UC Davis Health Education Building LEED Readiness

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Highlights

- Building operation is in the 67th percentile for energy performance based on ENERGY STAR Portfolio Manager tool results
- Ventilation rates conform with ASHRAE 62.1 requirements in most zones, however further analysis is needed to ensure all zones are getting sufficient fresh air
- Metering of data for all credits needs to be checked and sensors must be calibrated to ensure 12 months of high-quality data is available for the LEED certification
- Increased organization through checklists, clear labeling, and a folder hierarchy could make the LEED certification process faster and easier to complete

Executive Summary

The UC Davis Health Education Building has been nominated as a candidate for LEED certification. To begin the certification process four high-priority LEED prerequisites were assessed to determine the building's readiness for LEED certification. This study found that the building is operating better than average but may still require improvements in energy efficiency and indoor environmental quality to achieve a LEED certification. Analysis of four LEED energy and air quality prerequisites found:

- Defective metering needs to be identified and rectified early
- A current ENERGY STAR Score of 67
- Follow-up inspections are necessary for some zones to ensure adequate ventilation rates
- Enhanced organization could improve the LEED certification process

Overall, these results suggest that the Education Building is a promising candidate for LEED certification. The building is already relatively energy efficient; therefore, only minor adjustments should have to meet LEED requirements. The continuation of the LEED certification process involves continuing to collect high-quality data and sequentially progressing through each LEED credit.

Contents

1 Introduction

In support of the University of California's broader sustainability and carbon neutrality goals, the UC Davis's department of Energy and Engineering is working toward certifying the UC Davis Health (UCDH) campus' recently constructed Education Building with the U.S. Green Building Council (USBGC) under their Leadership and Energy and Environmental Design (LEED) framework (version 4), a commonly used and well-respected system for rating green buildings. The process of LEED certification provides a well-organized, comprehensive, and reputable method for determining whether a given building is operating under progressive energy and human health standards. Thus, with LEED as a guide, recommendations for improving the energy efficiency and indoor environmental quality (IEQ) of the Education Building can be made. As part of this process, there are a variety of prerequisites focused on energy and IEQ. This report focuses on assessing the readiness of the Education Building for LEED certification with respect to four specific LEED-mandated prerequisites identified as high priority by the department of Energy and Engineering. The results of the analysis for each prerequisite are presented in a dedicated section, with the methods, results, and recommendations nested within each section.

2 Building-Level Energy Metering

The intent of this prerequisite is "*[t]o support energy management and identify opportunities for additional energy savings by tracking building-level energy use*" [1]. The prerequisite requires the building to have at least 12 months of at least monthly energy data for all sources of energy consumption in the building. Because UC Davis produces and manages its own energy, there is high resolution data available for analysis to meet this requirement.

The energy delivered to the Education Building consists of electricity, heated water (HHW), and chilled water (CHW). The UCDH campus operates a combined heat and power plant to supply its buildings with electrical power, HHW and CHW, all of which are metered by UC Davis upon entering the building. The electricity is metered by UC Davis and data is available for the entire building's consumption in kW at 15-minute intervals. HHW and CHW energy inputs for the Education Building are not directly available and must be calculated using thermodynamic principles. For HHW and CHW, the difference in supply and return temperatures and the associated flows are used to estimate energy consumption. This is possible for the HHW, but because the CHW flow meter was non-functioning (up until March 2021), air handler unit (AHU) direct and mixed air temperatures as well as the associated air flows were used to estimate the energy used via CHW in the building. This method does not account for latent heat or thermal losses from imperfect insulation of the system but provides the best available estimate of CHW energy consumption in the building.

2.1 Methods

Electrical power data with a sampling frequency of 15 minutes and a date range of 2017-08-17 07:30:00 to 2021-05-05 07:30:00 was provided by Facilities Management in a workbook entitled "Z033-Utility-Use.xlsx". The data used for this analysis is found on the "kW" sheet within this workbook. The PointName "adx-svr:NCE-23/Programming.Folder1.33-KW-N.#85" and PointID 8392 were used because the other data included in the sheet contain mostly zeros and thus appear to be irrelevant or insignificant. Observations with a value of 0 or observations with identical repeated energy consumption values were not considered, as these appeared to be erroneous measurements (54,647 observations removed [42.9%]). Days with incomplete data were also removed (8,855 observations removed [6.9%]). Figure 1 shows the electrical data after performing these cleaning steps. The significant drop in electricity consumption due to the COVID-19 pandemic is clearly visible and observed to be about 100 kW.

