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HVAC System Energy Audit for Leverett Elementary School

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HVAC SYSTEM ENERGY AUDIT FOR LEVERETT ELEMENTARY SCHOOL

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1 EXECUTIVE SUMMARY

Leverett Elementary School is located in Fayetteville, AR. The school needs significant upgrades to its infrastructure. The Fayetteville Public School District has voted to pursue an Energy Services Performance Contract (ESPC) in order to finance the desired upgrades to Leverett Elementary, among other schools in the district.

The scope of this thesis was to perform an energy audit on the existing heating, ventilation, and air conditioning (HVAC) system. By using an energy modeling software, eQuest, the building and the existing base system were modeled to determine utility consumption. Three different HVAC system alternatives were analyzed against the base system by inputting them into eQuest. Alternative 1 is a plant system with secondary fan coil units. Alternative 2 is a decentralized packaged system. Alternative 3 is a plant system with a secondary air handler that serves terminal variable air volume (VAV) boxes.

The three alternatives were compared against each other within three criteria: economic, environmental, and social benefits. For the economic analysis, capital and operating costs were analyzed to determine the net present value and internal rate of return for each alternative. For the environmental analysis, the utility consumption output from the eQuest models was input into an online tool, CometFarm, to calculate total energy consumption and CO_2 equivalent emissions. For the social analysis, knowledge from extensive systems research and industry experience guided the consideration and assessment of potential impacts.

The Plant System with Secondary Fan Coil Units, i.e., Alternative 1, was determined to be the optimal system recommendation for the client. It had the lowest CO_2 equivalent greenhouse gas emissions and the greatest net present value and rate of return.

2 PROJECT OVERVIEW

2.1 Client Profile

Leverett Elementary School is located at the corner of Garland Avenue and Cleveland Street in Fayetteville, AR. The school was originally constructed in 1939 as a part of the Fayetteville Public School District (FPSD). Renovations and additions were completed in 1985 and 2012. The current structure has a gross floor area of 49,530 square feet. The current enrollment stands at 301 students. The facility is in dire need of infrastructure improvements due to the aging of the equipment and some level of deferred maintenance due to budgetary restrictions. The renovations in 2012 only addressed immediate problems without tackling significant overarching system issues.

2.2 Problem Statement

Currently, Leverett and several other schools in the FPSD are suffering from poor facility conditions, high maintenance costs, and utility costs due to inefficient mechanical (HVAC) and lighting equipment. The Fayetteville Public School Board and Fayetteville taxpayers want to improve the learning environment for their teachers and students, while also reducing their operating costs, fossil fuel consumption and carbon footprint on the natural environment. The Board has voted to pursue an Energy Services Performance Contract (ESPC) with a local energy services company, Entegrity Partners.

2.3 Goals and Scope

The goals of this project are to reduce energy usage and greenhouse gas emissions for Leverett Elementary School while achieving a rate of return of at least 10%.

While Entegrity's ESPC project encompasses the entire school district, the scope of this report (an undergraduate honors thesis) was concentrated solely on Leverett Elementary School. The full ESPC project consists of HVAC, lighting and building envelope upgrades (insulation, doors and windows); however, this honors thesis project and report focused on improving the HVAC system for the school. A report was produced with full replacement recommendations. These recommendations were based on energy modeling analysis and information gathered from onsite equipment audits and data logging. The report includes multiple alternatives for the client to consider. For each alternative, economic, environmental, and social factors were considered and analyzed.

3 INTRODUCTION

3.1 Energy Savings Performance Contracts

An ESPC can broadly be defined as a contracting framework for an energy services company to make efficiency-based improvements to a facility while guaranteeing the subsequent operational expenses will be sufficient to cover the capital cost of the project. Building owners can, therefore, make substantial upgrades to their facilities with little, or no, out of pocket expenses.

An ESPC generally consists of three stages. First, a feasibility study is used to identify savings opportunities by analyzing utility data, interviewing key personnel, and touring the facility. If there is determined to be significant potential for improvement, a project agreement is written up. This document defines the project's cost, benefit, and scope. A signed project agreement allows for the project development stage to begin. During this stage is when an in-depth facility audit is conducted with more detail into the building's systems. The goal of the project development stage is to identify specific energy and operational saving measures. Various tools such as energy modeling, building testing, and data logging can be used to identify opportunities. Once the project development stage has been completed, the facility owner can move to implementation. They have the option of seeking an outside financer and contractor for the project, but generally, these next steps are handled by another department within the same energy services company.

3.2 ESPC Legislation in Arkansas

The Arkansas legislature passed the "Guaranteed Energy Cost Savings Act," legalizing energy savings performance contracts in 2005 (Arkansas Code Annotated, 2005). These laws have been amended by successive bills in 2013, 2015 and 2019, expanding the entities that qualify for ESPC projects (Arkansas Code, 2013a, 2013b, 2015, 2019). Under current Arkansas law, an energy cost savings measure can be financed with future savings, therefore covering all project costs. The Arkansas Energy Performance Contracting program states that public entities may count guaranteed savings from avoided utility costs, avoided maintenance costs, and avoided capital costs as revenue. The energy services company is required to provide a guarantee on the energy savings, and, if this is not met, must pay the cost difference for their client. All savings must be verified through measurement or mutual, written agreement. The term of these contracts may not exceed 20 years or the weighted useful life of the installed equipment. These policies have allowed for thousands of ESPC projects to be completed, saving energy, the environment, and money across the state and the region.

3.3 HVAC Systems

Heating, Ventilation, and Air Conditioning (HVAC) Systems are incorporated into most modern occupied spaces to control temperature, humidity, pressure, air quality, and, thus, comfortability. These systems must be designed considering heat gain (solar radiation through windows, internal heat from lighting and occupants, heat gain through the building envelope) and heat loss (infiltration, heat loss through the building envelope) from the building to the environment (Hart, 2016). A wide variety of system types have been developed and are implemented to solve a range of building management issues. The most common system types used for educational spaces similar to Leverett Elementary can be divided into two main categories: decentralized systems and centralized systems (Brandemuehl, 2019).

<u>Refrigeration Cycle</u>. The refrigeration cycle is the driving mechanism behind many pieces of HVAC equipment that aim to cool a space. Equipment controls the phase change of refrigerant to achieve heat exchange from a cooler indoor space to a warmer outdoor space. Four main components drive the refrigeration cycle: condenser, expansion valve, evaporator, and compressor. The condenser receives refrigerant as a

high-pressure gas and forces it through a phase change to a high-pressure liquid. This phase change expels heat from the refrigerant to the outside air. The expansion valve receives refrigerant as a high-pressure liquid and reduces the pressure in the liquid refrigerant. The evaporator receives refrigerant as a low-pressure liquid. It then forces the refrigerant through a phase change from liquid to gas. This phase change causes the refrigerant to absorb heat energy from the interior space. The compressor receives refrigerant as a low-pressure gas and increases the pressure of the gas. The cycle then begins again with high-pressure gas reaching the condenser. This process can also be reversed to add heat to a warmer interior space from a cooler exterior space. This is called a heat pump (Hoffman, 2006). The primary system energy consumption is typically associated with an electric motor that drives the compressor, and the two fans associated with the two heat exchangers (one heat exchanger is inside the conditioned space, and the other is located in the outside ambient air).

Decentralized Systems

A decentralized system has heating and cooling infrastructure located adjacent to each occupied space. There are two primary sub-categories within the decentralized system categories:

Split systems. Split systems are considered to be the most basic HVAC system and typically consist of an outdoor condenser and an indoor cabinet with the condenser, evaporator and a dedicated air handler. They are preferred for residential buildings. The indoor unit can either provide heat from electric resistance heating coils, natural gas combustion, or heat pump heating (a reversal of the cooling mode). For cooling, an outdoor compressor cycles refrigerant through and uses a fan to expel heat to the outside air. The cooled refrigerant is then sent inside to the indoor unit, which houses the air handler with a cooling coil to condition the air before it enters the space. Split systems usually serve a single room/space in a commercial scenario. While this makes it convenient and simple to control a space, the indoor unit of the split system will take up valuable room inside, unless there is a nearby utility closet or adequate space in the attic. Generally, these systems require a lower capital investment compared to central systems (Split, 2019).

