CENTER FOR CERAMIC RESEARCH – ENERGY SIMULATION

An Open-Studio Project

ABSTRACT

Analyzing annual energy consumption of Center for Ceramic Research by drawing building model on Sketchup and running energy simulating on Open-Studio

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Energy Systems Modeling

Table of Contents

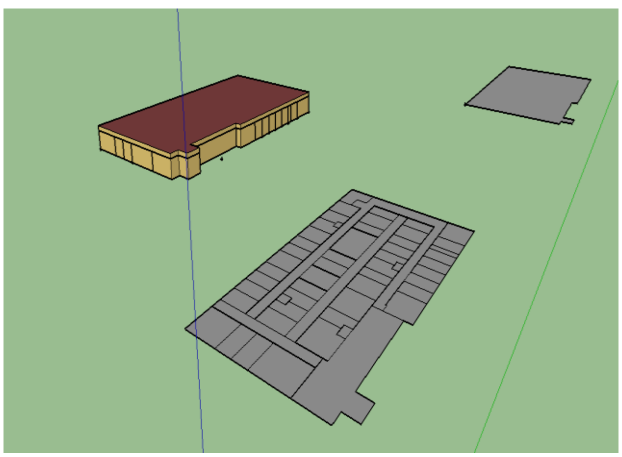
Introduction

Using the floor plan arranged by our professor for the Center for Ceramic Research a 3 D model was sketched in a user friendly software called 'SketchUp 2016'. This was then appropriately modeled using the real pictures of the building and important building data files, again arranged by our teacher, to approximate the building's performance as precisely as possible and make this commensurate to any graduate level project in engineering.

Modeling Procedure:

- **Defining Geometry/ Layout of the Building**

The Center for Ceramics Research (CCR) is located on the Rutgers New-Brunswick Busch Campus, in Piscataway NJ. It is a two story building, including a basement, taking up a footprint of approximately 21,186 ft2. The basement consists of mechanical/electrical equipment as well as the four air handling units (AHU). On the first and second floor there are various offices (department chair, professors/advisors, graduate students), and various labs such as ceramics machining and microscopy. The essential shape of the CCR is a rectangular prism, therefore the room layout is grid-like and nearly identical between the first and second floor. Window spacing is even across all facades of the building excluding one small section of the south elevation and a curtain wall in the lobby spanning the first and second floor. The modelling of the CCR was done in SketchUp as an OpenStudio file, where the energy analysis of the building was subsequently performed.



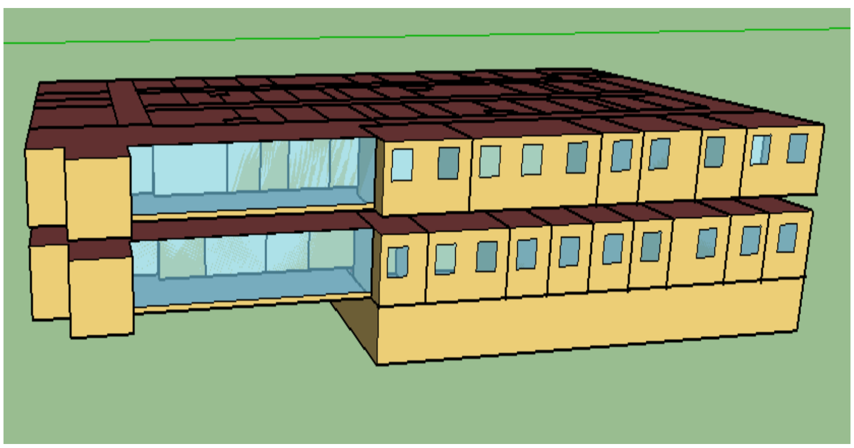
- **Recreating Floor Plans**

To begin the modelling process floor plans of the basement, first and second floor were uploading into SketchUp. To ensure that all floor had the same outer wall dimensions the 2-D image of the first floor was scaled up to match the dimensions indicated on the floor plan using the tape-measure tool. The outer walls were then traced over, giving the basic 2-D shell model, and duplicated to give the form for the basement and second floor. Using the scale tool, the floor plans to the basement and second floor were matched to the size of the corresponding 2-D shells that would become the 3-D model. Taking advantage of OpenStudio's x-ray function allowed each 2-D floor plan model to be overlaid exactly on the floor plan image, then precise inner walls to be drawn onto each 2-D model.