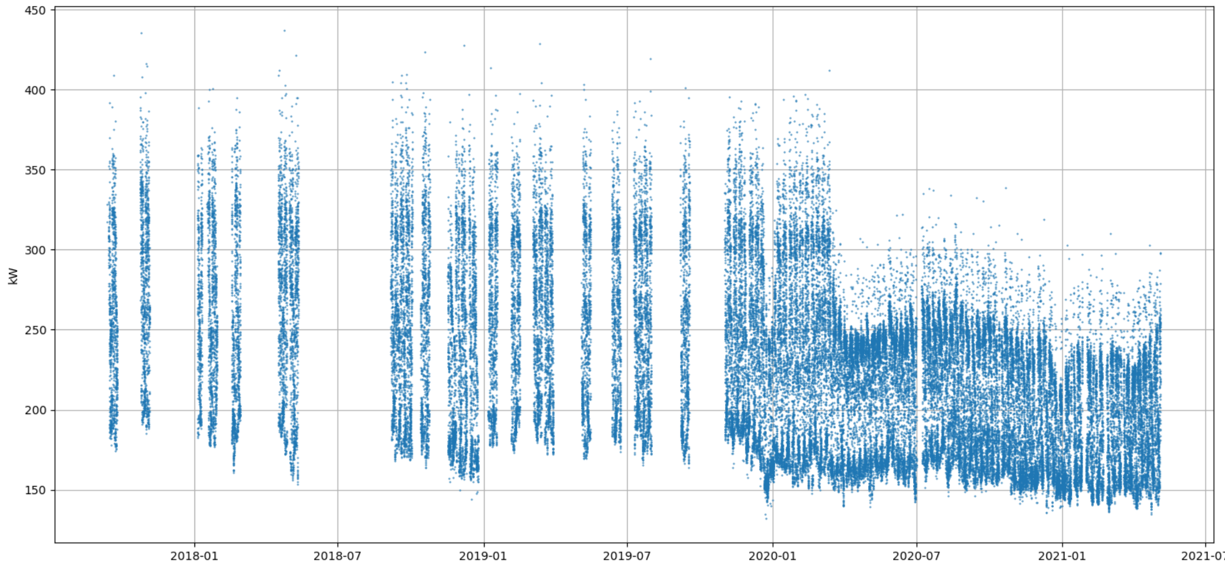

Figure 1. Initial cleaned electricity consumption data (kW) 15-minute intervals.

An inspection of Figure 1 indicates that the electricity data before roughly November of 2019 is quite inconsistent. Use of this data for LEED is not advised due to the complicated and uncertain modeling that would be required to fill in the large gaps. This LEED prerequisite only requires 12 months of data, so for this analysis we only consider electricity data from 2019-11-01 to 2021-05-01. Kilowatts (kW) were converted to kWh after ensuring that every observation in the dataset had the same 15-minute time step and missing observations were filled with the corresponding monthly median kWh consumption (17.8% of the observations from 2019-11-01 to 2021-05-01). The data were then aggregated to the monthly level for use with the ENERGY STAR Portfolio Manager tool. Figure 2 displays the complete (filled) and converted final data. The retrocommissioning effort to reduce energy consumption in this building occurred between August and December of 2020 and the effects of that effort might be evident in the reduced energy consumption around that period; however, the pandemic and seasonality make it difficult to determine the impact of the retrocommissioning effort on reduced electricity consumption.

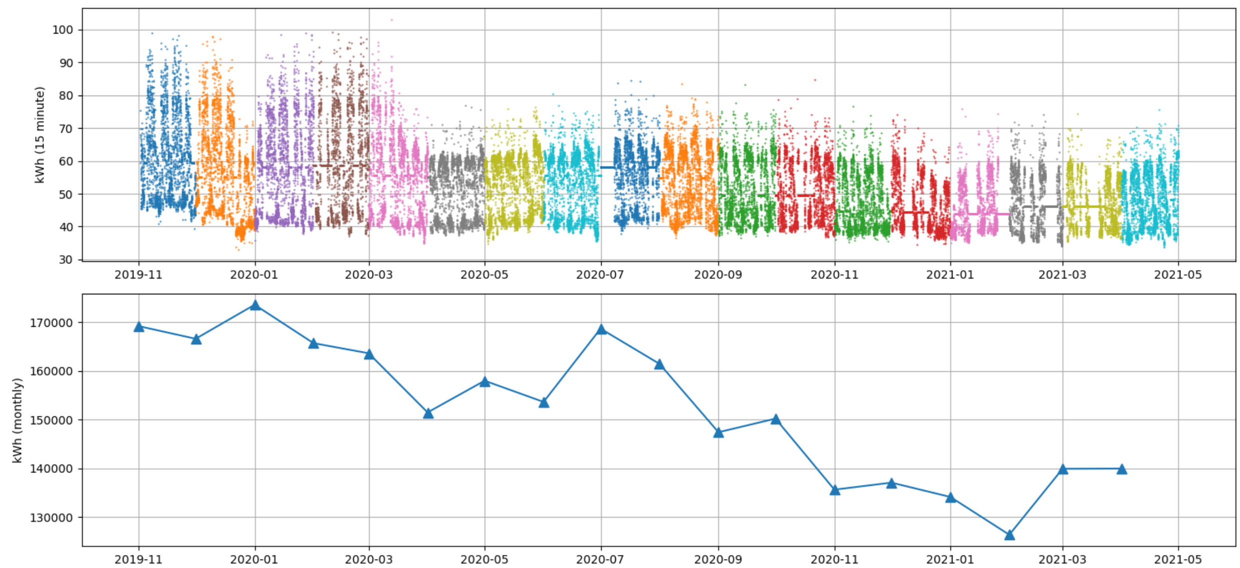

Figure 2. Electrical consumption for the Education Building with 15-minute data color coded by month (includes filled data).