Packaged Units. Packaged units house the heating, cooling, and air handling mechanisms in a single enclosure on the exterior of the building. They consist of a heating coil, cooling coil, air filters, return fan, and supply fan. Cooling coils circulate refrigerant and cool air as the fans pass air over it. Heating can either be accomplished by reversing the refrigerant cycle (i.e., heat pump mode), electric resistance heating, or natural gas heating. Packaged units can be installed either on the roof or on the ground outside of the building. Insulated ducts are installed to transport conditioned air into the building. They can serve single or multiple zones. Packaged systems are a popular choice for buildings with limited space as they provide more flexibility when it comes to installation compared to split systems. However, they do tend to be less energy efficient. Generally, these systems require lower capital investment compared to central systems (Kuntz, 2019).

Centralized Plant Systems.

Plant systems consist of a centralized boiler and chiller with terminal units to serve individual spaces. Boilers are units that heat water to a set temperature for space heating. They can either use electric resistance or natural gas combustion for heating. Chillers are units that cool water to a set temperature. There are multiple types of chillers: air, water, and evaporative condensed (Oza, 2015). Chillers lower the temperature of the condensing water by forcing a heat exchange between one of the three medias listed above, while utilizing the refrigerant cycle. From the plant equipment, hot water and cold water pumps transport the heated and chilled water separately throughout the building to terminal units. Centralized systems such as these typically demand larger and subsequently more expensive equipment that has higher quality, efficiency and life span. The complex nature of these systems does require concentrated and consistent maintenance (Hart, 2016).

Plant systems rely on the use of terminal equipment to heat and cool spaces. There are two main options for terminal equipment, namely fan coils and air handling:

Fan Coils. Fan coil units are terminal to plant systems. These units receive heated and chilled water directly from the boiler and chiller in a plant system through a network of insulated pipes. At these units, the conditioned water is sent through coils (a small heat exchanger). A fan circulates the space's air through the coils to achieve the desired temperature. Fan coil units can easily be added and removed from a plant system, which makes them desirable for commercial spaces with varying sizes and load requirements.

When paired with the plant system, these units consistently provide the highest efficiency across varying building loads. A factor to consider with fan coils is that they do not usually include the circulation of any outdoor air or ventilation or make-up air. A lack of outside air can cause several issues, including high humidity and carbon dioxide levels. While a central plant with fan coils system requires a higher capital cost than the decentralized systems, it is not quite as expensive as a secondary air handling system. (Hart, 2016)

Air Handling. Air handling units (AHU) are centralized fan and duct systems that provide heating, cooling, and ventilation for multiple spaces within a medium to large industrial or commercial building. These units serve as secondary HVAC equipment to a plant system. They begin with air dampers which control the air flow into the AHU. Dampers also manage the mixture of air between outside air and return air. Next, the air will pass through air filters to clean out debris. The air will then hit a cooling coil and a heating coil. Finally, a supply fan pushes air into a duct and throughout the building. Return and exhaust fans are also included in some systems to control ventilation and recycling. Additional components, such as an energy recovery wheel, humidifier, and pre-heat coil, can also be included in these units (Evans, 2018). Air handler ducts, usually insulated, lead throughout the building to terminal VAV (variable air volume) units. These control the temperature and air flow to specific rooms. Return air will be recirculated and mixed with new outside air to reduce energy usage. These setups typically provide better air quality compared to plant systems with fan coil units. Just like plant systems, air handling systems allow for larger, higher quality, more efficient and longer lasting equipment to be installed. Additions, like an energy recovery wheel, provide the opportunity for more energy efficient systems to be constructed. The added complexity does require regular maintenance and in-depth system knowledge. These systems achieve their highest efficiencies with larger buildings, where a single plant system can serve multiple air handlers.

A summary of the characteristics of the four HVAC systems is shown in Table 1.

Table 1: Comparison of various HVAC system types across multiple categories, with ratings from 1 (low) to 4 (high).

System Type	Capital Cost	Maintenance Costs	Energy Efficiency	Installation	Complexity	Comfort
Split	2	1	2	3	1	4
Packaged	2	2	1	4	1	4
Plant with Fan Coils	3	3	4	1	4	3
Plant with Air Handler	4	4	3	1	4	2

3.4 Energy Modeling Software

Energy modeling software is a tool for engineers to create models of residential or commercial buildings that simulate HVAC, lighting, water, and envelope design alternatives to estimate energy usage and resource consumption. eQuest is a free, online, energy modeling software package that was developed with funding mostly from the

United States Department of Energy. This software is one of the best on the market, and the only one that is available for free. An accurate building model can be created in the schematic creation wizard with the help of construction documents and detailed building knowledge. Specifying the building location allows for yearly weather patterns to be estimated from a proximate weather station. With the input data, building energy loss can be calculated. eQuest allows for various building zones to be defined and HVAC equipment to be assigned to each zone within the design creation wizard. By modifying the HVAC equipment, different alternatives can be compared directly using the output data provided. eQuest and other energy modeling software serve as powerful tools for comparing energy consumption between various design options (Hirsch, 2016).

3.5 Sustainability Opportunities

HVAC systems account for 39% of commercial building energy usage across the United States. Replacing outdated mechanical equipment has the potential to decrease energy usage by anywhere from 10% to 40% depending on the building. Energy savings performance contracts offer a path to decrease energy usage and associated emissions from a large portion of the energy consumption of the United States (Graham, 2016). Sustainability balances the needs of society, the economy and the environment. An ESPC project embodies these goals. New mechanical equipment will achieve an improved level of comfort and health for the occupants. The project financing allows for the installation of new equipment, which will generate a profit within the lifespan of the system. A decreased utility bill means a decreased carbon footprint for the facility.

Energy savings performance contracts are a proven way to decrease society's impact on the environment, while creating a prosperous, sustainable, and comfortable future.

4 EXISTING CONDITIONS

4.1 Facility Overview

Leverett Elementary School is located in Fayetteville, Arkansas at the corner of Garland Avenue and Cleveland Street. A photograph of the front of the school is shown in Figure 1. Fayetteville lies in the hills of the Ozarks. The city is located in a deciduous forest climate. Drake Field Weather Station is the nearest one to Leverett and was used for the weather inputs within the energy modeling software.

<u>Figure 1:</u> Image of the Front of Leverett Elementary School, Fayetteville, Arkansas.

The school was originally constructed in 1939. Two expansions and renovations were completed in 1985 and 2012. The expansions continued the architectural style used for the initial construction, using the same red brick for the entire exterior. Construction documents are typically used to ascertain the specific materials that were used for construction. The remaining plans from the 1939 construction were limited to simple architectural layout drawings. For both the 1985 and 2012 projects, only the mechanical sections (heating and cooling equipment) of the construction documents were made available from the school district. The 1985 plans showed that the original section of the school went under renovation while the additions were being completed. The entire HVAC system was upgraded and installed during this project. Therefore, the existing HVAC system, insulation, roofing, and fenestration originates from the 1985 project. Unfortunately, the school district no longer possessed the materials lists, so the exact equipment and materials used must be assumed or determined based on-site visits. The 2012 project mainly involved interior renovations and some simple HVAC maintenance, so they were not essential to the energy modeling process. Floorplans were provided showing dimensions and layouts for the entire school.

