ABSTRACT

Title of Thesis: ENERGY CONSUMPTION REDUCTION OF COMMERCIAL BUILDINGS THROUGH THE IMPLEMENTATION OF VIRTUAL AND EXPERIMENTAL ENERGY AUDIT ANALYSIS

Ji Han Bae, Master of Science, 2022

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According to the U.S. Energy Information Administration (EIA), about 38 quads of the total U.S. energy consumption was consumed by residential and commercial buildings in 2017, which is about 39% of the total 2017 annual U.S. energy consumption (EIA, 2018). Additionally, the building sector is responsible for about 75% of the total U.S. electricity consumption as well as for about 70% of the projected growth in the U.S. electricity demand through 2040. It is clear that the potential for energy savings and greenhouse gas emissions reduction in existing buildings today remain largely untapped and that there is still much left to explore in respect to determining the best protocols for reducing building energy consumption on a national and even a global scale. The present work investigates the effectiveness of coupling an initial virtual energy audit screening with the conventional, hands-on, energy audit processes to more quickly and less costly obtain the potential energy savings for high energy consumption buildings. The virtual screening tool takes advantage of a customized cloud-based energy efficiency management software and the readily available building energy

consumption data to identify the buildings that have the highest energy savings potential and should be given priority for performing onsite walkthroughs, detailed energy audits, and the subsequent implementation of the identified energy conservation measures (ECMs). By applying the proposed procedure to a group of buildings, the results of this study demonstrated that a combination of the software-based screening tools and a detailed experimental/onsite energy audit as necessary can effectively take advantage of the potential energy consumption and carbon footprint reduction in existing buildings today and that the low-cost/no-cost energy conservation measures alone can oftentimes result in significant savings as documented in this thesis. However, selection of the appropriate software was deemed critically important, as certain software limitations were observed to hinder the obtainment of some energy savings opportunities.

ENERGY CONSUMPTION REDUCTION OF COMMERCIAL BUILDINGS THROUGH THE IMPLEMENTATION OF VIRTUAL AND EXPERIMENTAL ENERGY AUDIT ANALYSIS

by

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Dedication

This thesis is dedicated to my immigrant parents, Jung Mi Kim and Su Won Shin, whose sacrifices have continually allowed me to succeed in reaching my goals.

Acknowledgements

I truly thank my advisor, Dr. Michael Ohadi, for the opportunity as well as the provision of the necessary guidance for me to complete this thesis. I am grateful to have been entrusted to experience a leading role on the Smart and Small Thermal Systems Laboratory (S2TS) energy audit team and to have participated in numerous energy audit projects for the Maryland Department of General Services (DGS). I would also like to thank Associate Research Professor Dr. Amir Shoostari for all of his guidance as well as my former and current S2TS energy audit team members for all of their help. It has sincerely been a pleasure working with you all, despite the limitations caused by the COVID-19 pandemic.

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Nomenclature

AHU – Air Handling Unit
ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BAS – Building Automation System
BTU – British Thermal Unit
CBECS – Commercial Buildings Energy Consumption Survey
CO_2 – Carbon Dioxide
DDC – Direct Digital Controls
DGS – Department of General Services
ECM – Energy Conservation Measure
EIA – U.S. Energy Information Administration
EPA – U.S. Environmental Protection Agency
EUI – Energy Usage Index
HVAC – Heating, Ventilation, and Air-Conditioning
KW – Kilowatt
KWH – Kilowatt-Hour
MSD – Maryland School for the Deaf
NREL – National Renewable Energy Laboratory
UMD – University of Maryland
S2TS – University of Maryland Smart and Small Thermal Systems Laboratory
SRECs – Solar Renewable Energy Credits
SQ. FT. – Square Foot
VAV – Variable Air Volume

Chapter 1: Introduction

1.1 Project Background and Goals

Despite the numerous technological advancements that are currently being made today in order to improve building energy efficiency, current data show that there are still plenty more improvements left to be made. Building system manufacturers are continuously investing a substantial amount of funding into research and development for improving the performance of building systems. However, these performance improvements do not always equate to improvements in their energy consumption and costs. According to the U.S. Energy Information Administration (EIA), about 38 quads of the total U.S. energy consumption was consumed by residential and commercial buildings in 2017, which is about 39% of the total 2017 annual U.S. energy consumption (EIA, 2018). Additionally, the building sector is responsible for about 75% of the total U.S. electricity consumption as well as for about 70% of the projected growth in the U.S. electricity demand through 2040. Furthermore, in 2019, the U.S. total primary energy consumption was about 100 quads, which is about 17% of the total world primary energy consumption of about 604 quads (EIA, 2020). It is clear that the potential for energy savings and greenhouse gas emissions reduction in existing buildings today remain largely untapped and that there is still much left to explore in respect to determining the best protocols for screening building energy efficiencies and for minimizing building energy consumption on a national and even a global scale.

Previously, the University of Maryland Smart and Small Thermal Systems Laboratory (S2TS) energy audit team had worked with the University of

Maryland's (UMD) Energy Sustainability Office and Facilities Management to perform energy audits for campus buildings within their own university in order to reduce the campus' building energy consumption and carbon footprint. This work had been directly funded and supported by the UMD's Center for Environmental Energy Engineering (CEEE), which was co-founded by Professor Dr. Michael Ohadi. However, the projects discussed in this thesis is separate from the campus energy audit work previously mentioned and is a continuation of the ambitious efforts enacted by the S2TS energy audit team to support Governor Hogan's Executive Order 01.01.2019.08 – Energy Savings Goals for State Government, which was issued in July 2019 in order to initiate a plan of action to improve the energy efficiency of Maryland state-owned buildings, reduce their negative environmental impacts, and save taxpayers' money. An energy savings goal of 10% was set by the executive order with respect to the 2018 energy consumption data as a baseline (Hogan, 2019). The executive order also requires energy audits to be performed for at least 2 million square feet of Maryland state facilities annually as well as energy audit reports to be submitted to each building owner respectively. It also states that each state facility that undergoes the energy audit process must implement the proposed energy conservation measures to the fullest extent practicable.

The Maryland Department of General Services (DGS) Office of Energy and Sustainability is the state division responsible for managing the efforts being invested into carrying out this executive order in order to ensure that the established goals are being met. The S2TS energy audit team was chosen to collaborate with

Maryland DGS and has been continually providing ASHRAE Level 2 energy audit services in order to assist in meeting the goals of the executive order. The S2TS energy audit team has been led by Dr. Michael Ohadi, the principal investigator and project director, as well as Dr. Amir Shoostari, the project deputy director. The following list shows the results from Year I on the project (UMD S2TS, 2021):

- Energy audits were performed for 1.73 million square feet of building area.
- Energy models were created for 15 different state-owned buildings.
- Proposed energy conservation measures (ECM) amounted to a total annual savings of about $641,000.
- Average energy savings for each building was about 20%, which was about $0.37 per square foot.
- Energy savings for an individual building ranged from 8% to more than 41%.
- Corresponding annual CO_2 emissions reduction amounted to about 3 million pounds per year.

The findings from Year I also showed that the majority of the existing state facilities used outdated building systems that were far past their useful operational life and were most likely operating with low energy efficiency due their old age. These types of building systems included but were not limited to HVAC systems, lighting systems, building automation systems, and building envelopes. Inefficiencies in any of these types of systems would ultimately result in unnecessary losses in electricity, natural gas, and/or oil consumption. Notably, HVAC systems alone account for an average of 40% of the total energy usage in commercial buildings

(Bonacorda, 2015). Therefore, there is currently an apparent need for a more time and cost-efficient method for performing energy audits on existing buildings in order to determine their current energy usage indices (EUIs), necessary energy conservation measures, as well as their total potentials for energy savings and greenhouse gas emissions reduction.

Like other existing energy auditing firms, the S2TS energy audit team has continuously made the necessary adjustments to sharpen and refine their energy audit methods throughout their years of work to improve the efficiency and effectiveness at which the energy audits are performed. This study discusses the effectiveness of implementing an initial virtual screening to the conventional, hands-on, energy audit processes used today by taking advantage of a customized cloud-based energy efficiency management software to determine which buildings have the highest energy savings potentials and should be given priority for performing onsite walkthroughs and detailed energy audits so that the total energy savings as well as the efficiency at which energy audits are performed can be maximized. The software of focus in this thesis is kWh360, which is provided by a technology and services company called Singh360. This user-friendly software allows for the input of key building utility data, calculates comparable energy consumption and cost measures associated with the building on a monthly and annual basis, as well as generates comprehensible tables and graphs associated with the various energy-related data. All this can be done while storing all of the data on a dedicated cloud server. A group of Maryland state government buildings were initially screened with this software in order to determine the greatest opportunities for energy savings and greenhouse gas emissions reduction as well as their short-term and long-term payback periods. Once the buildings with the highest savings potentials were determined, more in-depth experimental energy audits were performed on the selected buildings by attending physical building walkthroughs in order to identify the existing building systems and conditions. Then, an energy model was created for each building through careful model calibration with the associated actual utility data in order to determine the necessary ECMs to be implemented as well as the energy savings and greenhouse gas emissions reductions associated with them. By testing the implementation of a virtual screening to the energy audit of this group of buildings, the results of this study demonstrated that a combination of software tools and an in-depth experimental/onsite energy audit as necessary can effectively take advantage of the potential energy consumption and carbon footprint reduction in existing buildings today and that the low-cost/no-cost energy conservation measures alone can oftentimes result in significant savings as documented in this thesis. However, the software selection process was deemed to be significant as certain software limitations were observed to hinder the obtainment of other desired energy-related data.

The breakdown of this thesis is as follows. Chapter 2 describes the procedures and purposes of the virtual screening process as well as gives an overview of the kWh360 software and other tools related to energy auditing. Chapter 3 describes the methodology of the complete in-depth energy audit process to be performed on the buildings that are selected from the initial virtual screening process with high energy savings potential. Chapter 4 provides an example and the results of an energy audit that was previously performed on a particular group of buildings by utilizing the virtual screening and proceeding with the in-depth energy audit as discussed throughout this thesis. Finally, Chapter 5 provides a conclusion of the results and observations that were made regarding the effectiveness of the implementation of the virtual screening to the existing energy audit methods used today as well as proposes several items of future work that may offer solutions to the various flaws of the virtual screening process and the energy efficiency management software that are used today.

Chapter 2: Virtual Energy Audit Screening

2.1 Purpose of Virtual Screening

A complete energy audit from start to finish can be a very tedious and detailed process that may potentially consume a significant amount of time and resources depending on the size of the building and scope of the project. With a countless number of state-owned facilities (well over 3,000 buildings) in Maryland and finite available staffing, it was important for the S2TS energy audit team to establish some sort of filtering process where buildings with higher energy savings potentials can be isolated from the rest of the buildings and be given priority for performing a complete energy audit. This would then allow for the optimization of their expenditure of time, cost, as well as labor. According to the S2TS Year I results shown in the DGS Annual Report, energy savings for an individual building ranged from 8% to more than 41% (UMD S2TS, 2021). In other words, it is clear that relatively higher energy savings are possible and can benefit from an earlier implementation when energy audits are performed on certain high opportunity buildings. If the buildings with the higher energy savings potentials can be determined, it would be beneficial to perform the in-depth experimental energy audits on those selected buildings before the other ones because this would result in the maximum amount of energy consumption, utility cost, and CO_2 emissions reduction for Maryland state-owned buildings as a whole. This is because the proposed ECMs would generally be implemented in the order of which the complete energy audits were performed. Therefore, proposing ECMs first for buildings with higher energy savings potentials will result in higher actual energy savings in the long term. In order for this type of plan to come into fruition, there would certainly have to be a use of some sort of reliable software tool. This would allow for the analysis of buildings from an energy standpoint only by using an online set of data and without the need of a physical building walkthrough where on-site presence is mandatory. This would then allow for the necessary buildings to be selected for the in-depth experimental energy audits as well as other associated critical decisions to be made with quickness and efficiency.

2.1.1 Annual EUI Benchmark Comparison

For the purposes of gauging as well as comparing the energy efficiencies of buildings, the annual EUI is often used. The annual EUI is calculated by dividing the total annual energy consumption of a building by the total building floor area. The total annual energy consumption should include consumption of all major energy types, including electricity, natural gas, etc. In order to determine if a building has a high energy savings potential, the latest annual EUI of the building is usually compared to a reliable benchmark or average value in respect to the corresponding building type. There are several resources available online to provide these benchmark or average values, and the tools discussed in the following sections include kWh360, the Commercial Building Energy Consumption Survey (CBECS), as well as ENERGY STAR. Although kWh360 is the only tool among these that provides a customized and integrated protocol for automatically determining energy-efficient buildings, all of these tools mentioned can be used for validation purposes to be able to be manually perform the comparisons necessary in order to accurately determine if a certain building is energy-efficient or not by analyzing the annual EUI values. A building that is not energy-efficient is also considered as a building with a high energy savings potential. Therefore, the buildings that are considered as not energy-efficient can be given priority for performing an in-depth experimental energy audit, which is further discussed in Chapter 3 of this thesis.

2.2 kWh360 by Singh360

2.2.1 Introduction to kWh360

kWh360 is a customized cloud-based energy efficiency management software provided by a technology and services company called Singh360, which was founded by Dr. Abtar Singh who is an alumnus of S2TS and graduated from UMD in 1995 with a Ph.D. in Mechanical Engineering. He specializes in HVAC systems and holds a total of 32 patents related to the field (Singh360, 2022). kWh360 is a user-friendly software that allows for the input of key building utility data, calculates comparable energy consumption and cost measures associated with the building on a monthly and annual basis, as well as generates comprehensible tables and graphs associated with the various energy-related data. All this can be done while storing all of the data on a dedicated cloud server. Ultimately, kWh360 can use building utility data in order to automatically determine if the building of concern is energy-efficient or not through its own calculation protocols and methods. This software can be used to provide the functions needed in order to complete the initial virtual screening process for the selection of buildings with high energy savings potentials, and the in-depth experimental energy audits can then be performed on those selected buildings.

2.2.2 Map View

The initial window of the application is shown in Figure 1. This initial window is a map view, which shows building icons placed on a map indicating the location of each building where energy data is readily available. When hovering over a building icon with the mouse cursor, a pop-up window appears on the screen showing the various energy information related to the highlighted building, depending on the energy type that is selected. There are also drop-down menus that a user may use in order to obtain energy data for a specific year or month from a previous time. For electricity, the following data is shown:

- Peak Demand (kW)
- Average Demand (kW)
- Annual Consumption (kWh)
- Annual Utility Cost ($)
- Annual Utility Cost Per Square Foot ($/sq. ft.)
- Average Utility Rate ($/kWh)
- EUI (kWh/sq. ft.)
- Average Outdoor Temperature (˚F)

Peak demand is the largest instance of power usage in a fifteen-minute timeframe (Setra, 2017). Average demand would then be average instance of power usage in a fifteen-minute timeframe for a given period of time. For natural gas, the following data is shown:

- Average Hourly Consumption (therms)
- Annual Consumption (therms)
- Annual Utility Cost ($)
- Annual Consumption Per Square Foot (therms/sq. ft.)
- Annual Utility Cost Per Square Foot ($/sq. ft.)
- Average Utility Rate ($/therm)

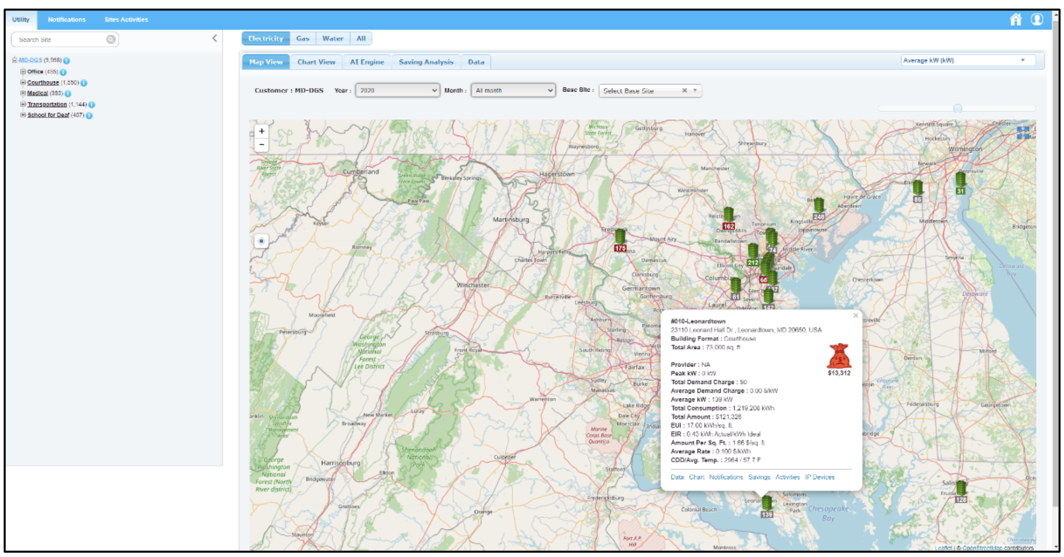


Figure 1: Map View of kWh360 (Singh360, 2022)

On the left panel of the window, there are expandable hierarchy drop-down lists that organize all of the buildings with available energy data into specific user-defined groups. For example, Figure 1 shows all of the Maryland state-owned buildings that are currently being tracked by Maryland DGS. The left panel shows that all of these building are organized into a total of five sections: Office, Courthouse, Medical, Transportation, and School for Deaf. This allows for the ease of browsing for specific buildings a user may be searching for.