The HHW temperatures and flows were provided in a comma separated value (CSV) file entitled "Z033_HW_Trends.csv". This file contains the hot water supply temperature ("adx-svr:NAE-33-1/N2 Trunk 1.UNT-97.AI3.#85", the hot water return temperature ("adx-svr:NAE-33-1/N2 Trunk 1.UNT-97.AI4.#85"), and the associated flows ("adx-svr:NAE-33-1/N2 Trunk 1.UNT-99.AI5#85") in Fahrenheit (F) and gallons per minute (gpm), respectively. The time steps for this data range from one minute to 33 minutes, so to simplify the calculations the hourly median was calculated for the entire date range for all data. The median was chosen over the mean because the distribution of flows is not symmetric and skews toward zero. The months 2017-10 and 2020-08 were removed due to abnormal and unusual readings. The month 2021-05 was removed because a full month of data was not available at the time of analysis. Flow data is missing from July of 2020 until March of 2021, as shown in Figure 3. Flow values less than zero (negative) were removed from the data. Using the hourly median, Equation 1 was used to estimate the energy consumed via HHW as shown in Figure 3.

$$\frac{BTU}{hr} = \frac{8.34\ lb}{gallon} \times (T_{supply} - T_{return}) \times Q \times \frac{60\ min}{hr} \tag{1}$$

Where

$T =$ Temperature [F]
$Q =$ Flow [gpm]

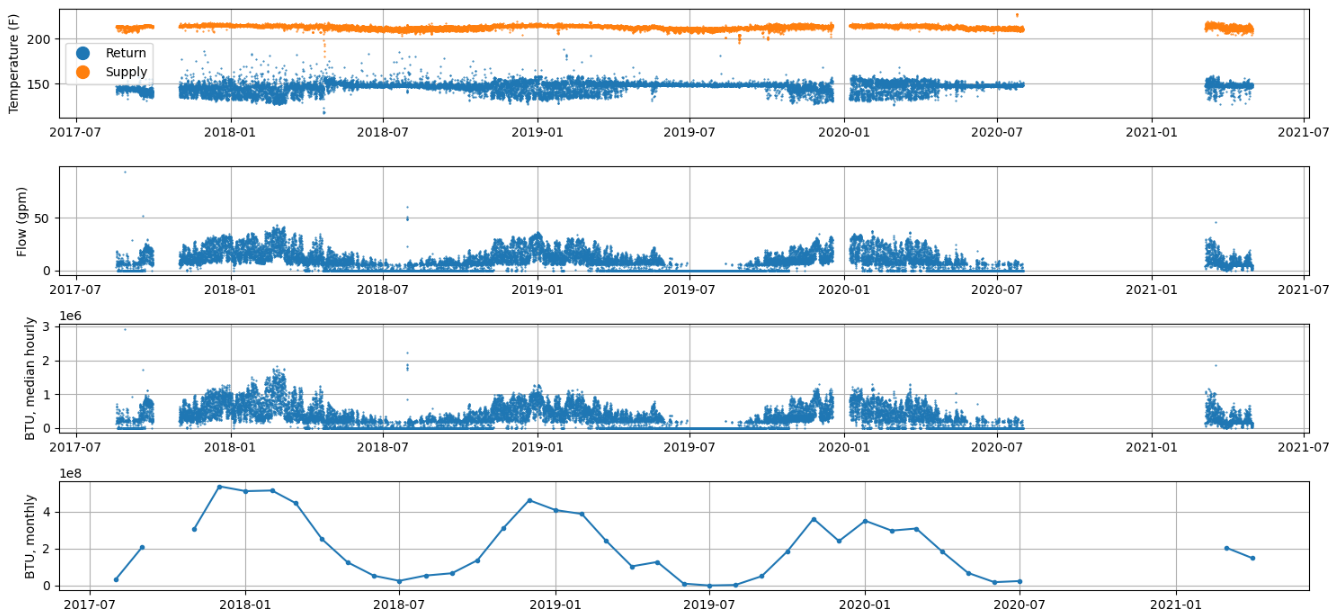

Figure 3. HHW data used for calculations and the resulting monthly output in BTUs.

CHW energy use was impossible to calculate directly due to missing flow data. Therefore, the best available method for estimating CHW energy consumption was to use temperatures and flows from the AHUs. This data was provided in the form of nine separate fixed-width files: three for DA, or “direct air” temperature (F), three for MA, or “mixed air” temperature (F), and three for SA, or “supply air” flow (cubic feet per minute, or cfm). There are 30 PointNames, as shown in Table 1, corresponding to the three data points from each of the 10 AHUs.

Table 1. AHU PointNames for Education Building.