The author made multiple site visits to the school as part of the energy audit process performed by Entegrity, an energy services company. From direct observations, it was found that Leverett Elementary School's HVAC system was a mixture of two systems: a plant system and multiple packaged single zone rooftop units. Most of the building zones were served by fan coil units that receive chilled water from a rooftop chiller and heated water from a boiler in one of the mechanical rooms. Only 6 zones were served by packaged units located on the roof.

Leverett Elementary had a total 2018 enrollment of 301 students. There are additionally 35 full-time employees, including teachers, administration, maintenance, cafeteria workers, and a nurse. The majority of the spaces in the building are classrooms with a student occupancy of 10 to 20 students. Other spaces included a cafeteria, kitchen, library, gymnasium and offices.

4.2 Base Year Utility Expenses

The annual utility data for Leverett Elementary School was compiled from 2016 to 2019. Benchmark values have been calculated to serve as typical yearly values for comparison against alternatives.

Electricity Usage:	306,000kWh/year
Electricity Unit Cost:	$0.0966/kWh
Electricity Cost:	$29,500/year
Natural Gas Usage:	872 MMBtu/year
Natural Gas Unit Cost:	$8.37/MMBtu
Natural Gas Cost:	$7,300/year

4.2.1. Base CO_2 Equivalent Emissions

The utility data from Leverett Elementary was provided by the Fayetteville Public School District, and then was input into CometFarm (Colorado State University, 2019) to determine the current building's environmental impact, see Table 2.

Table 2: Measured annual utility consumption data and the output from CometFarm for the estimated annual carbon dioxide equivalent emissions of global warming potential gases.

System	Electric Consumption (kWh/y)	Natural Gas Consumption (CCF/y)	Total Energy Consumption (MMBtu/y)	Tot CO_2 Eq (tons/y)
Base	311,000	8,250	1910	296

4.3 Base Maintenance Costs

Leverett Elementary School lacks detailed accounts of historic maintenance costs. Therefore, maintenance cost was assumed to be 15% of utility cost based on industry experience from employees within Entegrity Partners. The maintenance costs associated with the above electricity and natural gas consumption are shown below.

Maintenance (Electric Usage) $4,430/year

Maintenance (Natural Gas Usage) $1,090/year

Total Maintenance Costs: $5,520/year

4.4 Base Operating Costs

The operating costs for the base system consists of the reported electricity cost, reported natural gas cost, and estimated maintenance costs associated with those consumptions.

Electricity Cost: $29,500/year

Natural Gas Cost: $7,300/year

Total Maintenance Cost: $5,520/year

Total Operating Cost: $42,320/year

5 Energy Modeling

With knowledge of the existing building's condition, a representative model of the building and its systems was created in eQuest. This model was then used to model the base system using the given utility consumption as a guide. Once the base system was modeled, various alternative HVAC systems were inputted into the model to compare systems.

5.1 Model Inputs

eQuest has specific requirements to create and run a successful and representative model. These inputs are outlined in the following sections.

5.1.1. Building Shell

The first step when building an energy model in eQuest is to create the building shell. The software allows for multiple options to complete this process. Most recent construction projects will have a 3D AutoCAD drawing. eQuest can import AutoCAD files and render the shell from the structure in AutoCAD. eQuest also can create the entire building shell model by manually inputting the configuration within the software, using the layout information gathered from construction documents and floorplans. Since AutoCAD drawings were not available for Leverett School, the manual definition was the method that was used. An image of the building shell from eQuest can be found in Appendix 1.

5.1.2. Heating and Cooling Zones

After the building shell is completed, heating and cooling zones must be defined dividing up the interior space of the building. Zones determine the areas that individual HVAC units will serve. Since Leverett Elementary is a school, the majority of the zones are divided by classrooms so that each classroom will have an individual unit serving their zone. An image of the zone layouts for each section of the building can be found in Appendix 2.

5.1.3. Equipment

Assigning the correct equipment to each zone is essential to developing an accurate energy model. Equipment locations can be determined using complete mechanical construction documents. However, Leverett Elementary's construction documents were lacking detailed equipment schedules. The equipment location was determined from the on-site audit portion of the project. The base system consists of a boiler, chiller, air handling unit, and 46 fan coil units, plus six individual packaged units.

5.1.4. Location & Weather

eQuest allows for weather data to be individually input by the user, however, the most efficient approach is to locate the nearest weather station to the project site. The weather station will provide a weather data file that eQuest is able to read and produce an accurate model of the typical conditions. Building orientation is also important when considering solar radiation. The cardinal orientation of the building can be determined using construction documents or an onsite visit. The main axis of the building, parallel to Cleveland St, was input as due east-west. The weather station nearest Leverett Elementary school is Drake Field Weather Station. eQuest requires .bin weather files to run energy modeling calculations. The eQuest website provides links to various weather data sources. The most commonly used source is the Typical Meteorological Year (TMY3 being the most recently updated version). TMY3 compiles data from the National Solar Radiation Data Base and US Department of Energy to create a data set of hourly solar radiation values and meteorological events for a representative 1-year period.

5.2 Assumptions

When complete building information cannot be attained, certain assumptions must be made. Some assumptions were made when creating the heating and cooling zones. The majority of zones were easily identifiable (classrooms, offices, etc.), however, certain uniquely shaped spaces required intuition to determine zone layout. Additionally, the construction documents provided for Leverett lacked detailed materials lists within the construction documents. Therefore, exact R-values for building materials were assumed from the default building settings in eQuest. These ratings are based on standard values from AHRAE 90.1, which includes approximate insulation values of R-13 for the walls, R-19 for the roof, and U-0.6 for the windows. Assumptions may have the potential to skew the base system model results away from the utility data. The insulation assumptions could overestimate the actual envelope quality. Therefore, calibration was necessary to match the base system model output to the utility data.

5.3 Base System Output

With the above inputs, the energy model was successfully run for the Base System. Figure 2 shows the eQuest output for the Base System from Leverett Elementary School, namely the monthly electricity (MWh) and natural gas (MMBtu) consumption data.