2.2.3 Utility Data Input

Data input is the driving force of this software so that the necessary energy measures outputs can be obtained to be able to carry out the initial virtual screening process for the buildings of concern. A building can be created in the software with the respective building characteristics and descriptions. In order to input the utility data for each building, the user must move to the "Data" tab in kWh360. In this tab, kWh360 provides a template CSV file where utility data can be inputted by using the fields shown in the tables below depending on the energy type that is selected. The lists following each tables provide descriptions of each of the fields.

Meter ID	Start Date	End Date	Consumption	Actual Demand	Total Amount	Demand Charge	Unit

Table 1: kWh360 Electricity Data Input Fields

- Meter ID – The identification number associated with the electricity meter or submeter serving the selected building.
- Start Date – The start date of the billing cycle of the electricity bill.
- End Date – The end date of the billing cycle of the electricity bill.
- Consumption – The total consumption of electricity in units of kWh during the billing cycle.
- Actual Demand – The highest demand of electricity in units of kW in a fifteen-minute timeframe during the billing cycle

- Total Amount – The total cost of electricity consumption during the billing cycle.
- Demand Charge – The average cost of electricity in units of dollars per kW during the billing cycle.
- Unit – The measure used to quantify the amount of electricity consumed during the billing cycle.

Account Number	Start Date	End Date	Consumption	Total Amount	Unit

Table 2: kWh360 Natural Gas Data Input Fields

- Account Number – The identification number associated with the natural gas bills for the selected building. This number is provided by the utility company.
- Start Date – The start date of the billing cycle of the natural gas bill.
- End Date – The end date of the billing cycle of the natural gas bill.
- Consumption – The total consumption of natural gas in units of therms during the billing cycle.
- Total Amount – The total cost of natural gas consumption during the billing cycle.
- Unit – The measure used to quantify the amount of natural gas consumed during the billing cycle.

Once all of the data are entered in the fields mentioned for the respective energy type, the user may upload the CSV file, and the corresponding utility data will then populate in the software window accordingly and in chronological order.

2.2.4 Energy Measures Output

Once all of the data input fields have been entered and uploaded to kWh360, the software automatically performs the computations necessary to provide the related energy measures output that the user can finally use in order to compare the energy efficiencies for all of the users' buildings. These energy measures also vary depending on the energy type that is selected. The tables below show the energy measures output associated with each energy type. The lists following each table provide descriptions for each of the energy measures.

Month	Average Consumption	Average Utility Rate	EUI	EIR	Average Utility Cost Per Square Foot	Average Demand Charge

Table 3: kWh360 Electricity Energy Measures Output

- Month – The month associated with the electricity consumption data entered by the user.
- Average Consumption – The average usage of electricity in units of kW in a fifteen-minute timeframe during the month shown.
- Average Utility Rate – The average cost per unit of electricity consumption in units of dollars per kWh.
- EUI – The energy usage index calculated by dividing the total annual building consumption by the total building floor area.
- EIR – A unitless measure used to determine the efficiency of a building that uses refrigeration systems. This is also known as the inverse of the coefficient of performance.
- Average Utility Cost Per Square Foot – The average cost of electricity consumption per square foot of the building floor area.

- Average Demand Charge – The average cost of electricity in units of dollars per kW during the month shown.

Month	Average Hourly Consumption	Average Utility Rate	Average Consumption Per Square Foot	Average Utility Cost Per Square Foot

Table 4: kWh360 Natural Gas Energy Measures Output

- Month – The month associated with the natural gas consumption data entered by the user.
- Average Hourly Consumption – The average consumption of natural gas for a given hour during the month shown.
- Average Utility Rate – The average cost per unit of natural gas consumption in units of dollars per therm.
- Average Consumption Per Square Foot – The average consumption of natural gas per square foot of the building floor area.
- Average Utility Cost Per Square Foot – The average cost of natural gas consumption per square foot of the building floor area.

All of these various energy measures can be used to perform some form of comparison regarding energy efficiencies for different buildings. As previously mentioned, the most important and useful energy measure is usually proven to be the annual EUI. The annual EUI alone can be used to determine if a specific building is energy-efficient or not by comparing it to a reliable benchmark or average value associated with the matching building characteristics, and this is further discussed in Section 2.3 of this thesis. If a building is considered as not energy-efficient, this also means that the building has a high energy savings potential. Therefore, these particular buildings can then be given priority for performing an in-depth experimental energy audit, which is further discussed in Chapter 3 of this thesis.

2.2.5 Determination of Energy-Efficient Buildings

Although annual EUI benchmarking discussed in the previous section as well as in Section 2.3 is a valid method for determining if a certain building is energy-efficient or not, kWh360 uses its own customized calculations protocols and methods to automatically make this determination for the user, relieving the user of this burden. As shown in Figure 2, the "AI Engine" tab of the tool shows a chart for the relationship between EUI and Dollar Use Intensity, which is also known as the annual utility cost per square foot. Each dot on the chart represents a building that was created with respective utility data entered by the user. The vertical blue line and horizontal green line represents averages of each of the axes for all the buildings stored in the user's cloud, and these averages determine the thresholds used to decide whether a building is considered energy-efficient or not. These lines create four different quadrants on the graph, and all the dots that are in the top-right quadrant of the chart represent buildings that are considered as not energy-efficient and have high energy savings potential. It is important to note that the EUI and dollars per square foot values are calculated for only electricity because the software considers the consumption and cost of gas and water as insignificant to that of electricity and not affecting the determination of energy-efficient buildings.

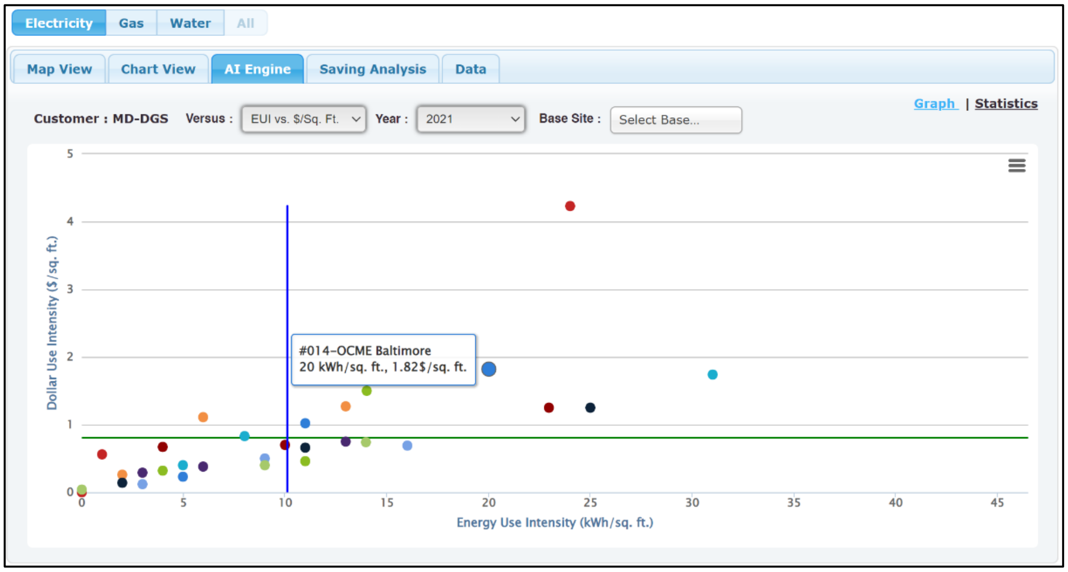
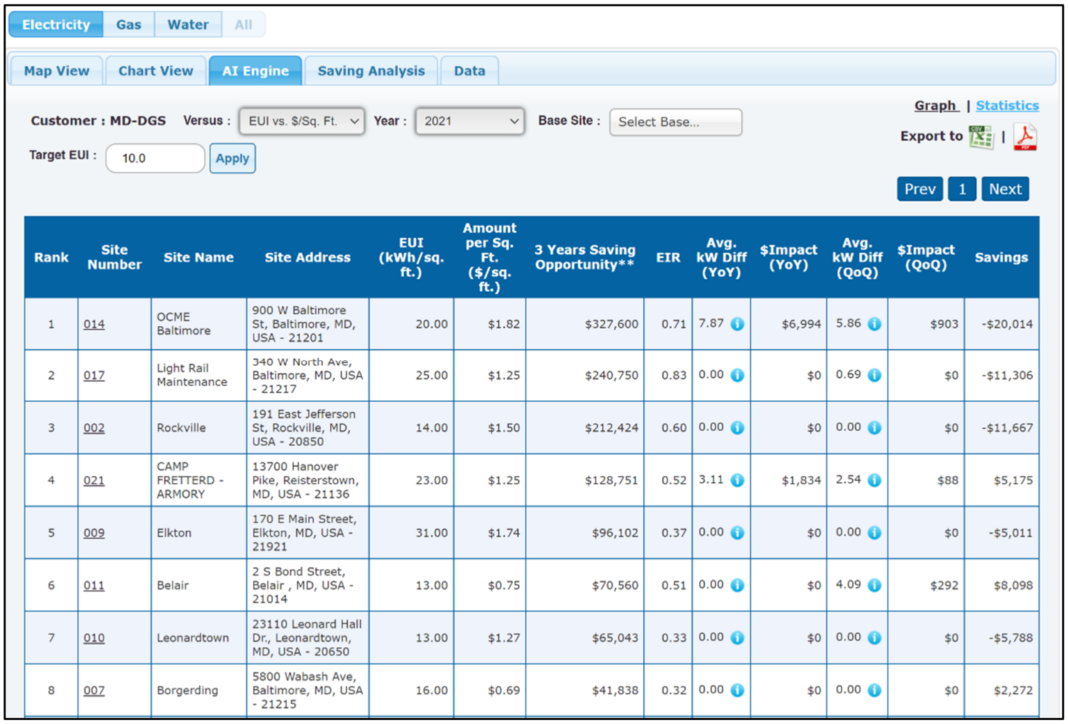


Figure 2: kWh360 EUI vs. Dollar Use Intensity Chart

Ultimately, the table shown in Figure 3 will be the table that the user will use to make the final decision on what buildings will be given priority for the in-depth experimental energy audit process. After the user enters a target EUI, which is automatically set as the average EUI of all the users' buildings stored in the software, kWh360 will calculate the 3-year savings opportunity for each building based on their latest recorded annual EUI. Then, all the buildings will be ranked with the highest rank showing the highest 3-year savings opportunity. The building that is first in the ranking can be given the highest priority for performing a complete energy audit.



Rank	Site Number	Site Name	Site Address	EUI (kWh/sq. ft.)	Amount per Sq. Ft. ($/sq. ft.)	3 Years Saving Opportunity**	EIR	Avg. kW Diff (YoY)	$Impact (YoY)	Avg. kW Diff (QoQ)	$Impact (QoQ)	Savings
1	014	OCME Baltimore	900 W Baltimore St, Baltimore, MD, USA - 21201	20.00	$1.82	$327,600	0.71	7.87	$6,994	5.86	$903	-$20,014
2	017	Light Rail Maintenance	340 W North Ave, Baltimore, MD, USA - 21217	25.00	$1.25	$240,750	0.83	0.00	$0	0.69	$0	-$11,306
3	002	Rockville	191 East Jefferson St, Rockville, MD, USA - 20850	14.00	$1.50	$212,424	0.60	0.00	$0	0.00	$0	-$11,667
4	021	CAMP FRETTERD - ARMORY	13700 Hanover Pike, Reisterstown, MD, USA - 21136	23.00	$1.25	$128,751	0.52	3.11	$1,834	2.54	$88	$5,175
5	009	Elkton	170 E Main Street, Elkton, MD, USA - 21921	31.00	$1.74	$96,102	0.37	0.00	$0	0.00	$0	-$5,011
6	011	Belair	2 S Bond Street, Belair , MD, USA - 21014	13.00	$0.75	$70,560	0.51	0.00	$0	4.09	$292	$8,098
7	010	Leonardtown	23110 Leonard Hall Dr., Leonardtown, MD, USA - 20650	13.00	$1.27	$65,043	0.33	0.00	$0	0.00	$0	-$5,788
8	007	Borgerding	5800 Wabash Ave, Baltimore, MD, USA - 21215	16.00	$0.69	$41,838	0.32	0.00	$0	0.00	$0	$2,272

Figure 3: kWh360 AI Engine Table

As the case with many existing energy efficiency management softwares, kWh360 does come with its own disadvantages that may prevent the user from obtaining other desired energy-related data. As previously mentioned, the calculation of the total EUI with respect to all major energy types is not yet fully integrated into the software. Currently, the EUI is only calculated for electricity. There is a separate energy consumption per square foot calculation made for natural gas, but the user must manually calculate the total EUI of the building by performing the necessary unit conversions and adding the EUIs for each major fuel type together. Also, it is worth emphasizing that the software does not compare the calculated EUIs to other benchmark or average values and that it only compares EUIs with buildings within the user's cloud. The software does allow the user to categorize the buildings into user-defined building groups so that the building EUIs can be compared to the average EUI for each of those building categories, but the comparisons are not automatically made with respect to benchmark or average values of the national or global scale, which could potentially be useful to get a perspective on how the building is performing compared to other buildings in the U.S. or around the world. Furthermore, the average EUI calculated by the software may not be completely reliable due to potential outliers such as buildings that show an EUI of zero as a result of incomplete or unavailable utility data for those buildings. This would affect the energy and utility cost savings calculations because these are based on the average EUI that is calculated by the software and set as the target EUI.

Despite all these limitations, kWh360 can reliably be used for the ranking capabilities that it provides for the energy savings potentials of buildings since the variation of the target EUI value will not affect the rankings. It is also important to reiterate that a complete energy audit cannot be performed with a virtual screening alone. Flaws in the building systems will not be able to be accurately determined because these can only be confirmed by successfully performing a physical building walkthrough. As a result, an accurate baseline energy model cannot be generated, and the necessary ECMs for the building cannot be determined as well. The ideal use of kWh360 in an energy audit process would be for its capabilities of ranking groups of buildings to initially determine which buildings should be given priority for performing a full energy audit in order to optimize the use of time and resources throughout the entire energy audit process.

2.2.6 Generation of Chart

kWh360 also be used to generate a wide variety of tables and graphs, which can be used to better visualize a set of input or output data as well as to determine any noteworthy trends associated with them. These tables and graphs can be generated by moving to the "Chart View" tab in the software. In this tab, a drop-down menu may be used to select an energy measure output discussed in section 2.2.4 that the user would like to analyze. Once this is selected, the user may then specify the year they would like to see the monthly data for, or they may also select the "Year Wise" option to see the overall yearly trend within the chronological limits of the available utility data that have been entered and stored for the selected building. Finally, the chart type can be selected among three options: line, series, and bar. The following figures show various examples of charts that can be generated by using the kWh360 software.