PointName	Description
adx-svr:NAE-33-1/N2 Trunk 1.AHU-110.AI3.#85	Direct Air (DA) Temperature (F)
adx-svr:33-01-NAE-3/FC-1.33-1-AHU-02.DA-T.#85	
adx-svr:NAE-33-1/N2 Trunk 1.AHU-112.AI3.#85	
adx-svr:NAE-33-1/N2 Trunk 1.AHU-114.AI3.#85	
adx-svr:33-01-NAE-3/FC-1.33-2-AHU-03.DA-T.#85	
adx-svr:33-01-NAE-3/FC-2.33-3-AHU-03.DA-T.#85	
adx-svr:33-01-NAE-3/FC-2.33-4-AHU-03.DA-T.#85	
adx-svr:NAE-33-2/N2 Trunk 1.AHU-54.AI3.#85	
adx-svr:NAE-33-2/N2 Trunk 1.AHU-56.AI3.#85	
adx-svr:NAE-33-2/N2 Trunk 1.AHU-58.AI3.#85	
adx-svr:NAE-33-1/N2 Trunk 1.AHU-110.AI2.#85	Mixed Air (MA) Temperature (F)
adx-svr:33-01-NAE-3/FC-1.33-1-AHU-02.MA-T.#85	
adx-svr:NAE-33-1/N2 Trunk 1.AHU-112.AI2.#85	
adx-svr:NAE-33-1/N2 Trunk 1.AHU-114.AI2.#85	
adx-svr:33-01-NAE-3/FC-1.33-2-AHU-03.MA-T.#85	
adx-svr:33-01-NAE-3/FC-2.33-3-AHU-03.MA-T.#85	
adx-svr:33-01-NAE-3/FC-2.33-4-AHU-03.MA-T.#85	
adx-svr:NAE-33-2/N2 Trunk 1.AHU-54.AI2.#85	
adx-svr:NAE-33-2/N2 Trunk 1.AHU-56.AI2.#85	
adx-svr:NAE-33-2/N2 Trunk 1.AHU-58.AI2.#85	
adx-svr:NAE-33-1/N2 Trunk 1.AHU-110.ADF25.#85	Supply Air (SA) Flow (cfm)
adx-svr:33-01-NAE-3/FC-1.33-1-AHU-02.DA-F.#85	
adx-svr:NAE-33-1/N2 Trunk 1.AHU-112.ADF25.#85	
adx-svr:NAE-33-1/N2 Trunk 1.AHU-114.ADF25.#85	
adx-svr:33-01-NAE-3/FC-1.33-2-AHU-03.DA-F.#85	

adx-svr:33-01-NAE-3/FC-2.33-3-AHU-03.DA-F.#85
adx-svr:33-01-NAE-3/FC-2.33-4-AHU-03.DA-F.#85
adx-svr:NAE-33-2/N2 Trunk 1.AHU-54.ADF25.#85
adx-svr:NAE-33-2/N2 Trunk 1.AHU-56.ADF25.#85
adx-svr:NAE-33-2/N2 Trunk 1.AHU-58.ADF25.#85

The time resolution for the AHU data is not constant, so the data was aggregated to an hourly median for DA, MA, and SA. This data is for the most part high quality and there are few outliers or missing observations. For DA, any values greater than 90 F or less than 50 F were replaced with NaN and filled later via linear interpolation. For MA, any values greater than 90 F and less than 40 F were replaced with NaN and filled via linear interpolation. The exclusion of these outlier points is unlikely to significantly impact the calculation, as very few observations were removed. The temperatures and flows were then used in Equation 2 to estimate the energy consumed, as shown in Figure 4.

$$\frac{BTU}{hr} = (T_{MA} - T_{DA}) \times Q_{SA} \times \frac{0.24\ BTU}{lb\ F} \times \frac{0.075\ lb}{ft^3} \times \frac{60\ min}{hr} \tag{2}$$

Where

$$T_{MA/DA} = \quad \text{Temperature [F]}$$

$$Q_{SA} = \quad \text{Flow [cfm]}$$

$$\frac{0.24\ BTU}{lb\ F} = \quad \text{Specific heat of air } (C_p)$$

$$\frac{0.075\ lb}{ft^3} = \quad \text{Industry standard air density at 70 F and at sea level [2]}$$