Before the rooms were traced, however, two more duplicates of the floor plans were made to function as the building's plenums above the first and second floor. During the tracing process some errors were encountered. Looking over the 2-D model can show some bolded lines, indicating that line is not connected at both ends. The simple fix is to delete and redraw the line to ensure it gets attached correctly.

- **From 2-D to 3-D**

Once the 2-D floor plans were finished in OpenStudio, a 'create spaces from diagram' tool was used to create the 3-D models of each floor. This tool only requires selecting the diagram and specifying the height of the spaces to be made. Following the floor plans provided by Professor Ghofrani, the first and second floor were made to 12 ft. (plenums being 3 ft. tall meant a total of 15 ft.), and the basement was made to 10 ft. Using the inspector tool, the space names, schedule type, and construction type were all set based on the information in the floor plans provided.



The building type was set to a 'Medium Office' and the template used was DOE Ref 1980-2004. Space names were copied exactly as they were written on floor plan documents, schedule and construction type were chosen to match as closely as possible what each space's function was. There was no template that included laboratory rooms so most spaces were defined as closed offices. After all spaces were properly identified, the three floors were stacked to resemble the full CCR building. The final step to represent the CCR building as accurately as possible was to add windows. OpenStudio has a 'window-to-wall ratio' function that will automatically add windows depending on the ratio set by the user. This method is useful because it is quick however it does not accurately depict the geometry and layout of the windows on the facades of the building. For this reason the windows were added based on the floor plan diagrams. In OpenStudio simply drawing a rectangle on the wall surface created a window subsurface. After adding windows and glass doors our 3D model was intersected, matched and equipped with 'thermal zones'. Thereafter, the file is exported as an 'osm file' which enabled us to run energy simulation.

- **Setting up HVAC & Air Handling Units**

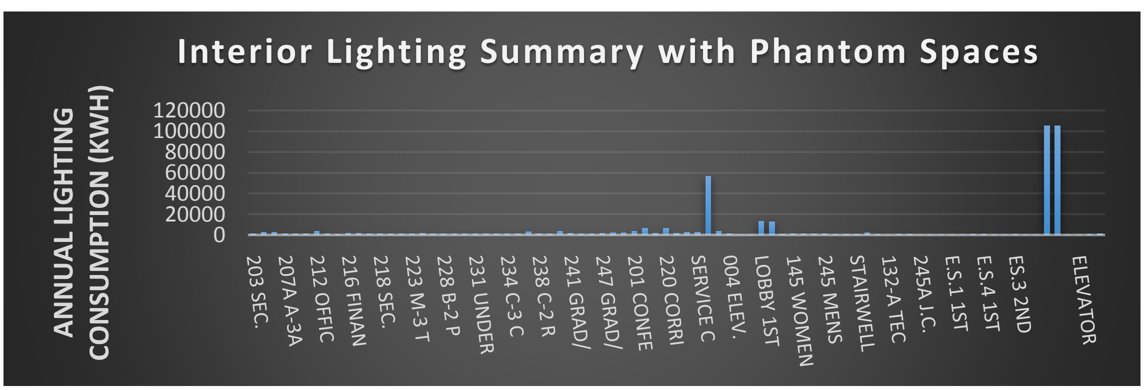
But before simulations are run, it is important that building model is furnished with indispensable equipment that constitute a major portion of building energy consumption. For this building 'The Center for Ceramic Research' **(CCR)** - according to the "Equipment Schedules" file - there are three active AHU units used to regulate and circulate air as part of a heating, ventilating, and air-conditioning (HVAC) system in CCR. Using OpenStudio, all three units were added and connected to their apropos spaces. Equipment such as furnace, oven, auto pycnometer, and screen printer are usually accompanied by canopy hood. These canopy hoods are then added as exhaust fans to the HVAC system according to the “Canopy Hood Schedule”. For all three AHUs, OpenStudio creates three different sets of “Chilled Water Loop” and “Hot Water Loop.” These three were then all merged into two overall loops of chilled water and hot water. Coil Heating Water components of all three AHUs are joint together through Hot Water Loop, and the same thing happens to Coil Cooling Waters; they were all connected through Hot Water Loop as supply-side equipment.

