BUILDING ENERGY ANALYSIS FOR HUMBOLDT STATE UNIVERSITY

HUMBOLDT STATE UNIVERSITY

By

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A Thesis

Presented to

The Faculty of The Department of Environmental Resources Engineering

In Partial Fulfillment

Of the Requirements for the Degree

Masters of Science

In Environmental Systems:

Energy, Environment, and Society option

December 2010

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ABSTRACT

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Chhimi Dorji

This thesis proposes a campus wide strategy for Humboldt State University (HSU) to improve energy efficiency in buildings, ranks buildings based on energy use and presents an analysis of retrofit opportunities for two of the most energy intensive buildings. The research is based on analysis of actual monthly energy data, interviews, walkthrough survey of buildings, detailed energy auditing, DOE2 - eQUEST modeling of the selected buildings, literature review of relevant policies, technical assessments and evaluation using economic analysis tools.

HSU spends about $2.8 million annually on energy emitting 12 thousand metric tonne (MT) of CO_2. Campus-wide strategies for reductions include preparing an action plan for energy management, forming an energy team with an energy manager, listing immediate tasks, studying the possibility and initiating complete building shutdown during breaks, commissioning buildings, implementing energy efficiency improvements, advocating for behavior change, and creating awareness. Consideration of a 30 kW Capstone Microturbine for the main campus is also recommended.

The ranking of nineteen buildings with adequate data was carried out through a two stage analysis. As the two most energy intensive buildings from the study, the Telonicher Marine Lab in Trinidad and the Ceramics Lab on the main HSU campus were selected for detailed auditing and analysis. About 200 MWh of electricity and 6,634 gal of propane are consumed by the Marine Lab annually, which costs $38,700 and results in 113 $MTCO_2$. From eight retrofit alternatives identified, replacing the propane boiler and seawater re-circulation pumps are found to be viable options. Replacing the propane boiler will be paid back in 9.2 years from investment of $4,800 and save 1.68 $MTCO_2$/yr. New seawater re-circulation pumps will cost $6,300 and save 2.85 $MTCO_2$/yr with payback period of 3.4 years.

The Ceramics Lab uses 114 MWh of electricity and 6,750 Therms of natural gas annually that costs $22,900 and emits 77.9 $MTCO_2$. From the six retrofit alternatives identified for the Ceramics Lab, capturing the heat exhausted from electric kilns in combination to reducing the air infiltration rate was the best alternative, with a simple payback of 5.9 years from an investment of $7,900 and potential to save 5.25 $MTCO_2$/year. Only reducing the air infiltration rate will also save 4.26 $MTCO_2$/year with an investment of $6,900 and simple payback of 6.0 years. Capturing heat from gas kilns using pebble bed heat exchangers could also be appropriate.

ACKNOWLEDGEMENTS

This dissertation would not have been possible without the guidance and help of several individuals and agencies who in one way or another contributed their valuable support for my study and this research.

I wish to thank the organization and officials in the Norwegian Agency for Development Cooperation (NORAD), the Government and people of the Kingdom of Norway, the Department of Energy and the Royal Government of Bhutan for having faith in me and sponsoring my master's degree. The same appreciation also goes to students, faculty and staff involved with the Humboldt Energy Independence Fund, the Renewable Energy Student Union and Plant Operations at Humboldt State for planning and executing the Building Energy Project, providing me the opportunity and helping me with the internship that resulted in my thesis study.

I heartily thank my advisor and thesis committee chair, Dr. Arne Jacobson, whose encouragement, guidance and support started from the assistance for admission, payment of rent deposits, advice on jobs, to all the wonderful classes, and to completion of my thesis.

I am grateful to my other thesis committee members, Dr. Charles Chamberlin, Dr. Tom Borgers and Peter Alstone, for consenting to and providing their valuable time and support. Peter deserves a special mention for his knowledge, patience, being meticulous and providing morale support all throughout. Dr. Borgers proved to be another inspiration for me with tons of great ideas, admirable energy and kindness to guide me during retirement. My sincere gratitude also goes to the Graduate Coordinator Dr. Chris Dugaw and other staff from the office of Graduate and Research Studies, the International Programs Office, and all Building Engineers and Building Managers for the Ceramics and Marine Laboratories.

I would like to thank all my other professors, supervisors, friends and co-workers in Plant Operations, RESU, HEIF, CCAT and HSU Housing and Dining Department for all the education, friendship and encouragement. I am also indebted to my American, Bhutanese and other international friends for teaching me how to navigate the American customs and your awesome friendship. The past and present cohort of EES and ERE folks deserve another special mention for being a great group of guys to live, work, learn and have fun together.

I wish to thank my entire family and extended family for providing a loving environment for me. A special mention for Asho, Ashi, Apa Chagay and Ama Tashi for being the best parents!

Lastly, and most importantly, I wish to thank my darling Seday and Jimmy for all the patience, love, encouragement and taking care of each other. I dedicate this achievement to you guys!

Tashi Delek!

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CHAPTER 1 INTRODUCTION

Humboldt State University (HSU) spends around $2.8 million on natural gas and electricity for buildings annually, emitting about 12 thousand Metric Tonnes (MT) of CO_2. Buildings have tremendous potential for efficiency improvements (McKinsey, 2009). A number of building retrofits, renewable energy generation, education, awareness and efficiency projects have been carried out in HSU through initiatives taken by faculty, staff and students, but without any regular fund commitments or master plan or database in particular. The Humboldt Energy Independence Fund (HEIF), a student paid fund, has been supporting several such initiatives in the recent past. Few projects have been supported by university funds on intermittent basis, and some projects have been successful at securing money from state rebate programs or external donors.

Hitherto, some building data for HSU buildings were collected and stored by Plant Operations' Building Engineers while others were not recorded or analyzed after payment of utility bills. A project was thus conceived by students in the Renewable Energy Student Union (RESU) with the goal of having adequate and properly analyzed building energy data for past and future energy efficiency projects on the HSU campus. This thesis came from part of that project which is funded by HEIF. The data collected by building engineers, records from the utility website, and payment details from the finance sections were used for this study in addition to interviews and site visits.

The goals of this thesis were to analyze detailed building information and energy data, develop a building ranking system for buildings with adequate data, select two buildings with high savings potential for further study, and conduct a thorough analysis of those buildings to recommend retrofit alternatives based on technical feasibility and economic prospects. Campus-wide energy system management was also studied and relevant improvements proposed.

The Background chapter, Chapter 2, has information on the importance of the study, details of other studies, funding sources, and organizations working in the field. A detailed explanation of the methods, programs, and analysis carried out is in Chapter 3, which is the Methodology chapter. Chapter 4 on Buildings and Energy at HSU has a brief overview on the building energy system and management followed by a campus-wide building energy reduction strategy. In Chapter 5, nineteen buildings with adequate energy records were ranked. The top five buildings were selected for further analysis. A walkthrough of the five buildings was done to determine more in-depth information and energy saving potential for each of the buildings and two energy intensive buildings were selected for thorough auditing, modeling and study. Chapters 6 and 7 describe detailed energy analysis and modeling for the Ceramics and Telonicher Marine Lab to determine potential retrofit alternatives. Presented in Chapter 8 are the economic evaluations performed to compare and contrast the retrofit options. The recommendations for further study and evaluating such projects in the future along with the conclusion from the study are listed at the end in Chapter 9.

CHAPTER 2 BACKGROUND

Buildings in the United States represent 40% of energy use in the country. This corresponds to about 10% of global energy use and contributes as much as 30 percent of a building's operating cost (Stroupe, 2010). It was identified in the National Action Plan for Energy Efficiency (EPA and DOE, 2006) that improving the energy efficiency of our homes, businesses, schools, governments, and industries is one of the most constructive, cost-effective ways to address climate challenges. Increased investment in energy efficiency can lower energy bills, reduce demand for fossil fuels, help stabilize energy prices, enhance electric and natural gas system reliability, and help reduce air pollutants and greenhouse gases (EPA and DOE, 2006).

With increased attention on environment and climate change it is nearly certain that drastic emissions reductions will be required for California University campuses in the near future (CSU, 2005). California's Global Warming Solutions Act of 2006 (Assembly Bill 32) mandates California to reduce its greenhouse gas emissions back to the 1990 level by 2020. It also orders that emissions reductions continue by an unspecified amount thereafter. In addition, Governor Schwarzenegger's Executive Order S-3-05 mandates that California reduce its emissions to 80% below 1990 levels by 2050. [1]

[1] http://gov.ca.gov/executive-order/1861/

The Executive Order No.987, Policy Statement on Energy Conservation, Sustainable Building Practices, and Physical Plant Management for California State University (CSU), from the CSU Chancellor Charles B. Reed on August 2006, mandated all CSU campuses to continue energy reduction by 15% by end of fiscal year 2009/10. This was further elaborated by a memo from Executive Vice Chancellor Richard West to the CSU Board of Trustees. The Chancellor's Office recognized specific obligations under AB 32 on September 18, 2007. To fulfill all these obligations at the state and university level, it is indispensible for Humboldt State University (HSU) to work for reduction in energy consumption and emissions.

Due to rising energy costs over the years and the recent budget cuts in the CSU system, [2] it is even more crucial to look for ways to reduce energy consumption in buildings on campuses. The State of California mandates energy efficient buildings through the California Code of Regulations Part 6-Title 24, which is the Energy Efficiency Standards for Residential and Nonresidential Buildings, established in 1978. However, most buildings on HSU campus were built before 1978 and were therefore not subject to the requirements in the standard. The list of buildings at HSU and their year of construction are in APPENDIX B.

According to a study by Lawrence Berkeley National Laboratory for universities in California, it was found that buildings rarely perform as intended, resulting in energy use that is higher than estimated (Mills & Mathew, 2009). The most common deficiencies

[2] http://www.calstate.edu/PA/News/2009/budget_feb.shtml

were in HVAC equipment (65%), followed by air-handling and distributions systems (59%), cooling plants (29%), heating systems (24%), and terminal units (24%). It was found that the most common interventions were adjusting building heating set-points, modifying operation schedule, calibration, and other mechanical fixes. There is a lot of room for energy efficiency improvements at university campuses throughout the United States, as well (Simpson, 2003).

The CSU Report on Sustainability and Energy Efficiency Goals (CSU, 2005), which is an authoritative study by the CSU Chancellor's Office, has done a thorough study on the projects that have been carried out on various CSU campuses regarding sustainability issues and possible strategy. The key findings from the study indicate that there is a good potential for energy efficiency improvements in CSU campuses with typical paybacks of 3 - 7 years. The first step was to identify the major opportunities system-wide, determine their impact on energy use, estimate their cost-effectiveness, and prioritize them accordingly. Details of the important results are in APPENDIX A.

HSU has a fund on campus called the Humboldt Energy Independence Fund (HEIF) that is maintained through the Instructionally Related Activities Fees from students. HEIF was established in 2007 with the mission to reduce environmental impact of energy use at HSU by student initiated and implemented projects (HEIF, 2010). Six out of eight projects so far have been directly targeted for energy consumption on campus which accounts for about 90% of the total HEIF fund (HEIF, 2010). Some relevant HEIF projects are described in APPENDIX A.

The Green Campus Club is part of the Alliance to Save Energy's Green Campus Program (GCP), which is a state-wide, student-led energy efficiency and water conservation outreach program. A team of five student program coordinators and two student interns work to promote energy efficiency and water conservation at HSU through design and implementation of energy-saving and energy education projects (HSU, 2010).

There is only one whole campus building energy analysis report readily available for HSU which was conducted by Peter Johnstone (Johnstone, 2007). According to this report, the SCI D&E building was listed as the most promising building for efficiency improvement. The Wildlife Building and Ceramics Lab were bigger energy users, but they were assumed to have large functional equipment demands which are not elastic. A relevant section from the report has been produced in Table 2.1.

Table 2.1 Summary of building energy consumption from Johnstone, 2007

Building	Area (ft^2)	kBtu elec /yr* ft^2	kBtu gas/yr* ft^2
Ceramics Lab	7,906	56.42	106.9
SCI D E	39,893	38.08	103.2
Wildlife	40,428	71.06	87.41

The same study has suggested greenhouse gas intensity per square foot by energy type and results in kg CO_2 equivalent/ft^2*year as a useful measurement for evaluating and comparing buildings.

CHAPTER 3 METHODOLOGY

This chapter includes a description of methods used in the course of this study. The first step of this study was to look at building information and energy management systems for HSU buildings. Afterwards, considerations were made of campus-wide energy management strategies that could be adopted. Actual building energy analysis was carried out in a two phase system: In the first phase, buildings were ranked based on their energy intensity and total energy consumption. In the second phase, five energy intensive buildings were evaluated by a walkthrough survey. Detailed auditing and analysis for two of the selected buildings were carried out to determine the potential retrofit alternatives. Economic evaluations of the options were done separately in another chapter to help recommend the best alternatives.

3.1 Data Compilation and Analysis

Total campus energy consumption data were provided by the student Energy Manager at Plant Operations for 2007 - 2009. This information was used to determine the annual total expense on energy and its related carbon emission for different years using the average tariff and carbon contents.

Data regarding building natural gas and electricity consumption for buildings with individual meters were collected from the Pacific Gas and Electric's (PG & E) website. PG & E has historical information for the last three years. The building per square foot expense and total expenditure were used to rank buildings.

The natural gas readings for large buildings on campus are recorded by respective building engineers. Data on purchase of propane for the Telonicher Marine Lab were received from the Accounts Payable department of HSU. The large buildings did not have adequate electricity and thus only nineteen building on PG & E meters with both natural gas and electricity data were used for analysis in this study. The last column of Table B.1 in APPENDIX B indicate buildings that have been considered for detailed study from the comprehensive list of campus. Once complete data are available for the buildings that were not considered, a future study should expand the work presented here to include those additional buildings.

A two tier matrix system was adopted to rank and select the most energy intensive buildings on campus for thorough auditing and analysis. In the first phase of the method, nineteen HSU buildings with complete energy data were ranked according to their Building Energy Use Intensity (BEUI) (i.e., $/ft^2) and Building Energy Use (BEU) (i.e., total $). From this ranking of buildings, five of the most energy intensive buildings were chosen for a quick walkthrough survey to determine possibility of improvements and re-ranking.

3.2 Walkthrough Survey

For the second phase, all five selected buildings were visited with respective building engineers to conduct a quick walkthrough survey. Important building details, use and equipment in the building were reviewed. A standard form for the walkthrough survey was prepared and used for all the buildings, which is shown below in Table 3.1. The details of this process are shown in APPENDIX F. Results from the walk through were compared against each other to select candidate buildings for thorough analysis. This process is performed to ensure that the candidate buildings have some potential for efficiency improvement in addition to the indication from consumption data.

Table 3.1 Form for walkthrough survey

Area (ft^2)	**Building name and its details**
Built Year	
Building Type	
Engineer/Manager	
Major Use	
Building Material	
Lighting	
Domestic Hot Water	
Heating	
Major Equipment	

3.3 Detailed Survey and Analysis

For the two buildings identified as most promising, technical auditing and study about the building materials, activities in the building, and interviews with building managers and engineers were carried. Hobo data loggers were used to find the schedule of important equipment, and light meters were used to test light intensity in some rooms. Both the buildings were visited more than five times at different times of the day on different occasions. The information collected from these visits was used to develop an eQUEST model and the details are in APPENDIX H and APPENDIX O.

3.4 DOE2 Modeling

The DOE2 program was used for analysis of buildings in this work. According to its developer (Hirsch, 2003), DOE2 is claimed to be the most renowned and common building energy program in use today. DOE2 is a computer program that calculates the hourly energy use of a building based on the location of our site and description of the building. Using DOE2, one can decide the choice of building factors to improve energy efficiency by trying various alternatives (LBNL, 2010). The inputs required for the analysis are geographic location, building orientation, building materials, envelope components (walls, windows, doors, shading surfaces, etc.), operating schedules, occupancy, lighting details, miscellaneous equipment loads in the building, HVAC system and controls and utility rate schedule.

DOE2 calculates the building energy consumption over the entire year using hourly weather data for the location and other inputs. This is processed by the Building Description Language (BDL) processor that translates it into computer identifiable form. Based on inputs, the combinations of loads (LOADS), Heating Ventilation and Air Conditioning system details (HVAC), and economics (ECON), the building operation is simulated by the program. The outputs are energy consumption, demand and related cost of the energy. Figure 3.1 represents the way in which DOE2 is used for analyzing a building.

eQUEST (Quick Energy Simulation Tool), a Graphical User Interface (GUI) for using the DOE2 program, has been used for the modeling and analyzing the buildings in this work.

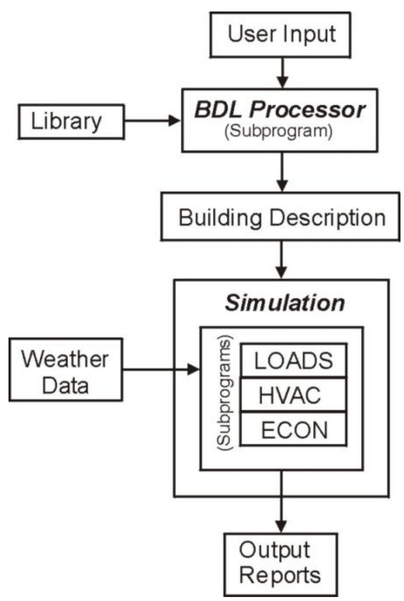

Figure 3.1 Flow chart of DOE2 program (Hirsch, 2003).

3.5 Alternatives and Economic Analysis

The different alternatives found using eQUEST models and literature reviews are compared by their energy saving potential and corresponding cost of implementation through a cash-flow analysis. Investments required for alternatives were determined from unit costs mentioned in Job Order Contracts (JOC) from Plant Operations and some from other websites. A 2% increase in energy cost has been considered in addition to the underlying inflation, while the discount factor was considered as 3%. Two cash-flow analyses were done, one of which assumes no cost of CO_2 and the other one considers a \$20/MTCO_2. Net Present Value (NPV) of the investments, simple and discounted payback periods, and Internal Rate of Return (IRR) were determined for each alternative. Additional costs of 20% for installation and 15 % for contingency were added to all the alternatives.

CHAPTER 4 BUILDINGS AND ENERGY AT HSU

An analysis of the building energy consumption record, types of data available, trends, problems and energy management system at HSU are included in this chapter. It resulted in the creation of a set of campus-wide building energy reduction plans, and identification of a few immediate tasks to reduce energy use quickly at HSU.

4.1 HSU Buildings

There are 90 buildings that are owned or leased by HSU both on campus and off-campus. HSU Plant Operations is responsible for maintenance and operation of 60 buildings, which consists of 26 Large Buildings (gross area > 10,000 ft^2), 29 Small Houses on campus, as well as two Small Houses and three Large Buildings at off-campus locations. The total gross area of buildings is 1,562,123 ft^2. Many of the buildings were built more than 30 or 40 years ago and few have been built recently. A table listing building name, building id, acronym, gross area, type of building, building use, department and built year has been compiled in APPENDIX B.

A preliminary statistical analysis was carried out by a graduate student at HSU (Scheidler, 2010) on a building subset with 14 large buildings and 18 small buildings which consisted of six labs and 26 offices. Using the same data set compiled through this study some interesting relations regarding those particular were found as follows:

- *There is no significant trend in building electricity use for labs with regard to building age.*
- *Natural gas consumption per square foot for office buildings was smaller for newer buildings.*
- *Consumption of natural gas per square foot for labs was larger for newer buildings.*
- *Electricity use in office buildings is on average higher than lab buildings*

At the end, it was concluded that the results are inferable only to the building subset analyzed and campus-wide data analysis would be necessary for such studies to identify retrofit potentials through statistical analysis.

4.2 Energy Data for HSU Buildings

HSU, as part of the CSU system, bought electricity through a direct access contract from Arizona Public Service (APS) Energy Services, an Arizona based Power Company, for 2006 and 2007. For 2008 and 2009, the campus purchased electricity from Constellation New Energy (CNE). Supply of natural gas and actual distribution of electricity is done by Pacific Gas and Electric Company (PG & E). Shell North America (SENA) is the new electricity provider beginning January 2010 for the CSU system including HSU. Propane is purchased from Blue Star Gas.

Total HSU natural gas and electricity consumption data for 2006 - 2008 have been collected from the Energy Manager and analyzed. At the time of the study in March

2010, campus-wide energy data were available only for 2006 – 2008. In an average year, HSU consumes about 11,100 MWh of electricity at a cost of $1.51 million at 13.5 cents/kWh, while the natural gas consumption is 1.44 million Therms costing $1.28 million at the rate of $0.89/Therm. Between these two sources of energy HSU emits around 12,200 MT of CO_2.[3] The corresponding expenditure is about $2.79 million per year which is almost 2.9% of HSU's operating budget for 2010-2011 and 75% of total utilities budget.[4] Because data are only available for a few years, no inference could be made on any trends in consumption or emission patterns at HSU.

There was an increase in electricity consumption and decrease in natural gas consumption in 2008 compared to 2007 and 2006, but the overall carbon emissions declined. This was caused by switching the electricity provider from APS to CNE in 2008, who has a slightly cleaner mix of power supplied to California. The current energy mix of SENA is not available and there are no valid documents to verify the carbon content of electricity supplied to CSU, as the power is purchased on the market by SENA (Green Campus, 2010). SENA claims that they have a sustainable energy plan with clean mix and are also exploring for more renewable and clean energy in their mix (Shell, 2010). Table 4.1 shows the detailed information of electricity and gas consumed, the rate

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[3] The natural gas emission factor used is 53.06 $kgCO_2$/MMBtu (CCAR, 2009). Electricity in HSU for 2008 was from CNE @ 328.399 $kgCO_2$/MWh (CNE, 2008). For 2007 and 2006 it was from APS @ 468.18 $kgCO_2$/MWh with power content label projected from 2006 and verified by a detailed study in CSU East Bay where they had the same source of energy as part of CSU contract with the supplier (Garbesi, 2008).

[4] http://www.humboldt.edu/budget/documents/FY10-11/FY10-11%20HM500%20Base%20Budget%20for%20Website.pdf

and carbon dioxide generated by HSU from 2006 - 2008. A graphical representation of the consumption in is shown in Figure B.1 of APPENDIX B.

Table 4.1 Comparison of total energy consumption in HSU on annual basis.

Year	Electricity (MWh)	Electricity Cost ($)	Rate $/MWh	Natural Gas (MMBtu)	Nat. Gas Cost ($)	Rate $/MMBtu	total $(M)	MTCO2 x1000
2006	10,214	1,437,370	140.73	141,830	1,137,438	8.02	2.57	12.3
2007	9,996	1,208,505	120.90	151,500	1,198,759	7.91	2.41	12.7
2008	13,075	1,884,212	144.10	139,279	1,513,517	10.9	3.40	11.7
Mean	11,095	1,510,029	135.24	144,203	1,283,237	8.93	2.79	12.2

4.3 Building Energy System in HSU

A well designed, operated and managed Energy Management System can save energy in modern buildings (McKinsey, 2009). Energy in all 25 large buildings on campus is controlled by an Energy Management System (EMS), which is also connected to the main campus meters. The EMS system was produced by Control Pak and maintained by K.M. Urfer Engineering at the local level until recently. It is now managed by Ethan Crick Controls (new management). The central station at Plant Operations controls the EMS and collects necessary trend logs or makes changes. The trend logs only had instantaneous kW reading, which could be in intervals of any time frame. However, the EMS contractor is now trend logging electricity consumption of buildings and stores them on a network folder which is accessible to building energy interns. There are two main gas meters and an electric meter which supplies gas and electricity to most parts of the main campus which are read by PG & E. Individual natural gas meters for large buildings are manually read, entered into the engineers' computer and then transferred to Plant Operations local network for downloading and viewing by other concerned people.

Currently there are nineteen electric meters and ten gas meters that are served independently by PG & E. Some of the small houses on campus do not have gas connections, while others are connected directly from other meters or straight from the main campus meter. The Telonicher Marine Laboratory on the other hand uses propane as it is outside the natural gas distribution territory. Natural gas and electricity data from 2006-2009 were used for analysis and comparisons which is attached as APPENDIX C.

4.4 Building Operation and Management

Buildings owned and operated by HSU have Building Engineers who are responsible for preventive maintenance of their respective buildings in addition to troubleshooting and operational maintenance. Most of the buildings with Heating Ventilation and Air-Conditioning (HVAC) systems are operated manually or turned on 24 hours a day leading to increased energy consumption compared to better managed buildings. According to building engineers, building coordinators/managers and users are very particular about comfort levels and thus Building Engineers do not take the risk of trying to save energy by scheduling or managing differently (West, 2009). Building Engineers often pre-heat, over heat or ventilate more simply to avoid complaints instead of managing for energy savings. Even on weekends and holidays, buildings are hardly shut down and are operated as normal to address the need of few individuals who might be using the buildings.

There are also rare occasions when buildings do not get preventive maintenance for a long time due to lack of resources (Elliot, 2009). Some houses on campus have been retrofitted within the last few years, but there are many buildings which have been earmarked as temporary buildings for more than 20 years and still function as an important office or academic laboratory without any immediate replacement plan in near future (Moxon, 2009). Those “temporary” buildings are oftentimes passed over for maintenance and upgrades.

Presently, Plant Operations supports some new retrofit/modification projects using money from the campus general fund that is allocated for operation and maintenance of facilities on campus. This is justified by Plant Operations as part of regular maintenance through investment in physical equipment such as pipes, meters, poles, panels or brackets which must be maintained by them regardless of concerns about energy efficiency (Moxon, 2009). Potential savings from energy reductions remain with the general university budget. The budget allocated for operation and maintenance of facilities by the university is not connected to investments that Plant Operations makes for efficiency improvements. Therefore, there is no direct budgetary incentive for Plant Operations to pursue energy efficiency improvements and reduce utility bills. Furthermore, any increase in energy expense does not affect the Plant Operations directly as utility bills are completely dealt by the Accounts Payable department.

4.5 Campus-Building Energy Reduction Strategy

Buildings repeatedly have higher energy consumption than anticipated by the design and engineering estimates (LBNL, 2009). While in-depth study and modification potentials for individual buildings are necessary, it is also likely that a campus-wide solution can be applied for many buildings at HSU to decrease energy consumption. Actions for reduction in building energy consumption are explained below.

4.5.1 Energy conservation through behavior change

Energy conservation means avoiding energy demand. This is often done by advocating for behavior change. “Even an energy saving lamp saves most energy when turned off” (Norgard, 2008). The Intergovernmental Panel on Climate Change (IPCC, 2001) said that ‘‘the energy use in a building also depends on the behavior and decisions of occupants and owners.’’

Energy conservation through behavior change on the HSU campus could be initiated through low cost awareness campaigns to educate people about the negative consequences of excessive energy use. Currently Green Campus and the Humboldt Energy Independence Fund (HEIF), both of which are student run organizations with faculty and staff support, work on such initiatives. According to Energy Sustainability and the Green Campus (Simpson, 2003), “the first step a campus should take toward greening is to reinforce, reinvigorate, and expand its energy conservation program.” Energy awareness campaigns have the possibility of changing campus cultures and creating a sense of conservation (Simpson, 2003). Some viable options for behavior change programs at HSU are listed below:

- Developing building energy consumption reports with guidelines on reducing energy use in buildings which could be displayed in buildings. This will give people a sense on how the building is performing and the impact of their behavior.
- Stickers and flyers informing people to turn off lights, close windows and doors.
- A website on building energy information and tips on ways to save energy (which is presently under development through a HEIF project along with some other awareness activities).

4.5.2 Building commissioning

The process of assessing a building to check if it delivers expected energy savings is called Building Commissioning.[5] A study by Lawrence Berkeley National Lab (LBNL) for UC Berkeley defines commissioning as a systematic, detailed way to assure quality control; the authors identify commissioning as an underutilized approach for saving energy and money (Mills, 2009).

According to a case study on University of California/California State University/ Monitoring Based Commissioning (UC/CSU MBCx) projects, the aggregate

[5] The term commissioning is often meant only for new buildings and retro-commissioning for old buildings; however, in this report commissioning is for both.

commissioning cost for the 24 projects was \$2.9 million. From one study the average cost was \$0.73/ft^2 and saving was \$0.24/ft^2 (Mills, 2009), while the other one found cost as \$1.00/ft^2 and saving as \$0.25/ft^2 (Mills & Mathew, 2009). Average energy cost savings from the two studies were \$0.24/ft^2-year and the cost is \$0.87/ft^2. The details of both the studies are shown in Table 4.2.

Table 4.2 Detailed cost and savings of commissioning from case studies

Study - Mills 2009	**\$/ft^2**	**Building Type**	**Payback (yrs)**	**Average \$/ft^2**
Normalized cost	0.30	Existing	1.10	0.73
	1.16	New	4.20	
Median cost savings/yr	0.29	Existing	-	0.24
	0.18	New	-	
Study - Mills and Mathew 2009	**\$/ft^2**	**Million \$**	**Payback (yrs)**	
Commissioning Cost with MBCx	1.00	2.90	-	-
Median cost savings/yr	0.25	-	2.50	-
Average Cost from two studies	**0.87**	**\$/ft^2**	**-**	**-**
Average Saving from two studies	**0.24**	**\$/ft^2**	**-**	**-**

Assuming the average cost of a commissioning upgrade is \$0.87/ft^2 and savings are \$0.24/ft^2/yr, an investment of about \$700,000 would be required to fully commission 50% of the built up area of HSU. The annual savings on this investment are estimated at almost \$200,000, which corresponds to a simple payback of less than four years. Only 50% of built up area is considered so that the investment requirement will not be high and to keep the risk factor low. With the current assumptions, the investment required would be about 20% of current annual expense on energy bills and the saving is about 6% of annual energy expenditure. The net savings from such a project with the life span of about 15 years would be more than $2 million. This is a very rough calculation, but we can verify that such projects hold great energy and cost savings potential (Graham, 2009). Details of calculations for HSU case are in APPENDIX D.

Analyses of two case studies of commissioning buildings were calculated using the above figures from the study as mentioned in Table D.1 of APPENDIX D. According to the calculation, in 15 years, a net saving of $44,000 and $26,000 could be achieved respectively, from commissioning the Marine Lab and Ceramics Lab with paybacks of 3.7 years for both the buildings.

4.5.3 Energy efficiency improvement

Energy efficiency is reduction of waste. It is usually carried out through replacing old, inefficient equipment and building components with higher efficiency ones. An improvement in energy efficiency is to provide the best level of goods and services with minimum waste (Polymenopoulos, 2006). On the national level, a study (McKinsey, 2009) stated that improving energy efficiency in buildings could reduce GHG emissions by 1.1 gigatons a year, “the equivalent of taking all the entire U.S. fleet of passenger vehicles and light trucks off the roads.” Similarly, we can expect that energy efficiency improvements can be cost effective and environmentally friendly in HSU.

A energy efficiency project was executed at University of California San Diego (UCSD) (Graham, 2009). From a $60 million energy-saving improvement project, it cut electricity consumption by 20 percent and saved the university more than $12 million annually. Inspired by the previous success, UCSD has again started a $73 million program to increase the energy efficiency of 25 of its older buildings to further decrease their combined energy consumption by $6 million per annum. This project is part of a larger $247.4 million UC plan to reduce greenhouse-gas emissions and cut energy costs $36 million annually at all UC campuses. The $73 million project is not expected to cost UCSD anything in the long run.

4.5.4 Action plan for energy management at HSU

To accomplish any of the broad multiple alternatives identified before, it is necessary to reiterate the actual situation in HSU, work out how to implement the different possibilities and overcome identified barriers. Following are some of the activities that should be considered:

a) Form an Energy Team.

It is necessary to form a multi-disciplinary and dedicated energy team with a full time Energy Manager to study and manage the energy system on a campus (Hignite, 2009). It was suggested that all mid to large-size campuses should have a full-time energy officer besides energy managers who is assigned to supervise energy management system operations or energy purchase (Simpson, 2003). Currently, HSU does not have a full time Energy Manager and building energy issues are dealt by a quarter-time (10 hrs/week) student Energy Manager under the supervision of the Plant Operations senior Director. There is also a short term Building Energy Internship funded by HEIF to work on building energy data, auditing and listing of potential buildings for retrofit (this report is part of that work). It is recommended to have a full time energy manager and other interns working on energy issues for the campus. In addition, representatives from few academic departments, university management, HEIF and relevant stakeholders such as Green Campus and Plant Operations could collaborate to help ensure success.

b) Set Goals.

The energy team in consultation with other stakeholders should develop goals and objectives for activities and continuous improvements in the system. These would include framing out a roadmap for reducing carbon emissions and building energy consumption.

c) Evaluate Performance and Situation.

It is essential to understand the current and past energy use of each building to evaluate their performances and produce building baseline information. Based on the baseline information, buildings can be audited for identifying potential opportunities for retrofit or modifications. The HEIF Building Energy Interns are presently collecting, analyzing and auditing some building to determine building prioritization through technical assessments.

d) Detailed Analysis.

The HEIF Building Energy Internship is expected to produce a campus-wide building baseline report and rank buildings based on energy use. The information would indicate potential for retrofit which could then be used by interested individuals and agencies decide which buildings should be commissioned or evaluated further. Once a prioritization list has been made, a campus-wide portfolio detailed auditing could be done. Another alternative will be to select top 5-10 buildings and conducting a walkthrough to gather further information and cut down the list to 2-3 buildings. In the later part of this work, I selected two buildings and analyzed them to demonstrate how the technical part of the recommendations could be carried out.

4.5.5 Immediate tasks

While building commissioning, efficiency and energy conservation are important; there are also some maintenance and operational aspects of building energy management that could be implemented immediately. Selected applicable measures that could be implemented in HSU based on other studies and research are as follows:

- It was observed that a lot of classrooms, labs and offices have thermostat settings at 70^{o}F or even as high as 80^{o}F at times. Controlling classroom thermostats are considered to save a lot of energy (every 1°F ≈ 1% energy savings in buildings) (KPPC, 2009). Thus it would be ideal if all the thermostats on HSU campus could be turned down to design temperature settings which are usually 68^{o}F. This could be increased if there are consistent complaints of cold in a room or building, while at the same time, educating building occupants on ideas such as dressing appropriately for the weather.

- Initiating a “Keep Doors and Windows Closed” campaign in the campus which would minimize building envelope penetrations. These could result be 1-2% annual energy use savings in buildings by such an initiative (KPPC, 2009).
- Almost all the buildings on HSU campus are kept “on” during the two and half month of summer break and four weeks of winter break although there are far fewer occupants, and buildings only shut down for a week during Christmas break (West, 2009). According to the preliminary analysis on monthly energy consumption at HSU for last three years (2006-2008 data) there is no significant energy reduction during summer or winter break months as indicated in Table B.2 and Figure B.2 of APPENDIX B. The average energy consumption in summer months of June, July and August decrease only by 29%, 27% and 33% respectively from average monthly consumption. These decreases could be probably due to warmer summer weather, while the university is almost entirely closed from May mid- August mid (two and half months). The energy consumption in January and December are also higher than average monthly energy consumption even though the school is closed for winter break from mid December to mid January every year (four weeks).

In a study and pilot project carried out in University of Hawai at Manoa (Cutshaw, 2009) it was found that by shutting down some buildings during the Christmas break they could reduce utility demand by 45-88%, from that 75% reduction was air conditioning load. A similar initiative could be tried here on HSU campus as well. At Stanford University, the residential buildings are completely shut down during long Christmas and summer breaks including emptying and unplugging refrigerators (Standford, 2009). There should be a study to determine the possibility of shutting down buildings during breaks, calculate potential savings from adjustments to room scheduling, planning a strategy and implementing the idea.

CHAPTER 5 SELECTION OF BUILDINGS

A two-tier matrix system was used to screen buildings for further study among those that are not on the main campus Energy Management System (EMS). Large buildings on the EMS system do not have recent electricity data and hence could not be considered for further analysis in this study. For the first phase of the selection, Building Energy Use Intensity (BEUI) in $/ft^2, which is the total expenditure of the building on energy per square foot of gross area, was used to rank the building based on recent historical average prices. In conjunction, the total annual Building Energy Use (BEU) in total dollars, which is the total expenditure on energy in the building, was also used to rank buildings. This was done to ensure that we do not focus our potential savings on very small buildings which might have high energy intensity but minimal scope of savings due to sheer size of the building. For the ranking, priority was give to the BEUI, while BEU was also considered.

In the second phase, the five most energy intensive buildings were ranked based on the results from a walkthrough survey. From the revised ranking, two target buildings were selected for further detailed analysis.

5.1 Data Source

The building energy data were downloaded and updated based on information from the PG & E website while data for the Ceramics and Sculpture Labs were collected from the monthly readings done by Building Engineers. Some small houses did not have gas connections, and the marine lab uses propane whose consumption record was received from purchase records with Accounts Payable department. A few houses had natural gas supplied directly from the main campus gas meter.

The average cost of electricity and natural gas paid by HSU for the last three years was used to quantify the total cost of energy for each building and their corresponding rate on a per square feet basis. The actual energy data for the buildings mentioned above have been cleaned and formatted in an easily readable table in the APPENDIX C.

5.2 First Phase of Selection

To find out the relation between gross area of buildings and their respective expense on energy, a regression line was plotted as displayed in Figure 5.1. The correlation between the total expense spent on energy consumption and building gross area is given by 0.829*Area in ft^2 + 263.2.[6] The R-Squared value which can be interpreted as the proportion of the variance in y attributable to the variance in x is 0.410

[6]New electricity data for the Ceramics Lab was found from the detailed auditing phase. The new numbers were used for the selection process as well and the analysis revised.

and the 95% confidence interval for the mean expense spent per square foot of area is mean ± 0.24, which is the confidence interval around the slope. In the graph there are some outliers that had extremely high energy consumption such as Telonicher Marine Lab and Ceramics Lab due to the nature of the activities in the Lab, while the University Annex and Boat facility has very small consumption since they are mostly vacant or hardly have any energy intensive activities. A histogram of buildings on the $/ft^2 ($/SFT) has been plotted as well. The average BEUI is $0.95/ft^2 of gross area as shown in Figure 5.2. Therefore, it was confirmed that $/ft^2 is a reasonable comparison of building energy consumption for further analysis for this particular set of data.