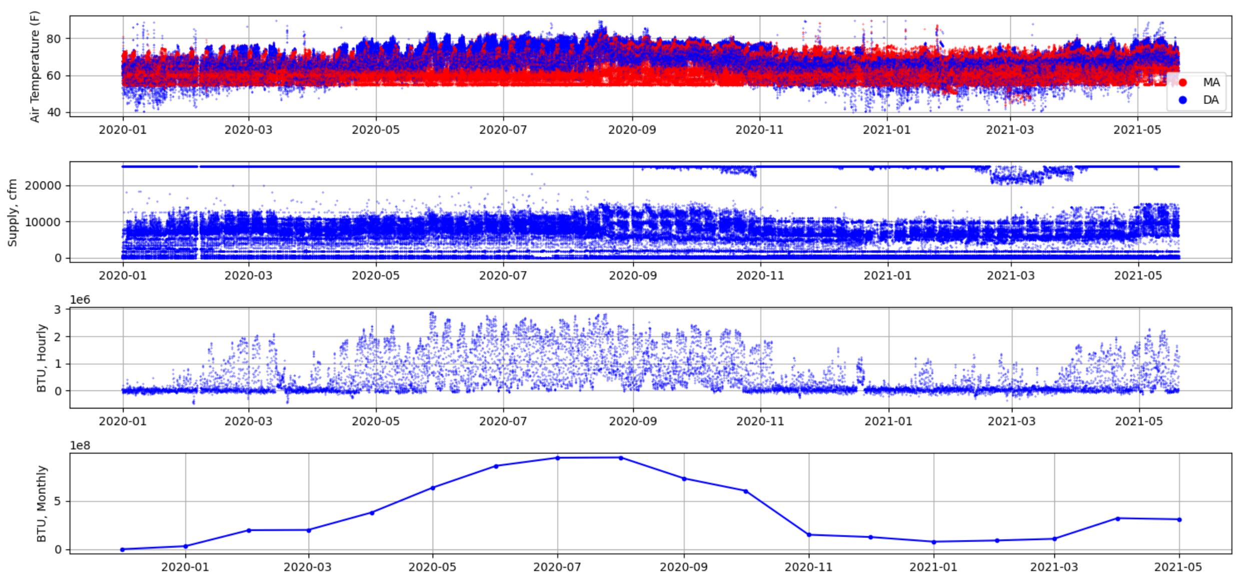

Figure 4. AHU data and resulting monthly energy estimates in BTUs.

2.2 Results

The primary result of this data analysis is the conclusion that the data are correctly being metered and can be manipulated for use in a LEED certification, apart from CHW energy. The summarized monthly energy consumption results are shown in Figure 5 and are used as part of the Minimum Energy Performance LEED prerequisite. The estimates are consistent with what one would expect for a building of this type in Sacramento: more energy is required to cool the building in the summer than to heat it in the winter. Additionally, the electricity consumption is consistent with the effects of the pandemic and possibly with the effects of the retrocommissioning effort undertaken between August and December of 2020.

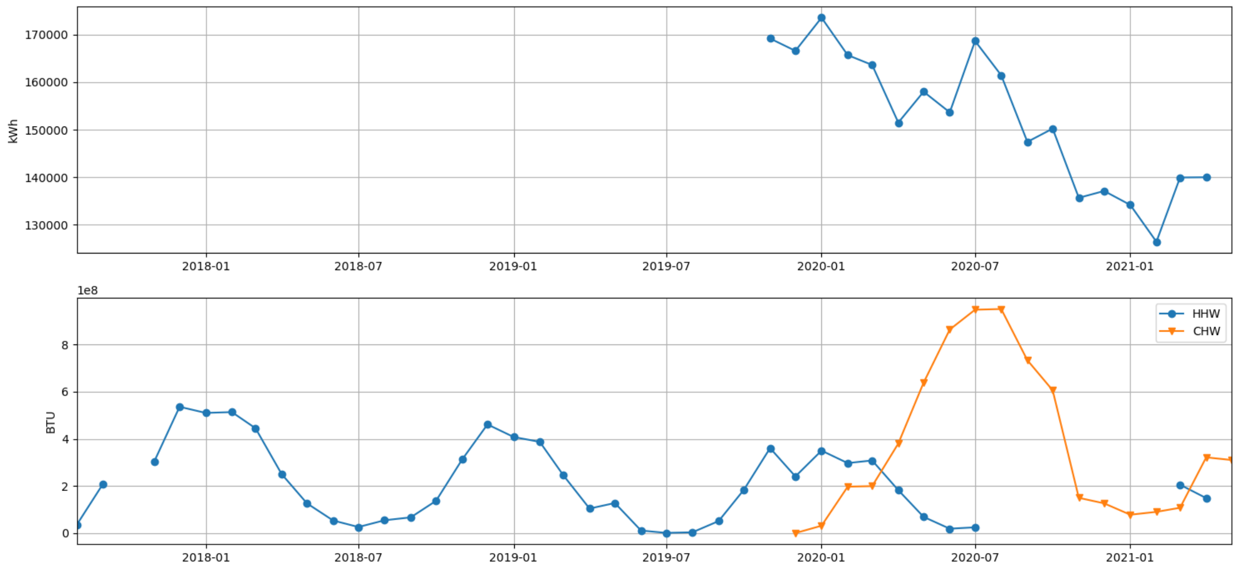

Figure 5. Summarized monthly energy consumption results for electricity, HHW, and CHW for the Education Building.

There is a moderate amount of uncertainty in these results, as data cleaning was required, and missing observations were imputed. The CHW estimates have the most uncertainty due to being estimated from AHU data. More sophisticated modeling could increase the confidence in these numbers, but the best way to achieve better results would be to ensure the data is being collected correctly and consistently.

2.3 Recommendations

The chief recommendation from this prerequisite is to make sure that all data required for LEED is being collected (i) at all (meters/sensors exist), (ii) consistently (defective meters are fixed and brought back online in a timely fashion), and (iii) correctly (sensors are frequently calibrated). In the case of CHW, the AHU-derived estimates are adequate for preliminary assessment, but for actual LEED certification, calculations like those used for the HHW energy estimate (with supply and return water temperature and flows) should be used. Therefore, making sure all sensors are installed and functioning correctly is of utmost importance, especially at the beginning of a project, since LEED requires 12 months of continuous data for certification.

