

EFFICIENT ENERGY MODELING: A LOW CARBON SOURCE ENERGY
ASSESSMENT OF PROPOSED BUILDING INTERCONNECTIONS
BASED ON EMERGING MARKET MODELING TOOLS

by

Joshua William Talbert

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Mechanical Engineering

MONTANA STATE UNIVERSITY
Bozeman, Montana

April 2014

©COPYRIGHT

by

Joshua William Talbert

2014

All Rights Reserved

TABLE OF CONTENTS

1. PROJECT INTRODUCTION	1
Project Background.....	1
Project Chronology and Development.....	1
Purpose.....	2
Primary Purpose.....	2
Secondary Purpose.....	2
Scope.....	4
Objective:.....	4
Scope of Services:.....	4
Process:	5
Project Team	5
2. ENERGY MODELING DISCUSSION	7
Industry Role.....	7
Evolution of Energy Modeling Tools	9
Simulation Tool Selection for this Project.....	12
Garbage In – Garbage Out	14
Big Uglies	15
3. MODEL DEVELOPMENT.....	19
Campus Building Group	19
Building Descriptions	20
Leon Johnson	20
Cooley Lab.....	20
Lewis Hall.....	20
Chemistry BioChemistry Building	20
Tietz Hall	21
Montana Hall	21
Wilson Hall	21
Jake Jabs College of Business	21
Survey	21
Operation and Schedule Review	24
Space Type Selection.....	26
Interior Equipment	29
System Types	31
Leon Johnson	31
Cooley Lab.....	32
Lewis Hall.....	33
Chemistry BioChemistry Building	33

TABLE OF CONTENTS CONTINUED

Tietz Hall	34
Montana Hall	35
Wilson Hall	35
Jake Jabs College of Business	35
4. MODEL CALIBRATION	36
Metering Plan.....	37
Metering Plan Design and Process	37
Metering Equipment	41
Figure 12. Light and Occupancy Logger, M-2.	41
Data.....	42
Metered Results Discussion.....	46
Model Calibration	47
Calibration Technique.....	48
Calibration Results.....	48
5. PROPOSED SYSTEM ANALYSIS	50
Proposed System Description	50
System Schematic	50
Proposed Simulation Results	52
6. CONCLUSIONS.....	55
Project Assessment	55
Recommendations for Future work	56
REFERENCES CITED.....	60
APPENDICES.....	62
APPENDIX A: Project Proposal.....	62
APPENDIX B: Metering Plan.....	65
APPENDIX C: Laboratory Metering Data.....	90
APPENDIX D: Building Photos.....	97
APPENDIX E: Project Administration.....	115
APPENDIX F: Energy Plus Simulation Reports.....	123
APPENDIX G: Calibration Log.....	172
APPENDIX H: Defense Presentation.....	187

LIST OF TABLES

Table	Page
1. ASHRAE Published Occupancy Information.....	16
2. ASHRAE Published Values for Internal Equipment Loads.....	17
3. Research Building Drawing Log.....	23
4. Metering Equipment Schedule.....	41
5. Laboratory Equipment Energy Modeling Values.....	46
6. Proposed and Baseline Energy and Greenhouse Gas Results.....	54

LIST OF FIGURES

Figure	Page
1. Project Gantt Schedule.....	3
2. Building Energy Consumption.....	7
3. Statewide Energy Code Adoption Map.....	8
4. Energy Modeling Tool Graphic Comparison.....	11
5. SketchUP Photograph Based Geometry Development.....	14
6. Campus Map – Project Building Group.....	19
7. Example Building Energy Information	25
8. Example Occupancy Schedule	26
9. Example Space Type Definition	27
10. Example Space Type Assignment Distribution	29
11. Heat Recovery Heat Pump Operation Schematic	32
12. Cooley Lab Electrical Panel Monitoring Installation Picture	39
13. Metering Equipment Installation Detail	40
14. Light and Occupancy Logger, <u>M-2</u>	41
15. Laboratory Energy Monitoring Sample Data Selection	43
16. Cooley Lab Filtered Occupancy and Lighting Data	44
17. Tietz Hall Calibration Graphs	49
18. Proposed Energy Plant Interconnection Schematic Drawing	51
19. Energy Plant Runtime Modes	53

ABSTRACT

Building energy consumption studies based on whole building energy consumption modeling (Energy Modeling) are not widely applied for performance planning and assessment. The origins of energy modeling as a design resource extend back almost 50 years, but recent developments in computing power and international attention to green house gas emission reduction has brought the benefits of energy modeling to the forefront of building designers, managers, and policy makers. The research herein provides a two-fold benefit to the Montana State University and energy modeling communities by providing energy assessment information and proving the efficacy of modern energy modeling tools currently under development. The procedure followed in this research proves that effective energy modeling can be completed with a significant reduction in the time resource required by harnessing the new energy modeling tools and methods. The University also gains ownership of valuable assessment tools for future application towards energy upgrades, building maintenance, and capital expenditure decisions. Features employed in this research include photographic based model development, model calibration, and proposed system component assessment. The University, based on its need for information about the carbon footprint of campus buildings, commissioned this research through Facilities Services. Modeling results support an overall reduction of campus building related green house gas emissions and prove that emerging energy modeling tools can significantly reduce the time spent on accurate model development.

PROJECT INTRODUCTION

Project Background

Montana State University (MSU) in Bozeman operates a selection of academic research laboratories. Through the University's commitment to energy use reduction a central plant heat pump system was installed to serve a group of adjacent buildings. The buildings in the group include laboratory facilities as well as more predictable seasonal based load facilities. Josh Talbert's graduate research work is modeling – through computer simulation – the load profiles of this building group. The research project is designed to assist the University Facilities Services with balancing the load profiles of the buildings connected through the installed central heat pump plant.

Computer Aided Whole Building Energy Simulation, herein referred to as Energy Modeling, is a building design resource undergoing significant growth in the recent decade. Energy Modeling provides a tool for obtaining important design assessment information. The recent developments in Energy Modeling tools decreases the time investment required to conduct audit level analysis. This project capitalizes on these developments to provide the scope described herein in a time frame attributed to classically a less rigorous analysis.

Project Chronology and Development

Project Development began in March 2013 with discussions about applying Energy Modeling to a process scoped around the Mechanical Engineering Department's

graduate research requirement. Subsequent meetings followed with Dan Stevenson from the University Facilities Services and he provided a context framework around the needs of the University. With a mutual benefit established, Facilities Services provided funding for the research with a scope designed to fulfill both the Department and University's needs. Project Proposal and Administration documents are included in Appendix A and D, respectively. Figure 1 on the following page depicts the project Gantt Chart.

Purpose

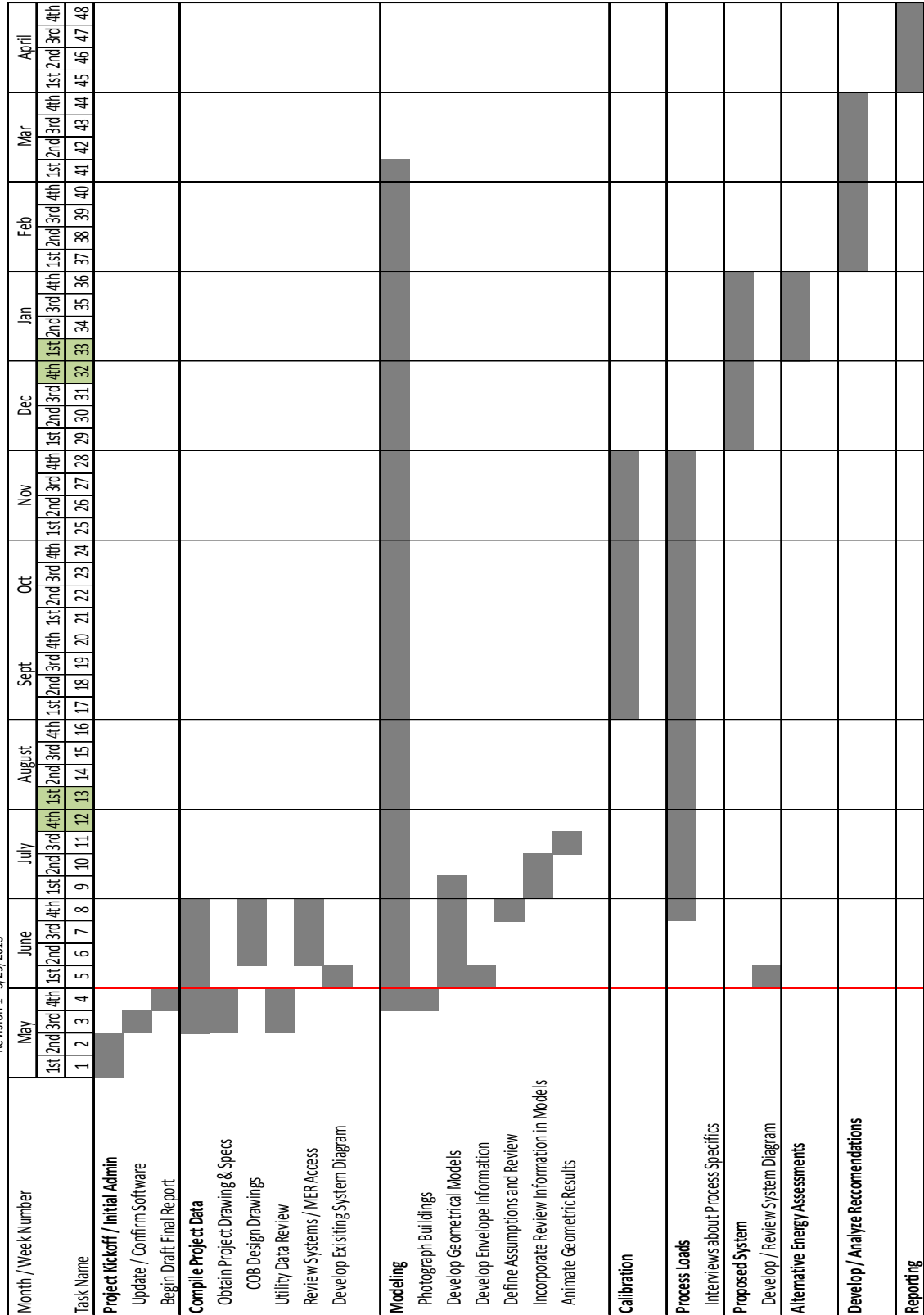
The project constraint time added a secondary project purpose. To complete a project scope tailored to the University's needs, traditional energy modeling tools employed with the desired fidelity would have been time prohibitive in the framework of a Master's Thesis requirements. So the secondary project goal was defined as demonstrating a 'proof of concept' in using emerging market energy modeling tools to meet the rigor required of a valuable University Energy Simulation Project.

Primary Purpose

The Primary Purpose is to produce a calibrated energy model for energy consumption evaluation of hypothetical campus building energy system interconnections. Evaluation is based on providing alternative low carbon source energy contribution effectiveness.

Secondary Purpose

The Secondary Purpose is to complete a 'proof of concept' study on utilizing emerging market energy modeling tools to complete the appropriate scope.



Scope

Objective:

Assess energy requirements of interconnected buildings factoring potential geothermal, solar thermal, and existing central heat pump system efficacy. Evaluate low carbon energy resources.

Scope of Services:

- Model select facilities (see Appendix)
 - Establish internal process energy profiles
 - Review existing data
 - Interview facilities and academic personal
 - Measure internal process energy criteria
 - Develop data acquisition experiments
 - Incorporate undergraduate participation opportunities
- Model central plant systems
- Review available utility data
 - Identify needs for additional data granularity
 - Develop data acquisition experiments
- Calibrate computer building models to utility data
 - Verify model to acceptance of *International Performance and Measurement and Verification Profile* (IPMVP): option D
- Assess low carbon contributions
 - Equipment retrofit options
 - Local energy resources
 - Load reduction efforts
 - Incorporate undergraduate participation opportunities
- Develop learning modules based on project experience
 - Presentations
 - Papers
 - Articles
 - Classroom lectures
 - Experiments

Process:

Utilize established and developing building simulation tools to develop climatological simulation components. Conduct interview / review meetings between associated academic and operational departments. Review available utility and cost data, develop and implement data acquisition exercises. Develop energy simulations; establish criteria for appropriate model fidelity. Assess low carbon energy concepts. Establish and defend process energy modeling criteria. Report on interconnected contributions and energy sharing strategies. Establish appropriate interval for project review with academic and operation committee members.

Project Team

The project team members and their anticipated roll are as follows:

Joshua Talbert, PE, LEED-AP

Master's Degree Candidate Mechanical Engineering
Lead Researcher

Kevin Amende, PE

Assistant Professor
Academic Project Advisor

Dan Stevenson, PE, LEED-AP

Assistant Director, Facilities Services
Facility Department Project Advisor

Matt Carr, PE, LEED-AP

Resource Conservation Specialist
Facilities Services Project Engineer

Chelsea Guenette

Master's Degree Candidate Mechanical Engineering
Researcher

Tom Nowak
Electrician/Foreman
Project Electrician

ENERGY MODELING DISCUSSION

Industry Role

Energy Modeling as a design service is situated to add significant value to the commercial building sector in the years to come. Recent advancements in software development have drastically reduced the level of complexity for using Energy Modeling tools and have poised these tools for a much broader range of application and utilization. Despite such significant recent progress the general software concept has been around for approximately forty years.

Recent political developments, in response to concerns about rising Green House Gas (GHG) emissions, are establishing mandates for future building design that will all but require Energy Modeling as a design component for decision evaluation and compliance documentation. According to the US Department of Energy (DOE), commercial buildings account for 41% of total national energy consumption¹. Figure 3 demonstrates the magnitude of energy consumption attributed to the US commercial building sector.

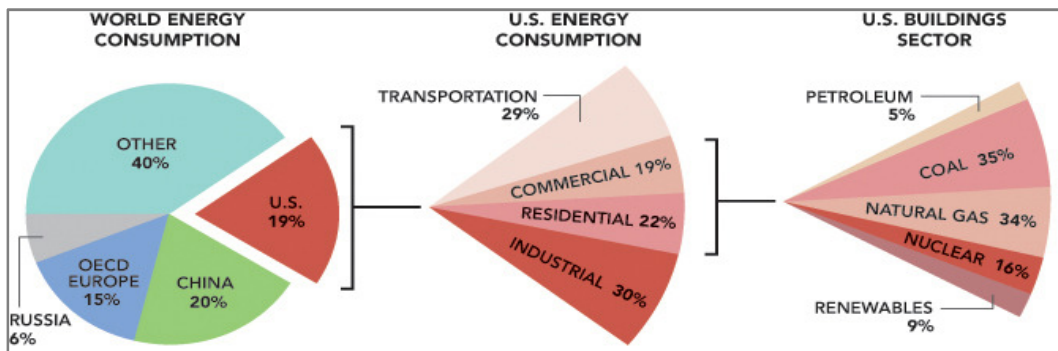
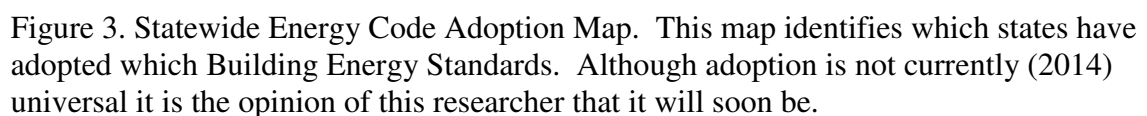


Figure 2. Building Energy Consumption²: The building sector in the US accounts for a significant portion of our total energy consumption and reveals the importance and realizable benefit of using Energy Simulation for added value in the design process.



The United State Green Building Council (USGBC) with the Leadership in Energy and Environmental Design (LEED) program has spurred significant application of Energy Modeling in the Building Design Services market. The LEED program provides a metric for rating the sustainability features of a commercial building. In a few instances there are municipal level incentives for voluntary LEED participation in new and retrofit commercial but most LEED participation is voluntary. Amongst the metrics on which LEED rates a building are energy performance improvement levels. In new construction a design concept is rated against the performance of similar code minimum design energy consumption as reported through an Energy Simulation process. LEED partnered with ASHRAE to develop a modeling requirements document which is published as Appendix G to the ASHRAE Standard 90.1 Energy Efficiency Standard for Commercial Construction Except Low Rise Residential Building. The market shift towards sustainable building design spurred by the success of LEED has demonstrated and defined the need for Energy Modeling.

Evolution of Energy Modeling Tools

Development of whole building energy simulation software began in the early 1970s when two government agencies began funding these tools. The US Department of Defense (DoD) developed a simulation tool call Building Loads Analysis and System Thermodynamics, referred to as BLAST³. While development at the US Department of Energy (DOE) began on a simulation framework referred to as DOE-2. Computer and computing power advancements in the 1990s spurred the need and desire to combine elements from both DOE-2 and BLAST simulation engines. Elements from each engine

were combined through a new Program administered by the DOE call EnergyPlus. Beyond research application, EnergyPlus was not widely applied by building design professional for design and energy performance assessment. EnergyPlus was limited to high functionality users because simulation development is built on text file input processing where the level of iterations necessary for design feedback were prohibitively expensive. The resources required to complete EnergyPlus were not available to the majority of designer and industry adaptation and application were not widely implemented. The need arose then for an ‘easier’ modeling tool.

Development at the National Renewable Energy Lab (NREL) began on a program called *The QUick Energy Simulation Tool*, or eQuest. This tool was based on an enhanced version of the original DOE-2 simulation tool, but was developed to include Graphics and Wizards to aid with Energy Efficiency Measure (EEM) assessments and building model development. EQuest development was funded in large part by the DOE with development assistance from James J. Hirsch and Associates and the Lawrence Berkeley National Laboratory (LBNL)⁴. Equest and the DOE-2 engine have always been distributed as freeware on the internet with updates and software support provided by the DOE. Additionally an array of training programs are hosted by the DOE and private industry. Recently in 2009 a new interface for EnergyPlus was released for public testing called OpenStudio. OpenStudio is a cross platform tool for connecting the power of EnergyPlus to the ease of use of Graphical User Interfaces (GUI)s. OpenStudio is aligned with the powerful three dimensional drawing program called SketchUP. SketchUP is an open source solid modeling program originally hosted by Google, but

which is now run by the Trimble Group. An OpenStudio Plugin built for SketchUP in the Ruby programming language allows users to draw geometry and building envelopes instead of using a text based data entry format. Figure 4 presents the difference between the eQuest building development and the OpenStudio and SketchUP building development environment.

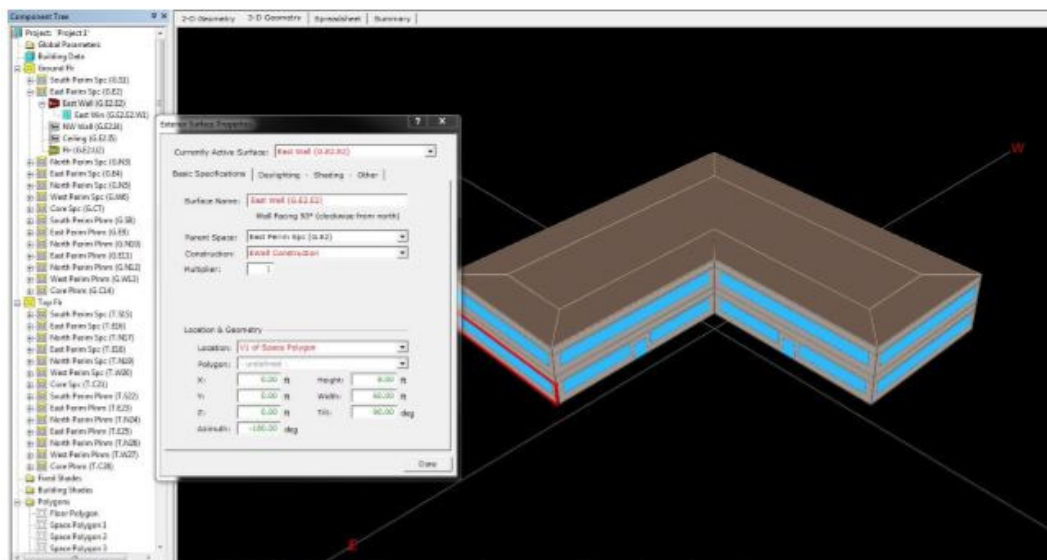


Figure 4A: eQuest Building Development, data entry based environment.

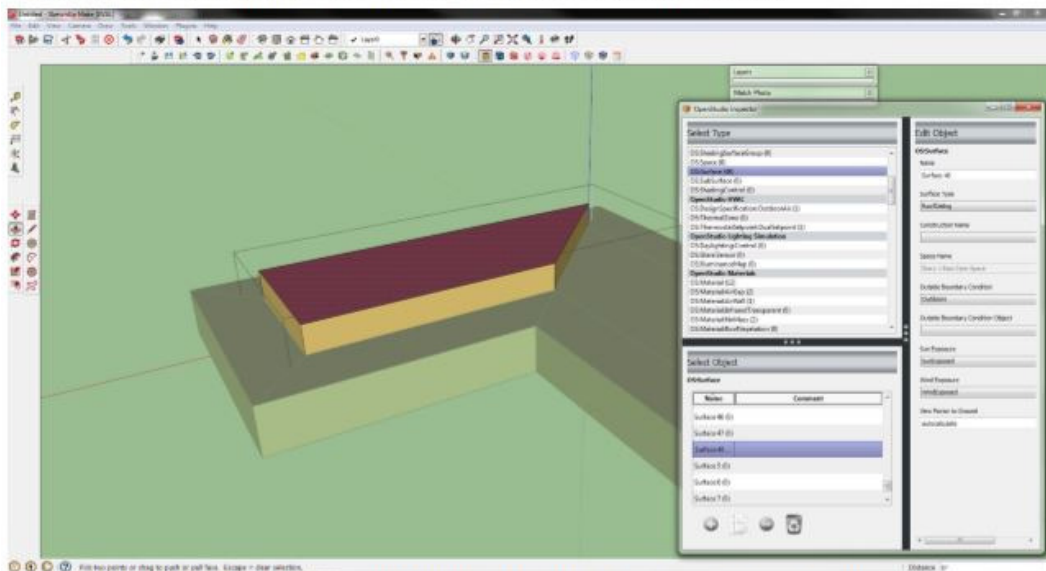


Figure 4B: SketchUP & OpenStudio Building Development, drawing based environment.

The visual interface of using SketchUP for OpenStudio building geometry development drastically increases the speed of doing parametric analysis and rapid building geometry prototyping. But OpenStudio has limitations, primarily because it is still a young program in development stages. When the research described herein began, OpenStudio was still in a beta release with version 0.8. During the progress of this project NREL has released version updates to OpenStudio where the version being used at the time of this report is version 1.2. The largest downfall for the OpenStudio cross platform tool is that the full power of EnergyPlus is not yet implemented into the OpenStudio interface. EnergyPlus is the leading energy simulation tool when it comes to AirLoop and PlantLoop objects and system flexibility, but most of the features are not supported with the OpenStudio interface yet, so use of OpenStudio is limited to EnergyPlus power users, or users that have experience working solely in the building input text file environment of EnergyPlus.

Simulation Tool Selection for this Project

To complete the research scope, outlined previously, it is necessary to select a Energy Modeling tool to apply to this project. Previous Energy Modeling experience and exposure to aforementioned simulation tools provided the framework for the selection basis. The secondary project purpose projects the researcher into an OpenStudio evangelist role. Previous project experience informed the team that the research scope presented herein equates to approximately a four thousand hour (4,000 hr) project. This is an order of magnitude of cost and time prohibitive necessary for the scope of a Master's of Science research thesis. The 4,000 hour assessment is based on 'traditional'

data entry based simulation tools like eQuest, or EnergyPlus. The secondary goal is to prove the increased efficacy of using emerging market tools like OpenStudio and SketchUP. Specifically the SketchUP capability of drawing buildings provides vast time reduction in obtaining and building virtual building geometry. SketchUP has built-in functionality that supports using photographs to help build the geometry of a building into an Energy Modeling format. Previous experience by the research team indicated that the significant time savings inherent in the SketchUP and OpenStudio building model information development reduced the theoretical completion time by seventy five percent (75%), bringing the scope into a reasonable level of effort for a Master's research project. As such part of the goal of this project is to prove the efficacy of these tools, and to spur broader acceptance and application of these tools. It is the belief of the researcher that by adding to the existing body of knowledge and applying the emerging market tools of OpenStudio and EnergyPlus to an actual Energy Modeling scope will help promote a broader application and acceptance of these open source tools. Figure 5, provides a screen shot of the photograph based building geometry development for Cooley Lab. In this image red and green 'horizon' lines are used to align the model to a photograph.

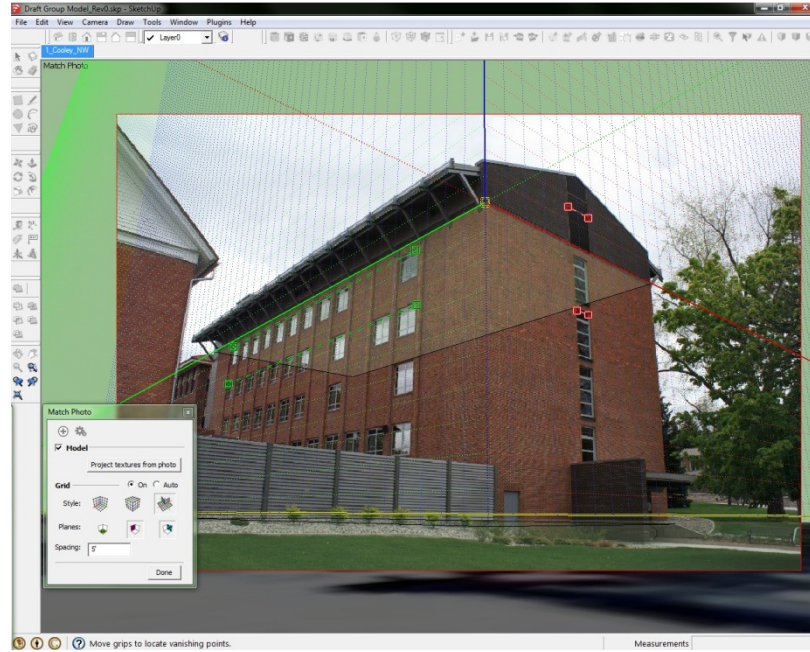


Figure 5: SketchUP Photograph Based Geometry Development

Garbage In – Garbage Out

Garbage In – Garbage Out is the Achilles heel for wider application of whole building energy simulation. Garbage In – Garbage Out is an expression used in the industry to explain the importance of documenting and applying assumptions about the operation and physical characteristics of a facility when ‘translating’ from the physical real world to a virtual simulated world of energy modeling software. This adage also speaks to value in experience for Energy Modelers. Many variables exist in a building and all of them need to be quantified in an appropriate matter to establish a valid translation of a specific facility into a virtual energy model. Most building related variables can be assigned values based on data and/or appropriate assumptions, but there are some factors that are difficult to align a translation for between the actual and the virtual. Because of the difficulty with assigning some assumptions, and by the nature of

being a research project at a University with research implications, a component of this project was measuring some building usage factors to help corroborate assumptions with significant energy implications. Beyond the scope of the measuring project discussed in a later section there are still four factors considered as holes in the validity of an Energy Model. These four factors are colloquially called the *Big Uglies* amongst Energy Modeling professionals.

Big Uglies

The four factors deemed as the Big Uglies of the Energy Modeling trade are as follows.

- Occupancy
- Plug and equipment loads
- Weather
- Infiltration

Specific discussion on what the issue with each of these factors and how they contribute to the efficacy of the modeling results continues below.

Occupancy definitions are crucial to defining how a building facility is used and how its programmatic design supports its defined function when translated into an Energy Model. Basically occupancy is defined by three factors, a schedule of occupation, a type of activity, and a quantity of occupants. Examples of these definitions are: a 9-5 occupancy schedule with occupants assumed to be doing ‘medium office work’ releasing so many BTUs per person of energy for this activity, with an occupant density assumed to be one hundred and twenty five square foot per person (125 sqft / ppl). Some building types are much easier to define than others. In this example an ‘office definition’ is relatively straightforward to design, whereas inside the scope of this research project with

multi use academic and research facilities these definitions are much more complicated to define. Table 1 presents some corroboratory information published by ASHRAE for occupancy assumptions.

Table 1. ASHRAE Published Occupancy Information. Excerpted from ASHRAE Fundamentals Handbook 2009. Section 18.4.

Degree of Activity	Location	Total Heat, Btu/h		Sensible Heat, Btu/h	Latent Heat, Btu/h	% Sensible Heat that is Radiant ^b	
		Adult Male	Adjusted, M/F ^a			Low V	High V
Seated at theater	Theater, matinee	390	330	225	105		
Seated at theater, night	Theater, night	390	350	245	105	60	27
Seated, very light work	Offices, hotels, apartments	450	400	245	155		
Moderately active office work	Offices, hotels, apartments	475	450	250	200		
Standing, light work; walking	Department store; retail store	550	450	250	200	58	38
Walking, standing	Drug store, bank	550	500	250	250		
Sedentary work	Restaurant ^c	490	550	275	275		
Light bench work	Factory	800	750	275	475		
Moderate dancing	Dance hall	900	850	305	545	49	35
Walking 3 mph; light machine work	Factory	1000	1000	375	625		
Bowling ^d	Bowling alley	1500	1450	580	870		
Heavy work	Factory	1500	1450	580	870	54	19
Heavy machine work; lifting	Factory	1600	1600	635	965		
Athletics	Gymnasium	2000	1800	710	1090		

Notes:

1. Tabulated values are based on 75°F room dry-bulb temperature. For 80°F room dry bulb, total heat remains the same, but sensible heat values should be decreased by approximately 20%, and latent heat values increased accordingly.