Fortunately, since most of the vital stuff of this project is conducted in SketchUp, all that is left to do in OpenStudio is to do little tweaks in the software such as editing the ‘Weather File’ for our building (Newark Weather File) and adding HVAC and Air Handling Units (which is already discussed). Now the first simulation was run. But first time running of any building simulation invariably serves with some sorts of errors. Luckily again there were only few errors devoid of any seriousness thus they were easily addressed in four or five attempts.

➢ Checking Errors

Running the OpenStudio model was the means to check for errors. This allowed for a detailed read out of what was wrong in the model, for example certain subsurface that have no “parent surface” or thermal zones assigned to no space. One error that continued to arise through every iteration of the model was a skylight being generated, by OpenStudio, on the first floor plenum. This caused one of many “subsurface attached to no surface” errors, that OpenStudio would not know how to interact with. Accessing the Energyplus “.err” file allowed for quick location of the error source and appropriate solutions to be enacted. In the case of the “phantom skylight” that was generated the solution was to simply delete the line-segments that created it, thus deleting the subspace entirely from the CCR OpenStudio file. So the simulation ran successfully (100 percent) and the results were analyzed. Seemingly the results were reasonable too until the ‘Interior Lighting’ and ‘Plug Load’ results were analyzed:

Upon analyzing and plotting their graphs (shown below) a peculiarity was manifested.



Two phantom spaces had appeared in the model that consumed exorbitant amount of electricity thus depicting an anomaly in these two graphs. This oversight would not have been dealt with had it not been for these two graphs. Consequently the extra-generated spaces were deleted from the ‘Spaces’ section in OpenStudio and all the errors were eventually redressed.

Model Summary

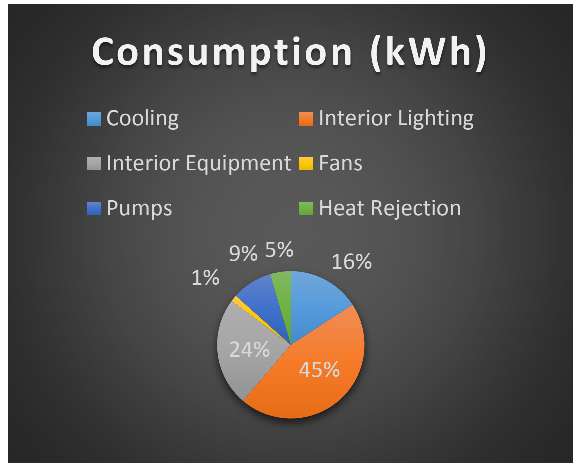
➢ Overview

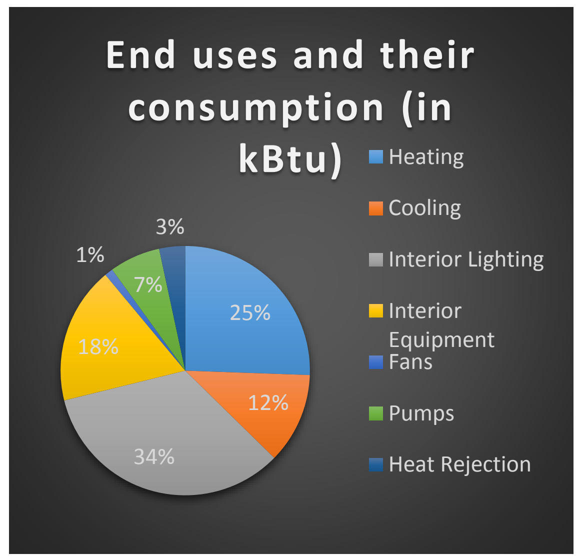
Center for Ceramic Research (CCR) fulfills its quota of energy using two sources: Electricity & Natural Gas.