3 Minimum Energy Performance

The reasoning behind this prerequisite is to "*to encourage exceptional energy efficiency*" [1]. The prerequisite benchmarks the building against similar buildings to determine whether its energy performance is 25% better than the median energy performance of typical buildings.

3.1 Methods

The calculation was performed following the preferred method of Option 1, Path 1 (benchmarking against typical buildings with national average data available). The ENERGY STAR Portfolio Manager tool was used to determine the building's energy performance [3]. An ENERGY STAR score is calculated by inputting energy consumption data, normalizing for weather and operating characteristics, and comparing against similar buildings nationwide. Scores range between 1-100 with 50 representing median performance; a higher score is better than average and lower is worse.

The following building details were defined in the ENERGY STAR Portfolio Manager tool to normalize the energy consumption data:

- Location: "Sacramento" (CA climate zone 12)
- Primary Function[*]: "Office"
- Gross Floor Area (GFA): 178,000 ft^2

Utility energy consumption data for the building was obtained from meters. Data processing details are explained previously in the previous prerequisite. Aggregated monthly energy usage for electricity (kWh), CHW (kBTU) and HHW (kBTU) were uploaded to calculate an ENERGY STAR Score for the building.

3.2 Results

The ENERGY STAR Portfolio Manager tool found the Education Building is performing better than average but below the 75^{th} percentile energy performance threshold required for LEED. Figure 6 (a) shows the building received an ENERGY STAR Score of 67, implying the building is operating in the top 67^{th} percentile of similar buildings. Figure 6 (b) shows a graph of the building's energy consumption (electricity, CHW and HHW) over the year. Energy consumption peaks in the summer with a large CHW demand to cool the building. There appears to be little seasonality in the electrical power demand, which remains relatively steady at about 500 MBTU/month (150 kWh/month).

[*] The building is used for several purposes, including classrooms, laboratories, library/study space, and offices. The primary function was defined as "office" since offices account for about 40% of the building floor area.

Metric	Apr 2021 (Energy Current)
ENERGY STAR Score (1-100)	67
Source EUI (kBtu/ft²)	125.9
Site EUI (kBtu/ft²)	67.8
Energy Cost ($)	Not Available
Total GHG Emissions Intensity (kgCO2e/ft²)	4.0

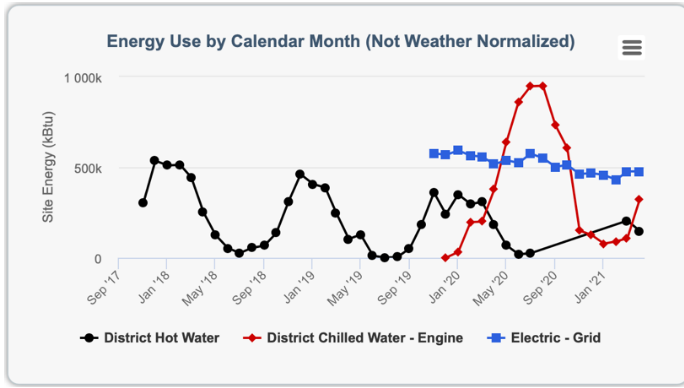

Figure 6.ENERGY STAR Portfolio Manager tool dashboard: (a) metrics summary; (b) energy usage time series.

It is important to note that CHW energy consumption was estimated from AHU data. LEED requires that energy consumption data be obtained from actual metered data. By using estimated consumption data, the results are merely illustrative of how the building is likely performing and not applicable for actually evidence of meeting the requirement.

3.3 Recommendations

It is important to continue updating the ENERGY STAR Portfolio Manager tool with new energy data when it becomes available. It is recommended that new data be uploaded monthly. All future CHW data should be derived directly from CHW flow and supply and return temperature sensors now that the CHW flow meter is online again. This will yield more accurate energy data, and consequently a more precise ENERGY STAR Score. If the ENERGY STAR Score remains below 75, then it is recommended to consider additional energy efficiency measures (EEMs) to reach the LEED requirement. Additionally, a more sophisticated modeling approach may be useful to better gauge the building's current energy performance and increase confidence in the ENERGY STAR Score. Models appropriate for time series data include ARIMAX/SARIMAX regression models, which include autoregressive and moving average factors in addition to including seasonality and independent explanatory variables.

4 Minimum Indoor Air Quality Performance

The purpose of this prerequisite is "*[t]o contribute to the comfort and well-being of building occupants by establishing minimum standards for indoor air quality (IAQ)*" [1]. It is especially important for the Education Building to have sufficient fresh air, as the building contains laboratories that need to exhaust pollutants and classrooms that need to ensure carbon dioxide levels stay low for optimal student learning and productivity.