2. Also see Table 4, [Chapter 9](#), for additional rates of metabolic heat generation.

3. All values are rounded to nearest 5 Btu/h.

^aAdjusted heat gain is based on normal percentage of men, women, and children for the application listed, and assumes that gain from an adult female is

85% of that for an adult male, and gain from a child is 75% of that for an adult male.

^bValues approximated from data in Table 6, [Chapter 9](#), where *V* is air velocity with limits shown in that table.

^cAdjusted heat gain includes 60 Btu/h for food per individual (30 Btu/h sensible and 30 Btu/h latent).

^dFigure one person per alley actually bowling, and all others as sitting (400 Btu/h) or standing or walking slowly (550 Btu/h).

Plug and Equipment loads relate directly to the types of activities and functions that a facility supports. These definitions are also related to the occupancy definitions discussed previously. To support energy modeling credibility ASHRAE has studied equipment loads as a means to provide standard values for application in modeling assumptions. In general these ASHRAE values are a starting place for these definitions and are encouraged to be updated or confirmed when additional information is available. Table 2 presents some of the assumptions for these factors as published by ASHRAE in the Fundamental Handbook.

Table 2. ASHRAE Published Values for Internal Equipment Loads: Excerpted from ASHRAE Fundamental Handbook Section 18.10.

Load Density of Office	Load Factor, W/ft ²	Description
Light	0.5	Assumes 167 ft ² /workstation (6 workstations per 1000 ft ²) with computer and monitor at each plus printer and fax. Computer, monitor, and fax diversity 0.67, printer diversity 0.33.
Medium	1	Assumes 125 ft ² /workstation (8 workstations per 1000 ft ²) with computer and monitor at each plus printer and fax. Computer, monitor, and fax diversity 0.75, printer diversity 0.50.
Medium/Heavy	1.5	Assumes 100 ft ² /workstation (10 workstations per 1000 ft ²) with computer and monitor at each plus printer and fax. Computer and monitor diversity 0.75, printer and fax diversity 0.50.
Heavy	2	Assumes 83 ft ² /workstation (12 workstations per 1000 ft ²) with computer and monitor at each plus printer and fax. Computer and monitor diversity 1.0, printer and fax diversity 0.50.

Source: Wilkins and Hosni (2000).

Weather data is listed as a Big Ugly in the energy modeling community because the data used in a simulation is based on weather averages. The modeling tools discussed herein use an 8760 weather file, typically in a TMY file format. The 8760 refers to a total year's worth of data, or 8,760 hours. Each hour in that file has averages of weather factors for that specific hour on an annual basis. Examples of these weather factors are Dry Bulb Temperature, Wet Bulb Temperature, Incident Solar Radiation, et cetera. The problem lies within the fact that averaging these factors takes out the extremes or outlying data. The TMY file format is an abbreviation for Typical Meteorological Year, and broad data base of these files is maintained by the DOE. Additionally information is published for authoring a TMY file based on collected data. In general the TMY data base includes data based on meteorological recordings obtained by the National Oceanic and Atmospheric Association (NOAA) at most United States regional airports. This project used the TMY data file for Gallatin Field in Bozeman.

Translation of a facility from the physical world to the virtual world requires accounting for some level of building infiltration. Infiltration adds significant additional load to a building's HVAC system and is very important factor to include in a model. In general infiltration addresses the leakage of air into or out of a building based on the natural world. Wind pressure is one of the biggest drivers of air leakage into a building, but is also exceptionally hard to approximate and model. Significant variation in weather, and surrounding buildings effects the level infiltration on a building, current industry practice is to translate infiltration into an Air Change per Hour (ACH) number for a space. One ACH describes a space where it is assumed that a volume of air equal to that of the space volume is exchanged into the space within 1 hour.

MODEL DEVELOPMENT

Campus Building Group

The University's continued focus on utilizing and increasing their consumption of lower carbon source energy led to the development of the proposed building interconnections discussed herein. The buildings included in this assessment project are central to the academic function of the University and consume significant fractions of the total campus energy. The variation in the occupancy and function of these buildings provides the theory behind the effectiveness of sharing energy production between them versus the current configuration of individualized energy production. Figure 6 indicates the building group selected for the project.

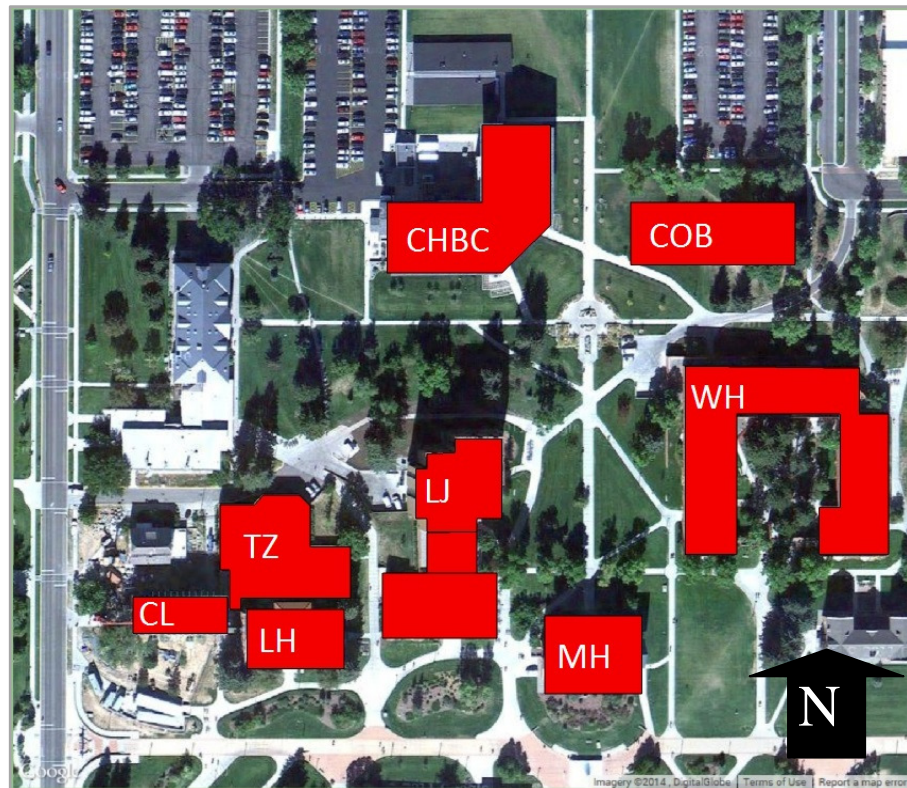


Figure 6. Campus Map – Project Building Group

Building Descriptions

Leon Johnson

Leon Johnson Hall (LJH) is an eight story laboratory facility that houses Earth, Ecology, and Biological Research laboratories. Annual Energy use is characteristic of off season demand loads.

Cooley Lab

Cooley Laboratory (CL) is National Health Foundation specification facility designed for biological research. Annual Energy use is characteristic of off season demand loads.

Lewis Hall

Lewis Hall (LH) is a primarily an administrative / office area for the Ecology, Computational Biology and Microbiology Departments. The basement of Lewis Hall is retrofitted as a laboratory space serving as additional space for adjacent Tietz Hall. The remaining floors of Lewis Hall are characterized by natural and diurnal seasonal and daily energy use.

Chemistry BioChemistry Building

The Chemistry and Biochemistry Building (CHBC) houses research laboratories for these departments at MSU, as well as a small auditorium. Annual Energy use is characterized as natural and diurnal seasonal and daily loads with a steady off season demand.

Tietz Hall

Animal Resource Center: Tietz Laboratory (TZ) is a laboratory facility serving as the Animal Resource Center for University Research. Annual Energy is characterized by natural and diurnal seasonal and daily energy use.

Montana Hall

Montana Hall (MH) is an office and administrative facility serving the entire University that includes the Office of the Registrar and Students Accounts. Annual Energy use is characterized by natural and diurnal seasonal and daily use.

Wilson Hall

Wilson Hall (WH) houses many departments in the College of Letters and Sciences, including English, History, Mathematics, and the College Dean's office. Annual Energy use is characterized by natural and diurnal seasonal and daily use.

Jake Jabs College of Business

The Jake Jabs College of Business (COB) is an under-construction facility designed to serve the College of Business. The facility is characterized as a classroom building and is expected to have natural and diurnal seasonal and daily energy consumption.

Survey

This project began with three distinct modes of Field Survey. The aforementioned modeling tool, OpenStudio, combined with SketchUP was selected for this research project in part because of a photograph matching characteristic. This

characteristic was seen as advantageous to an existing building energy modeling study as it allows photos to be taken of the facilities and used for translating the building into the virtual energy modeling environment. The simulation tool selection of OpenStudio and SketchUP added a unique field survey component to this project of photography all of the project buildings. The photographs obtained for the purpose of this project are included in the appendices. Two other modes of Field Survey were implemented and these are traditional modes of information compiling for an energy study project of this research's scope.

Obtaining the design and construction documents for these existing facilities provided a wealth of corroboratory information for developing the respective energy models. As an active and busy educational institution Montana State University had a document maintenance protocol and was able to provide a respectable depth of information for a group of buildings which spanned almost a 100 year time frame between their occupancy dates. University Facility Services through their records department provided the record drawing packages for the research buildings. Table 3 is a list of the drawings documents disseminated to this research team, with the date of each facility shown.

Table 3. Research Building Drawing Log

Drawing Log	Received File Names	Title	Version	Scale	Titleblock Date
Chemistry / Biochem Buildings	04-0040-Vol_1-A.pdf 04-0040-Vol_1-B.pdf 04-0040-Vol_2-A.pdf 04-0040-Vol_2-B.pdf 144-Bldg-B.pdf	Complete Set	AS-BUILTS RECORD DRAWINGS AS-BUILTS AS-BUILTS Floor Plan	Scale: 1"=20'	1/24/2008 1/28/2008 1/24/2008 1/24/2008
Cooley Laboratories	CooleyVolume1of2.pdf CooleyVolume2of2.pdf 118-Bldg-B.pdf	Complete Set	BID SET BID SET Floor Plan	Scale: 1"=10'	3/14/2011 3/14/2011
Leon Johnson Labs	120-Bldg-B.pdf		Floor Plan	Scale: 1"=20'	
Lewis Hall	21-0001 by Wm Plew.pdf 21-0001 98-0024 98-0058 98-0060 99-0093 103-Bldg-B.pdf 1933 by Wm Plew.pdf	Architectural Set Mech Rm 16A Exh Fan RM# 204 Renovation RM# 805c/d Cust. Clst Remodel EPICenter Pilot Proj. LH BSMT	Floor Plan AS-BUILTS AS-BUILTS Construction Doc Floor Plan Floor Plan	Scale: 1/4" = 1'-0" Scale: 1/8" = 1'-0" Scale: 1/4" = 1'-0" As Noted As Noted As Noted Scale: 1"=10' Scale: 1/8" = 1'-0"	Very Old 11/20/1921 4/5/1999 5/3/2000 12/18/1998 11/12/1999 4/28/1933
Montana Hall	01-0058.pdf 101-Bldg-B.pdf Montana Hall 1933 Drawing Set.pdf Montana Hall Drawings 2.pdf Montana Hall Drawings.pdf Montana Hall Reconstruction Drawing Set - around 1920.pdf	Window Submittal Reconstruction Reconstruction Reconstruction	Floor Plan	As Noted Scale: 1"=12' Dims listed Scale: 1/4" = 1'-0" Scale: 1/4" = 1'-0" Scale: 1/4" = 1'-0"	5/23/2002 4/28/1933 Undated - Old 1920???
Tietz Hall	81-0055.pdf 133-Bldg-B.pdf	Central Lab. Animal Facility	Construction Doc? Floor Plan	Scale: 1"=20' Scale: 1"=20'	8/30/1982
Wilson Hall	74-0001.pdf Wilson Mechanical 1977 129-Bldg-B.pdf Wilson Hall MSU O&M's updated 2-28-11	Classroom - Office Building Updated	AS-BUILTS AS BUILTS O&M Manual	Scale: 1/30" = 1' - 0" Scale: 1/30" = 1' - 0" Scale: 1"=30'	6/3/1977 6/3/1977 2/28/2011

The last component of the Field survey phases was conducting physical site visits.

In most cases these site visits were conducted in conjunction with either one of two coincident tasks, either during the photographic documentation or during the Metering Plan implementation. The metering plan is discussed in a subsequent section of this report. Site visits can be a very involved and very detailed assessment of a facility, and are an important verification step for evaluating the Life Cycle Cost (LCC) of specific pieces of equipment. The nature of this project and the time resource constraint limited the scope of the site visits on this project to spot checking of significant energy usage equipment and confirming holes in the data provided by the University Records department.

Operation and Schedule Review

Another vital component of defining the corroboratory information to support the energy modeling assumptions was operating and maintenance personnel interviews. A lot of this information was collected during project team meetings by specifically enquiring about and addressing operational characteristics of HVAC equipment. The University Facilities department does maintain energy related operational information about buildings as a service to the school community and this information was documented and accounted for when developing the building models. Meeting Minutes and Agenda's from the project meetings throughout this project are included in the appendices and include notes made based on operation feedback from the Operation and Maintenance teams. Figure 7 provides an example of the information publicly available that the University Facility's department maintains on the University website.

The information presented above and discussed with Facility Services, is vital to supporting accurate development of building energy models. A significant assumption in a building model is the schedule profiles assigned to various components. Schedules in energy modeling are applied to various factors to account for time of day, month, or year activities and input variable variation. In general occupancy, lighting, and equipment schedules use a type of schedule based on percent of full load. Figure 8 below provides an example of a building occupancy schedule as applied to Cooley Lab.

Building Information
Chemistry Building
System Information
System Type: Variable Air Volume with Hot Water Reheat
Occupied Space Temperature Control: Individual/Zone VAV Control
Does this Building Offer Simultaneous Heating and Cooling?: Yes
Occupied Hours
Monday-Friday: 7am -6pm
Saturday: 8am -6pm
Sunday: 8am -6pm
Heating
Is the building Heated?: Yes
Heating Minimum & Maximum: 65°-72°F
Cooling
Is the Building Cooled?: Yes
Cooling Minimum & Maximum Guidelines: 70°-80°F
Date on Which Cooling is Enabled: N/A
Date on Which Cooling is Disabled: N/A
Switchover Controls
Type of Switchover Controls in Place: Automatic
Switchover Point: No Seasonal Changes

Figure 7: Example Building Energy Information. Published and maintained by MSU Facility Services. <http://www.montana.edu/us/fs/energy/buildings.php>

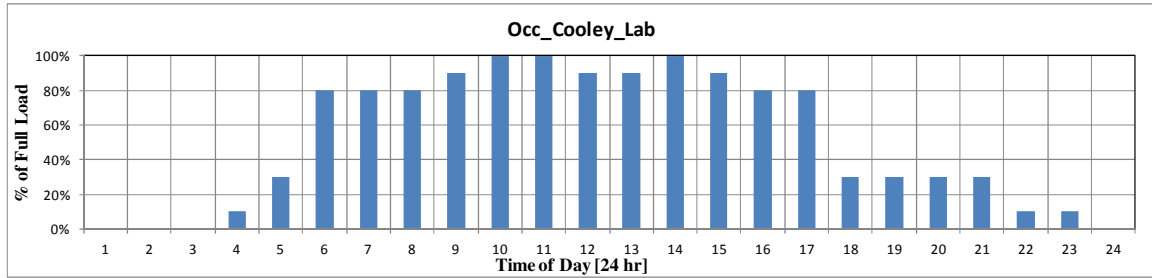


Figure 8. Example Occupancy Schedule: Cooley Lab initial occupancy schedule.

Application of schedules to an Energy Model is an iterative process. The schedule example provided in Figure 8, was a schedule applied to an early model iteration, eventually data obtained through the sub project metering effort and continued operation discussion refined the above schedule, but it became the original basis for simulating the theoretical occupancy of this facility. When comparing the energy performance across facilities, whether they are baseline and design models, or models of different buildings assessed for comparison, it is very important that identical schedules be utilized.

Space Type Selection

Energy Modeling consists of assigning space usage properties to various spaces inside a facility. These assignments are known as the Space Types and can range on a Energy Model from one facility wide space type definition to many different designations for every space in a facility. The onus of understanding the implications of these definitions and applying them with an appropriate fidelity to a specific model lies with the Energy Modeler. Previous project experience with Energy Modeling is the best source for experience with developing these definitions. Generalized examples of the

forms of space type definitions used in modeling are: corridor spaces, bathroom spaces, offices spaces, mechanical and electrical equipment spaces, and entry vestibules. The accuracy and relevance of a building model can hang on successful and defensible application of space types to a facility. Space types allow for unique values of installed lighting power, occupant density, usage schedules, equipment distribution, thermostat setpoints etc to be allocated to different regions of a building. Figure 9 presents an example of a space type definition as defined in the employed modeling tool OpenStudio.

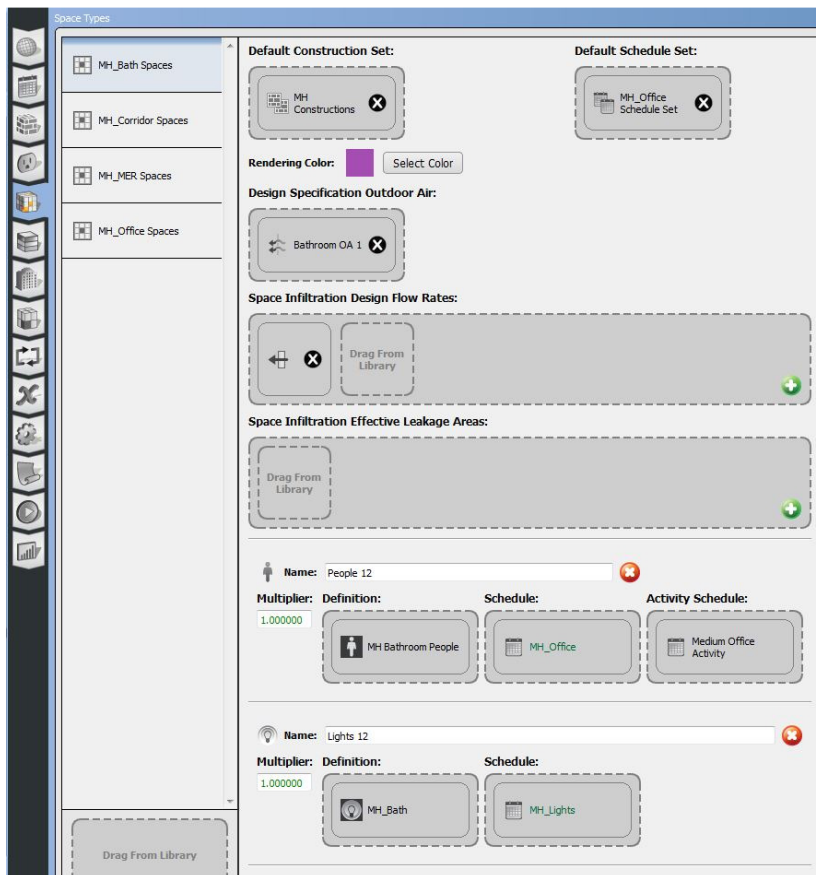


Figure 9. Example Space Type Definition: OpenStudio Interface

Unfortunately the Law of Diminishing Returns comes into play for a modeler when assigning space types, where the assignment of a great number of unique definitions exponentially increase model development and processing time without adding significant fidelity to the assessment results. Modeling experience aids the model with appropriate application of number and quality of space type. Space type assignment leads into appropriate thermal zone assignment, where a modeler may cluster certain building spaces together to evaluate specific HVAC system traits, to evaluate load sharing strategies, or where a range of heating and cooling equipment is incorporated in the facility.

The scope, desired outcomes, and information availability influenced this modeler's decisions on the level of fidelity to apply to each facility and the space type assignments. Generally each building in the group was allowed four unique space types, these are: *Office or Lab*, *Corridor*, *Mechanical Equipment Rooms (MER)*, or *Bathrooms*. In some cases where office occupancy and laboratory occupancy exist in a building then a fifth space type was used to split those definitions apart. Figure 10 illustrates the application of these space type assumptions across a selection of the research buildings.

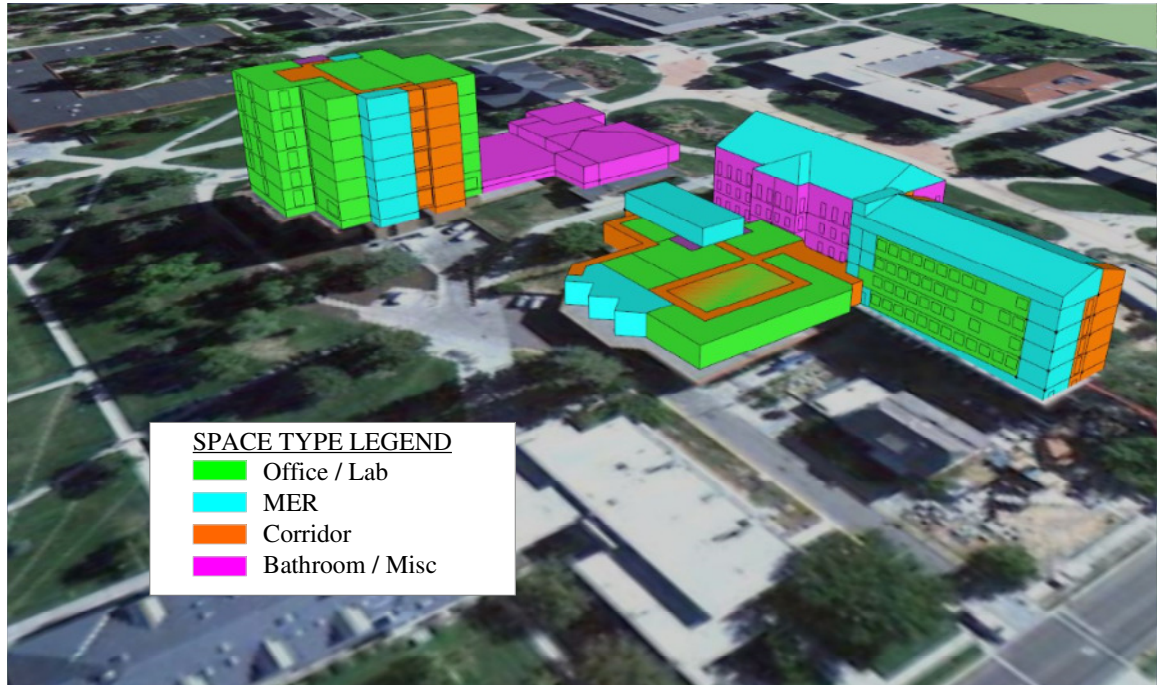


Figure 10: Example Space Type Assignment Distribution

Interior Equipment

As mentioned as a *Big Ugly* and in the context of being a degrading factor to the quality of an Energy Model, interior equipment is an important characteristic of a facility to address. ASHRAE has done testing and published values that a modeler may use to corroborate their assumptions, these are included previously as Table 2, but are fairly narrow of a definition to apply to the unique laboratory facilities in this building group. Interior equipment in Cooley Lab, Leon Johnson, Tietz Hall, and Chemistry BioChemistry is well outside the narrow scope of applicability of the office use definitions accumulated by ASHRAE and previously presented herein as Table 2. Site survey work identified a sample of items in these laboratories and confirmed the assessment that standard ‘office’ type equipment densities cannot be applied directly to

models of these buildings. Electrical equipment definitions in energy models are often applied as a power density in Watts per square foot [W/sqft], which is consistent with the ASHRAE published values. The concept behind the additional power density applied to represent interior equipment is that lots of interior equipment like printers, copiers, and coffee machines release a great deal of heat to their residence space. Similarly the same assumption should be made for laboratory research equipment. A sample list of the types of laboratory equipment identified during spot checking is:

- Steam Autoclaves
- Centrifuges
- Imaging Lasers
- Fume Hoods
- Mass Spectrometry Equipment
- Nuclear Magnetic Resonance Equipment

The sample of equipment identified points to the need for significant power density assignments in the laboratory spaces to translate the real world usage characteristics to the virtual building models. The question presented is “what should that assignment be?” The existence of the laboratory research in these spaces is the driving force behind this energy exchange study, it is because of these *process* loads that the lab buildings create off season demands. Off season meaning, at points these lab buildings need cooling in the winter. To validate the interior equipment assignments in the energy model versions of these facilities the team designed a data acquisition exercise to establish an interior equipment power density with some background corroboration. The subsequent portion of this report details the design, implementation, and results from the interior equipment load power density data acquisitions exercise.

System Types

The buildings in this campus group range over a couple generations of preferred system types and equipment selections and a general system type does not exist. Some of the facilities have heating and cooling, others have only heating. Some of the buildings employ setback schedules and others have constant temperature schedules. Tietz Hall for instance is occupied twenty four hours a day for seven days a week. Actual system type details came from the drawings packages, operation and maintenance staff interviews, and from mechanical equipment room survey. The reality that ongoing maintenance, building usage evolution, and equipment replacement creates deviations between the As-Built record drawings and the actual equipment operating in place dictated the need for a Mechanical Equipment survey, but the time constraints on the project demanded that general system types be modeled with appropriate equipment approximations using the record drawings versus completing an investment level upgraded equipment survey and documentation exercise. System types for each facility as obtained from the project drawings indicated in Table 3 are discussed in following sections.

Leon Johnson

Leon Johnson Hall has had an energy efficiency upgrade with 400 Tons of a modular heat recovery heat pump building level plant which generates heating and cooling water distributed to variable air volume air handlers, reheat coils, and fan coil units throughout the building. In some instances – laboratory spaces – the variable air volume supply air tracks a partner variable exhaust valve whose exhaust flow rate is aligned with a specific fume hood or group of specific fume hoods' operation. The

energy upgrade to LJ in 2011 converted the building from local source generation of building heating and cooling water from Boilers and Chillers to heating and cooling water production from the modular heat recovery heat pumps. The modular nature and freed up space in the basement of LJ adds the ability to increase the capacity of the Heat Pump plant. The heat pumps in LJ are of a Heat Recovery style, which allows them to heat, heat and cool, or cool which has significant energy reduction opportunities when employed in a laboratory facility like LJ. Figure 11 presents a schematic diagram of this type of heat pump's operation.

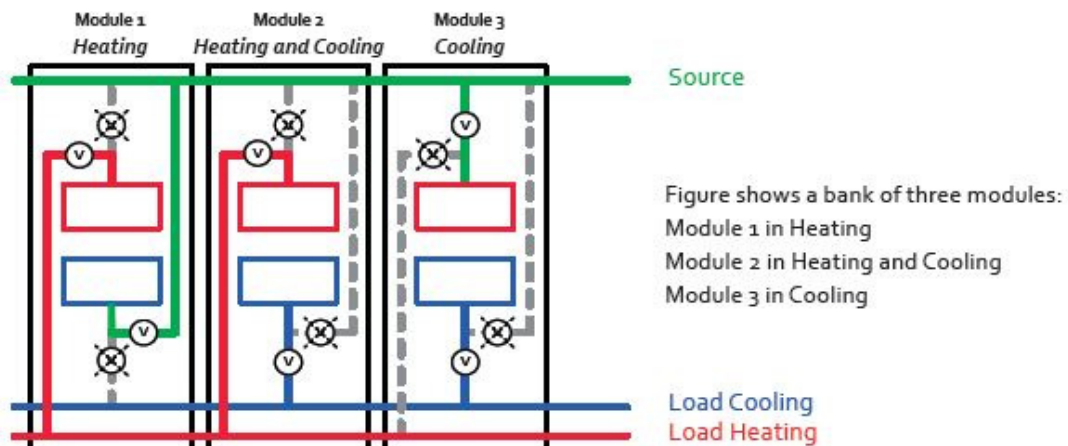


Figure 11. Heat Recovery Heat Pump Operation Schematic⁵

Cooley Lab

Cooley Lab utilizes variable air volume air handlers, with select fan coil units and cabinet unit heaters distributed in some corridor, vestibule, and mechanical spaces. The variable volume air handlers provide supply air to laboratory spaces based on a modulation controlled by either temperature demands or by tracking the volume of exhaust air through a local fume hood or fume hood group. Heating and cooling coils in

the air handlers and other fan coil units is provided by building level generation of chilled water and hot water conversion of campus steam. The chiller in Cooley lab is of the water cooled centrifugal type with a partner cooling tower outside of the north side of the building. The proposed system assessment presented later replaces the local chiller and hot water converter in this building with connection to the Energy Plant in Leon Johnson.

Lewis Hall

Lewis Hall is served primarily by heating and ventilation systems and does not have building wide cooling. In 1999 cooling was added to the basement level of Lewis Hall which is connected to Tietz Hall and became part of the programmatic functions of Tietz. Cooling in the basement portion of Lewis is supported with a direct expansion evaporator coil installed directly in an air handler servicing the basement. The evaporator coil is partnered with a remote air cooled condensing unit located on the adjacent roof of Tietz Hall. Heating in the basement is provided by a hot water converter connected to the campus steam system. The proposed system assessment presented later proposes replacing the direct expansion evaporator coil in the basement air handler with a chilled water coil fed from the LJ Energy Plant and replacing the local steam to hot water converter with a connection to the heating water generated by the LJ Energy Plant. Heating on the remaining floors above is provided with steam radiators and will not be connected to the proposed LJ Energy Plant.