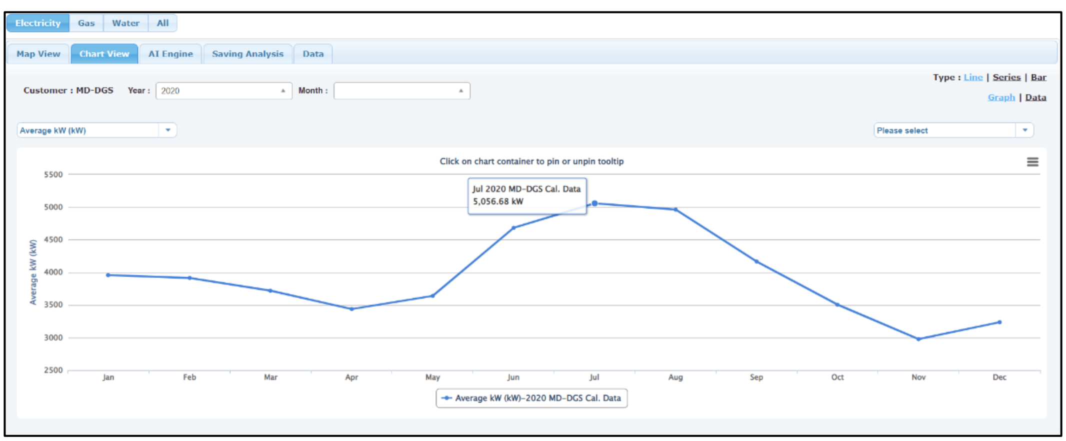


Figure 4: Line Graph of the 2020 Average Consumption of Electricity by Month (Singh360, 2022)

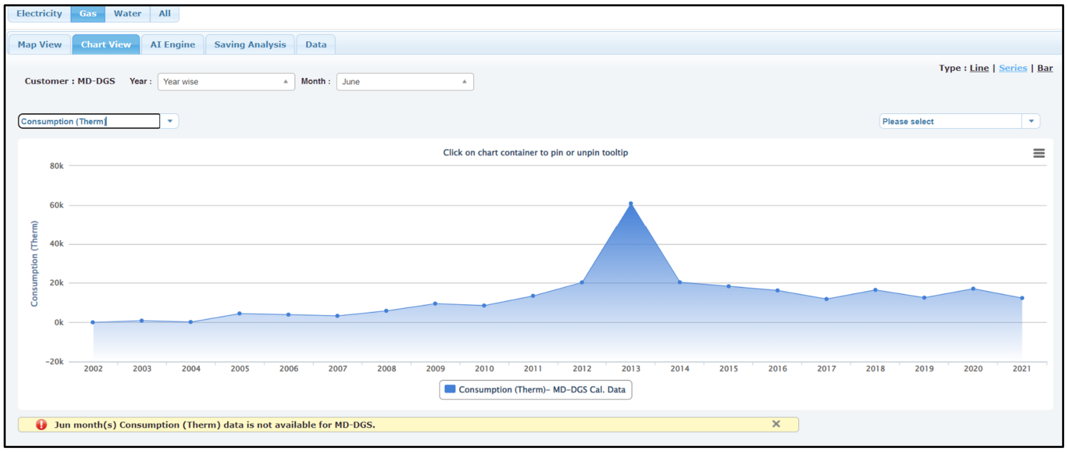


Figure 5: Series Graph of the Total Consumption of Natural Gas for the Month of June by Year (Singh360, 2022)

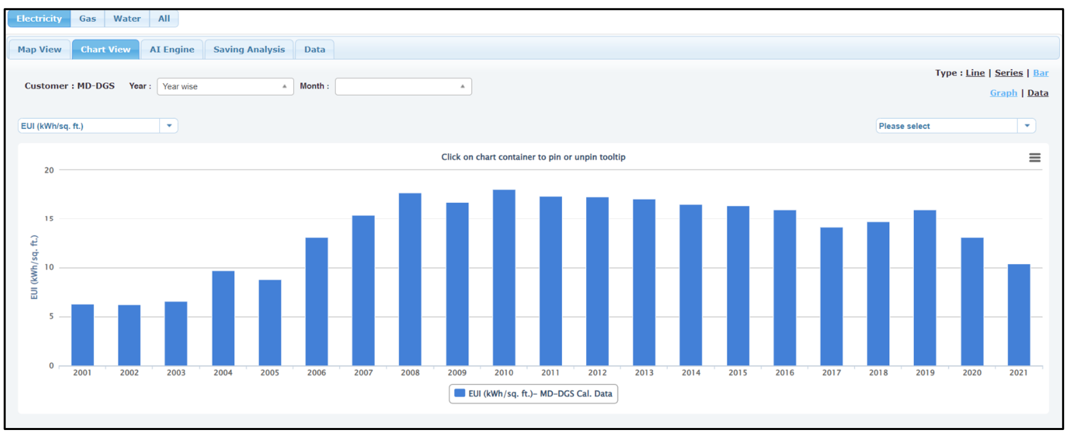


Figure 6: Bar Graph of the Electricity Consumption EUI by Year (Singh360, 2022)

2.3 Annual EUI Benchmarking Tools

Although kWh360 by Singh360 uses its own methodology on ranking buildings based on their potential for energy savings as discussed in Section 2.2.5, annual EUI benchmarking can also be used to manually determine these rankings by using the right and reliable sources. Annual EUI benchmarking is useful in that it can be used to validate the results of energy efficiency management softwares, such as kWh360. In this section, the sources of benchmark values that are discussed include CBECS and ENERGY STAR.

2.3.1 Commercial Building Energy Consumption Survey (CBECS)

CBECS is a database created by EIA that contains a vast amount and a wide variety of building characteristics and energy consumption data for over 5000 commercial buildings in the US. As shown in Table 5, these data are organized into several categories that were selected by the EIA. The data is then further organized into various sections where additional comparisons can be made based on a specific building attribute such as principal building activity, year of construction, census region, number of floors, and many more. In order to help visualize how this is exactly done, the following table and figure show how these data are organized into categories as well as an example of a specific data table in the CBECS database.

Building Characteristics	**Consumption & Expenditures**
Geographic Region	Major Fuels
Size and Age	Electricity
Building Activity	Natural Gas
Employment and Occupancy	Fuel Oil
Energy Sources and End Uses	District Heat
Floorspace Heated, Cooled, and Lit	End-Use Consumption
End-Use Equipment	

Table 5: Category Organization for CBECS Database

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COMMERCIAL BUILDINGS ENERGY CONSUMPTION SURVEY (CBECS)

OVERVIEW | DATA | ANALYSIS & PROJECTIONS | GLOSSARY › | FAQS ›

‹ BACK TO ALL 2012 CBECS TABLES

Table C1. Total energy consumption by major fuel, 2012

Released: May 2016

	All buildings		Total energy consumption (trillion Btu)					
				Electricity				
	Number of buildings (thousand)	Total floorspace (million square feet)	Sum of major fuels	Primary	Site	Natural gas	Fuel oil	District heat
All buildings	5,557	87,093	6,963	12,934	4,241	2,248	134	341
Building floorspace (square feet)								
1,001 to 5,000	2,777	8,041	723	1,357	445	256	21	Q
5,001 to 10,000	1,229	8,900	646	1,179	386	248	10	Q
10,001 to 25,000	884	14,105	876	1,655	543	304	20	Q
25,001 to 50,000	332	11,917	823	1,549	508	284	14	17
50,001 to 100,000	199	13,918	1,067	1,996	654	338	23	52
100,001 to 200,000	90	12,415	1,035	1,974	647	290	20	77
200,001 to 500,000	38	10,724	1,026	1,876	615	310	14	88
Over 500,000	8	7,074	767	1,349	442	219	12	94
Principal building activity								
Education	389	12,239	842	1,396	458	291	28	65
Food sales	177	1,252	262	634	208	53	Q	N
Food service	380	1,819	514	850	279	227	Q	Q
Health care	157	4,155	718	1,114	365	265	20	68
Inpatient	10	2,374	549	766	251	219	16	62
Outpatient	147	1,781	169	348	114	46	Q	Q
Lodging	158	5,826	564	928	304	221	8	31
Mercantile	602	11,330	1,008	2,151	705	291	9	Q
Retail (other than mall)	438	5,439	364	857	281	74	7	Q
Enclosed and strip malls	164	5,890	644	1,293	424	217	Q	Q
Office	1,012	15,952	1,241	2,637	865	282	18	76
Public assembly	352	5,559	480	837	275	135	7	64
Public order and safety	84	1,440	133	223	73	41	2	Q
Religious worship	412	4,557	173	247	81	87	5	N
Service	619	4,630	272	389	127	122	16	Q
Warehouse and storage	796	13,077	429	866	284	139	5	Q
Other	125	2,002	286	581	191	81	10	Q
Vacant	296	3,256	41	80	26	13	Q	Q

Figure 7: CBECS Table C1 – Total Energy Consumption by Major Fuel, 2012 (EIA, 2012)

Out of all of the countless data available on CBECS, the one set of data that should be considered paramount from an energy efficiency comparison standpoint is Table C1, which is the table for the total energy consumption data by major fuel. In this table, the energy consumption data is broken down based on energy type. There is also a section for principal building activity, which can be later used to gauge the EUI of a building in respect to that building's classification. Most importantly, there are columns in this table that show the combined total energy consumption as well as the combined total floor area for all of the buildings surveyed by EIA. The combined energy consumption can be divided by the combined floor area in order to determine the average annual EUI for a specific building type. Therefore, the following procedure describes how exactly a benchmark EUI comparison can be done for a specific building with the use of the CBECS data.

1. Determine the latest annual EUI for the building of concern.
2. Refer to Table C1 in the CBECS Database.
3. In the "Principal Building Activity" section, locate the building type that best describes and classifies the building of concern.
4. In the row for the selected building type, locate the combined total energy consumption as well as the combined total floor area for all of the buildings surveyed by EIA for that specific building type.
5. Divide the located combined energy consumption by the combined floor area in order to determine the average annual EUI for the selected building type.
6. If the building's latest annual EUI is higher than the calculated average annual EUI, consider the building as not energy-efficient.

7. If the building's latest annual EUI is lower than the calculated average annual EUI, consider the building as energy-efficient.

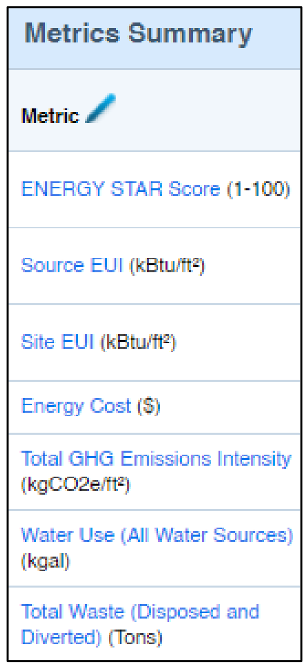
Therefore, CBECS is a tool that can be used for reliable annual EUI benchmarking and can also be used to determine buildings that are considered as not energy-efficient. Priority can be given to those buildings to perform in-depth experimental energy audits, which will be further discussed in Chapter 3.

2.3.2 ENERGY STAR

ENERGY STAR is a program run by the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) that promotes energy efficiency (EPA, DOE). The program provides information on the energy consumption of products and devices of 75 different categories by using different standardized methods. Products that are evaluated as energy-efficient based on these standardized methods receive labels that prove their ENERGY STAR certification.

ENERGY STAR has a dedicated standardized method for determining the relative energy efficiency of commercial buildings in the US. EPA has provided a tool called ENERGY STAR Portfolio Manager where utility and building characteristics data can be entered in order to output various energy measures, similar to how kWh360 works. Because the building characteristics data is also entered during the input phase, the resulting energy measures are also associated with the relevant building type, and comparisons can be made on a national scale with respect to an average building in the US. Therefore, this tool can also be used for the purposes of reliable building energy efficiency benchmark comparisons.

Figure 8 shows the various default energy measures that ENERGY STAR Portfolio Manager can provide. However, these output windows can also be fully customized in order to display different metrics from a wide variety and a countless number of options provided by ENERGY STAR.



Metrics Summary
Metric
ENERGY STAR Score (1-100)
Source EUI (kBtu/ft²)
Site EUI (kBtu/ft²)
Energy Cost ($)
Total GHG Emissions Intensity (kgCO2e/ft²)
Water Use (All Water Sources) (kgal)
Total Waste (Disposed and Diverted) (Tons)

Figure 8: ENERGY STAR Portfolio Manager Default Energy Measures Output

Similar to kWh360, ENERGY STAR Portfolio Manager can provide the typical energy measures, such as annual EUI, total annual consumption, and even total greenhouse gas emissions intensity. However, this tool also provides an output known as the ENERGY STAR score, which provides a comprehensive snapshot of the building's energy performance, taking into account the building's physical assets, operations, and even occupant behavior (EPA, DOE). In other words, the ENERGY STAR score can be used to determine the building's overall relative energy efficiency. The ENERGY STAR score ranges from 1 to 100, where 1 is the lowest possible score and 100 is highest possible score. A score of 50 is considered the medium or the average. Lower than this score is considered worse than the average, and higher than this score is considered higher than the average. By using ENERGY STAR as a benchmarking tool for building energy efficiency, the building of concern can be considered as energy-efficient if the ENERGY STAR score for the building is greater than 50. However, if the ENERGY STAR score for the building less than 50, the building should be considered as not energy-efficient.

Therefore, ENERGY STAR can also be used to determine if a building is energy-efficient or not. Once this is done, the buildings that are not energy-efficient can be given priority for performing in-depth experimental energy audits, which will be further discussed in Chapter 3 of this thesis.

Chapter 3: In-Depth Experimental Energy Audit Methodology

Once the buildings that are not energy-efficient and have high energy savings potentials are determined, in-depth experimental energy audits can be performed on those selected buildings. For a successful energy audit, careful and detailed organization is necessary in order minimize human error, which can occur due to the large scope of the analysis of a countless number of parameters. Figure 9 illustrates a flow chart of the in-depth experimental energy audit process. This flow chart has routinely been followed S2TS throughout the years, and it proved to be greatly effective in performing an energy audit for any type of building or project. Each energy audit project can be divided into three phases: Building Comprehension, Energy Model Development, and Energy Conservation Measure Analysis. The following sections of this chapter discuss each phase in detail.

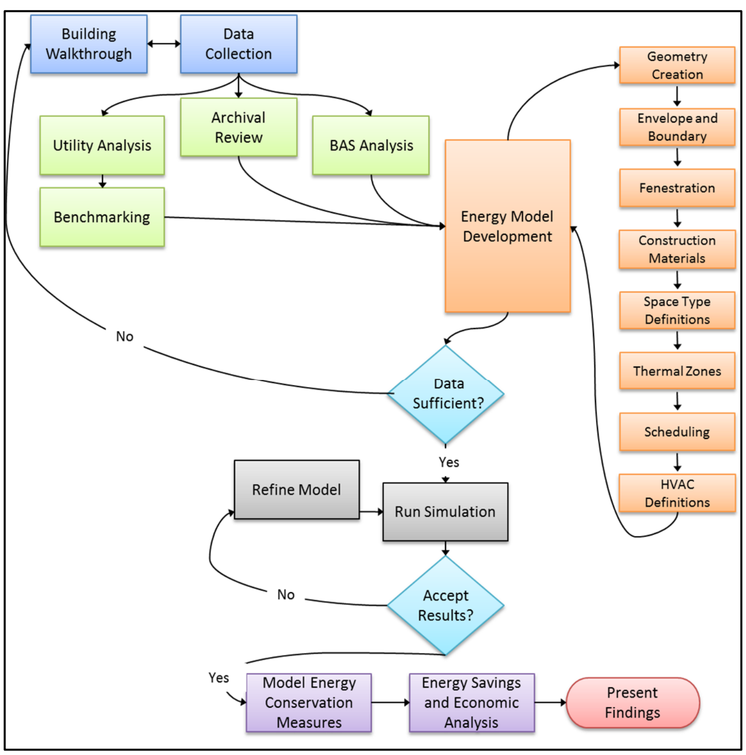


Figure 9: In-Depth Experimental Energy Audit Flow Chart (Levy, 2014)

3.1 Building Comprehension

The initial step of an energy audit would be the building comprehension process. During this process, the process of data collection and analysis is performed in 4 steps: Utility Analysis, Building Walkthrough, Archival Review, and Building Automation System (BAS) Monitoring.