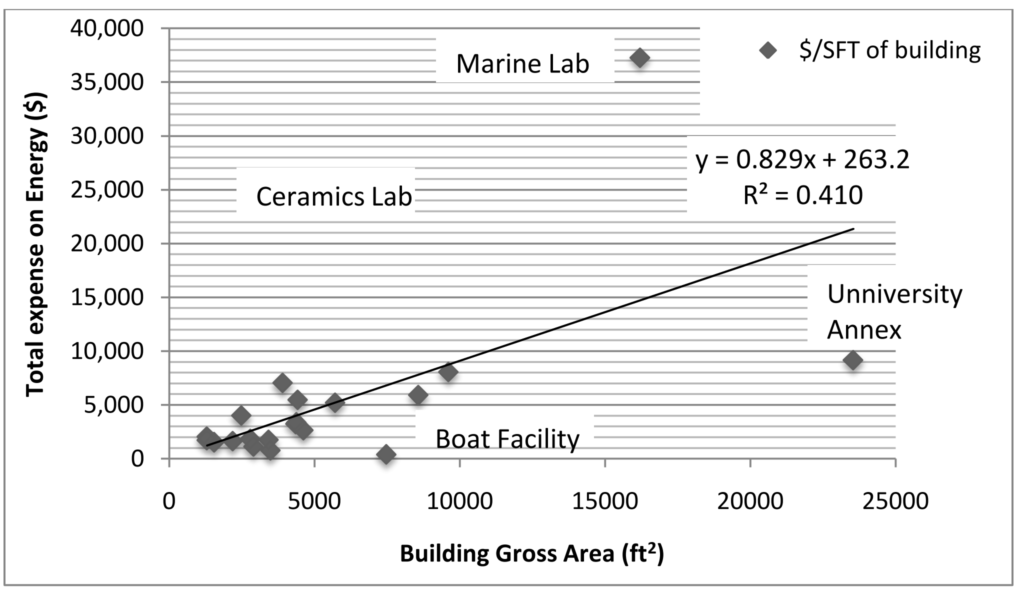


Figure 5.1 Correlation of gross area vs. expenditure on energy

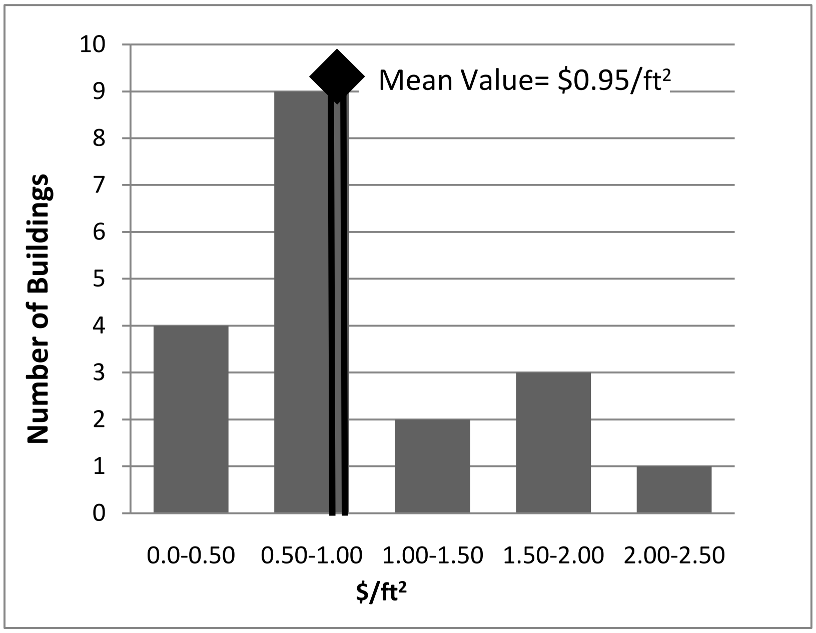


Figure 5.2 Histogram of $/ft^2 in buildings

The energy intensity of buildings and total expense on energy by each of the buildings were used to rank the buildings and determine a combined ranking for the buildings with adequate energy data. The ranking of the buildings in the study with adequate data from each condition are as follows.

a) Building Energy Use Intensity (BEUI).

Based on the energy intensity in terms of $/ft^2 for both electricity and natural gas/propane, the Telonicher Marine Lab had the highest cost for energy per square foot with $2.40/ft^2 while the boat facility had the least with only $0.05/ft^2. The average value for the building set analyzed was $0.95/ft^2.

b) Building Energy Use (BEU).

The total expense spent on a building (BEU) is an important parameter to help determine where we need to focus our effort on building improvements (Stroupe, 2010). This is done to avoid investing time and resources on buildings with small energy use even if their use intensities are high. The Telonicher Marine Lab has the highest BEU of $39,000/year, while the least is the Boat Facility at $400/year. The average expenditure for nineteen buildings in the study is $6,600/year for a building.

c) Combined Ranking.

A final building ranking was worked out based on both the BEUI and BEU ranks. While consideration was given on the BEU, priority was given on higher BEUI for the ranking. The Telonicher Marine Lab is the overall worst, followed by Ceramics Lab, Building 88 (Corner of 14 and B St), Walter Warren House and Baiocchi House. The BEU, BEUI and final ranking of twenty buildings are given below in Table 5.1

Table 5.1 Combined ranking of buildings based on BEUI ($\$/ft^2$) and BEU ($).

Building	BEUI		BEU		Combined Rank
	($\$/ft^2$)	Rank	$	Rank	
Telonicher Marine Lab	2.39	1	38,670	1	**1**
Ceramics Lab	2.36	2	22,707	2	**2**
CNR OF 14TH & B ST #88	1.76	3	7,046	4	**3**
Walter Warren House	1.59	4	4,018	7	**4**
Baiocchi House	1.56	5	2,052	11	**5**
Jensen House	1.30	6	1,726	14	**6**
Natural History Museum	1.21	7	5,483	6	**7**
Little Apartments	0.75	9	3,378	8	**8**
Sculpture Lab	0.69	12	5,910	5	**9**
Feuerkweker House	0.73	11	3,235	9	**10**
Mary Warren House	0.98	8	1,536	16	**11**
University Annex	0.37	17	9,160	3	**12**
Marine Wildlife Care Center	0.57	14	2,664	10	**13**
Hadley House	0.73	10	1,642	15	**14**
Brero House	0.65	13	1,857	12	**15**
Art Center at Eureka	0.50	15	1,762	13	**16**
Korbel Forest Research Station	0.38	16	1,135	17	**17**
Hagopian House	0.22	18	776	18	**18**
CCAT	0.15	19	439	19	**19**
Boat Facility	0.05	20	406	20	**20**
Average	0.95		6,559		

The top five buildings mentioned above that had maximum BEUI ($\$/ft^2$) intensity and also substantial BEU ($) expenditure have been selected as candidate buildings for the second phase of the selection system.

5.3 Phase Two Ranking of Buildings

All five building that were ranked as the most energy intensive in the first phase were surveyed and compared. During the walkthrough, basic information on the building, building materials, heating and lighting systems, major equipment used, interesting pictures and other relevant information about the buildings were collected as detailed in APPENDIX F. The building parameters were further compared and evaluated in a single sheet that is in Table F.6. The final evaluation sheet for comparing the buildings was developed in Table 5.2.

After going through the evaluation sheet by checking different factors and possibility of energy savings, a ranking was prepared with justifications for retaining their ranks. The Marine Lab still is the first, followed by Ceramics Lab, Marketing and Communications, Walter Warren and Baiocchi House respectively. This is the final ranking of the building, which reflects the feedback that I have collected from the survey and considers the possibility of efficiency improvements.

Table 5.2 Evaluation sheet to compare and rank buildings.

New Rank	Old Rank	Building	Area	Built Year	Building Type	Primary reasons for retaining the rank
1	1	Telonicher Marine Lab	16,208	1977	Off campus, Large	Propane heater, pumps and lots of other old equipment. Permanent building. Poor insulation.[7]
2	2	Ceramics Lab	9,615	1950	On-Campus Small House	Very poor insulation, heat loss from kilns. No immediate plan for renovation or demolition, student interest in further study of the building.
3	3	CNR OF 14TH & B ST #88	3,906	1992	On-Campus Small House	Has gas connection although it does not have a gas meter, poor insulation. Need to observe after the new thermostats have been installed.
4	4	Walter Warren House	2,486	1950	On-Campus Small House	Regular office use and lab for students, poor insulation, old furnace.
5	5	Baiocchi House	1,303	1950	On-Campus Small House	Toddler center with general use.

Based on the results from the second phase of selection process, I selected the Telonicher Marine Lab and Ceramics Lab for detailed analysis to determine their possible energy saving alternatives.

[7] Insulation levels: Very Poor- Single Pane windows, cracks on doors and windows, no false ceiling or insulation, poor flooring, minimal wall insulation. Poor - Single Pane windows, minimal wall, ceiling and wall insulation, Good –Double pane windows, tight doors, nominal wall, ceiling and floor insulation, Very Good – Double Pane or more windows, Proper door, ceiling, wall and floor insulation.

CHAPTER 6 TELONICHER MARINE LABORATORY

The Telonicher Marine Lab was the most energy intensive building and thus selected for detailed analysis. The information was used to develop a model and determine technically viable alternatives for energy savings in the building. The economic analyses are explained in Chapter 8 on Economic Evaluation.

6.1 Building Description and Function

The Telonicher Marine Lab is a single story building located on Ewing Street, Trinidad, California about 14 miles north of the Humboldt State University's main campus. Figure 6.1 shows the location of the facility on a map. The original building was constructed in 1977 and several modifications were carried out on the building over the years including a current remodeling of the wet lab (Hoskins, 2010).

The building serves as the lab for HSU students in oceanography, biology and fisheries departments. It also provides a marine exhibition for visitors to the facility. There are lecture rooms and labs for biological oceanography, chemical oceanography, geological oceanography, marine biological sciences, mariculture, a computer lab, fisheries instruction and student research (Marine Lab, 2010).

There are hundreds of live marine animals housed in the facility. More than 100 students, 6 graduate student researchers and 12 faculty and staff use the building on a weekly basis, while some ten to fifteen thousand visitors visit the marine lab in a year (Hoskins, 2010). The building is used from 8:00 to 17:00 hrs Monday to Friday and 12:00 - 16:00 hrs on weekends for classes and public visits. Researchers, staff and faculty typically work till 7:00 PM or 8:00 PM in the evening during the school season and for fewer hours during breaks. Most of the equipment in the building is operated throughout the year for the whole day due to the nature of the facility

The building gross area is 16,208 square feet. It is composed of standard wood frames with R13 insulation in the wooden framed walls with wood siding. The building height is 12 feet with 2 feet of crawl space for the inner portion of the building. Rooms on sides have 11feet floor to ceiling height. The roof is a flat concreted - slab covered with building paper, felt, and gypsum board on the inside. The flooring is concrete slab with linoleum tiles. Some doors are 1-3/4” solid wood, while others are metal or glass. The building has large windows on the north side which are single pane glass on aluminum frames, but there are also some double pane windows on other sides. Details of the building components, materials, schedule and equipment are documented in APPENDIX H.

The building is on a Pacific Gas and Electric Company (PG & E) meter for electricity.[8] Heating energy is supplied using propane that is delivered every month or

[8] A10S tariff schedule on PG & E metering system.

two to on-site tanks. A plan of the building and picture are below in Figure 6.2 to Figure 6.4.

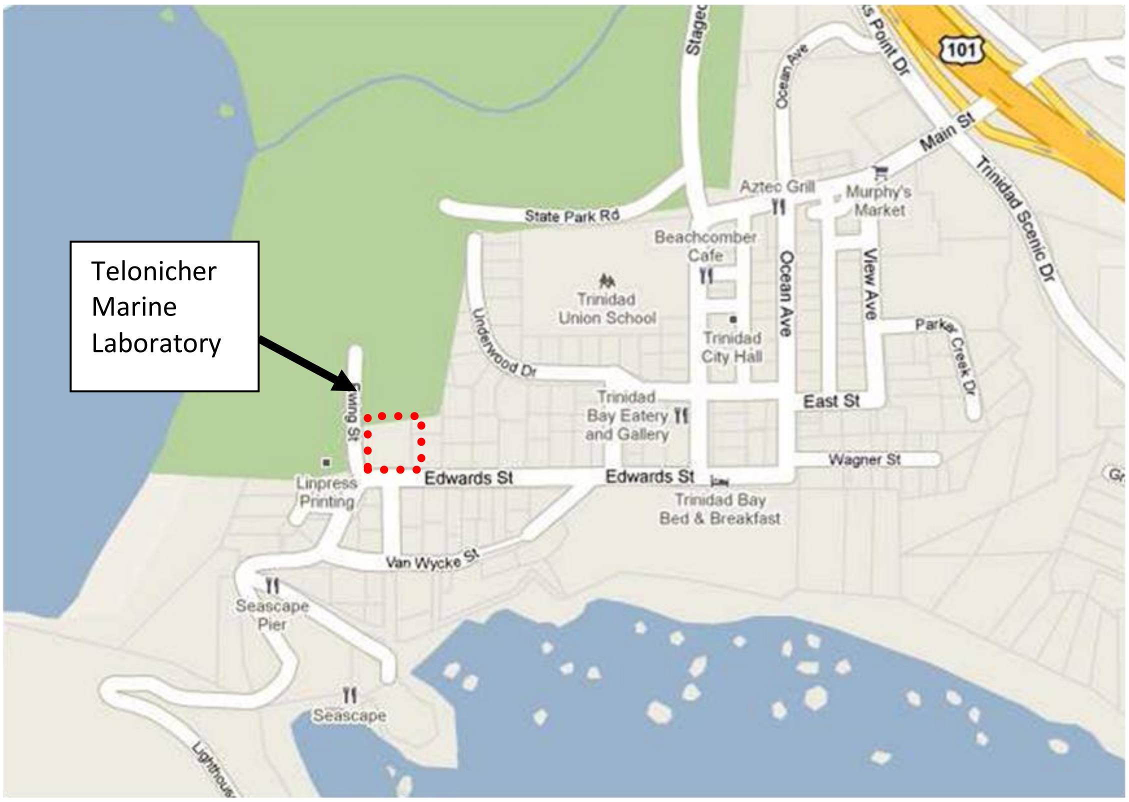
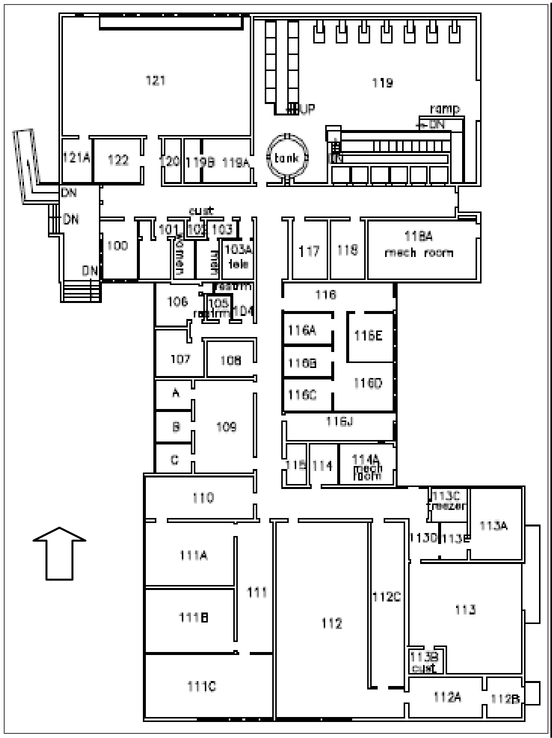


Figure 6.1 Map showing location of Telonicher Marine Laboratory, Trinidad.[9]

[9] http://maps.google.com/maps?oe=utf-8&rls=org.mozilla:en-US:official&client=firefox-a&um=1&ie=UTF-8&q=marine+lab+in+trinidad,+ca&fb=1&gl=us&hq=marine+lab&hnear=Trinidad,+CA&cid=0,0,6923625445801917430&ei=SqPITMqPM4a8sAPAscTOCA&sa=X&oi=local_result&ct=image&resnum=1&ved=0CBcQnwIwAA



Room	Function
100	Reception/Office
101-105	Restrooms and storage
106-109	Faculty Offices
111-112	Labs and classrooms
113	Storage, cooler and workshop
114-116	Machine room, lab & offices
117	Student Computer Room
118	Mechanical Room 2
119	Wet Lab
121	Lab

Figure 6.2 Floor plan of the Telonicher Marine Lab with room allocation.

Figure 6.3 Telonicher Marine Lab building from back and side (East and North).

Figure 6.4 Telonicher Marine Lab building from the front (West view).

6.2 Heating System

The Telonicher Marine Lab is heated by hot water coils which are heated by a Liquefied Petroleum Gas (LPG)/propane boiler. The hot water loop supplies heat to all parts of the building and is driven by two 1/6 hp pumps. Zone 1, which is the Wet Lab, is unconditioned. Forced heating air to Zones 2, 3 and 4 are supplied through un-insulated rectangular aluminum ducts of varying sizes which is fed from the central air handling unit. These zones also have return air ducts connected with return exhaust air fans. There are no centralized air ducts to Zone 5 and 6, which have unit ventilators at 4 different locations. The zones in the Marine Lab are shown in Figure 6.5 and a schematic diagram of the heating system is shown below in Figure 6.6.

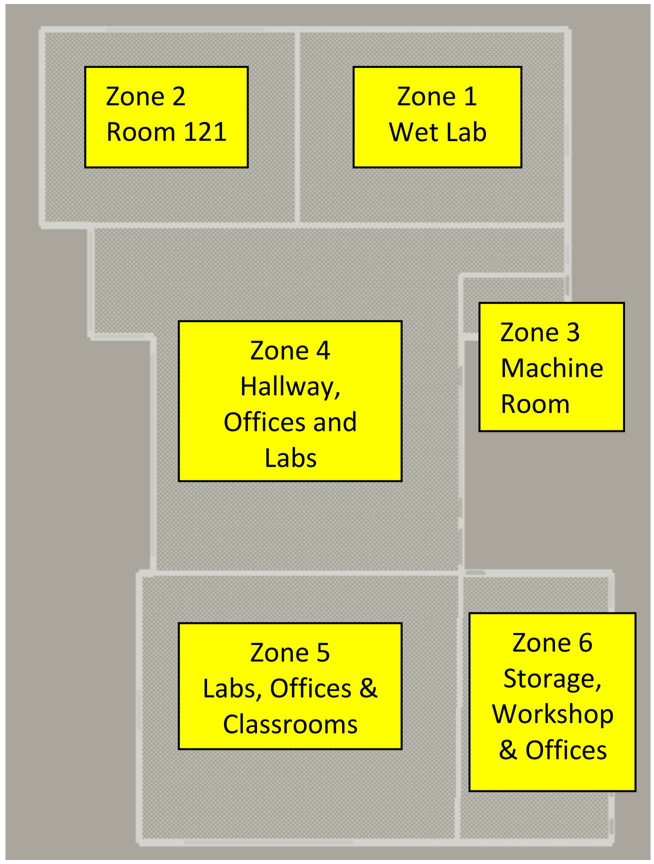


Figure 6.5 Heating ventilation zones in the Marine Lab.

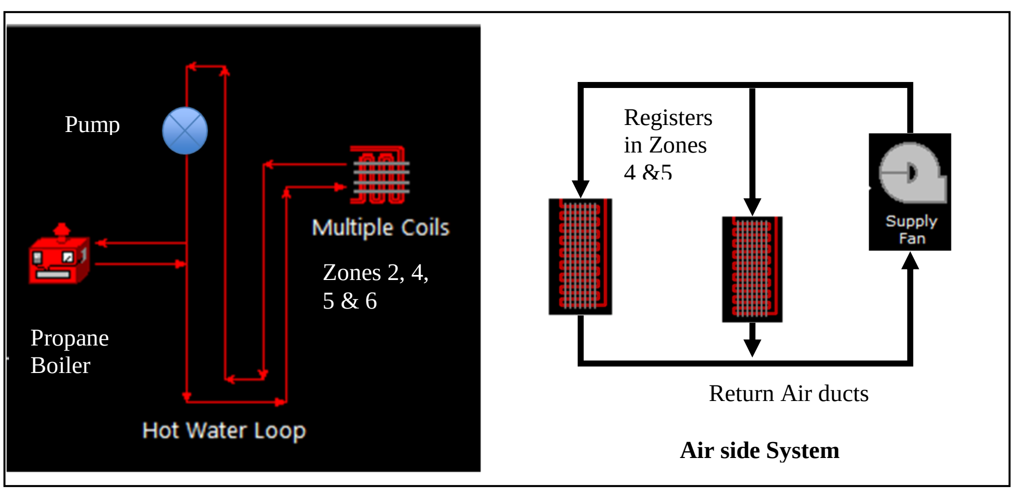


Figure 6.6 Schematic diagram of the heating system in the Marine Lab.

Domestic hot water for the building is provided by a propane powered 40 kBtu/hr, R19.2, 50 gallon water heater located in the Machine Room (118A). The heating, ventilation and lighting system in the building is controlled through a stand-alone Control Pak Energy Management System. There is a heating schedule programmed at 68^{o}F for the building from 6:00 - 18:00 hrs on Mondays to Fridays, 9:00 - 14:00 hrs on weekends and 8:00 - 10:00 hrs on holidays (i.e., 70 hrs/week on average).

6.3 Lighting System

Most of the light fittings in the building are modern, efficient, T8 fluorescent tubes with electronic ballasts which were all replaced a few years ago (2004). Three rooms and a hallway have occupancy sensors. The average lighting power density in the building is 0.67 W/ft^2. Lighting intensity in all the rooms was fairly consistent and adequate except for the Culture Lab (Room 116J). This room is a food production lab for fishes with a lighting intensity of 2.4 W/ft^2 (total of 896 W). Algal cell growth is dependent on the amount of light on it (Ovie et al., 1990). Figure 6.7 below shows the Culture Lab.

Figure 6.7 The Culture Lab with lights on the sides to provide enough light for photosynthesis.

6.4 Equipment in the Building

In addition to office equipment there is a lot of lab equipment in the Marine Lab to maintain favorable conditions for marine life-forms, research, and display purposes. The energy consumption in the building is more or less consistent all throughout the year and decreases very little during breaks as the lab equipment has to be kept on at all times. Table 6.1 below lists some of the major appliances in the building. Specific details of the components and their corresponding schedules are in APPENDIX H**.**

Table 6.1 List and schedule of equipment in the Marine Lab.

System and make	Numbers	Comment/ Schedule
Re-circulation pumps, US Electrical Motors, Ingersoll Dresser Pump Co.	2x10 hp	For recycling sea water, 87.5% efficiency. One is used at a time for 24 hrs/day. More than 10 years old,
Chillers – Heatcraft, Compressor – Copeland Discus	2x10 hp	The chillers are used to cool down sea-water that is re-circulated in the building to 12^{o}C. More than 10 years old. Both run at the same time when needed.
Water Pump at Pier	1x 24 hp	6-7 hrs a week. In very good shape (Hoskins, 2010). Separate energy meter. Provides fresh sea water to the Lab.
Compressor for Toilet Actuators - Baldor	1x10 hp	89.5%, 1.2 hrs/day.
Bench Vacuum – General Electrical	1x3 hp	0.45 hrs/day.
Walk in Refrigerator- North Star 1974.	1x150 W	+4^{o}C, R-12
Walk-in Freezer, Copeland	3 hp	Full time on
Computers, LCD	15x200 W	Normal office hours
Printers, lasers	5x200 W	Normal office hours
Incubator	1x800 W	Full time on when used
Chest Freezer - Kenmore	357 kWh/yr	Full time on
Refrigerator(Fisher Scientific)	300 W	Full time on
Electrical radiator Heater, Dayton 9 fins	1000 W	2-3 hrs/day in winter
Dishwasher	1800 W	2 loads/week @1 hr

6.5 Energy and Impact of the Telonicher Marine Lab

Based on three years of data that have been presented earlier in the report, the electricity and propane consumption have been compared. The complete lists of energy consumed are in APPENDIX G. Total annual electricity consumption is 200 MWh and 6,634 gal of propane are used in a year. The key findings have been tabulated below in Table 6.2.

Table 6.2 Details of propane and electricity consumption in the Marine Lab

Parameter		Quantity	Unit	Quantity	Unit
Electricity					
Annual Electricity consumption		200	MWh	683	MMBtu
Avg. monthly		16.7	MWh	57.0	MMBtu
Peak Demand	Summer	57	kW	190	KBtu/h
	Winter	39	kW	130	KBtu/h
Avg. demand		23	kW	78	KBtu/h
Propane					
Annual propane consumption		6634	Gal	607.1	MMBtu
Avg. monthly		552.9	Gal	50.59	MMBtu
Avg. demand		1.82	Gal/hr	167	KBtu/hr

According to the average cost of energy and carbon content mentioned in Chapter 4 on Buildings and Energy in HSU, the actual cost of energy for the Marine Lab building was calculated along with its related emission. In a typical year the Marine Lab spent an average of $38,700 for energy emitting 113 $MTCO_2$ into the atmosphere. To compare the cost to some practical daily figures, all students enrolling at a CSU campus pay the system-wide State University Fee which is currently $4,026 per academic year for undergraduate students (CSU, 2009). A ton of carbon dioxide on the other hand is a cube of 27 feet wide by 27 feet high by 27 feet deep at atmospheric pressure (EnergyRace.com, 2008). The details of expenses on energy and specific emission from each fuel are below in Table 6.3.

Table 6.3 Details of expenses on energy and specific emissions for the Marine Lab.

	Energy used	Rate	Cost ($)	Carbon content ($kgCO_2$/ kWh)	Carbon content ($kgCO_2$/ Therm)	Emission ($MTCO_2$)
	(MWh)	**($/MWh)**				
Electricity	200	135.24	26,900	0.37	-	75.0
	(Gallons)	**($/gal)**				
Propane	6634	1.77	11,800	-	5.74	38.1
Total /yr			**38,700**			**113**

6.6 Highlights from the Audit and Analysis

There were no updated drawings readily available for the current heating and ventilation system. The boilers and ducting systems have been modified when the building was extended, but no records were available. For instance, the duct works in the Wet Lab (119) are not connected to the air handler, but the ducts are still there and also shown on old drawings. In the second mechanical room (114A), there is a bench vacuum and compressor as mentioned in Table 6.1 which are used on-demand. The number of hours used for these equipment were collected by a Hobo Motor On/Off logger from 4/5/2010 - 5/10/2010. The chillers were considered to be run for an average of 13.1 hrs/day in a typical year based on calculations to account for the missing tanks in addition to the Hobo data logger reading. Details of the calculation of the chiller use are in APPENDIX H.

There does not seem to be any serious maintenance or operation issues with the building at the moment. However, it was noticed that the front office (Room 100) which faces west with large windows is very hot at times. Upon study it was discovered that the thermostat for this front room is combined with an inner computer room (117) which does not receive any direct sunlight and is often unoccupied. There was a small note by the thermostat in the computer room explaining the situation.

6.7 DOE2 eQUEST Model of the Telonicher Marine Lab

Based on the details that have been collected through the audit, as built drawings, interviews with Building Engineers, users, and Managers, the information was used to create a DOE2/ eQUEST model. A 3D display of the Marine Lab model from eQUEST has been captured and presented below in Figure 6.8.

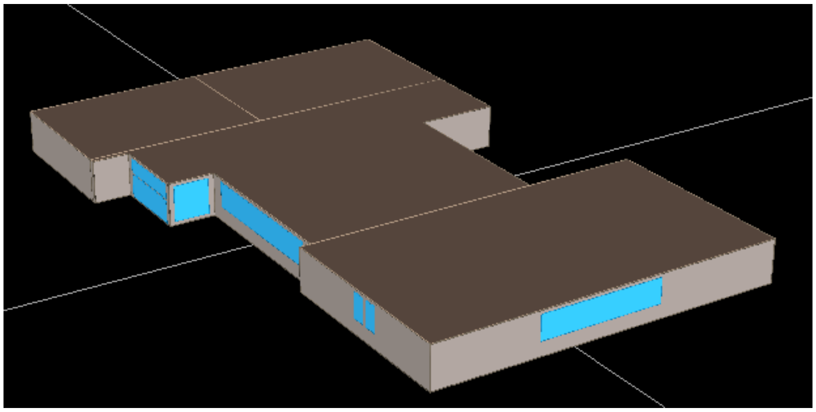


Figure 6.8 eQUEST model of the Telonicher Marine Lab.

Some minor assumptions and simplification about the building have been made which were not vital for the model. This includes combination of window widths and placement of doors and windows at approximate locations. Calibrations were carried out on models to reasonably estimate the building's energy use for a year. Air infiltration rates and some equipment schedules (chillers, compressors, pumps and HVAC settings) were altered to get a model that deviated least from the actual building, but also not making unreasonable assumptions. The final modeled building has very similar energy demands compared to the actual energy consumption of the building as shown below in Figure 6.9 and Figure 6.10, which are based on Tables J1 and J.2 in APPENDIX J. The propane use of the model is not reliable comparison since propane data is from purchase record which is not always procured monthly. The propane use in 2007 was high, but there are no valid justifications or any efficiency improvements in 2008 and later (Hoskins, 2010).

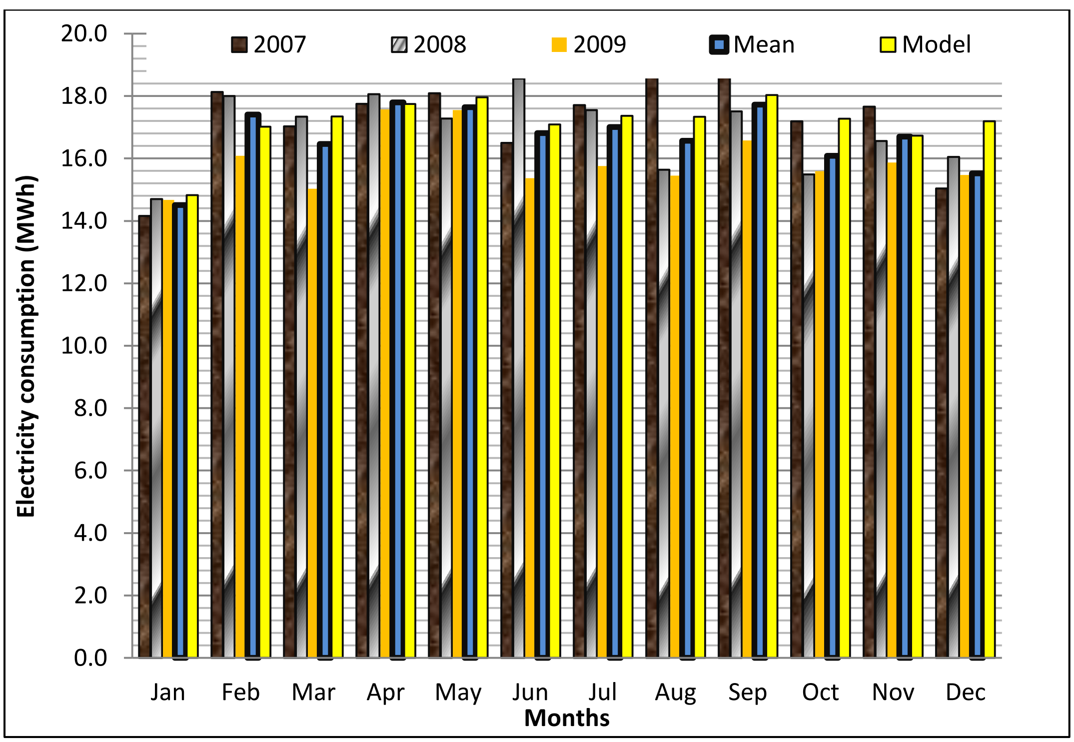


Figure 6.9 Comparison of electricity consumption of the Marine Lab and the model.

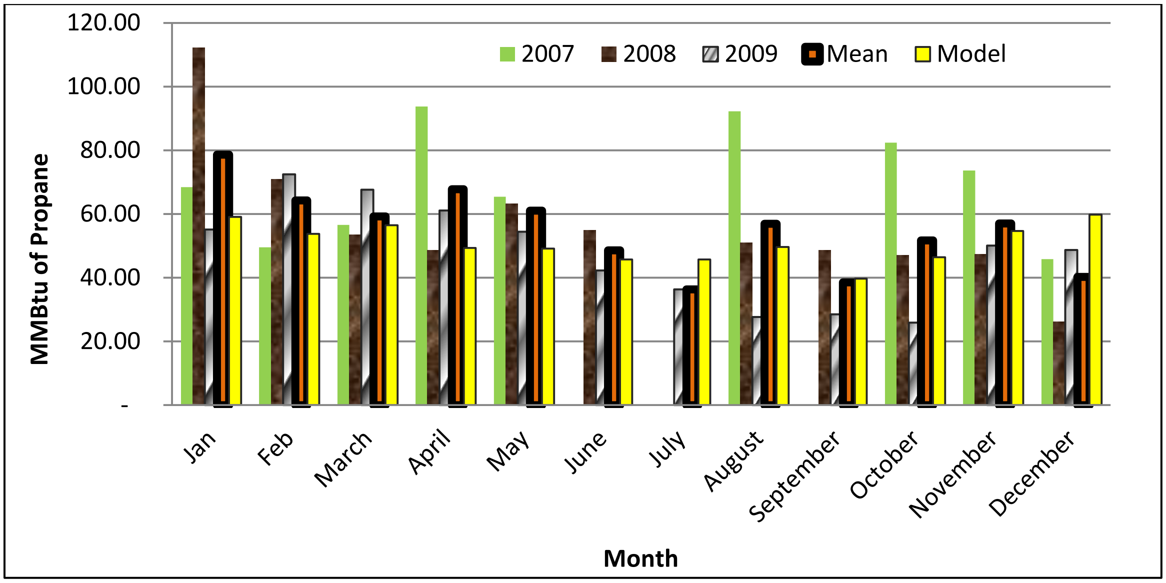


Figure 6.10 Comparison of propane delivered to the Marine Lab and consumption in the eQUEST model.[10]

6.8 Energy Saving Alternatives for the Marine Lab

From site visits and audits it was evident that most of the building loads are from equipment use and space heating load. The actual ratio, from the eQUEST model, is shown below in Figure 6.11. Propane use is 86% for space heating the building and 73% of the electricity is used for equipment. Thus, my intention to find out the energy saving alternatives is focused on these two issues. However, other scenarios were also modeled for comparison.

[10] For some months in 2007 and 2008, there were no purchase records as propane is stored on-site and supplied as needed.

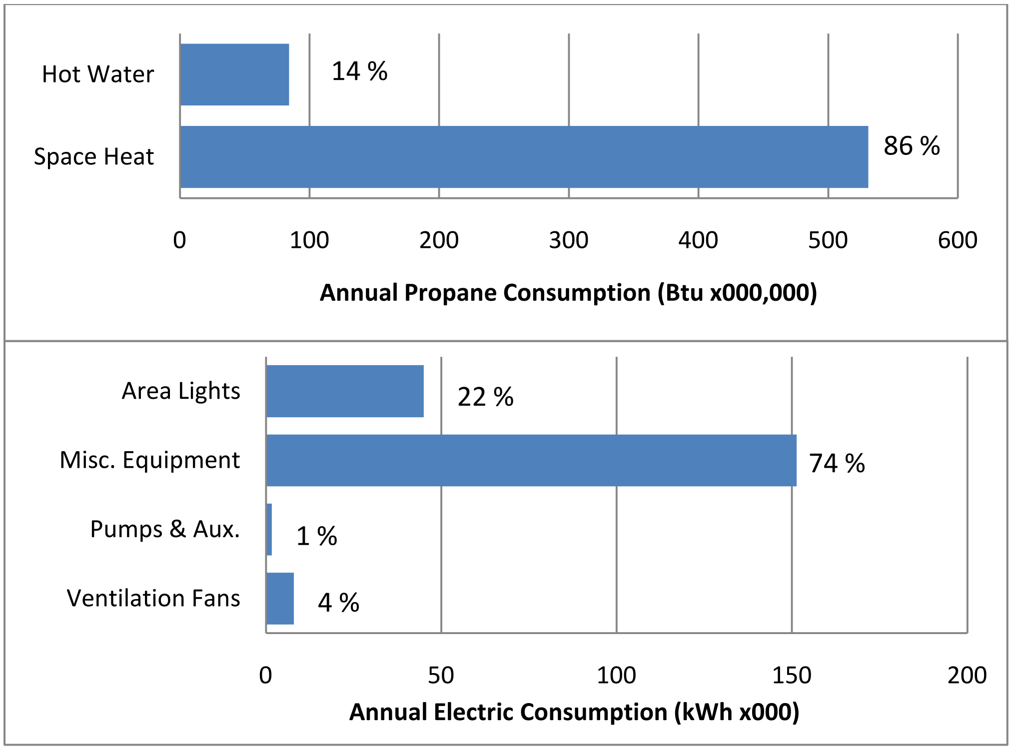


Figure 6.11 eQUEST result of the building energy use.

Some technically viable options for reducing energy use at the Telonicher Marine Lab and corresponding energy savings estimates from the eQUEST model are listed the in the following section. Economic evaluations of the alternatives are shown in Chapter 8 which focuses on economic analysis.

6.8.1 Reduce air infiltration rate in the building by installing revolving doors at the entrance

Most of the rooms in the building are fairly impermeable and assumed to have low air infiltration rates from 0.25 to 2.00 ACH as mentioned in Table 6.4 below. However, for Zone 4, which consists of the long hallway/corridor and few labs and offices, the baseline infiltration rate has been estimated at 3.00 ACH. This is due to frequent opening and closing of the front door with 10,000 - 15,000 visitors in a year and the zone being directly exposed to outside air via glass doors on two sides of the building.

Table 6.4 Air infiltration rates for the building

Zone and rooms	Air Infiltration Per Hour in the model	New Air Infiltration Per Hour
NW (121)	0.25	0.25
NE (119, Wet Lab)	2.00	2.00
SSE (118A, Machine Room)	0.50	0.50
SW (Zone 5, 111&112)	0.25	0.25
E Perim (113, Workshop)	3.00	3.00
SW (Zone 4 with corridor)	**3.00**	**1.50**

There is a possibility of reducing the infiltration rate in Zone 4 by installing a revolving glass door. In a pilot project at MIT (MIT, 2009), a revolving door project had determined that far more air is exchanged when a swing door is opened as opposed to a revolving door. This additional new air needs to be heated or cooled. The project team estimated that if everyone used the revolving doors in a pilot building (E25, MIT), it would save more than 75,000 kilowatt-hours of energy—about 1.5 percent of the total required to heat and cool the building—and prevent 14.6 tons of carbon dioxide from being emitted, while saving MIT almost $7,500 (MIT, 2009). It was also found that every time a swing door is opened 78 Wh (270 BTU) of heat is lost from the building (Horton, 2010). However, we should note that the case might be more in cases where they have high cooling load and multi-storied buildings. There were no studies easily available for single storied/low rise buildings with heating loads alone.

Based off of those studies carried out and the revolving door system advantages, if we assume that we can reduce the air from 3 ACH in the model to 1.5 ACH by installing a revolving door at the front entrance, there is a potential energy saving of 17.7 MMBtu/yr (2.88%) of propane according to the eQUEST model (Details in APPENDIX K.).

6.8.2 Solar lighting in the building and Culture Lab room

“Micro Algal culture for fish food production requires adequate light” (Ovie et al., 1990). The Culture Lab room in the Marine Lab does not have any natural lighting and all the fluorescent tubes (totaling to 896 W) are kept on all the time. This is equal to 645 kWh/month, which is about $90 per month. Different technical alternatives were explored and the easiest one is to relocate the Lab in a room with better natural lighting through windows and transparent ceilings. There are two other options for providing solar lighting in the Culture Lab room which are explained below:

1. Light tube or Solar tube

Light tubes also called a solar tube, are tubes placed through a roof to transmit light on an interior room inside the building. It consists of a reflective tube, a transparent roof-mounted light collector and diffusers on the ceiling of the room to be lighted. A schematic picture of a solar tube (Kühn, 2010) is shown in Figure 6.12. The Marine Lab has flat roof, a penetrable roof slab and the culture lab room is right in the middle without any day light, where artificial lights are kept on all the time. This makes a very good candidate for this alternative.