Chemistry BioChemistry Building

The Chemistry BioChemistry Building utilizes variable air volume air handlers, with select fan coil units and cabinet unit heaters distributed in some corridor, vestibule,

and mechanical spaces. The variable volume air handlers provide supply air to laboratory spaces based on a modulation controlled by either temperature demands or by tracking the volume of exhaust air through a local fume hood or fume hood group. Heating and cooling coils in the air handlers and other fan coil units is provided by building level generation of chilled water and hot water conversion of campus steam. The chiller in the Chemistry BioChemistry facility is of the water cooled centrifugal type with a partner cooling tower outside of the north side of the building. The proposed system assessment presented later replaces the local chiller and hot water converter in this building with connection to the Energy Plant in Leon Johnson.

Tietz Hall

Tietz Hall or the Animal Resource Center utilizes variable air volume air handlers, with select fan coil units and cabinet unit heaters distributed in some corridor, vestibule, and mechanical spaces. The variable volume air handlers provide supply air to laboratory spaces based on a modulation controlled by either temperature demands or by tracking the volume of exhaust air through a local fume hood or fume hood group. Heating and cooling coils in the air handlers and other fan coil units is provided by building level generation of chilled water and hot water conversion of campus steam. As part of the Leon Johnson Energy Plant upgrades completed in 2011, with follow up work completed in 2013 the chiller was removed from Tietz and interconnection with the LJ Energy Plant was established.

Montana Hall

Montana Hall is served by just heating and ventilation systems; there are a few exceptions where local direct expansion split system air conditioning is supplied to a few spaces in Montana Hall. Heating is provided with steam radiators connected to the campus steam system.

Wilson Hall

Wilson Hall is served with cooling and heating through window mounted four pipe fan coil units. Ventilation is provided with a constant volume air side system heated and cooled by connection to the building hot and chilled water loops. The source generation for the building heating water is through a steam to hot water converter. The chilled water loop is connected to a steam driven absorption chiller generating chilled water in the summer from the campus steam plant. Proposed system interconnections to LJ Energy Plant will replace the building chilled water source from the existing absorption chiller to the Leon Johnson heat recovery heat pump plant.

Jake Jabs College of Business

The Jake Jabs College of Business (COB) is under construction during the scope of this project. This building is being constructed with a variable air volume system supplied with heating and cooling water. The design source for the building heating and cooling water is the LJ Energy Plant. The scope of construction for the College of Business includes drilling fifty two geothermal exchange wells for connection to the source side the LJ Energy Plant.

MODEL CALIBRATION

As mentioned previously in the context of the *Big Uglies* of energy modeling along with the garbage in garbage out mantra a whole building energy consumption model when developed poorly can be entirely erroneous at predicting or aligning with the actual utility consumption. Many energy engineers, energy modeling professionals and facility managers understand this conundrum and treat model reported claims about energy usage and resource consumption with very little veracity. To combat this common perception and to validate the results presented later it was first crucial to prove that the virtual energy model edition of the buildings mentioned previously perform from a utility standpoint the same as their physical world counterparts. To accomplish this proof a substantial calibration effort is included with this project to tune appropriate input variables to a point that the energy model outputs align with actual consumption data. Before being able to calibrate a model, which is commonly done by adjusting schedules and setpoints within reasonable ranges, the reasonable ranges for certain values need to be established. The values of most interest, which lie outside the scope of supporting standards like the ASHRAE values published herein previously in Table 2, are usage factors relating to the laboratory functions. The subsequent section details a data acquisition exercise employed on this project to obtain information about the energy consumption related to the various laboratory functions.

Metering Plan

The existence of laboratory facilities in the scope of this research project dictated the need for a metering plan. It can generally be said that the laboratory activities dictate the energy usage characteristics of that facility more so than the HVAC needs. The following test plan implementation provide a means to obtain data designed to help translate the laboratory related energy usage into a format that can be processed in a whole building energy simulation. The actual metering plan implemented in this research project is included in the appendices to this report.

Metering Plan Design and Process

The metering plan sub project goal is to obtain data that can inform energy related variables in the building energy simulation models. Two modes of data sets are proposed in the metering plan; one set is for data obtained from measuring the electrical consumption of electrical panels assigned to a selection of laboratory spaces. The data will provide the total consumption in Kilowatt-hours and the peak demand for the panel in Kilowatts. The other mode of data is for obtaining lighting and occupancy use profiles. The second mode of data is assumed to be obtained and transformed into % full consumption profiles and occupancy schedules, similar to the occupancy schedule presented in Figure 8. This data was statistically processed to provide corroboration to the variable assignments used in the Energy Simulation models for that overall laboratory facility.

Two general types of data acquisition instruments were employed by this testing plan. Data Mode 1 obtained Alternating Current measurement on electrical equipment panels. The testing process consisted of installing and monitoring data acquisition tools on a selected set of electrical panels. Electrical panels are chosen based on the downstream connected loads. This process consists of installing current transformers around specified panel feeds and mounting a receiving unit adjacent to the selected panel. The acquired data is designed to inform energy simulation variables that represent usage profiles and maximum electrical demand load for laboratory space process loads. The other Data Mode 2, installation process consists of installing a small light and occupancy logger inside a laboratory space. This logger will need to remain free of obstruction, and will require occupancy acceptance of its presence and placement.

Field work was required to confirm space is available for the installation in the electrical rooms and electrical panel enclosures. Data acquisition unit installation adhered to all applicable electrical codes. Field survey determined installation details. Existing document review established potential electrical panel candidates for metering. The goal of this metering process is to establish laboratory process equipment use. To this end it was important for data validity that electrical panels serving laboratory receptacles only be measured. The following panels were identified in pre field survey drawing review:

CHBC

LP1B – BioChem Inorganic Research Lab – 1st Floor West

LP3L – Organic Chemistry Research Lab – 3rd Floor North

Cooley

L3A – NHF Spec. Laboratory (Room 306)

EML3A – Emergency Power, NHF Lab (Room 306)

The CHBC Panels were selected because panel schedules identified them as unique to the adjacent lab space.

The Cooley Panels, were selected because the panel schedule identified them as unique to the laboratory space in room 306. It is important to understanding the true equipment load in this space that these two panels L3A and EML3A be metered coincidentally. Figure 13 on the following page depicts the installation details presented in the Metering Plan included in this document's appendix. Figure 12, below shows a picture of an electrical panel metering equipment installation.

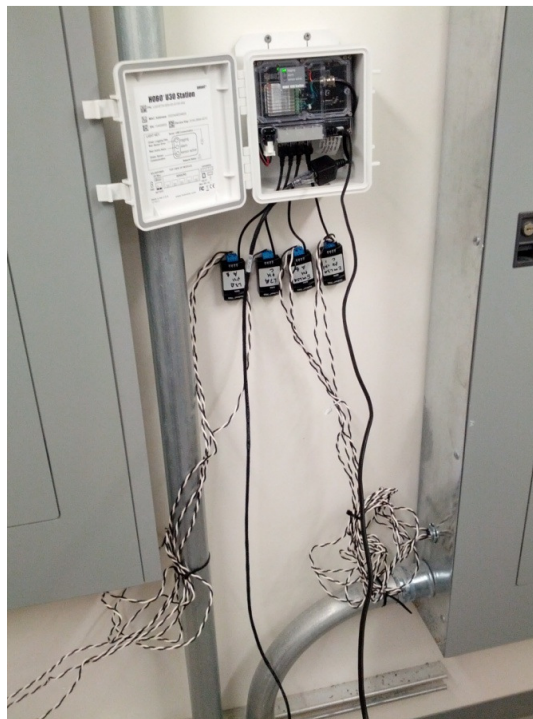


Figure 12. Cooley Lab Electrical Panel Monitoring Installation Picture.

University Information Technology Services was required to authorize and address the unit's Ethernet connection. Installation processes required coordination with University IT departments.

Notification to the Laboratory researchers was required for acceptance of the light and occupancy logger installation. A brief project summary was posted with the light and occupancy loggers and submitted to the laboratory researchers.

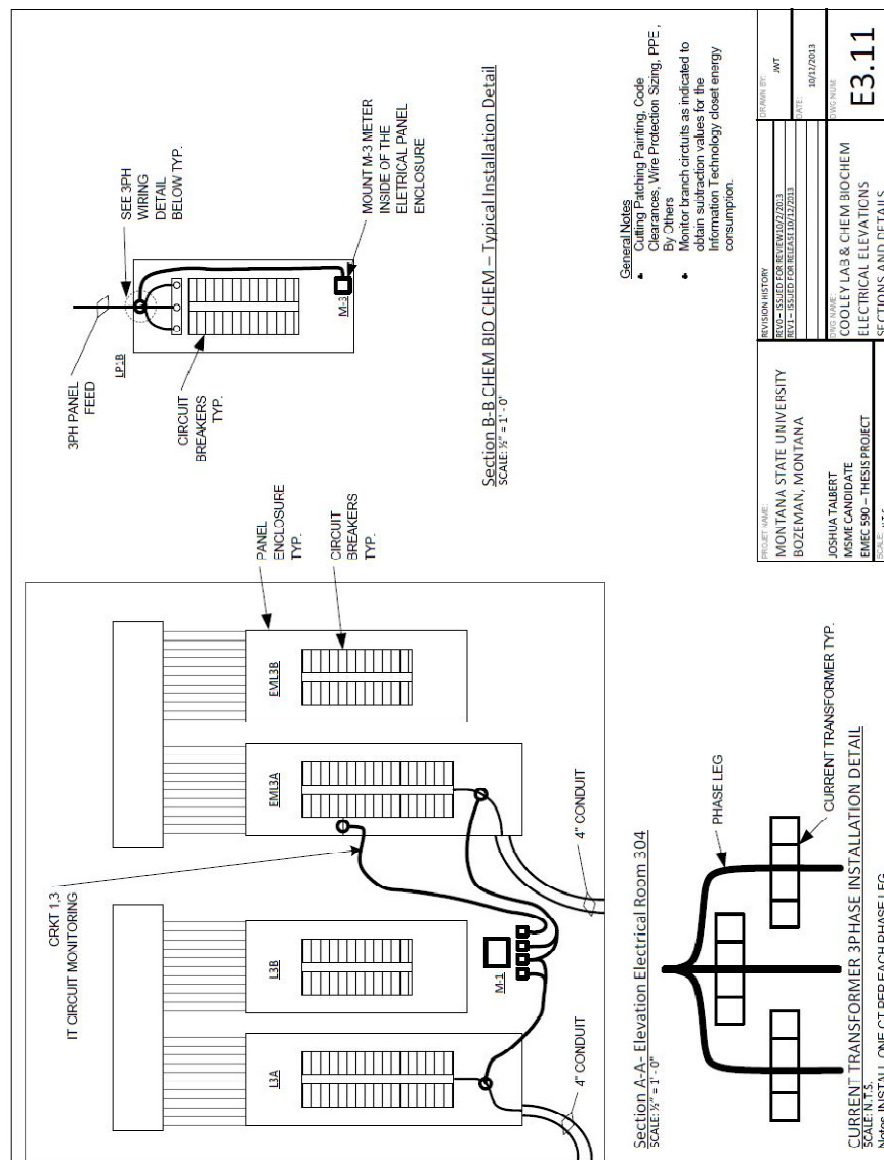


Figure 13. Metering Equipment Installation Detail. Excerpted from the project metering plan document.

Metering Equipment

Metering equipment was purchased specifically for this project and for the installation requirements. The Onset Computer Corp manufactures energy related metering equipment. Table 3 provides a metering equipment schedule. Detailed information about these instruments is provided in the appendices. Figure 14 shows the occupancy and light logger.

Table 4. Metering Equipment Schedule

Equipment Schedule				
Tag	Description	Manufacturer / Make	Details	Quantity
<u>M-1</u>	Data Logger	onset HOBO-U30-ETH	15 Channel Indoor/Outdoor Web Based Data Logger	1
	External Sensor	Magnelab T-MAG-SCT-200	0-200 Amp Split Core AC Current Transformer 333mV Output	8
	Digital Converter	onset FlexSmart S-FS-TRMS A D	333mV Input converted to Digital Signal based on a RMS Value	4
	Data Acquisition Plan	onset HoboLINK - SP-002	Standard Download Plan 1 min logging / 1 hr connection	1
<u>M-2</u>	Occupancy / Light Logger	onset HOBO UX90-006	Occupancy / Light Logger - 12 m range	1
<u>M-3</u>	Data Logger	onset HOBO U12-006	4 channel 3.5mm input Indoor Data Logger	2
	External Sensors	onset CTV-D	0-200 Amp Split-core AC Current Sensor	4
SFTWR	HOBOWare PRO	onset BHW-PRO-CD	Instrument Management Software	1



Figure 14. Light and Occupancy Logger, M-2.

Data

Two modes of data were collected to establish energy usage characteristics for labs spaces. The data acquisition plan described previously was applied to a selection of laboratory facilities. The labs that were chosen were somewhat arbitrarily selected, although selection was not entirely random. The two labs that were monitored were selected from sets of labs identified by the construction documents and site visits as having a electrical distribution panel unique to that lab space. A sample lab was selected from Chemistry BioChemistry and a lab was selected from Cooley Lab. Generally most of the labs in either of these facilities have a unique electrical distribution panel, but occasionally there were labs whose panel also fed some corridor lights, a common area, IT closet, or an alcove. It was important to identify labs which had electric service from a panel without any distribution to a common area. This was important because the purpose of the metering was to identify lab space only energy characteristics.

The equipment installed to monitor the energy usage of the labs has run time features that allowed us to leave them installed for upwards of ninety days. In general data was collected from December 17th, 2013, through the Fall Semester break, to February 19th, 2014. Obtaining data over the break was considered advantageous to the assessment as that holiday break is characterized by very low campus participation and might reveal what some base load energy characteristics are.

The raw data collected is included in the appendices. The general form of the two modes of data was; electrical panel power consumption was measured as an Amperage in each of the supply legs, and the occupancy and lighting information was logged as either a ONE or a ZERO. Occupancy and Lights ON were identified by a ONE value being

logged. Conversion from the amperage measurement to power consumption is a straight forward calculation:

$$\text{Watts} = \text{Volts} * \text{Amps}$$

Figure 13 provides a sample of the data obtained from Chemistry BioChemistry Lab #124. The two modes of data collected in this lab used different time scales during the acquisition phase, so part of the post processing required aligning the two time formats. The electrical panel monitoring equipment logged at a specified interval, chosen as five minutes for this project, whereas the occupancy and light logger logged a value at arbitrary times whenever it sensed a change in state for either the lights or the occupancy. Figure 15, presents the data acquired during the entire period, and then also illustrates a ‘zoomed in’ sample for a specific day.

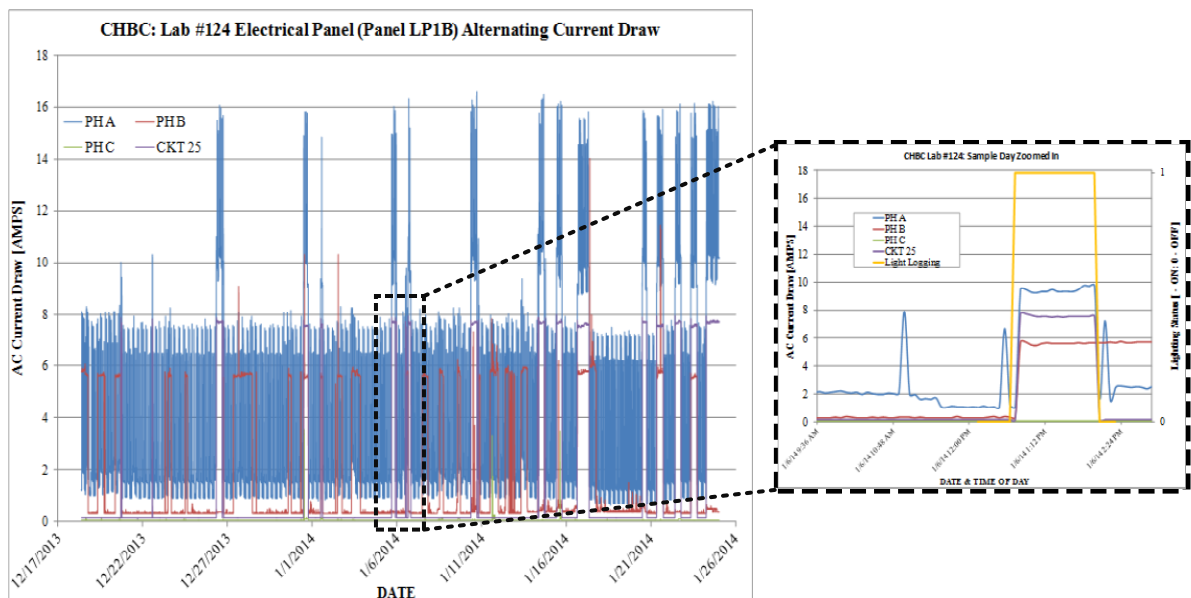


Figure 15. Laboratory Energy Monitoring Sample Data Selection

The raw format of the collected data was difficult to interpret because of the difference in the timestamp of the electrical panel current being measured in five minute increments to the timestamp of the occupancy and light sensed data being recorded in real time. To address this discrepancy some filtering logical organized the lighting and occupancy data into a qualitative statement about the occupancy and lighting status.

Figure 16 presents the filtered occupancy and lighting data for Cooley Lab.

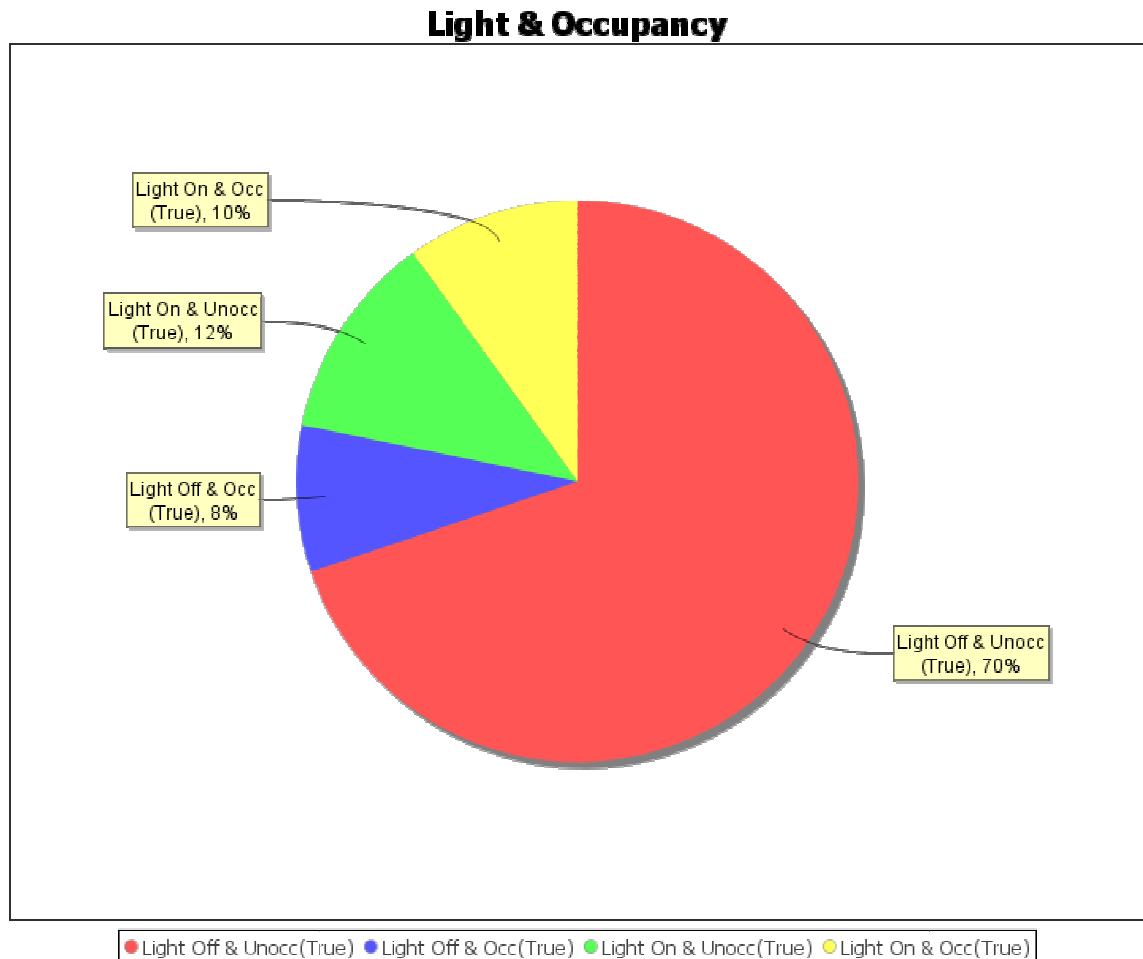


Figure 16. Cooley Lab Filtered Occupancy and Lighting Data

The results that Figure 14 reveal is that this specific lab in Cooley appears to only be occupied and with the lights proved on for ten percent of the metering period. Intuition about how Cooley lab is used raises suspicions about these results. Cooley is an active building, with researchers working away for much more than 2.4 hours on an average day. Additional evaluation of the types of data acquisition tools is necessary to really develop an accurate translation of this information into a suitable form for application in an energy model. One issue with the occupancy logger is that it registered movement from in and out of its viewpoint, and not necessarily in and out of the lab. The occupancy logger was installed on the top of the door frame as means to quantify occupancy of the lab, but the actual results appear to show movement inside the lab that is in and out of the logger's field of view. Another aspect of Cooley Lab is that the lights in the lab spaces is controlled by a day lighting control system, so that the lights may have been turned off by the controller because day light provided enough lighting. The same conditions were typical in the Chemistry BioChemistry data acquisition. Nonetheless the importance of obtaining this data to corroborate the translation of this energy usage into an energy model form cannot be understated.

The form of this information in the energy model environment is a bit different than the form of the collection. The selected way of simulating this information for a lab space in the models is to apply a power density [W/sqft] and a percent of full power load schedule. The role of this data is to back up the assumptions made in that translation from acquired data in a small sample of lab spaces, to a power density and schedule applied to the entire range of modeled labs. By nature a very small sample set is being

stretched to represent a very broad range of assumptions, but even a weak total representation is better for proving validity than no corroborating information at all.

Translation of the data consisted of calculating a value for lab equipment power density and developing a usage schedule. The usage schedule for the lab equipment power developed with this data acquisition exercise ended being ‘tuned’ in the model calibration process discussed in subsequent sections. The laboratory power density was calculated by determining the daily average peak electric draw from each phase and using that in the power equation to determine total watts delivered from that panel on an average basis. This wattage number is divided by the lab space square footage to establish a power density. Table 5 presents the translations applied to lab spaces in this model.

Table 5. Laboratory Equipment Energy Modeling Values

Equip Power Density	Usage Schedule
Cooley Lab	
6.74 W / sqft	
CHBC Lab	
4.91 W / sqft	

Metered Results Discussion

The purpose of the metering project was to provide corroboratory data for the broad brush stroke laboratory definition needed in the energy model. The process, and

technique employed by the metering plan was an effective way to obtain this information and is a good starting point for further detailed analysis of what a lab's process based energy usage is. Limitations of the occupancy and light logger installation above the lab door frames yielded some spurious results, but with some logic applied to the output data insight into the usage profiles or schedules was still available for informing the modeling assumptions. Another weak spot in applying the data obtained to a broad brush stroke space type assignment is that only two labs were in the sample population. There are hundreds of research labs in Leon Johnson, Cooley Lab, and Chemistry Biochemistry alone, and we are in some ways claiming that the two lab sample population is an accurate representation of all of the modeled research spaces, which is certainly is not. But this data is better than none at all when it comes to proving the validity and veracity of energy modeling inputs.

Model Calibration

Calibrated models help defeat the garbage in garbage out. Lots of variables go into working on an energy model, documentation is important to the veracity. Additionally the calibration effort helps address the Big Uglie components of these models. This calibration effort measures occupancy and plug loads. It aligns the weather file by comparing the models to average utility data. In general the research facilities lie outside the scope of any ASHRAE supporting documentation and therefore need to be calibrated based on some measured data to be developed into a viable energy model.

Calibration Technique

International Performance Measurement Verification Protocol (IPMVP) Option D based on the Leadership in Environment and Energy Design (LEED) v3 Energy and Atmosphere Credit 5 requirements, which requires BEM calibration. IPMVP Option D provides a standard for appropriate level of statistical conformance to the actual utility data. Conformance is shown at twenty percent [20%] or less Mean Bias Error.

$$\text{MBE [\%]} = \frac{\frac{\sum_1^n \text{Error}}{n}}{\frac{\sum_1^n \text{Actual}}{n}}$$

Two types of loads on a building

- Cyclic – based on either annual or diurnal cycles
- Periodic – based on a physical schedule

Examples of measuring these two types of loads are using current transducers on electrical panel feeds obtains plug loads which are of a periodic nature. Measuring space temperature or HVAC equipment load profiles is an example of a cyclic load.

Calibration Results

Each building was calibrated, by tuning certain input parameters based on further information. This modeling process follows a pattern of a variable assignment beginning simple and progressing to complex. Figure 14 shows the consumption profiles of Tietz Hall, showing a calibration error of 6% MBE on the natural gas consumption and -1% on the electricity consumption.

PROPOSED SYSTEM ANALYSIS

Proposed System Description

A central plant heat pump system called an Energy Plant already exists in Leon Johnson. The proposed system connections calls for tying all of the project buildings into the Energy Plant by connecting downstream of the individual chilled and heating water production equipment. The benefit of replacing the individualized energy generation with the central Energy Plant becomes the interconnected buildings ability to share energy. The configuration of these heat pumps, also known as heat recovery chillers, allows simultaneous distribution of heating and cooling water. These heat recovery chillers can actually move heat from a building rejecting heat to a building calling for heat. The proposed system schematic brings additional increases in the pumping energy associated with these buildings as the pumps move energy between building along interconnections longer then in the baseline configuration. However the additional pumping energy does not approach the inefficiencies in generating energy in isolation for the multiple facilities. The proposed system schematic and a discussion follow.

System Schematic

The system schematic identifies some important components in this low carbon source energy assessment. The heat recovery chillers or heat pumps that make up the Leon Johnson energy plant have six piping connection to them. Four of these connections serve the load side of the system, providing both and simultaneous, chilled water and heating water, which means as long as neither the total cooling load or total heating load is above the total plant size then the plant can serve both loads without a call for heat or cooling from either the local building level equipment or from the campus central plant system. The remaining two piping connections provide the source loop side of these heat pumps where there are some source side energy connection options. There are two very low carbon source energy connections designed as the primary source side connections, these are a solar thermal array and the ground loop well bore field. Additionally a steam connection and a cooling tower are included on the source loop to allow mechanical input and rejection of heat if the capacity of the low carbon sources is inadequate or for energy production when other components are down for maintenance or repair.

Proposed Simulation Results

The calibrated group of energy models indicates that with the current energy plant sizing not all of the required annual heating energy can be produced by the energy plant. Some steam input from the campus central steam system is required to meet all of the building loads. System run time estimates establish the operation characteristics and

balance points between the energy plant and campus steam systems. Figure 16 illustrates the various run time modes of the proposed heat plant.