3.1.1 Utility Analysis

The first objective during the building comprehension phase is to understand the buildings' energy consumption patterns through the analysis of the building's existing utility data. Once notable patterns and characteristics of a building energy consumption are known, they can be compared to respective benchmark data to assess a building's relative performance and to prepare for potential ECMs to propose in the later steps of the energy audit process. For example, energy consumption for a building can be seen as notably high for a specific season of the year when compared to the expected energy consumption trend for a building with the same building characteristics. By discovering these aspects of concern in the early stages of the energy audit, this will allow for issues associated with the building to be found more easily throughout the entire energy audit process, and the ECMs to serve as the solutions for those issues can be rightfully determined and proposed later on. Chapter 4 discusses an example of a building where an energy audit was performed by S2TS, and the utility analysis process is shown for those buildings.

3.1.2 Building Walkthrough

A building walkthrough is also performed during the initial stages of the energy audit and may be performed multiple times in order to obtain all of the necessary information to complete the building comprehension phase. The building walkthrough is ideally conducted with a facility manager, and the goal is to provide a first-hand examination of all building spaces and equipment as well as establish relationships with those involved in the buildings' operations. A building walkthrough is crucial in that it often reveals operational issues and help elucidate building use patterns that cannot be found elsewhere. It also reveals data including the integrity of the mechanical systems, building envelopes, construction materials, thermal zoning, temperature controls, temperature setpoints, building schedules, system schedules, as well as occupant behavior.

3.1.3 Archival Review

Before an energy model is developed for the building, an archival review of all of the available building documentation is conducted alongside the findings from the utility analysis that was previously performed. The referenced documents may include but are not limited to architectural drawings, mechanical drawings, electrical drawings, and plumbing drawings associated with the building. These documents are usually provided by the facility manager in printed or PDF format. For information or data that are unavailable or inaccessible, educated assumptions must be made after due diligence of trying to locate them. Additional conversations with the facility manager may assist in receiving confirmation regarding the unavailable data. Due to the possibility of multiple renovations that may have occurred for a building, the building documentation have to be carefully examined in order to gain a complete understanding of the building's present state and condition.

3.1.4 Building Automation System (BAS) Monitoring

In the final step of the building comprehension process, the building's BAS is sought out and analyzed. A BAS is a central system that provides controls to various individual building systems such as mechanical systems, electrical systems, security systems, shading, and lighting. It is important to note that not all buildings may have a BAS. This is especially the case for buildings that are older because the BAS technology may not have been easily accessible during the time the building was first constructed. Data provided by the BAS can provide crucial insights to numerous aspects of the buildings' functions, and the most notable would be related to the operation of the mechanical systems of the building. The BAS can provide current as well as historical trend data of air temperatures for AHUs, room temperatures of building spaces, building schedules, system schedules, instances of equipment failure, and much more.

3.2 Energy Model Development

The energy model development process is carried out in four steps: Energy Modeling Software Selection, Baseline Model Development, Baseline Model Calibration, and Results Validation.

3.2.1 Energy Modeling Software Selection

There are currently various softwares to choose from for energy modeling. In the previous years, the S2TS energy audit team had performed most of their energy modeling in eQuest, which is a free energy modeling software that uses the same software engine as DOE-2 (DOE2, 2009). eQuest is regarded for simple user interfaces and combines a simplified building creation wizard, an energy conservation measure (ECM) wizard, as well as graphical reporting in order to provide all of the functions necessary to successfully create a working energy model. However, in 2020, the S2TS energy audit team transitioned into using a more advanced energy modeling software called Trane Trace 3D Plus (UMD S2TS, 2020), which is similar to eQuest but has more integrated features and capabilities useful for more in-depth energy modeling. Trane Trace 3D Plus allows for more input of data and provides more energy measures as well as associated graphical outputs when compared to eQuest. This thesis describes the energy modeling process as well as discusses examples of in-depth experimental energy audits performed on buildings with the use of Trane Trace 3D Plus. However, both softwares can allow for qualifications for commercial building tax reductions and have been widely used in comprehensive building energy analysis for nearly 50 years (DOE). In particular, Trane Trace 3D Plus provide capabilities of 3D building geometry generation as well as access to editable project templates with standardized values for key parameters such as load densities and ventilation rates. In addition to these, additional features and capabilities of Trane Trace 3D Plus have been listed below.

- Select building location associated with integrated ASHRAE climactic weather design data for accurate design load calculations.
- Accurately sketch building geometries by importing correctly scaled floor plans in PDF format and tracing over them.
- Add adjacent building geometries to the building sketch in order to account for shading.
- Specifically define the construction, airflows, and loads for each room.
- Create zones to group rooms that are similar to each other.
- Add renewable energy sources such as solar PV and wind power to be included in the total energy generation calculations.
- Select and fully customize HVAC systems to serve each defined zone.
- Run energy simulations to calculate total and monthly building energy consumption and cost.
- Obtain a vast list of simulation outputs, including but are not limited to HVAC load profile, power generation, power consumption, greenhouse gas emissions, life cycle cost analysis, and many more.

3.2.2 Baseline Model Development

The early stages of energy model development begin after the completing the utility analysis and building walkthrough as well as once the archival review begins. Figure 10 describes the general flow of data in energy models. Building geometry, weather data, HVAC system data, internal loads, operating schedules, and simulation specific parameters are inputted in the simulation engine, which then simulates the energy consumption for the building. Figure 11 also illustrates a preferential order of operations in energy model development and the associated archival review documentation associated with each step in the model development process (Savage, 2017).

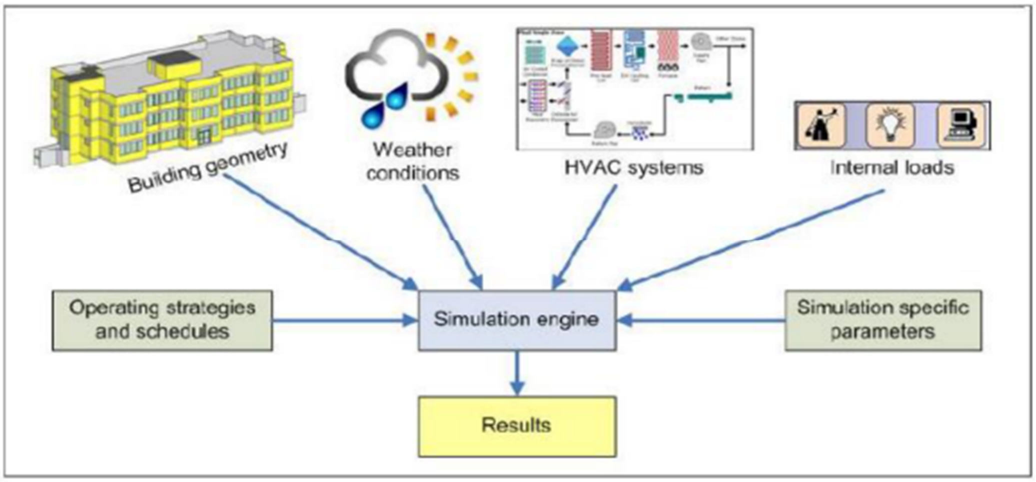


Figure 10: General Data Flow of Building Energy Modeling Software (Savage, 2017)

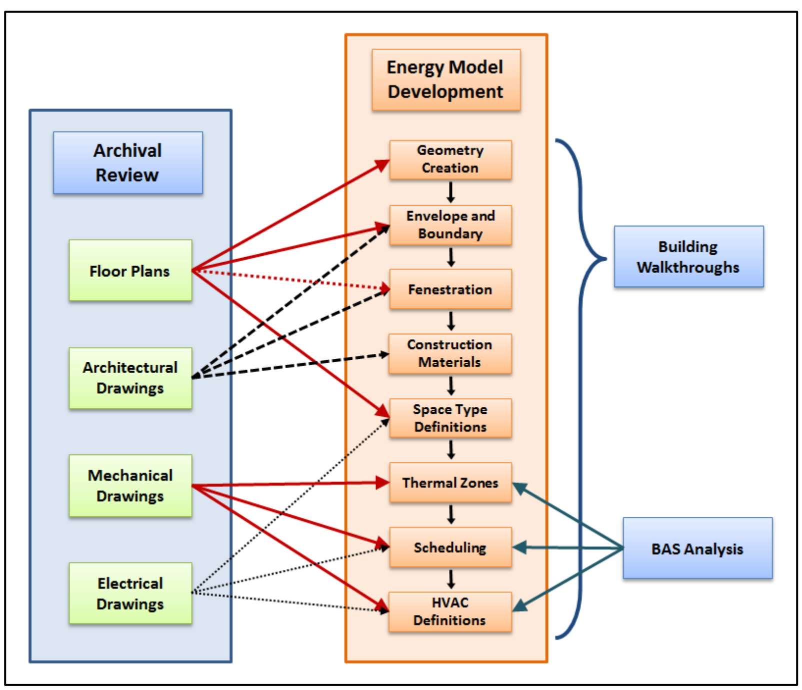


Figure 11: Energy Model Development Flow and Associated Archival Documentation (Savage, 2017)

For the baseline energy modeling process, the physical structure of the building is first developed in Trane Trace 3D Plus. Initially, PDF images of the architectural plans are imported into the software to generate the initial building geometry. Floor dimensions are then calculated by applying proper dimensional scaling based on the documented reference scale. Then, the required zones are modeled into the floor layout, and the subsequent HVAC systems are designed to be selected for the respective zones. The required model information such as building envelope construction are derived from the building plans as well as the data gathered during the building walkthrough. Certain informed assumptions are made for the unavailable data through physical observations, building plan analyses, and discussions with the facility personnel. All of the spaces in each of the floors of the building are modeled and zoned in order to make the model as accurate as possible, and the specific fenestration details such as doors and windows are also implemented. Figure 12 shows an example of a 3-D representation of a building model as rendered in Trane Trace 3D Plus.

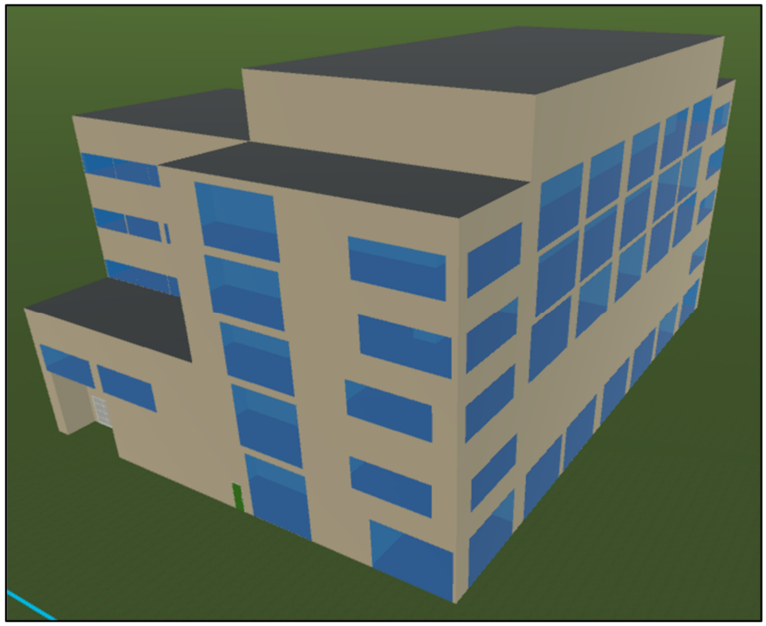


Figure 12: Example of Building Geometry Rendered in Trane Trace 3D Plus

After the building geometry is generated for the baseline energy model, thermal zones need to be specified. Each thermal zone represents a group of rooms served by an AHU or another HVAC system. Figure 13 illustrates the method by which a thermal zone layout was created. Each zone is provided with unique air terminal unit specifications, exhaust capacities, and thermostats derived from the original mechanical drawings. Unconditioned thermal zones are also considered for spaces, such as stairways, that are assumed as insignificant compared to the model as a whole in order to increase efficiency and create ease of modeling.

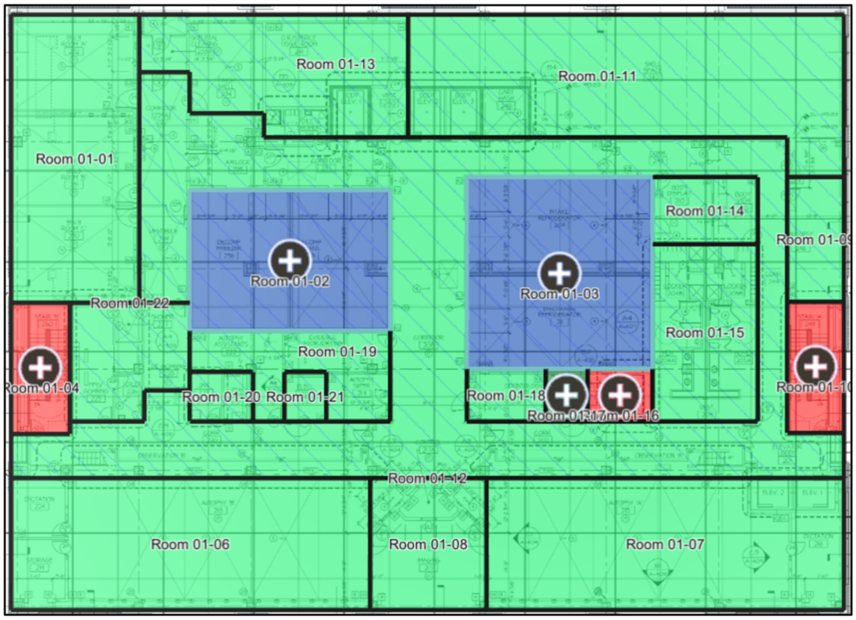


Figure 13: Example of Thermal Zones Assigned to an Energy Model

Finally, the lighting loads, plug loads, and occupancy loads are defined for each room, and these definitions are developed through the process of building comprehension. Trane Trace 3D Plus has several modes for data entry, including ones for building envelopes, boundary conditions, fenestrations, construction materials as well as for space type definitions, plant loops, and HVAC equipment types, and all of these entered into the software. The occupancy, equipment, lighting, and temperature set-point schedules are implemented as well.

3.2.3 Baseline Model Calibration and Validation

Calibrating the baseline energy model to ensure that the simulated energy consumption data closely matches with the actual building energy consumption data is crucial because this will allow for energy savings associated with the ECMs proposed and implemented for the project to be accurately predicted. As discussed earlier, the main energy commodities include electricity and natural gas. The existing utility data need to be compared to the energy consumption data shown in the Trane Trace 3D Plus simulation results. ASHRAE Guideline 14-2002 state baseline model calibration recommendations with a deviation of up to 15% when compared to the actual building data (ASHRAE, 2002). If the baseline model energy consumption data is found to not be calibrated to the existing utility data, further analysis and troubleshooting of the baseline energy model is required, and the changes needed in order to ensure that the baseline energy model closely resembles the actual building will have to be determined. Once the baseline energy model's simulated energy consumption data has been validated to be the calibrated to the existing utility data, the baseline energy model can be considered as suitable to use for the energy auditing process. The following figures show the examples of a baseline energy model's monthly energy consumption as compared to the building's actual monthly energy consumption data for both electricity and natural gas.