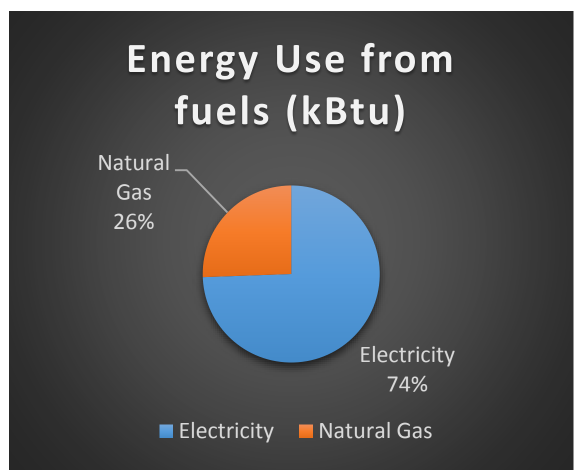
Natural Gas was solely used to cater the heating needs of the building that amounted to 0.68 million kBTU consumption whereas electric energy consumption amounted to 1.97 million kBTU. What is important to note is that electricity was assumed to be bought by the utility companies and there were not any kind of modes of independent electric generation by the building itself (that is, zero renewable influence on electricity supply of the building).

Simulation using Open-Studio software for the aforementioned building, using the predefined settings of Climate Zone (ASHRAE 4C) and location (Newark, NJ), presented an annual summary classifying the energy consumption with regard to different parameters. The simulation broadly broke down the energy consumption into 14 classes of 'End Uses' whereof 7 were assumed to be zero by the software. The rest 7 'End Uses' are shown in the pie chart. What is manifest is that 'Interior Lighting' and 'Interior Equipment' are responsible for large chunks of energy usage in CCR. Following these two, 'Heating' takes the third position in most consumption of British Thermal Units. Nevertheless, 'Heating', as mentioned before, is powered by natural gas. Therefore, it must not be confounded as an electricity dependent aspect. Fortunately, the report classifies 'consumption' using just the electricity as well.

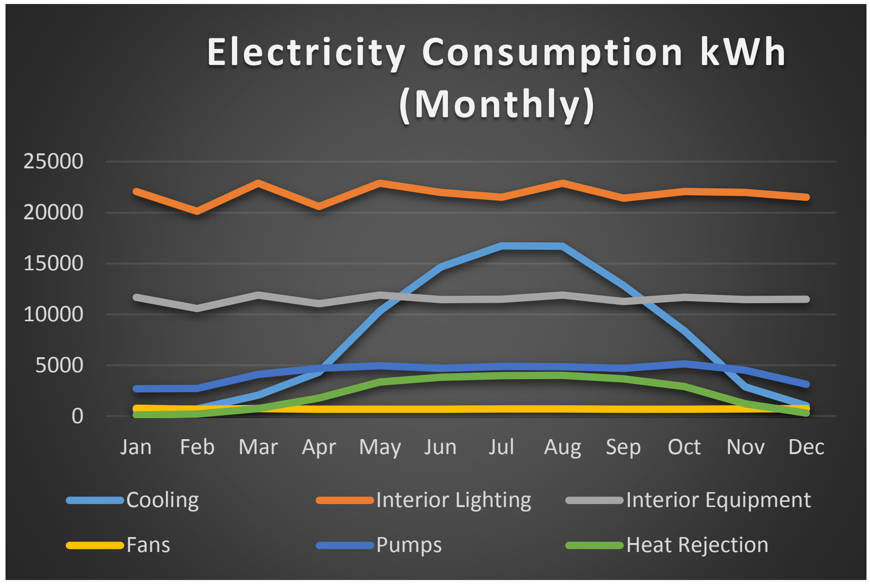
Thus, under the ambit of electricity, 'Cooling' is the third highest component, succeeded by 'Fans', 'Pumps', and 'Heat Rejection'. But still the complexion of the top two consumers does not change. Since the chart on the right denotes an unusually high percentage of 'Interior Lighting' and 'Interior Equipment' requirement, it necessitates a breakdown of their summary provided by the report. But before this precise analysis is done, it is necessary to understand the monthly summary provided by the simulation.