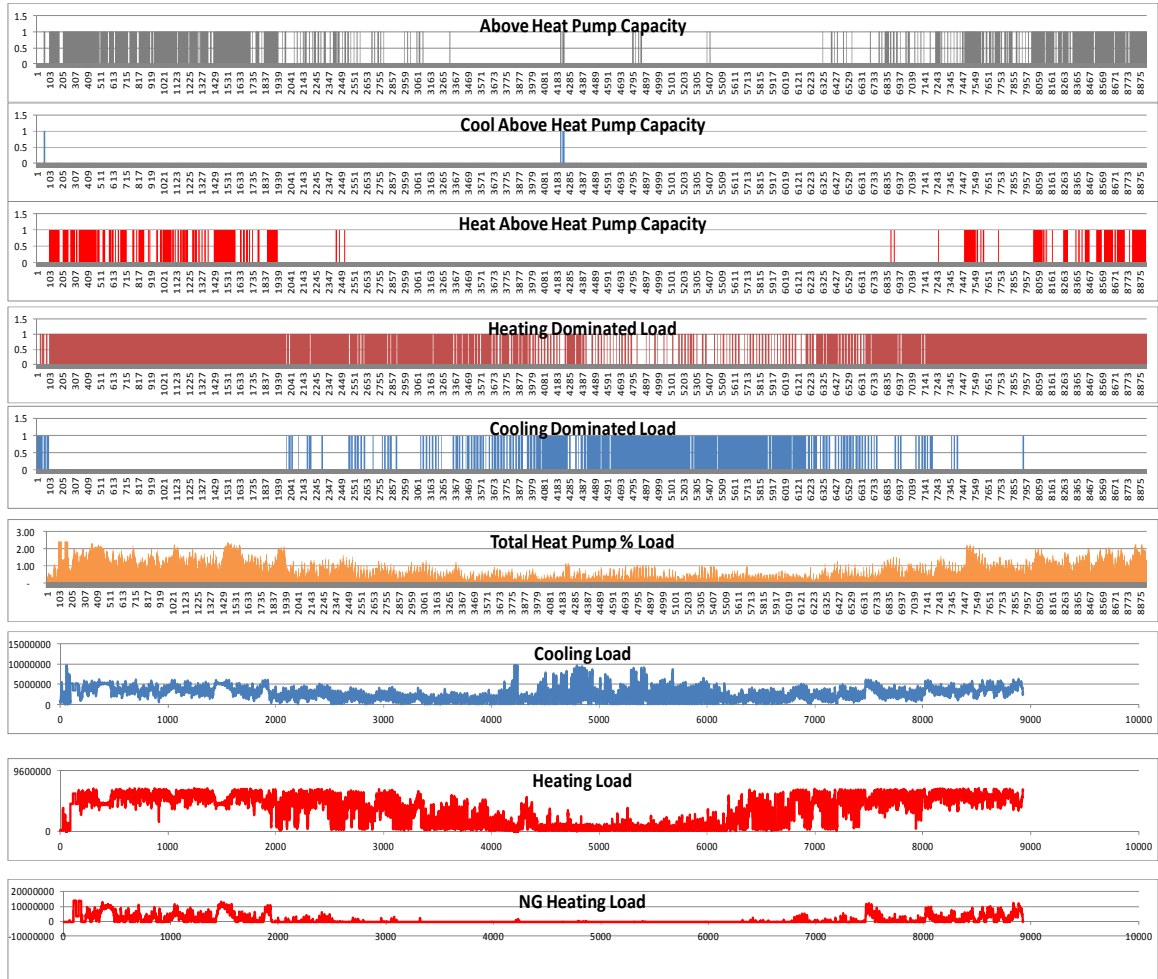


Figure 19. Energy Plant Runtime Modes.

Final operational analysis of the proposed system interconnections yield some promising results and predict with a previously discussed level of accuracy legitimate greenhouse gas and source energy reductions. Table 6 reveals these results.

Table 6. Proposed and Baseline Energy and Greenhouse Gas Results

	Baseline Results (Sum of Calibrated Models)	Proposed Results	% Reductions
EUI :	273.6 [kBtu / sqft / yr]	253.8 [kBtu / sqft / yr]	7.24%
GHGe:	4941.1 [MtCO ₂ e / yr]	4237.6 [MtCO ₂ e / yr]	14.26%

Notes:

Source Energy Use Intensity = EUI

Greenhouse Gas Emission Equivalent = GHGe

Natural Gas 69%

Electricity (-38%)

CONCLUSIONS

Project Assessment

Project results support capital expenditure for conversion of these project buildings into a grouped common central energy plant format. This central plant conversion transfer's energy from a fossil fuel source to an electric source and the results confirm the intuition that is that case. Additional energy reduction are apparent as well, and this design proposal achieves those not by just switching source energy from fossil fuel to electrics, but which is apparent by natural gas usage declines sharply, by almost seventy percent, without a similar order of magnitude increase of Electrical energy. Electrical consumption as reported by the proposed building models increase only thirty eight percent.

The secondary project purpose to demonstrate the effectiveness of the EnergyPlus, SketchUP, and OpenStudio partnership is inherent in the production of the final results. Simple analysis of this researcher's previous energy modeling projects yields an average production value of approximately one hour of modeling time required for every one hundred square feet of simulated building area (0.01 hrs / sqft). Based on the total project square footage of 439,091, historical project time involvement is estimated at three thousand nine hundred and ninety five hours (3,995 hours). The recorded project time for this project was logged at one thousand two hundred and forty two hours (1,242). A reduction of time that represents a total project production effort that is over three times faster than historical modeling methods. This secondary result is

huge, and important to note for the rapidly burgeoning energy modeling services and tools market.

Recommendations for future work

Future work recommendations based on this project and results include:

- Increased equipment and occupancy metering
- Stochastic based model calibration
- Heat Pump ground source loop analysis
- Detailed electric source energy analysis and carbon component verifications
- OpenStudio work flow optimization and analysis

REFERENCES CITED

1. EnergyPlus: DOE's Next Generation Simulation Program, Drury B. Crawley, Ph.D. U.S. Department of Energy: Building Technologies Program 2/16/2010
2. 2011 Buildings Energy Data Book, US DOE, March 2012
3. Center for Building Science Newsletter, Summer 1998, pg 6.
http://eetd.lbl.gov/newsletter/cbs_nl/nl18/cbs-nl18-energyplus.html, Dru Crawley
4. www.doe2.com
5. ClimaCool, Sales Brochure SHC onDEMAND Modular Chillers UCH series, Doc# SHC-R_Brochure, 2010

APPENDICES

APPENDIX A

PROJECT PROPOSAL



April 12th, 2013

Dan Stevenson, PE, LEED-AP
 Assistant Facilities Director
 Facility Services
 PO Box 172760
 Bozeman, MT 59715

RE: Talbert MSME Thesis Project Proposal

Good Afternoon Dan,

It is with great excitement that I present you with the following proposal for energy simulation services. The proposal to conduct an energy modeling, calibration, and low carbon assessment project in collaboration with the College of Engineering (College) and the Facilities Department (Department) will provide the rare opportunity to align academic and operation demands. My skills and expertise as a professional building energy consultant and design engineer will bring the appropriate experience to the table to bridge the information exchange and align the various expectations. Multi-faceted benefits of this project are:

- The Department collaboratively defines the direction and necessary project deliverables
- The College gains access to relevant and exciting learning modules and undergraduate participation potential
- The validated energy models developed can be maintained by the Department for future energy assessments
- Functions as a test case for future, broader campus energy simulation
- Fulfills Josh Talbert's graduate thesis requirements

At your convenience please review the attached information, including a proposed scope of services, a project budget, and a proposed facility selection. Additional faculty members included on the project committee are: Kevin Amende, Pravin Bhiwapurkar, and Erick Johnson. The contributions from each of these gentlemen from the Architecture and Engineering departments will provide valuable perspective and assistance developing models, modeling strategies, and experiments.

Please do not hesitate to let me know if you have any questions or comments. I am very excited to work with you on this spectacular opportunity contributing towards the University's sustainability goals. Thank you for your time and consideration.

Sincerely,

A handwritten signature in blue ink, appearing to read 'Josh W. Talbert'.

Joshua W. Talbert, PE, LEED-AP
 MSME Graduate Candidate Spring 2014
jwitalbert@gmail.com
 Roberts Hall 105

**Department of
 Mechanical &
 Industrial Engineering**

P.O. Box 173800
 Bozeman, MT 59717-3800

Tel (406) 994-2203
 Fax (406) 994-6292

Cc: Amende, Bhiwapurkar, Johnson, Jenkins



Campus Building Energy Study: Plant Level Energy Exchange

Joshua Talbert

Montana State University

Spring 2013: April 12, 2013

Master of Science Mechanical Engineering: Thesis Project Proposal

Objective: Assess energy requirements of interconnected buildings factoring potential geothermal, solar thermal, and existing central heat pump system efficacy. Evaluate low carbon energy resources.

Scope of Services:

- Model select facilities (see Appendix)
- Establish internal process energy profiles
 - Review existing data
 - Interview facilities and academic personal
 - Measure internal process energy criteria
 - Develop data acquisition experiments
 - Incorporate undergraduate participation opportunities
- Model central plant systems
- Review available utility data
 - Identify needs for additional data granularity
 - Develop data acquisition experiments
- Calibrate computer building models to utility data
 - Verify model to acceptance of *International Performance and Measurement and Verification Profile* (IPMVP): option D
- Assess low carbon contributions
 - Equipment retrofit options
 - Local energy resources
 - Load reduction efforts
 - Incorporate undergraduate participation opportunities
- Develop learning modules based on project experience
 - Presentations
 - Papers
 - Articles
 - Classroom lectures
 - Experiments

Process: Utilize established and developing building simulation tools to develop climatological simulation components. Conduct interview / review meetings between associated academic and operational departments. Review available utility and cost data, develop and implement data acquisition exercises. Develop energy simulations; establish criteria for appropriate model fidelity. Assess low carbon energy concepts. Establish and defend process energy modeling criteria. Report on interconnected contributions and energy sharing strategies. Establish appropriate interval for project review with academic and operation committee members.

Department of Mechanical & Industrial Engineering

P.O. Box 173800
Bozeman, MT 59717-3800

Tel (406) 994-2203
Fax (406) 994-6292


Campus Building Energy Study: Plant Level Energy Exchange

Joshua Talbert

Montana State University

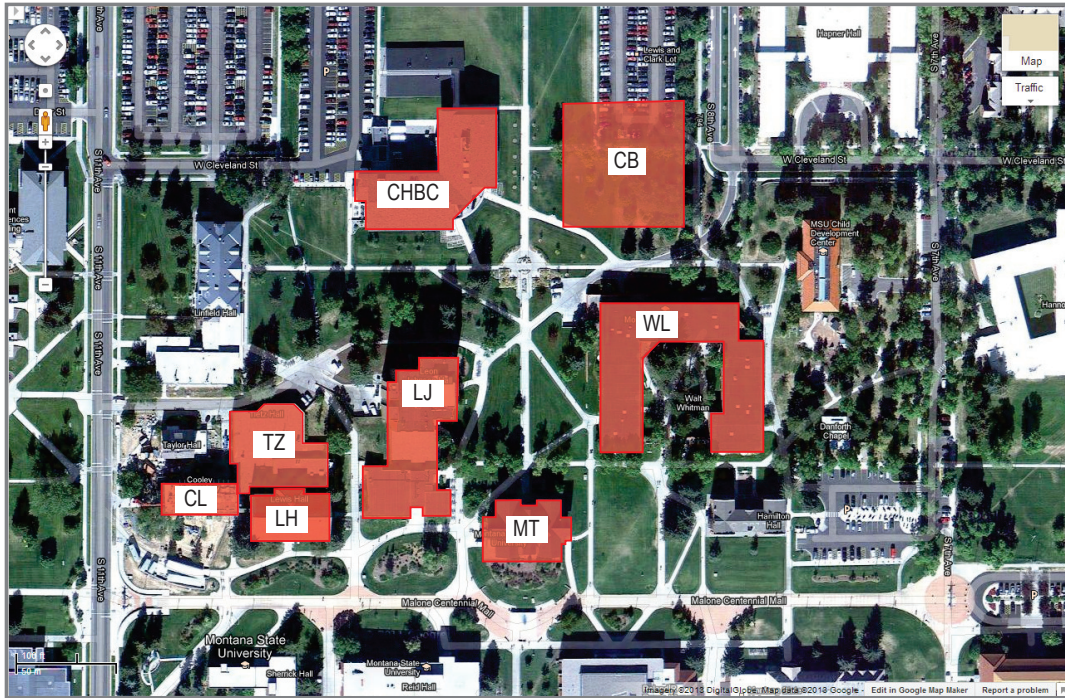
Spring 2013: April 12, 2013

Master of Science Mechanical Engineering: Thesis Project Budget

				FY 2013	FY 2014
Tuition (est)					
Fall 2013	\$	2,398			
Spring 2014	\$	2,398			
Sub Tot			\$ 4,796		\$ 4,796
Health Insurance					
Fall 2013	\$	955			
Spring 2014	\$	955			
Sub Tot			\$ 1,910		\$ 1,910
Fees					
Fall 2013	\$	618			
Spring 2014	\$	618			
Sub Tot			\$ 1,236		\$ 1,236
Summer Research Position					
Summer 2013	\$	2,750 /mo	\$ 11,000		
May, June, July, August		4 mo			
Sub Tot			\$ 11,000	\$ 5,500	\$ 5,500
Graduate Research Assistant (GRA) Position					
Fall 2013					
Spring 2014	\$	1,500 /mo			
Sept 13 - May 14		9 mo	\$ 13,500		
Sub Tot			\$ 13,500		\$ 13,500
Instrumentation and Equipment Purchase (estimated and Not to Exceed)					
			\$ 3,000		\$ 3,000
Totals				FY 2013	FY 2014
				\$ 5,500	\$ 29,942



Appendix 1: Proposed Facility Selection



<i>Legend</i>	<i>Abbrv.</i>
Leon Johnson	LJ
Tietz Hall	TZ
Lewis Hall	LH
Cooley Laboratories	CL
Montana Hall	MT
Wilson	WL
College of Business	CB
Chemistry / Biochemistry	CHBC

**Department of
Mechanical &
Industrial Engineering**

P.O. Box 173800
Bozeman, MT 59717-3800

Tel (406) 994-2203
Fax (406) 994-6292

APPENDIX B

METERING PLAN



Receptacle and Equipment Loads Metering Plan

Montana State University – Bozeman
Bozeman, MT

EMEC 590 – Thesis Project
Joshua Talbert

**Department of
Mechanical &
Industrial Engineering**

P.O. Box 173800
Bozeman, MT 59717-3800

Tel (406) 994-2203
Fax (406) 994-6292

Revision History

Revision	Date	Description of Change
0	9/20/2013	Initial DRAFT Release for Team Member Review
1	10/1/2013	Field Survey Updates
2	10/10/2013	IT/Networking and Electrical Engineer Feedback
3	10/12/2013	Issued for RELEASE

1. Introduction	4
1.1. <i>Project Description</i>	4
1.2. <i>Building Descriptions</i>	4
1.2.1. <i>Cooley Laboratory</i>	4
1.2.2. <i>Lewis Hall</i>	4
1.2.3. <i>Tietz Laboratory</i>	4
1.2.4. <i>Leon Johnson Hall</i>	4
1.2.5. <i>Montana Hall</i>	5
1.2.6. <i>Wilson Hall</i>	5
1.2.7. <i>College of Business</i>	5
1.2.8. <i>Chemistry and Biochemistry Building</i>	5
1.3. <i>Project Outcome</i>	5
1.4. <i>Document Purpose</i>	5
1.5. <i>Project Team</i>	6
2. Test Plan Details	6
2.1. <i>Process</i>	6
2.2. <i>Test Preparation</i>	7
2.3. <i>Testing</i>	7
2.3.1. <i>Documents</i>	7
2.3.2. <i>Procedure</i>	7
2.3.3. <i>Commissioning</i>	8
2.3.4. <i>Data Handling</i>	8
2.4. <i>Post Testing Requirements</i>	8
Appendix	9

1. Introduction

1.1. Project Description

Montana State University (MSU) in Bozeman operates a selection of academic research laboratories. Through the University's commitment to energy use reduction a central plant heat pump system was installed to serve a pod of adjacent buildings. The buildings in the pod include laboratory facilities as well as more predictable seasonal based load facilities. Josh Talbert's graduate research work is modeling – through computer simulation – the load profiles of this building pod. The research project is designed to assist the University Facility's Department with balancing the load profiles of the buildings connected through the installed central heat pump plant.

The testing project herein is designed to provide additional data on the energy use attributed to the laboratory activities directly. Energy Simulation is the process of assigning values to the variables unique to a specific facility or process as a means to develop statistical approximations of the actual energy use at any given time or operating condition. The activities attributed to the occupants and internal processes are much harder to statistically define than are the tangible and steady state properties such as insulation characteristics or mechanical equipment. The laboratory facilities that MSU maintains have such robust energy processes going on internally that off season demands show on the utility bills. These facilities require cooling in the winter and heating in the summer. The installed central plant heat pump facility will take advantage of complementary load profiles of the pod of buildings.

1.2. Building Descriptions

A brief description of the facility type and current energy use annual profile is described below for the buildings included in research project pod.

1.2.1. Cooley Laboratory

Cooley Laboratory (CL) is National Health Foundation specification facility designed for biological research. Annual Energy use is characteristic of off season demand loads.

1.2.2. Lewis Hall

Lewis Hall (LH) is a primarily an administrative / office area for the Ecology, Computational Biology and Microbiology Departments. The basement of Lewis Hall is retrofitted as a laboratory space serving as additional space for adjacent Tietz Hall. The remaining floors of Lewis Hall are characterized by natural and diurnal seasonal and daily energy use.

1.2.3. Tietz Laboratory

Tietz Laboratory (TZ) is a laboratory facility serving as the Animal Resource Center for University Research. Annual Energy is characterized by natural and diurnal seasonal and daily energy use.

1.2.4. Leon Johnson Hall

Leon Johnson Hall (LJH) is an eight story laboratory facility that houses Earth, Ecology, and Biological Research laboratories. Annual Energy use is characteristic of off season demand loads.

1.2.5. Montana Hall

Montana Hall (MH) is an office and administrative facility serving the entire University that includes the Office of the Registrar and Students Accounts. Annual Energy use is characterized by natural and diurnal seasonal and daily use.

1.2.6. Wilson Hall

Wilson Hall (WH) houses many departments in the College of Letters and Sciences, including English, History, Mathematics, and the College Dean's office. Annual Energy use is characterized by natural and diurnal seasonal and daily use.

1.2.7. College of Business

The Jake Jabs College of Business (COB) is an under-construction facility designed to serve the College of Business. The facility is characterized as a classroom building and is expected to have natural and diurnal seasonal and daily energy consumption.

1.2.8. Chemistry and Biochemistry Building

The Chemistry and Biochemistry Building (CHBC) houses research laboratories for these departments at MSU, as well as a small auditorium. Annual Energy use is characterized as natural and diurnal seasonal and daily loads with a steady off season demand.

1.3. Project Outcome

This metering sub project goal is to obtain that can inform energy related variables in the building energy simulation models. To modes of data sets are proposed in this Metering Plan, one set is of data obtained from measuring the electrical consumption of electrical panels assigned to a selection of laboratory spaces. The data will provide the total consumption in Kilowatt-hours and the peak demand for the panel in Kilowatts. The other mode of data is a lighting and occupancy use profiles. The second mode of data is assumed to be obtained and transformed into % full consumption profiles and occupancy schedules. This data will then be statistically processed to provide corroboration to the variable assignments used in the Energy Simulation models for that overall laboratory facility.

1.4. Document Purpose

This document serves as the test plan for obtaining the necessary data. This plan provides pre, post, and during testing procedures. Testing procedures will be completed by a project team with members ranging across University Departments. The University Facilities Department is providing support for the installation of testing apparatus, while data manipulation and acquisition will be conducted by the academic researchers. The goal of this document is to provide clear detail and straightforward expectations for each Team Member.

1.5. Project Team

The project team members and their anticipated roll are as follows:

Joshua Talbert, PE, LEED-AP

Master's Degree Candidate Mechanical Engineering
 Lead Researcher

Kevin Amende, PE

Professor
 Academic Project Advisor

Dan Stevenson, PE, LEED-AP

Assistant Director, Facilities Services
 Facility Department Project Advisor

Matt Carr, PE, LEED-AP

Resource Conservation Specialist
 Facilities Services Project Engineer

Chelsea Guenette

Master's Degree Candidate Mechanical Engineering
 Researcher

Tom Nowak

Electrician/Foreman
 Project Electrician

2. Test Plan Details

2.1. Process

Two general types of data acquisition instruments are employed by this testing plan. Data Mode 1 is obtaining Alternating Current measurement on electrical equipment panels. The testing process consists of installing and monitoring data acquisition tools on a selected set of electrical panels. Electrical panels are chosen based on the down stream connected loads. This process consists of installing current transformers around specified panel feeds and mounting a receiving unit adjacent to the selected panel. The acquired data is designed to inform energy simulation variables that represent usage profiles and maximum electrical demand load for laboratory spaces. The other Data Mode 2, installation process consists of installing a small light and occupancy logger inside a laboratory space. This logger will need to remain free of obstruction, and will require occupancy acceptance of it placement.

2.2. Test Preparation

Field work is required to confirm space is available for the installation in the electrical rooms. Data acquisition unit installation will adhere to all applicable electrical codes. Field survey will determine installation details. Existing document review established potential electrical panel candidates for metering. The goal of this metering process is to establish laboratory process equipment use. To this end it is important for data validity that electrical panels as unique to laboratory receptacles only be measured. The following panels were identified in pre field survey drawing review:

CHBC

- LP1B – BioChem Inorganic Research Lab – 1st Floor West
- LP3L – Organic Chemistry Research Lab – 3rd Floor North

Cooley

- L3A – NHF Spec. Laboratory (Room 306)
- EML3A – Emergency Power, NHF Lab (Room 306)

The CHBC Panels were selected because panel schedules identified them as unique to the adjacent lab space.

The Cooley Panels, were selected because the panel schedule identified them as unique to the laboratory space in room 306. It is important to understanding the true equipment load in this space that these two panels L3A and EML3A be metered coincidentally. See installation details in the appendices.

University Information Technology Services is required to authorize and address the units Ethernet connection. Installation processes will require coordination with University IT departments.

Notification to the Laboratory researchers will be required to obtain acceptance of the light and occupancy logger installation. A letter from this Test Team may be adequate to inform the Laboratory Researchers.

2.3. Testing

2.3.1. Documents

Site Plans, Electrical Riser Diagrams, Equipment Schedules, and Installation Details are provided in the Appendix.

2.3.2. Procedure

Meter installation will be conducted by the University Electrician; the University Facilities Department will be the liaison for the coordination of this work. All required code, clearances, physical access, and attention to personal protective equipment will be the responsibility of the University Electrician. Academic researchers will participate with data acquisition tool installation as observers only. Upon successful calibration and commissioning of acquisition instruments data will be obtained weekly. Weekly access will be required for the Academic Researchers for interval data downloads, and ongoing

commissioning. A web-based data logger is proposed for installation in Cooley Laboratories because of the significant access restriction in that facility. Chem Biochem electrical panels are accessible from public spaces. It is expected that keyed access will be provided to the Academic Researchers for unlocking the CHBC electrical panels.

Equipment purchase requirements may dictate breaking data acquisition into Phases. Project meetings will inform any phasing decisions.

2.3.3. Commissioning

Meter commissioning will be completed prior to recorded data acquisition. In addition to meter installation the University Electrician will aid with instrument calibration and commissioning. It is assumed, at this time, that commissioning and data acquisition will take only about a half hour of extra time during meter installation. University Electrician will be expected to furnish Amp Clamps or a similar tool to aid the calibration of the acquisition products. Academic Researchers will provide commissioning documents and all required software.

2.3.4. Data Handling

Weekly data downloads will be handled by the Research team.

An Electrical Panel key for Chem BioChem is needed by the Academic Researchers.

2.4. Post Testing Requirements

Patching, and painting to be completed as deemed necessary by the facilities department.
All installed Metering Equipment will be returned to the Researchers.

Appendix

Equipment Schedule							
Tag	Description	Manufacturer / Make	Details	Quantity	Unit Cost		Sub Total
<u>M-1</u>	Data Logger	onset HOBO-U30-ETH	15 Channel Indoor/Outdoor Web Based Data Logger	1	\$ 694	ea	\$ 694
	External Sensor	Magnelab T-MAG-SCT-200	0-200 Amp Split Core AC Current Transformer 333mV Output	8	\$ 55	ea	\$ 440
	Digital Converter	onset FlexSmart S-FS-TRMS A D	333mV Input converted to Digital Signal based on a RMS Value	4	\$ 105	ea	\$ 420
	Data Acquisition Plan	onset HoboLINK - SP-002	Standard Download Plan 1 min logging / 1 hr connection	1	\$ 120	yearly	\$ 120
<u>M-2</u>	Occupancy / Light Logger	onset HOBO UX90-006	Occupancy / Light Logger - 12 m range	1	\$ 199	ea	\$ 199
<u>M-3</u>	Data Logger	onset HOBO U12-006	4 channel 3.5mm input Indoor Data Logger	2	\$ 113	ea	\$ 226
	External Sensors	onset CTV-D	0-200 Amp Split-core AC Current Sensor	4	\$ 115	ea	\$ 460
SFTWR	HOBOWare PRO	onset BHW-PRO-CD	Instrument Management Software	1	\$ 99		\$ 99

