%	0%	2%	0%
heaters	7%	36%	2%	0%
fans	7%	7%	7%	0%
speakers	11%	0%	1%	0%
air purifiers	5%	7%	0%	0%
fridge (sm)	5%	7%	2%	0%
fridge (med)	2%	7%	2%	0%
fridge (lg)	2%	0%	1%	0%
microwave	2%	0%	3%	0%
hot pot	22%	7%	5%	0%
coffee pot	13%	14%	7%	0%
printer	13%	21%	4%	0%
tv	2%	7%	2%	50%
radio	5%	7%	1%	0%
pencil sharpener	5%	0%	2%	0%
toaster	0%	0%	1%	0%
scanner	2%	0%	2%	0%

Appendix D: Table utilized to calculate estimated HVAC consumption and emissions in the Dana building

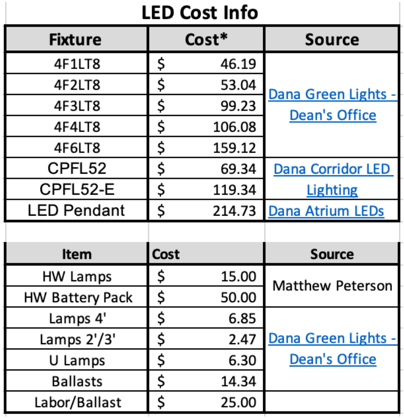
Equipment Type	Supply CFM	Return CFM	Exh CFM	VFD	HP	Volts	Amps	kW	Operation Hours (per yr)	kWh/yr	VFD (% speed)	Final kWh/yr	Annual Emissions
Air Handler	23,000	N/A	N/A	Yes	40	200		26.856	4045.5	108645.9	43%	46609.11	35305.6663
Air Handler	11,000	N/A	N/A	Yes	15	200		10.071	4045.5	40742.23	80%	32593.78	24689.2772
Air Handler	20,000	N/A	N/A	Yes	25	200		16.785	8760	147036.6	97%	142037.4	107591.055
								0					
Return Fan	N/A	10,400	N/A	Yes	7.5	200		5.0355	8760	44110.98	35%	15218.29	11527.613
Return Fan	N/A	11,000	N/A	Yes	7.5	200		5.0355	8760	44110.98	74%	32642.13	24725.8946
								0					0
Exhaust Fan	N/A	N/A	20,500	Yes	30			20.142	8760	176443.9	69%	121040.5	91686.2901
Exhaust Fan	N/A	N/A	20,500	Yes	30			20.142	8760	176443.9	69%	121040.5	91686.2901
Exhaust Fan	N/A	N/A	10,000	No	5	200		3.357	8760	29407.32		29407.32	22275.5807
Exhaust Fan	N/A	N/A	10,000	No	5	200		3.357	8760	29407.32		29407.32	22275.5807
Exhaust Fan	N/A	N/A	4,500	No	7.5	208		5.0355	8760	44110.98		44110.98	33413.371
Exhaust Fan	N/A	N/A	300	No	0.1	115		0.06714	8760	588.1464		588.1464	445.511614
Exhaust Fan	*N/A*	*N/A*		*No*	*2*			1.3428	8760	11762.93		11762.93	8910.23227
								0				0	0
Air Handler	6000	N/A	N/A		7.5	208		5.0355	8760	44110.98		44110.98	33413.371
Air Handler	1500	N/A	N/A	Yes	2	208		1.3428	8760	11762.93	38%	4493.438	3403.70873
Air Handler	3,100	N/A	N/A	No	5	208		3.357	3744	12568.61		12568.61	9520.52215
Air Handler	4,000	N/A	N/A	No	5			3.357	8760	29407.32		29407.32	22275.5807
Air Handler	3rd Floor C	N/A	N/A	No	5			3.357	4045.5	13580.74		13580.74	10287.1988
Air Handler	Atrium - All	N/A	N/A	No	5			3.357	8760	29407.32		29407.32	22275.5807
Fan Coil Unit	565	N/A	N/A	No	0.2			0.13428	8760	1176.293		1176.293	891.023227
Fan Coil Unit	565	N/A	N/A	No	0.2			0.13428	8760	1176.293		1176.293	891.023227
Fan Coil Unit	Lab G140	N/A	N/A	No	0.2			0.13428	8760	1176.293		1176.293	891.023227
Fan Coil Unit	565	N/A	N/A	No	0.2			0.13428	8760	1176.293		1176.293	891.023227
Fan Coil Unit	Lab G136A	N/A	N/A	No	0.2			0.13428	8760	1176.293		1176.293	891.023227
Fan Coil Unit	565	N/A	N/A	No	0.2			0.13428	8760	1176.293		1176.293	891.023227
Fan Coil Unit	565	N/A	N/A	No	0.2			0.13428	8760	1176.293		1176.293	891.023227
Fan Coil Unit	565	N/A	N/A	No	0.2			0.13428	8760	1176.293		1176.293	891.023227
Fan Coil Unit	565	N/A	N/A	No	0.2			0.13428	8760	1176.293		1176.293	891.023227
Fan Coil Unit	565	N/A	N/A	No	0.2			0.13428	8760	1176.293		1176.293	891.023227
Fan Coil Unit	Ground Flo	N/A	N/A	No	0.2			0.13428	8760	1176.293		1176.293	891.023227
Fan Coil Unit	Ground Flo	N/A	N/A	No	0.2			0.13428	8760	1176.293		1176.293	891.023227
	GPM							0					0
Chilled Water Pump	968			Yes	50	208		33.57	8760	294073.2	58%	171444.7	129866.635
Chilled Water Pump	968			Yes									
Domestic Water Pump	63			No	5			3.357	8760	29407.32		29407.32	22275.5807
Domestic Water Pump	63			No									
Heating Hot Water Pump	Heating Water			No	5			3.357	8760	29407.32		29407.32	22275.5807
Heating Hot Water Pump	Heating Water			No									
Radiant Panel Chilled Water Pu	180			Yes	3	200		2.0142	8760	17644.39	97%	17044.48	12910.9266
Radiant Panel Chilled Water Pu	180			Yes									