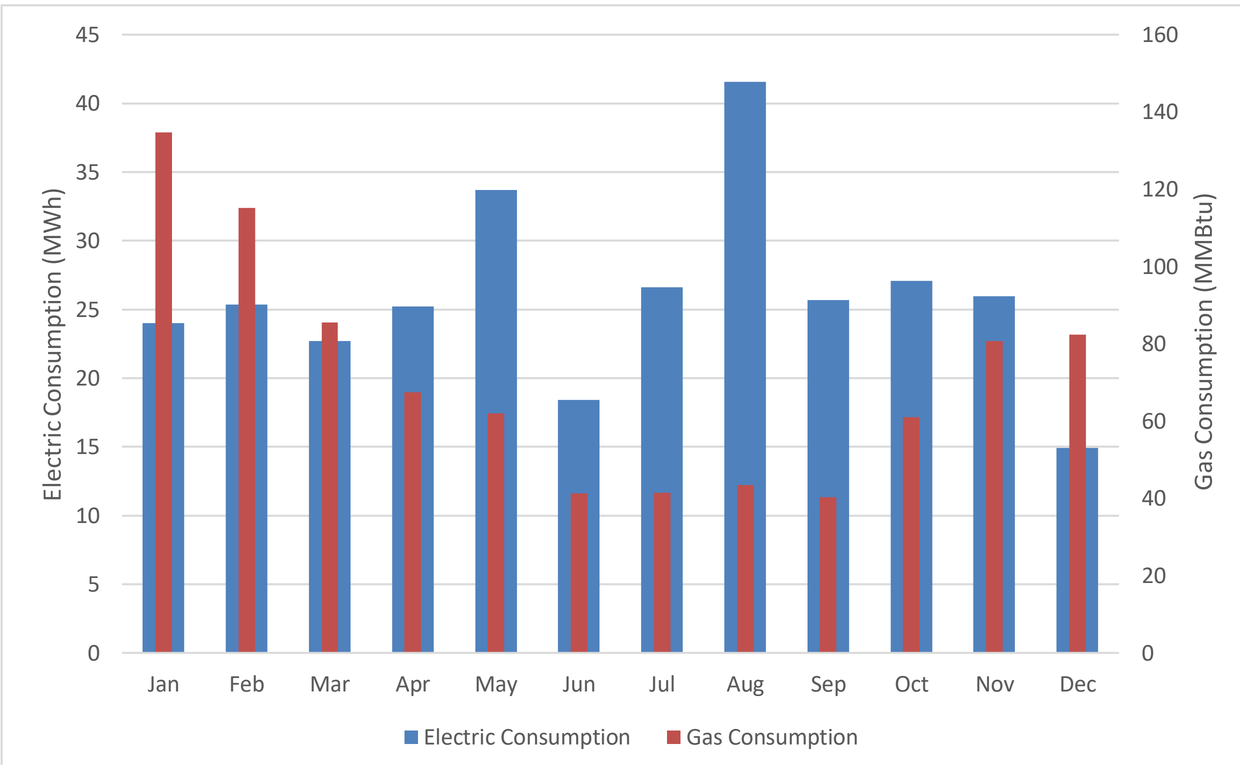

Figure 2: Base System eQuest Output for Electric (MWh) and Gas (MMBtu) Consumption.

5.3.1. Calibration

The industry standard is to calibrate energy modeling outputs using the utility data gathered for the building. In eQuest, this is typically done by adding miscellaneous plug loads to the system. These loads mainly account for equipment efficiency losses that might not be apparent based on analysis of the building documents and physical visits to the school. Since any of the proposed upgrades would include all new equipment with specific performance ratings, these added plug loads will only be included on the Base System. This factor is included in the total energy usage graphed above. The addition of plug loads to the Base System will allow for a more accurate comparison between the various alternatives. There is a possibility for the plug loads to encompass losses due to an overstated building envelope quality in the base model. This could lead to a slight overestimation in economic and environmental benefits of each system relative to the base system. However, this will not negatively affect any relative comparisons made between different alternatives. Moreover, any existing envelope deficiencies will probably be upgraded as part of Entegrity Partners comprehensive plan. Thus, the energy consumption predictions for the Alternatives will not include these biases.

5.4 Equipment Sizing for Alternative Systems

Three alternatives were modeled in eQuest to explore electricity and natural gas utility savings compared to the base.

Alternative 1 — Plant System with Secondary Fan Coil Units

Alternative 2 — Decentralized Packaged Systems

Alternative 3 — Plant System with Secondary Air Handler

Equipment was sized based on predicted heating and cooling loads for each space from the model outputs. Loads were given in heating or cooling (in Btu). These values were divided by 12,000 to convert from Btus to tons (of refrigeration), an industry preferred unit of cooling capacity. Utilizing industry contacts, preferred equipment (manufacturer, series and models) were selected to meet the calculated load criteria for each space. The following sections contain descriptions equipment selected for each of the three alternatives.

5.5 Alternative 1: Plant System with Secondary Fan Coil Units

5.5.1. Scope of Work

For Alternative 1, the base system will be replaced by a full plant system. The plant system will consist of an air-cooled chiller and hot water boiler. The chilled and heated water will then be pumped throughout the building to terminal 4-valve fan coil units within each control zone. A few zones lack the piping infrastructure for a fan coil unit to be installed, therefore, piping will need to be run to 6 spaces, where the base system previously had packaged units.

5.5.2. HVAC Equipment Summary

The system will consist of one replacement chiller, one replacement boiler, and 52 replacement fan coil units. The equipment selected was based on the following energy modeling output. The chiller is a York YLAA0120 120 ton air cooled chiller. The boiler is a Lochinvar FBN1751 140 ton hot water boiler. The fan coil units are York FWXX-320 four-valve fan coil units. Six 1 ton units, thirty-two 2 ton units, eight 3 ton units, two 4 ton units, two 5 ton units and two 7 ton units will be installed based on eQuest loads calculated for each space.

5.6 Alternative 2: Decentralized Packaged Systems

5.6.1. Scope of Work

Alternative 2 involves removing all existing plant system equipment. Every space will be served by a single-zone rooftop or ground packaged unit. Therefore, the building will require 52 new packaged units to replace the base system. The current system only has 6 spaces served by package units. The remaining 46 spaces will require short stretches of ductwork be run from their respective units outside the building into the space.

5.6.2. HVAC Equipment Summary

The system will consist of 52 single-zone packaged units. These were sized based on the energy modeling output in Appendix 3. The packaged units are Goodman GPC14XXH ground and rooftop single zone packaged units. Six 1 ton units, thirty-two 2 ton units, eight 3 ton units, two 4 ton units, two 5 ton units and two 7 ton units will be installed based on eQuest loads calculated for each space.

5.7 Alternative 3: Plant System with Air Handling Unit and Terminal VAV Boxes

5.7.1. Scope of Work

Alternative will replace the base system with new plant equipment and a secondary air handling system. A new air-cooled chiller and hot water boiler will be installed. Instead of being run to fan coil units throughout the building, the heated and chilled water will be pumped to a centralized single duct rooftop air handler. This air handler will heat, cool, and filter the air before sending the treated air through ductwork throughout the building to terminal VAV boxes that serve each control zone. This system is furthest from the base system, so extensive ductwork installation will be required.

5.7.2. HVAC Equipment Summary

This system will consist of a new chiller, boiler, air handler, and 52 VAV terminal boxes. These units were sized based on the following energy modeling output. The chiller is a York YLAA0120 120 ton air cooled chiller. The boiler is a Lochinvar KBL801 70 ton hot water boiler. The air handler is a Daikin DCC300 300,000 CFM air handling unit. The VAV boxes are Trane VSWFXX variable air volume boxes.

Six 1 ton units, thirty-two 2 ton units, eight 3 ton units, two 4 ton units, two 5 ton units and two 7 ton units will be installed based on loads calculated for each space.

5.8 eQuest Model Output for All Alternatives

The following two graphs (Figure 3 and 4) display the monthly consumption data calculated by the eQuest models for each alternative. Figure 3 shows the electricity consumption for the alternative systems in terms of MWh. Figure 4 shows the natural gas consumption for the alternative systems in terms of MMBtu.