Equipment Total \$ 2,658

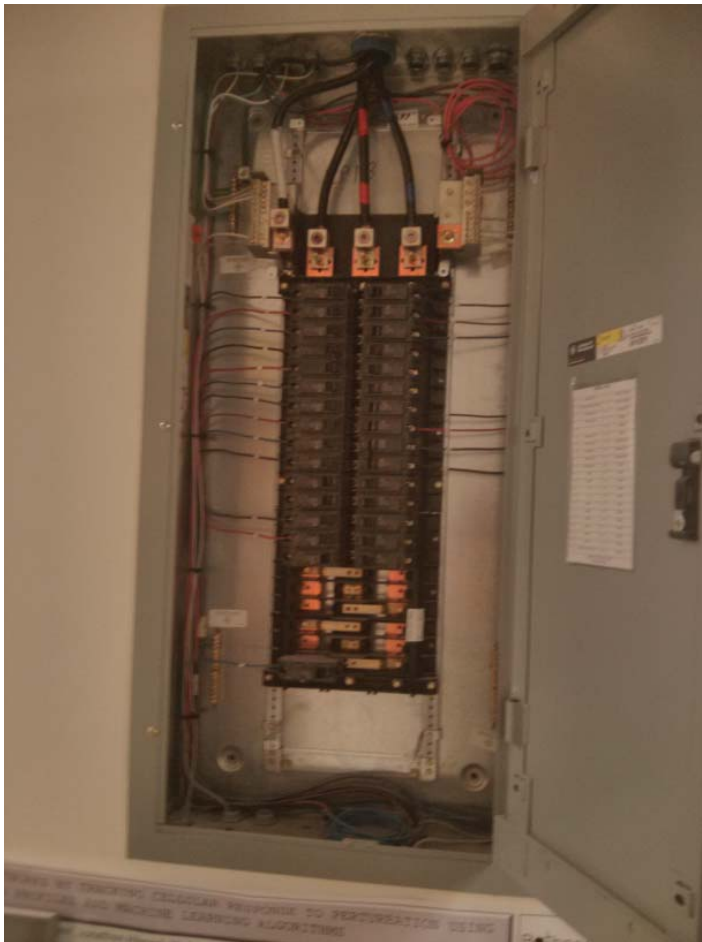
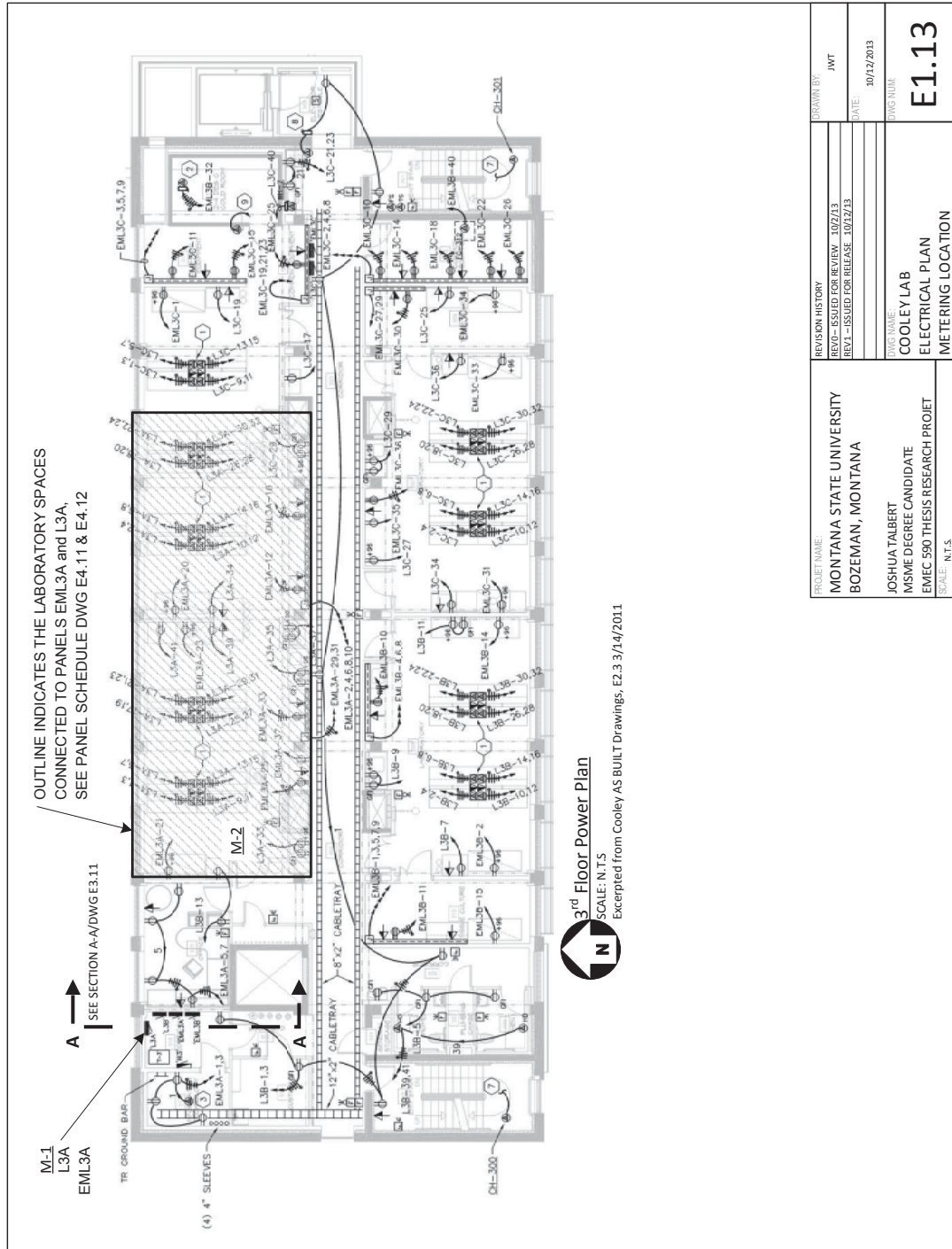
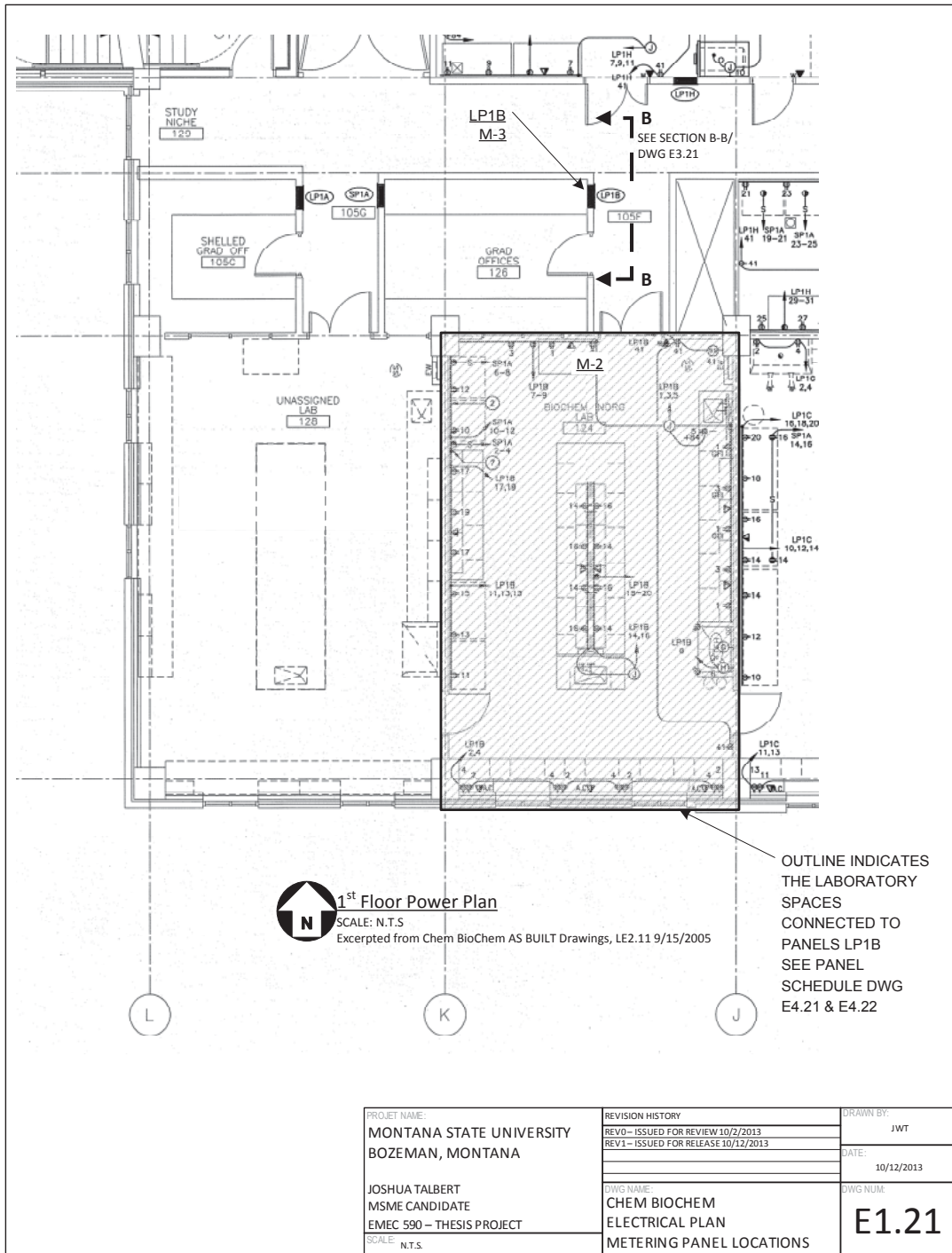
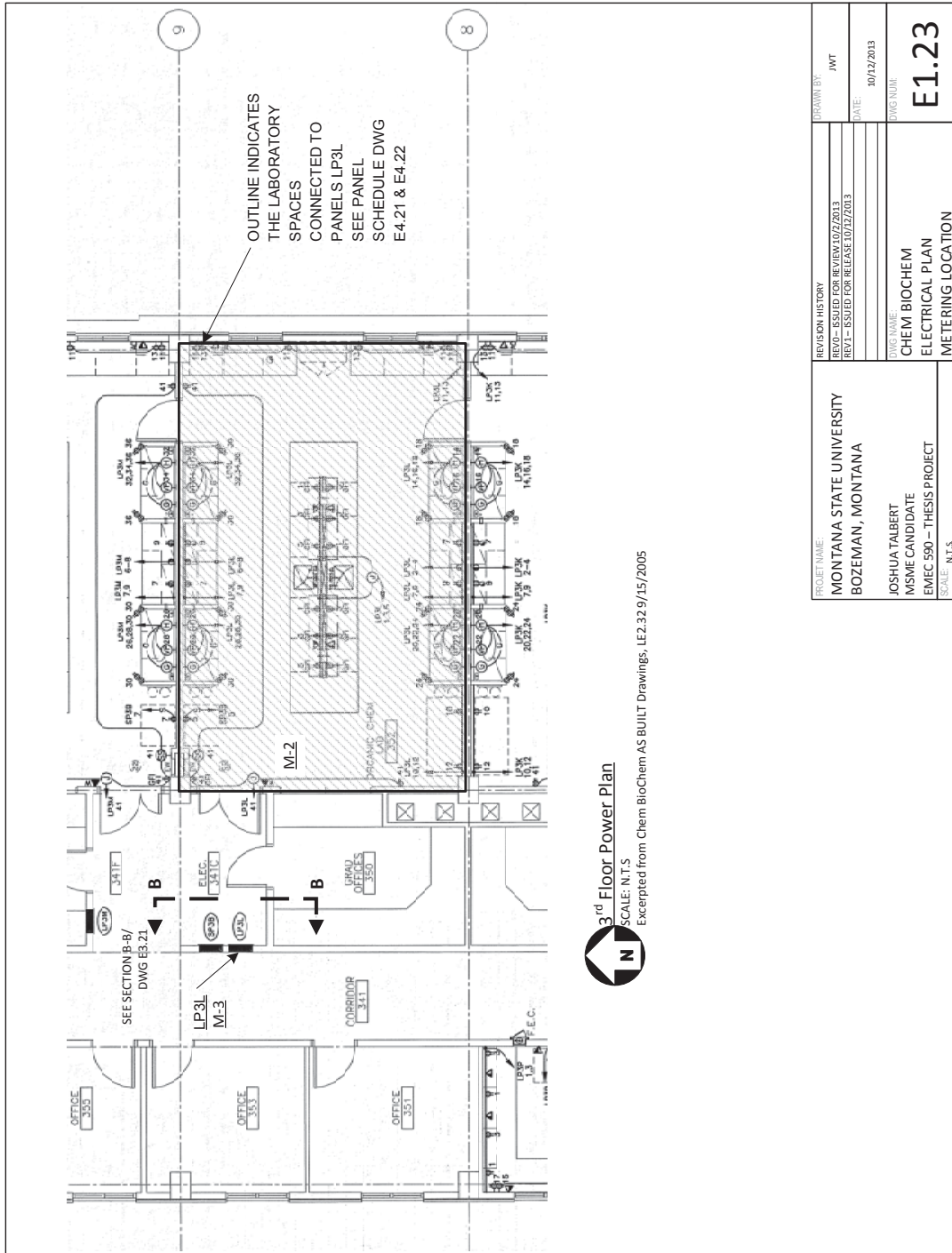


Figure 1: Panel LP1B opened, shows top feed, 208V/3 ϕ , see detail drawings for specifics of each panel.







L3A PANEL SCHEDULE SCALE: N.T.S. Excerpted from COOLEY LAB AS BUILT Drawings; E04 3/14/2001	PROJECT NAME:	REVISION HISTORY	DRAWN BY:
	BONTANA STATE UNIVERSITY	REV0 - ISSUED FOR REVIEW 10/12/2013	JMT
	BOZEMAN, MONTANA	REV1 - ISSUED FOR RELEASE 10/21/2013	
		DATE:	10/12/2013
	OWNER NAME:	DWG. NUM.	
JOSHUA TALBERT	COOLEY LAB		E4.11
MISME CANDIDATE	PANEL SCHEDULES		
EMEC 590 - THESIS PROJECT			
SCALE: N.T.S.			

PANELBOARD SCHEDULE

PANEL: EML3A MAIN BREAKER: 150A MOUNTING: SURFACE FEED LOCATION: BOTTOM MINIMUM AIC: 10KAMPS
CHARACTERISTICS: 120/208V,3Ø,4W FEEDERS: SEE ONE-LINE RISER DIAGRAM MAIN BUSS: 225A
MISCELLANEOUS: **PROVIDE FEED-THRU LUGS**

WIRE SIZE	ID	LOAD DESCRIPTION	KVA LOAD ØA ØB ØC	CIRCUIT BREAKER #	CKT #	CIRCUIT BREAKER #	CKT #	CIRCUIT BREAKER #	ØA ØB ØC	KVA LOAD	LOAD DESCRIPTION	WIRE ID
#12 E	R	DATA RACK - I.T. ROOM 223	0.50	20A-1P	1	20A-1P	1	20A-1P	0.18		CO - RACEWAY, LAB 306	R #12
#12 R	CO	I.T. ROOM 223	0.54	20A-1P	3	20A-1P	3	20A-1P	0.18		CO - RACEWAY, LAB 306	R #12
#12 R	CO	OFFICE 315	0.36	20A-1P	5	20A-1P	5	20A-1P	0.18		CO - RACEWAY, LAB 306	R #12
#12 R	CO	OFFICE 315	0.36	20A-1P	7	20A-1P	7	20A-1P	0.18		CO - RACEWAY, LAB 306	R #12
		SPARE		20A-1P	9	20A-1P	9	20A-1P	0.18		CO - RACEWAY, LAB 306	R #12
		SPARE		20A-1P	11	20A-1P	11	20A-2P	0.40		2P RECEPTACLE, LAB 306	E #10
		SPARE		20A-1P	13	20A-1P	13	20A-2P	0.40		2P RECEPTACLE, LAB 306	E #10
		SPARE		20A-1P	15	20A-1P	15	20A-2P	0.40		2P RECEPTACLE, LAB 306	E #10
		SPARE		20A-2P	17	20A-2P	17	20A-1P	0.40		2P RECEPTACLE, LAB 306	E #10
		SPARE		20A-1P	19	20A-1P	19	20A-1P			HOOD - LAB 306	E #12
#12 E	HOOD	LAB 306	0.35	20A-1P	21	20A-1P	21	20A-1P			SPARE	
#12 E	HOOD	LAB 306	0.35	20A-1P	23	20A-1P	23	20A-1P			SPARE	
#10 E	2P	RECEPTACLE, LAB 306	0.40	20A-2P	25	20A-2P	25	20A-1P			SPARE	
#10 E			0.40	20A-2P	27	20A-2P	27	20A-1P			SPARE	
#12 R	CO	RACEWAY, LAB 306	0.18	20A-1P	29	20A-1P	29	20A-1P			SPARE	
#12 R	CO	RACEWAY, LAB 306	0.18	20A-1P	31	20A-1P	31	20A-2P			SPARE	
#10 E	2P	RECEPTACLE, LAB 306	0.40	20A-2P	33	20A-2P	33	20A-1P			SPARE	
#10 E			0.40	20A-1P	35	20A-1P	35	30A-2P			SPARE	
		SPARE		20A-1P	37	20A-1P	37	30A-2P			SPARE	
		SPARE		20A-1P	39	20A-1P	39	30A-2P			SPARE	
		SPARE		20A-1P	41	20A-1P	41	30A-2P			SPARE	
		SPARE		20A-1P	43	20A-1P	43	30A-2P			SPARE	

SUB-TOTAL LOADS				SUB-TOTAL LOADS			
1.1				1.0			
1.7				1.3			
CONNECTED LOADS:				DEMAND RESULTS:			
PHASE A 2.55 KVA				TOTAL DEMAND LOAD: 7.3 KVA			
PHASE B 2.45 KVA				SPARE LOAD: 46.7 KVA			
PHASE C 2.27 KVA				DESIGN LOAD: 54.0 KVA			
TOTAL: 7.27 KVA				FEEDER AMP, 150.0 Amps			

EML3A PANEL SCHEDULE

SCALE: N.T.S
Excerpted from: COOLEY LAB AS BUILT Drawings.
E05 3/14/2001

REVISION HISTORY	DRAWN BY:
REV - AS BUILT REVIEW 10/27/2013	JWT
REV - ISSUED FOR RELEASE 10/27/2013	DATE:
PROJECT NAME:	10/12/2013
MONTANA STATE UNIVERSITY	SING NUNE
BOZEMAN, MONTANA	
JOSHUA TALBERT	
MSME CANDIDATE	
EMEC 590 - THESIS PROJECT	
SCALE: N.T.S	
COOLEY LAB	
PANEL SCHEDULES	

E4.12

PANEL: LP1B				VOLTAGE: 208/120 V, 3 ϕ 4 W				BUS SIZE: 225A				MAIN: M.L.O.			
LOC: SEE PLANS				MOUNTING: FLUSH				AIC RATING: 'E' DWGS.				FEED: TOP ☒ BOTTOM ☐			
CIRCUIT CODE: blank or N : NON-CONTINUOUS				L : LONG-CONTINUOUS				R : N.E.C Art 220-3 RECEPT				K : KITCHEN			
ITEM	CODE	BKR	#	ϕ A	ϕ B	ϕ C	#	BKR	CODE	ITEM					
REC - RACEWAY RM 124	R	20	1	720			2	20	R	REC - WALL RM 124					
REC - RACEWAY RM 124	R	20	3	720	720		4	20	R	REC - WALL RM 124					
REC - WATER PURIFIER RM 124		20	5			1200	6	20		FUME HOOD RM 124					
EQ. REC - RACEWAY RM 124		30	7	2080		1000	8	20		SPARE					
-			9	X			10	20		SPARE					
EQ. REC - RACEWAY RM 124		20	11		2080		12	20		SPARE					
EQ. REC - RACEWAY RM 124		20	13	1200	X		14	20	R	REC - RACEWAY RM 124					
EQ. REC - RACEWAY RM 124		20	15	720		1200	16	20	R	REC - RACEWAY RM 124					
REC - RACEWAY RM 124	R	20	17			720	18	20		EQ. REC - RACEWAY RM 124					
REC - RACEWAY RM 124	R	20	19	180		360	20	2		-					
SPARE		20	21	1650	X	1650	22	20		SPARE					
SPARE		20	23		X		24	20		SPARE					
LIGHTS		20	25	X		X	26	20		SPARE					
LIGHTS		20	27	X	X		28	20		SPARE					
SPARE		20	29		X		30	20		SPARE					
SPACE			31	X	X		32			SPACE					
SPACE			33		X		34			SPACE					
SPACE			35		X		36			SPACE					
SPACE			37	X		X	38			SPACE					
SPACE			39	X	X		40			SPACE					
REC - CONV/S.S.ALARM RM 124		20	41			360	42			SPACE					
CONN. VA ϕ A	7270	CONN. VA (CODE N)		13620	PANEL DEMAND KVA		18.5								
CONN. VA ϕ B	5440	CONN. VA (CODE L)		0	PANEL DEMAND AMPS		51.3								
CONN. VA ϕ C	5770	CONN. VA (CODE R)		4860	PANEL CONN. AMPS		51.3								
TOTAL CONNECTED VA	18480	CONN. VA (CODE K)		0	HIGH ϕ AMPS W/LCL		60.6								

* = AS BUILT CORRECTION (CALLOUT ONLY - LOADS NOT UPDATED)

LP1B PANEL SCHEDULE

SCALE: N.T.S

Excerpted from Chem BioChem AS BUILT
Drawings, LE3.02 9/15/2005

PROJECT NAME:
MONTANA STATE UNIVERSITY
BOZEMAN, MONTANA

JOSHUA TALBERT
MSME CANDIDATE
EMEC 590 - THESIS PROJECT

SCALE: N.T.S.

REVISION HISTORY
REV0 - ISSUED FOR REVIEW 10/2/2013
REV1 - ISSUED FOR RELEASE 10/12/2013
DWG NAME:
CHEM BIOCHEM
PANEL SCHEDULES

DRAWN BY:
JWT

DATE:
10/12/2013

DWG NUM:

E4.21

PANEL: LP3L		VOLTAGE: 208/120 V. 3 ϕ 4 W		BUS SIZE: 225A		MAIN: M.L.O.	
LOC: SEE PLANS		MOUNTING: FLUSH		AIC RATING: 'E' DWGS.		FEED: TOP ☒ BOTTOM ☐	
CIRCUIT CODE: blank or -N : NON-CONTINUOUS		L : LONG-CONTINUOUS		R : N.E.C Art 220-3 RECEPT		K : KITCHEN	
ITEM	CODE	BKR	#	ϕ A	ϕ B	ϕ C	ITEM
REC. - RACEWAY RM 352	R	20	1	720 2080			EQ. REC. - RACEWAY RM 352
REC. - RACEWAY RM 352	R	20	3		720 2080		-
REC. - RACEWAY RM 352	R	20	5			720 2080	EQ. REC. - RACEWAY RM 352
REC. - RACEWAY RM 352	R	20	7	360 2080			-
REC. - RACEWAY RM 352	R	20	9		360 1200		EQ. REC. - RACEWAY RM 352
REC. - WALL RM 352	R	20	11			540 1200	EQ. REC. - RACEWAY RM 352
REC. - WALL RM 352	R	20	13	540 1000			FUME HOOD RM 352
SPARE		20	15		X 1000		REC. - VAC. PMP. RM 352
SPARE		20	17			X 1000	FUME HOOD REC. RM 352
SPARE		20	19	X 1000			FUME HOOD RM 352
SPARE		20	21		X 1000		REC. - VAC. PMP. RM 352
SPARE		20	23			X 1000	FUME HOOD REC. RM 352
LIGHTS		20	25	X 1000			FUME HOOD RM 352
LIGHTS		20	27		X 1000		REC. - VAC. PMP. RM 352
SPARE		20	29			X 1000	FUME HOOD REC. RM 352
SPACE			31	X 1000			FUME HOOD RM 352
SPACE			33		X 1000		REC. - VAC. PMP. RM 352
SPACE			35			X 1000	FUME HOOD REC. RM 352
SPACE			37	X			SPACE
SPACE			39		X		SPACE
REC. - CONV./S.S.ALARM RM 352		20	41			360 X	SPACE
CONN. VA ϕ A		9780		CONN. VA (CODE N)		23080	
CONN. VA ϕ B		8360		CONN. VA (CODE L)		0	
CONN. VA ϕ C		8900		CONN. VA (CODE R)		3960	
TOTAL CONNECTED VA		27040		CONN. VA (CODE K)		0	
				PANEL DEMAND KVA		27.0	
				PANEL DEMAND AMPS		75.1	
				PANEL CONN. AMPS		75.1	
				HIGH ϕ AMPS W/LCL		81.5	

* = AS BUILT CORRECTION (CALLOUT ONLY - LOADS NOT UPDATED)

MSU-04030

INDICATED FOR SUBTRACTION METERING

PROJECT NAME: MONTANA STATE UNIVERSITY BOZEMAN, MONTANA		REVISION HISTORY REV0 - ISSUED FOR REVIEW 10/2/2013 REV1 - ISSUED FOR RELEASE 10/12/2013		DRAWN BY: JWT	
JOSHUA TALBERT MSME CANDIDATE EMEC 590 - THESIS PROJECT SCALE N.T.S.		DWG NAME: CHEM BIOCHEM PANEL SCHEDULES		DATE: 10/12/2013	

E4.22

LP3L PANEL SCHEDULE

SCALE: N.T.S.

Excerpted from Chem BioChem AS BUILT
Drawings, LE3.05 9/15/2005

PROJECT NAME:

MONTANA STATE UNIVERSITY
BOZEMAN, MONTANAJOSHUA TALBERT
MSME CANDIDATE
EMEC 590 - THESIS PROJECT

SCALE: N.T.S.

REVISION HISTORY

REVO - ISSUED FOR REVIEW 10/2/2013
REV1 - ISSUED FOR RELEASE 10/12/2013DWG NAME:
CHEM BIOCHEM
PANEL SCHEDULES

DRAWN BY:

JWT

DATE:

10/12/2013

DWG NUM:

E4.22



HOBOn® U30 Remote Monitoring Systems

Real-time access to data from any web browser

HOBOn U30 Remote Monitoring Systems enable real-time, remote access to your data via cellular, Wi-Fi, or Ethernet communications. They can be configured with any combination of external Smart Sensors, and have been designed with an industrial-grade, tamperproof enclosure.

Supported Measurements:

Indoor Environmental: Temperature, Relative Humidity, Dew Point, CO₂, Air Velocity, VOC

Energy/Power: 4-20mA, AC Current, AC Voltage, Amp Hour, Amps, Compressed Air Flow, DC Current, DC Voltage, Differential, Pressure, Gauge Pressure, kW, kWh, Power Factor, Pulse Input, Volt-Amp Reactive, Volt-Amp Reactive Hour, Volt-Amps, Volts, Water Flow, Watt Hours, Watts



Key Advantages:

- Web-based energy and environmental monitoring
- Electronics are housed in an industrial-grade, tamperproof enclosure
- Setup is quick and easy with plug-and-play sensors
- Measures a wide range of energy and environmental parameters
- GSM Cellular, Wi-Fi, Ethernet, direct USB options available
- Optional analog inputs with configurable sensor power

Minimum System Requirements:



*A complete U30 remote monitoring system requires a data plan (U30-NRC is data logger only and does not require a data plan).
¹AC power adapter or solar panel required. For more details, please visit onsetcomp.com.

► For complete information and accessories, please visit: www.onsetcomp.com

Part number	U30-GSM	U30-WIF	U30-ETH
GSM Wireless Comm (U30-GSM)	Quad-Band GSM/GPRS 850/900/1800/1900 MHz		
Wi-Fi Wireless Comm (U30-WIF)	2.412 - 2.484 GHz IEEE 802.11 b/g		
Ethernet (U30-ETH)	10Base-T or 100Base-TX (using external RJ45 jack) 256-bit AES Rijndael encryption		
Alarm Relay	Can be activated, deactivated or pulsed on user-defined sensor alarms.		
Alarm Notification Latency	Logging interval plus 2 to 4 minutes (typical)		
Smart-Sensor Inputs	5 or 10		
Data Channels	Maximum of 15 (some sensors use more than one data channel)		
Normal Operating Range	-20 to 40°C (-4 to 140°F)		
Extended Operating Range	-40 to 60°C (-40 to 140°F) see battery life		
Local Communication	USB		
Data Storage Memory	512K bytes local storage in non-volatile flash memory		
Logging Interval	1 minute to 18 hours, user-specified		
Station-to-Internet Upload Interval	10 minutes minimum, user-specified (depends on HOBOLink data service plan)		
Power	An Onset solar panel (1.2w, 3w, 6w) or AC adapter is required		
Battery Life	3-5 years, 4 volt 10 AHr rechargeable sealed lead acid		
Dimensions	17.8 x 11.7 x 19.3 cm (7.0 x 4.6 x 7.6 in)		
CE Compliant	Yes		

Contact Us

Sales (8am to 5pm ET, Monday through Friday)

- Email sales@onsetcomp.com
- Call 1-800-564-4377
- Fax 508-759-9100

Technical Support

- (8am to 8pm ET, Monday through Friday)
- Contact [Product Support](#)
- Call 877-564-4377



HOBO® U12 Logger

Multi-channel energy & environmental monitoring

HOBO U12 data loggers provide flexibility for monitoring up to 4 channels of energy and environmental data with a single, compact logger. They provide 12-bit resolution measurements for detecting greater variability in recorded data, direct USB connectivity for convenient, fast data offload, and a 43K measurement capacity.

Supported Measurements: Temperature, Relative Humidity, Dew Point, 4-20mA, AC Current, AC Voltage, Air Velocity, Carbon Dioxide, Compressed Air Flow, DC Current, DC Voltage, Gauge Pressure, Kilowatts, Light Intensity, Volatile Organic Compound (some sensors sold separately)

Key Advantages:

- Records up to 4 channels
- Your choice of three models, with flexible measurement options
- Programmable as well as push-button start
- Compatible with a broad range of external sensors

Minimum System Requirements:



Software



USB cable*



► For complete information and accessories, please visit: www.onsetcomp.com

Part number	U12-006 (4 Ext)	U12-012 (Temp/RH/Light/Ext)	U12-013 (Temp/RH/2 Ext)
Memory	43,000 measurements		
Sampling rate	1 second to 18 hours, user-selectable		
Battery life	1 year typical, user-replaceable, CR2032		
	Temperature		
Max range	-20° to 70°C (-4° to 158°F)		
Accuracy	± 0.35°C from 0° to 50°C (± 0.63°F from 32° to 122°F)		
Resolution (12-bit)	0.03°C @ 25°C (0.05°F @ 77°F)		
	Relative Humidity		
Measurement range	5% to 95% RH (non-condensing)		
Accuracy	± 2.5% typical, 3.5% maximum, from 10 to 90% RH		
Resolution (10-bit)	0.03% RH		
	Light Intensity		
	Designed for general purpose indoor measurement of relative light levels		
Range	1 to 3000 footcandles (lumens/ft ²) typical 0-32,300 lumens/m ²		
	External Input		
Range	0 to 2.5 VDC		
Accuracy	± 2 mV, ± 2.5% of absolute reading		
Resolution	0.6 mV		
CE compliant	Yes		

*USB cable included with software

For stand-alone data logging applications in harsh indoor environments, see the 4-channel HOBO U12 Industrial data logger (U12-008) at onsetcomp.com

Contact Us

Sales (8am to 5pm ET, Monday through Friday)

- Email sales@onsetcomp.com
- Call 1-800-564-4377
- Fax 508-759-9100

Technical Support

- (8am to 8pm ET, Monday through Friday)
- Contact [Product Support](#)
- Call 877-564-4377



HOBOn® UX90 Loggers

Next-generation time-of-use loggers for fast, reliable monitoring

The award-winning HOBOn UX90 Series is the industry's lowest-cost, most comprehensive family of "time-of-use" data loggers. The new toolbox suite includes LCD-display data loggers for measuring motor on/off status, electronic pulses, state changes, and occupancy and light-use patterns.

Leveraging patent-pending technology, HOBOn UX90 data loggers streamline energy audits and make field deployment fast and reliable.

Accompanying HOBOnware software also reduces deployment time. Time-saving features allow HOBOn UX90 users to batch-configure and readout hundreds of loggers in a fraction of the time. Additionally, the software features a Bulk Export Tool that allows users to export data files to text format for use in spreadsheets and other programs.