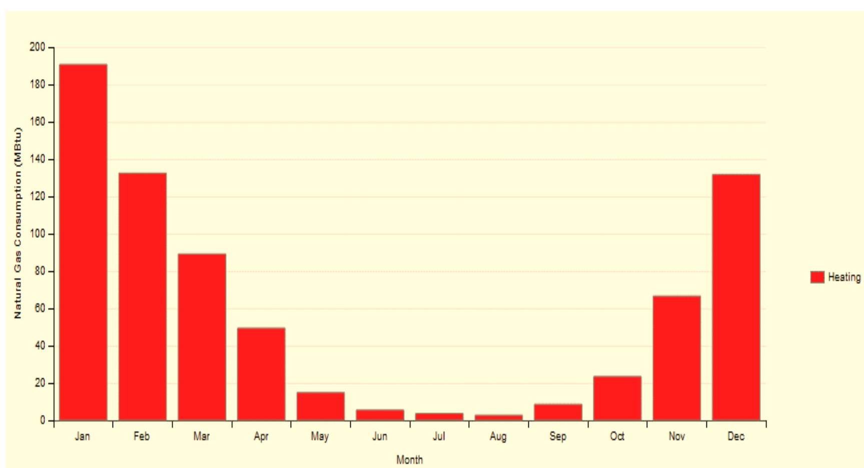




➢ Monthly Consumption Summary



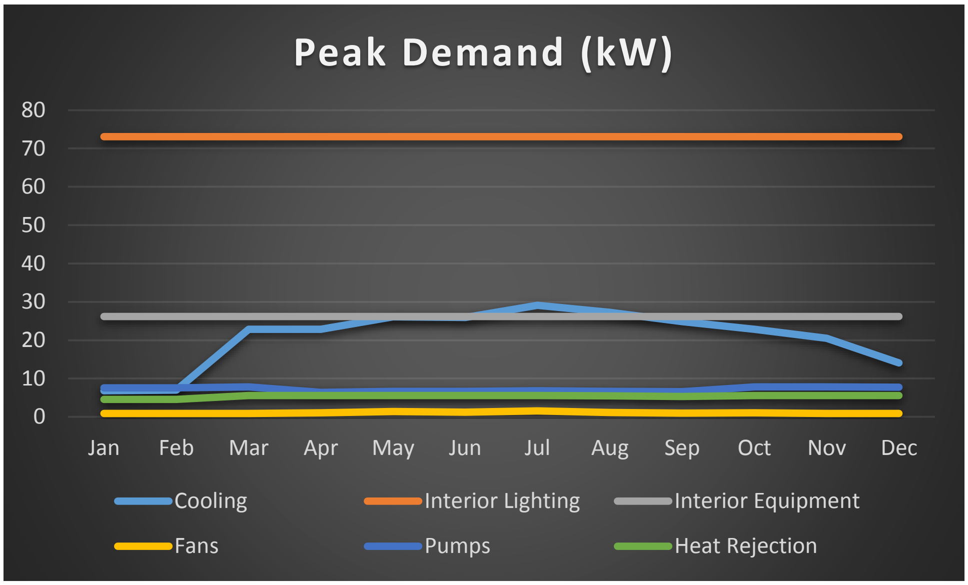
The interior lighting, which is the highest receiver of annual electricity proportion that goes into CCR, happens to undergo a lot of fluctuations throughout the year. A drop in approximately 3000 kWh in one month is followed by a gain of a few hundred units more than this amount the next month. However, after reaching October, the consumption trend starts to decline steadily till the end of December. Likewise is the trend for the second highest electricity consumer (Interior Equipment) which is emulated until October wherefrom it becomes stagnant for the rest of the year. These two trends give a general impression of a possible saving opportunity; since this fluctuating trend in interior equipment and lighting – especially – connote an arbitrariness in their occurrence with time thus we imply that they do not have a strong correlation with weather. Indirectly, it means this is something which can be controlled hence their consumption patterns are to be analyzed more carefully to achieve as much savings as possible.