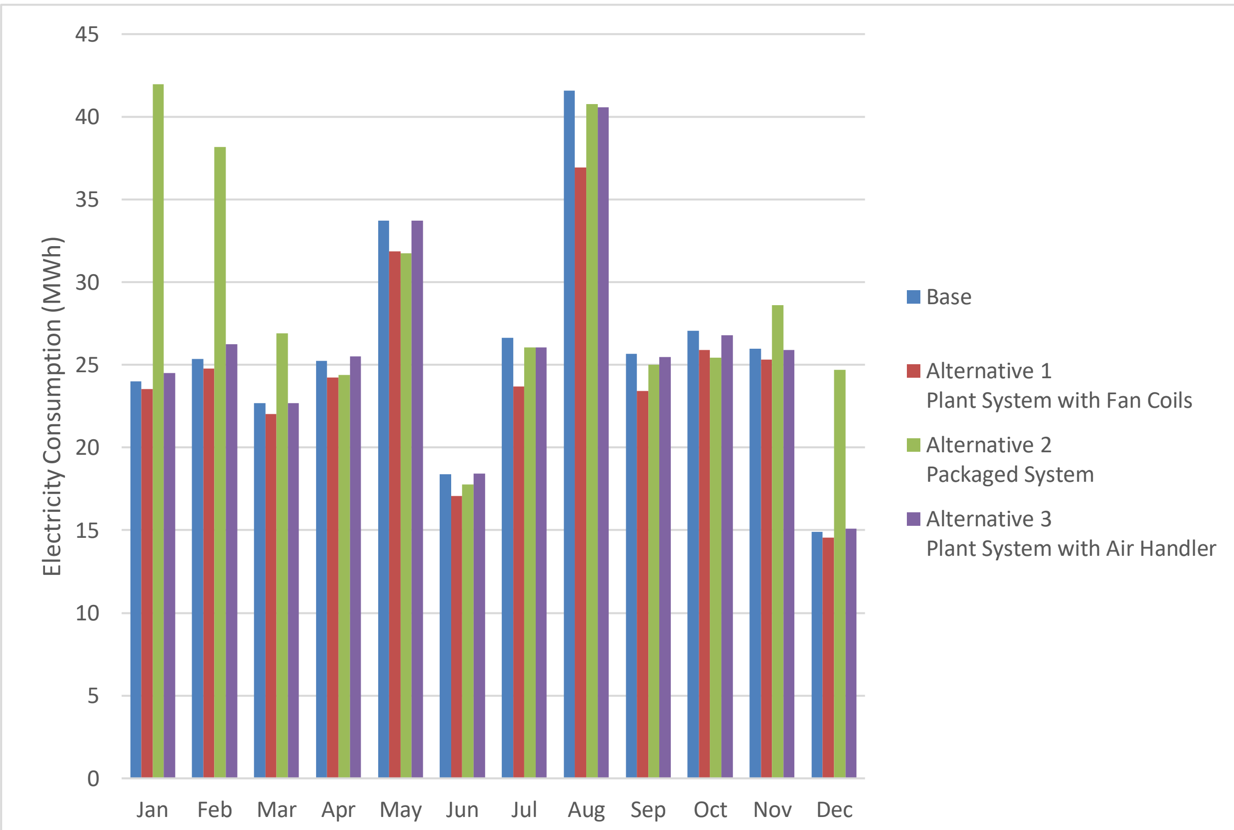

Figure 3: eQuest Electricity Consumption Output for All Alternatives and Base

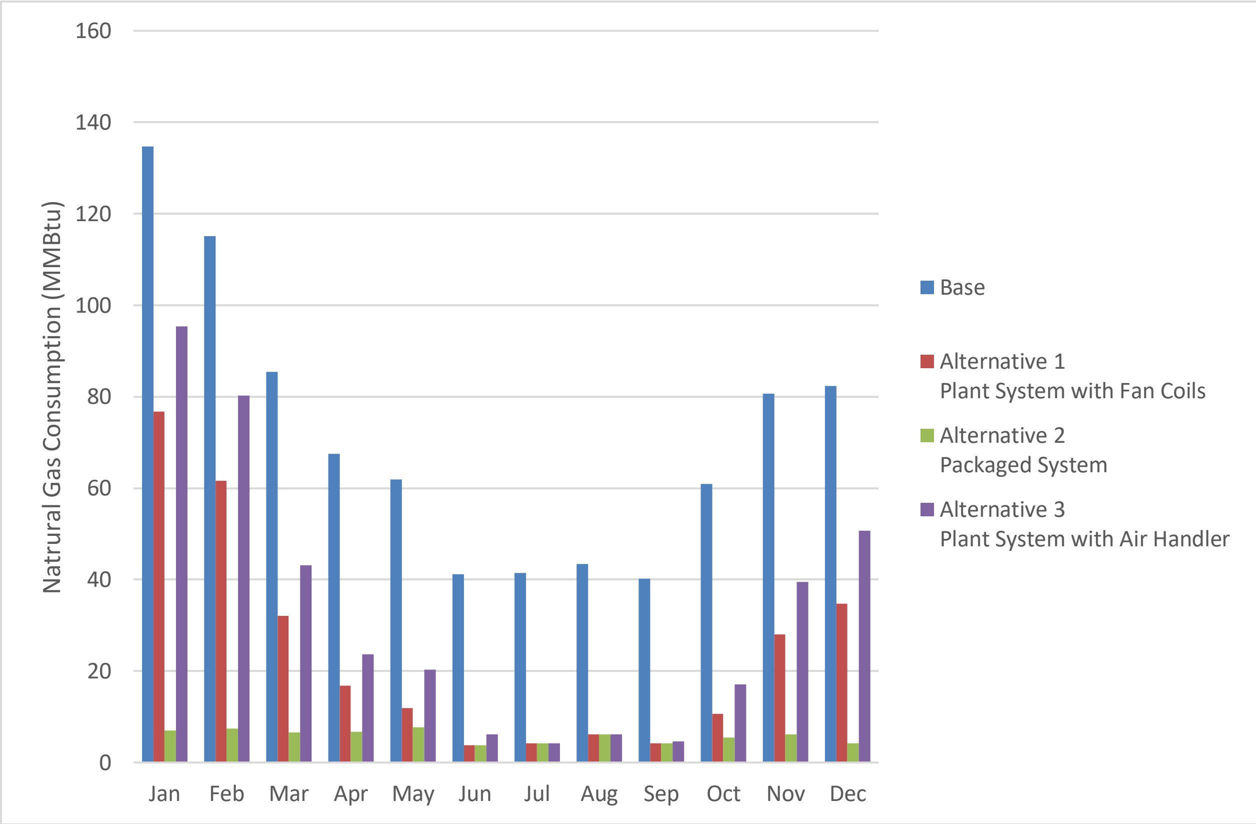

Figure 4: eQuest Natural Gas Consumption for All Alternatives and Base.

6 Results & Discussions

The following section will compare and analyze each alternative against the base system for economic, environmental, and social feasibility.

6.1 Economic Comparison

Capital costs, operating costs, and the useful life (25 years) were used to create a cash flow diagram to yield the net present value (at a 10% interest rate) and internal rate of return for implementing each alternative.

6.1.1. System Lifespans

The life of the systems has been determined to be 25 years. This is the longest allowable financing term allowable by state law, unless the equipment is warrantied for a longer period. All the equipment selected has an estimated life span of 25 years.

6.1.2. Interest Rate

For the purpose of calculating net present value, an interest rate of 10% was selected. Entegrity Partners has a minimum acceptable interest rate of 10% for all performance contracting projects they undertake.

6.1.3. Capital Costs

The capital costs for each alternative consists of equipment costs and installation costs, including labor and infrastructure upgrades. This is a one- time investment at the beginning of the life of the given system.

6.1.4. Operating Costs

The operating costs for each alternative consists of utility usage and maintenance costs associated with system upkeep. Maintenance costs will fluctuate depending on the integrity and complexity of the system. These costs are factored in as a percentage of utility usage. Based on research and industry knowledge, varying percentages were assigned to each alternative to represent their relative projected maintenance needs: Alternative 1 = 12.5%, Alternative 2 = 10%, and Alternative 3

= 15%. Alternative operating costs are compared against the operating cost of the base system to determine the annual savings for the cash flow diagram used for economic calculations.

6.1.5. NPV and IRR

Using Excel cost equivalent formulas, a uniform annual series (operating costs) can be added to an initial investment (capital costs) to determine the net present value and internal rate of return for each alternative.

6.1.6. Economic Comparison of Alternatives

From the modeling results, each of the three alternatives achieved significant operating cost savings compared to the base system, see Table 3. This is evidence that each alternative is more efficient than the base system. Alternative 1 and Alternative 2 have nearly identical capital costs of approximately $78,000. However, Alternative 1 has a significant economic edge due to a nearly $4,000 a year advantage in operating cost savings. Alternative 3 is inferior in every economic analysis category. Alternative 1 presents the best economic opportunity with the highest net present value and internal rate of return of $36,900 and 16%, respectively.

Table 3: Lifetime Economic Analysis including Capital Costs, Operating Costs, Operating Cost Savings, Net Present Value and Internal Rate of Return.