Appendix E: LED wattage and cost data utilized in energy efficient lighting analysis



Fixture Info & Wattage

Fixture	Existing Watts	LED Watts	Source
4F1LT12	40	11.5	Dana Green Lights - Dean's Office
4F2LT12	80	23.0	
4F3LT12	120	34.5	
4F4LT12	160	46.0	
4F1LT8	30	11.5	
4F2LT8	60	23.0	
4F3LT8	80	34.5	
4F4LT8	120	46.0	
4F6LT8	180	69.0	

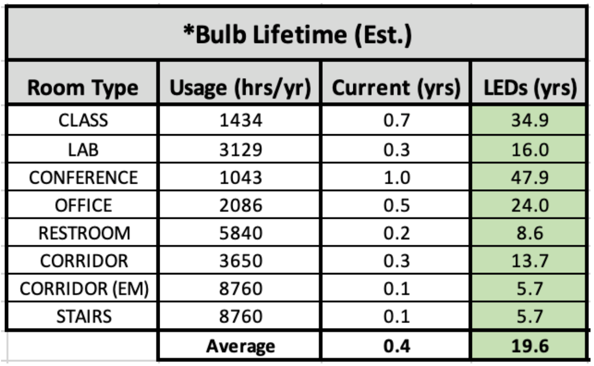


LED Cost Info

Fixture	Cost*	Source
4F1LT8	$ 46.19	Dana Green Lights - Dean's Office
4F2LT8	$ 53.04	
4F3LT8	$ 99.23	
4F4LT8	$ 106.08	
4F6LT8	$ 159.12	
CPFL52	$ 69.34	Dana Corridor LED Lighting
CPFL52-E	$ 119.34	
LED Pendant	$ 214.73	Dana Atrium LEDs