Supported Measurements: State, Pulse, Event, Runtime, Light On/Off, Motor On/Off, Occupancy/Light

Key Advantages:

- LCD displays Time On or % On, providing instant feedback
- Auto-calibration & signal strength indicator ensure proper deployment
- 84k or 346k measurement capacity enables longer deployments with fewer site visits
- Rare-earth magnets, 3M Command™ Strips, or mounting tabs for reliable mounting
- Flexible logger Start and Stop options
- HOBOnware Pro's time-saving features allow for easy setup of hundreds of loggers



Minimum System Requirements:



Software



USB cable*

*USB cable included with software

Common Features of HOBO UX90 Series Loggers



► For complete information and accessories, please visit: www.onsetcomp.com

Part number	UX90-001 (State)	UX90-002 (Light On/Off)	UX90-004 (Motor On/Off)	UX90-005 (Occupancy)	UX90-006 (Occupancy)
Memory	84,000 measurements				
Part number	UX90-001M (State)	UX90-002M (Light On/Off)	UX90-004M (Motor On/Off)	UX90-005M (Occupancy)	UX90-006M (Occupancy)
Memory	346,000 measurements				
INTERNAL SENSOR					
Maximum state, event, runtime frequency	1 Hz	--	--	--	--
Light threshold	--	65 lux	--	65 lux	
Light type	--	LED, CFL, fluorescent, HID, incandescent, natural	--	LED, CFL, fluorescent, HID, incandescent, natural	
AC magnetic field threshold	--	--	> 40 mGauss at 60 Hz	--	--
Maximum sensor detection range	--	--	--	5 m (15.4 ft)	12 m (39.4 ft)
EXTERNAL INPUT					
External contact input	solid state closure or logic driven voltage output	--	solid state closure	--	--
Maximum state, event, runtime frequency	1 Hz	--	1 Hz	--	--
Maximum Pulse Frequency	50 Hz	--	--	--	--
Battery life	1 year typical, user replaceable, CR2032				
Operating range	-20° to 70°C (-4° to 158°F); 0-95% RH (non-condensing)				
Dimensions	3.66 x 5.94 x 1.52 cm (1.44 x 2.34 x 0.6 in)		3.66 x 8.48 x 1.52 cm (1.44 x 3.34 x 0.6 in)	3.66 x 8.48 x 2.36 cm (1.44 x 3.34 x 0.93 in)	3.66 x 8.48 x 2.87 cm (1.44 x 3.34 x 1.13 in)
CE compliant	Yes				

Contact Us

Sales (8am to 5pm ET, Monday through Friday)

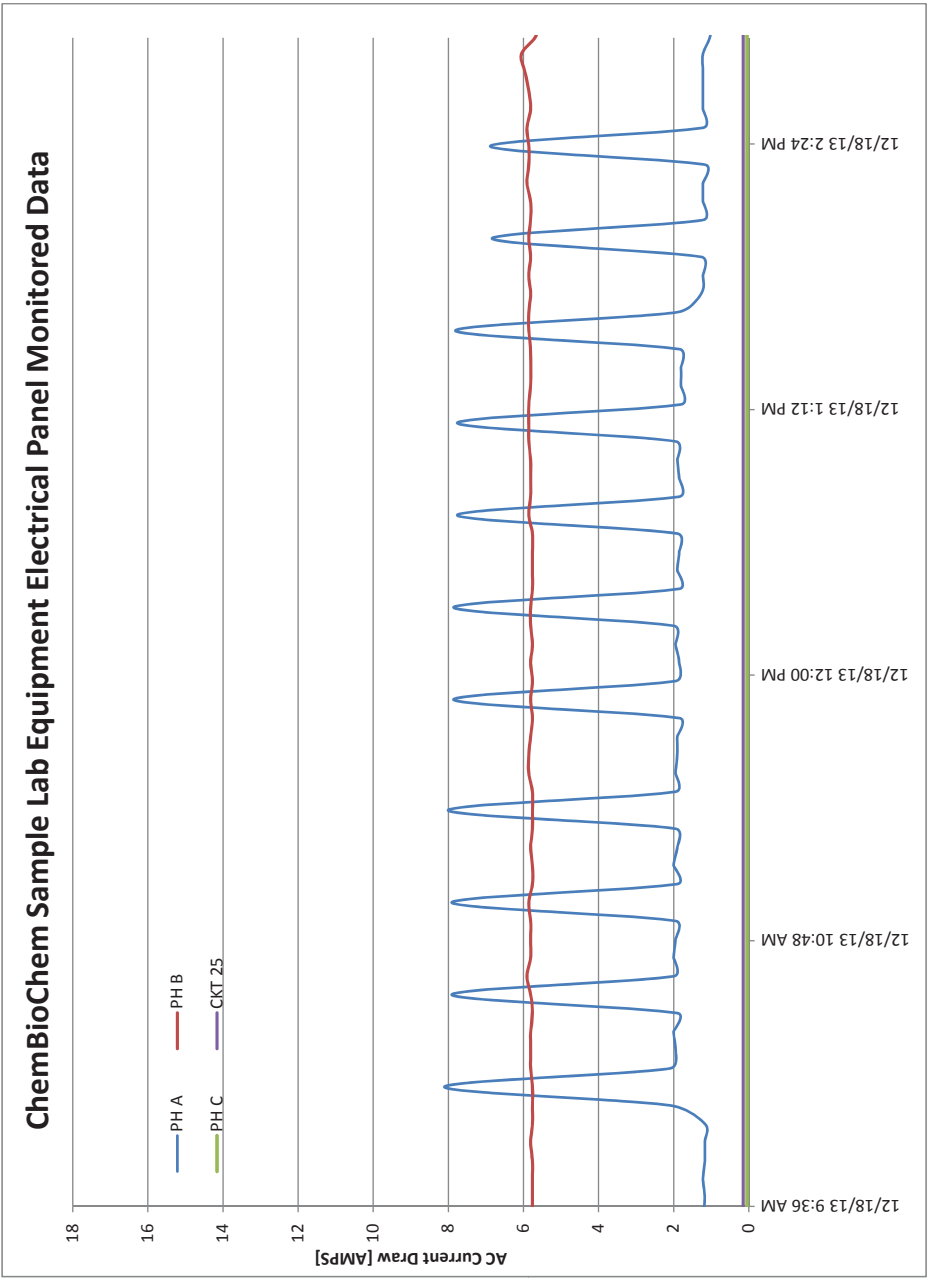
- Email sales@onsetcomp.com
- Call 1-800-564-4377
- Fax 508-759-9100

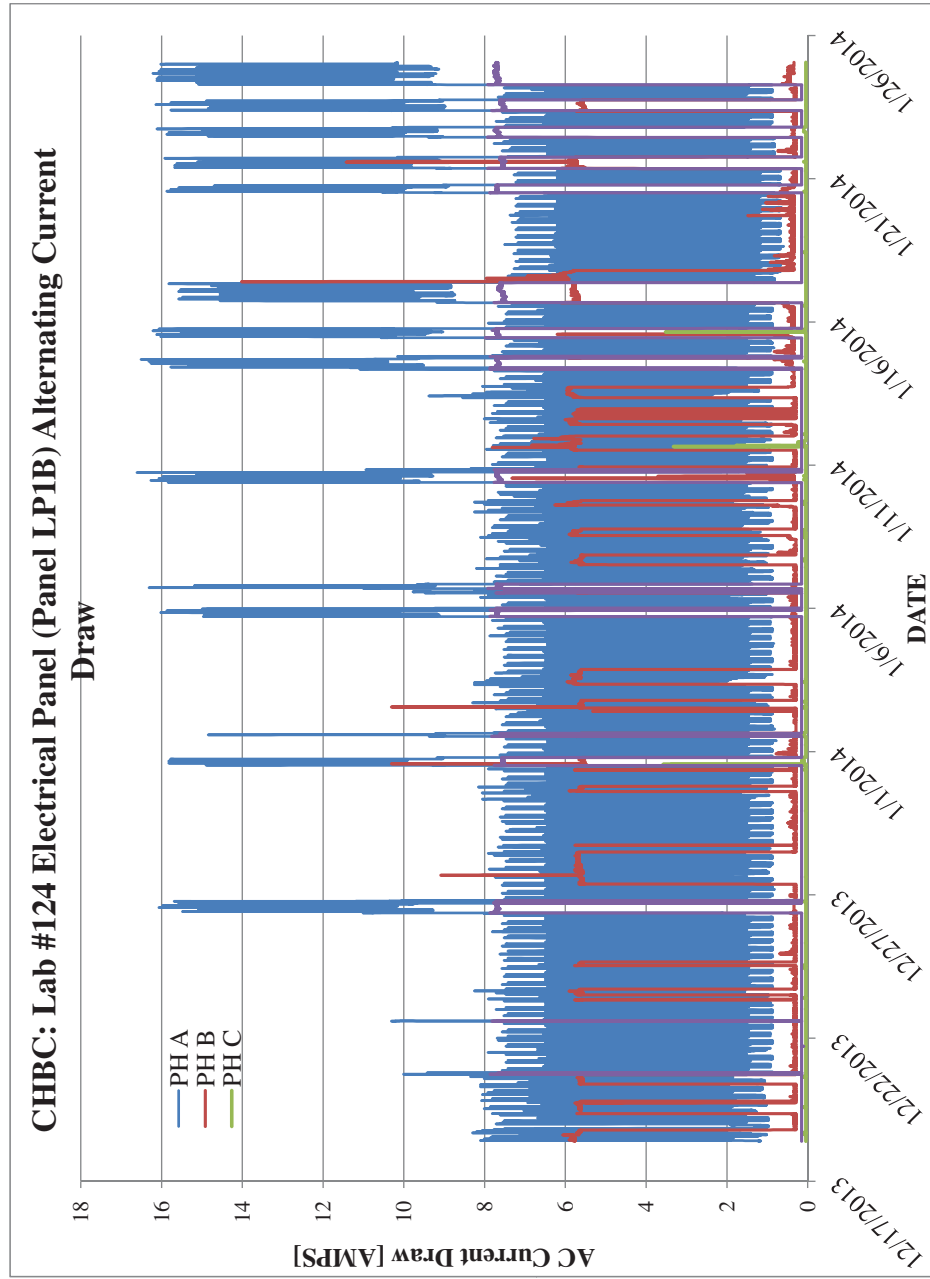
Technical Support

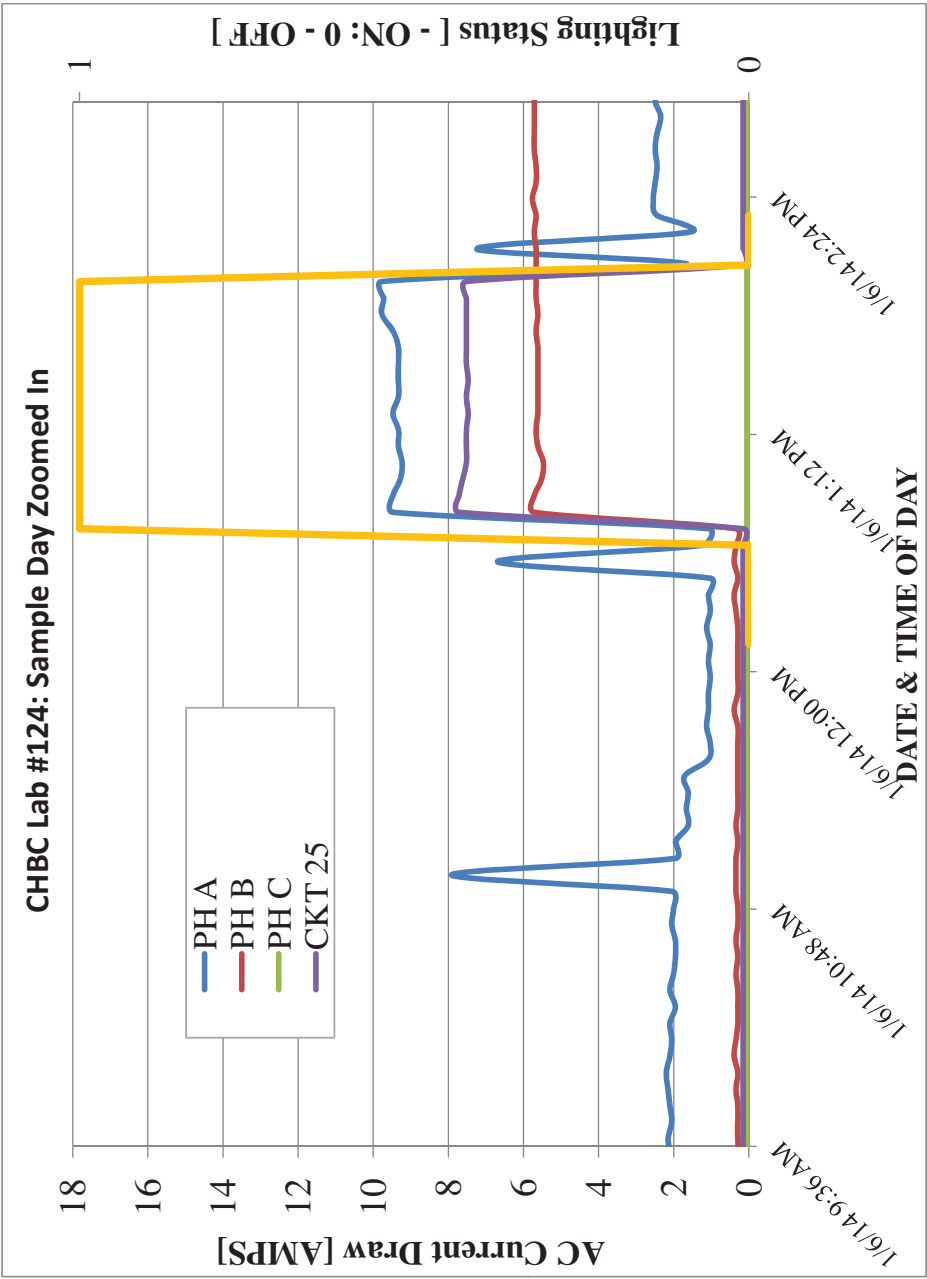
- (8am to 8pm ET, Monday through Friday)
- Contact [Product Support](#)
- Call 877-564-4377

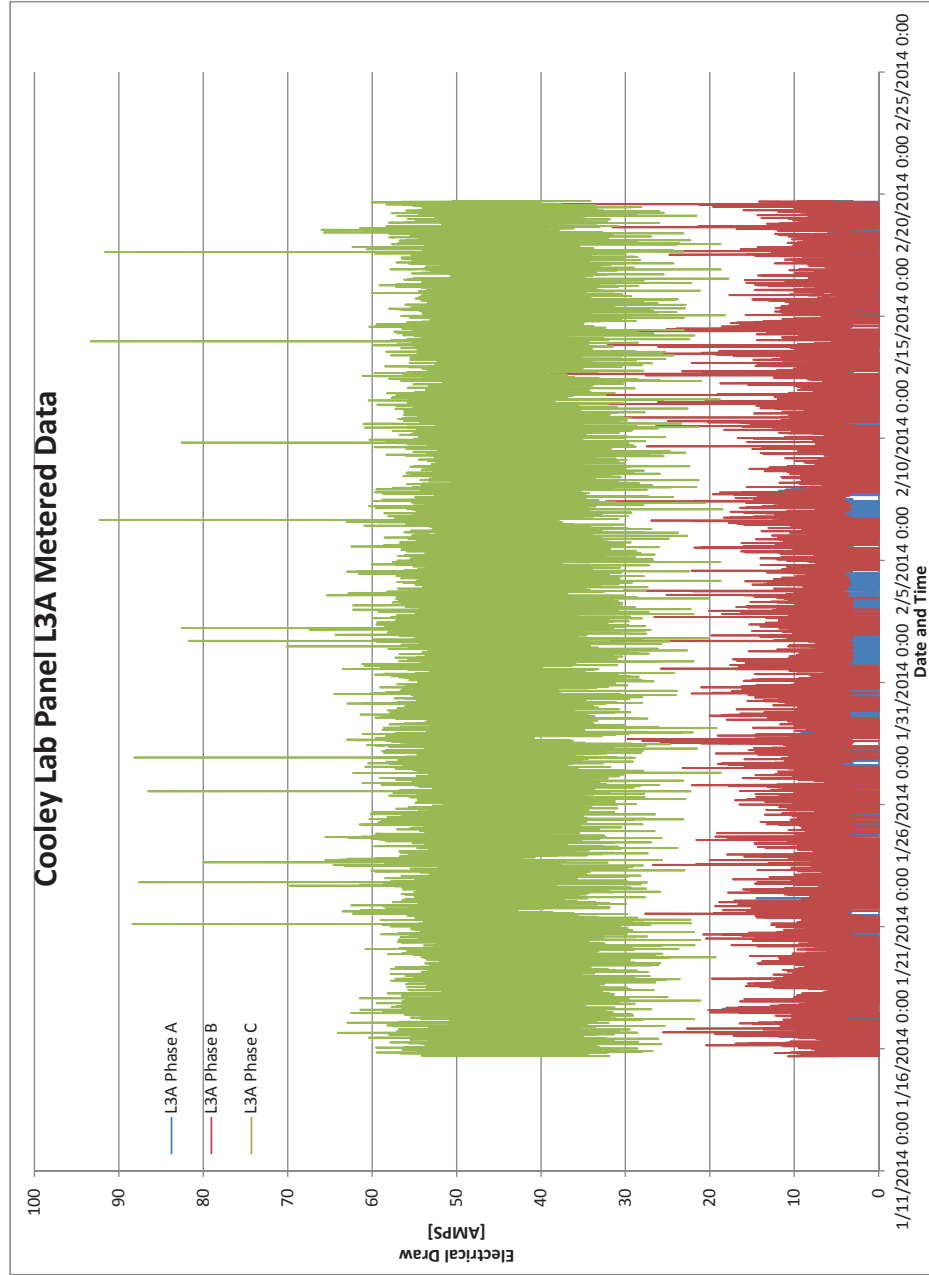
APPENDIX C

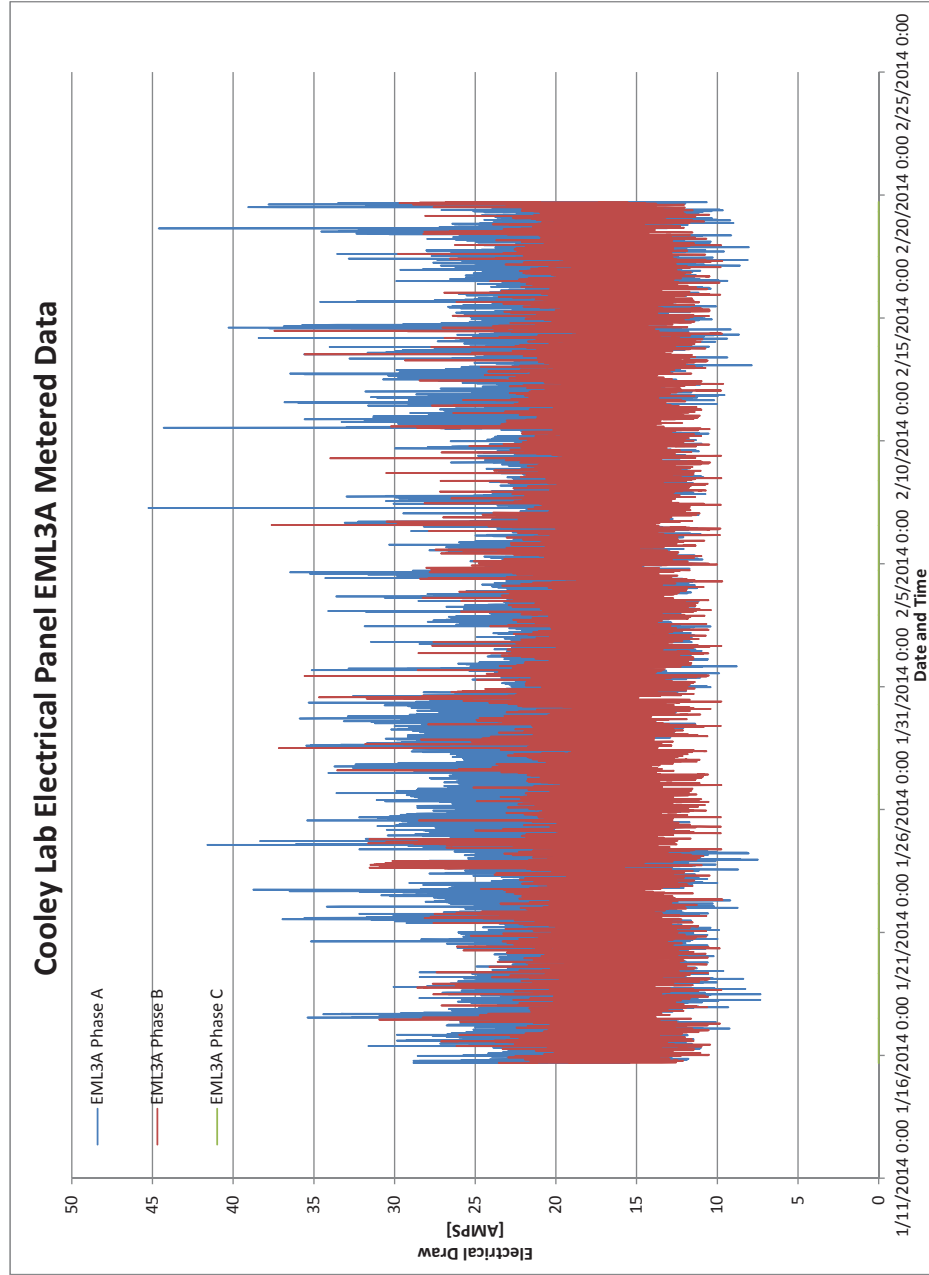
LABORATORY METERING DATA



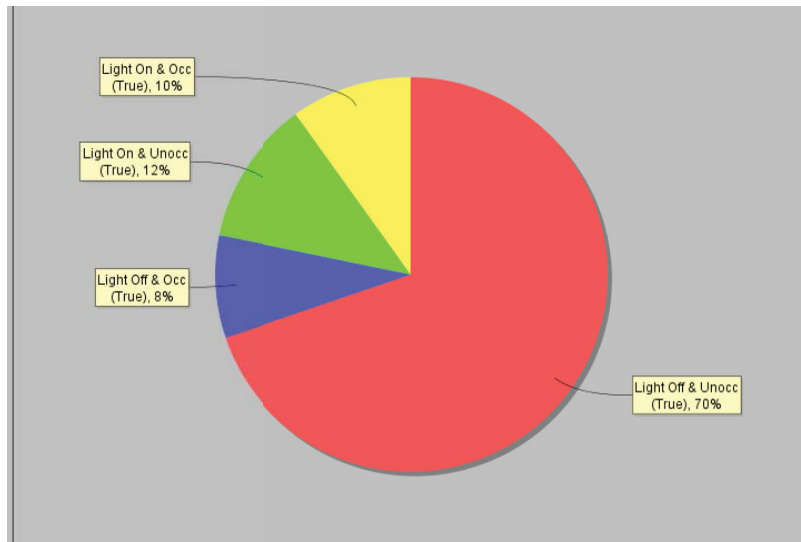




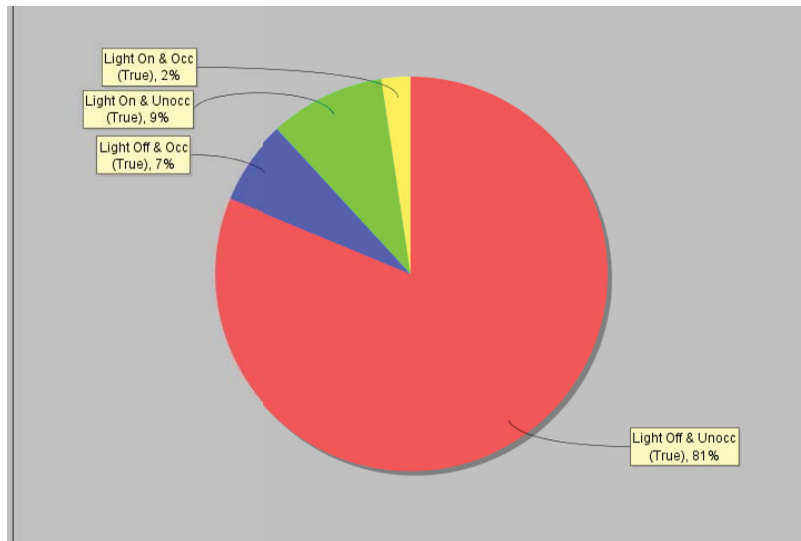




COOLEY LAB OCC AND LIGHT METERING DATA



CHBC LAB OCC AND LIGHT METERING DATA



APPENDIX D

BUILDING PHOTOS























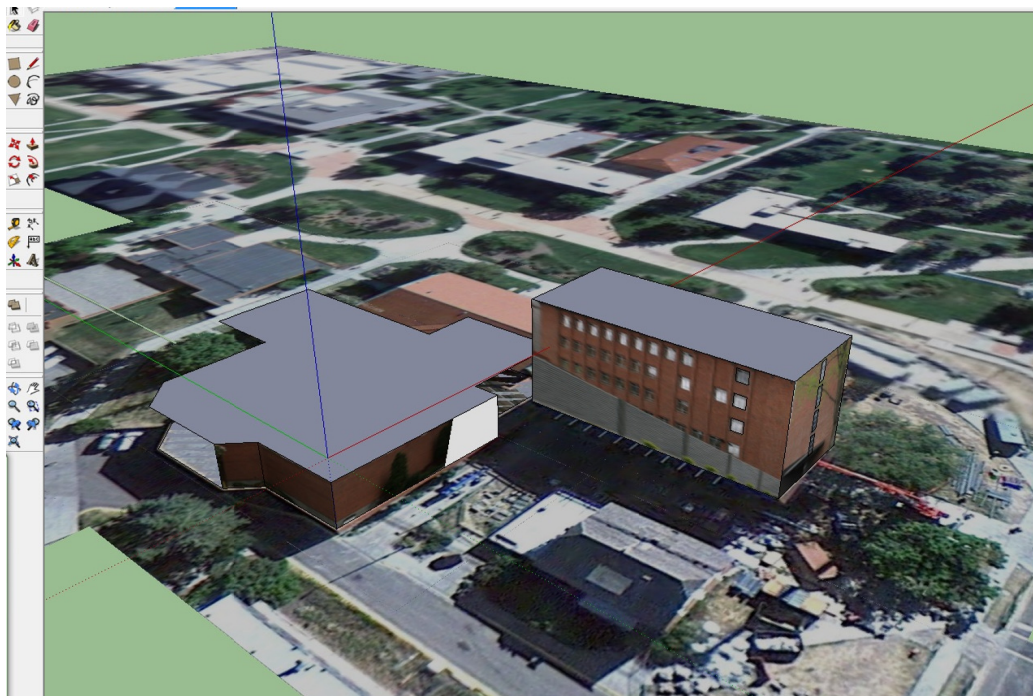
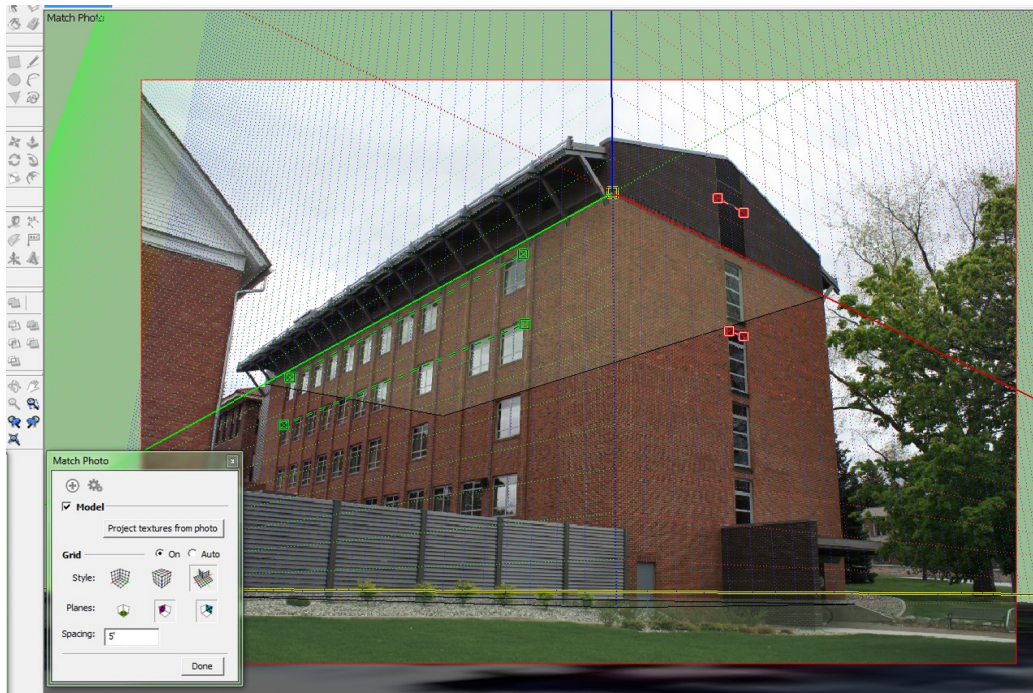












APPENDIX E

PROJECT ADMINISTRATION DOCUMENTS



May 16, 2013

RE: Talbert MSME Thesis Project

Kickoff Meeting Agenda

- Review and discuss
 - Objective: Assess energy requirements of interconnected buildings factoring potential geothermal, solar thermal, and existing central heat pump system efficacy. Evaluate low carbon energy resources.
 - Scope
 - Confirm Proposed Buildings
 - Process
 - Energy Plus, OpenStudio, Sketchup
 - Interview and data acquisition
 - Schedule
 - Deliverables / Project Goals
- Establish and align our expectations regarding:
 - Communication
 - Oversight
 - Documentation
- Arrange and Coordinate
 - Building / MER Access / Office Keys
 - Utility Data
 - Develop communication networks / relevant staff members
 - Drawings and Specs
 - Financial Logistics
 - Graduate Research Employment Paperwork
- Questions or Concerns?

**Department of
Mechanical &
Industrial Engineering**

P.O. Box 173800
Bozeman, MT 59717-3800

Tel (406) 994-2203
Fax (406) 994-6292



June 26, 2013

RE: Talbert MSME Thesis Project

Team Meeting 03 Agenda

- Review Drawing Log:
 - Necessary drawings still outstanding
 - College of Business
 - Leon Johnson – from Matt
 - Discuss Printing and Binding Costs
 - Review Selbys quote, Facilities Account?

- Review System Schematic, H4.00 REV 1:
 - College of Business, Source Water or CHW / HW?
 - Identify New Work and Existing Connections
 - Discuss Montana Hall and Lewis Hall Upper Floor Connections
 - Steam vs Heat Pump: heat pump is low grade?
 - Montana has Split System units for cooling
 - Source Loop Steam Connection?

- Review Zoning Maps
 - Minimize Total Number
 - Appropriate Fidelity?
 - Zone Specific Schedules

- Review Draft Equipment List
 - What are the biggies?
 - Fume hood knowledge or studies?
 - Other Process Loads (e.g.)
 - Elec Humidifiers
 - UV Sterilizing

- Coordinate future meeting time/location/frequency

- Questions or Concerns?