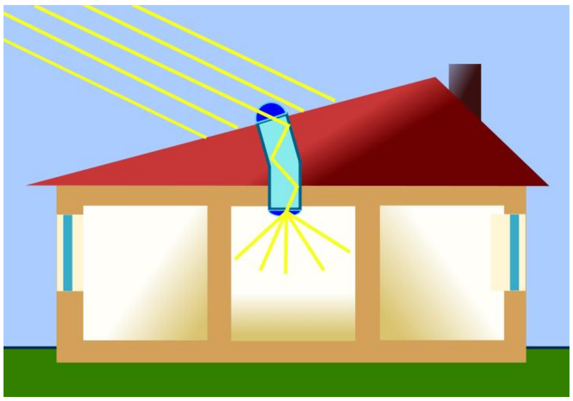


Figure 6.12 Solar/Light tube

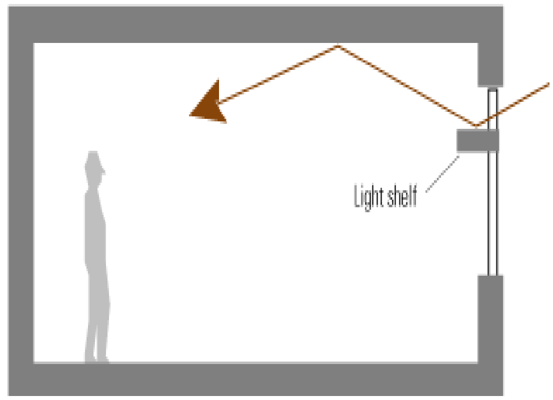


Figure 6.13 Light shelf

2. Light Shelves

Light Shelves are horizontal overhang reflectors placed above eye-level for reflecting natural sunlight into the building. “They are best installed on south facing windows outside the window” (Business Energy Advisor, 2009). Figure 6.12 shows the concept of Light Shelves from the same source. The south and west side of Marine Lab has about half of its walls covered with windows. The hallways running in both the directions are lighted up by artificial lights, in addition to the Culture Lab which is “on” all the time. Installing Light Shelves on the south facing windows or the western windows are extremely appealing options to be considered. Light shelves will reduce glare and reflect sunlight onto the ceiling, distributing daylight further into the building.

Although both the technologies are proven and executed in many places, I could not find a good way to prove the suggestion by way of energy saving calculations and costs associated with the problem due to the complexity of the issue. A detailed understanding of algae growth and light would be also required.

6.8.3 Double pane windows and more ceiling insulation

If all the existing single pane windows and glass doors with double pane low-e glass are replaced with double pane low-e glasses there is a saving of 6.05 MMBtu/yr (0.98%) of propane. Installing an additional layer of insulation on the ceiling by six inches of glass wool results in 25.1 MMBtu (4.08%) saving every year. If both of these options are implemented together, according to the eQUEST model, there is a possibility of reducing 32.6 MMBtu (5.30%) of propane consumption per annum, as shown in APPENDIX L.

6.8.4 More efficient boiler

The current N700 Thermific propane boiler in the building is more than 10 years old (installed 9/19/99) and is only 85% efficient. There are new boilers which are more than 95% efficient (Revision Energy, 2010). If a new a boiler calculated as 95% efficiency is installed there will be a saving of 26.6 MMBtu (4.32%) of propane every year for same energy demand in the building. APPENDIX M has the savings from the boiler while APPENDIX CC shows the calculations and details for the current boiler and a feasible replacement option.

6.8.5 More efficient re-circulation pumps

One of the two sea water recirculation pumps for the aquaria is on all the time. The existing pumps are 60% efficient Ingersoll Dresser Pumps (GRP 3 x 1.5 x 13), 98 ft of head, and 150 gpm which requires 6.36 hp power. The motors are US Electrical Motors (3 Phase, 10 hp, model no T779A) with guaranteed efficiency of 87.5%. There are new pumps from Flowserve, the company which has taken over Ingersoll Dresser, that have an efficiency of 70%. State Electric has US Electrical Motors (AS700) with 91.7% (Aron, 2010). If we replace the pump with a new pump from Flowserve and a US Electrical Motors AS700, there is a potential to save 8,670 kWh (4.21%) in a year. The details of the existing pump, potential replacement and calculations are in APPENDIX BB. One of the current Ingersoll Dresser pumps could remain as a backup for emergency purpose.

6.8.6 More efficient chillers

The two current 10 hp chillers in the Marine Lab are more than 10 years old. There are more efficient multi-staged chillers available in the market (Rocha, 2010). However, no actual technical details of the current chiller system were available besides the compressor specifications as the chiller was custom made at the site for the Lab. Thus, no reliable cooling capacity of the chiller could be determined for comparison or further study. Currently the chillers are turned off due to the remodeling work in the Wet Lab (Hoskins, 2010).

6.8.7 Cogeneration at the facility by using a Microturbine

The facility is not connected to a natural gas line but it has electrical connection to the California electric grid and heating fuel is provided by propane at the site. A cogeneration system also known as combined heat and power (CHP) system was studied for the site, by using a Microturbine. “Cogeneration technology is simultaneous production of electricity and useful heat from the same fuel or energy” (Cogeneration.net, 2002). More detailed information on the technology and advantages are explained in APPENDIX N. Various heuristics for CHP suitability at the site were checked against authoritative literature from LBNL (Owen et al., 2002) and the following results were obtained:

- Electric and thermal loads are relatively coincident - **Yes**
- There are thermal energy loads in the form of steam or hot water **- Yes**
- Thermal demand (steam and hot water) to electric demand ratios are similar to the ratios for available CHP technologies (for this analysis, a ratio of about 3:1) – **Yes** (683 MMBtu of electricity and 607 MMBtu of propane, details are in Table FF.1).
- The building energy system is operated > 4,000 hours per year – **No** (heating demand of 3,640 hrs/year).

Microturbines are small gas turbines with capacities from 30 kW to about 100 kW (Ovie et al., 1990). Microturbines can burn a variety of fuels including natural gas, gasoline, diesel, alcohol, and propane. The CSU Report on Sustainability and Energy

Efficiency Goals lists cogeneration through Microturbines at campus locations as one of the ways to achieve sustainability and reduction in carbon emission (CSU, 2005).

For the Marine Lab with peak demand of 58 kW and base load of about 23 kW, a 30 kW system manufactured by Capstone is fitting. The thermal output from a 30 kW propane system is about 174 kBtu/hr while the average hourly heating demand for the building is about 133 kBtu/hr. The details of the design assumptions and parameters are in Table 6.5 below and the analysis results are also mentioned in APPENDIX FF. A picture and layout of an installed 30 kW Capstone Microturbine has been shown in APPENDIX N.

Table 6.5 Calculation and design parameters for 30 kW Capstone Microturbine

Parameter	Quantity	Unit
Total Electric Use	200,000	kWh
Average Electric Use	23	kW
Total Propane Use per annum	603	MMBtu
Annual Heating	3,640	Hours
Average Thermal Demand	133,000	Btu/hr
Net CHP Power	30	kW
Net Thermal Output	5,800	Btu/kWh
CHP Electric Efficiency	23.0	%
CHP Fuel	15,000	Btu/kWh
Thermal Output	170,000	Btu/hr
Thermal Output	630	MMBtu/Yr
CHP Power to Heat Ratio	0.59	-
CHP Efficiency	62.1	%
Displaced Thermal Efficiency	80.0	%
Thermal Utilization	100.0	%

6.8.8 Savonius wind turbine

According to a staff paper from California Energy Commission (Yen-Nakafuji, 2005) and the California Energy Maps (California Energy Commission, 2008) the site at Trinidad is not considered as a very good site for wind energy generation. However, it is possibility that a Savonius wind turbine might be feasible and economically viable at the site and worth studying in detail. The principal motivations for that are:

- To demonstrate wind technology at the site for students as an educational material
- Generate on-site renewable energy
- Provide energy independence for the lab
- Experiment vertical-axis wind turbine (VAWT) technology which are used for converting the force of the wind into torque on a rotating shaft. This is considered neighborhood friendly with minimal noise, and also resistant against turbulent winds or storms from the ocean with harsh conditions (Windside, 2009).

A complete analysis of the option could not be carried out within the scope of this study as it involved collection and analysis of wind data, analysis and thorough study on the VAWT technology.

The following Table 6.6 presents the savings from the alternatives that could be quantified for the Marine Lab. The economic evaluations of the alternatives are in Chapter 8.

Table 6.6 Summary of savings for retrofit alternatives in the Marine Lab

Alternative	Consumption/yr		Savings/yr		% Saving
	MWh	MMBtu	MWh	MMBtu	
Baseline	205.91	615.14			
Decrease air infiltration	205.91	597.45	-	17.69	2.88%
Double Pane windows	205.91	609.09		6.050	0.98%
Ceiling insulation	205.91	590.02		25.12	4.08%
Ceiling insulation with double pane windows	205.91	582.54	-	32.60	5.30%
New Boiler	205.91	588.57	-	26.57	4.32%
New Pump			8.663		4.21%

CHAPTER 7 CERAMICS LAB

As the second worst building from the nineteen building studied, the Ceramics Lab was evaluated in-depth to determine energy efficiency improvement alternatives. Following sections cover the details of the building information, energy use, and schedule. A DOE2 eQUEST model was also developed and various retrofit alternatives discussed.

7.1 Building Description and Function

The Ceramics Laboratory is a single story laboratory building located on the south end of HSU campus. Figure 7.1 shows the lab on a map of the campus. It was built in 1950 as a temporary building. Minor maintenance has taken place over the years, and the latest remodeling was done in 1999. A new air cleaning system was installed in 2003 - 2004. The building serves as the Ceramics Lab for the campus where about 160 students are enrolled every semester in various classes on ceramics. The building is open from 8:00 AM to 5:00 PM Monday through Thursday for classes, and until 10:00 PM everyday during school seasons for laboratory use. The lab is closed most of the time during breaks and sparingly used by faculty and staff.

The building gross area is 9,615 square feet. It is built of standard wood frames with no insulation on wooden frames and concrete wall with wooden siding. A plan of the building and pictures are below in Figure 7.2 and Figure 7.3. The building consists of a Lecture Room (102), two Offices (102A and 112), 2 Restrooms (104 and 106), an Independent Study Lab (115), Gas Kiln Room (108), Electric Kiln Room (111) and a Forming Room (101) which is directly connected to the Electric Kiln Room and subdivided without proper walls into Glazing Room (107), a Hot Box (109) and Spray Booth (105).

Most of the wooden shingle pitched roof is exposed directly into the rooms without any ceiling or insulation. Three rooms have false ceilings with R-21 fiber glass insulation. The flooring is concrete slab without any finishing. The doors are 1-3/4” solid wood, but many of them are old and worn out with cracks and holes. All the windows on the buildings are single pane glass or plastic sheet either on wood or steel frames. There are crown skylights on two rooms facing south (111 and 115). Details of the building components, materials, heating, lighting, equipment and their schedule are documented in the Energy Audit Worksheet for Ceramics Lab, APPENDIX O.

Electricity and natural gas for the building are from the main campus connection and the rate is similar to the rest of campus. Actual consumption readings for the Ceramics Lab are read by the Building Engineer on a monthly basis and stored in the Plant Operations network.

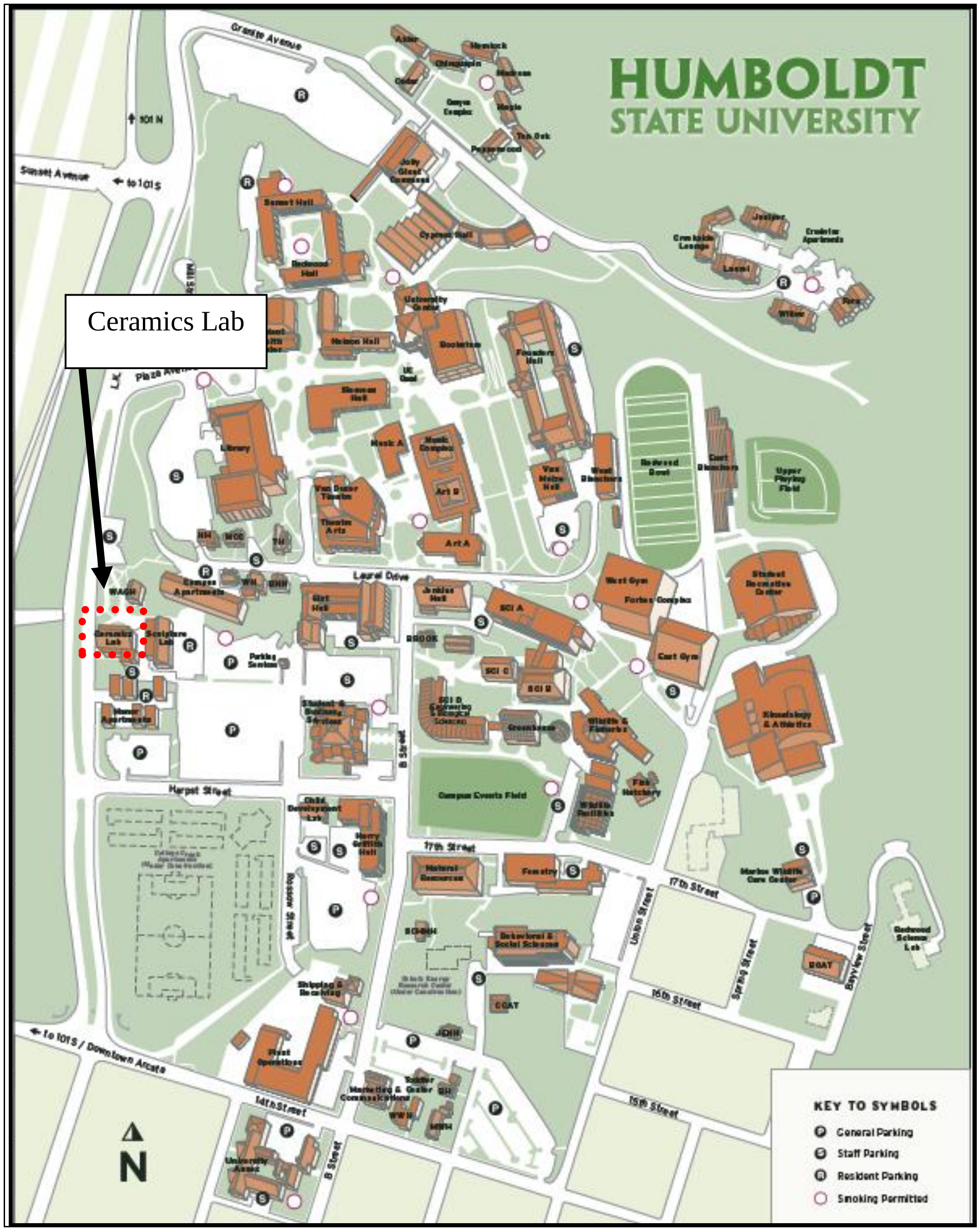


Figure 7.1 Map of HSU campus showing the Ceramics Lab.[11]

11 http://www.humboldt.edu/facilityplan/floor_plans.php

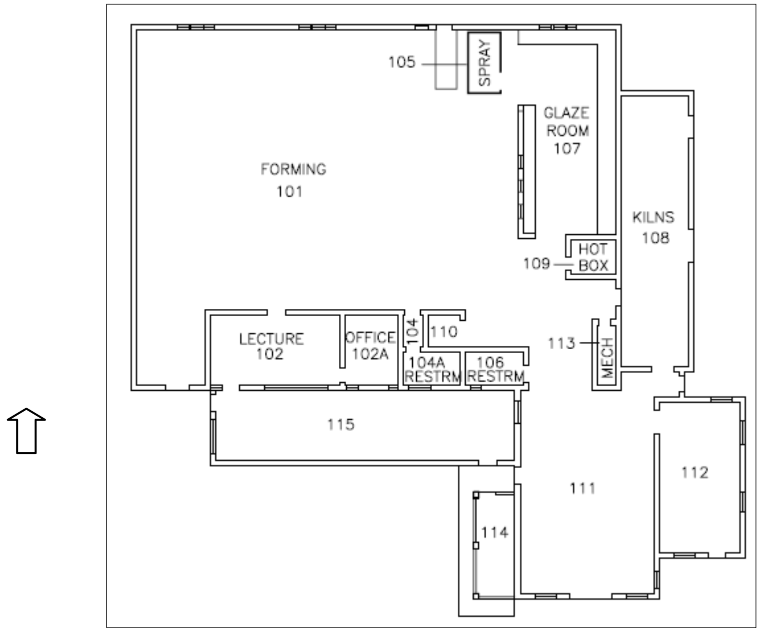


Figure 7.2 Floor plan of the Ceramics Lab.[12]

Figure 7.3 Ceramics Lab building from sides (South and East)

[12] http://www.humboldt.edu/facilityplan/floor_plans.php

7.2 Heating System

The building is heated by five natural gas unit heaters, most of which were installed during the building construction in the 1950s. Some repairs, modifications and replacements were carried out in 1999. Room 108, the gas kiln room, is separated by a solid 6" concrete wall, and a door which is often closed, so it was considered as a different unconditioned zone. The heaters are 80% efficient, fanned by 2-4A Robertshaw and Honeywell motors, ceiling mounted, and made by Janitrol. Two of the heaters have an input of 65,000 Btu/hr while three others have input of 100,000 Btu/hr. Four of the heaters are in the forming room (101) and the fifth one is in the electric kiln room (111). Theoretically the set points are expected to be 68^{o}F, but during the numerous visits to the building it was found that the thermostats were always 70^{o}F or more. Hot water for the building is provided by a natural gas powered 30 gal American Water Heater located in the Forming Room (101) that has an insulation of R 16.7.

7.3 Lighting System

Most of the light fittings in the building are T8 fluorescent tubes with electronic ballasts. The forming room has 400 W metal halide lamps. Restrooms have CFLs and there are a few incandescent lamps in the gas kiln room and the hot box. Details of the light fittings are in APPENDIX O. The power density is 0.83 W/ft^2 and 0.72 W/ft$^{2`}$ for the gas kiln room and rest of the building, respectively. Average lighting levels in lux measured by an EXTECH 403125 Light Probe Meter in the gas kiln room was 239 lux and 790 lux for the rest of the building. Only the Independent study room (115) had excessive light intensity of 1,770 lux with both natural sunlight through the skylight and tube lights turned on during the daytime. The result from the light intensity measurement for the Ceramics Lab is in APPENDIX P. None of the lights had occupancy sensors or timers on them.

7.4 Energy Use by the Ceramics Lab

On thorough review of the energy meter in the Ceramics Lab and historical data, it was found that the electric consumption in kWh has to be multiplied by a factor of 32 for the E-Mon D-Mon brand electric meter installed in the building. This was not noticed by the Building Engineer and not considered in the historical data. The corrected electrical energy consumption figure was used everywhere in this work. Three complete years of electric data (2007 - 2009) and only two years of data for natural gas (2008 - 2009) were available. The details for each energy use and their impacts are in the following sections.

7.4.1 Electricity

The average annual electricity consumption in the Ceramics Building is 114 MWh/yr, which works out to 11.8 kWh/ft^2/yr and 40.4 kBtu/ft^2/yr. No one year is either high or low in particular. The detailed electricity data for 2007 - 2009 are in Table 7.1.

Table 7.1 Recent electricity data for the Ceramics Lab for 2007 - 2009.

Electricity in MWh				
	Years			
Month	**2009**	**2008**	**2007**	**Mean**
Jan	5.98	7.14	10.1	7.74
Feb	11.8	14.1	8.86	11.6
Mar	17.4	33.2	12.0	20.9
Apr	15.7	3.17	14.3	11.0
May	6.11	2.56	7.26	5.31
Jun	2.46	3.20	3.22	2.95
Jul	4.35	4.38	2.05	3.59
Aug	4.45	7.07	6.98	6.17
Sep	9.63	10.2	13.2	10.9
Oct	9.82	17.9	0.42	12.0
Nov	14.2	8.29	17.4	13.3
Dec	11.2	5.80	7.78	8.26
Total	113	117	112	114
Area (ft^2)	9615	9615	9615	9615
kWh/ ft^2/yr	11.8	12.2	11.6	11.8
kBtu/ ft^2/yr	40.2	41.5	39.6	40.4

7.4.2 Natural gas

Total annual natural gas consumption in the building is 675 MMBtu (1MMBtu = 10 Therms), which is 7.02 kBtu/ft^2*yr. Data for the two years are overlapping each other and no one year is higher or lower than the other. The monthly gas data for Ceramic Lab for 2008 & 2009 are below in Table 7.2.

Table 7.2 Monthly natural gas data for the Ceramics Lab for 2008 & 2009

	MMBtu/year		
Month	**2009**	**2008**	**Mean**
January	67.6	118	92.7
February	80.9	129	105
March	106	104	105
April	70	8.25	39.1
May	22.4	8.25	15.3
June	7.5	4.2	5.85
July	2.5	4.4	3.45
August	4.5	5.4	4.95
September	22.3	34.8	28.6
October	47.2	83.4	65.3
November	76.7	50.4	63.6
December	119	174	146
Annual Total	626	723	675

7.4.3 Economic and environmental effect of energy consumed in the Ceramics Lab

Based on the average cost of energy and carbon contents mentioned in Chapter 4, the actual cost of energy for Ceramics Building was calculated along with its related emission. In a typical year, the energy costs for the Ceramics Lab are about $22,900, emitting 77.9 $MTCO_2$. The details of the expenses on energy and specific emission from each fuel are below in Table 7.3.

Table 7.3 Details of the expenses on energy and specific emission for the Ceramics Lab.

	Energy used (MWh)	Rate ($/kWh)	Cost ($)	Carbon content ($kgCO_2$/ kWh)	Carbon content ($kgCO_2$/ Therm)	Emission ($MTCO_2$)
Electricity	112.14	0.14	15,300	0.37	-	42.0
	(Therm)	**($/Therm)**				
Natural Gas	6746.60	1.13	7,640	-	5.31	35.8
Total /Yr			**22,900**			**77.9**

7.5 Equipment in the Building

The Ceramics lab has several ceramics related pieces of equipment, such as kilns and air purifiers that are tabulated below in Table 7.4. The specific details of the components including their power rating (which are all varied), and their corresponding schedules are presented in APPENDIX O.

Table 7.4 List and schedule of equipment in the Ceramics Lab.

System	Numbers	Schedule
1. **Gas Kilns in room 108**	4	16 hrs@ twice a week during the semester.
2. **Electric Kilns in room 108, 111 and 115**	12	16 hrs per firing @ 4/week in the beginning of semester, 8/week mid semester and 17/week at the end.[13]
3. **Glaze Mixing Hood**	3	2 hr/day
4. **Containment Hood**	3	2 hr/day
5. **Kiln Fume Vent/Air cleaners**	7	12 noon – 6 pm everyday
6. **Air Purifiers/cleaners**	8	12 noon – 6 pm everyday
7. **Exhaust Fans**	2	3 hrs/day
8. **Grinder**	1	30 mins/week
9. **Hot Box**	1	Maintained at 70^{o}F
10. **Brent Potter Wheel**	8	6 hr/week
11. **Shimp RK Whisper**	4	3 hr/week

[13] The detailed schedule of electric Kiln firing as obtained from interviews and reservation sheet.

7.6 Highlights from the Audit

The Ceramics Lab was evaluated and audited by more than five visits at different occasions. Numerous critical observations about the building were made which are explained below.

7.6.1 Open doors and high temperature set points

A lot of emergency exits and regular doors were kept wide open. Some building users in the gas kiln room mentioned that they keep the door open in the kiln room when the kilns are fired to dilute the air which they expect might have carbon monoxide. This is a very valid issue with ceramics industry (EPA, 2010). The Building Manager however, informed that they try to keep all the doors closed when not needed (Schneider, 2010). Pictures of the doors kept open are in Figure 7.4 to Figure 7.6 below.

Figure 7.4 Room 108, 1 PM, 4/9/2010

Figure 7.5 Room 111, at 1 PM, 4/9/2010

Figure 7.6 Room 111, 3 PM, 4/15/2010

It was noticed that the immediate vicinity of the kilns were hot, whereas the rest of the building is temperate or cold, thus demanding more heat to maintain the set point temperature.

7.6.2 Cracks and leaks on doors

There are many cracks on doors, huge leaks surrounding doors and unregulated louvers and vent holes as shown in Figure 7.7 to Figure 7.9.

Figure 7.7 Room 108 cracks on walls, doors and vent holes.

Figure 7.8 Cracks on doors and vents

There is no ceiling other than the underside of the roof in the main forming room (101, 105, and 107) and gas kiln room (108). They cover more than 50% of the building area, and have 4 of the 5 gas heaters. The roof opens directly into the room without any insulation. There are also four 2 ft x 2 ft roof vents. Figure 7.9 below shows the situation.

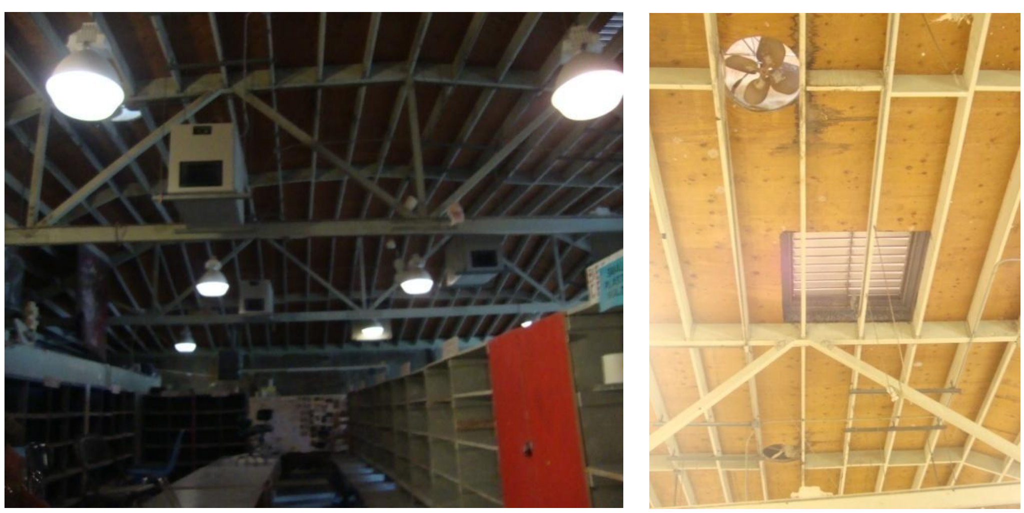


Figure 7.9 Roof without ceiling or insulation and with roof vents.

The set points for unit heaters in the building are supposed to be at 68°F. However, during visits to the building it was always observed that one or more thermostats were set at 70°F or more. An example is shown in Figure 7.10 below, where the thermostat has been set at 70°F and the room temperature indicates 80°F.

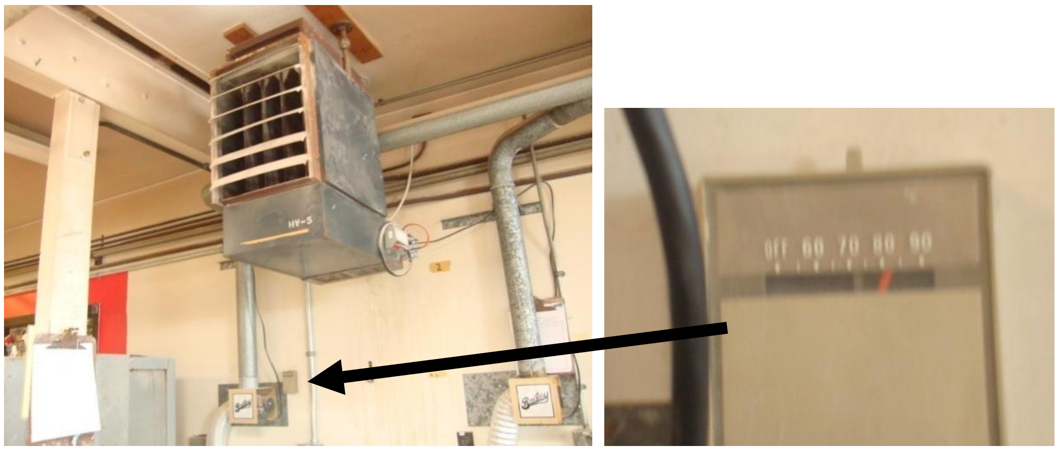


Figure 7.10 Room 111 Thermostat at 12.20 PM 4/9/2010.

7.6.3 Unlabelled light switches

Room 111 has light switches for many other rooms at the same location but none of the light switches are labeled well. It is hard to tell which switch operated a given, which could prohibit turning them off. Some of the light switches have a “Turn off Lights” stickers besides them. Figure 7.11 shows a switch box in the building.

Figure 7.11 Light switches in room 111 with worn out labels on them.

7.7 Building Models

Minor assumptions and generalizations about the building have been made which were not crucial for the model that was created for the building. This includes considering the whole building as pitched roof, combining some skylights and placement of doors and windows at approximate locations. A 3D display of the Ceramics Lab model from eQUEST has been captured and presented below in Figure 7.12 and also presented in APPENDIX R.

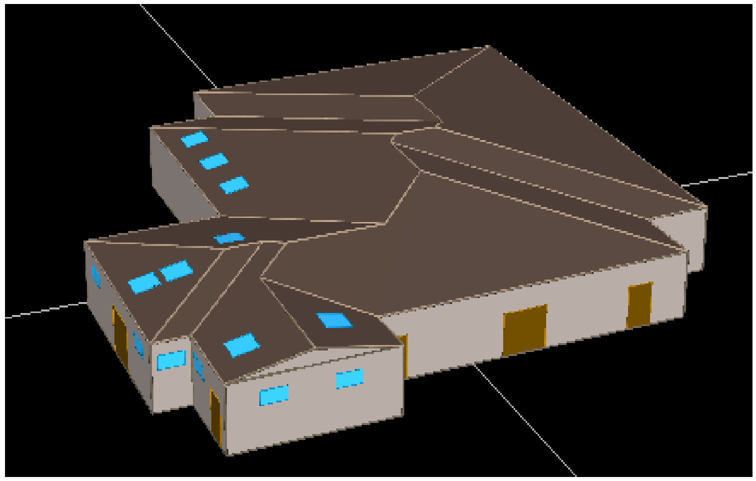


Figure 7.12 eQUEST model picture of the Ceramics Lab.

The model was calibrated by altering some assumptions such as the infiltration rate, and kiln schedule as they were highly variable for the model without very good data input. Numerous iterations were carried out to determine a reasonable air infiltration rate. The final air infiltrations rate is assumed to be 10 ACH. After calibrations, the final model's energy consumption is comparable to the actual energy consumption of the building as shown below in Figure 7.13. Details of annual consumption determined from the model are in APPENDIX R.

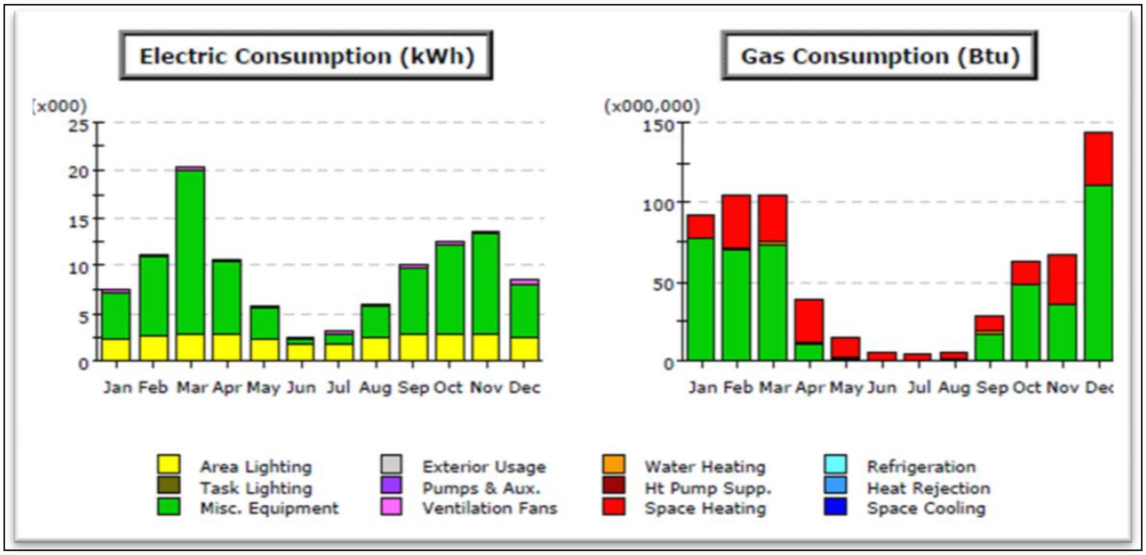


Figure 7.13 eQUEST result of energy consumption in the Ceramics Lab by end use.

Although the figures for some months in the model are away from the actual, it is probably due to the weather patterns and the energy consumption in the building itself changing. Comparision of the model and actual building energy consumption are shown in Figure 7.14 and Figure 7.15 and Table R.2 in APPENDIX R. No particular reason was found for March 2009’s extremely high electricity consumption.

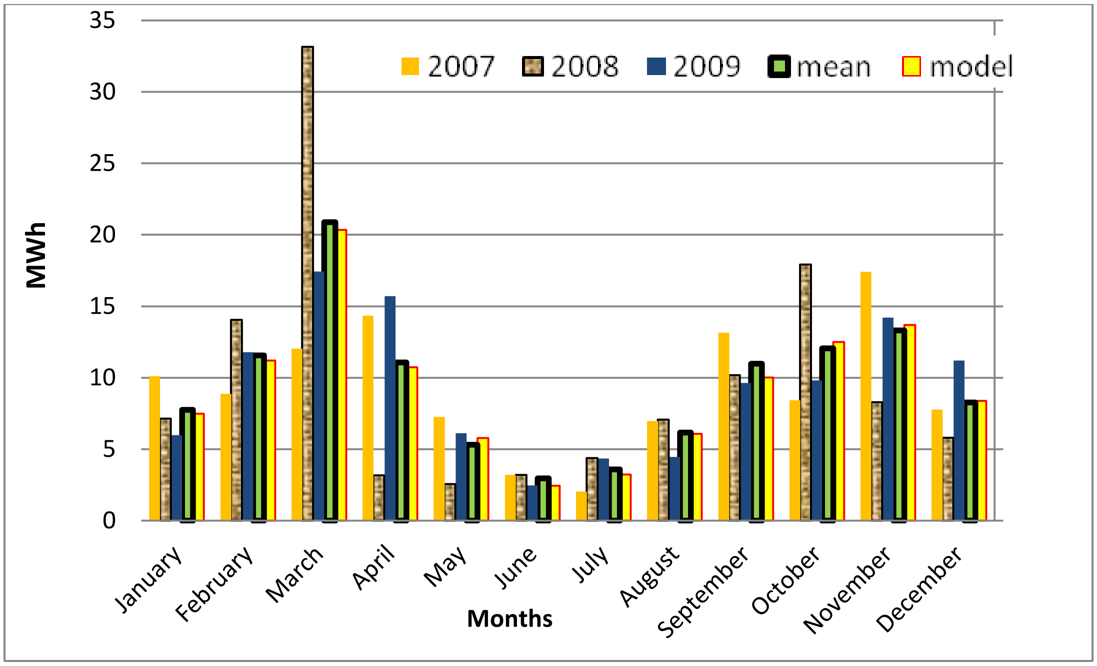


Figure 7.14 Comparison of electricity consumption of actual building and the model.

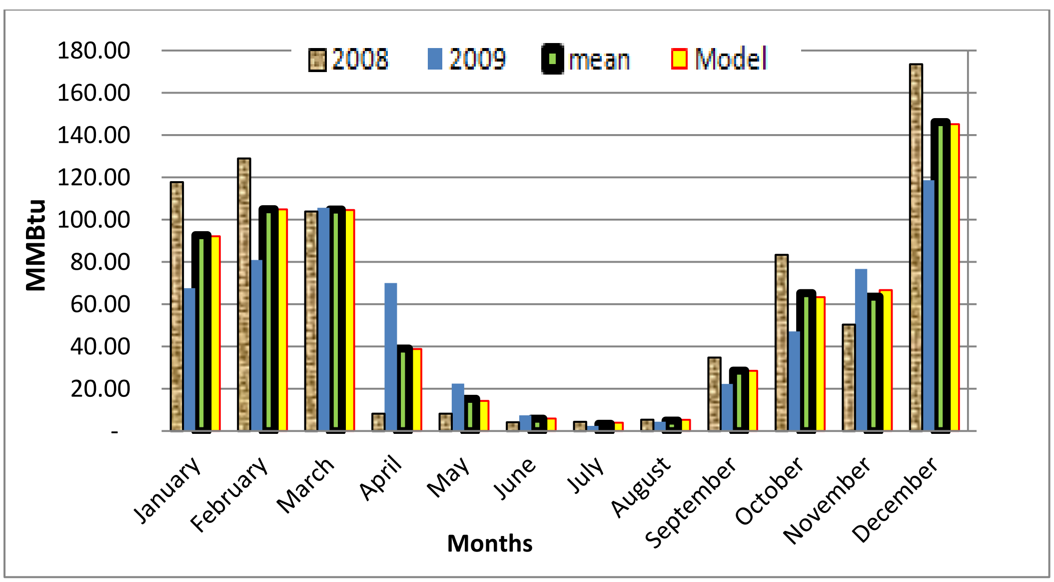


Figure 7.15. Comparison of natural gas consumption in actual building and the model.[14]

14 Data for 2007 were not available

7.8 Energy Saving Alternatives for the Ceramics Lab

The major part of the building’s energy expenses (dollar amount) are for electricity which is used for lighting, fans and heating up the kilns, but more natural gas in terms of energy (Btu) is used in the building. Since the majority of the electrical energy in the building is used for kilns, lighting and the air cleaning system there was minimum scope for electrical load reduction. I decided to look into ways of reducing the natural gas consumption through reduction in heating energy requirements or capturing heat and other behavior change options. All potential alternatives are listed below with their description.

7.8.1 Behavior change alternative

Even the most energy-efficient equipment is fruitless if individual actions are not aligned with the school’s energy goals (Norgard, 2008). Energy is wasted when lights and equipment are kept on when not used or when windows and doors are kept open in an artificially heated or cooled building. Increasing awareness of energy use and knowledge about specific energy-saving opportunities would educate and enable end-users to act better for making behavior changes (McKinsey, 2009).

One of the first things that could be done to the ceramics lab building is to advocate for behavioral change by building users, which is a no cost or minimal investment. This would involve putting up labels on light switches identifying them, signs with “turn off when not needed”, signs on thermostats not to turn them above 68^oF, and signs on doors in the building informing people to shut the door behind them. The information on energy use in the building and ways to save energy could also be printed on a chart and displayed in the building to create awareness on energy saving for building users. Few sample signs and posters have been compiled and prepared which are attached in APPENDIX Q.