Item	Cost	Source
HW Lamps	$ 15.00	Matthew Peterson
HW Battery Pack	$ 50.00	
Lamps 4'	$ 6.85	Dana Green Lights - Dean's Office
Lamps 2'/3'	$ 2.47	
U Lamps	$ 6.30	
Ballasts	$ 14.34	
Labor/Ballast	$ 25.00	

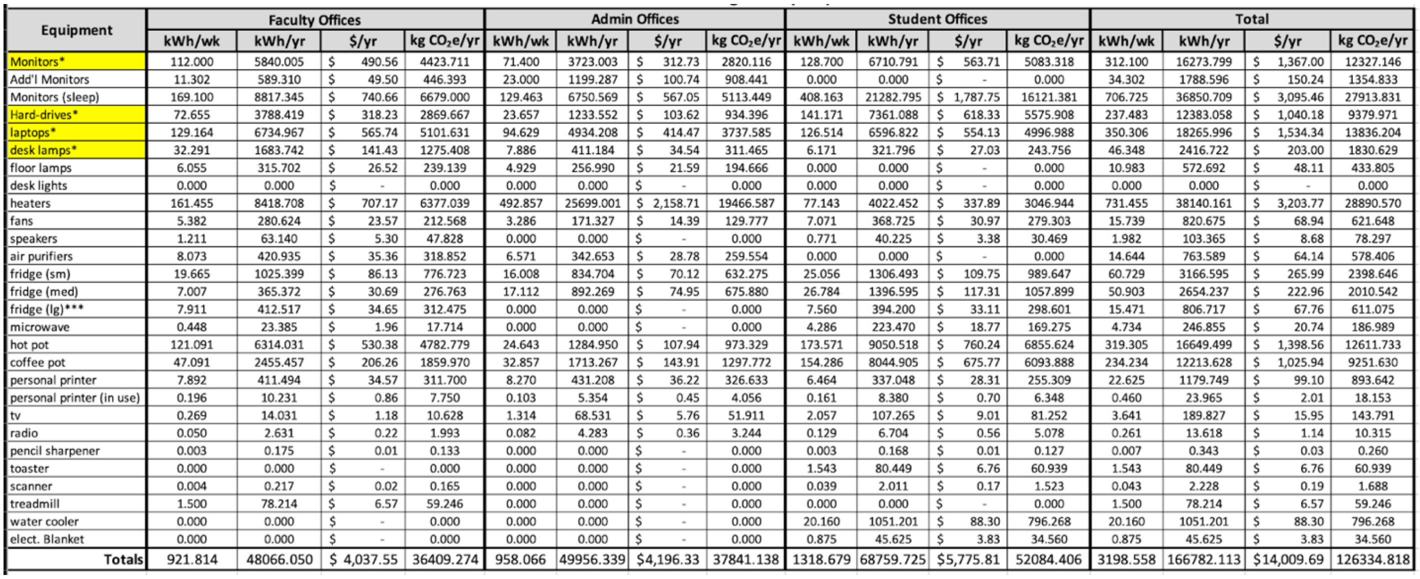
Appendix F: LED vs Incandescent bulb lifetimes based on room type & assumed usage