**Department of
Mechanical &
Industrial Engineering**

P.O. Box 173800
Bozeman, MT 59717-3800

Tel (406) 994-2203
Fax (406) 994-6292



June 5, 2013

RE: Talbert MSME Thesis Project

Team Meeting 02 Agenda

- Discuss Availability and JWT acquisition:
 - Design Data
 - Drawings and Specs
 - College of Business
 - Drawings
 - eQuest Models
 - Envelope Information (*Energy Data Sheets*)
 - Construction Data
 - Submittals and Balance Reports
- Review:
 - Gantt Schedule
 - Utility Data
 - Natural Gas units?
 - Steam consumption included?
 - Energy Data Sheets, others available?
 - <http://www.facilities.montana.edu/fs/energy/> "Specific Building Heating & Cooling Information"
 - Leon Johnson, Chemistry Building
 - Draft System Schematic, dwg H4.00
 - Discuss Connections
 - Heat Pump Operation
 - Building Level Systems
 - 2 Pipe or 4 Pipe site distributions?
 - Geometric Model Building
 - Raw Photos
 - Cooley Lab Progress
- Coordinate future meeting time/location/frequency
- Questions or Concerns?

Department of Mechanical & Industrial Engineering

P.O. Box 173800
Bozeman, MT 59717-3800

Tel (406) 994-2203
Fax (406) 994-6292



Talbert MSME Thesis Project

October 28th, 2013

Meeting Minutes 04

Attendee: Josh Talbert Matt Carr
 Dan Stevenson Chelsea Guennette
 Kevin Amende
 Location / Time: Roberts Hall, Room 106 3PM-3:45PM

On Thursday October 24th, the above attendees participated in a working meeting.

1. 2013-10-24 Meeting_04_Agenda.pdf was distributed to all attendees
2. Meeting Notes
 - 2.1. We reviewed the Equipment Metering Plan REV3 dated 10/12/13 FOR RELEASE
 - 2.2. Coordination Based on our Meeting included the following items
 - 2.2.1. Facilities will coordinate with the electricians (Matt will assist with this)
 - 2.2.1.1. Access to equipment will have to be coordinated, Josh cannot be given an access key because of Arc Flash restrictions and University Insurance requirements.
 - 2.2.2. Kevin agreed to fund the equipment purchase
 - 2.2.3. Dan agreed to fund the equipment installation
 - 2.2.3.1. Estimated as Not-To-Exceed ~\$300
 - 2.2.4. Dan elected that Tom Nowak can decide about whether painting and patching is needed after equipment removal. He indicated that as a locked electrical closet it may not be a big deal
 - 2.2.5. Electricians will address all PPE requirements
 - 2.2.6. Ownership of the metering instruments upon project completion will return to Kevin Amende
 - 2.2.7. Dan discussed if there is any concern about the M-2 meter "walking away", we discussed as a group that the risk exists but is not a high possibility. Installation of the occupancy sensing meter will not include theft protection
 3. Dan requested that signage indicating the roll of the installed meters to the respective laboratory researchers be provided. Josh will develop this
 4. Dan requested that a brief project summary document be developed so that he may distribute it to University Administration officials.
 5. Kevin will provide the Department Purchase Order form (DPO) so that Josh may proceed with equipment purchase.
 - 5.1. Kevin followed up on Friday 10/25 with the DPO form.
6. TBD in two weeks

Please review and forward any questions or concerns.
 Respectfully Submitted,


 Joshua Talbert

**Department of
 Mechanical &
 Industrial Engineering**

P.O. Box 173800
 Bozeman, MT 59717-3800

Tel (406) 994-2203
 Fax (406) 994-6292



Talbert MSME Thesis Project

July 1st, 2013

Meeting Minutes 03

Attendee: Josh Talbert
 Dan Stevenson
 Kevin Amende

Location / Time: Plew Facilities Bldg – Conference Room: 3:30-4:45 PM

On Wednesday June 26th, the above attendees participated in a working meeting.

1. 2013-6-25 Meeting_03_Agenda.pdf was distributed to all attendees
 2. Meeting Notes
 - 2.1. Dan indicated that he can help with attaining the College of Business Drawings
 - 2.2. When Matt returns from vacation he can work with me to obtain Leon Johnson Drawings. Dan indicated there is not much available on Leon.
 - 2.3. Dan will provided a Heat Plant Index Number so that I may assign drawing printing and binding to a MSU Facilities account appropriately.
 - 2.4. We reviewed the system schematic
 - 2.4.1. Identified existing and future connections
 - 2.4.2. Steam in Leon has 3 way valves so that it may add heat to heat pump source or supply side loops
 - 2.4.3. Montana Hall is due for an upgrade; President Cruzado moved it down the priority list.
 - 2.5. We reviewed the Model Zoning proposal and discussed tradeoffs of fidelity versus simulations sizes. I indicated that there are already 230 potential zones, each which will have a group of schedules assigned to it: Occupancy, Lighting, Equipment, Infiltration, Setpoints, Equipment Availability
 - 2.5.1. Dan and Kevin deferred to my judgment on establishing appropriate zoning.
 - 2.6. We reviewed the Energy Plus schedules I developed based on the schedule information Matt provided me earlier through email.
 - 2.7. We discussed the laboratories and the difficulty with establishing the associated lab gear energy loads.
 - 2.7.1. I discussed the panel schedule / electrical current draw first take assessment strategy.
 - 2.7.1.1. Dan inquired about monitoring, and we discussed the use of undergrad students as project members to help establish some better lab load estimates. This could be some ground breaking work, as laboratory energy use is difficult to assess.
 - 2.7.1.2. Dan suggested getting Roush O'Toole involved with establishing the "biggies" i.e. large energy draw laboratory equipment.
 - 2.8. We reviewed modeling progress through geometry photos and modeling screen shots.
 3. **Follow Up Items**
 - 3.1. Obtain COB and Leon Drawings
 - 3.2. Provide a Heat Plant Index # for printing and binding.
 4. TBD in two weeks
-

Please review and forward any questions or concerns.
 Respectfully Submitted,

Joshua Talbert

**Department of
 Mechanical &
 Industrial Engineering**

P.O. Box 173800
 Bozeman, MT 59717-3800

Tel (406) 994-2203
 Fax (406) 994-6292



Talbert MSME Thesis Project

June 7th, 2013

Meeting Minutes 02

Attendee: Josh Talbert
 Dan Stevenson
 Kevin Amende
 Matt Carr

Location / Time: Plew Facilities Bldg – Conference Room: 3:30-4PM

On Wednesday June 5th, the above attendees participated in a working meeting.

1. 2013-6-5 Meeting_02_Agenda.pdf was distributed to all attendees
2. Meeting Notes
 - 2.1. Dan and Matt informed that Terry Sutherland and Gary Grammer are the appropriate contacts for getting Drawings and Specs
 - 2.1.1. Matt followed up with Terry and Gary's contact information. (x4792 and x7089)
 - 2.2. Utility Data Notes:
 - 2.2.1. We identified that steam consumption at each building is converted into Natural Gas units so that all buildings may be measured on an equal metric.
 - 2.2.2. The unit DKT employed on the Utility Data pivot table represents Decatherm (Dth) = 1,000,000 Btus
 - 2.2.3. Steam consumption is represented in the Utility Data information by a prorated conversion from condensate measurements into total natural gas consumption.
 - 2.3. We reviewed the project schedule
 - 2.4. System Schematic Review drawing H4.00 yielded the following notes:
 - 2.4.1. Leon Johnson Central Plant HPs are a 4-Pipe system
 - 2.4.2. HPs source loop includes the Solar Thermal, Geo Thermal Bore Field, Cooling Tower, backup Steam HX.
 - 2.4.3. Dan identified which facilities were Low Temp and High Temp:
 - 2.4.3.1. LT: COB, CL, LJ
 - 2.4.3.1.1. LT Temps: 135°F HWS and 45°F CHWS
 - 2.4.3.2. HT: CHBC, LH (part steam also), TZ
 - 2.4.3.2.1. HT Temps 180°F HWS and 45°F CHWS
 - 2.4.3.3. Airside Systems were identified as:
 - 2.4.3.3.1. CL – 100% OA, near CV, elec humidifiers
 - TZ - VAV RH almost no variation
 - LH - Basement Cooling ACC
 - No Cooling elsewhere
 - Steam Radiators
 - CHBC - VAV RH not much turndown, Fume Hoods
 - COB - LT VAV RH
 - 2.5. We reviewed modeling progress through geometry photos and modeling screen shots.
 3. **Follow Up Items**
 - 3.1. **Establish a regularly scheduled meeting**
 4. TBD in two weeks

Please review and forward any questions or concerns.
 Respectfully Submitted,

Joshua Talbert

**Department of
 Mechanical &
 Industrial Engineering**

P.O. Box 173800
 Bozeman, MT 59717-3800

Tel (406) 994-2203
 Fax (406) 994-6292



Talbert MSME Thesis Project

May 20, 2013

Meeting Minutes 01

Attendee: Josh Talbert
 Dan Stevenson
 Kevin Amende

Location / Time: Plew Facilities Bldg – Stevenson's Office: 10AM

On Thursday May 16th, the above attendees participated in a project kickoff meeting for the Talbert MSME Thesis Project. The purpose of the meeting was to review the project goals, establish communication protocols and finalize project paperwork.

1. 2013-5-16 Kickoff Meeting _ Agenda.pdf was distributed to all attendees
 2. Meeting Notes
 - 2.1. Dan confirmed his acceptance of the proposed building selection
 - 2.2. Josh indicated the Energy Plus (*.IDF) input files would be included in the deliverable to the University. These files are property of the University and may be used to continue energy evaluation beyond the scope of this project.
 - 2.3. Dan indicated that he would like to get Matt Carr involved and introduced on the project.
 - 2.3.1. Matt has a working knowledge of the facilities department and will provide assistance with items such as building MER access, and working with the Utility Data pivot table
 - 2.4. Dan will forward along a Utility Data Pivot Table for 252 Buildings on Campus which includes data as far back as 2007.
 - 2.5. We agreed on holding weekly meetings initially
 - 2.5.1. Discussed as being informal
 - 2.5.2. Meetings may transition to bi-weekly
 - 2.6. Josh will provide project documentation in the form of Meeting Minutes
 - 2.7. Dan and Kevin arranged the financial logistics and allocated appropriate funding
 - 2.7.1. Dan and Kevin followed up later on 5/16/2013 and transferred Facilities funding to the ME Department, for single source fund disbursement.
 - 2.7.2. Michele Woodbury arranged the appropriate paperwork and Josh Talbert signed off on 5/20/13
 - 2.8. Josh addressed the idea of exploring alternate energy pricing structures
 3. **Follow Up Items**
 - 3.1. **Dan will forward the Utility Pivot Table file**
 - 3.2. **Dan will introduce Matt Carr to the project**
 - 3.3. **Josh will advise his Thesis Committee on the project status.**
 4. The next meeting will be scheduled for the first week of June
-

Please review and forward any questions or concerns.

Respectfully Submitted,

Joshua Talbert

**Department of
 Mechanical &
 Industrial Engineering**

P.O. Box 173800
 Bozeman, MT 59717-3800

Tel (406) 994-2203
 Fax (406) 994-6292

APPENDIX F

ENERGY PLUS SIMULATION REPORTS

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:53:14 - EnergyPlus

Program Version: EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 20:52

[Table of Contents](#)

Tabular Output Report in Format: HTML

Building: Building 1

Environment: RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797

Simulation Timestamp: 2014-04-07 20:53:14

Report: Annual Building Utility Performance Summary

[Table of Contents](#)

For: Entire Facility

Timestamp: 2014-04-07 20:53:14

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	4180.93	1001.24	1001.24
Net Site Energy	4180.93	1001.24	1001.24
Total Source Energy	7741.77	1853.97	1853.97
Net Source Energy	7741.77	1853.97	1853.97

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050
Other Fuel 1	1.000
Other Fuel 2	1.000

Building Area

	Area [m2]
Total Building Area	4175.77
Net Conditioned Building Area	4175.77
Unconditioned Building Area	0.00

End Uses

	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	0.00	2030.06	0.00	0.00	0.00	0.00

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=-726797 2014-04-07 20:53:14 - EnergyPlus

Cooling	27.93	0.00	0.00	0.00	0.00	0.00
Interior Lighting	520.13	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	444.74	609.99	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	343.01	0.00	0.00	0.00	0.00	0.00
Pumps	195.39	0.00	0.00	0.00	0.00	0.00
Heat Rejection	9.68	0.00	0.00	0.00	0.00	275.20
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	1540.87	2640.06	0.00	0.00	0.00	275.20

Note: Natural gas appears to be the principal heating source based on energy usage.

End Uses By Subcategory

	Subcategory	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	Boiler	0.00	2030.06	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	27.93	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	520.13	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	444.74	609.99	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	343.01	0.00	0.00	0.00	0.00	0.00
Pumps	General	195.39	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	9.68	0.00	0.00	0.00	0.00	275.20
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	124.56	0.00	0.00	0.00	0.00	0.00
HVAC	137.94	486.15	0.00	0.00	0.00	0.07
Other	106.51	146.08	0.00	0.00	0.00	0.00
Total	369.00	632.23	0.00	0.00	0.00	0.07

Utility Use Per Total Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	124.56	0.00	0.00	0.00	0.00	0.00

file:///C:/Users/josh.talbert/Documents/Projects/EMEC%20590%20-%20Thesis%20Project/Final%20Presentation/ALL%20CALIBRATED/2014-03-20%20LE... 2/62

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#-726797 2014-04-07 20:53:14 - EnergyPlus

HVAC	137.94	486.15	0.00	0.00	0.00	0.07
Other	106.51	146.08	0.00	0.00	0.00	0.00
Total	369.00	632.23	0.00	0.00	0.00	0.07

Electric Loads Satisfied

	Electricity [GJ]	Percent Electricity [%]
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power	0.00	0.00
Net Decrease in On-Site Storage	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	1540.87	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	1540.87	100.00
Total On-Site and Utility Electric Sources	1540.87	100.00
Total Electricity End Uses	1540.87	100.00

On-Site Thermal Sources

	Heat [GJ]	Percent Heat [%]
Water-Side Heat Recovery	0.00	
Air to Air Heat Recovery for Cooling	0.00	
Air to Air Heat Recovery for Heating	0.00	
High-Temperature Geothermal*	0.00	
Solar Water Thermal	0.00	
Solar Air Thermal	0.00	
Total On-Site Thermal Sources	0.00	

Water Source Summary

	Water [m3]	Percent Water [%]
Rainwater Collection	0.00	0.00
Condensate Collection	0.00	0.00
Groundwater Well	0.00	0.00
Total On Site Water Sources	0.00	0.00
-	-	-
Initial Storage	0.00	0.00
Final Storage	0.00	0.00
Change in Storage	0.00	0.00
-	-	-
Water Supplied by Utility	275.20	100.00
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	275.20	100.00
Total Water End Uses	275.20	100.00

4/14/2014

Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:53:14 - EnergyPlus

Comfort and Setpoint Not Met Summary

	Degrees [deltaC]
Tolerance for Zone Heating Setpoint Not Met Time	0.20
Tolerance for Zone Cooling Setpoint Not Met Time	0.20

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	1915.67
Time Setpoint Not Met During Occupied Cooling	1694.83
Time Not Comfortable Based on Simple ASHRAE 55-2004	8388.83

Note 1: An asterisk (*) indicates that the feature is not yet implemented.

Table of Contents

[Top](#)
[Annual Building Utility Performance Summary](#)
[Input Verification and Results Summary](#)
[Demand End Use Components Summary](#)
[Source Energy End Use Components Summary](#)
[Component Sizing Summary](#)
[Surface Shadowing Summary](#)
[Climatic Data Summary](#)
[Envelope Summary](#)
[Shading Summary](#)
[Lighting Summary](#)
[Equipment Summary](#)
[HVAC Sizing Summary](#)
[System Summary](#)
[Outdoor Air Summary](#)
[Object Count Summary](#)
[Energy Meters](#)
[Sensible Heat Gain Summary](#)
[Standard 62.1 Summary](#)
[LEED Summary](#)

BUILDING ENERGY PERFORMANCE - ELECTRICITY

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - NATURAL GAS

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - ELECTRICITY PEAK DEMAND

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - NATURAL GAS PEAK DEMAND

| [Meter](#) |

Life-Cycle Cost Report

| [Entire Facility](#) |

Report: **Input Verification and Results Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2014-04-07 20:53:14**

General

	Value
Program Version and Build	EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 20:52

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=-726797 2014-04-07 20:53:14 - EnergyPlus

RunPeriod	RUN PERIOD 1
Weather File	Bozeman Gallatin Field MT USA TMY3 WMO#=-726797
Latitude [deg]	45.80
Longitude [deg]	-111.2
Elevation [m]	1349.00
Time Zone	-7.0
North Axis Angle [deg]	0.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	5430.90	1859.35	856.10	1859.35	856.10
Window Opening Area [m2]	308.17	85.65	65.19	104.48	52.85
Window-Wall Ratio [%]	5.67	4.61	7.61	5.62	6.17

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	5430.90	1859.35	856.10	1859.35	856.10
Window Opening Area [m2]	308.17	85.65	65.19	104.48	52.85
Window-Wall Ratio [%]	5.67	4.61	7.61	5.62	6.17

Skylight-Roof Ratio

	Total
Gross Roof Area [m2]	4316.70
Skylight Area [m2]	39.46
Skylight-RoofRatio [%]	0.91

PERFORMANCE

Zone Summary

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Gross Wall Area [m2]	Window Glass Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
TZLH_0_CORRIDOR	135.77	Yes	Yes	475.91	1.00	333.64	0.00	8.6111	92.90	1.0764
TZLH_0_NE MER	49.42	Yes	Yes	173.24	1.00	100.43	3.87	10.7639	92.90	10.7639
TZLH_0_NORTH WORK SPACE	308.31	Yes	Yes	1080.70	1.00	313.93	0.00	16.1459	0.01	10.7639
TZLH_0_SOUTH MER	52.27	Yes	Yes	183.23	1.00	114.05	0.00	8.6111	92.90	1.0764
TZLH_0_SOUTH WORK SPACE	294.05	Yes	Yes	1030.72	1.00	368.15	9.26	8.6111	11.61	10.7639
TZLH_1_CORRIDOR	178.50	Yes	Yes	625.67	1.00	358.71	6.76	8.6111	92.90	1.0764
TZLH_1_NE WORK SPACE	183.69	Yes	Yes	643.89	1.00	216.70	16.93	8.6111	11.61	10.7639
TZLH_1_NW WORK SPACE	183.69	Yes	Yes	643.89	1.00	216.70	8.47	8.6111	11.61	10.7639
TZLH_1_SE WORK SPACE	144.05	Yes	Yes	504.92	1.00	178.24	19.05	8.6111	11.61	10.7639

4/14/2014

Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=-726797 2014-04-07 20:53:14 - EnergyPlus

TZLH_1_SW WORK SPACE	144.05	Yes	Yes	504.92	1.00	178.24	19.05	8.6111	11.61	10.7639
TZLH_2_CORRIDOR	178.50	Yes	Yes	625.67	1.00	358.71	8.17	8.6111	92.90	1.0764
TZLH_2_NE WORK SPACE	183.69	Yes	Yes	643.89	1.00	216.70	24.17	8.6111	11.61	10.7639
TZLH_2_NW WORK SPACE	183.69	Yes	Yes	643.89	1.00	216.70	22.05	8.6111	11.61	10.7639
TZLH_2_SE WORK SPACE	144.05	Yes	Yes	504.92	1.00	178.24	19.05	8.6111	11.61	10.7639
TZLH_2_SW WORK SPACE	144.05	Yes	Yes	504.92	1.00	178.24	19.05	8.6111	11.61	10.7639
TZLH_3_CORRIDOR	178.50	Yes	Yes	979.31	1.00	561.46	15.03	8.6111	92.90	1.0764
TZLH_3_NE WORK SPACE	183.69	Yes	Yes	1007.82	1.00	339.19	33.07	8.6111	11.61	10.7639
TZLH_3_NW WORK SPACE	183.69	Yes	Yes	1007.82	1.00	339.19	30.07	8.6111	11.61	10.7639
TZLH_3_SE WORK SPACE	144.05	Yes	Yes	790.31	1.00	278.99	27.06	8.6111	11.61	10.7639
TZLH_3_SW WORK SPACE	144.05	Yes	Yes	790.31	1.00	278.99	27.06	8.6111	11.61	10.7639
TZLH_4_ATTIC	833.98	Yes	Yes	1859.33	1.00	105.68	39.46	10.7639	92.90	81.0461
Total	4175.77			15225.25		5430.90	347.62	9.6229	0.13	23.1221
Conditioned Total	4175.77			15225.25		5430.90	347.62	9.6229	0.13	23.1221
Unconditioned Total	0.00			0.00		0.00	0.00			
Not Part of Total	0.00			0.00		0.00	0.00			

Report: Demand End Use Components Summary

[Table of Contents](#)

For: Entire Facility

Timestamp: 2014-04-07 20:53:14

End Uses

	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Time of Peak	03-AUG-13:09	12-JAN-15:00	-	-	-	07-AUG-16:00
Heating	0.00	776737.42	0.00	0.00	0.00	0.00
Cooling	11475.05	0.00	0.00	0.00	0.00	0.00
Interior Lighting	33051.24	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	26545.20	19342.69	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	11134.32	0.00	0.00	0.00	0.00	0.00
Pumps	7873.31	0.00	0.00	0.00	0.00	0.00
Heat Rejection	1105.39	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	91184.51	796080.11	0.00	0.00	0.00	0.00

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:46:28 - EnergyPlus

Program Version:EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 20:46

[Table of Contents](#)

Tabular Output Report in Format: HTML

Building: **Building 1**

Environment: **RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797**

Simulation Timestamp: **2014-04-07 20:46:28**

Report: **Annual Building Utility Performance Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2014-04-07 20:46:28**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	9167.32	1183.91	1183.91
Net Site Energy	9167.32	1183.91	1183.91
Total Source Energy	17257.27	2228.69	2228.69
Net Source Energy	17257.27	2228.69	2228.69

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050
Other Fuel 1	1.000
Other Fuel 2	1.000

Building Area

	Area [m2]
Total Building Area	7743.24
Net Conditioned Building Area	7743.24
Unconditioned Building Area	0.00

End Uses

	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	0.00	5653.20	0.00	0.00	0.00	0.00

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=-726797 2014-04-07 20:46:28 - EnergyPlus

Cooling	530.87	0.00	0.00	0.00	0.00	0.00
Interior Lighting	1030.05	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	1514.12	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	196.01	0.00	0.00	0.00	0.00	0.00
Pumps	197.66	0.00	0.00	0.00	0.00	0.00
Heat Rejection	45.41	0.00	0.00	0.00	0.00	1261.67
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	3514.11	5653.20	0.00	0.00	0.00	1261.67

Note: Natural gas appears to be the principal heating source based on energy usage.

End Uses By Subcategory

	Subcategory	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	Boiler	0.00	5653.20	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	530.87	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	1030.05	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	1514.12	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	196.01	0.00	0.00	0.00	0.00	0.00
Pumps	General	197.66	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	45.41	0.00	0.00	0.00	0.00	1261.67
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	133.03	0.00	0.00	0.00	0.00	0.00
HVAC	125.26	730.08	0.00	0.00	0.00	0.16
Other	195.54	0.00	0.00	0.00	0.00	0.00
Total	453.83	730.08	0.00	0.00	0.00	0.16

Utility Use Per Total Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	133.03	0.00	0.00	0.00	0.00	0.00

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:46:28 - EnergyPlus

HVAC	125.26	730.08	0.00	0.00	0.00	0.16
Other	195.54	0.00	0.00	0.00	0.00	0.00
Total	453.83	730.08	0.00	0.00	0.00	0.16

Electric Loads Satisfied

	Electricity [GJ]	Percent Electricity [%]
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power	0.00	0.00
Net Decrease in On-Site Storage	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	3514.11	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	3514.11	100.00
Total On-Site and Utility Electric Sources	3514.11	100.00
Total Electricity End Uses	3514.11	100.00

On-Site Thermal Sources

	Heat [GJ]	Percent Heat [%]
Water-Side Heat Recovery	0.00	
Air to Air Heat Recovery for Cooling	0.00	
Air to Air Heat Recovery for Heating	0.00	
High-Temperature Geothermal*	0.00	
Solar Water Thermal	0.00	
Solar Air Thermal	0.00	
Total On-Site Thermal Sources	0.00	

Water Source Summary

	Water [m3]	Percent Water [%]
Rainwater Collection	0.00	0.00
Condensate Collection	0.00	0.00
Groundwater Well	0.00	0.00
Total On Site Water Sources	0.00	0.00
-	-	-
Initial Storage	0.00	0.00
Final Storage	0.00	0.00
Change in Storage	0.00	0.00
-	-	-
Water Supplied by Utility	1261.67	100.00
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	1261.67	100.00
Total Water End Uses	1261.67	100.00

4/14/2014

Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:46:28 - EnergyPlus

Comfort and Setpoint Not Met Summary

	Degrees [deltaC]
Tolerance for Zone Heating Setpoint Not Met Time	0.20
Tolerance for Zone Cooling Setpoint Not Met Time	0.20

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	0.00
Time Setpoint Not Met During Occupied Cooling	0.00
Time Not Comfortable Based on Simple ASHRAE 55-2004	5114.50

Note 1: An asterisk (*) indicates that the feature is not yet implemented.

Table of Contents

[Top](#)
[Annual Building Utility Performance Summary](#)
[Input Verification and Results Summary](#)
[Demand End Use Components Summary](#)
[Source Energy End Use Components Summary](#)
[Component Sizing Summary](#)
[Surface Shadowing Summary](#)
[Climatic Data Summary](#)
[Envelope Summary](#)
[Shading Summary](#)
[Lighting Summary](#)
[Equipment Summary](#)
[HVAC Sizing Summary](#)
[System Summary](#)
[Outdoor Air Summary](#)
[Object Count Summary](#)
[Energy Meters](#)
[Sensible Heat Gain Summary](#)
[Standard 62.1 Summary](#)
[LEED Summary](#)

BUILDING ENERGY PERFORMANCE - ELECTRICITY

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - NATURAL GAS

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - ELECTRICITY PEAK DEMAND

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - NATURAL GAS PEAK DEMAND

| [Meter](#) |

Life-Cycle Cost Report

| [Entire Facility](#) |

Report: **Input Verification and Results Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2014-04-07 20:46:28**

General

	Value
Program Version and Build	EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 20:46

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=-726797 2014-04-07 20:46:28 - EnergyPlus

RunPeriod	RUN PERIOD 1
Weather File	Bozeman Gallatin Field MT USA TMY3 WMO#=-726797
Latitude [deg]	45.80
Longitude [deg]	-111.2
Elevation [m]	1349.00
Time Zone	-7.0
North Axis Angle [deg]	0.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	4309.11	947.39	1210.36	944.91	1206.46
Window Opening Area [m2]	120.77	29.94	42.32	24.77	23.74
Window-Wall Ratio [%]	2.80	3.16	3.50	2.62	1.97

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	4309.11	947.39	1210.36	944.91	1206.46
Window Opening Area [m2]	120.77	29.94	42.32	24.77	23.74
Window-Wall Ratio [%]	2.80	3.16	3.50	2.62	1.97

Skylight-Roof Ratio

	Total
Gross Roof Area [m2]	7743.24
Skylight Area [m2]	0.00
Skylight-RoofRatio [%]	0.00

PERFORMANCE

Zone Summary

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Gross Wall Area [m2]	Window Glass Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
TZ: WH BATHROOMS	235.24	Yes	Yes	1003.83	1.00	151.85	0.00	9.6875	20.44	3.2292
TZ: WH CLASSROOMS EAST	599.28	Yes	Yes	2557.26	1.00	393.44	0.00	11.8403	3.72	16.1459
TZ: WH CLASSROOMS NS	1345.72	Yes	Yes	5742.47	1.00	891.27	0.00	11.8403	3.72	16.1459
TZ: WH CLASSROOMS WEST	775.28	Yes	Yes	3308.26	1.00	432.46	0.00	11.8403	3.72	16.1459
TZ: WH CORRIDOR	1538.63	Yes	Yes	6565.66	1.00	524.97	7.23	8.6111	92.90	2.1528
TZ: WH MER	345.09	Yes	Yes	1472.58	1.00	254.38	0.00	9.6875	92.90	10.7639
TZ: WH OFFICES EAST	625.35	Yes	Yes	2668.51	1.00	427.26	36.13	8.6111	11.15	10.7639
TZ: WH OFFICES NS	1351.08	Yes	Yes	5765.34	1.00	886.53	58.84	8.6111	11.15	10.7639

file:///C:/Users/josh.talbert/Documents/Projects/EMEC%20590%20-%20Thesis%20Project/Final%20Presentation/ALL%20CALIBRATED/2014-04-07%20Wils... 5/52

4/14/2014

Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#-726797 2014-04-07 20:46:28 - EnergyPlus

TZ: WH OFFICES WEST	927.56	Yes	Yes	3958.07	1.00	346.95	18.58	8.6111	11.15	10.7639
Total	7743.24			33041.97		4309.11	120.77	9.8262	7.56	10.7147
Conditioned Total	7743.24			33041.97		4309.11	120.77	9.8262	7.56	10.7147
Unconditioned Total	0.00			0.00		0.00	0.00			
Not Part of Total	0.00			0.00		0.00	0.00			

Report: Demand End Use Components Summary

[Table of Contents](#)

For: Entire Facility

Timestamp: 2014-04-07 20:46:28

End Uses

	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Time of Peak	18-JUN-16:00	28-DEC-08:09	-	-	-	07-AUG-15:00
Heating	0.00	330265.40	0.00	0.00	0.00	0.00
Cooling	293653.11	0.00	0.00	0.00	0.00	0.00
Interior Lighting	68478.29	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	74669.54	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	8033.05	0.00	0.00	0.00	0.00	0.00
Pumps	9135.81	0.00	0.00	0.00	0.00	0.00
Heat Rejection	5773.66	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	459743.46	330265.40	0.00	0.00	0.00	0.00

End Uses By Subcategory

	Subcategory	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Heating	Boiler	0.00	330265.40	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	293653.11	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	68478.29	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	74669.54	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	8033.05	0.00	0.00	0.00	0.00	0.00
Pumps	General	9135.81	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	5773.66	0.00	0.00	0.00	0.00	0.00
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:48:09 - EnergyPlus

Program Version:EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 20:47

[Table of Contents](#)

Tabular Output Report in Format: HTML

Building: **Building 1**

Environment: **RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797**

Simulation Timestamp: **2014-04-07 20:48:09**

Report: **Annual Building Utility Performance Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2014-04-07 20:48:09**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	5128.66	1062.09	1062.09
Net Site Energy	5128.66	1062.09	1062.09
Total Source Energy	10177.37	2107.62	2107.62
Net Source Energy	10177.37	2107.62	2107.62

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050
Other Fuel 1	1.000
Other Fuel 2	1.000

Building Area

	Area [m2]
Total Building Area	4828.84
Net Conditioned Building Area	4828.84
Unconditioned Building Area	0.00

End Uses

	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	0.00	2911.72	0.00	0.00	0.00	0.00

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=-726797 2014-04-07 20:48:09 - EnergyPlus

Cooling	116.15	0.00	0.00	0.00	0.00	0.00
Interior Lighting	767.61	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	737.10	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	251.19	0.00	0.00	0.00	0.00	0.00
Pumps	296.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	48.89	0.00	0.00	0.00	0.00	1163.12
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	2216.95	2911.72	0.00	0.00	0.00	1163.12

Note: Natural gas appears to be the principal heating source based on energy usage.