On the other hand, Fans and Pumps usage remains stagnant whereas Cooling and Heat rejection follows a *sinusoidal half-wave* like trend. The peak of those waves occurs in August ostensible which makes sense since August is the highest averaging (temperature) month of the year. The boggling aspect is however, the trend of increase in pump usage from February to March and September to October which immediately dwindles after one or two months each year. As for the comparison between the cooling and heating pattern, they are in stark contrast; represented by the diagram on the right, the natural gas consumption dwindles from the month of January (which is the peak heating month and lowest cooling month) to August (which experiences the least amount of heating and most amount of cooling). The winter season starting from December till February is the most energy (natural gas energy) consuming season. What is ironic is to see that despite negative temperatures, there arises a need for cooling in CCR with the cooling energy quota of

January (the lowest month for cooling) being 2200 kWh. Although it is low but these 2200 kWh should be looked as units that can be easily saved. Small savings in energy will eventually accrue to become an ocean of energy units that will save a lot of money.

➢ Monthly Demand Summary

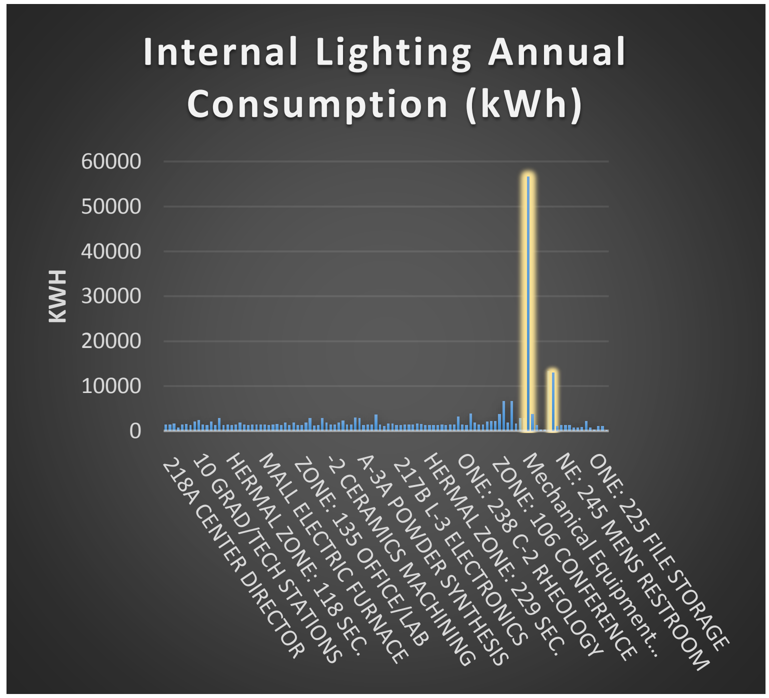


Important is to note that the amount consumed per month and the rate at which it was consumed per month was different for CCR. Presented by the simulation, the trend is essentially the same for heating provided by natural gas. But it is not exactly the same for cooling. The **cooling energy consumption** happens to be the highest in the month of **August** whereas the **rate at which electricity was consumed** was highest for **July**. This trend of increasing power demand for cooling becomes appreciable, and almost comparable to the succeeding months, already when the month of March begins. However, the trend in energy consumption depicts a considerable difference in energy consumption between March and August. Thus, this will belie the reality if 'Electricity Peak Demand' is ignored.