***Bulb Lifetime (Est.)**

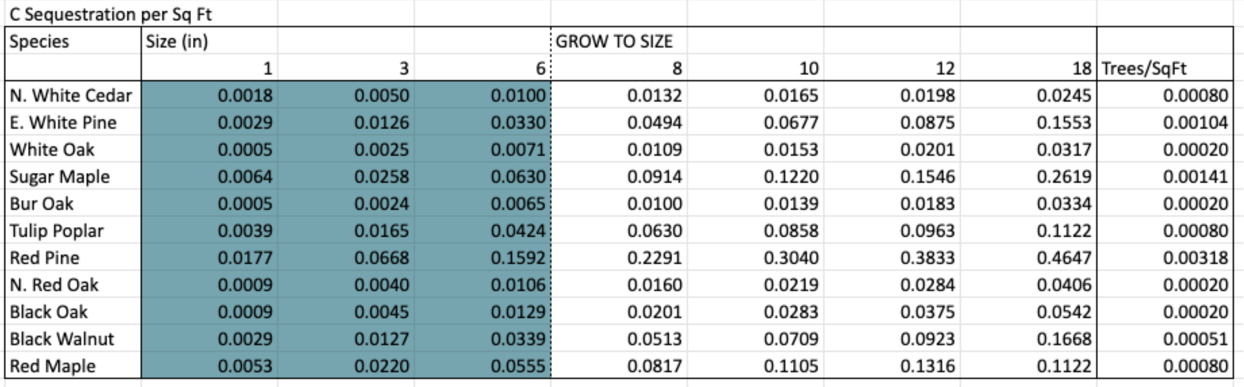
Room Type	Usage (hrs/yr)	Current (yrs)	LEDs (yrs)
CLASS	1434	0.7	34.9
LAB	3129	0.3	16.0
CONFERENCE	1043	1.0	47.9
OFFICE	2086	0.5	24.0
RESTROOM	5840	0.2	8.6
CORRIDOR	3650	0.3	13.7
CORRIDOR (EM)	8760	0.1	5.7
STAIRS	8760	0.1	5.7
	Average	**0.4**	**19.6**

Appendix G: Table summarizing plug load data for each type of office located in the Dana Building