Lifetime Economic Analysis					
System	Capital Cost	Annual Operating Cost	Annual Operating Cost Savings	Net Present Value[a]	Internal Rate of Return
Alternative 1	$78,200	$29,300	$13,100	$36,900	16%
Alternative 2	$78,600	$32,800	$9,600	$7,740	11%
Alternative 3	$119,000	$32,900	$9,500	($30,100)	6%

[a] With 10% interest and useful life of 25 years.

6.2 Environmental Comparison

Environmental impact has been determined using CometFarm by inputting the electricity and natural gas consumption outputs from the eQuest models for each alternative.

6.2.1. CO_2 Equivalent Emissions

The utility consumption outputs from eQuest that were input into CometFarm. CometFarm is an online tool developed by Colorado State University in conjunction with the Natural Resources Conservation Service and the National Renewable Energy Lab (Colorado State University, 2019). The program calculates greenhouse gas emissions and air pollutants associated with energy consumption from electricity and liquid & gas fossil fuels. The values are calculated using data gathered by the U.S. Energy Information Administration and U.S. Environmental Protection Agency. The output from CometFarm for Total Energy Consumption and Total CO_2 Equivalent Emissions are displayed in Table 4. The Total CO_2 Equivalent

Emissions for each Alternative were compared against the base to determine the amount of emissions that could be avoided by implementing each alternative system.

Table 4: Annual Greenhouse Gas Emissions, Avoided Greenhouse Gas Emissions and Total Energy Consumption from eQuest Consumption Outputs for Each Alternatives.

Annual System Fossil Fuel Consumption					Annual Greenhouse Gas Emissions	
	Electric (kWh)	**Natural Gas (MMBtu)**	**Nat Gas (CCF)**	**Total Energy (MMBtu)**	**Total CO_2 Eq (lbs)**	**Total CO_2 Eq AVOIDED (lbs)**
Base	311,000	855	8,250	1,910	592,000	-
Alt 1	244,000	291	2,810	1,120	421,000	171,000
Alt 2	302,000	69.6	672	1,100	488,000	104,000
Alt 3	262,000	391	3,780	1,280	461,000	131,000

6.2.2. Environmental Comparison of Alternatives

Each of the three alternatives presents an improved environmental situation relative to the base system. Each alternative reduced both electric consumption and natural gas consumption. Alternative 2 reduced the Total Energy Consumption the most. However, due to the fact that the majority of the energy consumption is electricity, Alternative 2 reduced the Total CO_2 Equivalent Emissions by the least amount. Alternative 1 reduced the Total CO_2 Equivalent Emissions the most. While reducing energy consumption in and of itself prevents negative environmental practices such as fracking, mining, and shipping of fuel, more weight is typically given to reducing overall carbon emissions. Therefore, Alternative 1 achieved the most favorable environmental improvement compared to the base system.

6.3 Social Comparison

The social impacts to the building occupants and community were considered and a comparison of these effects are summarized below. The main impacts that were considered were: comfort, space, noise, disruptions from construction, and air quality.

6.3.1. Social Impacts from Alternative 1

Compared to the base system, this system is an improvement on all impacts that were considered. The units currently in use at Leverett Elementary allow for minimal control over each spaces temperature, and when functioning properly, many of them can be loud and disruptive to the classroom environment.

The plant system with secondary fan coils proposed for Alternative 1 will give more individualized control over each space. This will give teachers the ability to optimize the learning environment and comfort for their students.

While this system will continue to take up minimal floor space in the classroom (the fan-coil units are installed as small cabinets with air discharge registers, located along one wall), the existence of much of the needed infrastructure will reduce the installation time. This reduces the probability that the construction process will disrupt the school year. Additionally, new, high efficiency equipment should reduce noise compared to the old units.

One downside this system presents is that outside air is not provided directly to the fan coil units. The spaces rely on outside air leaking into the building. Since Leverett Elementary is an old building, this does not present a large issue, but if the building envelope is upgraded substantially, then outside airflow may need to be addressed. If outside air is not circulated into the building properly, carbon dioxide and humidity can build up inside the building opening up the possibility for detrimental effects to the occupants' health, as well as the potential for condensation on the windows.

6.3.2. Social Impacts from Alternative 2

Compared to the base system, Alternative 2 was an overall social improvement. The units currently in use at Leverett Elementary allow for minimal control over each spaces temperature, and when functioning properly, many of them can be loud and disruptive to the classroom environment.

The packaged unit system proposed for Alternative 2 will give more individualized control over each space. This will give teachers the ability to optimize the learning environment for their students.

Due to the units being installed on the exterior of the building, no interior space will be taken up by equipment. While the existing units take up little space, their removal will open that area up to be used for a more functional learning purpose by the teachers. Also, the only noise associated with these units within the classrooms will be from air flowing into the rooms through ductwork. This system presents the lowest noise impact compared to the other alternatives. Alternative 2 requires a shorter distance for the treated air to travel from the equipment to the space. Therefore, a lower maximum air velocity is needed, leading to less duct noise. Also, due to the fan coil units being located within the space, fan operating will create more noise pollution than the exterior fans of the packaged units.

Because only 6 of the 52 spaces have infrastructure to support the use packaged units, a fair amount construction will have to be done throughout the school. While this can be completed during the summer break, there is a possibility that construction could interfere with the school year.

6.3.3. Social Impacts from Alternative 3

Compared to the base system, Alternative 3 provided net social improvements for the client. The units currently in use at Leverett Elementary allow for minimal control over each spaces temperature, and when functioning properly, many of them can be loud and disruptive to the classroom environment.

The plant system with secondary air handling proposed for Alternative 3 will give more individualized control over each space. This will give teachers the ability to optimize the learning environment for their students.

This system will not take up any floor space. Teachers will be able to use the space taken up by existing equipment for more functional purposes. The VAV boxes will be installed in the duct work above each room. Therefore, there is a possibility of slight disruptive noise from the units. Although, this is unlikely because they are new, high efficiency units.

Unfortunately, this system will require the most construction because almost none of the infrastructure needed for this system currently exists within the building. Duct work will need to be run throughout the entirety of the school from the air handler to each of the VAV boxes. This long construction process may be able to be completed over the summer but presents the possibility of interfering with the school year.

6.3.4. Social Comparison of Alternatives

The social impacts associated with each alternative that were described above were rated so that they could compared. The ratings are presented in Table 5.

Table 5: Social Comparison Table; (best = *** to worst = *).

Social Comparison						
	Installation	Noise	Air Quality	Comfort	Footprint	Summary
Alternative 1 Plant System w/ Fan Coils	***	**	*	***	*	*
Alternative 2 Packaged System	**	***	***	***	***	***
Alternative 3 Plant System w/ Air Handler	*	**	**	***	***	**

Based on the summary table above, Alternative 2: Packaged System provided the most social improvement from the base system. Alternative 1: Plant System with Fan Coil Units seemed to yield the least social benefits. However, all three alternatives created an overall increase in social capital compared to the base system.

7 Recommendation to Client

Based on the economic, environmental, and social comparisons, Alternative 1 (Plant System with Secondary Fan Coil Units) is the most favorable replacement system. Alternative 1 is far more economically beneficial with a net present value of $36,900 and internal rate of return of 16%. While Alternative 2 yields the greatest energy consumption reduction, Alternative 1 reduces CO_2 equivalent emissions by far more than the other two systems, indicating that Alternative 1 creates the most positive environmental impact. Alternative 1 does present one significant social issue, namely the lack of an integrated fresh air input. This can be successfully mitigated by monitoring the natural infiltration and air quality after installation to determine if external air inlets (powered or passive) need to be installed. Overall, Alternative 1 is the optimal alternative system for Leverett Elementary School to implement for the replacement of their existing HVAC system.