4.1 Methods

The LEED Minimum Indoor Air Quality Performance Calculator was used to check compliance with this prerequisite [4]. This calculator is based on the ASHRAE 62.1 standard, which specifies minimum ventilation rates to ensure adequate IAQ for human occupants [5]. The building was disaggregated into 10 AHUs that were each given a separate sheet in the Excel-based calculator. A building AHU map ("Building 33 AHU Service Floor Map.pdf") was compared to a building WiFi map ("Z033-Education HVAC_ Wifi Zones.pdf") to find all the VAV boxes supplied by each AHU. Each VAV was recorded as its own row on its corresponding AHU sheet. The individual room numbers served by each VAV box were identified by looking again at the WiFi map and the type of space (office space, classroom, etc.) was recorded under the "occupancy category" column. The zone population was estimated by assuming default values for occupant densities. The floor area was found by matching the room number to the area column on the room inventory sheet ("Room Inventory.xlsx"). Air distribution and recirculation constants were assumed to be 0.8 and 1.0, respectively, to represent a conservative calculation. The airflow through each VAV box was found in the Excel sheet entitled "ToolsShell.xls". With these inputs, the calculator automatically determined the ASHRAE 62.1 required ventilation rate and compared this to the actual ventilation rate to check compliance.

4.2 Results

Based on the assumptions of the ventilation calculation, many zones were identified to have insufficient airflows. The complete IAQ calculator and results can be reviewed in the supplementary material. Overall, about 90% of rooms seem to be adequately ventilated while about 10% of rooms are under-ventilated.

The analysis for this prerequisite was limited since there were incomplete data (missing ventilation flows) for the "Telemed" wing of the Education Building. Therefore, AHUs 1-2, 2-3, 3-3, and 4-2 were excluded from the analysis. Additionally, because the current calculation is conservative, it is likely some zones that were initially identified as having insufficient ventilation do in fact have sufficient ventilation rates. This can happen for two reasons: (i) the actual zone population is less than the estimated zone population, or (ii) the air distribution and recirculation constants are better than assumed.

4.3 Recommendations

The current IAQ calculations should be reviewed and corrected where necessary to better represent the building's ventilation system. Data on the mechanical systems for the Telemed wing should be recorded in a similar fashion as done for the rest of the Education Building to complete the IAQ calculator. Subsequently, a walkthrough should be conducted to count exact occupancy (e.g., number of seats in a classroom) and find air distribution and recirculation constants for every room. If any rooms are still found to have insufficient ventilation rates, these airflow rates should be increased to meet the minimum requirement. Additionally, the outdoor air quality should be evaluated to determine how "fresh" it is.

5 Energy Efficiency Best Management Practices

The primary goal of this prerequisite is to "*to promote continuity of information to ensure that energy-efficient operating strategies are maintained and provide a foundation for training and system analysis*" [1]. This consists of an eight-step process of gathering and consolidating materials related to the building's operation and performing an ASHRAE Level 1 energy audit.

5.1 Methods

Completing this prerequisite within the timeframe for this project was not feasible, a fact that was acknowledge by all parties from the start. The goal was to complete as much as possible and report the findings. To facilitate the gathering of the diverse sets of information required for this prerequisite, the LEED reference manual's guidance was codified in a spreadsheet tool, as shown below in Figure 7.

Step	Requirement	Complete	If not, actions to be taken	Notes
1	**Review current facility requirements (cfr) and available operations and**			
1.1	***Current facility requirements (cfr)***	***No***		
1.1.1	*Functional Space Requirements*	No		
1.1.1.1	Building functions by space type	Yes		
1.1.1.2	Occupancy schedules	No	requested	
1.1.1.3	Cleaning schedules	No	requested	
1.1.2	*Operational Space Requirements*	No	requested	
1.1.2.1	Required temperature setpoints for occupied spaces	No	requested	
1.1.2.2	Required temperature setpoints for process spaces	No	requested	
1.1.2.3	Lighting levels	No	requested	
1.1.2.3	Humidity setpoints	No	requested	
1.1.3	*Building drawings, where available*	No		
1.1.3.1	As-built drawings	No		

Figure 7. Spreadsheet checklist tool designed to track and streamline progress on the Energy Efficiency Best Management Practices LEED prerequisite.

This spreadsheet tool allows for efficient tracking of what has been completed and the status of what has not been completed. This tool will enhance collaboration, reduce confusion, increase efficiency, and ensure satisfactory completion of the prerequisite. In addition to the spreadsheet tool, a filing system was adopted to mirror the spreadsheet, as shown in Figure 8. Systematically organizing files and tracking their completion will greatly aid the certification process.