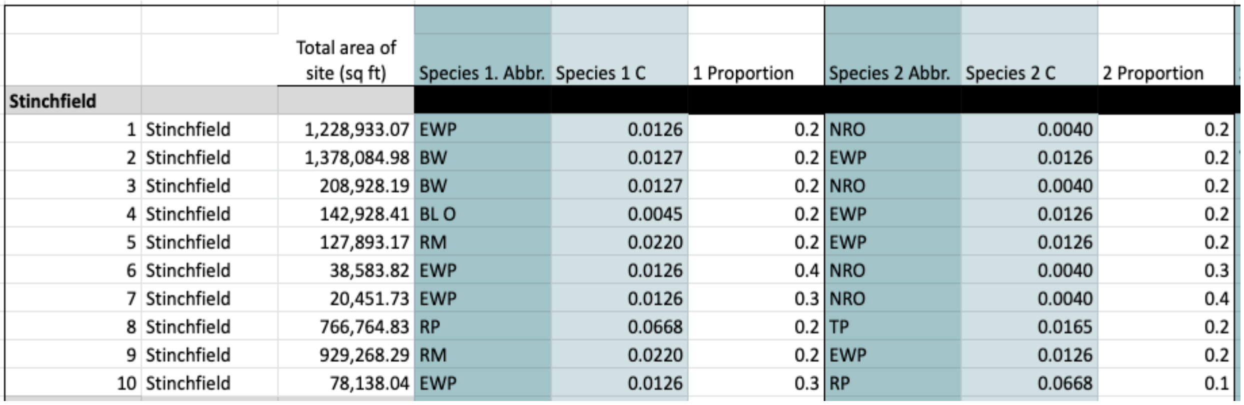
Equipment	Faculty Offices				Admin Offices				Student Offices				Total			
	kWh/wk	kWh/yr	$/yr	kg CO_2e/yr	kWh/wk	kWh/yr	$/yr	kg CO_2e/yr	kWh/wk	kWh/yr	$/yr	kg CO_2e/yr	kWh/wk	kWh/yr	$/yr	kg CO_2e/yr
Monitors*	112.000	5840.005	$ 490.56	4423.711	71.400	3723.003	$ 312.73	2820.116	128.700	6710.791	$ 563.71	5083.318	312.100	16273.799	$ 1,367.00	12327.146
Add'l Monitors	11.302	589.310	$ 49.50	446.393	23.000	1199.287	$ 100.74	908.441	0.000	0.000	$ -	0.000	34.302	1788.596	$ 150.24	1354.833
Monitors (sleep)	169.100	8817.345	$ 740.66	6679.000	129.463	6750.569	$ 567.05	5113.449	408.163	21282.795	$ 1,787.75	16121.381	706.725	36850.709	$ 3,095.46	27913.831
Hard-drives*	72.655	3788.419	$ 318.23	2869.667	23.657	1233.552	$ 103.62	934.396	141.171	7361.088	$ 618.33	5575.908	237.483	12383.058	$ 1,040.18	9379.971
laptops*	129.164	6734.967	$ 565.74	5101.631	94.629	4934.208	$ 414.47	3737.585	126.514	6596.822	$ 554.13	4996.988	350.306	18265.996	$ 1,534.34	13836.204
desk lamps*	32.291	1683.742	$ 141.43	1275.408	7.886	411.184	$ 34.54	311.465	6.171	321.796	$ 27.03	243.756	46.348	2416.722	$ 203.00	1830.629
floor lamps	6.055	315.702	$ 26.52	239.139	4.929	256.990	$ 21.59	194.666	0.000	0.000	$ -	0.000	10.983	572.692	$ 48.11	433.805
desk lights	0.000	0.000	$ -	0.000	0.000	0.000	$ -	0.000	0.000	0.000	$ -	0.000	0.000	0.000	$ -	0.000
heaters	161.455	8418.708	$ 707.17	6377.039	492.857	25699.001	$ 2,158.71	19466.587	77.143	4022.452	$ 337.89	3046.944	731.455	38140.161	$ 3,203.77	28890.570
fans	5.382	280.624	$ 23.57	212.568	3.286	171.327	$ 14.39	129.777	7.071	368.725	$ 30.97	279.303	15.739	820.675	$ 68.94	621.648
speakers	1.211	63.140	$ 5.30	47.828	0.000	0.000	$ -	0.000	0.771	40.225	$ 3.38	30.469	1.982	103.365	$ 8.68	78.297
air purifiers	8.073	420.935	$ 35.36	318.852	6.571	342.653	$ 28.78	259.554	0.000	0.000	$ -	0.000	14.644	763.589	$ 64.14	578.406
fridge (sm)	19.665	1025.399	$ 86.13	776.723	16.008	834.704	$ 70.12	632.275	25.056	1306.493	$ 109.75	989.647	60.729	3166.595	$ 265.99	2398.646
fridge (med)	7.007	365.372	$ 30.69	276.763	17.112	892.269	$ 74.95	675.880	26.784	1396.595	$ 117.31	1057.899	50.903	2654.237	$ 222.96	2010.542
fridge (lg)***	7.911	412.517	$ 34.65	312.475	0.000	0.000	$ -	0.000	7.560	394.200	$ 33.11	298.601	15.471	806.717	$ 67.76	611.075
microwave	0.448	23.385	$ 1.96	17.714	0.000	0.000	$ -	0.000	4.286	223.470	$ 18.77	169.275	4.734	246.855	$ 20.74	186.989
hot pot	121.091	6314.031	$ 530.38	4782.779	24.643	1284.950	$ 107.94	973.329	173.571	9050.518	$ 760.24	6855.624	319.305	16649.499	$ 1,398.56	12611.733
coffee pot	47.091	2455.457	$ 206.26	1859.970	32.857	1713.267	$ 143.91	1297.772	154.286	8044.905	$ 675.77	6093.888	234.234	12213.628	$ 1,025.94	9251.630
personal printer	7.892	411.494	$ 34.57	311.700	8.270	431.208	$ 36.22	326.633	6.464	337.048	$ 28.31	255.309	22.625	1179.749	$ 99.10	893.642
personal printer (in use)	0.196	10.231	$ 0.86	7.750	0.103	5.354	$ 0.45	4.056	0.161	8.380	$ 0.70	6.348	0.460	23.965	$ 2.01	18.153
tv	0.269	14.031	$ 1.18	10.628	1.314	68.531	$ 5.76	51.911	2.057	107.265	$ 9.01	81.252	3.641	189.827	$ 15.95	143.791
radio	0.050	2.631	$ 0.22	1.993	0.082	4.283	$ 0.36	3.244	0.129	6.704	$ 0.56	5.078	0.261	13.618	$ 1.14	10.315
pencil sharpener	0.003	0.175	$ 0.01	0.133	0.000	0.000	$ -	0.000	0.003	0.168	$ 0.01	0.127	0.007	0.343	$ 0.03	0.260
toaster	0.000	0.000	$ -	0.000	0.000	0.000	$ -	0.000	1.543	80.449	$ 6.76	60.939	1.543	80.449	$ 6.76	60.939
scanner	0.004	0.217	$ 0.02	0.165	0.000	0.000	$ -	0.000	0.039	2.011	$ 0.17	1.523	0.043	2.228	$ 0.19	1.688
treadmill	1.500	78.214	$ 6.57	59.246	0.000	0.000	$ -	0.000	0.000	0.000	$ -	0.000	1.500	78.214	$ 6.57	59.246
water cooler	0.000	0.000	$ -	0.000	0.000	0.000	$ -	0.000	20.160	1051.201	$ 88.30	796.268	20.160	1051.201	$ 88.30	796.268
elect. Blanket	0.000	0.000	$ -	0.000	0.000	0.000	$ -	0.000	0.875	45.625	$ 3.83	34.560	0.875	45.625	$ 3.83	34.560
Totals	921.814	48066.050	$ 4,037.55	36409.274	958.066	49956.339	$4,196.33	37841.138	1318.679	68759.725	$5,775.81	52084.406	3198.558	166782.113	$14,009.69	126334.818