7.8.2 Reduce air infiltration rate in the building

Currently the building has very high air infiltration rate due to open doors, cracks and holes on the doors, walls, and ceiling. The maximum air exchange rate for the model was assumed to be 10 Air Changes per Hour (ACH) and varied by the time of day and over the course of year according to the occupancy schedule of the building. If the air exchange rate of the building is reduced to an average of 5 ACH, according to the eQUEST model, an energy saving of 76.3 MMBtu (11.3%) of natural gas and 0.63 MWh (0.56%) of electricity could be achieved every year. The details of the energy consumption in this scenario are attached as APPENDIX S. It should be noted that there might be dust in the building from ceramic works and the design should ensure that the air filtration and recirculation systems are accordingly maintained or upgraded to avoid any health risks.

The infiltration rate can be simply decreased by closing doors every time they are opened, sealing the leaks on doors and walls and having a controlled ventilation system operating roof vents.

7.8.3 Low air infiltration and more insulation

The building currently has no proper insulation on its walls, roof and ceiling. In addition to the decrease in the air infiltration rate to 5 ACH, if the insulation of the walls, ceiling and roofs are R-30 insulation, the natural gas consumption could be reduced by 82.1 MMBtu/yr (12.2%) and the electricity requirement by 0.67 MWh/yr (0.60%). The details of the savings from this alternative are shown in APPENDIX T.

7.8.4 Low air infiltration, increase insulation and double pane windows

In addition to reducing the air infiltration rate, and increasing the insulation of walls, ceiling and roof frames with R-30, if single plane and plastic sheet windows are replace with double pane low-e glasses, the building can achieve an energy saving of 83.4 MMBtu (12.4%) of natural gas and 0.68 MWh (0.61%) of electricity per annum. The details of the savings are in APPENDIX U. Double-glazed high-solar-gain low-e windows are recommend in the Ceramics Lab as high-solar-gain low-e glass products are best suited for buildings located in heating-dominated climates like Arcata (Alliance to Save Energy, 2010).

7.8.5 More efficient heaters

The Janitrol brand gas heaters in the building are only 80% rated efficient, very old, and out dated. The company has been taken over by another brand called Goodman who does not produce the same model but manufactures new Goodman heaters (HVAC, 2010). According to reviews in the same source[15] and experience in the building (Schneider, 2010), they are generally reliable, but hard to repair or improve. If newer 95% efficient Goodman heaters[16] replace the old heaters, 35.0 MMBtu (5.2%) of natural gas could be saved annually. The details of the energy consumption with this alternative are in APPENDIX V.

7.8.6 Low air infiltration, R30 insulation, double pane windows and more efficient heaters

If the unit heaters are replaced with efficient heaters (95%) in addition to sealing cracks and holes, reducing the infiltration to 5 ACH, installing double pane low-e window panes and using R30 insulation on exterior walls and ceilings, there is a total saving of 105 MMBtu (15.6%) of natural gas and 0.68 MWh (0.61%) of electricity annually. The details of the energy consumption with this alternative are in APPENDIX W.

7.8.7 Capturing heat exhausted from kilns

A kiln's temperatures get up to 1,400 - 2,400^{o}F in order to fire pottery, and even then it takes days to ensure the pottery is completely baked and prepared (Ehow, 2010). The kiln rooms get hot and doors are often kept open to cool down the building when the kilns are fired during favorable weather conditions.

[15] http://highperformancehvac.com/air-conditioner-furnace-reviews/gas-furnace-reviews/92-janitrol-gas-furnace-reviews.html & http://toad.net/~jsmeenen/goodman.html
[16] http://www.goodmanmfg.com/Home/Products/GasFurnaces/GMVC95MultiPositionVariableSpeed95AFUE/tabid/831/Default.aspx

There may be a possibility of installing heat exchangers in gas kiln room 108 to capture the heat that is currently exhausted through the door or chimney for heating the building. The best way to determine the viability of heat recovery is by confirming the concurrence of heating demand with kiln use. Figure 7.16, which is a graphical representation of the eQUEST model result for heating demand periods of the building and time of kilns use, shows 50% concurrence with gas kilns and 75% concurrence with electric kilns. Details of the calculations with individual graphs of kiln usage and heating load are in APPENDIX Y. Both of the options of capturing the exhaust heat from gas kilns and electric kilns were studied, which is explained below:

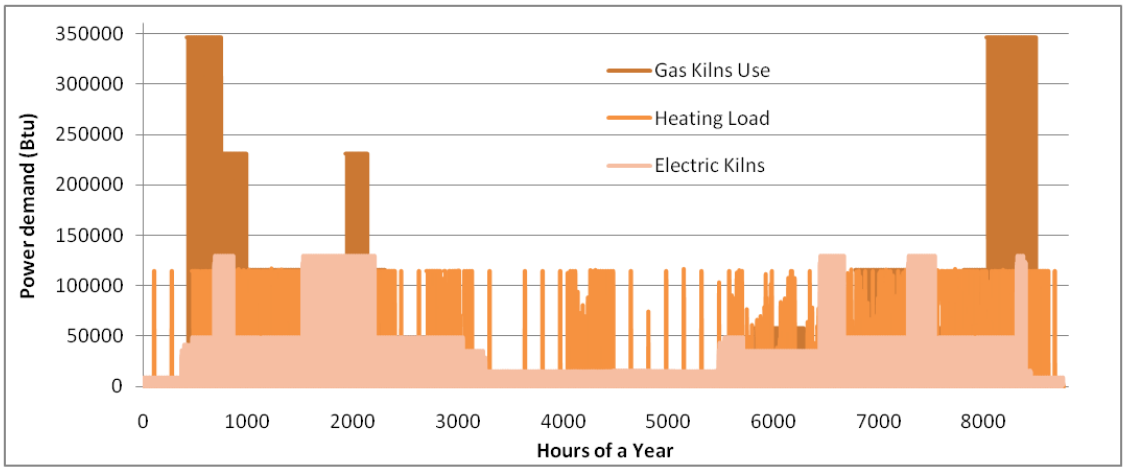


Figure 7.16 Overlap of gas and electric kiln use with heating load in the building.

<u>a. Gas Kilns.</u>

A case study from Bangladesh University of Engineering and Technology has proven both technical and financial viability of an air exchanger with pebble bed in Ceramics Industry (Hossain, 1997). The details of the case study are mentioned in APPENDIX Z. With 50% concurrence between natural gas kiln firing and heating demand, and considering 80% efficiency of the pebble bed, 1,800 Therms of natural gas in a year could be offset.

b. Electric Kilns.

For the electric kilns in room 111 and 115, there is no exhaust system or ventilation while the rooms are directly heated with unit gas heaters. We also see in Figure 7.16 that the use of electric kilns coincides by 75% with heating demand. If an air circulation system is installed to circulate hot air in the building in addition to reducing the air infiltration rate there is a potential to save 990 Therms (14.7%) of natural gas requirement for heating in a year. An air quality monitoring and intake air control device would be necessary for both the alternatives mentioned above.

The summary of all the alternatives for the Ceramics Lab are presented below in Table 7.5 and the economic analysis are in Chapter 8.

Table 7.5 Efficiency improvement alternatives for the Ceramics Lab and their savings.

Alternative	Natural Gas (MMbtu)/yr			Electricity (kWh)/yr		
	Total	Saving	% saving	Total	Saving	% saving
Baseline	673.70	-	-	111.88	-	-
Reduce Air Infiltration (ACH5)	597.42	76.28	11.3%	111.25	0.63	0.56%
ACH5 + R30 insulation (R30)	591.60	82.10	12.2%	111.21	0.67	0.60%
ACH5 + R30 + Double pane windows	590.29	83.41	12.4%	111.20	0.68	0.61%
New Heater	638.68	35.02	-	111.88	-	0.00%
ACH5 + R30 + Double pane windows + New Heater	568.61	105.09	15.6%	111.20	0.68	0.61%
Heat recovery in electric Kilns with ACH5		98.92	14.7%	-	-	-

CHAPTER 8 ECONOMIC ANALYSIS

Economic evaluation of energy conservation and energy efficiency alternatives is used to determine their benefits and estimate potential cost savings. The investment for each of the alternatives, their savings, and salvage values were then used to analyze both undiscounted and discounted net cash-flow of ten years for different alternatives. The Ceramics Lab has possibility of being demolished in future as it is earmarked as a temporary building, so the lifetime was selected as ten years, while for Marine Lab 20 year lifetime was used. The corresponding Net Present Value (NPV), payback and Modified Internal Rate of Return (MIRR) were then used to compare different alternatives. The assumptions, details of installation costs, sources of funds available, and economic benefits were used to determine the best options in this chapter.

8.1 Assumptions for Economic Analysis

Based on energy payment records for the last three years, the average cost of natural gas was at $1.13/Therm, electricity at $0.14/kWh,[17] and propane $1.77/gal. I assumed that the pattern of annual avoided energy consumption remains constant over the lifetimes of all alternatives.

[17] Note that in practice the university is not billed according to this average cost of electricity. The actual rate structure is more complex. For example, demand charges are a significant fraction of the cost of electricity, and an analysis that estimated the true cost of electricity on a time of use basis, including consideration of demand charges, would result in somewhat different economic results from those presented here. Information about time of electricity use was not available in a way that allowed for such an analysis.

I considered a 2% increase in energy prices over underlying inflation and a 3% discount rate as mentioned in the US DOE publication, *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2010* (Rushing et al., 2010). All alternatives for the Marine Lab have been calculated for a life of 20 years, and the salvage value was considered only for heaters and pumps at 10% of the cost of materials. Although different materials and equipment have varying lifetimes, an average lifetime of 10 years was considered for all of the options for the Ceramics Lab since there is a possibility that the building might get demolished in the near future (Schneider, 2010). To account for more durable items like heaters that have longer lives, a salvage value of 20% at the end of the lifetime as estimated. For all other alternatives, a salvage value of 10% was estimated at the end of first 10 years with the assumption that there will be some value of those materials.

The emissions of GHG other than CO_2 like CH_4 and N_2O for both the natural gas and electricity have been assumed negligible based on their low contents (0.0005 kgCO_2/Therm and 0.00001 kgCO_2/Therm respectively in natural gas and 0.003 kg/MWh and 0.007 kg/MWh respectively for electricity) (CCAR, 2009). I assumed a power content of electricity as 328.40 kgCO_2/MWh for electricity, 53.06 kgCO_2/MMBtu for natural gas (0.1MMBtu=1Therms) (Garbesi, 2008), and 5.74 kgCO_2/gallon for propane (CCAR, 2009).

Two scenarios were evaluated for all alternatives, one without any CO_2 price and the other with price of CO_2. Where needed, the cost per metric tonne of CO_2 was considered at $20 based on average current trading values of CO_2 in the European ETS market (Point Carbon, 2010).

The cost of materials and investment required for different materials have been collected from the Plant Operation's Building Trades Supervisor Zach Shelton, who referred the Job Order Contract (JOC) rates that the university uses for different projects on campus. Additional costs were also collected from reliable websites online and mentioned where necessary. The cost also takes into consideration of cost of installation at 20% of material cost and a contingency of 15% has been added on all the estimates to account for unforeseen circumstances.

8.2 Potential Funding Sources

Some of the most likely funding opportunities accessible to HSU for executing energy efficiency improvement projects have been explored. The details of each fund and their rate are mentioned in the following sections.

8.2.1 Humboldt Energy Independence Fund (HEIF)

The Humboldt Energy Independence Fund (HEIF) allocates funds to energy efficiency projects on campus. HEIF is a fund available to grant money for student proposed energy saving projects at the university. HEIF collects almost $150,000 every year from student fees. Although most of the projects are cost-shared with other departments, it is also possible that HEIF would fund the full cost of a project if all other external sources are exhausted when the project has good potential of energy reductions (Robinson, 2010). While this fund is available, it was not used for the evaluation of alternatives since it will be the same for everyone. Receiving funding from HEIF and some counterpart funding from HSU Plant Operations is our best option for most of the projects as done in the past.

8.2.2 University of California / California State University / Investor Owned Utility (UC/CSU/IOU) Energy Efficiency Partnership program (EEPP).

There is funding from the University of California / California State University / Investor Owned Utility (UC/CSU/IOU) Energy Efficiency Partnership program (EEPP) for energy efficiency improvements in California Universities. It was formed to grant public goods funds to public universities in California for energy efficiency projects. This fund will reimburse up to $0.24/kWh or $1.0/Therm of energy avoided in terms of first year savings, up to 80% of project costs as mentioned in the final report on the Strategic Energy Partnership for UCB (Newcomb Anderson McCormick, 2008).

The EEPP was established in 2004 - 05 and significantly exceeded its goals, saving approximately 32 million kWh and 1.5 million Therms of gas. Because of this success, the program was renewed for 2006 - 08, and again for the 2009 - 2012 program cycle (Higher Education Energy Partnership, 2007).

8.2.3 PG & E rebate program

There is a PG & E rebate program for its customers and the rates for these rebates for 2010 are lighting at $0.05/kWh, others at $0.09/kWh, natural gas at $1.00/Therm, and all measures at $100/peak KW for the installation. The rebate is “based on actual annual kWh or Therm savings that are achieved” (PG & E, 2010).

8.2.4 Self generation incentive program

California has a rebate program called the Self Generation Incentive Program (SGIP) for selected self generation technologies and fuels to be incentivized. In the 2007 revision (Section 3.1), cogeneration from Microturbines using non-renewable fuels have been included at the rate of $0.80/W of installed electricity generation capacity (PG & E, 2007). Other technologies eligible under this scheme are wind turbines, and fuel cells using both renewable and non-renewable fuels.

8.2.5 Federal tax credit

There is a federal incentive for combined heat and power systems (CHP) through the use of tax code. These incentives often are intended to support new technological developments until they become cost competitive. An investment tax credit allows the purchaser to directly offset a portion (e.g., 10%) of new capital investment against taxes owed (Elliott, 2001). HSU by itself will not be eligible for the tax incentive as it does not owe any tax to the government. However, if a third party is used for the project, 10% of the cost could be received as federal tax credit for CHP projects.

8.3 Economic Evaluation of Alternatives for the Marine Lab

The cost of materials and installation in addition to the contingency were computed for each of the six retrofit alternatives for the Marine Lab. The possibility of rebate from the UC/CSU/IOU EE partnership has also been considered for all options. The list of alternatives and their basic components are in Table 8.1. The analysis for cogeneration has been done separately in section 8.3.1 as it involved different parameters.

Table 8.1 Alternatives for the Marine Lab and their basic components.

Alternative number and name	Materials description and Sl. number in the quick cost estimate [18]
1. Reduce air infiltration rate	Installing a revolving glass door in the front. (6-6" diameter by 7'-0" height ,4nos. 4" wings)(1 &3).
2. Ceiling insulation	Insulation on roof (3a).
3. Double pane windows	Double pane windows with low-e glass (2).
4. Ceiling insulation with double pane windows	Insulation on roof, double pane windows with low-e glass and insulation on walls (1-3).
5. New Boiler	New 95% efficient boiler (Triangle Tube Prestige PS60 Propane Boiler) (4) (Boiler).
6. New Pump	New 70% efficient pump and 91.7% motor (Money Saver Pump™ 10 hp) (5) (Pump).

The details of the cost of materials for each of the alternative mentioned above are listed in APPENDIX DD. According to Table 8.2, only replacing the propane boiler and seawater re-circulation pumps at the Marine Lab are viable options with simple payback

[18] Quick cost estimate has list of items in it with individual costs which are referred in this table.

periods of 9.2 years and 3.4 years, Modified Internal rate of Return (MIRR) of 4.8% and 9.6% and NPV of $4,600 and $16,000 from investments of $4,800 and $6,300, respectively, for these two alternatives. The cash-flow analysis for the Marine Lab is in Table EE.1 of APPENDIX EE.

Table 8.2 Comparison of alternatives for the Marine Lab.[19]

Parameters		Alternatives					
		Reduce Air infiltration	Ceiling insulation	Double Pane windows	Ceiling insulation +double pane windows	New Boiler	New Pumps
Cost of Investment($)	Materials	17,250	14,960	29,125	44,085	3997	5289
	Installation	3,450	2,992	5,825	8,817	799	1,057
	Total	20,700	18,000	35,000	52,902	4,800	6,300
Avoided Energy savings	kWh/yr	0	0	0	0	0	8,660
	MMBtu/yr	17.7	25.1	6.05	32.6	26.6	0
	$/yr	343	486	117	631	514	1,210
Emissions reduced	(tCO2/Yr)	1.12	1.59	0.38	2.06	1.68	2.85
	$/yr	22.4	31.7	7.64	41.2	33.6	57.0
Life	Yrs	20	20	20	20	20	20
Salvage Value	($)	1,700	1,500	2,900	4,400	600	800
Rebate	($)	170	250	60	326	270	2100
NPV of investment without CO2	($)	-13,000	-8,500	-31,000	-39,000	**4,600**	**16,000**
Simple Pay back	Yrs	>20	>20	>20	>20	**9.2**	**3.4**
Discounted Payback	Yrs	>20	>20	>20	>20	**11**	**3.7**
MIRR	%	-3.4%	-1.2%	-8.1%	-2.7%	**6.1 %**	**11%**

[19] Contingency of 15% was added to all materials cost.

8.3.1 Economic analysis of capstone micro turbine for the marine lab

An analysis was carried out on the name plate specifications and costing through the U.S. EPA CHP Partnership to determine the feasibility of a cogeneration at the Marine Lab using a 30 kW Capstone Microturbine (Hedman, 2010). The study found that a C30 kW Microturbine will cost net investment of $57,000 and generate energy at $0.29/kWh which results in an annual operating loss of $2,600. This is a negative investment and proven not economically feasible. Details of the assumptions and calculations are in Table 8.3 of APPENDIX FF. The reason for a 30 kW Capstone Microturbine not being economically viable is attributed to very low operating hours (3,640 hrs/yr, i.e., 42% of the year) of the building heating system. A Capstone Microturbine is only good if the heating demand is more than 4,000 hrs/yr (Hedman, 2010). Therefore, a 30 kW Capstone Microturbine was checked for the main campus where the heating demand is higher.

Table 8.3 Rates assumed and economic analysis of 30 kW Capstone Microturbine for the Marine Lab

Parameter	Quantity
Incremental CHP O&M Costs, $/kWh	0.02
CHP Fuel Cost, $/MMBtu	19.0
Displaced Thermal Fuel Cost, $/MMBtu	19.0
Average electricity costs, $/kWh	0.14
Annualized Performance	
Annual CHP Power Generation, kWh	109,000
Annual Purchased Power Savings, $	-15,000
Annual CHP Fuel Costs, $	30,800
Annual Thermal Fuel Credit, $	-15,000
Annual CHP O&M Costs, $	2,200
Annual Operating Savings, $	-2,600
Operating Costs to Generate Power, $/kWh	0.16
Total Costs to Generate Power, including capital costs, $/kWh	0.29
Cost of providing and installation of 30 kW micro turbine, $	90,000
Rebates, [20] $	33,000
Total Capital Costs to User,$	57,000
Simple Payback, Years	- 22

8.3.2 Economic analysis of capstone micro turbine for the main campus

Currently the HSU campus has a 750 kW natural gas cogeneration plant which is out of order. An economic analysis of installing a Capstone 30 kW Microturbine fueled with natural gas was carried out to determine the potential of having such a system located at the main HSU campus, where there are more than adequate baseline electric loads and large demands for heat met by a centralized district heating system in part of campus. Even if we assume that the 30 kW Microturbine is utilized only about 83% of the time, the running hours are 7,271 hours a year. The cost of investment is still $57,000

[20] Federal tax credit rebate of 10% and SGIP incentive of $ 0.8/W

while the rate of energy generation is $0.15/kWh. Based on a cash-flow analysis, the simple payback is 6.5 years. Details of the assumptions, cash-flow analysis and calculation are in Table 8.4 below. Further details on analysis are in Table FF.2 and Table FF.3 of APPENDIX FF.

Table 8.4 Economic analysis of 30 kW Capstone Microturbine for the Main HSU campus

Parameter	Quantity
Incremental CHP O&M Costs, $/kWh	0.02
CHP Fuel Cost, $/MMBtu	11.0
Displaced Thermal Fuel Cost, $/MMBtu	11.0
Average electricity costs, $/kWh	0.14
Annual CHP Power Generation, kWh	220,000
Annual Purchased Power Savings, $	-31,000
Annual CHP Fuel Costs, $	37,000
Annual Thermal Fuel Credit, $	-18,000
Annual CHP O&M Costs, $	4,400
Annual Operating Savings, $	7,500
Operating Costs to Generate Power, $/kWh	0.11
Total Costs to Generate Power, including capital costs, $/kWh	0.15
Cost of providing and installation of 30 kW micro turbine, $	90,000
Rebates,[21] $	33,000
Total Capital Costs to User, $	57,000
Simple Payback, Years	**6.5**
MIIR without CO_2 benefit (%)	**7.5%**

[21] Federal tax credit rebate of 10% and SGIP incentive of $ 0.8/W

8.4 Economic Evaluation of Alternatives for the Ceramics Lab

For each of the six energy savings alternatives for the Ceramics Lab, the cost of materials and installation in addition to the contingency were computed and detailed out. A short description of the alternatives and their components are listed in Table 8.5 below.

Table 8.5 Alternatives for the Ceramics Lab and their basic components.

Alternative number and name	Materials description and Sl. Number in the quick cost estimate
1. Reduce Air Infiltration (ACH5)	New 1-3/4" wooden door (1) Sealing on walls (1)
	Controlled roof ventilation System - Exhaust fan with automatic controls (2)
2. ACH5 + R30 insulation (R30)	All of ACH5 (1&2)
	R30 insulation with fiberglass – Roof and Walls (3)
	Finishing on Ceiling to support fiberglass insulation (4&5)
	Finishing on Walls from Inside (4&5)
3. ACH5 + R30 + Double pane windows	All of ACH5 + R30 (1-5), and
	Double Pane Windows with low-e glass (6)
4. New Heater	Energy efficient unit heaters (95% efficient 115K BTU Variable Speed Upflow) (1 & 7)
5. ACH5 + R30 + Double pane windows + New Heater	All of ACH5+R30+Dpane and New Heater (1-7)
6. Heat recovery in electric Kilns with ACH5	All of ACH5 (1&2)
	Blowers which are 5” Diameter Single Shaft Open Fan/Blower Motor 1/12 HP (2)
	Cables, fittings and Sensors (1, 2, 8 & 9)

The details of the cost of materials for each of the alternative mentioned above are listed in APPENDIX GG. The benefits of energy saved from each of the options have also been estimated for a typical year and tabulated below in Table 8.6.

According to this calculation, the best alternatives for the Ceramics Lab are changing the air infiltration rate to 5 ACH and installing a system to capture the exhaust heat from electric kilns. The simple payback of the combined alternative is 5.9 years, MIRR is 6.0% and NPV is more than $4,300 from investment of $7,900. Only reducing the infiltration rate costs $6,900 and results in NPV of $3,300 with payback period of 6.0 years. The alternative of capturing exhausted heat from electric kilns might be even good without combing the air infiltration reduction option on it. However, technically it is only possible to capture exhausted heat properly if the building air exchange rate is reduced. The details of the cost estimation and economic analysis including annual cash-flow for different scenario of the Ceramics Lab alternatives are in APPENDIX HH.

Table 8.6 Comparison of each alternative for the Ceramics Lab.[22]

Parameters	Unit	Alternatives					
		ACH5	ACH5 + R30	ACH5 + R30 + Double pane windows	New Heater	CH5 + R30 + Double pane windows + New Heater	Heat recovery in electric Kilns with ACH5
Cost of Investment($)	Materials	5,750	17,643	26,700	5,313	3,2013	6,562
	Installation	1,200	3,500	5,300	1,100	6,400	1,300
	Total	6,900	21,000	32,000	6,400	38,000	7,900
Avoided Energy savings	kWh/yr	639	674	686	0	686	
	Therms/yr	763	821	834	350	1,051	990
	$/yr	953	1,000	1,040	396	1,290	1,120
Emissions reduced	(tCO2/Yr)	4.26	4.58	4.65	1.86	5.80	5.25
	$/yr	85	92	93	37	120	110
Life	Yrs	10	10	10	10	10	10
Salvage Value	($)	580	1,800	2,700	1,100	4,800	980
Rebate	($)	916	983	999	350	1,200	990

[22] Contingency of 15% is added to the cost of materials in the cost estimation section, APPENDIX GG.

Parameters	Unit	Alternatives					
		ACH5	ACH5 + R30	ACH5 + R30 + Double pane windows	New Heater	CH5 + R30 + Double pane windows + New Heater	Heat recovery in electric Kilns with ACH5
NPV of investment without CO2	($)	3,300	-9,400	-19,000	-1600	-22,000	4,300
NPV of investment considering CO2	($)	4,800	-8,600	-18,900	-1,200	-21,000	5,200
Simple Pay back	Yrs	**6.0**	>10	>10	>10	>10	**5.9**
Discounted Payback	Yrs	**6.7**	>10	>10	>10	>10	**6.5**
Discounted MIRR	%	7.0%	-4.6%	-7.8%	-0.8%	-6.2%	8.0%

According to the economic analysis carried out in a case study in Bangladesh (Hossain, 1997) on installing heat exchangers using pebble beds for natural gas kilns, the payback period was 15 months, Internal Rate of Return (IRR) was 75% and NPV of US $140,000 (Tk. 9,914,700) (Xe, 2010).[23] While the actual cost of labor and materials would be more expensive in the US, the cost of natural gas is five times higher in the US, so the estimate may still be good (Asian Tribune, 2009). Cash-flow and other details of this option could not be calculated due to inadequate information. Key economic findings from the study are shown below in Table 8.7.

[23] 1USD= 70Tk

Table 8.7 Key results for pebble bed heat exchanger from Hossain 1997.

Parameter	Quantity
Discount rate	12%
Life of the Project	15 years
Investment cost	35,000
Annual savings	25,000
NPV	$140,000
IRR	75%
Payback	15 months

The installation of the heat exchanger using pebble bed does involve a lot of labor. But the labor required could be unskilled and offer a valuable educational experience for students as hands-on opportunity under expert supervision and guidance by contractors of Plant Operations which could lower costs. A continuous air-quality sensing system could regulate proper control of supply air to the occupants.

CHAPTER 9 CONCLUSIONS AND RECOMMENDATIONS

There are sixty buildings managed by HSU Plant Operations covering gross area of 1,562,123 ft^2 excluding areas not covered by closed structures such as open sports stadiums and bleachers and student housing buildings that are under separate management. Nineteen buildings with adequate energy data were analyzed and ranked. Two most energy intensive buildings from the group were audited and modeled in DOE2- eQUEST. Retrofit alternatives for the Ceramics and Marine Lab were evaluated. The summary of main results based on the analysis carried out in preceding chapters is presented in this section followed by recommendations.

9.1 Conclusions

In 2006 - 2008, HSU spent an average of $2.8 million/yr for building energy services which resulted in emissions of 12 thousand $MTCO_2$ annually. HSU purchases electricity through direct access contract. Specific conclusions about the campus energy management system, strategies for improvement, ranking system developed and important aspects of the two buildings that were selected for detailed analysis are in the following sections.

9.1.1 Energy management in HSU

Twenty five of the large buildings on campus are on the Energy Management System (EMS) which are connected through the main campus energy meters. Building-wise monthly natural gas data for these buildings were available for six months to three years, but complete electricity data for large buildings were not available. There are nineteen electric and ten gas connections directly to the Pacific Gas and Electric (PG & E) service which have individual meters and records on their website. Many small houses on campus have been earmarked as temporary for last 20 - 25 years and given low or no priority for improvements.

There are engineers assigned for all buildings on campus to undertake preventive maintenance in addition to troubleshooting. Currently, energy saving is not on the priority list for their duty. New retrofits and modifications that save energy do not benefit the Plant Operations department, which initiate and execute such projects.

9.1.2 Campus-wide building energy reduction strategy

Energy conservation through behavior change by creating awareness and campaigns are possible at HSU to meet part of the energy reduction goals. Building commissioning, which is a process of evaluating buildings to ensure that they perform as designed, could save HSU almost $200,000 per annum (6% of annual energy expenses).

Energy efficiency improvements have been proven in other California University campuses and anticipated to be viable for HSU as well.

An action plan for energy management in HSU could involve forming a multi-disciplinary energy team to set goals, evaluate systems and performance, analyze situations and carry out a detailed analysis. The on-going HEIF internship is a possible segue into the formation of an energy team and taking the work further.

For the immediate future, resetting and checking on the thermostats in the buildings, encouraging and enforcing shutting of windows and doors, and shutting down buildings completely during breaks are the most viable and promising options for saving energy on the campus.

The option of installing a 30 kW Capstone Microturbine fueled by natural gas was found feasible and economically beneficial for the campus with a payback period of about 6.5 years from an investment of $57,000, and MIRR of 7.5%. This alternative could be considered as a pilot project for trying smaller distributed cogeneration since the existing larger 750 kW cogeneration plant has noise and maintenance issues.

9.1.3 Selection of buildings

A two-tier matrix system was developed for ranking and selecting candidate buildings for detailed analysis from buildings with adequate energy data. In the first phase, Building Energy Use Intensity (BEUI) and total Building Energy Use (BEU) were used to compare and rank nineteen buildings. Five of the most energy intensive buildings were chosen from that process. In the second phase, a walkthrough of the selected group was done to collect basic building envelope, utilization, and system information. The details of each building were listed and compared through an objective lens to select candidate buildings for further analysis. The Telonicher Marine Lab and Ceramics Lab were chosen for detailed auditing and analysis.

9.1.4 Telonicher Marine Lab

The Telonicher Marine Lab is an off-campus Marine Lab open throughout the year for 10 - 15 thousand visitors a year. It is a facility for hundreds of marine animals and location for various oceanography and fisheries instruction and research for about 100 students.

In 2007 - 2009, an average of 200 MWh/yr (12.4 kWh/ft^2/year) electricity and 6,630 gal/year (409 kBtu/year/ft^2) of propane were consumed in the building. This results in an expenditure of $38,700 and emitting 113 $MTCO_2$ per year. An eQUEST model of the building was created using site data; energy used information and some assumptions to replicate the existing building. Six energy saving alternatives were evaluated. The two promising options and their key economic evaluation result are shown in the Table 9.1 below.

According to economic evaluations of the six different alternatives for the Marine Lab, the best options are replacing the propane boiler and seawater re-circulation pumps. The simple payback periods for replacing the boiler and pump are of 9.2 years and 3.4

years, NPV of about \$4,600 and \$16,000 from investment of \$4,800 and \$6,300, emission savings are also 1.68 and 2.85 $MTCO_2$/year, respectively. The potential savings from commissioning the Marine Lab based on the LBNL study is \$44,000 in 15 years with a payback period of 3.6 years. All other options that were considered, like reducing the air infiltrations rates, more insulation and double pane windows are very cost prohibitive, and had negative NPV with payback periods of more than 20 years.

Table 9.1 Energy saving potential and economics of favored alternatives for the Marine Lab

Alternative	Energy saving /yr		CO_2 saving	Economics	
	kWh	MMBtu	$MTCO_2$/yr	Payback (years)	MIRR (%)
New Propane Boiler	0	26.6	**1.68**	**9.2**	**4.8**
New Sea water re-circulation Pump	8664	0.00	**2.85**	**3.4**	**9.6**

Additional possibilities also exist in having onsite generation using a Savonius wind turbines, natural lighting in the building by installing Solar Tubes and Light Shelving. The economic analyses for these options could not be conducted in time for inclusion in this document, but they are potential alternatives worth further study.

Replacement of the chiller system in the building could also be studied if more information were available from other sources, which could not be carried out in this study due to lack of enough information on chillers.

A technical feasibility and economic analysis of the Capstone Microturbine was assisted by a technical adviser from ICF international (Hedman, 2010). Based on the joint evaluation, it was found that the electrical output from a 30 kW Microturbine is sufficient for the base load of 23 kW, while the thermal output of 174 kBtu/hr is more than enough for hourly heating demand from the building which is about 133 kBtu/hr. However, the heating load in the building is only 3,640 hours in a year as the heating system is turned off at night and weekends. It was found that net investment of $57,000 is required to purchase and install the system and cost of operation is more than energy savings even with tax credits and incentives, thus proving that the alternative is not viable. A bigger unit of 60 kW might be better to produce cooling load, however the electricity base load in the building is too small to produce substantial heat for cooling which would not be ideal in our case in addition to not having full heating demand all the time (Hall, 2010).

Despite the fact that there might be some faults with the study, the cost of investments in most of the alternative is substantially higher than potential savings, therefore, there does not seem to be any room for minor adjustments either. However, the Capstone Microturbine is worth exploring especially if there is a possibility of converting the extra heat from the CHP plant to the cooling system when there is no heating load or with some additional heat storage system.

While most of the assumptions can be considered to be fairly reliable for the Marine Lab, the reduction of air exchange rates by installing a revolving door from 3 ACH to 1.5 ACH in zone 4 by is an assumption that is not supported by experiment. The figure used is a very conservative estimate based on previous research at MIT (MIT, 2009).

9.1.5 Ceramics Lab

The Ceramics Lab is an on campus Ceramics house where some 160 students are trained every semester. There is hardly any insulation on the building walls and ceilings, while the windows are all single-pane. Doors, ventilations and walls have cracks and holes in them. The Lab is connected to the main campus electricity and natural gas meters, but there are sub-meters in the building which are manually read monthly by building engineers.

The building is heated by five ceiling mounted unit natural gas heaters which are turned off at night manually. Lighting in the building is completely heterogonous which includes CFLs to incandescent to T8 tubes and 400 W metal halides. Average power density is 0.83 W/ft^2 and lighting intensity is 790 lux. The annual electricity consumption for the building is 114 MWh/yr which works out to 11.8 $kWh/ft^2/yr$ and 675 MMBtu of natural gas in a year (i.e., 7.02 $kBtu/ft^2/yr$). The corresponding average annual expenditure on energy is about $22,900 resulting in 77.9 $MTCO_2$.

The electricity consumption data for the Ceramics Lab had to be changed after the selection process by a factor of 32 due to a mistake in the meter reading that was discovered later. This made the Ceramics Lab even worse and altered the previous ranking in the first phase of the building selection process. Fortunately, it did not change the results of the second phase of ranking.

There are four Gas kilns which are fired twice a week for 16 hrs, twelve electric kilns which are fired 4, 8 and 17 times a week from the beginning to mid and end of semester respectively. An electric air purifier system works to clean the air everyday for 6 hours, while few potter's wheels and motors are used sparingly.

From the building auditing and site visits, it was discovered that most of the emergency exits and other doors are kept open during the day time. Unusual cracks and holes in doors and walls were also found which contributes to excessive heat losses. Temperature settings in the building were also not consistent and sometimes way above the design set point of 68^{o}F.

It was found that there are three promising alternatives which might be worth evaluating further. The list of alternatives and their economic features are listed below in Table 9.2. The information on the expected savings from installing pebble heat exchangers are based on a research done in 1997 in Bangladesh (Hossain, 1997). While the technology and study seems to be very reasonable, it has not been verified. Therefore, use of the detail specifications and assumptions has to be dealt with caution in future studies or projects. Similarly, the concurrences of heating load and gas and electric kiln loads have been plotted from the eQUEST model result. While effort has been made to ensure that it is true, it might be worth cross checking the results as yearly usage of kilns and occupancy changes every year.

The best alternatives for the Ceramics Lab are advocating for behavior change, changing the air infiltration rate to 5 ACH and installing a system to capture the exhaust heat from electric kilns. Their simple payback periods are 6.0 and 5.9, respectively. From investments of $6,900 and $7,800, the NPV are $3,300 and $4,300 while expected emission savings are 4.26 and 5.25 $MTCO_{2/}$year, respectively for these two alternatives.

The benefit of commissioning the Ceramics Lab according to the LBNL (Mills, 2009) is a saving of $27,000 in 15 years with a payback period of 3.6 years. However, commissioning is best suited for buildings with advanced HVAC systems and complex settings (Mills & Mathew, 2009), which is not true for the Ceramics Lab.

The simple payback period for a potential pebble bed heat exchanger was found from a previous study in a different context as 15 months (Hossain, 1997). Based on my analysis of the energy savings from electric kilns with payback of six years, it seems that the pebble bed heat exchanger option is worth further study and analysis. While the study looks too good to be true, it is indicating high probability of being cost effective.

Table 9.2. Energy saving potential and economics of potential alternatives for the Ceramics Lab

Alternative	**Energy saving/ yr**		**CO_2Saving**	**Economics**	
	kWh	**Therms**	**$MTCO_{2}$/yr**	**Payback (years)**	**IRR (%)**
ACH5	639	763	4.26	6.7	5 .0
Heat recovery in electric Kilns		990	5.25	6.5	6.0
Heat recovery from gas Kilns[24]		1800	10.5	1.25	75

[24] Case study from Bangladesh (Hossain, 1997)

Possible limitations of the model-based results are that energy consumption patterns have changed over the years for the same month without any specific reason; information is missing, generalization of equipment, and building use schedule which are not in line with the actual building use. Difference in actual weather conditions for the design year for the location and the built-in weather files in the program could have contributed to some differences as well.

The air exchange rate in the first place has been assumed to be 10 ACH by various iterations and not verified by any experiment or analysis. For an actual project implementation at the site, it would be ideal if something could be done to verify the assumptions. This would also be a point to keep in mind for future building modeling and auditing.

The cost of investment for the heat recovery in electric kilns includes both reduction of air infiltration to 5 ACH and heat capture equipment. Note, however, that for the energy saving calculations, only potential energy savings from capturing heat from the electric kiln were used and the numbers used do not include the benefits from the air infiltration rate reduction. This was done to avoid duplication of benefits and ensure that the estimate was conservative. Therefore, it is possible that the alternative of capturing exhaust heat from electric kilns is better than the results presented in this report.

There are issues with indoor air quality by ceramics kilns, thus any modification to the Ceramics Lab should include a thorough study on the negative effects of inadequate ventilation and design systems to address such conflicts.

9.2 Recommendations

Following are the recommendations for further study and implementation of energy efficiency improvements by HSU in general and for the Marine Lab and the Ceramics Lab in particular.