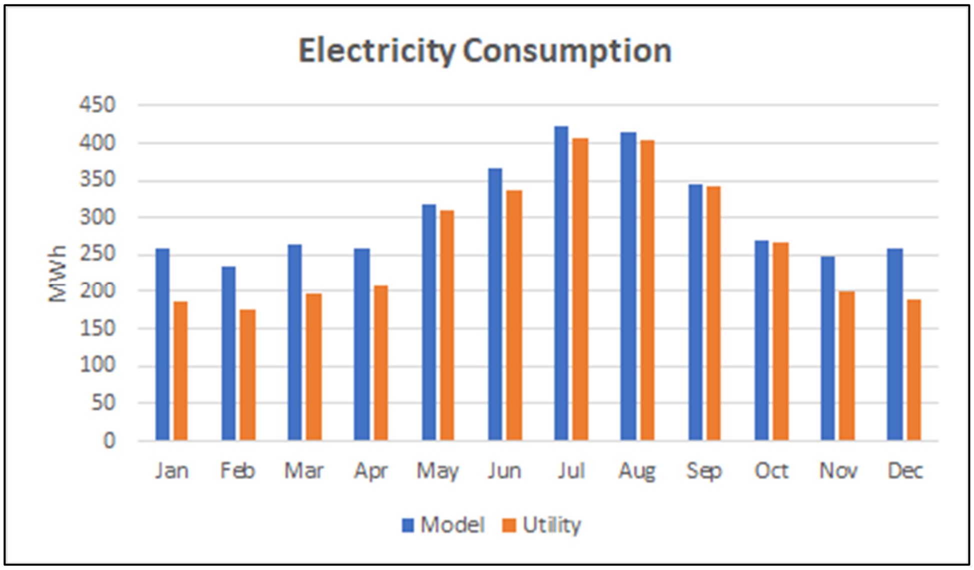


Figure 14: Example of Monthly Electricity Consumption Comparison

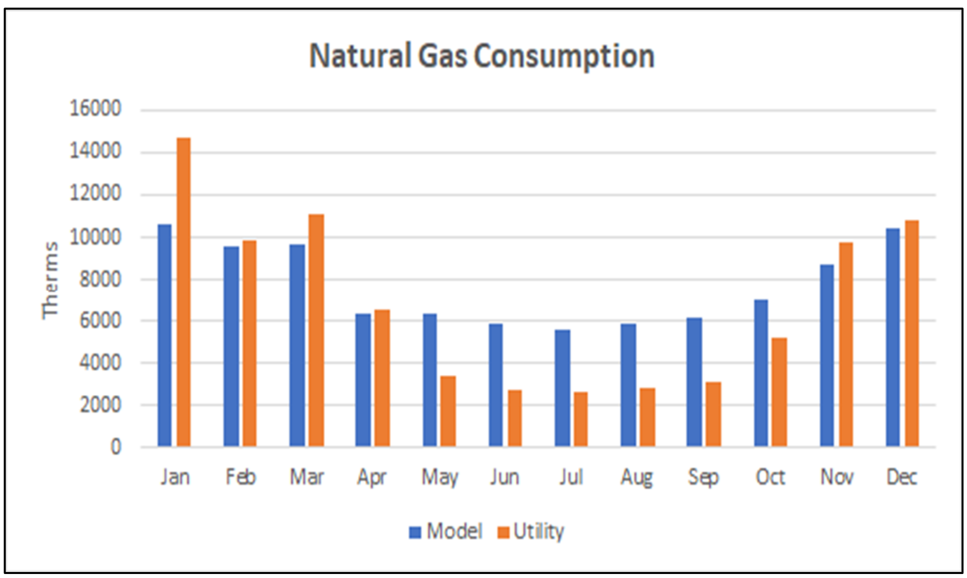


Figure 15: Example of Monthly Natural Gas Consumption Comparison

3.3 Energy Conservation Measures Analysis

The ECMs are selected primarily through data obtained during the building comprehension phase as well as referring to the relevant literature. For example, the ASHRAE Standard 90.1-2019: Energy Standard for Buildings Except Low-Rise Residential Buildings provides full-scope strategies and technical guidance for achieving at least 30% savings in building energy consumption (ASHRAE, ASRHAE Standard 90.1-2019 Energy Standard for Buildings Except Low-Rise Residential Buildings, I-P Edition, 2019). ASHRAE also provides registrants with function-specific advanced energy design guides for achieving additional energy savings up to 50% (ASHRAE, 2017). Once a group of potential ECMs are selected, these ECMs are tested to see if they would result in a sensible amount of energy savings when implemented. To do this, copies of the calibrated baseline energy models are created in the energy modeling software, and the parameters associated with a proposed ECM are changed to the optimal values. The altered energy model is then simulated to see what would result from the change in terms of energy consumption. This process is done for each proposed ECM, and the resulting energy consumption as well as energy savings in respect to the baseline model are recorded and prepared to be included in the energy audit report for the building. Typically, the resulting combined energy consumption and energy savings related to implementation of all of the proposed ECMs simultaneously is also included in the energy audit report.

Chapter 4: Example of a Hybrid Energy Audit Utilizing Virtual Screening and Detailed Experimental Audit

In this chapter, the methodology of the energy audit that was performed by the S2TS energy audit team for the Frederick Campus of the Maryland School for the Deaf (MSD) will be discussed in correspondence to the previous chapters of this thesis. In 2021, there was a total of 10 out of 16 buildings from this campus assigned for energy auditing as shown in Figure 16. Due to the limits of available time, resources, and staffing, it was essential to formulate a methodology for the filtering of buildings in need of priority for energy auditing. Therefore, the virtual screening process in combination with the in-depth experimental energy audit process as discussed in this thesis was tested for this group of buildings, and the effectiveness of the virtual screening as well as the results of the energy audit are also shown in the following sections.

4.1 Virtual Screening with kWh360

kWh360 was used as the software for the virtual screening process of the buildings mentioned, and Figure 16 shows the list of the buildings from MSD that were created in the software with the utility data entered for each building.

Figure 16: List of Buildings for the MSD Frederick Campus (Singh360, 2022)

Once the input of the MSD Frederick Campus buildings was complete, the 2020 EUI versus dollar use intensity chart was generated from the "AI Engine" tab of kWh360 as shown in Figure 17. In this chart, there were two dots shown in the top-right quadrant of the chart, indicating that there were two buildings that were considered as not energy-efficient according to the standards of kWh360. The dot that was furthest from the intersection of the two lines was the indication for the Veditz building. Information was provided by the facility manager that this particular building would undergo renovations in the near future, so there was not a need to carry out a complete energy audit for that building. The other dot on the top-right quadrant of the chart was the indication for the Kent McCanner Elementary School Building, and this building was shown by default to be the building with the highest priority for an in-depth experimental energy audit due to its location of the EUI versus dollar use intensity chart relative to the other dots on the chart.

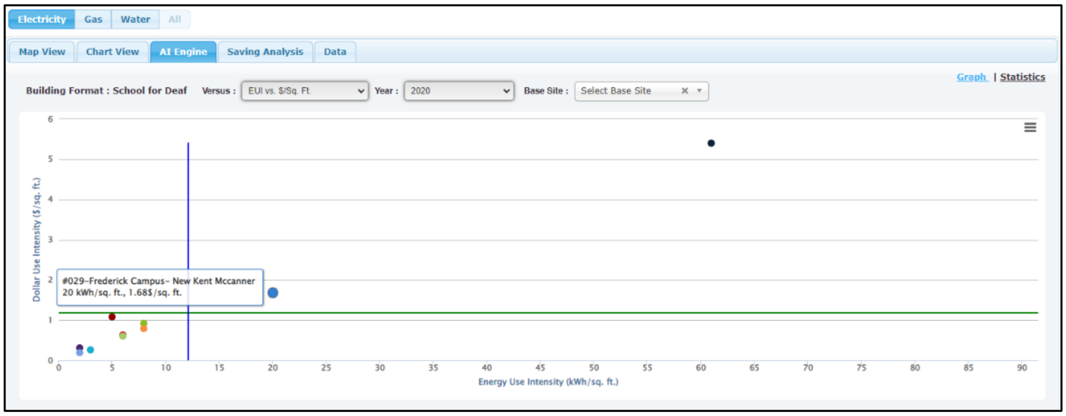
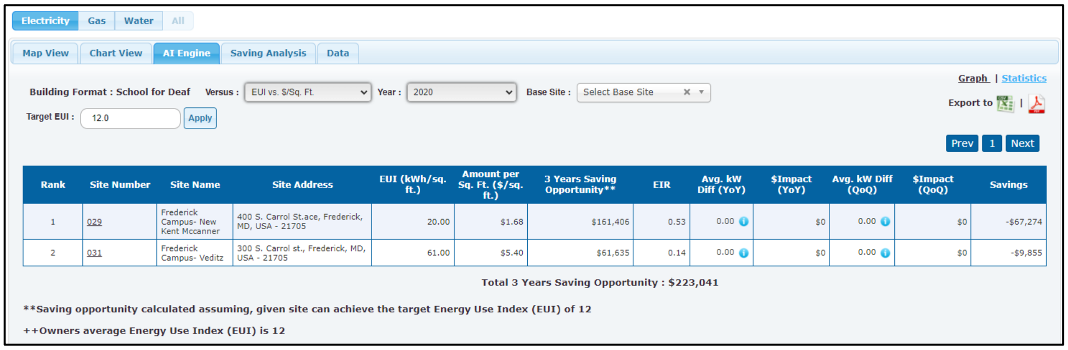


Figure 17: EUI vs. Dollar Use Intensity for MSD Frederick Campus Buildings (Singh360, 2022)

Furthermore, Figure 18 shows more detailed information in the AI Engine table regarding the energy efficiency of the Kent McCanner Elementary School. The table shows that the Kent McCanner Elementary School has the highest 3-year savings opportunity of $161,406 out of all the buildings in the MSD Frederick Campus. Therefore, it was determined that the Kent McCanner Elementary School building should be ranked number one in terms of priority for performing an in-depth experimental energy audit for the maximum amount of energy consumption and greenhouse gas emissions reduction. As a result, the complete energy audit was carried out for this building, and the results are discussed in the following sections.



Electricity Gas Water All

Map View Chart View AI Engine Saving Analysis Data

Building Format : School for Deaf Versus : EUI vs. $/Sq. Ft. Year : 2020 Base Site : Select Base Site

Target EUI : 12.0 Apply

Graph | Statistics

Export to |

Prev 1 Next

Rank	Site Number	Site Name	Site Address	EUI (kWh/sq. ft.)	Amount per Sq. Ft. ($/sq. ft.)	3 Years Saving Opportunity**	EIR	Avg. kW Diff (YoY)	$Impact (YoY)	Avg. kW Diff (QoQ)	$Impact (QoQ)	Savings
1	029	Frederick Campus- New Kent Mccanner	400 S. Carrol St.ace, Frederick, MD, USA - 21705	20.00	$1.68	$161,406	0.53	0.00	$0	0.00	$0	-$67,274
2	031	Frederick Campus- Veditz	300 S. Carrol st., Frederick, MD, USA - 21705	61.00	$5.40	$61,635	0.14	0.00	$0	0.00	$0	-$9,855

Total 3 Years Saving Opportunity : $223,041

**Saving opportunity calculated assuming, given site can achieve the target Energy Use Index (EUI) of 12

++Owners average Energy Use Index (EUI) is 12

Figure 18: AI Engine Table for MSD Frederick Campus Buildings (Singh360, 2022)

4.2 In-Depth Experimental Energy Audit

4.2.1 Building Comprehension

The Kent McCanner elementary school building is located at 101 Clarke Place, Frederick, MD, 21701. This building is one of 16 buildings in the MSD Frederick Campus. The building was constructed in 2009 and is a one-story building with an overall building floor area of 78,200 square feet, as specified by the facility manager. Figure 19 shows an overview of the building, and Table 6 shows the average annual utility consumption and cost for calendar years of 2017 to 2021. Water data was not available and was not included in the energy audit for this building (UMD S2TS, 2021).

Figure 19: Kent McCanner Elementary School Building Overview (Google Maps)

Electricity	1,657,919 kWh	$165,792
Natural Gas	27,206 Therms	$27,206

Table 6: 2017-2021 Average Annual Energy Consumption and Utility Cost for the Kent McCanner Elementary School Building (UMD S2TS, 2021)

Utility data for the Kent McCanner Elementary School from 2017 to 2021 were retrieved through the State of Maryland's EnergyCAP tool, which collects and stores energy consumption data from most facilities in the State of Maryland. Monthly energy consumption data for the electricity and natural gas were collected in the units of kWh and therms respectively (UMD S2TS, 2021). Then, these values were converted to units of kBtu using conversion factors provided by the US DOE as shown in the following table (ENERGY STAR). This was done so that the combined annual EUI for the building can be calculated.

	Electricity		Natural Gas		Total Site Energy	Site EUI	Source EUI
	MWh/ yr	kBtu/ yr	therms/ yr	kBtu/ yr	kBtu/ yr	kBtu/ SF/ Yr	kBtu/ SF/ Yr
Baseline Energy Usage	1,658	5,656,820	27,206	2,720,600	8,381.44	107.18	238.8

Table 7: Utility Analysis and EUI Calculations Summary for the Kent McCanner Elementary School Building (UMD S2TS, 2021)

The following figures illustrate the average monthly electrical and natural gas consumption for the years of 2017 to 2021.

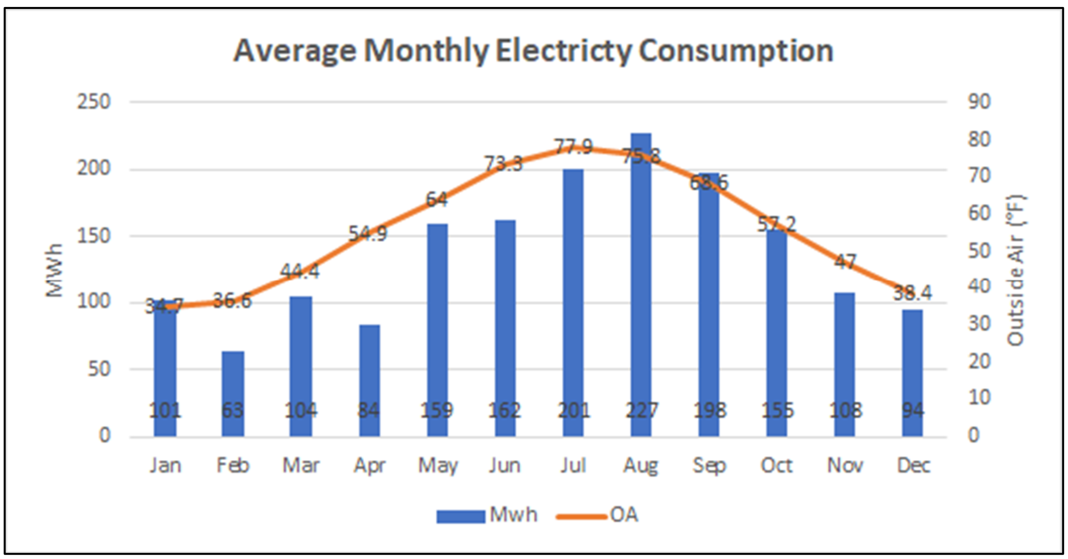


Figure 20: Average Monthly Electricity Consumption for the Kent McCanner Elementary School Building (UMD S2TS, 2021)

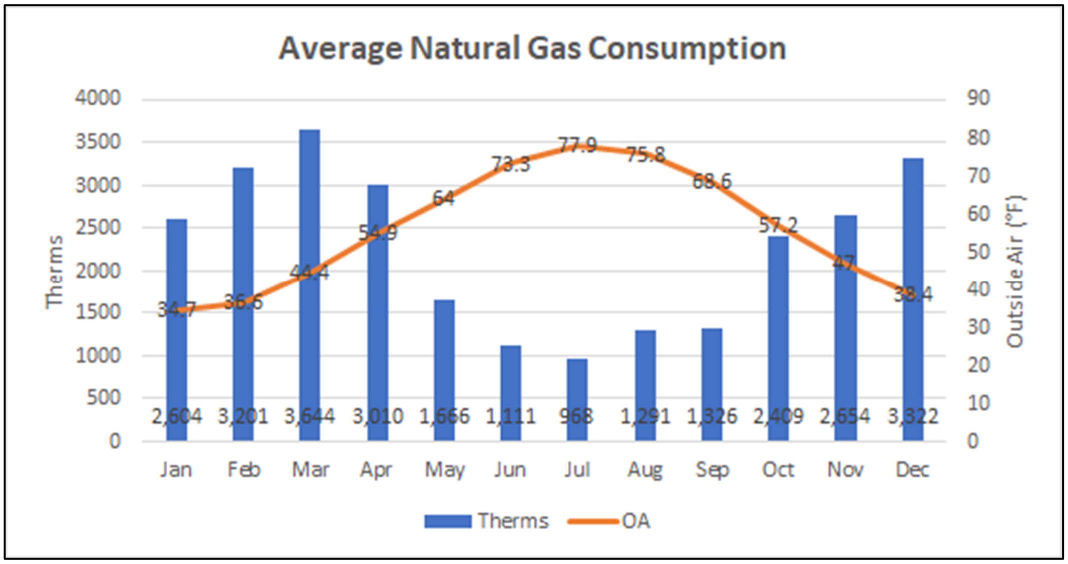


Figure 21: Average Monthly Natural Gas Consumption for the Kent McCanner Elementary School Building (UMD S2TS, 2021)

According to the utility data, an average of 5,656,820 kWh of electricity is consumed every year, and electricity consumption seems to increase during the summer months. Likewise, natural gas consumption increases during the winter months due to increased space heating requirements. According to the utility data, an average of 27,206 therms of natural gas is consumed every year. The natural gas consumption in the summer is due to the reheat operation required to provide adequate dehumidification and occupant comfort in certain spaces.