7.1 Deferred and Omitted Measures

Several potential measures that were omitted due to the scope of the project and knowledge of the building. A decentralized split system was not included as a possible alternative. This is due to the need to have an indoor furnace and dedicated air handler within each heating and cooling zone. From onsite visits, it was determined that the majority of zones do not have a practical storage space for the indoor equipment associated with a split system. The impracticality of the system for this building removed it from the alternatives list. Additional energy savings upgrades could be included beyond HVAC system upgrades. For example, the building envelope could receive significant upgrades to the replace windows and fix drainage issues. Also, LED lighting retrofits, lighting and HVAC controls, and a solar array could be included to increase the profitability of the project for the client. The limited scope of this project excluded these possibilities.

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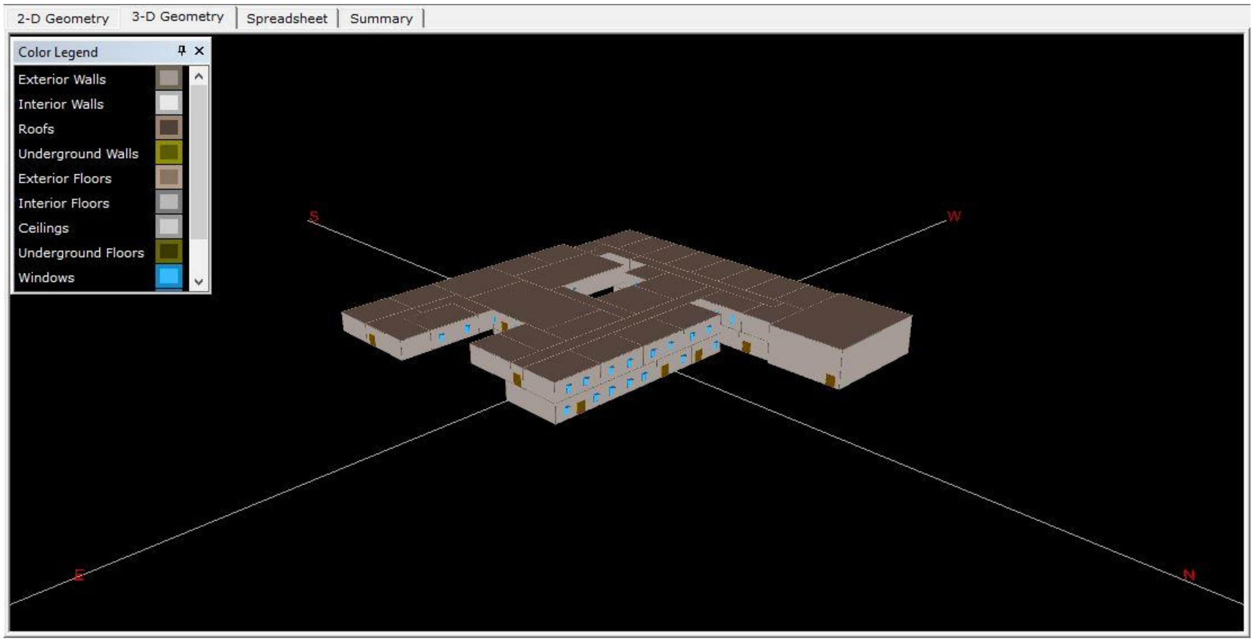
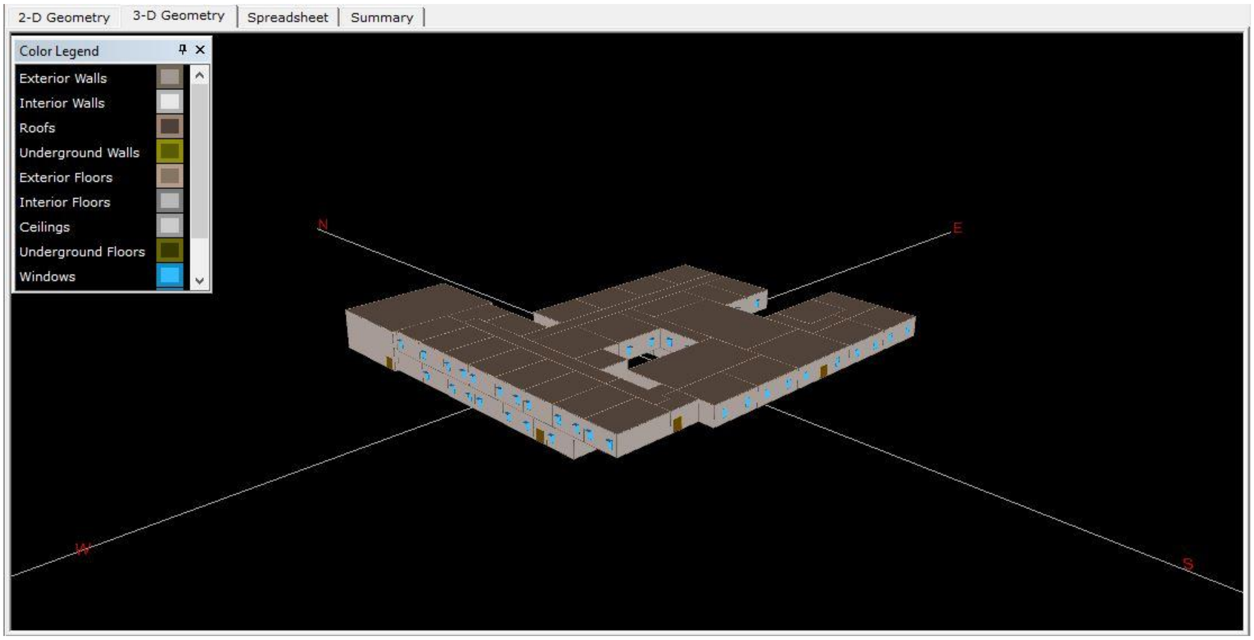
APPENDIX

<u>Appendix 1:</u> Building Shell Definition Input to eQuest

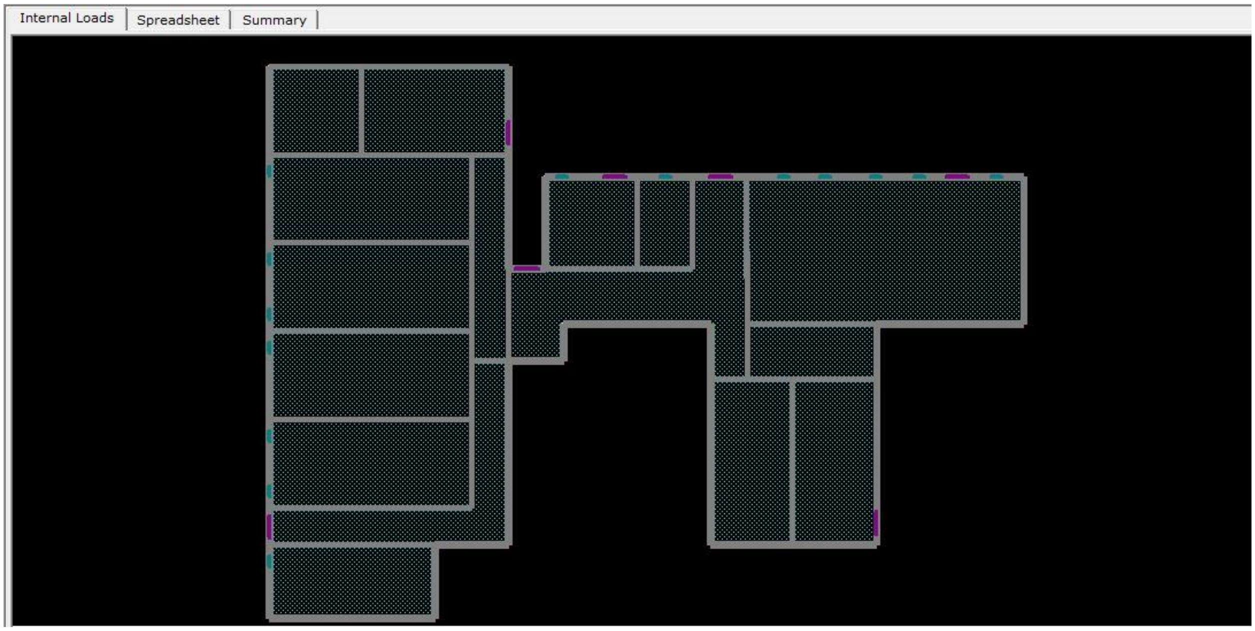


Building shell snapshot from eQuest from NE viewpoint.