- The current HEIF Building Energy Internship is a time bound project for two years. It is recommended to have an intern or student assistant to work on building energy for data analysis and updating information for future HEIF projects. A permanent position will be good for continuity to ensure responsibility for efficiency improvements.
- The current project has not focused much on awareness and advocacy campaigns as it was already done by the Green Campus program. A more comprehensive and coordinated effort between future HEIF interns and the Green Campus would be ideal.
- The building dashboard website with all building energy information is being developed by HEIF and the Building Energy internship project. The work needs to be expedited and also publicized to rest of campus community.
- It is imperative to have trend logged electricity consumption data from the EMS System for all large buildings on campus which could not be considered for this study. Work should be done to make that happen and a similar study conducted to analyze all HSU buildings

- The ranking process is recommended to be followed with minor modifications for the whole campus once enough data are available for all buildings.
- The most important recommendation for the whole campus is to initiate a complete building shut down system for long breaks to cut energy use completely. This is important because a single day of shut down will be as effective as an intensive energy efficiency improvement. Detailed analysis and study on the implications by such an initiative is recommended as early as possible.
- A 30 kW natural gas Capstone Microturbine could be installed on the main campus to learn and demonstrate distributed onsite cogeneration with a Microturbine while also saving some money and benefitting the environment in the long run.
- For the Marine Lab, it has proved that replacement of the existing boiler and the seawater re-circulation pump with energy efficient ones will be cost effective. It is recommended to execute these projects.
- Further study on the feasibility of installing a Savonius wind turbine at the site, improving the sea-water chiller efficiency, installing light tubes and light shelves to maximize use of natural light in the Culture Lab room are also recommended.
- The Ceramics Lab is designated as a temporary building. However, it is a very important lab and there are no immediate plans for demolishing or shifting the lab, so some energy efficiency measures are recommended. Creating

awareness in the building, requesting users to shut doors and windows, reducing air infiltration rate and capturing the exhaust heat from the kilns are recommended as they will be paid back fast and also do not involve any substantial investment. Some of these modifications could be removed and reinstalled at the new location if needed.

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APPENDIX A. ENERGY EFFICIENCY IN CSU AND HSU

The details of some projects carried out for whole CSU system and projects carried out in HSU are mentioned below along with their details.

CSU Energy Efficiency Policies

Some of the major findings and recommendations from the CSU Report on Sustainability and Energy Efficiency Goals (CSU, 2005) based on study of the projects that have been carried out on various CSU campus regarding sustainability issues and possible strategy are as follows;

> *Although CSU fell short of the goals, management believes that CSU's achievements in reducing the rate of energy usage during the past five years is noteworthy given the increase in enrollment both by headcount and full-time equivalents (FTE).*
>
> *Although Strategic Energy Plans (SEP's) were developed for all campuses under the Enron energy services contract of 1998, many of these plans were never completed due to Enron's default and lack of available funds at the campus to complete them.*
>
> *CSU's proposed sustainability policy states that beginning in 2005/2006, all major capital projects shall outperform current Title 24 standards significantly –*
>
> • *New construction projects shall outperform Title-24 by at least 15%, and*
>
> • *Major renovations shall outperform Title-24 by at least 10%.*
>
> *It was estimated that there is reduction in emissions resulting from CSU's investments in Energy Efficiency (EE) and Renewable Energy (RE). Over 97% of the avoided emissions is attributable to EE and less than 3% to RE.*
>
> *As a result of its efforts in EE, CSU has considerably reduced the total costs of its purchased utilities and estimate that the total savings from the various measures was about $41 million in the five years 2000/2001 through 2004/2005, and those savings are continuing to grow annually.*
>
> *Investments in EE are the most cost-effective way for CSU to reduce its energy usage and cost. The typical payback for EE is three (3) to seven (7) years*

– much quicker than any generation projects. Retrofits generally (but not always) have slower payback than efficiency investments for new construction or major rehabs. EE is also the most cost effective way to achieve CSU's green energy objectives, as EE avoids 100% of the associated emissions and environmental impacts.

EE reduces both energy costs and energy usage. It is very cost-effective.

As a general rule, investments in EE will be the most cost-effective and help support CSU's green objectives. Thus, EE should remain a high priority among energy options for CSU's scarce capital.

Much of the low-cost, short payback energy conservation measures have been done.

CSU has financed projects using lease-purchase financing, including San Diego State University's (SDSU) $22 million cogeneration project. This method of financing is very cost-effective and easy to procure. Potential investors are willing to finance good energy projects for CSU, and CSU should consider whether this option could be further used in CSU's financing portfolio.

The use of private capital to develop privately owned and financed projects may provide an opportunity to accelerate the installation of green energy projects while minimizing CSU's capital investment. (Private ownership is decidedly unattractive for EE projects).

Recommendations over the next 1 to 2 years (short-term) are as follows:

Energy Efficiency Projects: CSU should maximize its EE opportunities using its own capital to the extent practical, as those projects pay back quickly and are CSU's "greenest" option for energy.

Demand Reduction Programs: CSU should optimize its participation in CSU should optimize its participation in DR programs. These also pay back quickly and require very little investment.

For the medium-Term: 2 to 4 Years.

The most promising opportunities appear to be Cogeneration. Seventeen campuses have an interest in building new or expanding existing cogeneration plants. Some of these may prove cost-effective within the next few years, and these options should be vetted. Cogeneration projects, under the existing regulatory environment, should be designed to the standards of Combined Heat & Power (CHP) or CHP with Cooling (CHPC) unless the campus can contract for the export of excess power. Also, any campus that sells thermal or electric outputs to private parties should be aware of the "output" facilities rules related to taxation and tax-exempt finance.

> *The first step is to identify the major opportunities system-wide, determine their impact on energy use, estimate their cost-effectiveness and prioritize them accordingly.*
>
> *CSU needs to continue to improve its system-wide information on energy performance on an integrated and, ideally, real-time basis.*

Humboldt Energy Independence Fund

HSU has a fund on campus called the Humboldt Energy Independence Fund (HEIF) that is maintained through the Instructionally Related Activities Fees from students. This fund was established in 2007 with the mission to reduce environmental impact of energy use at Humboldt State University through student driven projects (HEIF, 2010). HEIF is a major partner in funding most of the major building modifications in recent years. Six out of eight projects so far has been directly targeted for energy consumption on campus which accounts for about 90% of the total HEIF fund (Robinson, James, 2009). Some of the relevant HEIF projects are below;

<u>Building Energy Internship project.</u> *This proposal received $35,960 in HIEF funding for the hiring of a building energy student intern endowed with the duties of aggregating, organizing, analyzing and publishing building specific energy consumption data at HSU for a two year pilot-position. The goal of the project is to help future energy reduction project proposers pinpoint the buildings and systems with the greatest need of retrofits or redesign for energy systems. The entire project is based around student labor and energy, data monitoring and analyzing. The current report is part of this project.*

<u>Old Music Building Photovoltaic Project Spring 2008</u>. A $100,000 project to install a 10 kW photovoltaic (PV) system accompanied by an art display and an interpretive sign installed in a highly visible, sunny location, the Old Music *Building roof. This project is expected to produce 360,500 kW over a 25-year period. The project included a monitoring device that would also be analyzed by students and interpretive signage elements.*

<u>*HVAC Efficiency Measures for Science D/E Fall 2008*</u>**.** *HEIF allotted $25,000 as counterpart funding for energy efficiency measures for the Heating Air Conditioning and Ventilation system within Sci D/E. Additional funds for the project came from Plant Operations and UC/CSU/CCC IOU Energy Efficiency program of California Energy Commission. The project entailed insulating the copper hot water distribution piping, converting the pneumatic air and heat controls to direct digital control and replacing the air handling fans with variable frequency drives.*

This retrofit is expected to help HSU avoid 45-72 MT of CO_2 emissions per year. At the time of study in fall 2010, the project has not been executed.

Solar Thermal Project Fall 2008. *Two evacuated tube panels accompanied by a data monitoring and collection system were erected on the roof of the Campus Center for Appropriate Technology (CCAT) to reduce the need for natural gas at CCAT while emphasizing education.*

Relight Redwood Bowl. *In the spring 2009 HEIF awarded $75,000 for new stadium lighting and a monitoring system for HSU outdoor stadium - Redwood Bowl. The project was also largely funded by Plant Operations and qualified for a substantial PG & E Partnership Rebate and only partial funding was from HEIF. This project reduces the amount of energy used to light the field and also highly reduces the impacts on wildlife due to excessive light pollution. This is an example of a project that was intended to be carried out by Plant Operations and the additional money from HEIF was used to upgrade the previous purchase choice to a more energy efficient and environmentally friendly option.*

APPENDIX B. BUILDINGS AND ENERGY AT HUMBOLDT STATE

The total energy consumption of energy in HSU and corresponding emission for the last 3 years have been calculated which is explained Table 4.1, the same information is in plotted in a graphical form below in Figure B.1.

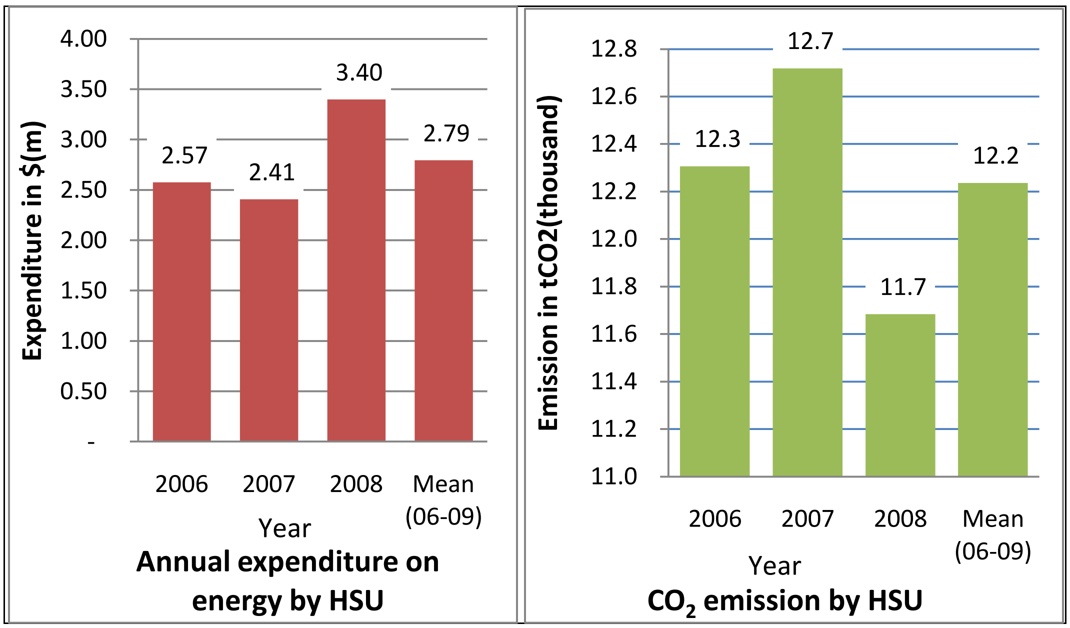


Figure B.1 Annual expense and CO_2 emission by HSU.

Following Table B.1 is the list of buildings in HSU and their corresponding gross area, building type, department and built year.

Table B.1 HSU Buildings and their details

Building ID	Building Name	Acronym	Gross Area (Sqft)	Building Type	Department	Built Year	Detail study
001	Siemens Hall	SH	42472	Large	President's office, International Programs, Business Administration and Economics	1959	No
002 A	Art A	ARTA	15819	Large	Arts	1959	No

Building ID	Building Name	Acronym	Gross Area (Sqft)	Building Type	Department	Built Year	Detail study
002 B	Art B & Music Complex	ARTB	56649	Large	Arts and Music	1969	No
003 A	Science A	SCIA	58490	Large	Physics & Chemistry	1962	No
003 B	Science B & C	SCIB & C	46180	Large	Botany, Zoology and Biology	1971	No
003 D	Science D & E	SCID	38570	Large	Engineering, Biological Sciences and Greenhouse	1983	No
004	Harry Grifith Hall	HGH	25841	Large	Environmental Engineering and School of Education	1962	No
005	Forestry	FR	22057	Large	Forestry and Natural Resources	1962	No
006	Founders and Van Matre Hall	FH	85646	Large	English, Geography, History, Geology and Political Science	1922, 1953	No
007	Jenkins Hall	JH	19560	Large	Industrial Technology	1950	No
008 A	Music A/Old Music	MUSA	9501	Small House	Music	1957	No
010	Theatre Arts & Van Duzer Theatre	TA	62185	Large	Arts and Theatres	1960	No
011	Wildlife and Fisheries Building	WFB	46096	Large	Wildlife and Fisheries	1955	No
012	Phys Sci Field Lab	PHYSO	670	Small House	Observatory	1972	No
013	Feuerkweker House	FWH	4356	Small House	Facilities Management Office	2001	Yes
014	Nelson Hall	NH	33917	Large	Career Center, Conference Rooms and Administration Offices	1940	No
017	Marine Wildlife Care Center	MWCC	4622	Small House	Marine Wildlife Care Center	1996	YB,es
018	Brookins House	BROOK	1926	Small House	Environmental Resource Engineering	1950	No

Building ID	Building Name	Acronym	Gross Area (Sqft)	Building Type	Department	Built Year	Detail study
023	Gist Hall	GH	52281	Large	Theater, Media and Nursing	1933	No
024 A	East Gym/PE	EGYM	40268	Large	Kinesiology and Recreation	2000	No
024 C	Student Recreation Center	SRC	41241	Large	Kinesiology and Recreation	2008	No
024 D	West Gym/ Forbes Complex	WGYM/ FC	52200	Large	Kinesiology and Recreation	1974	No
024 E	Cogeneration Unit (PlantOps)	COGEN P	450	Small House	Co-Generation Plant	2005	No
024 F	Kinesiology and Athletics/PE II	KA	90998	Large	Kinesiology and Recreation	2008	No
027	Telonicher Marine Lab	TML	16208	Off campus Large	Off-campus Marine Laboratory	1977	Yes
031	Child Development Lab (Swetman)	CDL	2701	Small House	Child Development/Liberal Studies	1967	No
033	Natural History Museum	NHM	4428	Small House	Museum	1989	Yes
036	Mary Warren House	MWH	1550	Small House	HSU Children's Center	1950	Yes
037	Baiocchi House	BH	1303	Small House	Toddler Center	1950	Yes
038	Walter Warren House	WWH	2486	Small House	Indian Natural Resource, Science and Engineering Program	1950	Yes
039	Toddler Center	TODC	1260	Small House	Child Care Center	2001	No
040	Natural Resources	NR	34300	Large	Environmental Science, Forestry and Oceanography	1972	No
041	Library	LIB	157043	Large	University Library	1976	No
042	Student Health Center	SHC	19849	Large	Health Center , Counseling and Psychological Center	1960	No

Building ID	Building Name	Acronym	Gross Area (Sqft)	Building Type	Department	Built Year	Detail study
045	University Center	UC	76419	Large	Bookstore, Associated Students cafeterias and lounge	1972	No
046	Plant Operations, Shipping and receiving	PLANT	26139	Large	Plant Operations, Shipping and receiving	1964	No
049	Redwood Bowl	REDBOW L	81610	Large	Physical Education		No
052	Bret Harte House	BHH	3480	Small House	Journalism and Mass Communication	1950	No
053	Warren House	WH	2231	Small House	Campus Recycling Program	1950	No
054	Telonchier House	TH	2705	Small House	Communication	1950	No
055	Multicultural Center/Balab anis House	MCC	3056	Small House	Multicultural Center	1950	No
056	Hadley House	HH	2189	Small House	Student Support Services, Educational Opportunity Program	1950	Yes
071	Little Apartments	LAPT	4380	Small House	Academic Support Programs	1950	Yes
072	University Annex	UANX	23544	Small House	Schatz Energy Research Center	1972	Yes
073	Wagner House	WAGH	2560	Small House	KHSUFM	1950	No
074	Ceramics Lab	CERAM	9615	Small House	Ceramics Lab	1950	Yes
075	Sculpture Lab	SCULPT	8580	Small House	Sculpture Lab	1950	Yes
088	Marketing and Communicati on/ Building 88	MKCOM	3906	Small House	Marketing, Communication and Graphics	1992	Yes
089	Behavioral & Social Sciences	BSS	93144	Large	Anthropology, Computers, Ethnic studies, Mathematics, Psychology,	2006	No

Building ID	Building Name	Acronym	Gross Area (Sqft)	Building Type	Department	Built Year	Detail study
090	Schmidt House	SCHMH	2196	Small House	Construction office	1950	No
091	Hagopian House	HAH	3488	Small House	YES (Youth Educational Services)	1950	Yes
093	Brero House	BRH	2792	Small House	ITEPP Curriculum Resource Center	1950	Yes
094	Jensen House	JENH	1304	Small House	Children's Center Administration	1950	Yes
097	CCAT	CCAT	3000	Small House	Campus Center for Appropriate Technology	2006	No
100	Student & Business Services	SBS	48854	Large	Office of Registrar, University Police and Financial Services	1990	No
105	Boat Facility	BOAT	7476	Small House	Storage and lab	1997	Yes
	Art Center at Eureka	GALLERY	3424	Off campus Small House	Art Gallery, exhibition halls, production, reception and an office.[25]	1875, 1997	Yes
	Korbel Forest Research Station	KFRS	2908	Off campus Small House	LW Schatz Demonstration Tree Farm Facilities	1997	Yes
	Offices and Maintenances Shops	OMSHOP	50000	Off campus Major	Plant Operations	2009	No
	Radio Transmitter at Kneeland	RADIO	5000	Off campus Small House	KHSUFM	1984	No
	Total Area		**1,567,123**				

[25] http://www.humboldt.edu/first/facility.html

Table B.2 Monthly building energy consumption by HSU

Month	2008			2007			2006		
	Electricity (MWh)	Nat. Gas (MMBtu)	Total (MMBtu)	Electricity (MWh)	Nat. Gas (MMBtu)	Total (MMBtu)	Electricity (MWh)	Nat. Gas (MMBtu)	Total (MMBtu)
Jan	895	14959	18014	791	18828	21528	699	11936	14320
Feb	1014	18903	22363	873	16093	19072	1086	12563	16267
Mar	1195	14397	18476	853	17397	20306	1142	14223	18120
Apr	1140	13479	17368	656	15871	18111	1097	13730	17471
May	1128	10955	14805	627	13576	15716	1046	10820	14389
Jun	856	8253	11174	590	7414	9426	753	9203	11774
Jul	904	7217	10300	669	10794	13076	609	7659	9737
Aug	861	6782	9719	491	7422	9098	569	9930	11871
Sep	1063	9169	12796	1215	5980	10126	710	12206	14629
Oct	1239	10765	14994	1184	10805	14844	666	13514	15785
Nov	1345	9904	14494	1127	12548	16392	733	13204	15706
Dec	1434	14497	19389	920	14772	17911	1104	12843	16611
Total	13075	139279	183892	9996	151500	185606	10214	141830	176680
Avg/ month	1090	11607	15324	833	12625	15467	851	11819	14723

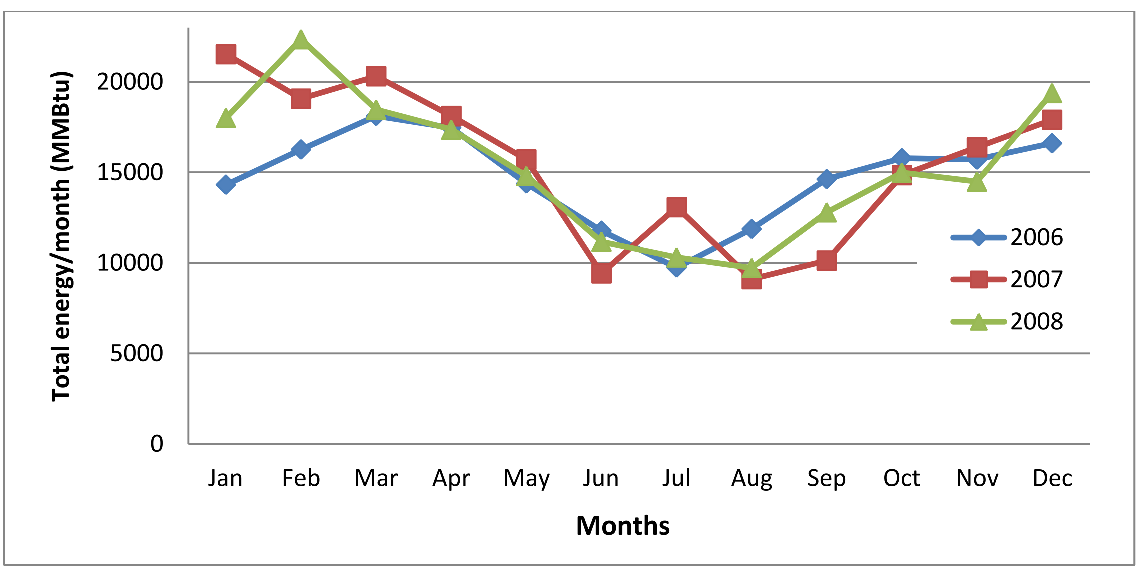


Figure B.2 Monthly total energy consumption by HSU buildings

APPENDIX C. ENERGY CONSUMPTION IN SMALL BUILDINGS

The average annual electricity consumption of each building for 2007 - 2009 is listed below in Table C.1 and the natural gas consumption are in Table C.2. Comparison of electricity and natural gas use in terms of kBtu/ft^2 were also done which are listed in Table C.3 and Table C.4 respectively. The consumption of propane for the Marine Lab is in Table C.5.

Table C.1 Total electricity consumed in small buildings/annum (kWh)

Year	Area	2009	2008	2007	Average
Marine Wildlife Care Center	4622	8959.00	8794.00	8650.00	8801.00
Art Center at Eureka	3424	11435.00	14852.00	14887.00	13724.67
Jensen House	1304	12760.00	13698.00	13165.00	13207.67
Mary Warren House	1550	8313.00	9313.00	7461.00	8362.33
Walter Warren House	2486	21144.00	23429.00	22986.00	22519.67
Hadley House	2189	12202.00	14468.00	13386.00	13352.00
Hagopian House	3488	6099.00	6766.00	6006.00	6290.33
Brero House	2792	13332.00	14565.00	16694.00	14863.67
Little Apartments	4380	25854.00	30120.00	28076.00	28016.67
University Annex	23544	30960.00	31920.00	105360.00	56080.00
Baiocchi House	1303	7181.00	7096.00	6805.00	7027.33
Korbel Forest Research Station	2908	8688.00	10497.00	8666.00	9283.67
CNR OF 14TH & B ST #88	3906	54040.00	57080.00	58200.00	56440.00
Feuerkweker House	4356	13104.00	15729.00	18293.00	15708.67
Natural History Museum	4428	24760.00	37375.00	37953.00	33362.67
Boat Facility	7476	2474.00	3847.00	3393.00	3238.00
Telonicher Marine Lab	16208	190985.00	202752.00	206923.00	200220.00
Ceramics Lab	9615	113,152.00	111,680.00	111,584.00	112,138.67
Sculpture Lab	8580	2935.00	901.00	988.00	1608.00
Total	108559	458761.00	506692.00	581379.00	515610.67

Table C.2 Comparison of natural gas consumed in small buildings (Therms)

Year	2009	2008		
Mary Warren House	537.00	391.00		
Baiocchi House	1030.00	1113.00		
University Annex	421.00	955.00		
Feuerkweker House	1018.00	1176.00		
Natural History Museum	1032.00	1273.00		
Walter Warren House	1048.00	1138.00		
Marine Wildlife Care Center	1180.00	1556.00		
Ceramics Lab	6259.00	7234.19		
Sculpture Lab	4855.00	5274.00		
CCAT	303.00	479.00		
Average	1768.30	2058.92		
Propane (Gallons)				
Year	2009	2008	2007	Avg
Telonicher Marine Lab	6231.10	6812.51	6859.65	6634.42

Table C.3 Comparison of electricity used for small buildings

	kBtu/ft^2*Yr			
Buildings	2009	2008	2007	Average
Art Center at Eureka	11.39	14.80	14.83	13.68
Baiocchi House	18.80	18.58	17.82	18.40
Boat Facility	1.13	1.76	1.55	1.48
Brero House	16.29	17.80	20.40	18.16
Ceramics Lab	40.15	39.63	39.60	39.79
CNR OF 14TH & B ST #88	47.21	49.86	50.84	49.30
Feuerkweker House	10.26	12.32	14.33	12.30
Hadley House	19.02	22.55	20.86	20.81
Hagopian House	5.97	6.62	5.88	6.15
Jensen House	33.39	35.84	34.45	34.56
Korbel Forest Research Station	10.19	12.32	10.17	10.89
Little Apartments	20.14	23.46	21.87	21.82
Marine Wildlife Care Center	6.61	6.49	6.39	6.50

Buildings	kBtu/ft²*Yr 2009	2008	2007	Average
Mary Warren House	18.30	20.50	16.42	18.41
Natural History Museum	19.08	28.80	29.24	25.71
Sculpture Lab	1.17	0.36	0.39	0.64
Telonicher Marine Lab	40.20	42.68	43.56	42.15
University Annex	4.49	4.63	15.27	8.13
Walter Warren House	29.02	32.16	31.55	30.91
Average Annual	16.52	18.57	18.79	17.96

Table C.4 Comparison of natural gas consumed in small buildings

Buildings	kBtu/ ft²*Yr		
Buildings with gas meters	**2009**	**2008**	**Average**
Baiocchi House	79.05	85.42	82.23
Ceramics Lab	65.10	75.24	70.17
Feuerkweker House	23.37	27.00	25.18
Marine Wildlife Care Center	25.53	33.67	29.60
Mary Warren House	34.65	25.23	29.94
Natural History Museum	23.31	28.75	26.03
Sculpture Lab	56.59	61.47	59.03
University Annex	1.79	4.06	2.92
Walter Warren House	42.16	45.78	43.97
CCAT	10.10	15.97	13.03
Average annual	36.16	40.26	38.21

Table C.5 Propane consumption for the Telonicher Marine Lab

Month	2007	2008	2009	Mean
KBtu/ ft²/yr	38.73	38.46	35.18	37.45

APPENDIX D. BUILDING COMMISSIONING IN HSU

Analysis of building commissioning in HSU based on the studies in UC Berkeley by LBNL (Mills, 2009) and (Mills & Mathew, 2009) were carried out. It was considered that 30% of gross area in HSU is built up and 50% of that is commissioned (i.e., 15% of total area). Using the cost of investments as $0.87/ft^2, total cost of investment is $0.67 m, while the corresponding saving is $.19 m/annum at the rate of $.24/ft^2. This compared to HSU's annual expenditure of $3.4 million (i.e., 2008) is only 20%. The saving is 6% of annual expenditure on energy in HSU. The details are shown in the calculations in Table D.1.

Table D.1 Calculation for building commissioning in HSU

Campus-wide Description	Quantity	Unit
Total Area in HSU	114	Acres
Built up Area (30%)	1,555,791	ft^2
Consider 50% to be commissioned	777,896	ft^2
Cost of improvement – based on the rate of $0.87/ft^2	672,880	$
Cost of Saving – based on saving rate of $0.24/ft^2	188,640	$
Pay Back	3.57	Years
Total Saving in 15 years	2,829,595	$
Net Saving in 15 years	2,156,715	$
HSU's expense on Energy- for 2008	3,400,000	$
Cost of improvement (% of present energy expenditure)	20%	
Saving (% of present energy expenditure)	6%	
Case study- Marine Lab	**Quantity**	**Unit**
Gross Area	16,208	ft^1
Cost of improvement – based on the rate of $0.87/ft^2	14,101	$
Cost of Saving – based on saving rate of $0.24/ft^2	3,890	$
Pay Back	3.625	Years
Net Saving in 15 years	44,248	$
Case study – Ceramics Lab	**Quantity**	**Unit**
Gross Area	9,615	ft^2
Cost of improvement – based on the rate of $0.87/ft^2	8,365	$
Cost of Saving – based on saving rate of $0.24/ft^2	2,308	$
Pay Back	3.625	Years
Net Saving in 15 years	26,249	$

APPENDIX E. COMPARISON OF EXPENSES FOR SMALL BUILDINGS

The individual Building Energy Use Intensity (BEUI) in $/ft^2/yr and total Building Energy Use (BEU) in $/yr were determined for all the small building which are listed below in Table E.1.

Table E.1 BEUI and BEU for small buildings.

Month	Area (ft^2)	Average BEUI ($/ft^2/yr)	Average BEU($)/yr
Marine Wildlife Care Center	4622	0.57	2664.12
Art Center at Eureka	3424	0.50	1761.55
Jensen House	1304	1.30	1725.79
Mary Warren House	1550	0.98	1535.54
Walter Warren House	2486	1.59	4018.43
Hadley House	2189	0.73	1642.30
Hagopian House	3488	0.22	776.17
Brero House	2792	0.65	1856.61
Little Apartments	4380	0.75	3378.48
University Annex	23544	0.37	9159.96
Baiocchi House	1303	1.56	2052.35
Korbel Forest Research Station	2908	0.38	1135.13
CNR OF 14TH & B ST #88	3906	1.76	7046.06
Feuerkweker House	4356	0.73	3235.19
Natural History Museum	4428	1.21	5483.15
Boat Facility	7476	0.05	405.53
Telonicher Marine Lab	16208	2.26	37273.23
Ceramics Lab	9615	0.84	8062.89
Sculpture Lab	8580	0.69	5909.64
Average	5714	0.90	5216.95

APPENDIX F. BUILDING WALK THROUGH RESULTS

The short survey report for each building walk through survey was prepared in a standard format. Table F.1 to Table F.5 shows the results of the five buildings evaluated during the walkthrough. The overall evaluation result from the walkthrough survey is detailed in Table F.6, while Figure F.1 to Figure F.5 has pictures from the survey process.

Table F.1 Short survey report for the CNR OF 14TH & B ST #88

Building	CNR OF 14TH & B ST #88
	Date: March 11, 2010
Area (SF)	3,906
Built Year	1992
Building Type	Small House
Engineer/Manager	Matt Elliot
Major Use	Office of Marketing and Communication, Graphics and Printing
Building Material	Framed building with minimum insulation on walls. No ceiling, insulation is directly on the roof which is exposed. Double pane window. The building was an old warehouse/University Storage facility remodeled for the Marketing and Communication.
Equipment	Heavy duty printing press, printers, cutters, plotters and lots of computers with LCD screens.
Lighting	T8 florescent lightings without sensors.
Heating	Even though the building does not have a gas meter, it has gas connection. There are 2 box-type Horizontal Gas Furnace (2,000 cfm), ceiling mounted with about 90% efficiency heating up the building 24 hrs a day. The dampers are open all the time for ventilation, but this is causing moisture problem to the papers inside the building. There is a manual thermostat to regulate heat but no sensors or other controllers as indicated in the drawings. It has an exhaust fan as well.
Other information	Building engineers are working to replace the thermostat which can schedule the building heating in addition to controls for economization and relays. The project is expected to cost about $600-700 and planned to be implemented fairly soon.

Table F.2 Short survey report for the Telonicher Marine Lab

Building	Telonicher Marine Lab
	Date: March 10, 2010
Area (SF)	16,208
Built Year	1977
Building Type	Off campus Major, not retrofitted in last 10-15 years.
Engineer/Manager	Matt Elliot/ Dave Hoskins
Major Use	Offices, class rooms, aquariums and Marine Labs
Building Material	Framed single storey building with wooden siding. Walls have minimal insulation. Single Pane windows. Ceiling has minimal 2” insulation with crawl space.
Lighting	Most of light fixtures are T8 installed few years ago. Some random classrooms/labs and bathrooms have sensors.
Domestic Hot Water	Propane fueled boiler. EnergyGuide certified.
Heating	Propane fueled heating boiler (278CFH). Circulation Pump. Constant Air Valve. Return air conduit. The Large room with Aquariums is not heated. Conduits are on the attic. EMS, Control Pak, Schedule: Mon-Fri: 6:00 -18:00 hrs, Sat &Sun: 9:00 -14:00 hrs, holidays: 8: - 10:00 hrs. 2 rooms at the back have their own heating with propane.
Major Equipment	1. 2 Chillers, 10 yrs old, run mostly during the summer for cooling. Heatcraft, UL 233R Condensing Unit. 2. Two 10 years old re-circulating pumps for water recycling, 10hp, 84% efficiency. Atleast one is run 24 hrs a day. 3. Rotatory Blower, 1/2hp, run 24 hrs a day, connected to PV system. 4. 24hp Pump at the Pier, used 6-8 hrs/month. 5. A New cooler system. 6. Compressor for toilet actuators. 7. 4 bench vacuum. 8. Back Up generator (Propane) 1964-65. 9. Walk in Freezer, 1974 North Star, r-12, 80A fan,+4^{o}C. 10. Walk-in Refrigerators.

Building	Telonicher Marine Lab
Other information	Deep freeze, Refrigerators- Fisher Scientific, EnergyGuide Certified. Incubators, Computers, Dishwasher, exhaust fans, electrical wall heaters. Lots of complaints by user s of cold air or over heating by the sun at other end. Building Engineer does Preventive Maintenance on monthly basis or troubleshooting. Some portion of the building was remodeled in 2003. Renovation of the Wet Lab/aquarium room is under process, including increasing opening sizes.

Table F.3 Short survey report for the Walter Warren House

Building	Walter Warren House
	Date: March 11, 2010
Area (SF)	2,486
Built Year	1950
Building Type	Small House
Engineer/Manager	Matt Elliot
Major Use	Indian Natural Resource, Science and Engineering Program. Computer Lab, offices and meeting rooms.
Building Material	Single Pane windows, proper ceilings and floor.
Equipment	8-10 computers with LCD screen, Refrigerators and ovens.
Lighting	T8 florescent tubes.
Heating	Two forced Air Heaters, one is about 80% efficiency and the other one with 70-75% is currently not running.
Other information	The building looks like any other office building and does not have additional appliances or special functions, but the higher consumption is not evident.

Table F.4 Short survey report for the Baiocchi House

Building	Baiocchi House
	Date: March 11, 2010
Area (SF)	1,303
Built Year	1950
Building Type	Small House
Engineer/Manager	Matt Elliot
Major Use	Toddler Center, playrooms and laundry room.
Building Material	Wooden framed building with siding. Mix of single and double pane windows. Proper ceilings and floor.
Equipment	TV, stereo players, washer and dryer
Lighting	T8 florescent tubes.
Heating	Two Gas Fired Furnace with about 80% efficiency.
Other information	Baiocchi House was found to be connected to the back part of Mary Warren House. However, from the actual facility plan of the building, from facilities management website[26] it was found that these rooms which are connected to Mary Warren House are included in the Area of Baiocchi House. There are no as built drawings for these buildings as they were acquired by the university.

Table F.5 Short survey report for the Ceramics Lab

Building	Ceramics Lab
	Date March 23, 2010
Area (SF)	9,615
Built Year	1950
Building Type	Small House
Engineer/Manager	Jim Brown
Major Use	Ceramics Lab, offices and classrooms
Building Material	Old building with minimum insulation on walls, no insulation on the ceilings, cracks on sides of windows and doors, exhaust fan on the roof which are basically like big holes on the roof. Ventilation windows, relief dampers.
Lighting	CFLs on the ceilings which seem to be a bit farther away than they actually should be. No task lighting. E-mon D-Mon electric meters.
Heating	Three natural gas heaters which are more than 10 - 15 years, roof mounted with non-programmable thermostats. Kept on most of the time, one is not even working.

[26] http://www.humboldt.edu/facilityplan/floor_plans.php

Building	Ceramics Lab
Equipment	Air purifiers- used every night for few hours. Air compressor- hardly used. Computers and foundry outside.
Kilns	Electric • Four numbers of Cress listed Electric Kilns – 23000 W, 14300 W, 14,300, 11000 W. • One Skutt electric Kiln -23600W. • natural gas • Five Furnace oven Kilns, AD Alpine Inc. 200,000 Btu/hr capacities with 10 Amp 1 phase motors.
Other information	The kiln heats are all being taken out from the building by chimney as there is no insulation and the chimney length inside the building is very short.

Table F.6 Evaluation result of buildings based on the walkthrough.

Rank	Building	Built Year	Building Type	Insulation[27]	Major Use	Equipment	Lighting	Heating	Building Status	Engineer/ Contact
1	Telonicher Marine Lab	1977	Off campus Major	Poor	Offices, class rooms, aquariums and Marine Labs	Pumps, computers, blowers, compressor, Chillers and freezers.	T8 installed few years ago with some sensors.	Propane fueled heating boiler (278CFH).	Permanent. Wet room remodeling under process.	Matt Elliot/ Dave Hoskins
2	CNR OF 14TH & B ST #88	1992	On-Campus Small House	Poor	Office of Marketing and Communication , Graphics and Printing	Printers, Plotters, cutters and Press machines.	T8 florescent lightings without sensors	2 Box-type Horizontal Gas Furnace (2000 cfm), ceiling mounted with 90% efficiency. Has gas supply although it does not have a Gas meter.	Temporary, remodeled from a storage building. Engineers are working to replace the thermostat with programmable ones.	Matt Elliot
3	Walter Warren House	1950	On-Campus Small House	Poor	Indian Natural Resource, Science and Engineering Program	Normal office and computers.	T8 florescent tubes.	Two forced Air Heaters, one is about 80% efficiency and the other one with 70-75% is currently not running.	Temporary	Matt Elliot
4	Baiocchi House	1950	On-Campus Small House	Poor	Toddler Center	Normal office with kitchen, washer and dryer.	T8 florescent tubes.	Two Gas Fired Furnace with about 80% efficiency.	Temporary. Area also includes the back portion of Mary Warren which is supplied with gas and electricity from meter on this building.	Matt Elliot
5	Ceramics Lab	1950	On-Campus Small House	Very Poor	Ceramics Lab, offices and lecture room	5 electric Kilns, 5 natural gas kilns and air purifiers.	High CFLs	Three natural gas heaters which are more than 10 - 15 years.	Temporary. There is no immediate plan for renovation or demolishment.	Jim Brown

[27] Insulation levels: Very Poor- Single Pane windows, cracks on doors and windows, no false ceiling or insulation, poor flooring, minimal wall insulation. Poor - Single Pane windows, minimal wall, ceiling and wall insulation, Good –Double pane windows, tight doors, nominal wall, ceiling and floor insulation, Very Good – Double Pane or more windows, Proper door, ceiling, wall and floor insulation.

Figure F.1 Inside the Telonicher Marine Lab

Figure F.2 The Telonicher Marine Lab from outside

Figure F.3 Building 88. Duct work, registers, printing press and horizontal gas furnace.

Figure F.4 Furnace in the Walter Warren House.

Figure F.5 Rear side of the Baiocchi House

APPENDIX G. ENERGY CONSUMPTION BY THE TELONICHER MARINE LAB

Both the electricity and propane consumption by the Marine Lab for 2007 - 2009 has been collected and their mean found which are tabulated below in Table G.1 and Table G.2.

Table G.1 Electricity consumption by the Telonicher Marine Lab for 2007 - 2009

Electricity in MWh				
Years				
Month	**2009**	**2008**	**2007**	**Mean**
Jan	14.67	14.70	14.16	14.51
Feb	16.08	18.00	18.13	17.40
Mar	15.03	17.34	17.03	16.47
Apr	17.57	18.06	17.75	17.79
May	17.55	17.28	18.09	17.64
Jun	15.37	18.56	16.50	16.81
Jul	15.76	17.55	17.71	17.01
Aug	15.45	15.64	18.60	16.56
Sep	16.58	17.51	19.07	17.72
Oct	15.59	15.49	17.19	16.09
Nov	15.87	16.56	17.66	16.70
Dec	15.47	16.05	15.04	15.52
Total	190.99	202.74	206.93	200.22
Area	16,208	16,208	16,208	16,208
kWh/ ft^2/yr	11.78	12.51	12.77	12.35
kBtu/ ft^2/yr	40.30	42.78	43.66	42.25

Table G.2 Propane consumption in the Marine Lab for 2007- 2009.