Although kWh360 was already used for the virtually screening process for this building, additional energy benchmarking assessment helps to identify the potential opportunities to improve energy efficiency and reduce the associated costs for utilities. To further verify the utility benchmarking calculations, benchmarking was performed using ENERGY STAR Portfolio Manager and the CBECS database. This comparison provides additional opportunities to determine the scope of improving overall energy efficiency.

The building utility data was entered in ENERGY STAR Portfolio Manager, including electricity and natural gas bills. Building characteristics data such as the building floor area, building use, and occupancy was also entered. The following table provides a summary of the result of benchmarking analysis as well as compares the obtained values with the benchmark ENERGY STAR and CBECS scores associated with a typical educational facility (EIA, 2012).

Parameter	Kent McCanner Elementary School Value	Benchmark Value	Reference
ENERGY STAR Score (1-100)	1	75	ENERGY STAR
Site EUI (kBtu/sf)	107.2	68.8	CBECS
Utility Cost Per Area ($/sf)	2.47	1.67	CBECS

Table 8: Benchmark Results Summary for the Kent McCanner Elementary School Building (UMD S2TS, 2021)

The overall ENERGY STAR score of 1 indicates that the building is performing significantly below the median energy performance. The EUI value of 107 was obtained using ENERGY STAR Portfolio Manager, and this is consistent with the EUI report shown in Table 7. According to the CBECS average data, the Kent McCanner Elementary School building currently has an EUI higher than the average for educational facilities (107 vs. 68.8). The utility cost per area is also higher than the average value (2.47 vs. 1.67). This means that he Kent McCanner Elementary School building is performing worse in terms of energy efficiency when compared other reference educational facilities in the United States and that there may many opportunities to increase the overall energy efficiency of building. As stated previously, the Kent McCanner Elementary School utility cost per area does not include water consumption as the annual average water consumption and cost could not be accurately determined due to the limited amount of archived utility data. However, this may suggest that the utility cost per area is actually even greater than what is shown in Table 8. The latest water utility bills would have to be obtained in its entirety in order to be able to accurately determine the comprehensive utility cost information for the building.

The building is a typical elementary school that houses primarily office spaces, classrooms spaces, a cafeteria, and a gym. The building also consists of several other miscellaneous spaces, such as mechanical rooms and electrical rooms. There is a mezzanine level that houses all of the nine air handling units (AHUs) for the building. The mechanical room located in the basement of the elementary school building houses one chiller, two boilers, and one cooling tower. All of these units work to serve and provide the HVAC needs of the entire building.

For the envelopes of the building, most of the exterior walls consist of 4-inch face brick, 2-inch rigid insulation, and 8-inch concrete masonry unit. The roofs throughout the building are sloped roofs, which consist of laminated asphalt shingles, 5/8-inch plywood sheathing, and R-38 12-inch fiberglass foil faced insulation. Finally, most of the existing windows for the building are glazed windows.

In terms of hours of operation, the facility exemplifies a typical elementary school in function. The entire building is operating on a 7:00am to 6:00pm building occupancy schedule on weekdays (Monday to Friday) throughout the year. Likewise, the building HVAC systems operate during all these hours, and they are off during unoccupied hours. The building is mostly unoccupied during the summer months because the students are on summer recess during this time. However, the existing mechanical drawing suggests that the HVAC system is still operating in full load during the day in the summer time.

The building consumes energy from two primary energy sources: electricity and natural gas. The electricity consumption is metered and supplied by PotomacEdison, while the natural gas is metered and supplied by Washington Gas. The building's annual average electricity consumption is 1,658 MWh, and the annual average natural gas consumption is 27,206 therms. The annual average water consumption and cost could not be accurately determined due to the very limited and incomplete water consumption archived utility data. Therefore, water information had to be excluded from the energy audit report for this building. The average annual utility cost of the building, excluding water, is $192,998. This average annual utility cost was determined by using the archived 2017-2021 monthly utility bills, which were obtained from EnergyCAP. The list below discusses the major findings of the S2TS energy audit team from the building comprehension phase (UMD S2TS, 2021).

- The annual building EUI is high compared to that of respective average educational facilities.

- There are stand-alone dehumidifiers and air purifiers constantly operating in unoccupied spaces.
- There are currently fluorescent lights serving the entire building.
- About 85% of the rooms in the building have functional occupancy sensors integrated to the existing lighting.
- Many of the appliances in the building are not ENERGY STAR certified.

For the building's HVAC system, the chilled water is supplied by a 250-ton York Model YT centrifugal compressor chiller. The chiller is controlled by the BAS, and the HVAC controls system was assumed to be direct digital controls (DDC) due to the fact there were no air compressors shown on the mechanical drawings. There are four chilled water pumps (P-1,2,3,4) and two condenser water pumps (P-5,6). All are included with variable speed drives, from which three are on standby. P-1 and P-2 are chilled water pumps rated at 7.5 HP each, and P-3,4,5,6 are 20 HP each. P-2, P-4, and P-6 operate as standby pumps. The chiller supplies the chilled water to the nine AHUs that serve the building. Figure 20 shows the chiller model installed in the mechanical room in the basement, and this chiller was installed in 2009 when the building was originally built. This chiller is served by a 250-ton cooling tower, which was also installed in 2009 when the building was first constructed (UMD S2TS, 2021).

Figure 22: Chiller Serving the Kent McCanner Elementary School Building

The hot water is supplied by two Smith gas-fired boilers, each with a capacity of 2100 MBH according to the existing base building mechanical drawings. These two boilers work in lead-lag operation and are controlled by the BAS as well. There are four identical hot water pumps with variable speed drive with one on standby and the remaining three working together simultaneously to supply hot water to the AHU heating coils and VAV reheat coils. Figure 21 shows the boiler units installed in the mechanical room. The boilers were also installed in 2009 when the building was originally constructed (UMD S2TS, 2021).

Figure 23: Boiler Serving the Kent McCanner Elementary School Building

There are nine AHUs in the building serving most of the building needs, and they are located at the mezzanine level with dedicated return air fans. The chiller water coil inlet and outlet temperatures for each of the AHU's are 44°F and 54°F, respectively. There are also several VAV boxes throughout the building serving different zones to provide temperature control for each of those respective zones (UMD S2TS, 2021).

In addition, there are several other HVAC systems serving the building to provide supplemental heating and cooling. These include unit heaters, finned tube radiators, as well as split systems serving IT rooms. The building's HVAC system schedule is consistent with the building schedule, and the occupied room setpoint temperatures are around 70°F and 75°F during the winter and summer season, respectively. There are also two water heaters original to the base building supplying domestic hot water. WH-1 is a 12 kW electric water heater with a 65 gal tank, and WH-2 is an 8 kW tankless water. There is also another electric water heater WH-3, which seems to have been added as a renovation sometime after the building was first constructed. There are three identical pumps serving the domestic hot water system, and they are tagged as CP-1,2,3. Each pump has a flow of 4 GPM and a pump motor of 1/6 HP (UMD S2TS, 2021). A summary of the specifications of the existing building HVAC system retrieved from the building's mechanical drawings is shown in Appendix A1.

4.2.2 Energy Model Development

Using the procedures discussed in section 3.2, the energy model was developed for the Kent McCanner Elementary School. Figure 24 shows the baseline building geometry rendered in Trane Trace 3D Plus, and Figure 25 shows the thermal zones assigned to the building. The baseline energy model had a total of 120 thermal zones. Each thermal zone represents the space served by a VAV unit.

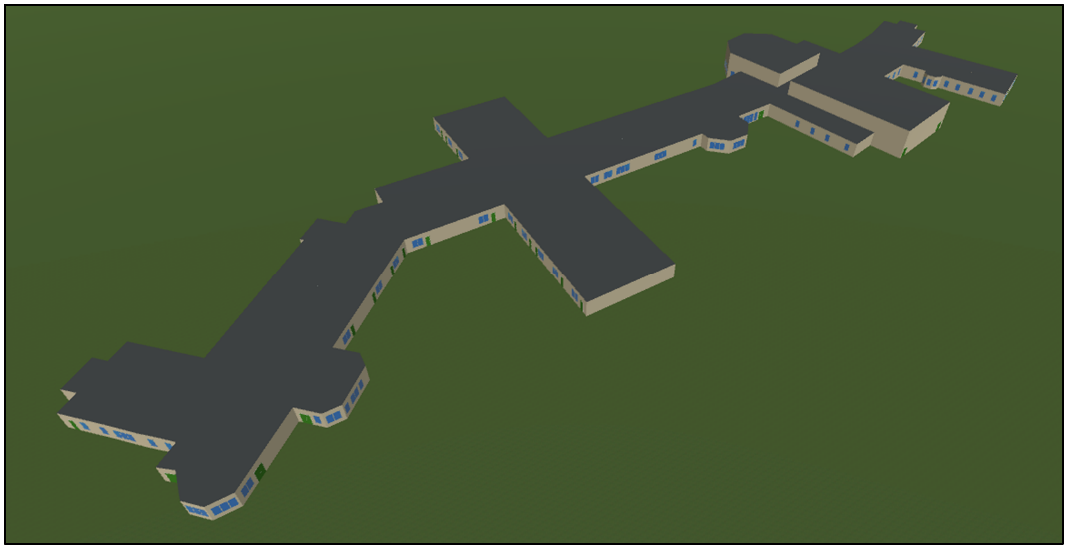


Figure 24: Baseline Building Geometry Rendered in Trane Trace 3D Plus for Kent McCanner Elementary School (UMD S2TS, 2021)

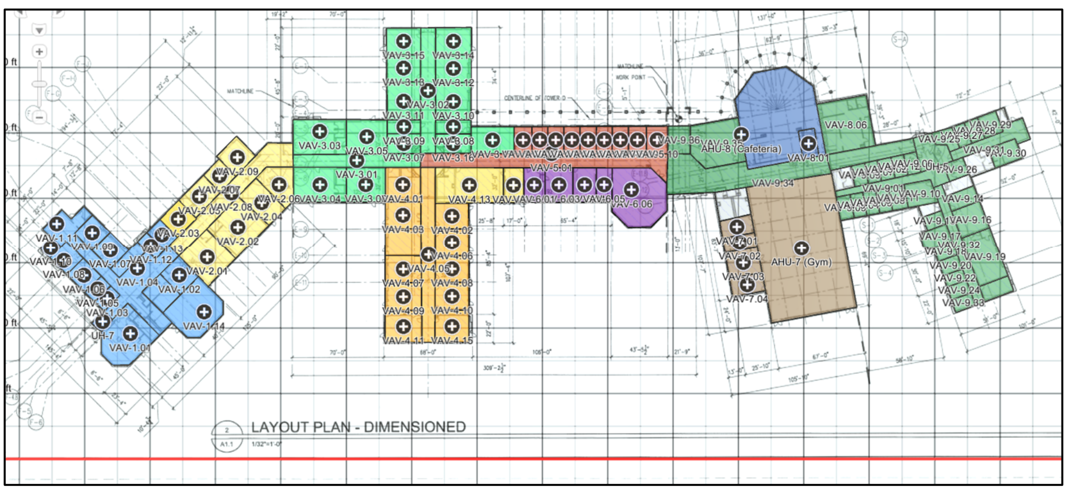


Figure 25: Thermal Zone Assigned for Kent McCanner Elementary School (UMD S2TS, 2021)

Calibrating the baseline energy model for this particular building was relatively difficult due to a potentially ongoing issue associated with the building that may be preventing the baseline energy model consumption data to resemble the actual utility data. Therefore, this building was considered as an exception to the ASHRAE calibration guidelines as given by ASHRAE Guideline 14-2002, which recommends a deviation of up to 15% (ASHRAE, 2002). As a result, it was determined that the baseline model was suitable to use for the energy auditing and analysis of the Kent McCanner Elementary School Building. The following figures show the results of the baseline energy model's monthly energy consumption when compared to the building's actual monthly energy consumption data for both electricity and natural gas. In the case of the modeled electricity consumption in comparison to the actual utility data, the values deviate by 19.3% while the natural gas consumption values deviate by 18.2% (UMD S2TS, 2021). The reason for the deviations in the electricity and natural gas consumption may be due to various reasons, such as the discrepancy in the occupancy and scheduling of the building. These potential discrepancies are further discussed in Section 4.2.3 of this thesis.

Overall, the predicted monthly energy consumption of the baseline energy model reasonably matched the trend of the average monthly energy consumption reported by utility bills between 2017 and 2021 except for the electricity consumption in the summer and shoulder months. The utility data showed that electricity consumption was relatively high in the summer and shoulder months compared to the predicted data, which indicates that an unnecessary amount of electricity may be being consumed during these months, thus presenting opportunities for reductions through appropriate energy conservation measures.