Appendix H: Data on different carbon sequestration rates (lbs. C per square foot) based on trunk diameter in inches determined by Carbon Sequestration Project Group



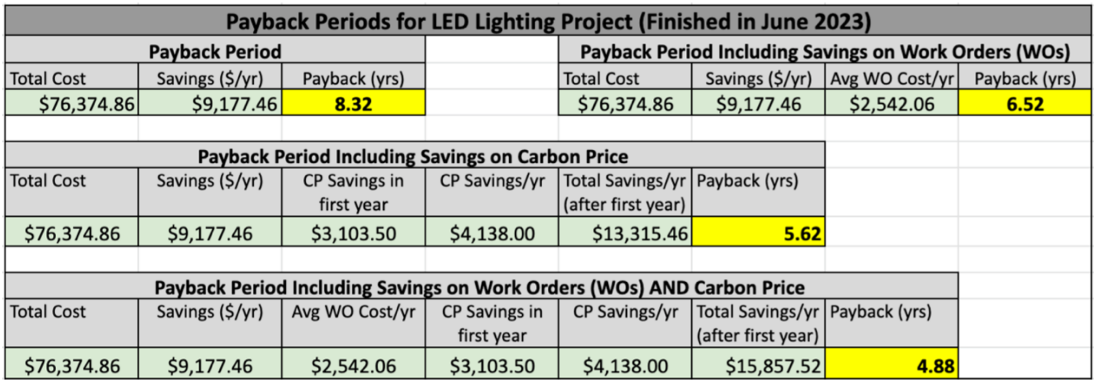
C Sequestration per Sq Ft								
Species	Size (in)			GROW TO SIZE				
	1	3	6	8	10	12	18	Trees/SqFt
N. White Cedar	0.0018	0.0050	0.0100	0.0132	0.0165	0.0198	0.0245	0.00080
E. White Pine	0.0029	0.0126	0.0330	0.0494	0.0677	0.0875	0.1553	0.00104
White Oak	0.0005	0.0025	0.0071	0.0109	0.0153	0.0201	0.0317	0.00020
Sugar Maple	0.0064	0.0258	0.0630	0.0914	0.1220	0.1546	0.2619	0.00141
Bur Oak	0.0005	0.0024	0.0065	0.0100	0.0139	0.0183	0.0334	0.00020
Tulip Poplar	0.0039	0.0165	0.0424	0.0630	0.0858	0.0963	0.1122	0.00080
Red Pine	0.0177	0.0668	0.1592	0.2291	0.3040	0.3833	0.4647	0.00318
N. Red Oak	0.0009	0.0040	0.0106	0.0160	0.0219	0.0284	0.0406	0.00020
Black Oak	0.0009	0.0045	0.0129	0.0201	0.0283	0.0375	0.0542	0.00020
Black Walnut	0.0029	0.0127	0.0339	0.0513	0.0709	0.0923	0.1668	0.00051
Red Maple	0.0053	0.0220	0.0555	0.0817	0.1105	0.1316	0.1122	0.00080