Propane consumption in Gallons				
Month	**2007**	**2008**	**2009**	**Mean**
Jan	747.60	1,226.51	602.40	858.84
Feb	541.60	774.10	791.80	702.50
Mar	618.20	585.00	739.00	647.40
Apr	1,024.00	531.10	667.70	740.93
May	714.70	691.30	594.80	666.93
Jun	N/A[28]	600.00	462.00	531.00
Jul	N/A	N/A	397.10	397.10
Aug	1,007.70	557.40	302.30	622.47
Sep	N/A	530.60	311.50	421.05
Oct	900.00	513.40	283.00	565.47
Nov	804.80	517.20	547.30	623.10
Dec	501.05	285.90	532.20	439.72
Total	6,859.65	6,812.51	6,231.10	6,634.42
MMBtu/ ft^2/yr	0.4232	0.4203	0.3844	0.4093

N/A [28] Propane is procured and stored in a tank at the site. In some months propane was not purchased at all. The volume data for each month account for the propane procured in that month and does not necessarily indicate anything about consumption in the same month.

APPENDIX H. ENERGY AUDIT WORKSHEET FOR THE TELONICHER MARINE LAB

Thorough energy audit of the Marine Lab was carried out which included study about the building operations, studying actual building materials and functions inside the building. The building was inspected more than five times and the combined results from these audits are presented below.

Average number of user in a semester:
12 staff and faculty, 6 graduate student researchers and 100 students a week.
Visitors:10,000 - 15,000 visitors in a year.

Table H.1 Building use profile

Weekdays	Weekends	Holidays
M-F , 8:00 AM-5:00 PM classes, lab is usually used till 10:00 PM. Open to public 8:00 AM – 5:00 PM	Some faculty and graduate students come and work. Open to public from 12:00 - 16:00 hrs. The system is on all the time.	Facility is open most of the time. Only few faculty and staff are not around. Classes are not held. But the system is on all the time.

Table H.2 Building materials

Component	Description
Frame	Wooden frame, single storey.
Exterior Walls	8” composite walls with wood siding.
Interior Walls	6” partition wood wall
Roof	Flat concreted slab is covered with building paper felt and gypsum board from inside
Floor	Concrete with direct contact on earth. No finishing on most zones, and carpet on some areas.
Window	Aluminum frames with single pane 3mm glasses considered for all
Door	1 3/4” wood doors and some steel/ glass doors

Table H.3 Domestic hot water

System – Name, make, year and model	Btu/hr	Comment
Propane Water Heater, Rheem energy Guide certified, 50Gal, 41VR50P **Pump – Bell and Gossett Circulator NRF-22**	40 kBtu, R 19.2, 92 W	Consumption is 269 ga/yr 240°F/115°C, 160PSI

Table H.4 Original building system

EQUIPMENT SCHEDULE-HEATING WORK

HEATING AND VENTILATING UNIT-
Blow-thru multizone type-Top discharge-2-16"Φ F.C. wheel-Class I
Capacity-10,200 Cfm @ 1½" S.P.
Maximum T.S.- 3450 FPM
Maximum BHP-5.25
7½ HP 208 V 3Φ

Heating coil- 10.5 Min. F.A.
345,500 Btuh min. capacity with 7140 Cfm of 66°F. E.A. & 18 GPM of 200°F. E.W. .5" S.P. Air press. drop.
2.0' W.C. Water pressure drop

Filters- 28 Φ Minimum F.A.

Mounts- Spring rails

RETURN-EXHAUST AIR FAN-
Vaneaxial type 30" Diameter
Capacity-8130 Cfm @ ⅝" S.P.
Max. air velocity thru fan casing 1710 FPM. 1½HP 208V 3Φ
Mounts- Anti-vibration hangers

ROOF EXHAUST FAN No. 1
-Curb-mounted centrifugal type
22" Minimum nominal diameter
Capacity- 3180 Cfm @ ¼" S.P.
Maximum tip speed- 3000 FPM
Max. BHP- .3 ⅓ HP 115 V 1Φ
Back draft damper-Belt driven

ROOF EXHAUST FAN No. 2
Curb-mounted centrifugal type
13½" Minimum nominal diameter
Capacity-1130 Cfm @ ⅜" S.P.
Maximum tip speed- 3600 FPM
Belt-driven. ¼ HP 115 V 1Φ
Back draft damper

PRIMARY HOT WATER CIRCULATING PUMP
Pipe supported centrifugal type. Capacity-18 GPM @ 12' TDH
⅙ HP 115 V 1Φ
Piping connections- 1"

SECONDARY HOT WATER CIRCULATING PUMP
Same as primary pump above

HOT WATER BOILER
Cast iron hot water type
Automatic controlled-LPG Gas-fired. 100% Shut-off.
Capacity 380,000 Btu/hr. min. output. Construction- ASME Code for 50 Psig.

EXPANSION TANK
Size- 20 gallons. ASME Code for 100 Psig

REFRIGERATION CONDENSING UNIT
Air-water cooled type
Min. capacity- 6750 Btu/hr. @ -5°F. suction and 90°F. ambient room temperature.
1½ HP 208V 3Φ 60∼.

REFRIGERATION EVAPORATOR
Electric defrost type
Min. capacity- 6500 Btu/hr. @ 10°F. T.D. Complete with heat exchanger and prewired control panel with automatic timer.
⅙ HP

WALL EXHAUST FAN
Wall-mounted propeller type. 18" Min. nominal diameter. 2310/1440 CFM @ ⅛" S.P. ⅙ HP, 115V, 1Φ, 60∼, & Two-speed motor. Provide gravity back-draft damper.

Mon-Fri: 6:00 – 18:00 hrs, Sat &Sun: 9:00 – 14:00 hrs, Holidays: 8:00 – 10:00 hrs.
Two zones at the back have their own heating with the same hot water loop, but different Unit Ventilators.

Table H.5 Heating schedule and HVAC system details

System/zone	System Type	CFM /hp	Comment
Hot Water Boiler – NP Thermific, N 700, LPG	CI hot water LPG	700,000 Btuh. 85% Efficiency	ASME code 2522 Btu/CFH Air Pr 1.4”WC

System/zone	System Type	CFM /hp	Comment
Air Handler Fan, Century Electric, SC-254VC-17C5-3	blow Through, 2.0' W.C water Pressure	10,200 cfm 7.5 hp 19,090 Btuh	Max BHP 5.25 Multi-zone, Motor is Squirrel Cage Induction Motor. www.eng-tips.com
Hot Water Circulating Pump x 2	Pry and 2ndry	1.5 hp	Pipe supported, 1"pipes
Return Exhaust Air Fan	Vaneaxial Fan	8150 cfm 1.5 hp	Mounts anti-vibration hangers
Roof Exhaust Fan 1	Centrifugal	3180 cfm 1/3 hp	Back draft damper –belt driven
Roof Exhaust fan 2	Centrifugal	1130 cfm ¼ hp	Back draft damper
Wall Exhaust Fan	1/6 hp, 2310 cfm		2 speed motor, gravity –draft damper
Unit Heaters – Nesbittaire M2-13	T0W415001B00 0K00-111TFX0DS	1/12 hp 1000 cfm	www.nesbittaire.com 2 locations
Unit heaters in welding shop	2-nos	1/20 hp	New motors

Table H.6 Motors in the Marine Lab

System – Name and make	Model	Rating/Efficiency	#	Schedule	Comment
Re-circulation pumps, >10 years old, for recycling sea water.	T779A, 1755rpm	10hp (7457 W), 87.5% efficiency.	1	24 hrs all the time	2 units but one is used at a time. US Electrical Motors Ingersoll Dresser Pump Co
Water Pump at Pier	Stainless steel Fairly new motor	24 hp (17,900 W), efficiency -	1	6-8 hrs/ week.	The pump and motor are said to be in great shape, well maintained and very expensive to be replaced. Different meter. It is hardly used anymore.
Compressor for Toilet Actuators - Baldor	HM33131-B 37B01737	10 hp, 89.5%	1	Typical use is 1.2 hrs/day	www.Baldor.com Logger data collected in 2 weeks of May = 7457W*1.2 hrs/day=373W/h =373/293.1ft^2=1.272W/ft^2
Bench Air Compressor	K55JXEP T-935	.5hp (373 W), Efficiency -	1	Connected to PV System.	Connected to PV System. **RPM**: 3450, **PHASE**: 1, **HP**. 1/2 **HZ**: 50HZ **RPM**: 2850

System – Name and make	Model	Rating/Efficiency	#	Schedule	Comment
Bench Vacuum – General Electrical	5K182A L 3449B	3 hp	1	Typical use is .45 hrs/day	40°C, type K, class A, code K, 1827. Data collected in 2 weeks of May 2237W*45min=1678wh/day = 70w/hr= .239W/ft^2

Table H.7 Other equipment in the Marine Lab

System – Name and make	Model	Rating/ Efficiency	No	Schedule
Electrical Wall Heaters	Dayton 9 fins radiator	1000 W	1	2-3 hrs/day in winter
Computers	LCD	200 W	15	Normal office hours
Printers	General	200 W	5	
Chest Freezer – Kenmore www.kenmore.com	16542	14.9 Cu.Ft 357 kWh/Yr	1	Full time on
Refrigerator(Fisher Scientific)		300 W	2	
Incubator - Thermo Precision	BOD 818	800 W	1	
Dishwasher		1800 W	1	2*1 hr/week

Table H.8 Cooling systems in the Marine Lab

System – Name and make	Model	Rating/ Efficiency	#	Comment
Chillers – Heatcraft, >10 years old Compressor – Copeland Disc	LDH1000D73 3DB3-100E-TFC-200 Heater	80Ax208V 10 hp 100 W	2 2 2	1/3 hp pump, 400-162PSIG, Refig R502/R22. Chiller Schedule is separate.
Walk in Refrigerator-	80A, +4°C	R-12, 150 W	1	North Star 1974.
Air compressors, LGH 106-H02	Sawp compressors	2 hp	1	
Refig condensing unit	Air-water cooled	1.5 hp, 6750 Btu/hr	1	
New Freezer, Copeland	FJAL-B301-TFC-020	3 hp	1	RLA 10.2, Min Air - 18.6A and Max 20A

APPENDIX I. CHILLER USE IN THE MARINE LAB

The usage data for the chillers were collected from May 9, 2010 to June 9, 2010 and the consumption determined accordingly by using a Current Transducer on one leg of wiring into one of the chiller and recorded on a Hobo data logger. The lab is currently having a remodeling project in the Wet Lab where are 7 huge fish tanks are usually placed. This most likely altered our consumption data by quite a substantial amount since it is a major missing component of the building sea water demand.

According to the Hobo logger, currently the chillers are turned on 9.6 hrs/day to cool down 20,748 Gal of water. By back calculating the cooling required when the Wet Lab is running with full load of (7,460 + 20,748 Gal) it works out that the chiller would have been turned on 13.05 hrs/day which results in reduction of 1,544 kWh of energy in a month. The actual reduction in energy consumption over the last four months after the modeling works have begun have been compared with energy consumption in the same month for last 3 years as shown in Figure I.1. There is an average reduction of energy consumption by 2,658 kWh/month from April-July. Although the numbers are not very close it definitely proves that the assumption I have made is valid. The difference in more energy saving could be due to lesser number of works and very few visitors which are not accounted in the calculation. The details of these calculations are in the following Table I.1 to Table I.3. The extra tanks were removed around March- April 2010 for the Wet Lab remodeling.

Table I.1 Electricity consumption in the Marine Lab (May, 2006 – June, 2010)

	Usage in kW						
Month	**2010**	**2009**	**2008**	**2007**	**2006**	**Mean of 06-09**	**Difference (Mean 2010)**
January	15265	14670	14702	14155		14509	
February	14796	16084	18002	18128		17405	
March	13667	15029	17344	17034		16469	2802
April	13801	17565	18060	17745		17790	3989
May	13705	17547	17280	18090	18627	17886	4181
June	15093	15371	18564	16501	17544	16995	1902
July	16718	15759	17552	17711	18082	17276	558
August		15449	15640	18601	18619	17077	
September		16582	17508	19066	18099	17814	
October		15594	15488	17186	17427	16424	

Month	Usage in kW 2010	2009	2008	2007	2006	Mean of 06-09	Difference (Mean 2010)
November		15868	16559	17663	18992	17271	
December		15467	16053	15043	15403	15492	
Average Decrease							2658

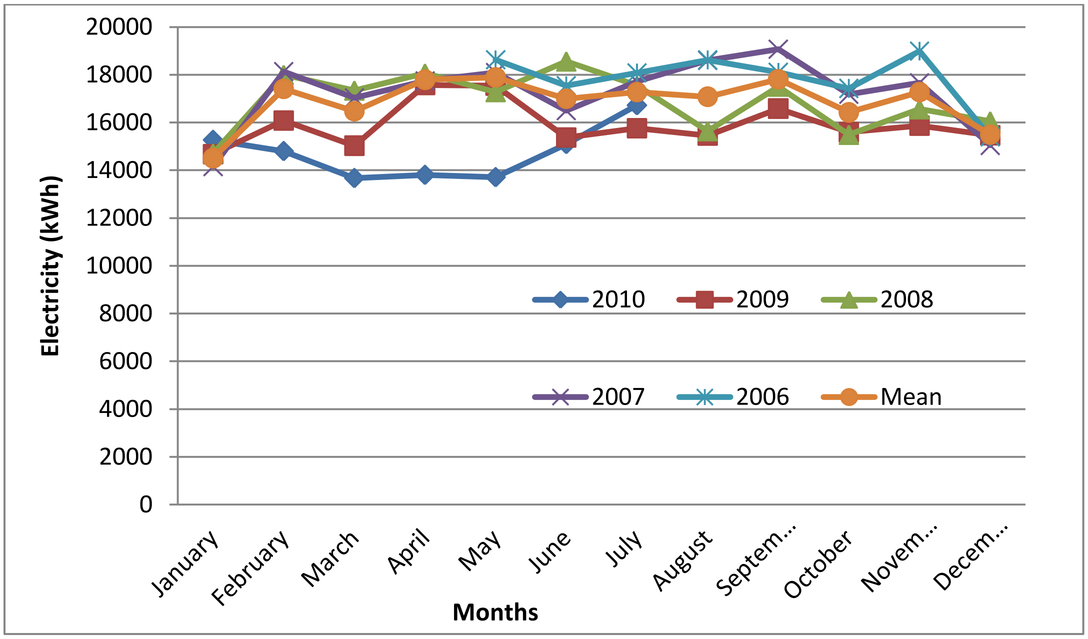


Figure I.1 Decrease in electricity consumption in 2010.

Table I.2 Calculation of volume reduced during the remodeling/data collection time

Tanks removed			
Size	No	Vol	Remarks
500	6	3,000	Public Display Tanks
1400	1	1,400	Public Display Tanks
100	2	200	Avaloni
250	10	2,500	Half are used at a time
30	12	360	Nalgene, used all the time
Total Vol removed		7,460	Gal

Current Tanks			
Size	No	Vol	Remarks
80	1	598	1Cft = 7.48 Gal, Seawater Tank in classroom
75	2	150	
20000	1	20,000	Seawater Tank, almost full all the time and chilled
Total Vol present		20,748	Gal

Table I.3 Extrapolation of data to get of hours of chiller use based on hobo logger data

Condition	**Volume (Gal)**	**Time of use hrs/day**	**Remark**
Current	20,748	9.6	From hobo logger
Before	28,208	13.05	extrapolation
Current Energy consumption	4,295.23	kWh	
Earlier Energy consumption	5,839.56	kWh	
Difference (kWh)	1544	kWh	

APPENDIX J. BASELINE MODEL FOR THE MARINE LAB

The energy use of the actual building was used to calibrate the eQUEST model of the building. After the various iterative process of tuning the model, mean energy use of the actual building was compared against the energy consumption by the model which is shown below in Table J.1 and J2.

Table J.1 Electricity consumption by the model and the actual Marine Lab.

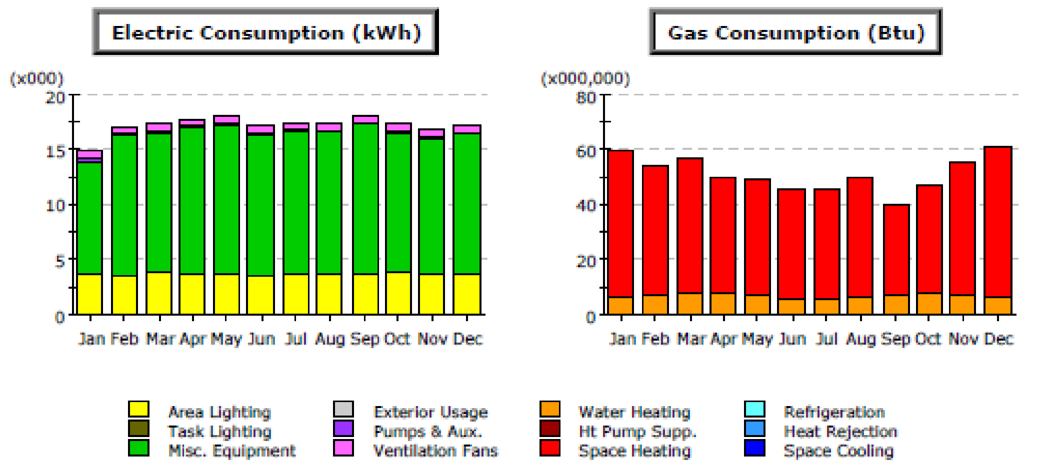
			Electricity in MWh			
Month	**2009**	**2008**	**2007**	**Mean**	**Model**	**Difference**
Jan	14.67	14.70	14.16	14.51	14.83	0.32
Feb	16.08	18.00	18.13	17.40	17.02	-0.38
Mar	15.03	17.34	17.03	16.47	17.35	0.88
Apr	17.57	18.06	17.75	17.79	17.74	-0.05
May	17.55	17.28	18.09	17.64	17.96	0.32
Jun	15.37	18.56	16.50	16.81	17.09	0.28
Jul	15.76	17.55	17.71	17.01	17.37	0.36
Aug	15.45	15.64	18.60	16.56	17.33	0.77
Sep	16.58	17.51	19.07	17.72	18.03	0.31
Oct	15.59	15.49	17.19	16.09	17.27	1.18
Nov	15.87	16.56	17.66	16.70	16.73	0.03
Dec	15.47	16.05	15.04	15.52	17.19	1.67
Total	190.99	202.74	206.93	200.22	205.92	5.70

Table J.2 Comparison of propane use by the model and the actual Marine Lab.

Propane consumption (MMBtu)						
Month	**2007**	**2008**	**2009**	**Mean**	**Model**	**Difference**
Jan	68.41	112.23	55.12	78.58	59.07	-19.51
Feb	49.56	70.83	72.45	64.28	53.73	-10.55
Mar	56.57	53.53	67.62	59.24	56.49	-2.75
Apr	93.70	48.60	61.09	67.80	49.38	-18.42
May	65.40	63.25	54.42	61.02	49.09	-11.93
Jun	-	54.90	42.27	48.59	45.75	13.36
Jul	-	-	36.33	36.33	45.73	33.62
Aug	92.20	51.00	27.66	56.96	49.61	7.35
Sep	-	48.55	28.50	38.53	39.71	14.03
Oct	82.35	46.98	25.89	51.74	46.45	5.29
Nov	73.64	47.32	50.08	57.01	54.65	2.36
Dec	45.85	26.16	48.70	40.23	59.8	19.57
Total	627.66	623.34	570.15	607.05	609.46	2.41

Figure J.1 Baseline model energy consumption

Project/Run: MarineL_Sept3_Baseline1 - Baseline Design | Run Date/Time: 09/18/10 @ 20:58



Electric Consumption (kWh x000)

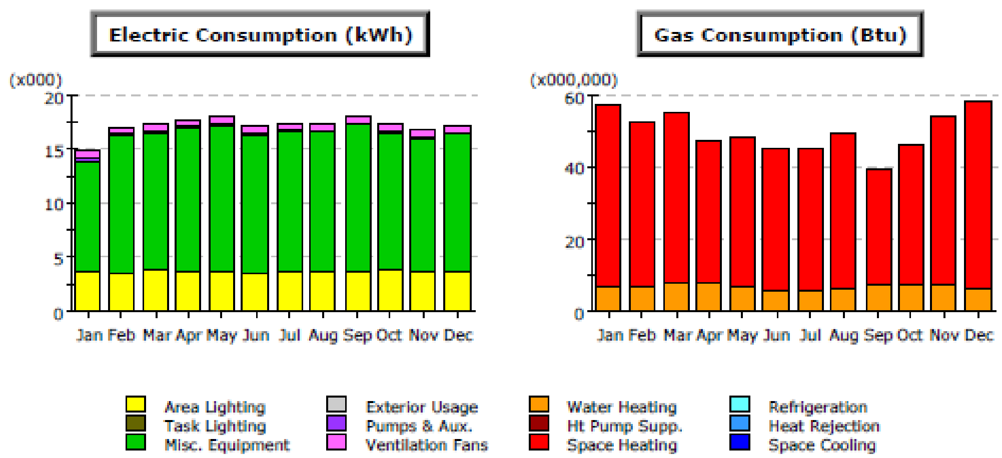
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	-	0.02
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.68	0.61	0.68	0.65	0.67	0.65	0.67	0.67	0.65	0.67	0.66	0.68	7.93
Pumps & Aux.	0.16	0.15	0.17	0.15	0.13	0.12	0.12	0.12	0.12	0.13	0.15	0.17	1.67
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	10.23	12.76	12.63	13.18	13.35	12.71	12.85	12.76	13.50	12.59	12.18	12.59	151.32
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	3.76	3.50	3.88	3.76	3.80	3.61	3.73	3.78	3.75	3.87	3.74	3.76	44.95
Total	14.83	17.02	17.35	17.74	17.96	17.09	17.37	17.33	18.03	17.27	16.73	17.19	205.92

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	52.62	46.97	49.32	41.95	42.40	40.20	40.13	43.38	32.49	39.55	48.24	53.68	530.92
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	6.78	7.22	8.09	7.86	6.97	5.73	5.84	6.65	7.39	7.63	7.36	6.69	84.22
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	59.40	54.19	57.41	49.81	49.37	45.93	45.97	50.02	39.88	47.18	55.60	60.38	615.13

eQUEST 3.63.6510 | Monthly Energy Consumption by Enduse | Page 1

APPENDIX K. eQUEST MODEL OF THE MARINE LAB WITH LOW INFILTRATION



Electric Consumption (kWh x000)

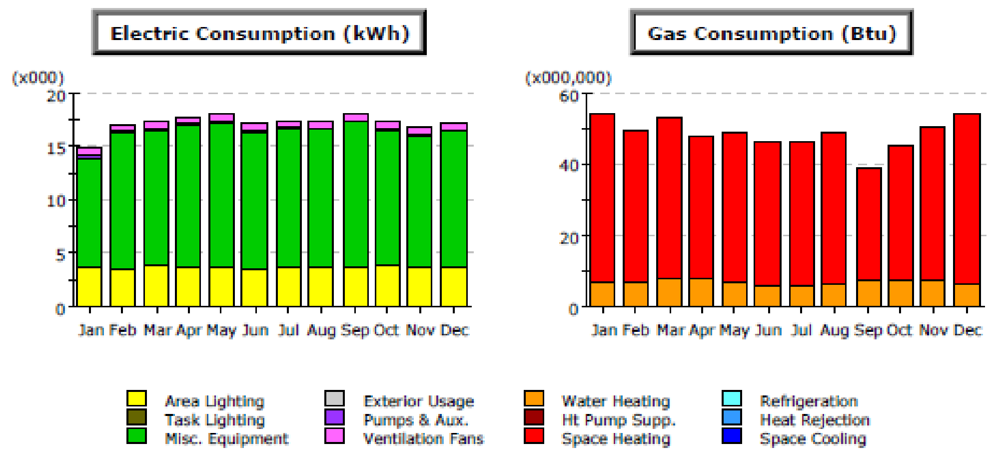
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	-	0.02
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.68	0.61	0.68	0.65	0.67	0.65	0.67	0.67	0.65	0.67	0.65	0.68	7.93
Pumps & Aux.	0.16	0.15	0.17	0.15	0.13	0.12	0.12	0.12	0.12	0.13	0.15	0.17	1.67
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	10.23	12.76	12.63	13.18	13.35	12.71	12.85	12.76	13.50	12.59	12.18	12.59	151.32
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	3.76	3.50	3.88	3.76	3.80	3.61	3.73	3.78	3.75	3.87	3.74	3.76	44.95
Total	14.83	17.02	17.35	17.74	17.96	17.09	17.37	17.33	18.03	17.27	16.73	17.19	205.91

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	50.74	45.07	46.87	39.51	41.06	39.16	39.22	42.61	32.04	38.62	46.78	51.57	513.24
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	6.78	7.22	8.09	7.86	6.97	5.72	5.84	6.65	7.39	7.63	7.36	6.69	84.20
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	57.52	52.29	54.96	47.37	48.03	44.88	45.06	49.25	39.43	46.25	54.15	58.26	597.44

APPENDIX L. eQUEST MODEL FOR THE MARINE LAB WITH DOUBLE PANE WINDOWS AND MORE CEILING INSULATION

Project/Run: CeilingInsDPane - Baseline Design | Run Date/Time: 09/08/10 @ 16:10



Electric Consumption (kWh x000)

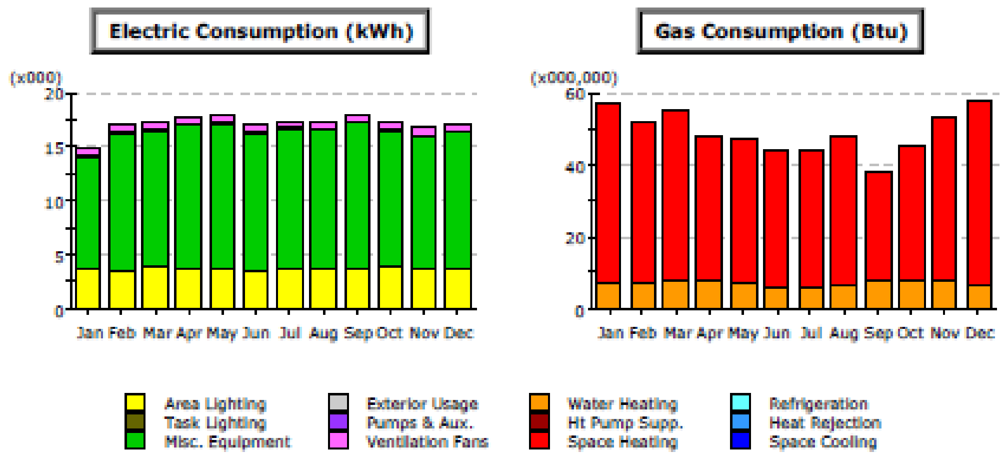
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	-	0.02
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.67	0.61	0.68	0.65	0.67	0.65	0.67	0.67	0.65	0.67	0.65	0.68	7.92
Pumps & Aux.	0.16	0.15	0.16	0.15	0.13	0.12	0.12	0.12	0.12	0.13	0.15	0.17	1.67
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	10.23	12.76	12.63	13.18	13.35	12.71	12.85	12.76	13.50	12.59	12.18	12.59	151.32
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	3.76	3.50	3.88	3.76	3.80	3.61	3.73	3.78	3.75	3.87	3.74	3.76	44.95
Total	14.83	17.02	17.35	17.74	17.96	17.09	17.37	17.33	18.03	17.27	16.73	17.19	205.90

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	47.33	41.91	45.16	39.97	41.68	40.28	40.16	42.23	31.72	37.11	43.24	47.57	498.35
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	6.78	7.22	8.09	7.86	6.97	5.73	5.84	6.65	7.39	7.63	7.36	6.69	84.21
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	54.11	49.13	53.24	47.83	48.65	46.00	46.00	48.87	39.11	44.74	50.60	54.26	582.56

APPENDIX M. eQUEST MODEL FOR THE MARINE LAB WITH NEW BOILER

Project/Run: NewBoiler - Baseline Design Run Date/Time: 09/08/10 @ 12:02



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	-	0.02
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.68	0.61	0.68	0.65	0.67	0.65	0.67	0.67	0.65	0.67	0.66	0.68	7.93
Pumps & Aux.	0.16	0.15	0.17	0.15	0.13	0.12	0.12	0.12	0.12	0.13	0.15	0.17	1.67
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	10.23	12.76	12.63	13.18	13.35	12.71	12.85	12.76	13.50	12.59	12.18	12.59	151.32
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	3.76	3.50	3.88	3.76	3.80	3.61	3.73	3.78	3.75	3.87	3.74	3.76	44.95
Total	14.83	17.02	17.35	17.74	17.96	17.09	17.37	17.33	18.03	17.27	16.73	17.19	205.92

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	49.99	44.62	46.85	39.85	40.28	38.19	38.12	41.21	30.86	37.57	45.82	51.00	504.37
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	6.78	7.22	8.09	7.86	6.97	5.73	5.84	6.65	7.39	7.63	7.36	6.69	84.22
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	56.77	51.84	54.94	47.71	47.25	43.92	43.96	47.85	38.25	45.20	53.19	57.69	588.59

APPENDIX N. INFORMATION ON COGENERATION AT THE MARINE LAB

A website on cogeneration explains the Cogeneration technology is simultaneous production of electricity and useful heat from the same fuel or energy (Cogeneration.net, 2002).

> *Cogeneration/CHP is the simultaneous production of electricity and useful heat from the same fuel or energy. Facilities with cogeneration systems use them to produce their own electricity, and use the unused excess (waste) heat for process steam, hot water heating, space heating, and other thermal needs.*
>
> *Cogeneration is a proven technology that has been around for over 100 years. Cogeneration systems are also available to small-scale users of electricity. Modular cogeneration systems are compact, and can be manufactured economically. These systems, ranging in size from 20 kilowatts (kW) to 650 kW produce electricity and hot water from engine waste heat. It is usually best to size the systems to meet the hot water needs of a building. They can be operated continuously or only during peak load hours to reduce peak demand charges, although continuous operation usually has the quickest payback period.*

Besides the fact that there is no natural gas line in Trinidad, propane is considered an environmentally friendly, reliable, safe, easy to store and good value fuel which has been listed as a clean alternative fuel in the *1990 Clean Air Act* and *National Energy Policy Act of 1992* (PERC, 2010). Another study for propane CHP in rural Alaska also mentions that propane which produces 91,600 Btu per gallon does not have any negative effect on machine parts and require lesser maintenance with extended lives leading to cheaper operation and ease (Bartz Englishoe and Associates, 2008). Therefore, it is reasonable to go ahead with a propane fueled CHP for the Marine Lab. A generic representation of a propane fuel delivery train for a Microturbine is in Figure N.1 below.

One of the most common CHP turbines and also chosen in an earlier study (ibid) are the Capstone Microturbines. Capstone Microturbines have already been demonstrated in Pierce College, Woodland Hills, California and also recently sponsored by the U.S. Department of Energy’s Energy Efficiency and Renewable Energy Office to do other research and development in the same field (Capstone Micro Turbine, 2010). The turbines are 2 to 2.5 times more efficient than a central fire plant and the Turbines cut the CO_2 footprint in half, or better (Flores, 2008).

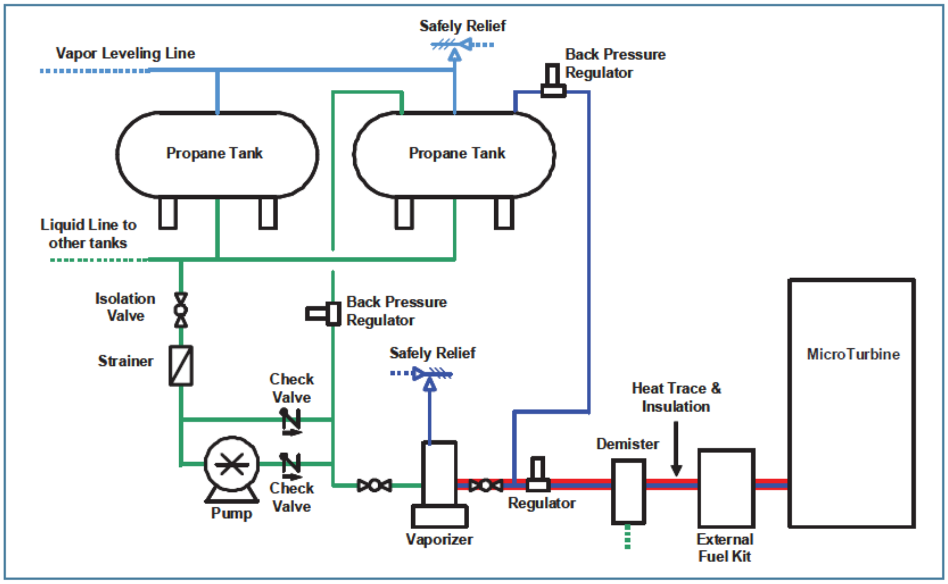


Figure N.1 Generic representation of Propane fuel-delivery train for a Capstone CHP.

Figure N.2 A 30 kW Microturbine (http://me1065.wikidot.com/microturbines)

APPENDIX O. ENERGY AUDIT WORKSHEET FOR THE CERAMICS LAB

Similar to the Marine Lab, the Ceramics Lab was also visited several times to understand the building usage properly, and the building components in detail. The important aspects of the audit which included inspections and referring drawings have been shown below.

Average number of students in a semester – 160/semester
Faculty/instructors - 3

Table O.1 Profile of building use

Weekdays	Weekends	Holidays
M-T , 8:00 AM-5:00 PM classes, lab is open till 10:00 PM F-Lab, open till 10:00 PM	8:00 AM -10:00 PM, students come and work	Closed most of the time. Only faculty and staff use some lights and plug loads.

Table O.2 Building materials

Component	Description
Frame	Wooden frame, single storey.
Exterior Walls	8” composite walls with wood siding.
Interior Walls	6” partition wood wall and 6” concrete wall between Room 101 and Room 108
Roof	Wood Shingle with built up roof. 12^{o}Slope for all
Floor	Concrete with direct contact on earth and no finishing
Window	Wood frames with single pane 3mm glasses
Door	1 3/4” wood doors

Table O.3 Domestic hot water

System – Name, make, year and model	Btu/hr	Comment
American Water Heater, G52-30T333N, 30 Gallon	33,000	EnergyGuide certified, inside the Forming Room. R- 16.7

Table O.4 Lighting details of the Ceramics Lab

Area/ Room	Type of fixture	No	Avg. Watt	Total	Comment
111	Sky lights	3	4*4'		
	Tube lights	6	32	192	
107 Glaze and Forming 101	Metal halide lamps	12	400	4800	
Forming 101	F32 T8 tubes	12	32	384	Left corner
109- Storage	Incandescent	1	57	57	
10 5- Spray	Incandescent	1	57	57	
104&6 restrooms	Incandescent	2	57	114	All lights are on 9AM-10PM.
102 Office		2	32	64	
102A lecture	F32 T8 tubes	8	32	256	
115	F32 T8 tubes	18	32	576	
114	F32 T8 tubes	8	32	256	
112	Incandescent	8	57	456	
115	Sky light	3	4*4'		
Total load				7,212.00	A=8894 ft^2
W/ft^2				0.81	
Gas Kiln room(108)					
108	Tubelight	12	32	384	Some are dead
	Tubelight	1	20	20	Dead
	Incandescent bulb	2	57	114	Corner
Total load				518	A= 721ft^2
W/ft^2				0.72	

Table O.5 Gas kilns in room 108

System – Name and make	Model, Sl No	Rating /Efficiency	Schedule
1. Skutt Automatic Kiln	KM-1627PK, 005143	208 V, 3W, 76 A, 23,600 W	Gas Kilns are preheated overnight. Firing twice (Tue and Friday)/week. 16 hours of firing up to 2350^{o}F. Annual schedule varies according to the semester. More at the end of the semester and lesser at the beginning.
2. Fujita Furnace, Oven & Kiln	ND-12, 127		
3. Geil Gas Kiln	DL B16, 161000599,	200,000 Btu/hr, 120 VAC, 10A	
4. West Coast Kiln	No details		
4. Geil Gas Kiln	DLD 20, 200498413	280,000 Btu/hr, 120 VAC, 10 A	

Table O.6 Electric Kilns

System – Name & make	Model, Sl No	Rating /Efficiency	Schedule
Kilns in room 111			BISQUE takes about 8hours of candling and 8 hrs of firing. 2/week. Started mid day and end the next day at mid night. GLAZE takes only 8 hrs of firing. From the Kiln signup sheet a typical week totals to about 17 firing/week at the end of semester. 16 hrs per firing @ four a week in the beginning of semester, 8 a week mid semester and 17 a week at the end.[29]
1. Cress Electric Kiln			
2. Cress Electric Kiln	FTX 27P	220 V, 42 A	
3. Cress Electric Kiln	FTX 280P, 9905	220 V, 44 A	
4. Cress Electric Kiln	FX27P,	220 V, 42 A	
5. Skutt Automatic Kiln	FX27P, 9703	220 V, 45 A	
6. Skutt Automatic Kiln	KM-1027-3”	208 V/3#, 31.7A, 11000 W	
7. Skutt Automatic Kiln	KM-614-3”, 3592	115 V, 20 A, 2300 W	
8. Cress Electric Kiln	KM-1227PK, 003154	208 V, 69 A, 14300 W	
Kilns in room 115	FXC-30FH, 8502	230 V, 60 A, 14000 W	
Cress Electric Kiln			
Cress Electric Kiln	FX27P,	220 V, 42 A	
Cress Electric Kiln	FX27P,	220 V, 42 A	

Table O.7 Other equipment in the Ceramics Lab

System – Name and make	Model	Rating/ Efficiency	No	Schedule
Compressor, US Electrical Motors, AMDP	Code J, S 1990050	1725 rpm, 12.8 A	1	Air cleaners are on 12-6 PM on working days. Turned off during breaks
Glaze Mixing hood, GMH -1	Airfiltronix HS-3000 A2	265 cfm, 200 W	3	
Containment Hood, CH-1	Airfiltronix G-50	265 cfm, 200 W	3	
Kiln Fume Vent (FV 1-7), Bailey	M-405-009 & 010	4.2 A, 115 V	7	
Air Purifiers/Cleaners (AC 1-8) Aerocology	2000-H	2000 cfm, 0.5 HP	8	
Fan Spray Booth, SB- 1, Bailey			1	1-2 hrs/day. Turned off

[29] The detailed schedule of electric Kiln firing as obtained from interviews and reservation sheet.