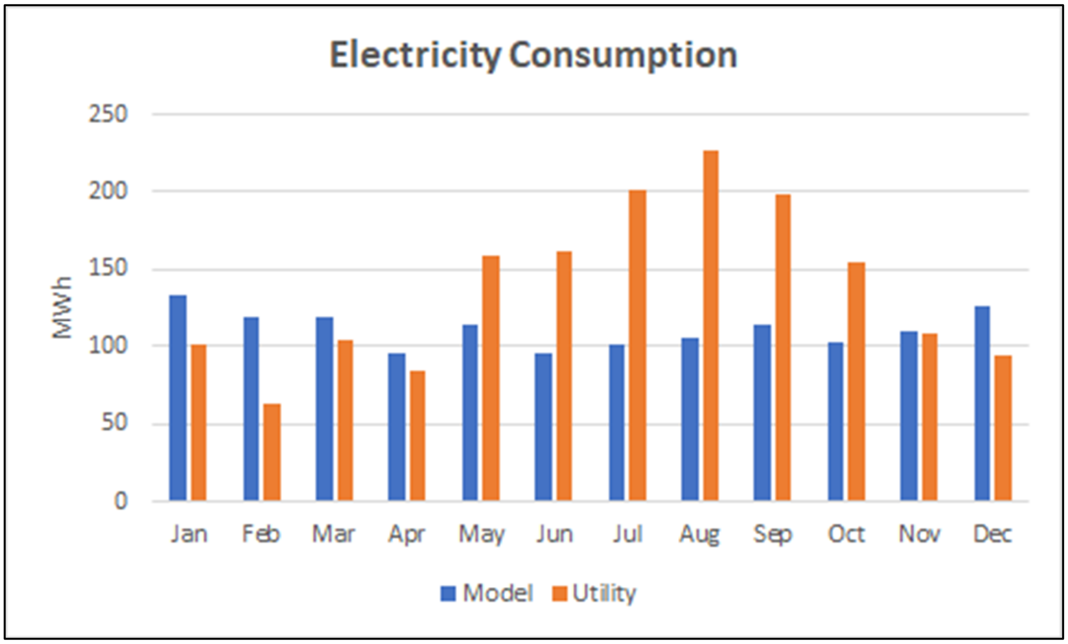


Figure 26: Average Monthly Electricity Consumption Comparison for the Kent McCanner Elementary School Building (UMD S2TS, 2021)

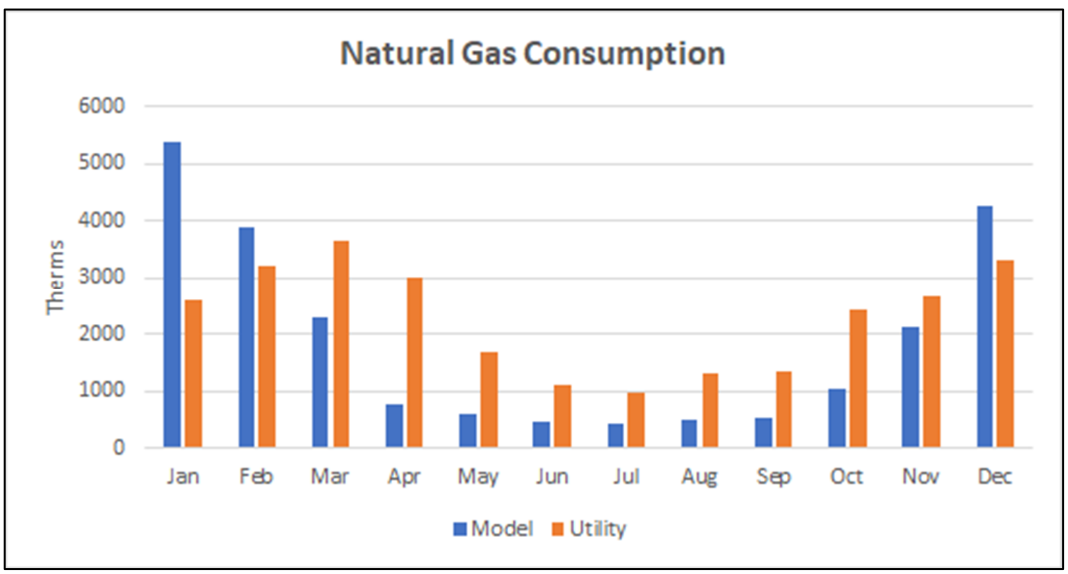


Figure 27: Average Monthly Natural Gas Consumption Comparison for the Kent McCanner Elementary School Building (UMD S2TS, 2021)

Finally, building load calculations were carried out and analyzed in order to determine and evaluate whether the existing building HVAC system is properly sized based on the calculated total design cooling load. The total cooling capacity of the building's existing HVAC system was estimated to be 277 tons by determining the sum of the sensible and latent cooling of the AHU's and split systems. The Trane Trace 3D Plus energy model calculated the site peak cooling load to be 248 tons, which is slightly lower than the building's existing HVAC system's total cooling capacity. Therefore, the existing chillers were determined to be oversized by 11.7% when comparing to the baseline energy model. The uncertainty can be due to several factors such as changes in the building conditions, changes in the building use, as well as human modeling error. However, the team has determined that the building was modeled as accurately as possible and that the difference is likely due to the account for redundancy when the chillers were first sized. Therefore, the model was further validated to be used to complete the energy audit for this building (UMD S2TS, 2021).

As for the boilers, the calculated site peak heating load from the energy model was 1,523 MBH and the capacity of the two current boilers are 2,100 MBH each. With the combined capacity of both boilers, the boilers seem to be oversized by 37.9% when compared to the heating needs of the building as calculated in the model. However, the oversizing is actually in accordance with ideal redundancy practice for boilers. The boilers are controlled in lead-lag operation. In addition, the boilers may be oversized to accommodate for higher demand due to unexpected extreme weather conditions as well as many other factors. Usually having some degree of redundancy is recommended, which is typically N+1 for boilers, depending on the nature of the building and its mission. For a typical school building, N+1 is an acceptable degree of redundancy for boiler sizing. Therefore, it can be determined that the existing boilers for this particular building have been sized properly (UMD S2TS, 2021).

4.2.3 Energy Conservation Measures Analysis

After the baseline energy model was validated, a series of actionable proposals aimed at increasing the building's energy efficiency were identified and simulated to estimate the energy and cost savings that would result from their implementation. The following discusses the ECMs that were carefully selected by the S2TS energy audit team as well as the results associated with implementing them.

<u>ECM #1 - Revisit HVAC Controls and Schedules</u>

It was proposed to ensure that the building's existing HVAC system is not operating in full load for spaces when they are unoccupied. The utility data showed that electricity consumption is relatively high in the summer compared to the predicted values, which indicates that an unnecessary amount of electricity may be being consumed during the summer. The trend for electricity consumption throughout the year should actually be more of a flatter trend throughout the year because students are on vacation during the summer. The high electricity consumption in the summer is suspected to result from the HVAC system running at full load, even when spaces are unoccupied during the day in the summer.

Generally, spaces are not used during unoccupied hours, so there is no need to cool the space in full load during these times. Therefore, energy consumption should decrease when the building's HVAC systems are not serving the unoccupied spaces in full load. The desired controls systems and system scheduling may need to be revisited so that cooling is supplied through the air terminal units for unoccupied spaces at the minimum values specified by the mechanical engineer during the day in the summer. The predicted savings in electricity consumption for EEM #1 was estimated by first creating a copied baseline energy model and assuming full occupancy and HVAC operations in the summer for that copied model. Then, a reduced occupancy was assumed to be 40% for the copied model for EEM #1 as recommended by the Trane Trace 3D Plus energy modeling software provider, CDS. After both models were simulated, energy consumption reductions were calculated to show what the total energy savings could potentially be for this particular EEM. The natural gas consumption was assumed to remain the same as there should not be a significant change of natural gas consumption during summer months regardless of the HVAC controls and scheduling.

ECM #2 - Lighting Upgrades

It was also proposed to replace all fluorescent lights in the building with new LED bulbs. The building mostly employs fluorescent lighting, and most of the building is served by T8's. Currently, there are functional occupancy sensors for about 85% of the spaces in the building. Upgrading the light fixtures to LED solutions has multiple end-user benefits. LED lighting can yield significant energy savings while also reducing the maintenance and labor costs associated with fluorescent lighting. LED light fixtures have a longer rated life, and this would mean fewer costs associated with replacing them. This work would need to be contracted out as the lights would need to be retrofitted to fit LED bulbs. Lighting control options can further enhance the energy savings potential of LED lighting. During the retrofit, controls for daylight saving, occupancy, and dimming can be integrated into the lighting system to yield additional energy savings. Transitioning towards LED lighting along with controls could yield electricity savings of around 50% of total annual lighting consumption (metroLED).

Additional Building Observations and Recommendations

ENERGY STAR Certified Appliances

There are currently several different appliances being used throughout the building, including but not limited to microwaves, refrigerators, and dishwashers for small kitchens as well as washers and dryers for the gymnasium and other spaces. Figure 28 shows examples of these types of appliances. These appliances can be high energy consumers depending on their energy ratings and age. Replacing all appliances that are more than five years old and are also not Energy Star certified with new ones that are Energy Star certified will result in savings in electricity consumption, and savings may be shown in water consumption as well.

Figure 28: Examples of Miscellaneous Appliances in the Kent McCanner Elementary School Building (UMD S2TS, 2021)

Stand-Alone Dehumidifiers and Air Purifiers in Non-Occupied Spaces

It was observed that there were a few standalone dehumidifiers and several air purifiers constantly running in spaces that were not occupied due to the fact students were on summer vacation. An example of these types of standalone units are shown in Fig. 3. Although the energy consumption of a single unit may not be significant compared to energy consumption of the building's central HVAC system, having several of these units constantly running throughout the day and night may cause unnecessary energy consumption to accumulate throughout the year to a point where it is noticeable. It is recommended to ensure that these units are not operating unnecessarily during unoccupied hours or to ensure that they are operating for only short periods at a time.

Figure 29: Typical Air Purifier in Non-Occupied Spaces in the Kent McCanner Elementary School Building (UMD S2TS, 2021)

Green Wall

Green walls in the lobby area of the facility could be considered to further condition the air in the space. Also, a drip free indoor living wall option (for water containment) can be considered in the lobby. Green and living walls contribute to indoor air quality by naturally providing oxygen, humidity, and reduction of particulates as well as volatile organic compounds. Additionally, studies have indicated plants enable more productivity among the building occupants while also increasing comfort levels. Indoor living wall solutions provided by LiveWall could be considered for the lobby space (LiveWall).

Smart Power Strips

Smart power strips, such as ones provided by Tricklestar, can reduce energy waste, prolong life of electronics, and offer premium fireproof surge protection. It will be advantageous from an energy savings standpoint to replace all power strips in the building with smart power strips in order to reduce annual electricity consumption.

Variable Frequency Drives

Many of the existing HVAC systems currently do not have variable frequency drives installed and integrated to them. Variable frequency drives modulate the frequency of fans and pumps in order to control the speed of these components so that they are not operating at a higher load than needed. This allows for improvements in energy efficiency of the HVAC systems, and there will be reductions in annual electricity consumption.

<u>Energy Conservation Measure Savings</u>

The savings associated with the previously-referenced recommended ECMs are listed below.

- Annual utility cost reduction of 11.2%, resulting in $21,555 annual utility savings.
- Annual electricity consumption reduction of 18.2%, resulting in $24,401 in annual utility savings.
- Annual natural gas consumption increase of 12.8%, resulting in $2,846 in additional annual utility costs.

The ECMs previously discussed were simulated into the baseline energy model, and the expected savings resulting from the implementation of these ECMs are summarized in the following table. The table also includes the predicted savings of implementing all the ECMs simultaneously, and this section is labeled as "Combined." Note that the savings predicted in the "Combined" row do not equate to the sum of the savings from each individual ECM. This is an expected result of the interaction between multiple model parameters in a dynamic whole building energy simulation. The ability to model multiple ECMs simultaneously is another powerful feature of the whole building energy modeling process. For the values in the summary table, the calculations are performed using the existing chiller and boiler capacities. For reference, "E" is used as an abbreviation for electricity, and "NG" is used as an abbreviation for natural gas.

ECM	**Modeled Annual Consumption**		**Projected Energy Savings**				**Utility Savings***		
	E (MWh/ yr)	**NG (therms/ yr)**	**E (MWh/ yr)**	**NG (therms/ yr)**	**E (%)**	**NG (%)**	**E ($/yr)**	**NG ($/yr)**	**Total ($/yr)**
ECM #1	1,146	22,244	192	0	14.4	0	19,201	0	19,201
ECM #2	1,286	25,090	52	-2,846	3.9	-12.8	5,200	-2,846	2,354
Combined	1,094	25,090	244	-2,846	18.2	-12.8	24,401	-2,846	21,555

Table 9: Energy and Utility Cost Savings Summary for the Kent McCanner Elementary School Building (UMD S2TS, 2021)

* The electricity rate considered was $0.10/kWh and for natural gas, the rate considered was $1/therm. These rates were estimated based on the utility analysis from EnergyCap.

The annual electricity usage and natural gas usage derived from the baseline model is 1,338 MWh and 22,244 therms, respectively. The total annual utility cost of electricity (1,338 MWh) and natural gas (2,224 MBtu) is $192,998. Implementing all of the proposed ECMs can reduce the annual utility cost by 11.2% and $21,555 (UMD S2TS, 2021). The following tables show the carbon footprint analysis and reduction results associated with the building as a result of implementing the proposed ECMs. Once again, "E" is used as an abbreviation for electricity, and "NG" is used as an abbreviation for natural gas.

ECM	**Projected Energy Savings**		**Carbon Dioxide Reduction**	
	E	**NG**	**E**	**NG**
	(MWh/yr)	**(therms/yr)**	**(lbs/year)**	**(lbs/year)**
ECM #1	192	0	140,743	0
ECM #2	52	-2,846	38,116	-33,254
Combined	244	-2,846	178,859	-33,254

Table 10: Carbon Footprint Analysis for the Kent McCanner Elementary School Building (UMD S2TS, 2021)

ECM	**Carbon Dioxide**	
	From E	**From NG**
	(lbs/year)	**(lbs/year)**
Without Combined Savings	1,215,314	317,766
With Combined Savings	1,036,455	351,020

Table 11: Carbon Footprint Reduction Results for the Kent McCanner Elementary School Building (UMD S2TS, 2021)

The carbon footprint analysis shown in Table 10 is estimated for a specific efficiency wherein the equipment degradation would result in an increase of carbon dioxide emissions both for the upgrade and baseline equipment. The values in the previous tables are based on EIA's estimates for the state of Maryland of 733 lbs. of CO_2 emissions per every MWh of electricity consumption based on the 2019 data (EIA, 2020) as well as 11.68 lbs. of CO_2 emissions per every therm of natural gas consumption (EPA, 2014). Based on the current average annual utility data, carbon dioxide emissions are 1,215,314 lbs. per year from electricity and 317,766 lbs. per year from natural gas. With the combined savings from the proposed ECMs, carbon dioxide emissions would become 1,036,455 lbs. per year from electricity and 351,020 lbs. per year from natural gas. As a result, implementation of the proposed ECMs would result in a total reduction of 11.7% or 145,605 lbs. of carbon dioxide emissions per year. However, it must be noted that the CO_2 emission per MWh for the grid electricity source is projected to continue to drop over time with a rate of 23 lbs. per MWh per year until 2030 and 8 lbs. per MWh per year afterward due to increasing use of cleaner fuels and renewable energy sources. The following figure illustrates the projection of CO_2 emissions over time.

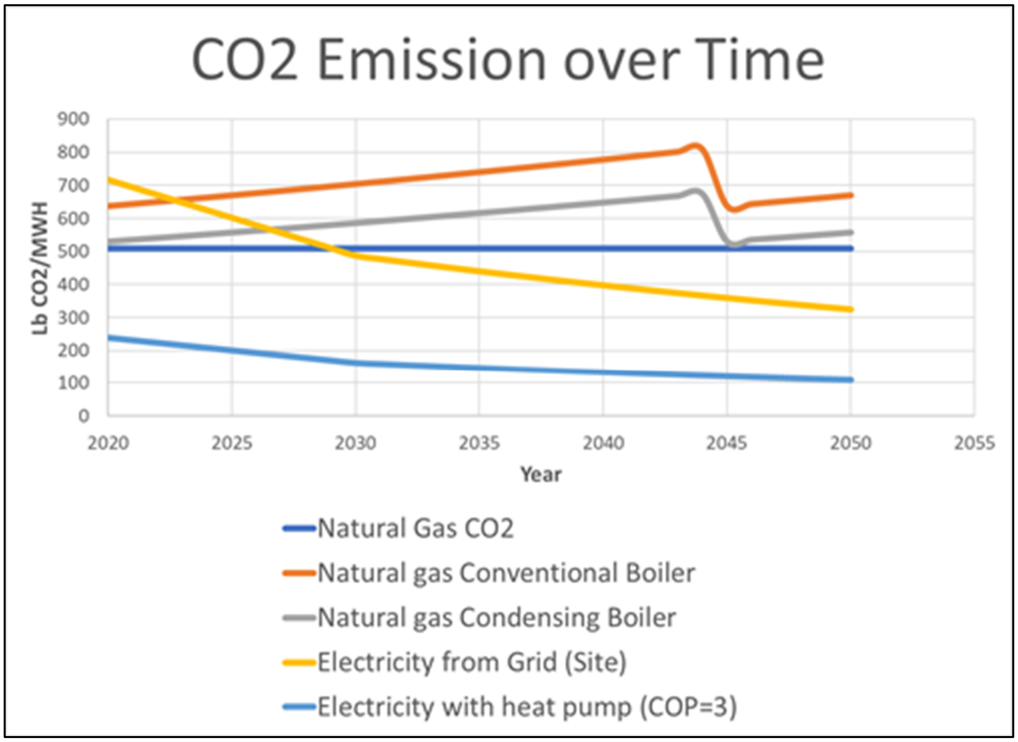


Figure 30: Projected CO_2 Emissions Over Time (DGS)

4.3 Comparison of Energy Audit Results

By comparing the result of the Kent McCanner Elementary School energy audit discussed in the previous sections with the results of an energy audit that was performed for another building on the MSD Frederick Campus, the effectiveness of implementing a virtual screening to the energy audit process can be clearly seen. Benson Gym is another building on the MSD Frederick Campus where a complete energy audit was performed. It is located at 301 South Carrol Street, Frederick Maryland. It was constructed in 1975 and is a one-story building with a total building floor area of 42,731 square feet. Table 12 shows the energy and utility cost savings summary from the energy audit. For the Benson Gym, ECM #1 involved upgrading all the existing lighting to LED bulbs, similar to what was proposed for

Kent McCanner Elementary School. ECM #2 involved upgrading the existing single-glazed windows with double-glazed tinted windows in order to reduce the incoming solar radiation (UMD S2TS, 2021). The table includes the predicted savings of implementing all the ECMs simultaneously, and this section is labeled as "Combined." Note that the savings predicted in the "Combined" row do not equate to the sum of the savings from each individual ECM. This is an expected result of the interaction between multiple model parameters in a dynamic whole building energy simulation. For reference, "E" is used as an abbreviation for electricity, and "NG" is used as an abbreviation for natural gas.