Appendix I: Spreadsheet created by the ENVIRON 391 Carbon Sequestration Project Group, known as the "Carbon Calculation Tool", designed to test different combinations of plant species at different sites in order to optimize carbon sequestration capacity at the SEAS properties. This is an example of recommendation results for the Stinchfield woods property



		Total area of site (sq ft)	Species 1. Abbr.	Species 1 C	1 Proportion	Species 2 Abbr.	Species 2 C	2 Proportion
Stinchfield								
1	Stinchfield	1,228,933.07	EWP	0.0126	0.2	NRO	0.0040	0.2
2	Stinchfield	1,378,084.98	BW	0.0127	0.2	EWP	0.0126	0.2
3	Stinchfield	208,928.19	BW	0.0127	0.2	NRO	0.0040	0.2
4	Stinchfield	142,928.41	BL O	0.0045	0.2	EWP	0.0126	0.2
5	Stinchfield	127,893.17	RM	0.0220	0.2	EWP	0.0126	0.2
6	Stinchfield	38,583.82	EWP	0.0126	0.4	NRO	0.0040	0.3
7	Stinchfield	20,451.73	EWP	0.0126	0.3	NRO	0.0040	0.4
8	Stinchfield	766,764.83	RP	0.0668	0.2	TP	0.0165	0.2
9	Stinchfield	929,268.29	RM	0.0220	0.2	EWP	0.0126	0.2
10	Stinchfield	78,138.04	EWP	0.0126	0.3	RP	0.0668	0.1

Appendix J: Payback period scenarios and cost analysis for LED lighting project based on ENVIRON 391 Carbon Pricing Project Team's analysis



Payback Periods for LED Lighting Project (Finished in June 2023)

Payback Period

Total Cost	Savings ($/yr)	Payback (yrs)
$76,374.86	$9,177.46	8.32

Payback Period Including Savings on Work Orders (WOs)

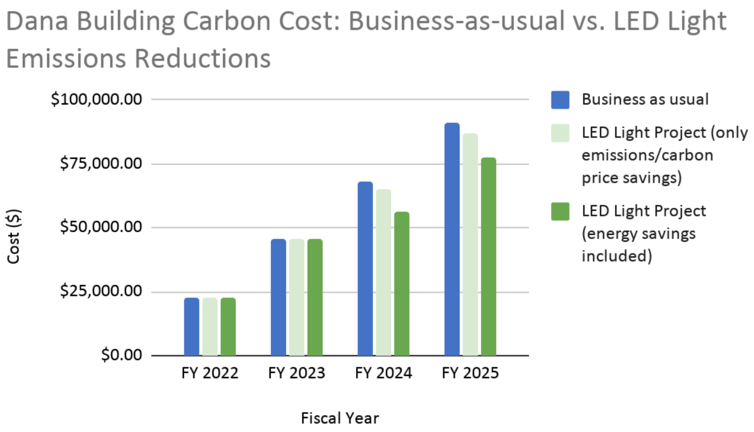
Total Cost	Savings ($/yr)	Avg WO Cost/yr	Payback (yrs)
$76,374.86	$9,177.46	$2,542.06	6.52

Payback Period Including Savings on Carbon Price

Total Cost	Savings ($/yr)	CP Savings in first year	CP Savings/yr	Total Savings/yr (after first year)	Payback (yrs)
$76,374.86	$9,177.46	$3,103.50	$4,138.00	$13,315.46	5.62

Payback Period Including Savings on Work Orders (WOs) AND Carbon Price

Total Cost	Savings ($/yr)	Avg WO Cost/yr	CP Savings in first year	CP Savings/yr	Total Savings/yr (after first year)	Payback (yrs)
$76,374.86	$9,177.46	$2,542.06	$3,103.50	$4,138.00	$15,857.52	4.88



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