System – Name and make	Model	Rating/ Efficiency	No	Schedule
Fan Spray Booth, SB- 2, Bailey	C-074-5	2150 cfm,	1	during breaks
Exhaust Fans (EF 1,2) Greenheck	G-90	500 cfm, 1/25 HP		
EF 3 and EF 4	G-160	2200 cfm, 1/3 HP		
Grinder, Baldor G7 302-30	712RE	3411 7A	1	1-2 hrs/day
Hot Box KOOH		70^{o}F	1	1-2 hrs/week
Microwave Oven, Sunbeam		1350 W		5-10 m/day
Brent Porter Wheel , C-12	Sl 86 8051	1/8 A, 110 V	8	6 hr/week
Shimp RK Whisper	63036270	9 A, 400 W	4	1-2 hrs/week
Computers	Desktop	250 W	1	8 AM-5 PM on working days. Half time on breaks

Table O.8 HVAC system

System/Zone	System Type	Fan	Efficiency	set point
HV-1 by the Hot Box, Room 101	UBS-65-85	Robertshaw 7200IPER-57C, 24V, 4A	Input- 65,000 Btu/hr Output-52,000 Btu/hr Efficiency- 80%	68^{O}F
HV-3 Beside Spray booth, Room 101				
HV-2 by the washbasin towards Glaze Room, R101	UBS-100-94	Honeywell 24V,1-2A	Input- 100,000 Btu/hr Output-80,000 Btu/hr Efficiency- 80%	68^{O}F
HV-4, Left corner of R101				
HV 5 in room 111				

Gas heater - Janitrol Unit heaters, natural gas fired, ceiling mounted.[30]

[30] The Janitrol Gas heaters seem to have good reliability. http://highperformancehvac.com/air-conditioner-furnace-reviews/gas-furnace-reviews/92-janitrol-gas-furnace-reviews.html & http://toad.net/~jsmeenen/goodman.html

APPENDIX P. LIGHTING LEVELS OF THE CERAMICS LAB

To verify that none of the room is over lighted while others are dark, the light intensity of the Ceramics Lab was measured by an EXTECH 403125 Light Probe Meter in LUX. Results from this survey are shown below in Table P.1.

Table P.1 Light intensity of the Ceramics Lab

Room	Measurements (lux)							Average	Room
101	210	530	460	450	430	320	370	373	Forming Room
	41	540	440	380	300				
102	880	520	800					733	Lecture
107	270	790	760	415	430	504		528	Glaze Room
108	125	250	460	360	160	70	80	**239**	Gas Kiln Room
	360	120	400						
111	760	300		550	1400	700	460	695	Kiln Room
112	390	450	600	820	830	750		640	Office and store
115	880	900	2800	3500	1250	1500	1550	1,769	Independent study
Building Average								711	
Building Average without room 108(Gas Kiln room)								790	

APPENDIX Q. ENERGY SAVING FLIER FOR THE CERAMICS LAB

Ceramics Lab in a typical year:

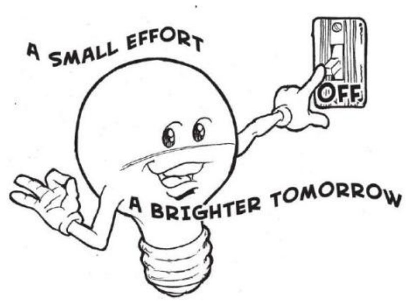
Consumption
- 112,100 kWh of electricity
- 6,750 Therms of natural gas

Cost \$22,900* &

emits 77.9 MTCO$_2$**

Do Something!

Save Energy to stop Global Warning and Save Money.



www.flexyourpower.org

Turn off your lights when not needed

Tune down your thermostat settings. Dot not set it above 68^{o}F.

Shut Doors and windows in the building to prevent heat loss.

A lot of heat from the Kilns is just lost through the doors while additional natural gas is used to heat up the building.

Turn off equipment such as printers, computers, microwave oven, Stereos and coffee makers at night and not when not in use.

** Average undergrad student in CSU pays only \$4,000 tuition fee in an academic year.*

*** One ton of CO$_2$ is equal to a cube which is 27'x27'x27' (CSU 2009 and energyrace.com).*

APPENDIX R. COMPARISION OF ENERGY CONSUMPTION BY eQUEST BASELINE MODEL AND THE ACTUAL CERAMICS LAB

The energy consumption by the actual building the building's eQUEST model, after calibrations were compared and shown below in Table R.1.

Table R.1 Comparison of electricity consumption by the model and the actual Ceramics Lab.

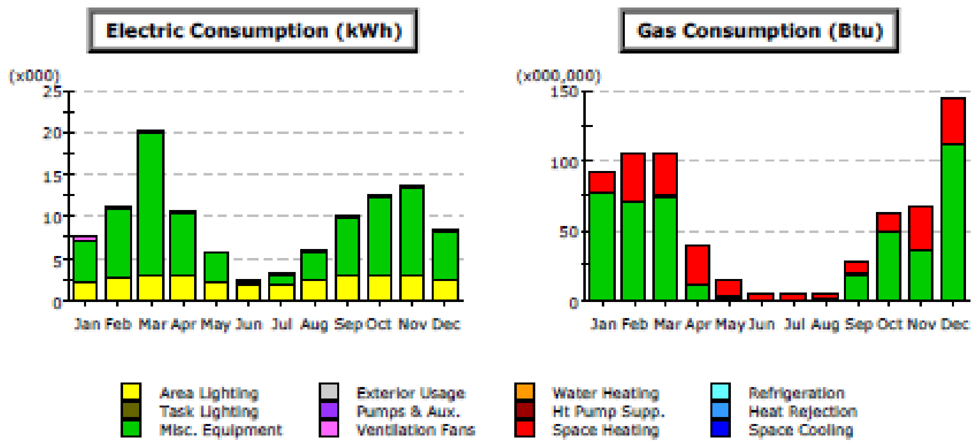
Electricity in MWh						
Month	**2009**	**2008**	**2007**	**Mean**	**Model**	**Difference**
Jan	5.98	7.14	10.11	7.74	7.49	(0.25)
Feb	11.78	14.05	8.86	11.56	11.21	(0.35)
Mar	17.44	33.15	12.03	20.87	20.34	(0.53)
Apr	15.71	3.17	14.34	11.07	10.74	(0.33)
May	6.11	2.56	7.26	5.31	5.78	0.47
Jun	2.46	3.2	3.2	2.95	2.44	(0.51)
Jul	4.35	4.38	2.05	3.59	3.23	(0.36)
Aug	4.45	7.07	6.98	6.17	6.07	(0.10)
Sep	9.63	10.18	13.15	10.99	10.01	(0.98)
Oct	9.82	17.92	8.42	12.05	12.5	0.45
Nov	14.21	8.29	17.41	13.30	13.7	0.40
Dec	11.2	5.8	7.78	8.26	8.39	0.13
Total	113.14	116.91	111.59	113.88	111.9	-1.98

Table R.2 Comparison of natural gas use by the model and the actual Ceramics Lab.

	MMBtu/year				
Month	2009	2008	Mean	Model	Difference
Annual Total	625.90	723.41	674.66	673.70	-0.95
December	118.70	173.60	146.15	145.24	-0.91
November	76.70	50.40	63.55	66.71	3.16
October	47.20	83.40	65.30	63.35	-1.95
September	22.30	34.80	28.55	28.53	-0.02
August	4.50	5.40	4.95	5.27	0.32
July	2.50	4.40	3.45	4.00	0.55
June	7.50	4.20	5.85	5.87	0.02
May	22.40	8.25	15.33	14.34	-0.98
April	70.00	8.25	39.13	38.80	-0.33
March	105.60	103.91	104.76	104.61	-0.14
February	80.90	129.00	104.95	104.85	-0.10
January	67.60	117.80	92.70	92.14	-0.56

APPENDIX S. eQUEST BASELINE MODEL FOR THE CERAMICS LAB

Project/Run: CeramicsLab_7_ACHschedule - Baseline Design Run Date/Time: 06/07/10 @ 18:53



Electric Consumption (kWh x000)

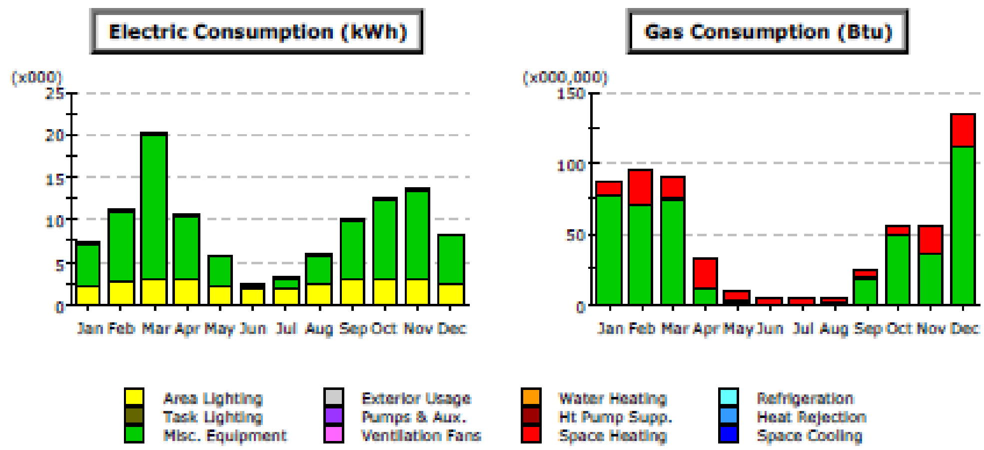
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.24	0.22	0.24	0.23	0.24	0.23	0.24	0.24	0.23	0.24	0.23	0.24	2.86
Pumps & Aux.	0.05	0.13	0.12	0.11	0.05	0.02	0.01	0.01	0.04	0.05	0.12	0.13	0.84
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	4.97	8.22	17.06	7.57	3.16	0.47	1.20	3.26	6.90	9.28	10.52	5.57	78.16
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	2.22	2.64	2.93	2.83	2.33	1.72	1.77	2.55	2.83	2.93	2.83	2.44	30.02
Total	7.49	11.21	20.34	10.74	5.78	2.44	3.23	6.07	10.01	12.50	13.70	8.39	111.88

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	14.00	33.96	29.96	27.06	12.00	5.55	3.68	3.90	10.35	14.63	30.02	33.77	218.88
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.46	0.60	0.67	0.64	0.49	0.31	0.32	0.45	0.61	0.63	0.62	0.50	6.29
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	77.68	70.28	73.98	11.10	1.85	-	-	0.92	17.57	48.09	36.07	110.98	448.53
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	92.14	104.85	104.61	38.80	14.34	5.87	4.00	5.27	28.53	63.35	66.71	145.24	673.70

APPENDIX S. eQUEST MODEL WITH LOW INFILTRATION FOR THE CERAMICS LAB

Project/Run: CeramicsLab_1_ACHS - Baseline Design Run Date/Time: 06/07/10 @ 20:45



Electric Consumption (kWh x000)

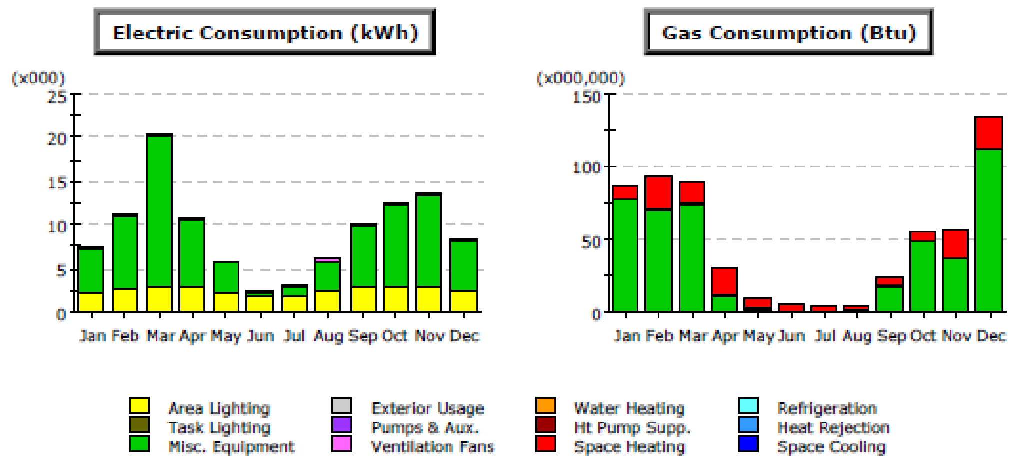
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.21	0.19	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	2.52
Pumps & Aux.	0.03	0.09	0.06	0.08	0.03	0.02	0.01	0.01	0.02	0.03	0.08	0.09	0.54
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	4.97	8.22	17.06	7.57	3.16	0.47	1.20	3.26	6.90	9.28	10.52	5.57	78.16
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	2.22	2.64	2.93	2.83	2.33	1.72	1.77	2.55	2.83	2.93	2.83	2.44	30.02
Total	7.44	11.14	20.26	10.68	5.73	2.41	3.20	6.04	9.96	12.44	13.63	8.32	111.25

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	8.77	24.00	15.68	19.77	7.31	4.61	3.15	2.65	5.82	7.37	20.00	23.49	142.62
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.46	0.60	0.66	0.64	0.49	0.31	0.32	0.45	0.60	0.63	0.62	0.49	6.27
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	77.68	70.28	73.98	11.10	1.85	-	-	0.92	17.57	48.09	36.07	110.98	448.53
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	86.91	94.88	90.33	31.51	9.65	4.92	3.47	4.02	24.00	56.09	56.69	134.96	597.42

APPENDIX T. eQUEST MODEL WITH LOW INFILTRATION AND R-30 INSULATION FOR THE CERAMICS LAB

Project/Run: CeramicsLab_1_ACH5_R30_dpane - Baseline Design   Run Date/Time: 06/09/10 @ 13:16



Electric Consumption (kWh x000)

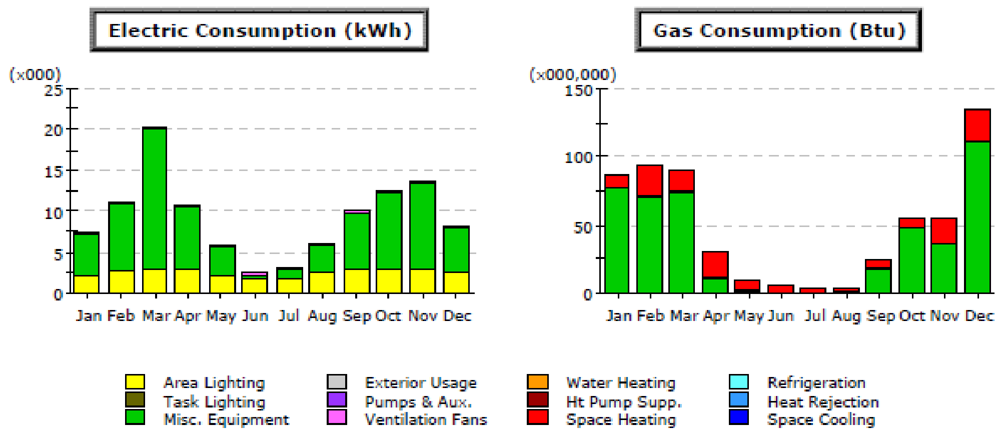
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.21	0.19	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	2.51
Pumps & Aux.	0.03	0.09	0.06	0.07	0.03	0.02	0.01	0.01	0.02	0.02	0.07	0.09	0.52
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	4.97	8.22	17.06	7.57	3.16	0.47	1.20	3.26	6.90	9.28	10.52	5.57	78.16
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	2.22	2.64	2.93	2.83	2.33	1.72	1.77	2.55	2.83	2.93	2.83	2.44	30.02
Total	7.43	11.14	20.26	10.68	5.73	2.41	3.20	6.04	9.96	12.44	13.63	8.31	111.21

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	8.40	22.99	14.99	19.29	7.07	4.66	3.17	2.62	5.36	6.73	19.05	22.48	136.80
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.46	0.60	0.66	0.64	0.49	0.31	0.32	0.45	0.60	0.63	0.62	0.49	6.27
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	77.68	70.28	73.98	11.10	1.85	-	-	0.92	17.57	48.09	36.07	110.98	448.53
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	86.55	93.87	89.64	31.03	9.41	4.97	3.49	3.99	23.53	55.45	55.73	133.95	591.60

APPENDIX U. eQUEST MODEL WITH LOW INFILTRATION, DOUBLE PANE WINDOW AND R-30 INSULATION FOR THE CERAMICS LAB

Project/Run: CeramicsLab_1_ACH5 - Baseline Design | Run Date/Time: 06/07/10 @ 21:11



Electric Consumption (kWh x000)

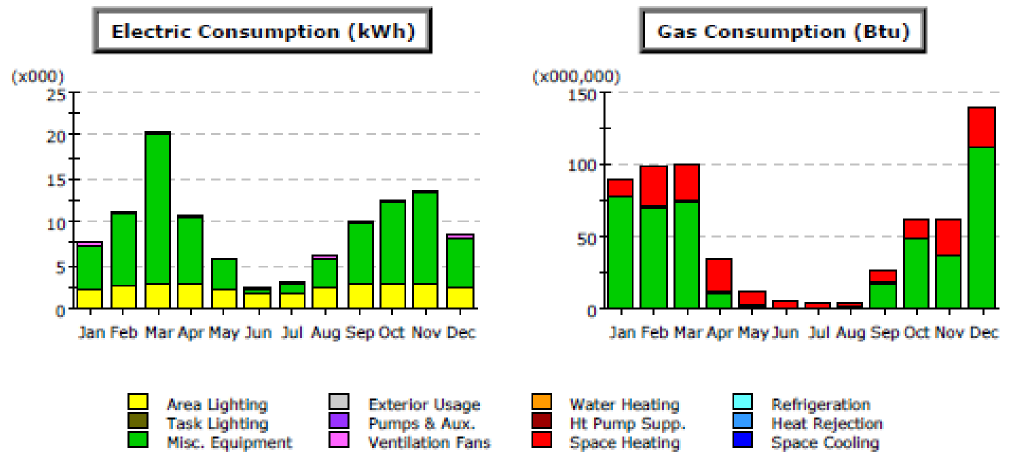
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.21	0.19	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	2.50
Pumps & Aux.	0.03	0.09	0.06	0.07	0.03	0.02	0.01	0.01	0.02	0.02	0.07	0.09	0.51
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	4.97	8.22	17.06	7.57	3.16	0.47	1.20	3.26	6.90	9.28	10.52	5.57	78.16
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	2.22	2.64	2.93	2.83	2.33	1.72	1.77	2.55	2.83	2.93	2.83	2.44	30.02
Total	7.43	11.14	20.25	10.68	5.73	2.40	3.20	6.04	9.96	12.44	13.63	8.31	111.20

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	8.31	22.75	14.79	19.19	7.04	4.67	3.18	2.61	5.30	6.58	18.82	22.25	135.49
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.46	0.60	0.66	0.64	0.49	0.31	0.32	0.45	0.60	0.63	0.62	0.49	6.27
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	77.68	70.28	73.98	11.10	1.85	-	-	0.92	17.57	48.09	36.07	110.98	448.53
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	86.45	93.63	89.43	30.93	9.38	4.99	3.50	3.98	23.48	55.30	55.51	133.72	590.29

APPENDIX V. eQUEST MODEL WITH NEW HEATERS FOR THE CERAMICS LAB

Project/Run: CL_Nheater2 - Baseline Design Run Date/Time: 10/14/10 @ 03:38



Electric Consumption (kWh x000)

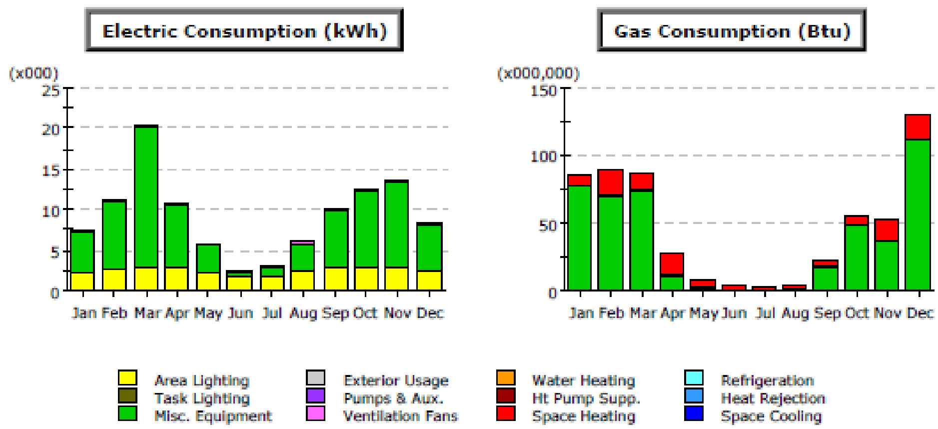
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.24	0.22	0.24	0.23	0.24	0.23	0.24	0.24	0.23	0.24	0.23	0.24	2.86
Pumps & Aux.	0.05	0.13	0.12	0.11	0.05	0.02	0.01	0.01	0.04	0.05	0.12	0.13	0.84
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	4.97	8.22	17.06	7.57	3.16	0.47	1.20	3.26	6.90	9.28	10.52	5.57	78.16
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	2.22	2.64	2.93	2.83	2.33	1.72	1.77	2.55	2.83	2.93	2.83	2.44	30.02
Total	7.49	11.21	20.34	10.74	5.78	2.44	3.23	6.07	10.01	12.50	13.70	8.39	111.88

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	11.76	28.53	25.17	22.73	10.08	4.66	3.09	3.27	8.69	12.29	25.22	28.37	183.86
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.46	0.60	0.67	0.64	0.49	0.31	0.32	0.45	0.61	0.63	0.62	0.50	6.29
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	77.68	70.28	73.98	11.10	1.85	-	-	0.92	17.57	48.09	36.07	110.98	448.53
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	89.90	99.42	99.81	34.47	12.42	4.98	3.41	4.65	26.87	61.01	61.90	139.84	638.68

APPENDIX W. eQUEST MODEL WITH LOW INFILTRATION, DOUBLE PANE WINDOW, R-30 INSULATION AND NEW HEATERS FOR THE CERAMICS LAB

Project/Run: CeramicsLab_1_ACH5_R30_dpane - Baseline Design Run Date/Time: 06/07/10 @ 21:44



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.21	0.19	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	2.50
Pumps & Aux.	0.03	0.09	0.06	0.07	0.03	0.02	0.01	0.01	0.02	0.02	0.07	0.09	0.51
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	4.97	8.22	17.06	7.57	3.16	0.47	1.20	3.26	6.90	9.28	10.52	5.57	78.16
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	2.22	2.64	2.93	2.83	2.33	1.72	1.77	2.55	2.83	2.93	2.83	2.44	30.02
Total	7.43	11.14	20.25	10.68	5.73	2.40	3.20	6.04	9.96	12.44	13.63	8.31	111.20

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	6.98	19.11	12.42	16.12	5.92	3.93	2.67	2.19	4.45	5.53	15.81	18.69	113.82
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.46	0.60	0.66	0.64	0.49	0.31	0.32	0.45	0.60	0.63	0.62	0.49	6.27
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	77.68	70.28	73.98	11.10	1.85	-	-	0.92	17.57	48.09	36.07	110.98	448.53
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	85.12	89.99	87.07	27.86	8.25	4.24	2.99	3.56	22.63	54.25	52.50	130.16	568.61

APPENDIX X. eQUEST SAVINGS CALCULATION FOR ALL ALTERNATIVES TOGETHER OF THE CERAMICS LAB

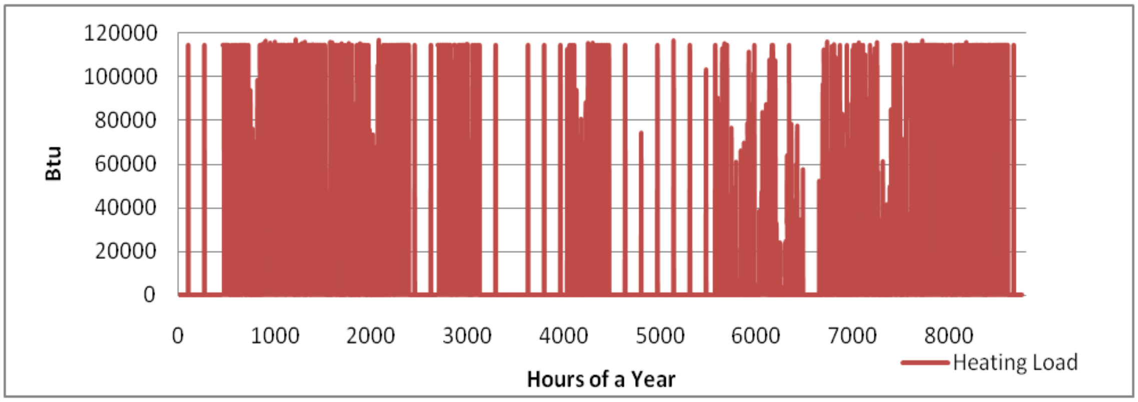
Project: CL_4runstogether   Run Date/Time: 06/09/10 @ 12:42

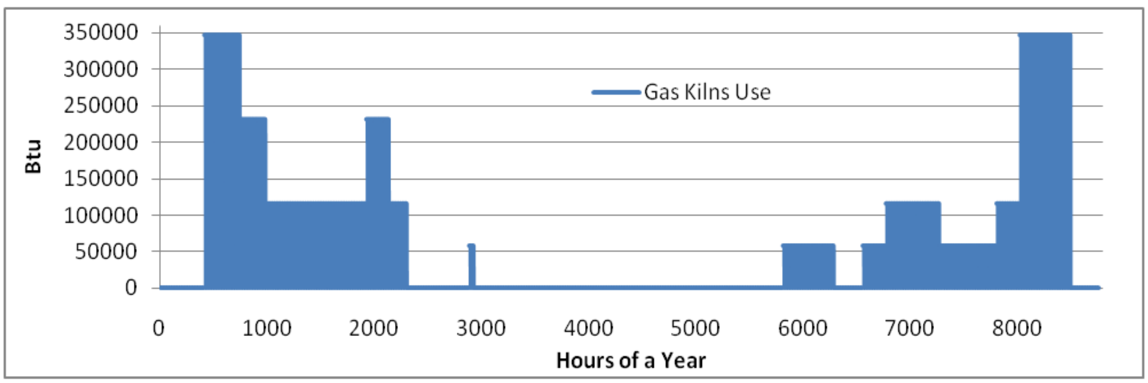
Annual Energy and Demand (pg 1 of 2)

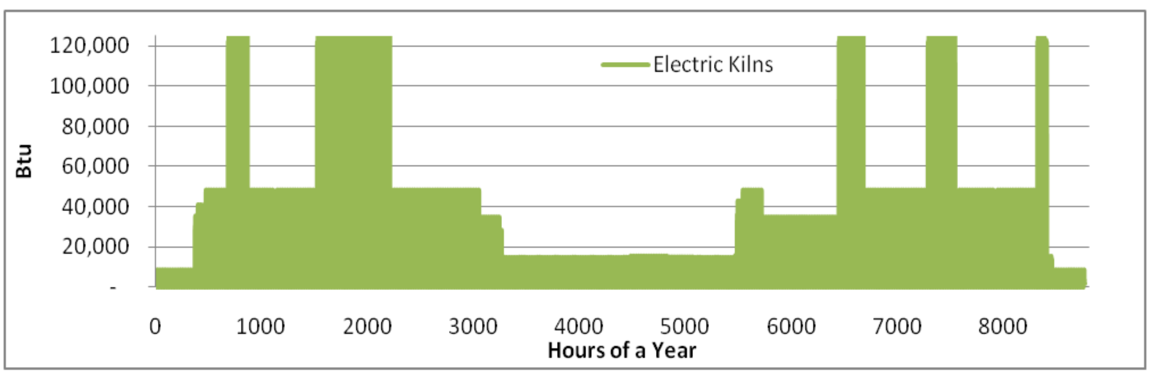
		Ann. Source Energy		Annual Site Energy		Lighting	HVAC Energy			Peak	
		Total Mbtu	EUI kBtu/sf/yr	Elect kWh	Nat Gas Therms	Electric kWh	Electric kWh	Nat Gas Therms	Total Mbtu	Elect kW	Cooling Tons
Annual Energy USE or DEMAND											
0	Base Design	1,819	276.80	111,884	6,737	30,024	3,702	2,189	232	44	--
2	0+ACH 5	1,736	264.20	111,245	5,974	30,024	3,063	1,426	153	44	--
3	0+ACH5_30__Dpane	1,729	263.05	111,198	5,903	30,024	3,016	1,355	146	44	--
4	0+NewHeater	1,784	271.48	111,884	6,387	30,024	3,702	1,839	196	44	--
5	0+ACH5_R30_DPane_NHeater	1,707	259.75	111,198	5,686	30,024	3,016	1,138	124	44	--
Incremental SAVINGS	**(values are relative to previous measure (% savings are relative to base case use), negative entries indicate increased use)**										
2	0+ACH 5	83	12.60 (5%)	639 (1%)	763 (11%)	0 (0%)	639 (17%)	763 (35%)	78 (34%)	0 (0%)	--
3	0+ACH5_30__Dpane	90	13.76 (5%)	686 (1%)	834 (12%)	0 (0%)	686 (19%)	834 (38%)	86 (37%)	0 (0%)	--
4	0+NewHeater	35	5.33 (2%)	0 (0%)	350 (5%)	0 (0%)	0 (0%)	350 (16%)	35 (15%)	0 (0%)	--
5	0+ACH5_R30_DPane_NHeater	112	17.06 (6%)	686 (1%)	1,051 (16%)	0 (0%)	686 (19%)	1,051 (48%)	107 (46%)	0 (0%)	--
Cumulative SAVINGS	**(values (and % savings) are relative to the Base Case, negative entries indicate increased use)**										
2	0+ACH 5	83	12.60 (5%)	639 (1%)	763 (11%)	0 (0%)	639 (17%)	763 (35%)	78 (34%)	0 (0%)	--
3	0+ACH5_30__Dpane	90	13.76 (5%)	686 (1%)	834 (12%)	0 (0%)	686 (19%)	834 (38%)	86 (37%)	0 (0%)	--
4	0+NewHeater	35	5.33 (2%)	0 (0%)	350 (5%)	0 (0%)	0 (0%)	350 (16%)	35 (15%)	0 (0%)	--
5	0+ACH5_R30_DPane_NHeater	112	17.06 (6%)	686 (1%)	1,051 (16%)	0 (0%)	686 (19%)	1,051 (48%)	107 (46%)	0 (0%)	--

APPENDIX Y. GRAPHS OF KILN USAGE AND HEATING LOAD TIME OF COINCIDENCE

The coincidence of heating demand of the building and scheduled use of kilns in the Ceramics Lab were tabulated from the eQUEST model. The hours over the years were then plotted on graphs to display the concurrence better in the following graphs.







APPENDIX Z. CASE STUDY OF AIR EXCHANGER WITH PEBBLE BED

Air exchangers which are fitted with pebble beds to absorb the heat generated from gas kilns in Ceramic industry have been researched at Bangladesh University of Engineering and Technology and proven viable both technically and financially (Hossain, 1997). The details of the design of an air exchanger with pebble bed are outside the scope of this work. However, some of the key research methods and findings from the research are as follow;

Background:

It was found that the sensible heat of the flue gas from kilns could be used to heat the casting shop. A pebble bed waste heat regenerator was chosen to collect the sensible heat of the flue gas. Experiments were performed on a pilot plant scale pebble bed to study its characteristics using a flue gas stream whose temperature and composition were similar to the factory conditions. The results of the heating cycle showed that 14 500 kcal h^{-1} *of heat can be collected from flue gas in a 0·126* m^3 *bed. This information was used to design a complete retrofit system. Financial analysis of the proposed project showed that it has a pay-back period of 15 months and IRR of 75%.*

Experiment

To establish the design and operational parameters of the pebble bed, a pilot plant study was conducted. The experimental set-up is shown in Figure Z.1 and consisted of a furnace, a double pipe heat exchanger, a pebble bed, two blowers and an Induction Draft (ID) fan. The pebbles used in the pebble bed were stones of ordinary construction having an average diameter of 2·54 cm(1inch). Temperature was measured through thermocouple ports located at various points in the bed with the help of chromel- alumel thermocouples connected to digital temperature indicators. The flow through the bed was measured with the help of a pitot tube inserted in the connecting pipe between the pebble bed and the ID fan.

To operate the pebble bed in the heating cycle, $132m^3\ h^{-1}$ *of natural gas was burned in the furnace. Since there was no lagging on the furnace, the flue gas temperature at the inlet of the double pipe heat exchanger was 600°C. The double pipe heat exchanger, which used tap water at ambient conditions in the annulus, was able to lower the gas temperature to approximately 300°C. The hot flue gas was allowed to mix with ambient air (supplied by the blower* B_1*) in the chamber below the distributor. It was found that the gas temperature at the inlet of the pebble bed was approximately 160°C.*

The mixing of ambient air with flue gas helped to produce a gas stream of approximately the same temperature and composition as that from the ceramic factory kilns.

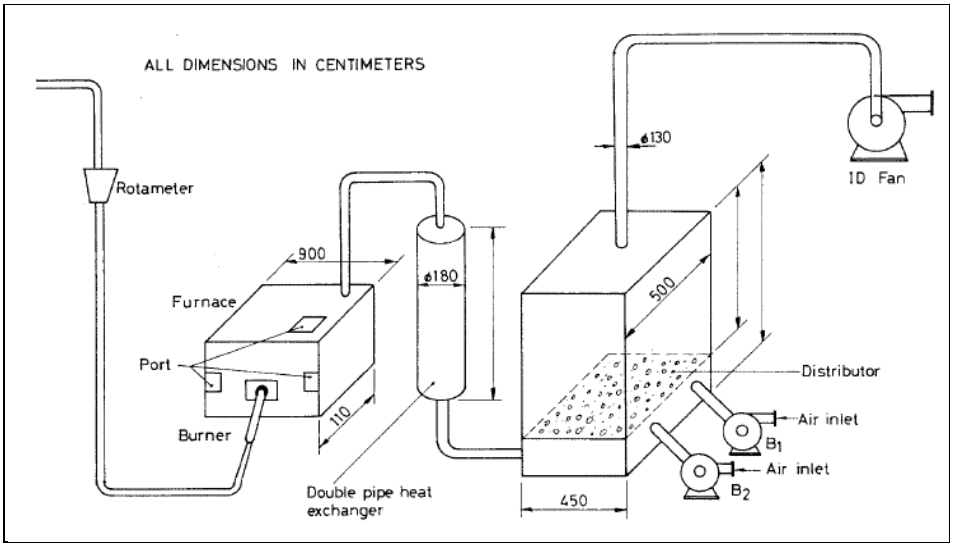


Figure Z.1 Set up for the heat exchanger with pebble bed.

<u>Design</u>

In the proposed design, the flue gas from the ceramic kilns were diverted from near the base through separate pairs of ducts to pairs of pebble beds at different locations inside the building. Pairs of pebble beds were required because when one is being heated, the other is being cooled. Heat blowers will be required to draw the flue gas through pebble beds during heating cycle.

The efficiency of the pebble bed design after accounting for losses is about 80%.

APPENDIX AA. ANNUAL ENERGY USE AND SAVINGS CALCULATION BASED ON ESTIMATED CONCURRENCE

Table AA.1 Savings from capturing exhausted heat from kilns

Item and Scenario	Energy (MMBtu)	Item and Scenario	Energy (MMBtu)
Gas Kilns use	448.53	Electric Kilns use	263.78
Half concurrence	224.26	Half concurrence	197.84
20% loss	44.85	50% loss	98.92
Heat recovered	179.41	Heat recovered	98.92
Energy saved from heating	**179.41**	**Energy saved from heating**	**98.92**
	1,794.11 Therms		**989.18 Therms**

APPENDIX BB. MARINE LAB PUMP DETAILS AND CALCULATIONS

Table BB.1 Savings from pump and its details

Item/Part	Old Conditions	New Conditions
Pump		
PUMP Manufacturer	Ingersoll Dresser Pumps	Money Saver
GPM (Gal Per Min)	150	150
TDH (Total Dy. Head)	98	98
Size	3*1.5*13	
SG(Specific Gravity)	1.03	1.03
RPM	1800	1800
Max Design temp(PSIG)	125	
Imp. Dia	10"	
Main Imp Dia	13.2"	
Efficiency	60	70
Reduced Power Requirements(bhp)	(f*Q*SG/3960)* (100/n1-100/n2)	
Shaft Power requirement (bhp)	6.37	5.46

Item/Part	Old Conditions	New Conditions
Motor		
Make	US Electrical Motors	State Electric
Model	T779A	AS70
HP	10	10
NOM efficiency	89.5	93.0%
Guaranteed Efficiency (%)	0.875	0.917
MAX KVAR	2.9	2.6
RPM	1755	1800
SF	1.25	
Code	H	
Time of use	8760	8760
Energy use (kWh/yr)	47,573.85	38,909.91
Energy saving (kWh/yr)	8,663.94	
Savings value($/yr)	1,212.95	
Material cost	$5,288.90[31]	
Installation	$793.34	
Total cost	$6,082.24	
Salvage Value	$100.00	$1,057.78
Life (yrs)	20	

[31] http://www.moneysaverpumps.com/pricing.htm

APPENDIX CC. MARINE LAB BOILER DETAILS

Table CC.1 Marine Lab boiler details

Item/Part	Old Conditions		New Conditions
Manufacturer	NP Thermific		Triangle Tube Prestige Gas Boilers
Model	N 700		PS60
Fuel	LPG		LPG
Efficiency (%)	85		95
Input (kBtuh)	595		565.25
Output (kBtuh)	700		700
Ratio	0.85		0.81
Material	Cast Iron		Stainless Steel
Time of use	As per demand		As per demand
Material cost			\$3,997.27[32]
Installation			\$399.73
Total cost			\$4,397.00
Salvage Value		200	\$799.45
Life (yrs)			10
Energy Saved (MMBtu/yr) from eQUEST			26.57
Energy Saved (gal/yr)			290.38
Savings value(\$/yr)			513.98

[32] http://www.houseneeds.com/shop/triangletube/triangletubeboileps60lpbuy.asp

APPENDIX DD. COST ESTIMATES FOR MATERIALS IN THE MARINE LAB

The unit cost of providing and installing each of component of the alternatives were provided from Plant Operations based on the JOC document. This was used in conjunction with some websites to determine total cost of each option. The details of the cost estimation are in Table DD.1 below.

Table DD.1 Materials costs for the Marine Lab

Marine Lab							
Sl. No	**Estimated cost of providing and installation**						
	Particulars	**No.**	**Size**	**Unit**	**Rate**	**Contingency (15%)**	**Amount**
1	Installing a revolving glass door in the front. (6-6" diameter by 7’-0" height, 4" wings) [33]	1	6'6"X7'0"		15000	2250	17250
2	Double Pane Windows with low-e glass		1165	ft^2	25	4369	29125
3	R30 insulation with fiberglass						
a	Roof		9350	ft^2	1.6	2244	14960
b	Walls short		1100	ft^2	1.6	264	1760
c	Walls long		1020	ft^2	1.6	245	1632
4	Finishing on Ceiling to support fiberglass insulation		9350	ft^2	1.21	1697	11314
5	Finishing on Walls from Inside		2120	ft^2	0.97	308	2056

[33] http://www.internationalrevolvingdoors.com/Ird_BuyMe.htm and http://web.mit.edu/mitei/campus/wtt-annual-2007-2008-final.pdf

APPENDIX EE. CASH-FLOW FOR THE MARINE LAB ALTERNATIVES

Considering a lifetime of 20 years for all the alternatives, cash-flow analysis was done for different parameters which are possible to be altered. Table EE.1 shows the cash-flow analysis for the Marine Lab.