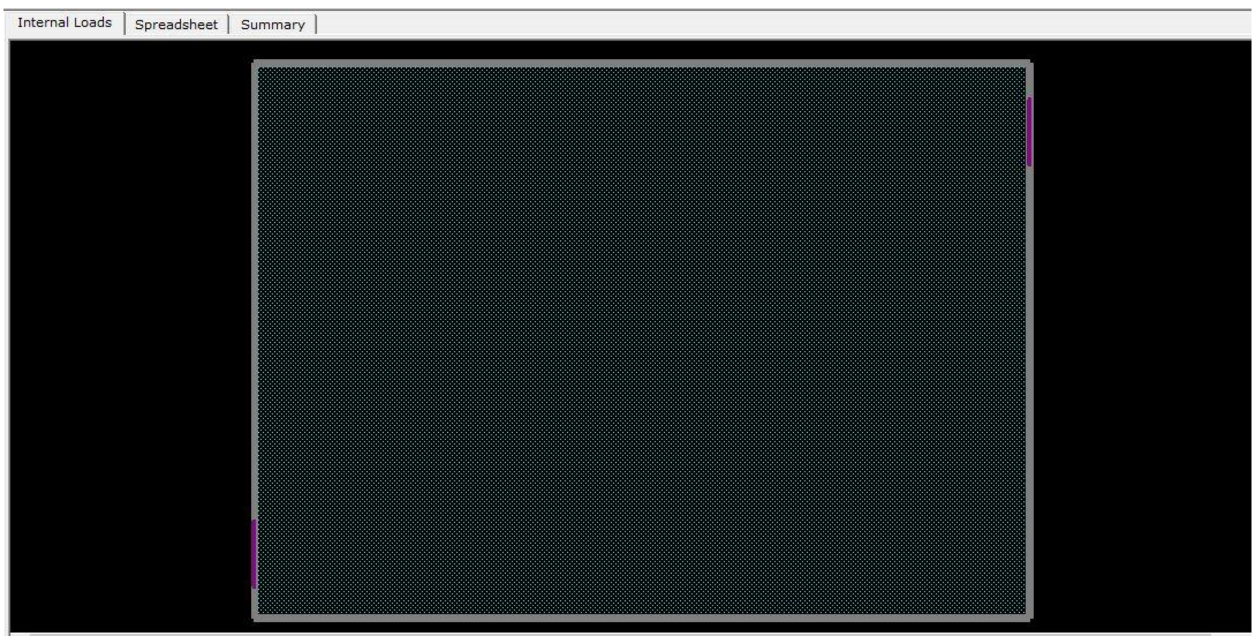


Building shell snapshot from eQuest from SW viewpoint.

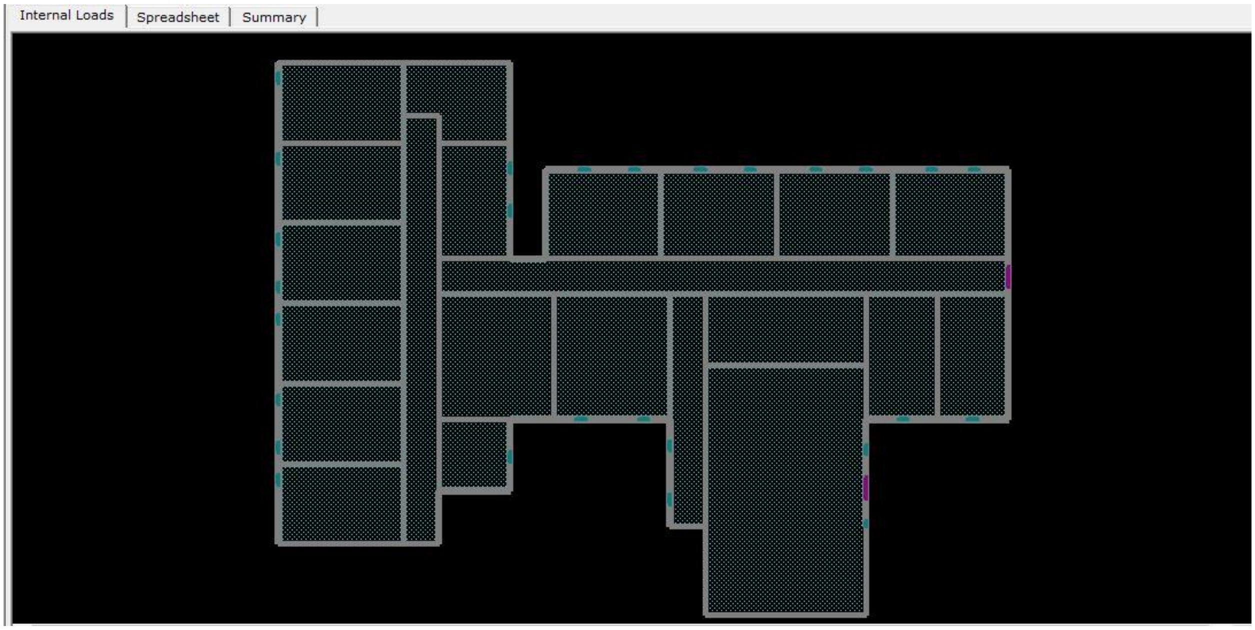
Appendix 2: Building Heating and Cooling Zones



Building heating and cooling zones from the bottom floor of the school.



Building heating and cooling zone for the gym.



Building heating and cooling zones for the top floor addition.

Building heating and cooling zones for the top floor original construction.

Appendix 3: **Energy Consumption Predictions for the Alternative HVAC Systems**

Electric Consumption (MWh)													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Base	24.0	25.3	22.6	25.2	33.7	18.4	26.6	41.5	25.6	27.0	25.9	14.9	311.2
Alternative 1 Plant System with Fan Coils	23.5	24.7	22.0	24.2	31.8	17.0	23.6	36.9	23.4	25.9	25.3	14.5	293.3
Alternative 2 Packaged System	41.9	38.1	26.9	24.3	31.7	17.7	26.0	40.7	25.0	25.4	28.6	24.6	351.5
Alternative 3 Plant System with Air Handler	24.5	26.2	22.7	25.5	33.7	18.4	26.0	40.5	25.4	26.7	25.9	15.1	311.0

Monthly and total electric consumption in MWh used to create Figure 2 and 3. Data output from eQuest.

Monthly Natural Gas Consumption (MMBtu)													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Base	135	115	85.4	67.5	61.9	41.2	41.4	43.4	40.2	60.9	80.6	82.2	855
Alternative 1 Plant System with Fan Coils	76.7	61.6	32.0	16.7	11.9	3.756	4.25	6.20	4.25	10.6	28.0	34.7	291
Alternative 2 Packaged System	6.93	7.38	6.52	6.66	7.68	3.75	4.24	6.20	4.25	5.51	6.2	4.19	69.5
Alternative 3 Plant System with Air Handler	95.3	80.2	43.1	23.7	20.2	6.17	4.25	6.21	4.59	17.1	39.4	50.7	391

Monthly and total natural gas consumption in MMBtu used to create Figure 2 and 4. Data output from eQuest.