ECM	**Modeled Annual Consumption**		**Projected Energy Savings**				**Utility Savings***		
	E (MWh/yr)	**NG (therms/yr)**	**E (MWh/yr)**	**NG (therms/yr)**	**E (%)**	**NG (%)**	**E ($/yr)**	**NG ($/yr)**	**Total ($/yr)**
ECM #1	233	51908	99	-1737	29.8	-3.5	9880	-1737	8143
ECM #2	270	48058	62	2113	18.6	4.2	6170	2113	8283
Combined	172	49795	161	376	48.3	0.7	16050	376	16426

Table 12: Energy and Utility Cost Savings Summary for the Benson Gym Building (UMD S2TS, 2021)

* The electricity rate considered was $0.10/kWh and for natural gas, the rate considered was $1/therm. These rates were estimated based on the utility analysis from EnergyCap.

When comparing the results in Table 12 with the results from Table 9, it is shown that the combined projected utility savings for Kent McCanner Elementary

School is $5,129 or 31% less than that of Benson Gym ($21,555 vs. 16,426) if all the proposed ECMs for each energy audit were to be implemented. For savings in electricity consumption alone, Kent McCanner Elementary School is project for 83 MWh per year or 52% more savings when compared to Benson Gym (244 vs. 161). Therefore, it is clear that performing a complete energy audit on the Kent McCanner Elementary School resulted in much favorable projected energy savings results and that the rankings of the energy savings potential shown in kWh360 were indeed accurate. Implementing the virtual screening process to the group of buildings in the MSD Frederick Campus allowed Kent McCanner Elementary School to be determined as the building with the highest energy savings potential and be given the highest priority for performing a complete energy audit. This allowed the first complete energy audit performed for a building at the MSD Frederick Campus to result in the maximum amount of energy and cost savings possible. The energy audit results and comparisons prove that through the selection of buildings with the highest energy savings potentials, time and resources can be spent at a maximum efficiency throughout the entire energy auditing process of large groups of buildings and that the energy savings results can also be maximized.

Chapter 5: Conclusion and Proposed Future Work

5.1 Conclusion

As discussed in this thesis, integration of an initial virtual energy audit screening process with the detailed experimental energy audit process practiced today can effectively take advantage of the potential energy consumption and carbon footprint reduction in existing buildings today as well as allows for increased efficiency in which energy audits are performed for large groups of buildings with the optimization of the expenditure of time, cost, and labor. By applying the proposed procedure to a group of buildings, the results of this study demonstrated that a combination of the software-based screening tools and a detailed experimental/onsite energy audit as necessary can effectively take advantage of the potential energy consumption and carbon footprint reduction in existing buildings today and that the low-cost/no-cost energy conservation measures alone can oftentimes result in significant savings as documented in this thesis. However, selection of the appropriate software was deemed critically important, as certain software limitations were observed to hinder the obtainment of the desired energy savings opportunities.

With this combined process, the maximum amount of energy and cost savings can be achieved through the selection of the buildings with the greatest savings potentials relative to the group of buildings they are associated with. This is because the proposed ECMs are generally implemented in the order of which the complete energy audits are performed. By being able to identify buildings with high energy savings potentials more quickly, this will allow the respective ECMs to be implemented more quicky as well as achieve higher energy and CO_2 emissions reduction, thus minimizing the missed opportunities. Therefore, proposing ECMs first for buildings with higher energy savings potentials will result in higher actual energy savings in the long term.

The combined process can be achieved through the use of simple, yet capable, software tools, such as kWh360, which provides the user with customized calculations protocols and methods in order to automatically make these selections for the user. For further validation purposed, annual EUI benchmarking is another method that can be used to manually select buildings with high savings potentials as long as the annual EUI is compared to reliable benchmark values, such as the ones given by CBECS or ENERGY STAR. However, it may be preferred to omit the annual EUI benchmarking process and solely rely on the selections made by kWh360 due to the fact that the annual EUI benchmarking process can become time-consuming as it requires the reorganization and repeated inputting of building utility data, which could already be stored and available in the kWh360 software. Furthermore, the additional steps required to calculate the annual EUI values as well as reference the respective benchmark values can further decrease the efficiency at which the buildings with high savings potentials are selected. This is especially the case for situations where energy auditing may be required for thousands of buildings at once. For these cases, annual EUI benchmarking may often be out of the question because of how long it will take to complete for each and every building as well as due to the fact that the results can rather be subjective and not as accurate in those types of situations. Therefore, simple and capable software tools like kWh360 can eliminate the need of annual EUI benchmarking completely and automatically select the buildings with high energy savings potentials for the user, thus allowing the virtual screening process to be completed quickly and efficiently.

5.2 Limitations of kWh360

As mentioned in Section 2.2.5, kWh360 does come with its own disadvantages that may prevent the user from obtaining other useful energy-related data. As previously mentioned, the calculation of the total EUI with respect to all major energy types is not yet fully integrated into the software. Currently, the EUI is only calculated based on electricity consumption, albeit for majority of buildings electricity consumption may be 70 to 80% of energy consumption. There is a separate energy consumption per square foot calculation made for natural gas, but the user must manually calculate the total EUI of the building by performing the necessary unit conversions and adding the EUIs for each major fuel type together. Also, it is worth emphasizing that the software does not compare the calculated EUIs to other benchmark or average values and that it only compares EUIs with buildings within the user's cloud. While this is useful in quick identification of high energy consuming buildings within a cluster of buildings, it is useful to also know how the building compares with "Best in Class" building of the same category. However, the software does allow the user to categorize the buildings into user-defined building groups so that the building EUIs can be compared to the average EUI for each of those building categories, but the comparisons are not automatically made with respect to benchmark or average values of the national or global scale, which could potentially be useful to get a perspective on how the building is performing compared to other buildings in the U.S. or around the world. Furthermore, the average EUI calculated by the software may not be completely reliable due to potential outliers such as buildings that show an EUI of zero as a result of incomplete or unavailable utility data for those buildings. This would affect the energy and utility cost savings calculations because these are based on the average EUI that is calculated by the software and set as the target EUI. However, this is not the fault of the software and a process of data cleanup is needed to feed reliable data to the selected software tool, regardless of what the software/vendor may be.

Despite all these limitations, kWh360 can reliably and should ideally be used for the ranking capabilities that it provides for the energy savings potentials of buildings within a cluster (e.g., the State of Maryland owned buildings) since the variation of the target EUI value will not affect the rankings. This will allow for successful and accurate determination of which buildings should be given priority for performing a full energy audit in order to optimize the use of time and resources throughout the entire energy audit process. It is also important to reiterate that a complete energy audit cannot be performed with a virtual screening alone. Flaws in the building systems will not be able to be accurately determined by the software because these can only be confirmed by successfully performing a physical and detailed building energy audit. As a result, an accurate baseline energy model cannot be generated, and the necessary ECMs for the building cannot be determined as well.

5.3 Summary of Results

The effectiveness of the implementation of the virtual energy audit screening process was tested on a group of buildings at the MSD Frederick Campus. Initially, kWh360 was used as the virtual screening software, which indicated that Kent McCanner Elementary School ranked the highest out of a total of 10 buildings from this campus in terms of energy savings potential. Therefore, this building was selected first for performing a complete energy audit. With the implementation of ECM #1 (Revisit HVAC Controls and Schedules) and ECM #2 (Lighting Upgrades), the total potential savings in electricity consumption was projected to be 244 MWh per year for. In terms of total savings in utility cost, this amounted to 11.2% savings or $21,555 per year. When these results were compared to an energy audit that was performed for Benson Gym, which is another building at the MSD Frederick Campus, the results showed that the combined projected utility savings for Kent McCanner Elementary School was $5,129 or 31% less than that of Benson Gym ($21,555 vs. $16,426) if all the proposed ECMs for each energy audit were to be implemented. For savings in electricity consumption alone, Kent McCanner Elementary School was projected for 83 MWh per year or 52% more savings when compared to Benson Gym (244 MWh vs. 161 MWh). Therefore, it was clear that performing a complete energy audit on the Kent McCanner Elementary School resulted in much favorable projected energy savings results and that the rankings of the energy savings potential shown in kWh360 were indeed accurate. Implementing the virtual screening process to the group of buildings in the MSD Frederick Campus allowed Kent McCanner Elementary School to be determined as the building with the highest energy savings potential and be given the highest priority for performing a complete energy audit. This allowed the first complete energy audit performed for a building at the MSD Frederick Campus to result in the maximum amount of energy and cost savings possible. The energy audit results and comparisons prove that through the selection of buildings with the highest energy savings potentials, time and resources can be spent at a maximum efficiency throughout the entire energy auditing process of large groups of buildings and that the energy savings results can also be maximized.

5.4 Proposed Future Work

When it comes to the energy audit process, there is always room for improvement. With due diligence, new methods should continually be explored and implemented to existing energy audit processes in order to increase the efficiency and effectiveness at which they are performed. Not only will this be beneficial from an energy auditing perspective, but it will also be better for the served clients to be able to directly present more quantitative energy and utility cost savings for the assigned buildings.

In terms of possible improvements to specifically the initial virtual screening process as discussed throughout this thesis and its implementation to the conventional, hands-on, energy audit process used today, the major items to propose would mainly be related the energy efficiency management software that is used. For kWh360, continual work and communication will be needed with Singh360, the provider of kWh360, in order to assist in making improvements to the software so that its utilization for the virtual screening process can be fully optimized. Moving forward, S2TS would ideally collaborate with Singh360 in order to improve the software as well as develop its own version of the software if needed.

The first item of improvement for kWh360 would be the addition of total monthly and annual EUI calculations as these are not yet fully integrated into the software. Currently, EUIs are only calculated for electricity, and if the total EUI involving all major fuel types is desired, the user must calculate this manually. This can become a very inconvenient and time-consuming process, so it may be beneficial if the software could automatically make this calculation for the user. Although it is true that the utility cost for natural gas is generally insignificant compared to that of electricity, a total EUI value may be useful for reference purposes as well as when a user desires to compare the EUI to a benchmark value.

The next item for improvement would be the integration of some sort of comparison chart showing the actual annual EUIs of the buildings stored in the software versus respective benchmark values that have been directly imported from reliable sources such as CBECS or ENERGY STAR. It may also be beneficial to include the calculated ENERGY STAR score, if possible. Although all of this information is not necessarily needed for ranking the buildings in order of energy savings potentials, they will be useful for reference purposes in case the user desires to further validate the findings and results shown in kWh360 as well as to compare the buildings with other reference buildings in the US. By allowing all of this information to be readily available to the user directly from kWh360, this may further increase the efficiency and accuracy of the virtual screening process as well as may prevent the user from having to refer back to multiple sources unnecessarily.

Another potential item for improvement would be the removal of all buildings that show an annual EUI of zero or an outlying value when the software calculates an average EUI of all of the buildings stored in the user's building category or cloud. This may be needed because the energy savings projections in the AI Engine tab of kWh360 is calculated based on the target EUI, which is automatically set as the average EUI of all of the stored buildings. If there are several outlying buildings that show an EUI of zero or close to zero, this may inaccurately skew the average EUI value to be lower than what it should be, and this would cause all of the energy savings calculations in the software to become inaccurate and unreliable. Because this risk currently exists, kWh360 should solely be used for its ranking capabilities at this moment. However, if these outlying EUIs and inaccurate average EUI calculation issues can be resolved, the energy savings calculations that are provided by kWh360 can be safely referenced and used for additional insight in the energy audit process.

Finally, the last item of improvement to propose for kWh360 would be the ability to store various building information, including but not limited to mechanical systems, construction, and lighting. The various data may consist of the manufacturer name, model number, age, etc. The ability to store all of this type of information may prove to be useful in that multiple energy audits may be performed on a single building throughout its lifetime. When the time comes to perform an additional energy audit for a certain building, having all of the building information readily organized and available for the energy auditors will greatly help them in saving cost and time throughout their energy audit process, especially throughout the building comprehension and the energy model development phases.

Appendices

A1: HVAC Specifications for the Kent McCanner Elementary School Building

Air Handling Units				
Designation	**Serves**	**Cooling Capacity (MBH)**	**Heating Capacity (MBH)**	**Model**
AHU-1	West	393	137	York
AHU-2	West	249	94	York
AHU-3	Central	505	187	York
AHU-4	Central	445	122	York
AHU-5	Central	113	116	York
AHU-6	Central	228	73	York
AHU-7	Gymnasium	377	46	York
AHU-8	Kitchen	486	51	York
AHU-9	East	474	54	York XTI

Ductless Split Systems			
Designation	**Location**	**Cooling Capacity (MBH)**	**Heating Capacity (MBH)**
ACU-1	IT Room E109	18	13
ACU-2	IT Room S118	18	13
ACU-3	IT Room IT1	12	8.3

Chiller				
Designation	**Location**	**Compressor Type**	**GPM**	**Model**
CH-1	Basement	Centrifugal	600	York Model YT

Cooling Tower				
Designation	**Location**	**Motor HP**	**GPM**	**Model**
CT-1	Basement	50	750	Baltimore Air Coil

Boilers				
Designation	**Location**	**Fuel**	**Output MBH**	**Model**
Boiler-1	Basement	Natural Gas	2100	Smith
Boiler-2	Basement	Natural Gas	2100	Smith

Pumps				
Designation	**Location**	**Service**	**HP**	**Flow Rate (GPM)**
Pump-1	Basement	Primary Chiller Water	7.5	600
Pump-2	Basement	Primary Chiller Water	7.5	600
Pump-3	Basement	Secondary Chiller Water	20	650
Pump-4	Basement	Secondary Chiller Water	20	650
Pump-5	Basement	Condenser Water	20	750
Pump-6	Basement	Condenser Water	20	750
Pump-7	Basement	Primary Heating Water	5	210
Pump-8	Basement	Primary Heating Water	5	210
Pump-9	Basement	Second Heating Water	5	270
Pump-10	Basement	Second Heating Water	5	270
Pump-11	Mezzanine	Preheat Water: AHU-1	1/4	7
Pump-12	Mezzanine	Preheat Water: AHU-2	1/4	5

Pump-13	Mezzanine	Preheat Water: AHU-3	1/4	9.5
Pump-14	Mezzanine	Preheat Water: AHU-4	1/4	7.5
Pump-15	Mezzanine	Preheat Water: AHU-5	1/4	2.5
Pump-16	Mezzanine	Preheat Water: AHU-6	1/4	4
Pump-17	Mezzanine	Preheat Water: AHU-7	1/4	5.5
Pump-18	Mezzanine	Preheat Water: AHU-8	1/4	10.5
Pump-19	Mezzanine	Preheat Water: AHU-9	1/4	7.5
Pump-20	Basement	Preheat Water: HC-1	1/4	4.5
Pump-21	Basement	Preheat Water: HC-2	1/4	4.5

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