Table EE.1 Cash-flow analysis for the Marine Lab

Reduce Air infiltration						
Year	Cost	Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
0	20,700.00	176.90	-20,523.10	-20,523.10	-20,523.10	
1	0.00	342.20	342.20	-20,180.90	332.23	-20,190.87
2	0.00	349.04	349.04	-19,831.86	329.01	-19,861.86
3	0.00	356.02	356.02	-19,475.83	325.81	-19,536.05
4	0.00	363.15	363.15	-19,112.69	322.65	-19,213.40
5	0.00	370.41	370.41	-18,742.28	319.52	-18,893.88
6	0.00	377.82	377.82	-18,364.46	316.42	-18,577.46
7	0.00	385.37	385.37	-17,979.09	313.34	-18,264.12
8	0.00	393.08	393.08	-17,586.01	310.30	-17,953.82
9	0.00	400.94	400.94	-17,185.07	307.29	-17,646.53
10	0.00	408.96	408.96	-16,776.11	304.31	-17,342.23
11	0.00	417.14	417.14	-16,358.97	301.35	-17,040.87
12	0.00	425.48	425.48	-15,933.48	298.42	-16,742.45
13	0.00	433.99	433.99	-15,499.49	295.53	-16,446.92
14	0.00	442.67	442.67	-15,056.82	292.66	-16,154.26
15	0.00	451.53	451.53	-14,605.29	289.82	-15,864.45
16	0.00	460.56	460.56	-14,144.74	287.00	-15,577.44
17	0.00	469.77	469.77	-13,674.97	284.22	-15,293.23
18	0.00	479.16	479.16	-13,195.81	281.46	-15,011.77
19	0.00	488.75	488.75	-12,707.06	278.72	-14,733.04

Reduce Air infiltration						
Year	Cost	Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
20	0.00	2,223.52	2,223.52	-10,483.54	1,231.11	-13,501.93
		MIRR=	**-0.03**			
	NPV of Benefits w/SV =		7,021.17			
	Total NPV w/SV =		-13,678.83			
	Simple Payback =		>20	years		
	Discounted Payback=		>20	years		

Double Pane Windows						
Year	**Cost**	**Benefits**	**Net Cash Flow**	**Accumulated Cash Flow**	**Discounted Net Cash Flow @3%**	**Discounted Accumulated Net Cash Flow @3%**
0	34,950.00	60.50	-34,889.50	-34,889.50	-34,832.97	
1	0.00	117.03	117.03	-34,772.47	113.62	-34,719.34
2	0.00	119.37	119.37	-34,653.09	112.52	-34,606.82
3	0.00	121.76	121.76	-34,531.33	111.43	-34,495.39
4	0.00	124.20	124.20	-34,407.14	110.35	-34,385.05
5	0.00	126.68	126.68	-34,280.46	109.28	-34,275.77
6	0.00	129.21	129.21	-34,151.24	108.21	-34,167.56
7	0.00	131.80	131.80	-34,019.45	107.16	-34,060.39
8	0.00	134.43	134.43	-33,885.01	106.12	-33,954.27
9	0.00	137.12	137.12	-33,747.89	105.09	-33,849.18
10	0.00	139.87	139.87	-33,608.02	104.07	-33,745.10
11	0.00	142.66	142.66	-33,465.36	103.06	-33,642.04
12	0.00	145.52	145.52	-33,319.85	102.06	-33,539.98
13	0.00	148.43	148.43	-33,171.42	101.07	-33,438.91
14	0.00	151.39	151.39	-33,020.03	100.09	-33,338.82
15	0.00	154.42	154.42	-32,865.60	99.12	-33,239.70
16	0.00	157.51	157.51	-32,708.09	98.16	-33,141.55
17	0.00	160.66	160.66	-32,547.43	97.20	-33,044.34
18	0.00	163.87	163.87	-32,383.56	96.26	-32,948.09
19	0.00	167.15	167.15	-32,216.41	95.32	-32,852.76

Reduce Air infiltration						
Year	Cost	Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
20	0.00	3,082.99	3,082.99	-29,133.41	1,706.98	-31,145.78
		MIRR=	**-0.08**			
	NPV of Benefits w/SV =		3,687.19			
	Total NPV w/SV =		-31,262.81			
	Simple Payback =		>20	years		
	Discounted Payback=		>20	years		

New Boiler						
Year	**Cost**	**Benefits**	**Net Cash Flow**	**Accumulated Cash Flow**	**Discounted Net Cash Flow @3%**	**Discounted Accumulated Net Cash Flow @3%**
0	4,796.72	265.70	-4,531.02	-4,531.02	-4,531.02	
1	0.00	513.98	513.98	-4,017.05	499.01	-4,032.02
2	0.00	524.26	524.26	-3,492.79	494.16	-3,537.86
3	0.00	534.74	534.74	-2,958.05	489.36	-3,048.49
4	0.00	545.44	545.44	-2,412.61	484.61	-2,563.88
5	0.00	556.35	556.35	-1,856.27	479.91	-2,083.97
6	0.00	567.47	567.47	-1,288.79	475.25	-1,608.72
7	0.00	578.82	578.82	-709.97	470.63	-1,138.08
8	0.00	590.40	590.40	-119.57	466.07	-672.02
9	0.00	602.21	602.21	482.63	461.54	-210.48
10	0.00	614.25	614.25	1,096.88	457.06	246.58
11	0.00	626.54	626.54	1,723.42	452.62	699.20
12	0.00	639.07	639.07	2,362.48	448.23	1,147.43
13	0.00	651.85	651.85	3,014.33	443.88	1,591.31
14	0.00	664.88	664.88	3,679.21	439.57	2,030.87
15	0.00	678.18	678.18	4,357.40	435.30	2,466.17
16	0.00	691.75	691.75	5,049.14	431.07	2,897.25
17	0.00	705.58	705.58	5,754.72	426.89	3,324.13

Reduce Air infiltration						
Year	Cost	Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
18	0.00	719.69	719.69	6,474.41	422.74	3,746.88
19	0.00	734.09	734.09	7,208.50	418.64	4,165.52
20	0.00	1,348.36	1,348.36	8,556.86	746.55	4,912.07
		MIRR=	**0.06**			
	NPV of Benefits w/SV =		**9,443.09**			
	Total NPV w/SV =		**4,646.37**			
	Simple Payback =		**9.18**	**years**		
	Discounted Payback=		**10.46**	**years**		

Ceiling insulation						
Year	**Cost**	**Benefits**	**Net Cash Flow**	**Accumulated Cash Flow**	**Discounted Net Cash Flow @3%**	**Discounted Accumulated Net Cash Flow @3%**
0	17,952.00	251.20	-17,700.80	-17,700.80	-17,700.80	
1	0.00	485.93	485.93	-17,214.87	471.77	-17,229.03
2	0.00	495.65	495.65	-16,719.23	467.19	-16,761.83
3	0.00	505.56	505.56	-16,213.67	462.66	-16,299.17
4	0.00	515.67	515.67	-15,698.00	458.17	-15,841.01
5	0.00	525.98	525.98	-15,172.01	453.72	-15,387.29
6	0.00	536.50	536.50	-14,635.51	449.31	-14,937.97
7	0.00	547.23	547.23	-14,088.27	444.95	-14,493.02
8	0.00	558.18	558.18	-13,530.10	440.63	-14,052.39
9	0.00	569.34	569.34	-12,960.75	436.35	-13,616.04
10	0.00	580.73	580.73	-12,380.03	432.12	-13,183.92
11	0.00	592.34	592.34	-11,787.68	427.92	-12,756.00
12	0.00	604.19	604.19	-11,183.49	423.77	-12,332.23
13	0.00	616.27	616.27	-10,567.22	419.65	-11,912.58
14	0.00	628.60	628.60	-9,938.62	415.58	-11,497.00
15	0.00	641.17	641.17	-9,297.45	411.54	-11,085.46

Reduce Air infiltration						
Year	Cost	Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
16	0.00	653.99	653.99	-8,643.45	407.55	-10,677.91
17	0.00	667.07	667.07	-7,976.38	403.59	-10,274.32
18	0.00	680.42	680.42	-7,295.96	399.67	-9,874.65
19	0.00	694.02	694.02	-6,601.94	395.79	-9,478.85
20	0.00	2,203.91	2,203.91	-4,398.03	1,220.25	-8,258.61
		MIRR=	**-0.01**			
	NPV of Benefits w/SV =		9,442.19			
	Total NPV w/SV =		-8,509.81			
	Simple Payback =		>20	years		
	Discounted Payback=		>20	years		

Ceiling insulation with double pane windows						
Year	**Cost**	**Benefits**	**Net Cash Flow**	**Accumulated Cash Flow**	**Discounted Net Cash Flow @3%**	**Discounted Accumulated Net Cash Flow @3%**
0	35,598.60	326.00	-35,272.60	-35,272.60	-35,272.60	
1	0.00	630.62	630.62	-34,641.98	612.26	-34,660.34
2	0.00	643.24	643.24	-33,998.74	606.31	-34,054.03
3	0.00	656.10	656.10	-33,342.64	600.42	-33,453.61
4	0.00	669.22	669.22	-32,673.42	594.60	-32,859.01
5	0.00	682.61	682.61	-31,990.81	588.82	-32,270.19
6	0.00	696.26	696.26	-31,294.55	583.11	-31,687.09
7	0.00	710.18	710.18	-30,584.37	577.44	-31,109.64
8	0.00	724.39	724.39	-29,859.98	571.84	-30,537.80
9	0.00	738.88	738.88	-29,121.11	566.29	-29,971.52
10	0.00	753.65	753.65	-28,367.45	560.79	-29,410.73
11	0.00	768.73	768.73	-27,598.73	555.34	-28,855.38
12	0.00	784.10	784.10	-26,814.63	549.95	-28,305.43
13	0.00	799.78	799.78	-26,014.85	544.61	-27,760.82

Reduce Air infiltration						
Year	Cost	Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
14	0.00	815.78	815.78	-25,199.07	539.33	-27,221.49
15	0.00	832.09	832.09	-24,366.97	534.09	-26,687.40
16	0.00	848.74	848.74	-23,518.24	528.90	-26,158.50
17	0.00	865.71	865.71	-22,652.53	523.77	-25,634.73
18	0.00	883.02	883.02	-21,769.50	518.68	-25,116.05
19	0.00	900.68	900.68	-20,868.82	513.65	-24,602.40
20	0.00	3,885.25	3,885.25	-16,983.57	2,151.17	-22,451.23
		MIRR=	**-0.02**			
	NPV of Benefits w/SV =		12,821.37			
	Total NPV w/SV =		-22,777.23			
	Simple Payback =		>20	years		
	Discounted Payback=		>20	years		

New Pumps						
Year	**Cost**	**Benefits**	**Net Cash Flow**	**Accumulated Cash Flow**	**Discounted Net Cash Flow @3%**	**Discounted Accumulated Net Cash Flow @3%**
0	6,346.68	2,079.35	-4,267.33	-4,267.33	-4,267.33	
1	0.00	1,212.95	1,212.95	-3,054.38	1,177.62	-3,089.71
2	0.00	1,237.21	1,237.21	-1,817.17	1,166.19	-1,923.52
3	0.00	1,261.95	1,261.95	-555.22	1,154.87	-768.65
4	0.00	1,287.19	1,287.19	731.98	1,143.66	375.00
5	0.00	1,312.94	1,312.94	2,044.91	1,132.55	1,507.55
6	0.00	1,339.20	1,339.20	3,384.11	1,121.56	2,629.11
7	0.00	1,365.98	1,365.98	4,750.09	1,110.67	3,739.78
8	0.00	1,393.30	1,393.30	6,143.39	1,099.88	4,839.66
9	0.00	1,421.17	1,421.17	7,564.56	1,089.21	5,928.87
10	0.00	1,449.59	1,449.59	9,014.15	1,078.63	7,007.50
11	0.00	1,478.58	1,478.58	10,492.73	1,068.16	8,075.66
12	0.00	1,508.15	1,508.15	12,000.88	1,057.79	9,133.44

Reduce Air infiltration						
Year	Cost	Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
13	0.00	1,538.32	1,538.32	13,539.20	1,047.52	10,180.96
14	0.00	1,569.08	1,569.08	15,108.28	1,037.35	11,218.31
15	0.00	1,600.46	1,600.46	16,708.74	1,027.28	12,245.59
16	0.00	1,632.47	1,632.47	18,341.22	1,017.30	13,262.89
17	0.00	1,665.12	1,665.12	20,006.34	1,007.43	14,270.32
18	0.00	1,698.43	1,698.43	21,704.77	997.65	15,267.96
19	0.00	1,732.39	1,732.39	23,437.16	987.96	16,255.92
20	0.00	2,560.38	2,560.38	25,997.54	1,417.62	17,673.54
		MIRR=	**0.11**			
	NPV of Benefits w/SV =		21,940.87			
	Total NPV w/SV =		15,594.19			
	Simple Payback =		3.43	years		
	Discounted Payback=		3.67	years		

APPENDIX FF. ECONOMIC ANALYSIS FOR CAPSTONE MICROTURBINES

Assisted by the Technical Adviser from ICF (Hedman, 2010), analysis of the Capstone Microturbine were carried out to determine their corresponding energy generation, cost of generation and potential savings by the alternatives. Two conditions were considered for the analysis. Table FF.1 shows the details of the Capstone Microturbine in the Marine Lab, whereas Table FF.2 shows the details if the Microturbine is installed in main HSU campus.

Table FF.1 Calculations for C30 kW Microturbine in the Marine Lab

CHP Screening - Humboldt 30 kW Microturbine				
Net CHP Power, kW	30	Total Electric Use	200,000	kWh
Net Thermal Output, Btu/kWh	5,800	Average Electric Use	22.8	kW
Annual Operating Hours	3,640	Total Propane Use	603.3	MMBtu
		Annual Heating Hours	3,640	
CHP Cost to Generate Power Estimator		Average Thermal Den	132,593	Btu/hr
Operating Assumptions				
CHP Electric Efficiency, %	23.0%	Typically 26 to 32% for engines, 36 to 40% for fuel cells		
CHP Fuel, Btu/kWh	14,835	Heat Rate - Calculated based on efficiency		
Thermal Output, Btu/hr	174,000			
Thermal Output, MMBtu/Year	633	User Inputs		
CHP Power to Heat Ratio	0.59			
CHP Efficiency	62.1%			
Displaced Thermal Efficiency	80.0%	Displaced heater efficiency		
Thermal Utilization, %	100.0%	Typically 80 to 100%		
Incremental CHP O&M Costs, $/kWh	$0.0200			
CHP Fuel Cost, $/MMBtu	$19.00			
Displaced Thermal Fuel Cost, $/MMBtu	$19.00			
		Annualized Performance		
Operating Cost to Generate		Annual CHP Power Generation, kWh	109,200	
CHP Fuel Costs, $/kWh	$0.2819	Annual Purchased Power Savings	($15,288)	
Thermal Credit, $/kWh	($0.1378)	Annual CHP Fuel Costs	$30,779	
Incremental O&M, $/kWh	$0.0200	Annual Thermal Fuel Credit	($15,042)	
		Annual CHP O&M Costs	$2,184	
Operating Costs to Generate Power, $/kWh	***$0.1641***	Annual Operating Savings	-$2,633	
Capital Cost				
Installed CHP System Cost, $/kW	$3,000	Total Capital Costs to User	$57,000	
Investment Tax Credit (10%)	($300)			
Other Incentives, $/kW	$800			
Installed cost to User, $/kW	$1,900			
Operating Hours	3,640			
Equipment Life, Yrs	10	**Simple Payback, Years**	**-21.6**	
Cost of Capital, %	8.0%			
Capital Charge, $/kWh	$0.1228			
Total Costs to Generate Power, $/kWh	***$0.2869***	***Average Power costs, $/kWh***	***$0.1400***	

Table FF.2 Calculations for C30 kW Microturbine for main campus

CHP Screening - Humboldt 30 kW Microturbine - on Campus

Net CHP Power, kW	30
Net Thermal Output, Btu/kWh	5,800
Annual Operating Hours	7,271

Total Electric Use	200,000	kWh
Average Electric Use	22.8	kW
Total Propane Use	603.3	MMBtu
Annual Heating Hours	7,271	
Average Thermal Dem	66,381	Btu/hr

CHP Cost to Generate Power Estimator

Operating Assumptions		
CHP Electric Efficiency, %	23.0%	Typically 26 to 32% for engines, 36 to 40% for fuel cells
CHP Fuel, Btu/kWh	14,835	Heat Rate - Calculated based on efficiency
Thermal Output, Btu/hr	174,000	
Thermal Output, MMBtu/Year	1,265	User Inputs
CHP Power to Heat Ratio	0.59	
CHP Efficiency	62.1%	
Displaced Thermal Efficiency	80.0%	Displaced heater efficiency
Thermal Utilization, %	100.0%	Typically 80 to 100%
Incremental CHP O&M Costs, $/kWh	$0.0200	
CHP Fuel Cost, $/MMBtu	$11.32	
Displaced Thermal Fuel Cost, $/MMBtu	$11.32	

Operating Cost to Generate	
CHP Fuel Costs, $/kWh	$0.1679
Thermal Credit, $/kWh	($0.0821)
Incremental O&M, $/kWh	$0.0200
Operating Costs to Generate Power, $/kWh	***$0.1059***

Annualized Performance	
Annual CHP Power Generation, kWh	218,124
Annual Purchased Power Savings	($30,537)
Annual CHP Fuel Costs	$36,630
Annual Thermal Fuel Credit	($17,901)
Annual CHP O&M Costs	$4,362
Annual Operating Savings	$7,447

Capital Cost	
Installed CHP System Cost, $/kW	$3,000
Investment Tax Credit (10%)	($300)
Other Incentives, $/kW	$800
Installed cost to User, $/kW	$1,900
Operating Hours	7,271
Equipment Life, Yrs	20
Cost of Capital, %	8.0%
Capital Charge, $/kWh	$0.0420
Total Costs to Generate Power, $/kWh	***$0.1479***

Total Capital Costs to User	$57,000
Simple Payback, Years	**7.7**
Average Power costs, $/kWh	***$0.1400***

Table FF.3 Cash-flow analysis of C30 kW Microturbine for main campus

Microturbine for Main Campus						
Year	**Cost**	**Benefits**	**Net Cash Flow**	**Accumulated Cash Flow**	**Discounted Net Cash Flow @3%**	**Discounted Accumulated Net Cash Flow @3%**
0	57,000.00	5,700.00	-51,300.00	-51,300.00	-51,300.00	
1	40,992.00	48,438.00	7,446.00	-43,854.00	7,229.13	-83,806.62
2	41,811.84	49,406.76	7,594.92	-36,259.08	7,158.94	-76,647.68
3	42,648.08	50,394.90	7,746.82	-28,512.26	7,089.44	-69,558.24
4	43,501.04	51,402.79	7,901.75	-20,610.51	7,020.61	-62,537.63
5	44,371.06	52,430.85	8,059.79	-12,550.72	6,952.45	-55,585.19
6	45,258.48	53,479.47	8,220.99	-4,329.73	6,884.95	-48,700.24
7	46,163.65	54,549.06	8,385.41	4,055.67	6,818.10	-41,882.14
8	47,086.92	55,640.04	8,553.11	12,608.79	6,751.91	-35,130.23
9	48,028.66	56,752.84	8,724.18	21,332.96	6,686.35	-28,443.88
10	48,989.23	57,887.89	8,898.66	30,231.62	6,621.44	-21,822.44
11	49,969.02	59,045.65	9,076.63	39,308.26	6,557.15	-15,265.29
12	50,968.40	60,226.56	9,258.17	48,566.42	6,493.49	-8,771.80
13	51,987.77	61,431.10	9,443.33	58,009.75	6,430.45	-2,341.35
14	53,027.52	62,659.72	9,632.19	67,641.94	6,368.02	4,026.66
15	54,088.07	63,912.91	9,824.84	77,466.78	6,306.19	10,332.85
16	55,169.83	65,191.17	10,021.34	87,488.12	6,244.97	16,577.82
17	56,273.23	66,494.99	10,221.76	97,709.88	6,184.33	22,762.15
18	57,398.70	67,824.89	10,426.20	108,136.08	6,124.29	28,886.45
19	58,546.67	69,181.39	10,634.72	118,770.80	6,064.83	34,951.28
20	59,717.60	70,565.02	10,847.42	129,618.22	6,005.95	40,957.23

Microturbine for Main Campus						
Year	**Cost**	**Benefits**	**Net Cash Flow**	**Accumulated Cash Flow**	**Discounted Net Cash Flow @3%**	**Discounted Accumulated Net Cash Flow @3%**
		MIRR=	**0.07**			
	NPV of Benefits w/SV =		858,645.68			
	Total NPV w/SV =		801,645.68			
	Simple Payback =		**6.52**	**years**		
	Discounted Payback=		13.37	years		

APPENDIX GG. COST ESTIMATES FOR MATERIALS IN THE CERAMICS LAB

The unit cost of providing and installing each of component of the alternatives were provided from Plant Operations based on the JOC document. This was used in conjunction with some websites to determine total cost of each option. The details of the cost estimation are below in Table GG.1.

Table GG.1 Cost of materials for the Ceramics Lab

Sl. No	**Ceramics Lab** Estimated cost of providing and installation						
	Particulars	No.	Size	Unit	Rate	Contingency (15%)	Amount
1	New 1-3/4" wooden door with sealing of cracks	4	7*6	ft^2	500	300	2300
2	Controlled roof ventilation System- Exhaust fan with automatic controls	2	200	W	1500	450	3450
3	R30 insulation with fiberglass						
a	Roof		2400	ft^2	1.6	576	4416
b	Walls short		600	ft^2	1.6	144	1104
c	Walls long		800	ft^2	1.6	192	1472

Sl. No	Ceramics Lab Estimated cost of providing and installation Particulars	No.	Size	Unit	Rate	Contingency (15%)	Amount
4	Finishing on Ceiling to support fiberglass insulation		2400	ft^2	1.21	436	3340
5	Finishing on Walls from Inside		1400	ft^2	0.97	204	1562
6	Double Pane Windows with low-e glass		315	ft^2	25	1181	9056
7	Energy efficient unit heaters(95% efficient)	3	115 kBtu/hr		1540[34]	693	5313
8	Blowers	2	1/12 hp		103.2[35]	31	237
9	cables, fittings, sensors	1	115V, 2.9 A		500	75	575

APPENDIX HH. CASH-FLOW STATEMENT FOR ALTERNATIVES IN THE CERAMICS LAB

The incentives from rebate programs have been considered as benefit for first year, while salvage value was used as benefit after the 10th year for all the alternatives. The following tables show the cash-flow for different alternatives corresponding to the different parameters considered.

Table HH.1 Cash-flow without CO_2 benefit for the Ceramics Lab

Year	Cost	Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
ACH5						
0	6,900.00	916.36	-5,983.64	-5,983.64	-5,983.64	

[34] HVAC direct gas furnaces 115K BTU variable speed upflow. http://ingramswaterandair.com/hvac-direct-furnaces-115k-variable-speed-upflow-p-93.html?cvsfa=1207&cvsfe=2&cvsfhu=3933

[35] 5" Diameter Single Shaft Open Fan/Blower Motor 1/12 HP http://www.cshincorporated.com/product_info.php?products_id=3770

Year	Cost	Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
1	0.00	953.18	953.18	-5,030.46	925.41	-5,058.23
2	0.00	972.24	972.24	-4,058.22	916.43	-4,141.80
3	0.00	991.68	991.68	-3,066.54	907.53	-3,234.27
4	0.00	1,011.52	1,011.52	-2,055.02	898.72	-2,335.55
5	0.00	1,031.75	1,031.75	-1,023.27	890.00	-1,445.55
6	0.00	1,052.38	1,052.38	29.11	881.35	-564.20
7	0.00	1,073.43	1,073.43	1,102.54	872.80	308.60
8	0.00	1,094.90	1,094.90	2,197.44	864.32	1,172.93
9	0.00	1,116.80	1,116.80	3,314.24	855.93	2,028.86
10	0.00	1,714.13	1,714.13	5,028.37	1,275.48	3,304.33
		MIRR=	**0.07**			
	NPV of Benefits w/SV =		10,204.33			
	Total NPV w/SV =		3,304.33			
	Simple Payback =		5.97	years		
	Discounted Payback=		6.65	years		

ACH5_R30

Year	Cost	Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
0	21,171.96	982.76	-20,189.20	-20,189.20	-20,189.20	
1	0.00	1,023.73	1,023.73	-19,165.47	993.91	-19,195.29
2	0.00	1,044.21	1,044.21	-18,121.26	984.26	-18,211.02
3	0.00	1,065.09	1,065.09	-17,056.17	974.71	-17,236.31
4	0.00	1,086.39	1,086.39	-15,969.78	965.25	-16,271.07
5	0.00	1,108.12	1,108.12	-14,861.66	955.87	-15,315.19
6	0.00	1,130.28	1,130.28	-13,731.37	946.59	-14,368.60
7	0.00	1,152.89	1,152.89	-12,578.49	937.40	-13,431.19
8	0.00	1,175.95	1,175.95	-11,402.54	928.30	-12,502.89
9	0.00	1,199.47	1,199.47	-10,203.07	919.29	-11,583.60
10	0.00	2,987.78	2,987.78	-7,215.29	2,223.19	-9,360.41
		MIRR=	**-0.04**			
	NPV of Benefits w/SV =		11,811.55			
	Total NPV w/SV =		-9,360.41			
	Simple Payback =		>10	years		
	Discounted Payback=		>10	years		

Year	Cost	Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
ACH5_R30_Dpane						
0	32,039.46	998.64	-31,040.82	-31,040.82	-31,040.82	
1	0.00	1,040.13	1,040.13	-30,000.69	1,009.83	-30,030.99
2	0.00	1,060.93	1,060.93	-28,939.76	1,000.03	-29,030.96
3	0.00	1,082.15	1,082.15	-27,857.61	990.32	-28,040.64
4	0.00	1,103.79	1,103.79	-26,753.82	980.71	-27,059.93
5	0.00	1,125.87	1,125.87	-25,627.95	971.18	-26,088.75
6	0.00	1,148.39	1,148.39	-24,479.57	961.75	-25,127.00
7	0.00	1,171.35	1,171.35	-23,308.21	952.42	-24,174.58
8	0.00	1,194.78	1,194.78	-22,113.43	943.17	-23,231.41
9	0.00	1,218.68	1,218.68	-20,894.76	934.01	-22,297.39
10	0.00	3,913.00	3,913.00	-16,981.75	2,911.64	-19,385.75
		MIRR=	**-0.07**			
	NPV of Benefits w/SV =		12,653.71			
	Total NPV w/SV =		-19,385.75			
	Simple Payback =		>10	years		
	Discounted Payback=		>10	years		
ACH5_R30_Dpane_NewHeater						
Year	**Cost**	**Benefits**	**Net Cash Flow**	**Accumulated Cash Flow**	**Discounted Net Cash Flow @3%**	**Discounted Accumulated Net Cash Flow @3%**
0	38,415.06	1,215.64	-37,199.42	-37,199.42	-37,199.42	
1	0.00	1,285.77	1,285.77	-35,913.65	1,248.32	-35,951.10
2	0.00	1,311.49	1,311.49	-34,602.16	1,236.20	-34,714.89
3	0.00	1,337.72	1,337.72	-33,264.44	1,224.20	-33,490.69
4	0.00	1,364.47	1,364.47	-31,899.97	1,212.32	-32,278.38
5	0.00	1,391.76	1,391.76	-30,508.21	1,200.55	-31,077.83
6	0.00	1,419.60	1,419.60	-29,088.61	1,188.89	-29,888.94
7	0.00	1,447.99	1,447.99	-27,640.63	1,177.35	-28,711.60
8	0.00	1,476.95	1,476.95	-26,163.68	1,165.92	-27,545.68
9	0.00	1,506.49	1,506.49	-24,657.19	1,154.60	-26,391.08
10	0.00	6,338.50	6,338.50	-18,318.69	4,716.44	-21,674.65
		MIRR=	**-0.06**			
	NPV of Benefits w/SV =		16,740.41			
	Total NPV w/SV =		-21,674.65			
	Simple Payback =		>10	years		
	Discounted Payback=		>10	years		

New Heater						
Year	**Cost**	**Benefits**	**Net Cash Flow**	**Accumulated Cash Flow**	**Discounted Net Cash Flow @3%**	**Discounted Accumulated Net Cash Flow @3%**
0	6,375.60	350.00	-6,025.60	-6,025.60	-6,025.60	
1	0.00	396.20	396.20	-5,629.40	384.66	-5,640.94
2	0.00	404.12	404.12	-5,225.28	380.93	-5,260.01
3	0.00	412.21	412.21	-4,813.07	377.23	-4,882.79
4	0.00	420.45	420.45	-4,392.62	373.56	-4,509.22
5	0.00	428.86	428.86	-3,963.76	369.94	-4,139.28
6	0.00	437.44	437.44	-3,526.32	366.35	-3,772.94
7	0.00	446.19	446.19	-3,080.14	362.79	-3,410.15
8	0.00	455.11	455.11	-2,625.03	359.27	-3,050.88
9	0.00	464.21	464.21	-2,160.82	355.78	-2,695.10
10	0.00	1,536.10	1,536.10	-624.72	1,143.00	-1,552.10
		MIRR=	**0.00**			
	NPV of Benefits w/SV		4,823.50			
	Total NPV w/SV =		-1,552.10			
	Simple Payback =		>10	years		
	Discounted Payback=		>10	years		

Heat recovery in electric Kilns						
Year	**Cost**	**Benefits**	**Net Cash Flow**	**Accumulated Cash Flow**	**Discounted Net Cash Flow @3%**	**Discounted Accumulated Net Cash Flow @3%**
0	7,874.83	990.00	-6,884.83	-6,884.83	-6,884.83	
1	0.00	1,120.68	1,120.68	-5,764.15	1,088.04	-5,796.79
2	0.00	1,143.09	1,143.09	-4,621.06	1,077.48	-4,719.32
3	0.00	1,165.96	1,165.96	-3,455.10	1,067.01	-3,652.30
4	0.00	1,189.27	1,189.27	-2,265.83	1,056.66	-2,595.65
5	0.00	1,213.06	1,213.06	-1,052.77	1,046.40	-1,549.25
6	0.00	1,237.32	1,237.32	184.55	1,036.24	-513.01
7	0.00	1,262.07	1,262.07	1,446.62	1,026.18	513.16
8	0.00	1,287.31	1,287.31	2,733.93	1,016.21	1,529.38
9	0.00	1,313.06	1,313.06	4,046.98	1,006.35	2,535.72
10	0.00	2,323.67	2,323.67	6,370.66	1,729.03	4,264.75
		MIRR=	**0.08**			
	NPV of Benefits w/SV		12,139.58			
	Total NPV w/SV =		4,264.75			
	Simple Payback =		5.85	years		
	Discounted Payback=		6.50	years		

Table HH.2 Cash-flow with CO_2 benefit for the Ceramics Lab

Year	Cost	Benefits	CO_2 Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
ACH5							
0	6900.00	916.36	0.00	-5983.64	-5983.64	-5983.64	
1	0.00	1038.34	85.17	1123.51	-4860.13	1090.79	-4892.85
2	0.00	1059.11	85.17	1144.28	-3715.86	1078.59	-3814.26
3	0.00	1080.29	85.17	1165.46	-2550.40	1066.56	-2747.71
4	0.00	1101.90	85.17	1187.06	-1363.33	1054.69	-1693.01
5	0.00	1123.94	85.17	1209.10	-154.23	1042.98	-650.03
6	0.00	1146.41	85.17	1231.58	1077.35	1031.43	381.40
7	0.00	1169.34	85.17	1254.51	2331.86	1020.03	1401.43
8	0.00	1192.73	85.17	1277.90	3609.75	1008.78	2410.21
9	0.00	1216.58	85.17	1301.75	4911.50	997.68	3407.89
10	0.00	1815.92	85.17	1901.08	6812.59	1414.58	4822.48
		MIRR=		0.09			
	NPV of Benefits w/SV =			11722.48			
	Total NPV w/SV =			4822.48			
	Simple Payback =			5.13	years		
	Discounted Payback=			5.63	years		
ACH5_R30_Dpane							
Year	Cost	Benefits	CO_2 Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
0	32039.46	998.64	0.00	-31040.82	-31040.82	-31040.82	
1	0.00	1040.13	93.01	1133.14	-29907.68	1100.13	-29940.69
2	0.00	1060.93	93.01	1153.94	-28753.74	1087.70	-28852.99
3	0.00	1082.15	93.01	1175.16	-27578.58	1075.44	-27777.55
4	0.00	1103.79	93.01	1196.80	-26381.78	1063.34	-26714.21
5	0.00	1125.87	93.01	1218.88	-25162.90	1051.41	-25662.79
6	0.00	1148.39	93.01	1241.40	-23921.51	1039.65	-24623.14

Year	Cost	Benefits	CO_2 Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
7	0.00	1171.35	93.01	1264.36	-22657.15	1028.04	-23595.10
8	0.00	1194.78	93.01	1287.79	-21369.36	1016.59	-22578.51
9	0.00	1218.68	93.01	1311.69	-20057.67	1005.30	-21573.21
10	0.00	3913.00	93.01	4006.01	-16051.66	2980.85	-18592.36
		MIRR=		**-0.06**			
	NPV of Benefits w/SV =			13447.10			
	Total NPV w/SV =			-18592.36			
	Simple Payback =			>10	years		
	Discounted Payback=			>10	years		
ACH5_R30_Dpane_NewHeater							
0	38415.06	1215.64	0.00	-37199.42	-37199.42	-37199.42	
1	0.00	1285.77	116.04	1401.81	-35797.61	1360.98	-35838.44
2	0.00	1311.49	116.04	1427.53	-34370.09	1345.58	-34492.86
3	0.00	1337.72	116.04	1453.75	-32916.33	1330.39	-33162.47
4	0.00	1364.47	116.04	1480.51	-31435.82	1315.41	-31847.06
5	0.00	1391.76	116.04	1507.80	-29928.02	1300.64	-30546.41
6	0.00	1419.60	116.04	1535.63	-28392.39	1286.07	-29260.35
7	0.00	1447.99	116.04	1564.03	-26828.36	1271.70	-27988.65
8	0.00	1476.95	116.04	1592.99	-25235.38	1257.52	-26731.13
9	0.00	1506.49	116.04	1622.52	-23612.85	1243.53	-25487.60
10	0.00	6338.50	116.04	6454.54	-17158.32	4802.78	-20684.82
		MIRR=		**-0.05**			
	NPV of Benefits w/SV =			17730.24			
	Total NPV w/SV =			-20684.82			
	Simple Payback =			>10	years		
	Discounted Payback=			>10	years		

Year	Cost	Benefits	CO_2 Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
				ACH5_R30			
0	21171.9	982.76	0.00	-20189.2	-20189.20	-20189.20	
1	0.00	1023.73	91.55	1115.28	-19073.92	1082.80	-19106.40
2	0.00	1044.21	91.55	1135.76	-17938.16	1070.56	-18035.84
3	0.00	1065.09	91.55	1156.64	-16781.52	1058.49	-16977.35
4	0.00	1086.39	91.55	1177.94	-15603.57	1046.59	-15930.76
5	0.00	1108.12	91.55	1199.67	-14403.90	1034.85	-14895.91
6	0.00	1130.28	91.55	1221.83	-13182.07	1023.27	-13872.65
7	0.00	1152.89	91.55	1244.44	-11937.63	1011.84	-12860.80
8	0.00	1175.95	91.55	1267.50	-10670.13	1000.57	-11860.23
9	0.00	1199.47	91.55	1291.02	-9379.11	989.46	-10870.77
10	0.00	2987.78	91.55	3079.34	-6299.78	2291.32	-8579.46
		MIRR=		**-0.03**			
	NPV of Benefits w/SV =			12592.5			
	Total NPV w/SV =			-8579.46			
	Simple Payback =			>10	years		
	Discounted Payback=			>10	years		

				New Heater			
Year	**Cost**	**Benefits**	**CO_2 Benefits**	**Net Cash Flow**	**Accumulated Cash Flow**	**Discounted Net Cash Flow @3%**	**Discounted Accumulated Net Cash Flow @3%**
0	6375.60	350.00	0.00	-6025.60	-6025.60	-6025.60	
1	0.00	396.20	37.14	433.34	-5592.26	420.72	-5604.88
2	0.00	404.12	37.14	441.27	-5150.99	415.94	-5188.94
3	0.00	412.21	37.14	449.35	-4701.64	411.22	-4777.73
4	0.00	420.45	37.14	457.59	-4244.05	406.57	-4371.16
5	0.00	428.86	37.14	466.00	-3778.05	401.98	-3969.18
6	0.00	437.44	37.14	474.58	-3303.47	397.45	-3571.73
7	0.00	446.19	37.14	483.33	-2820.14	392.99	-3178.74
8	0.00	455.11	37.14	492.25	-2327.89	388.59	-2790.15

Year	Cost	Benefits	CO_2 Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
9	0.00	464.21	37.14	501.35	-1826.54	384.25	-2405.91
10	0.00	1536.10	37.14	1573.24	-253.30	1170.64	-1235.27
		MIRR=		**0.00**			
	NPV of Benefits w/SV =			5140.33			
	Total NPV w/SV =			-1235.27			
	Simple Payback =			>10	years		
	Discounted Payback=			>10	years		

Heat recovery in electric kilns

Year	Cost	Benefits	CO_2 Benefits	Net Cash Flow	Accumulated Cash Flow	Discounted Net Cash Flow @3%	Discounted Accumulated Net Cash Flow @3%
0	7874.83	990.00	0.00	-6884.83	-6884.83	-6884.83	
1	0.00	1120.68	105.06	1225.74	-5659.09	1190.04	-5694.79
2	0.00	1143.09	105.06	1248.15	-4410.94	1176.50	-4518.29
3	0.00	1165.96	105.06	1271.01	-3139.93	1163.16	-3355.13
4	0.00	1189.27	105.06	1294.33	-1845.59	1150.00	-2205.13
5	0.00	1213.06	105.06	1318.12	-527.47	1137.02	-1068.11
6	0.00	1237.32	105.06	1342.38	814.91	1124.22	56.11
7	0.00	1262.07	105.06	1367.13	2182.03	1111.60	1167.71
8	0.00	1287.31	105.06	1392.37	3574.40	1099.15	2266.86
9	0.00	1313.06	105.06	1418.11	4992.51	1086.87	3353.72
10	0.00	2323.67	105.06	2428.73	7421.24	1807.20	5160.92
		MIRR=		**0.08**			
	NPV of Benefits w/SV =			**13035.7**			
	Total NPV w/SV =			**5160.92**			
	Simple Payback =			**5.39**	**years**		
	Discounted Payback=			**5.95**	**years**		