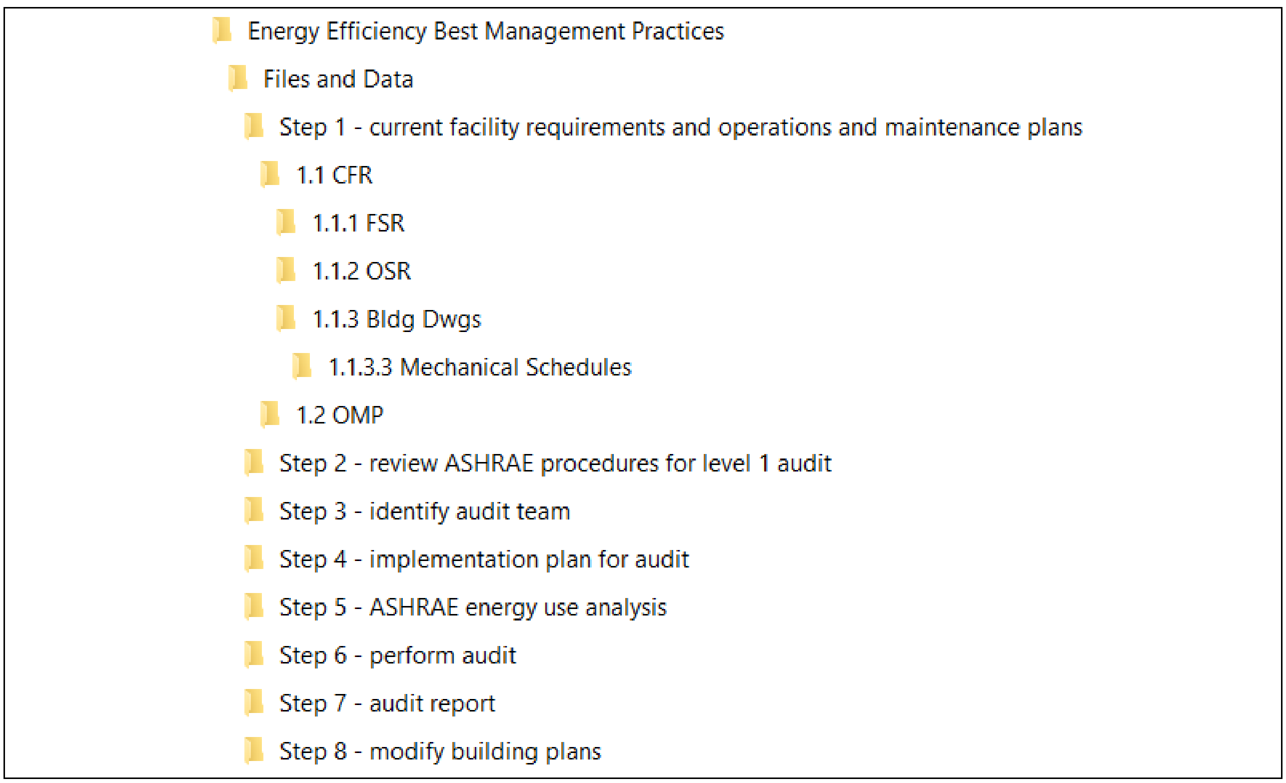

Figure 8. Systematic file structure to match spreadsheet tool to enhance productivity and efficiency.

5.2 Results

The spreadsheet tool and the systematic file structure are the main results of the work done on this prerequisite. Gathering this information is a slow process and requires coordination from many people. Members of the client's support staff were involved in all information requests in order to facilitate the transition of responsibilities.

5.3 Recommendations

The primary recommendation resulting from this work is the adoption of this spreadsheet tool and systematic file structure. This will make tracking progress easier, facilitate communication between team members, increase efficiency by eliminating unnecessary efforts, make transitions of responsibility within the project smoother, and ultimately increase the overall effectiveness of whoever is working toward achieving LEED certification. Extending this concept to the entire LEED certification process is also recommended. The initial work of creating the framework for all LEED prerequisites and credits will be paid back in terms of increased efficiency, especially on future LEED projects where the same materials will be highly useful.

6 Conclusions and Next Steps

Based on the analysis described here, there are three main conclusions. First, perform an audit of LEED's requirements and ensure all data collection is proceeding as needed. This includes continuously monitoring for abnormalities and calibrating sensors when necessary. Second, investigate the values used for the ventilation calculations shown in Section 4, as the preliminary results indicate that current ventilation practices in the Education Building are inadequate for meeting LEED requirements. Third, adopt a systematic approach to managing the files required for the Energy Efficiency Best Management Practices prerequisite. This will increase efficiency, reduce confusion and lost time, and simplify the LEED certification process. In fact, we recommend implementing a similar strategy for the entire LEED certification process. Recommended next steps are summarized as the following:

1. Check to make sure all LEED required data is being collected
    a. Routinely check meters are functioning and calibrated
2. Develop a protocol to make sure all collected data is continuously monitored for consistency and correctness (perhaps an automated script that checks for missing/suspicious data and sends alerts when something goes wrong)
3. Add more building-specific details to the IAQ calculator to refine the ventilation results
4. Implement a systematic file system for each prerequisite (or LEED certification as a whole) based on the model provided in Section 5.

Bibliography

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2. RuppAir. BTU Output.

3. Energy Star. ENERGY STAR Portfolio Manager. U.S. EPA; 2021. Available: https://www.energystar.gov/buildings/benchmark

4. U.S. Green Building Council. Minimum Indoor Air Quality Performance Calculator. LEED; 2014. Available: https://www.usgbc.org/resources/minimum-indoor-air-quality-performance-calculator

5. ASHRAE. Ventilation for acceptable indoor air quality. Atlanta, GA: ASHRAE Standard 62.1; 2016.