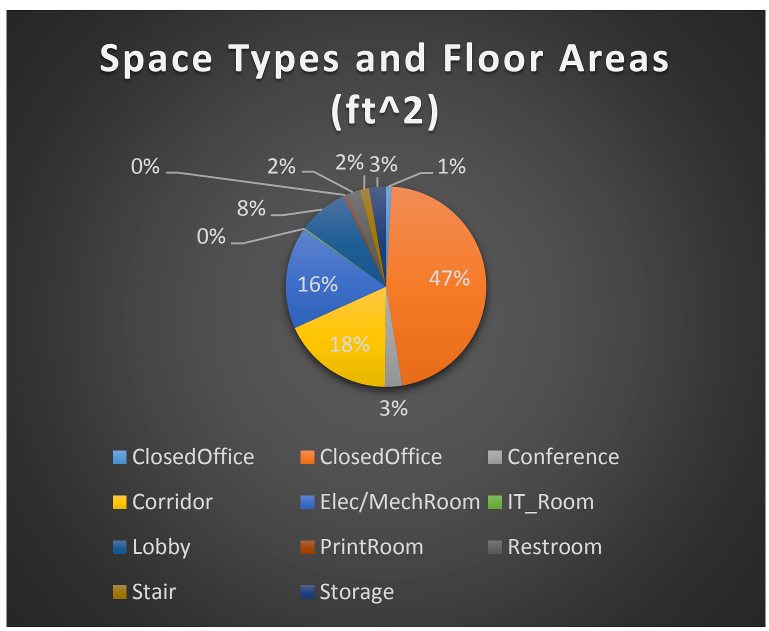
There are other ostensible disparities too between 'Consumption' and 'Peak Demand' chart. Unlike the 'Consumption' diagram, Interior Equipment and Lighting demand remain steady and it is only the 'Cooling' aspect which becomes a primary focus here. The image above helps in understanding better there is room to save money: by reducing the slope of the line – for cooling – between February and March and increasing the uniformity of the increase in demand that begins from February till July, significant amount of dollars can be saved that would have been spent on demand charge rates; given how the rates of electricity are based on the demand at a particular time it makes it worth a while to analyze the 'Peak Demand' metric.

➢ INTERIOR LIGHTING

The Energy analysis of the building boils down to Interior Lighting of CCR because of its peculiarly higher value. Interior lighting accounted for the most consumption of electricity in BTU. Although all the rooms in the building were scheduled for same number of hours per week (61.85) but each room had different power consumption just for lighting. Striking was to find out that there were two zones in the building that had the most annual consumption of electric energy associated with lighting: ***Mechanical Equipment Room*** with 56633.3 kWh annual consumption and ***1st Floor Lobby*** with 13290 kWh annual consumption. Now this maximum electric consumption associated with lighting is approximately three times higher than the second largest consumption of electricity due to lighting by a zone in the building. This denotes that there is a potential to observe any superfluous lighting expenditure occurring in the 'Mechanical Equipment Room' which will save appreciable amount of money.



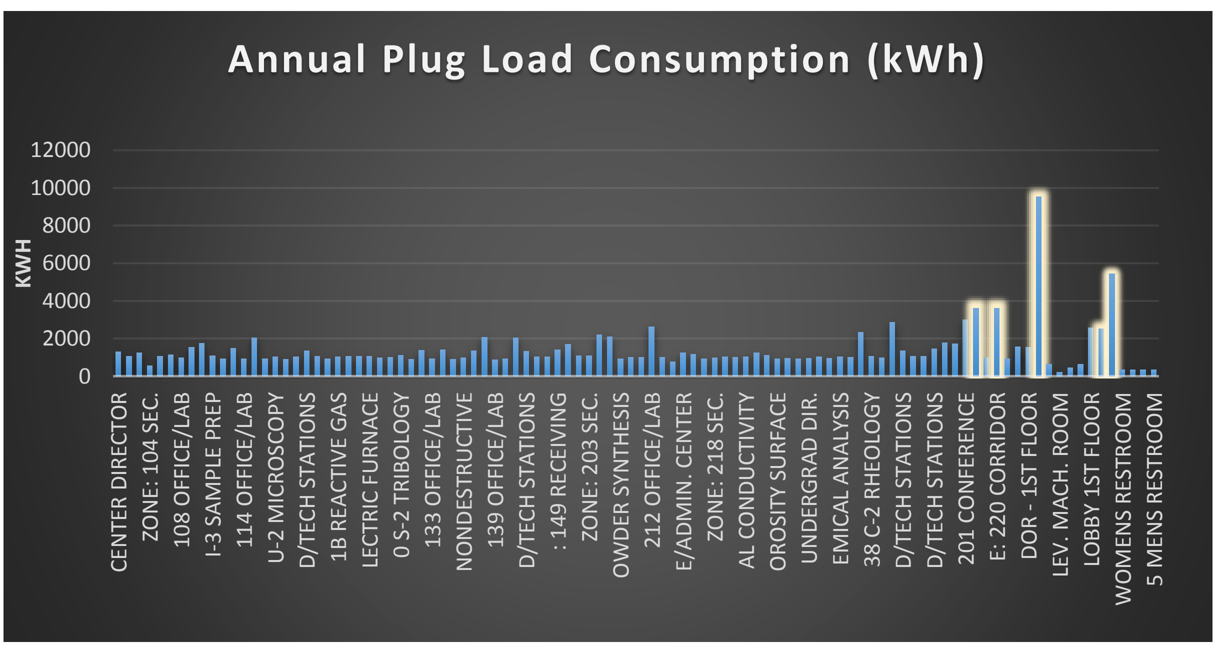
Interesting is to note that two types of zones in the CCR have a peculiar amount of lighting energy expenditure involved: the *lobby* at both floors has **8** times more consumption of light than all other zones *(excluding Lobby & Mechanical Equipment Room)*. And the corridors (two of the four corridors) have **4** times more consumption of light than all other zones *(excluding Lobby & Mechanical Equipment Room)*. When this aspect is analyzed, it leads to the reality that buildings like CCR splurge an awful amount of money on illuminating their corridors and lobby insofar that during the times when these buildings are vacant, the lighting remains on.



Another inconspicuous finding is that the ***Mechanical Equipment room's*** annual consumption, is unreasonably higher if their floor areas are considered: The *'Elec/Mech Room'* denoted by blue color in the pie chart is twice the size (in floor area) of 'First Floor Lobby' yet their electricity consumption is approximately 3 times high. This deems it necessary to examine the consumption pattern of this room to ensure that the wastage is slashed to minimum. Since it is an engineering equipment room, what usually occurs is that these rooms are least attended yet there are high power consuming devices that are left active even when they are not in use. So unlike the lighting which is left on due to carelessness, these devices have a much profound effect on the energy loss associated with it. Which is why it is an energy savings opportunity to be explored.

➢ PLUG LOAD

This telltale plug load summary reveals the reality of colossal energy wastage which is mostly overlooked. Corroborated by the report, the annual consumption of **0.14 million kWh** just from plug load only constitutes **24 percent** approximately of the total annual electricity consumption (0.6 million kWh) of the 'Center of Ceramic Research'! The external components that are plu gged in at different zones over different time periods consume electricity inchmeal which eventually becomes an appreciable amount (31 percent). The chart on the right denotes various anomalies that can be taken advantage of: the spike in the figure represented by Mechanical Equipment Room and Word Processing Rooms should place them under scrutiny because the second largest plug load contributor, which is the 'Word Processing Room', munches two times lesser electricity using plug loads. So that is a lot of difference. More striking is the fact that the Corridor (126 & 220) and Lobby (on both floors) have twice or in some case thrice the plug load consumption when compared with other important rooms of the building. Hence, analyzing these trends might open up room for viable energy cuts.



Building Performance

In the end, simulation report provided with two metrics to judge the performance of the building: Site to Source conversion factors and Energy Usage Index.

The reason they are important is because the 'Site Energy' that this software calculates does not reflect the energy losses that occur from the source by the time they reach the building because of transmission and other losses. This factor then calculates the approximate amount of energy that was being driven from the source to the receiver, which in this case is CCR.

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613

Site and Source Energy

	Total Energy (kBtu)	Energy Per Total Building Area (kBtu/ft^2)	Energy Per Conditioned Building Area (kBtu/ft^2)
Total Site Energy	2642703.6	52.0	85.9
Net Site Energy	2642703.6	52.0	85.9
Total Source Energy	6962057.8	136.9	226.3
Net Source Energy	6962057.8	136.9	226.3

Information	Value
Building Name	Center for Ceramic Research
Net Site Energy (kBtu)	2,642,704
Total Building Area (ft^2)	50,864
EUI (Based on Net Site Energy and Total Building Area) kBtu/ft^2	51.96

Between the aforementioned two parameters for building assessment, **Energy Usage Index** is more prevalently used since there is a lot of uncertainty associated with **'Site to Source Conversion Factor'**. That is why the main metric of focus here is the EU which for CCR is 51.96. Since this rating for most buildings is above 100, CCR, as per the simulation, has performed impressively by consuming lesser amount of energy per square foot.