End Uses By Subcategory

	Subcategory	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	Boiler	0.00	2833.06	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
	Other	0.00	78.65	0.00	0.00	0.00	0.00
Cooling	General	116.15	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	767.61	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	737.10	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	251.19	0.00	0.00	0.00	0.00	0.00
Pumps	General	296.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	48.89	0.00	0.00	0.00	0.00	1163.12
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	158.96	0.00	0.00	0.00	0.00	0.00
HVAC	147.50	602.98	0.00	0.00	0.00	0.24
Other	152.64	0.00	0.00	0.00	0.00	0.00
Total	459.10	602.98	0.00	0.00	0.00	0.24

Utility Use Per Total Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#-726797 2014-04-07 20:48:09 - EnergyPlus

Lighting	158.96	0.00	0.00	0.00	0.00	0.00
HVAC	147.50	602.98	0.00	0.00	0.00	0.24
Other	152.64	0.00	0.00	0.00	0.00	0.00
Total	459.10	602.98	0.00	0.00	0.00	0.24

Electric Loads Satisfied

	Electricity [GJ]	Percent Electricity [%]
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power	0.00	0.00
Net Decrease in On-Site Storage	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	2216.95	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	2216.95	100.00
Total On-Site and Utility Electric Sources	2216.95	100.00
Total Electricity End Uses	2216.95	100.00

On-Site Thermal Sources

	Heat [GJ]	Percent Heat [%]
Water-Side Heat Recovery	0.00	
Air to Air Heat Recovery for Cooling	0.00	
Air to Air Heat Recovery for Heating	0.00	
High-Temperature Geothermal*	0.00	
Solar Water Thermal	0.00	
Solar Air Thermal	0.00	
Total On-Site Thermal Sources	0.00	

Water Source Summary

	Water [m3]	Percent Water [%]
Rainwater Collection	0.00	0.00
Condensate Collection	0.00	0.00
Groundwater Well	0.00	0.00
Total On Site Water Sources	0.00	0.00
-	-	-
Initial Storage	0.00	0.00
Final Storage	0.00	0.00
Change in Storage	0.00	0.00
-	-	-
Water Supplied by Utility	1163.12	100.00
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	1163.12	100.00
Total Water End Uses	1163.12	100.00

4/14/2014

Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:48:09 - EnergyPlus

Comfort and Setpoint Not Met Summary

	Degrees [deltaC]
Tolerance for Zone Heating Setpoint Not Met Time	0.20
Tolerance for Zone Cooling Setpoint Not Met Time	0.20

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	92.00
Time Setpoint Not Met During Occupied Cooling	829.67
Time Not Comfortable Based on Simple ASHRAE 55-2004	4938.67

Note 1: An asterisk (*) indicates that the feature is not yet implemented.

Table of Contents

[Top](#)
[Annual Building Utility Performance Summary](#)
[Input Verification and Results Summary](#)
[Demand End Use Components Summary](#)
[Source Energy End Use Components Summary](#)
[Component Sizing Summary](#)
[Surface Shadowing Summary](#)
[Climatic Data Summary](#)
[Envelope Summary](#)
[Shading Summary](#)
[Lighting Summary](#)
[Equipment Summary](#)
[HVAC Sizing Summary](#)
[System Summary](#)
[Outdoor Air Summary](#)
[Object Count Summary](#)
[Energy Meters](#)
[Sensible Heat Gain Summary](#)
[Standard 62.1 Summary](#)
[LEED Summary](#)

BUILDING ENERGY PERFORMANCE - ELECTRICITY

[| Meter |](#)

BUILDING ENERGY PERFORMANCE - NATURAL GAS

[| Meter |](#)

BUILDING ENERGY PERFORMANCE - ELECTRICITY PEAK DEMAND

[| Meter |](#)

BUILDING ENERGY PERFORMANCE - NATURAL GAS PEAK DEMAND

[| Meter |](#)

Life-Cycle Cost Report

[| Entire Facility |](#)

Report: **Input Verification and Results Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2014-04-07 20:48:09**

General

	Value
Program Version and Build	EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 20:47

file:///C:/Users/josh.talbert/Documents/Projects/EMEC%20590%20-%20Thesis%20Project/Final%20Presentation/ALL%20CALIBRATED/2014-04-07%20CO... 4/55

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:48:09 - EnergyPlus

RunPeriod	RUN PERIOD 1
Weather File	Bozeman Gallatin Field MT USA TMY3 WMO#=726797
Latitude [deg]	45.80
Longitude [deg]	-111.2
Elevation [m]	1349.00
Time Zone	-7.0
North Axis Angle [deg]	0.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	7850.90	2926.94	975.88	2923.49	1024.59
Window Opening Area [m2]	942.74	274.11	12.80	587.59	68.24
Window-Wall Ratio [%]	12.01	9.37	1.31	20.10	6.66

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	7850.90	2926.94	975.88	2923.49	1024.59
Window Opening Area [m2]	942.74	274.11	12.80	587.59	68.24
Window-Wall Ratio [%]	12.01	9.37	1.31	20.10	6.66

Skylight-Roof Ratio

	Total
Gross Roof Area [m2]	4828.84
Skylight Area [m2]	0.00
Skylight-Roof Ratio [%]	0.00

PERFORMANCE

Zone Summary

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Gross Wall Area [m2]	Window Glass Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
TZ: COB CORRIDOR	1960.40	Yes	Yes	8589.51	1.00	3250.03	65.26	9.6875	92.90	2.1528
TZ: COB DINING SERVICE	63.08	Yes	Yes	276.40	1.00	140.48	24.94	12.9167	20.44	3.2292
TZ: COB MER	434.91	Yes	Yes	1723.99	1.00	538.73	6.40	9.6875	92.90	10.7639
TZ: COB NORTH OFFICES	1298.60	Yes	Yes	5689.81	1.00	2417.22	296.92	11.8403	11.15	10.7639
TZ: COB SOUTH CLASSROOMS	1071.84	Yes	Yes	4696.29	1.00	1504.44	549.22	16.1459	3.72	16.1459
Total	4828.84			20975.99		7850.90	942.74	11.7422	11.13	8.3642
Conditioned Total	4828.84			20975.99		7850.90	942.74	11.7422	11.13	8.3642
Unconditioned Total	0.00			0.00		0.00	0.00			
Not Part of Total	0.00			0.00		0.00	0.00			

4/14/2014

Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:48:09 - EnergyPlus

Report: Demand End Use Components Summary

[Table of Contents](#)

For: Entire Facility

Timestamp: 2014-04-07 20:48:09

End Uses

	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Time of Peak	18-JUN-16:00	24-FEB-06:19	-	-	-	07-AUG-15:00
Heating	0.00	718982.59	0.00	0.00	0.00	0.00
Cooling	42543.29	0.00	0.00	0.00	0.00	0.00
Interior Lighting	51031.04	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	36350.31	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	8223.01	0.00	0.00	0.00	0.00	0.00
Pumps	6786.89	0.00	0.00	0.00	0.00	0.00
Heat Rejection	4239.35	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	149173.90	718982.59	0.00	0.00	0.00	0.00

End Uses By Subcategory

	Subcategory	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Heating	Boiler	0.00	701608.67	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	42543.29	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	51031.04	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	36350.31	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	8223.01	0.00	0.00	0.00	0.00	0.00
Pumps	General	6786.89	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	4239.35	0.00	0.00	0.00	0.00	0.00
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Report: Source Energy End Use Components Summary

[Table of Contents](#)

For: Entire Facility

Timestamp: 2014-04-07 20:48:09

file:///C:/Users/josh.talbert/Documents/Projects/EMEC%20590%20-%20Thesis%20Project/Final%20Presentation/ALL%20CALIBRATED/2014-04-07%20CO... 6/55

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:47:26 - EnergyPlus

Program Version:EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 20:47

[Table of Contents](#)

Tabular Output Report in Format: HTML

Building: **Building 1**

Environment: **RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797**

Simulation Timestamp: **2014-04-07 20:47:26**

Report: **Annual Building Utility Performance Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2014-04-07 20:47:26**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	16625.92	4448.89	4448.89
Net Site Energy	16625.92	4448.89	4448.89
Total Source Energy	33894.33	9069.71	9069.71
Net Source Energy	33894.33	9069.71	9069.71

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050
Other Fuel 1	1.000
Other Fuel 2	1.000

Building Area

	Area [m2]
Total Building Area	3737.09
Net Conditioned Building Area	3737.09
Unconditioned Building Area	0.00

End Uses

	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	0.00	7834.03	0.00	0.00	0.00	0.00

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=-726797 2014-04-07 20:47:26 - EnergyPlus

Cooling	468.78	0.00	0.00	0.00	0.00	0.00
Interior Lighting	2231.46	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	4108.75	1172.20	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	632.61	0.00	0.00	0.00	0.00	0.00
Pumps	96.85	0.00	0.00	0.00	0.00	0.00
Heat Rejection	81.24	0.00	0.00	0.00	0.00	2411.97
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	7619.70	9006.23	0.00	0.00	0.00	2411.97

Note: Natural gas appears to be the principal heating source based on energy usage.

End Uses By Subcategory

	Subcategory	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	Boiler	0.00	7404.49	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
	Other	0.00	429.55	0.00	0.00	0.00	0.00
Cooling	General	468.78	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	2231.46	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	4108.75	1172.20	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	632.61	0.00	0.00	0.00	0.00	0.00
Pumps	General	96.85	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	81.24	0.00	0.00	0.00	0.00	2411.97
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	597.11	0.00	0.00	0.00	0.00	0.00
HVAC	342.37	2096.29	0.00	0.00	0.00	0.65
Other	1099.45	313.67	0.00	0.00	0.00	0.00
Total	2038.94	2409.96	0.00	0.00	0.00	0.65

Utility Use Per Total Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#-726797 2014-04-07 20:47:26 - EnergyPlus

Lighting	597.11	0.00	0.00	0.00	0.00	0.00
HVAC	342.37	2096.29	0.00	0.00	0.00	0.65
Other	1099.45	313.67	0.00	0.00	0.00	0.00
Total	2038.94	2409.96	0.00	0.00	0.00	0.65

Electric Loads Satisfied

	Electricity [GJ]	Percent Electricity [%]
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power	0.00	0.00
Net Decrease in On-Site Storage	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	7619.70	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	7619.70	100.00
Total On-Site and Utility Electric Sources	7619.70	100.00
Total Electricity End Uses	7619.70	100.00

On-Site Thermal Sources

	Heat [GJ]	Percent Heat [%]
Water-Side Heat Recovery	0.00	
Air to Air Heat Recovery for Cooling	0.00	
Air to Air Heat Recovery for Heating	0.00	
High-Temperature Geothermal*	0.00	
Solar Water Thermal	0.00	
Solar Air Thermal	0.00	
Total On-Site Thermal Sources	0.00	

Water Source Summary

	Water [m3]	Percent Water [%]
Rainwater Collection	0.00	0.00
Condensate Collection	0.00	0.00
Groundwater Well	0.00	0.00
Total On Site Water Sources	0.00	0.00
-	-	-
Initial Storage	0.00	0.00
Final Storage	0.00	0.00
Change in Storage	0.00	0.00
-	-	-
Water Supplied by Utility	2411.97	100.00
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	2411.97	100.00
Total Water End Uses	2411.97	100.00

4/14/2014

Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:47:26 - EnergyPlus

Comfort and Setpoint Not Met Summary

	Degrees [deltaC]
Tolerance for Zone Heating Setpoint Not Met Time	0.20
Tolerance for Zone Cooling Setpoint Not Met Time	0.20

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	165.33
Time Setpoint Not Met During Occupied Cooling	4699.83
Time Not Comfortable Based on Simple ASHRAE 55-2004	5098.17

Note 1: An asterisk (*) indicates that the feature is not yet implemented.

Table of Contents

[Top](#)
[Annual Building Utility Performance Summary](#)
[Input Verification and Results Summary](#)
[Demand End Use Components Summary](#)
[Source Energy End Use Components Summary](#)
[Component Sizing Summary](#)
[Surface Shadowing Summary](#)
[Climatic Data Summary](#)
[Envelope Summary](#)
[Shading Summary](#)
[Lighting Summary](#)
[Equipment Summary](#)
[HVAC Sizing Summary](#)
[System Summary](#)
[Outdoor Air Summary](#)
[Object Count Summary](#)
[Energy Meters](#)
[Sensible Heat Gain Summary](#)
[Standard 62.1 Summary](#)
[LEED Summary](#)

BUILDING ENERGY PERFORMANCE - ELECTRICITY

[| Meter |](#)

BUILDING ENERGY PERFORMANCE - NATURAL GAS

[| Meter |](#)

BUILDING ENERGY PERFORMANCE - ELECTRICITY PEAK DEMAND

[| Meter |](#)

BUILDING ENERGY PERFORMANCE - NATURAL GAS PEAK DEMAND

[| Meter |](#)

Life-Cycle Cost Report

[| Entire Facility |](#)

Report: **Input Verification and Results Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2014-04-07 20:47:26**

General

	Value
Program Version and Build	EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 20:47

file:///C:/Users/josh.talbert/Documents/Projects/EMEC%20590%20-%20Thesis%20Project/Final%20Presentation/ALL%20CALIBRATED/2014-04-07%20CH... 4/58

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:47:26 - EnergyPlus

RunPeriod	RUN PERIOD 1
Weather File	Bozeman Gallatin Field MT USA TMY3 WMO#=726797
Latitude [deg]	45.80
Longitude [deg]	-111.2
Elevation [m]	1349.00
Time Zone	-7.0
North Axis Angle [deg]	0.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	4700.59	1308.03	1011.30	1325.82	1055.44
Window Opening Area [m2]	633.32	59.62	250.86	260.62	62.22
Window-Wall Ratio [%]	13.47	4.56	24.81	19.66	5.90

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	4700.59	1308.03	1011.30	1325.82	1055.44
Window Opening Area [m2]	633.32	59.62	250.86	260.62	62.22
Window-Wall Ratio [%]	13.47	4.56	24.81	19.66	5.90

Skylight-Roof Ratio

	Total
Gross Roof Area [m2]	4650.78
Skylight Area [m2]	0.00
Skylight-Roof Ratio [%]	0.00

PERFORMANCE

Zone Summary

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Gross Wall Area [m2]	Window Glass Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
TZ: CHBC AUDITORIUM	113.01	Yes	Yes	964.51	1.00	78.15	4.29	53.8196	6.97	107.6391
TZ: CHBC CORRIDORS	556.20	Yes	Yes	5892.25	1.00	895.82	244.78	21.5278	92.90	10.7639
TZ: CHBC N LABS E	464.91	Yes	Yes	7935.40	1.00	968.07	144.24	53.8196	6.97	107.6391
TZ: CHBC N OFFICES W	203.47	Yes	Yes	1736.54	1.00	376.92	40.64	53.8196	6.97	107.6391
TZ: CHBC PENTHOUSE AND MER	1023.83	Yes	Yes	7729.48	1.00	384.06	0.86	17.7268	55.57	79.5674
TZ: CHBC STAIRS	28.43	Yes	Yes	485.24	1.00	257.53	6.98	21.5278	92.90	10.7639
TZ: CHBC W LABS S	1148.29	Yes	Yes	10495.42	1.00	1239.03	159.85	53.8196	6.97	107.6391
TZ: CHBC W OFFICES N	198.95	Yes	Yes	1697.90	1.00	501.02	31.68	53.8196	6.97	107.6391
Total	3737.09			36936.73		4700.59	633.32	38.8798	11.32	84.7935

file:///C:/Users/josh.talbert/Documents/Projects/EMEC%20590%20-%20Thesis%20Project/Final%20Presentation/ALL%20CALIBRATED/2014-04-07%20CH... 5/58

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:47:26 - EnergyPlus

Conditioned Total	3737.09			36936.73		4700.59	633.32	38.8798	11.32	84.7935
Unconditioned Total	0.00			0.00		0.00	0.00			
Not Part of Total	0.00			0.00		0.00	0.00			

Report: Demand End Use Components Summary

[Table of Contents](#)

For: Entire Facility

Timestamp: 2014-04-07 20:47:26

End Uses

	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Time of Peak	19-JUN-16:10	24-FEB-11:20	-	-	-	07-AUG-15:00
Heating	0.00	1689607.52	0.00	0.00	0.00	0.00
Cooling	192812.11	0.00	0.00	0.00	0.00	0.00
Interior Lighting	145297.22	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	246543.88	70337.06	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	37468.73	0.00	0.00	0.00	0.00	0.00
Pumps	1296.41	0.00	0.00	0.00	0.00	0.00
Heat Rejection	10117.54	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	633535.88	1759944.58	0.00	0.00	0.00	0.00

End Uses By Subcategory

	Subcategory	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Heating	Boiler	0.00	1631862.05	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	192812.11	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	145297.22	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	246543.88	70337.06	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	37468.73	0.00	0.00	0.00	0.00	0.00
Pumps	General	1296.41	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	10117.54	0.00	0.00	0.00	0.00	0.00
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:50:41 - EnergyPlus

Program Version:EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 20:50

[Table of Contents](#)

Tabular Output Report in Format: HTML

Building: **Building 1**

Environment: **RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797**

Simulation Timestamp: **2014-04-07 20:50:41**

Report: **Annual Building Utility Performance Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2014-04-07 20:50:41**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	2940.15	822.72	822.72
Net Site Energy	2940.15	822.72	822.72
Total Source Energy	5412.07	1514.41	1514.41
Net Source Energy	5412.07	1514.41	1514.41

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050
Other Fuel 1	1.000
Other Fuel 2	1.000

Building Area

	Area [m2]
Total Building Area	3573.72
Net Conditioned Building Area	3573.72
Unconditioned Building Area	0.00

End Uses

	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	0.00	1597.52	0.00	0.00	0.00	0.00

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=-726797 2014-04-07 20:50:41 - EnergyPlus

Cooling	27.85	0.00	0.00	0.00	0.00	0.00
Interior Lighting	394.03	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	304.72	274.50	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	238.56	0.00	0.00	0.00	0.00	0.00
Pumps	102.98	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	1068.14	1872.01	0.00	0.00	0.00	0.00

Note: Natural gas appears to be the principal heating source based on energy usage.

End Uses By Subcategory

	Subcategory	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	Boiler	0.00	1597.52	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	27.85	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	394.03	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	304.72	274.50	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	238.56	0.00	0.00	0.00	0.00	0.00
Pumps	General	102.98	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	110.26	0.00	0.00	0.00	0.00	0.00
HVAC	103.36	447.02	0.00	0.00	0.00	0.00
Other	85.27	76.81	0.00	0.00	0.00	0.00
Total	298.89	523.83	0.00	0.00	0.00	0.00

Utility Use Per Total Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	110.26	0.00	0.00	0.00	0.00	0.00

file:///C:/Users/josh.talbert/Documents/Projects/EMEC%20590%20-%20Thesis%20Project/Final%20Presentation/ALL%20CALIBRATED/2014-04-04%20MO... 2/52

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:50:41 - EnergyPlus

HVAC	103.36	447.02	0.00	0.00	0.00	0.00
Other	85.27	76.81	0.00	0.00	0.00	0.00
Total	298.89	523.83	0.00	0.00	0.00	0.00

Electric Loads Satisfied

	Electricity [GJ]	Percent Electricity [%]
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power	0.00	0.00
Net Decrease in On-Site Storage	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	1068.14	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	1068.14	100.00
Total On-Site and Utility Electric Sources	1068.14	100.00
Total Electricity End Uses	1068.14	100.00

On-Site Thermal Sources

	Heat [GJ]	Percent Heat [%]
Water-Side Heat Recovery	0.00	
Air to Air Heat Recovery for Cooling	0.00	
Air to Air Heat Recovery for Heating	0.00	
High-Temperature Geothermal*	0.00	
Solar Water Thermal	0.00	
Solar Air Thermal	0.00	
Total On-Site Thermal Sources	0.00	

Water Source Summary

	Water [m3]	Percent Water [%]
Rainwater Collection	0.00	-
Condensate Collection	0.00	-
Groundwater Well	0.00	-
Total On Site Water Sources	0.00	-
-	-	-
Initial Storage	0.00	-
Final Storage	0.00	-
Change in Storage	0.00	-
-	-	-
Water Supplied by Utility	0.00	-
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	0.00	-
Total Water End Uses	0.00	-

4/14/2014

Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:50:41 - EnergyPlus

Comfort and Setpoint Not Met Summary

	Degrees [deltaC]
Tolerance for Zone Heating Setpoint Not Met Time	0.20
Tolerance for Zone Cooling Setpoint Not Met Time	0.20

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	6416.00
Time Setpoint Not Met During Occupied Cooling	457.50
Time Not Comfortable Based on Simple ASHRAE 55-2004	7020.67

Note 1: An asterisk (*) indicates that the feature is not yet implemented.

Table of Contents

[Top](#)
[Annual Building Utility Performance Summary](#)
[Input Verification and Results Summary](#)
[Demand End Use Components Summary](#)
[Source Energy End Use Components Summary](#)
[Component Sizing Summary](#)
[Surface Shadowing Summary](#)
[Climatic Data Summary](#)
[Envelope Summary](#)
[Shading Summary](#)
[Lighting Summary](#)
[Equipment Summary](#)
[HVAC Sizing Summary](#)
[System Summary](#)
[Outdoor Air Summary](#)
[Object Count Summary](#)
[Energy Meters](#)
[Sensible Heat Gain Summary](#)
[Standard 62.1 Summary](#)
[LEED Summary](#)

BUILDING ENERGY PERFORMANCE - ELECTRICITY

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - NATURAL GAS

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - ELECTRICITY PEAK DEMAND

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - NATURAL GAS PEAK DEMAND

| [Meter](#) |

Life-Cycle Cost Report

| [Entire Facility](#) |

Report: **Input Verification and Results Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2014-04-07 20:50:41**

General

	Value
Program Version and Build	EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 20:50

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:50:41 - EnergyPlus

RunPeriod	RUN PERIOD 1
Weather File	Bozeman Gallatin Field MT USA TMY3 WMO#=726797
Latitude [deg]	45.80
Longitude [deg]	-111.2
Elevation [m]	1349.00
Time Zone	-7.0
North Axis Angle [deg]	0.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	2678.19	793.76	544.44	795.55	544.44
Window Opening Area [m2]	265.63	91.49	55.58	79.78	38.79
Window-Wall Ratio [%]	9.92	11.53	10.21	10.03	7.12

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	2678.19	793.76	544.44	795.55	544.44
Window Opening Area [m2]	265.63	91.49	55.58	79.78	38.79
Window-Wall Ratio [%]	9.92	11.53	10.21	10.03	7.12

Skylight-Roof Ratio

	Total
Gross Roof Area [m2]	4376.50
Skylight Area [m2]	0.00
Skylight-Roof Ratio [%]	0.00

PERFORMANCE

Zone Summary

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Gross Wall Area [m2]	Window Glass Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
TZ: MH PRES OFFICES	644.69	Yes	Yes	2751.01	1.00	432.25	68.92	9.1493	11.61	10.7639
TZ:MH_ATTIC	893.88	Yes	Yes	5292.93	1.00	581.57	59.92	10.7639	92.90	40.2716
TZ:MH_CORRIDOR	778.26	Yes	Yes	3321.00	1.00	618.56	18.38	9.1493	92.90	1.0764
TZ:MH_OFFICES	1256.89	Yes	Yes	5365.96	1.00	989.25	118.41	9.1493	11.61	10.7639
Total	3573.72			16730.91		2621.63	265.63	9.5532	19.66	16.0349
Conditioned Total	3573.72			16730.91		2621.63	265.63	9.5532	19.66	16.0349
Unconditioned Total	0.00			0.00		0.00	0.00			
Not Part of Total	0.00			0.00		0.00	0.00			

Report: Demand End Use Components Summary

[Table of Contents](#)

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:52:31 - EnergyPlus

Program Version:EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 20:52

[Table of Contents](#)

Tabular Output Report in Format: HTML

Building: **Building 1**

Environment: **RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797**

Simulation Timestamp: **2014-04-07 20:52:31**

Report: **Annual Building Utility Performance Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2014-04-07 20:52:31**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	7771.56	3654.19	3654.19
Net Site Energy	7771.56	3654.19	3654.19
Total Source Energy	15157.88	7127.25	7127.25
Net Source Energy	15157.88	7127.25	7127.25

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050
Other Fuel 1	1.000
Other Fuel 2	1.000

Building Area

	Area [m2]
Total Building Area	2126.75
Net Conditioned Building Area	2126.75
Unconditioned Building Area	0.00

End Uses

	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	0.00	3429.88	0.00	0.00	0.00	0.00

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=-726797 2014-04-07 20:52:31 - EnergyPlus

Cooling	221.86	0.00	0.00	0.00	0.00	0.00
Interior Lighting	723.51	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	1737.95	1109.07	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	278.57	0.00	0.00	0.00	0.00	0.00
Pumps	209.15	0.00	0.00	0.00	0.00	0.00
Heat Rejection	61.56	0.00	0.00	0.00	0.00	1706.43
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	3232.60	4538.95	0.00	0.00	0.00	1706.43

Note: Natural gas appears to be the principal heating source based on energy usage.

End Uses By Subcategory

	Subcategory	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	Boiler	0.00	3429.88	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	221.86	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	723.51	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	1737.95	1109.07	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	278.57	0.00	0.00	0.00	0.00	0.00
Pumps	General	209.15	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	61.56	0.00	0.00	0.00	0.00	1706.43
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	340.20	0.00	0.00	0.00	0.00	0.00
HVAC	362.59	1612.73	0.00	0.00	0.00	0.80
Other	817.19	521.49	0.00	0.00	0.00	0.00
Total	1519.97	2134.22	0.00	0.00	0.00	0.80

Utility Use Per Total Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	340.20	0.00	0.00	0.00	0.00	0.00

file:///C:/Users/josh.talbert/Documents/Projects/EMEC%20590%20-%20Thesis%20Project/Final%20Presentation/ALL%20CALIBRATED/2014-03-27%20TIE... 2/48

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:52:31 - EnergyPlus

HVAC	362.59	1612.73	0.00	0.00	0.00	0.80
Other	817.19	521.49	0.00	0.00	0.00	0.00
Total	1519.97	2134.22	0.00	0.00	0.00	0.80

Electric Loads Satisfied

	Electricity [GJ]	Percent Electricity [%]
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power	0.00	0.00
Net Decrease in On-Site Storage	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	3232.60	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	3232.60	100.00
Total On-Site and Utility Electric Sources	3232.60	100.00
Total Electricity End Uses	3232.60	100.00

On-Site Thermal Sources

	Heat [GJ]	Percent Heat [%]
Water-Side Heat Recovery	0.00	
Air to Air Heat Recovery for Cooling	0.00	
Air to Air Heat Recovery for Heating	0.00	
High-Temperature Geothermal*	0.00	
Solar Water Thermal	0.00	
Solar Air Thermal	0.00	
Total On-Site Thermal Sources	0.00	

Water Source Summary

	Water [m3]	Percent Water [%]
Rainwater Collection	0.00	0.00
Condensate Collection	0.00	0.00
Groundwater Well	0.00	0.00
Total On Site Water Sources	0.00	0.00
-	-	-
Initial Storage	0.00	0.00
Final Storage	0.00	0.00
Change in Storage	0.00	0.00
-	-	-
Water Supplied by Utility	1706.43	100.00
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	1706.43	100.00
Total Water End Uses	1706.43	100.00

4/14/2014

Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:52:31 - EnergyPlus

Comfort and Setpoint Not Met Summary

	Degrees [deltaC]
Tolerance for Zone Heating Setpoint Not Met Time	0.20
Tolerance for Zone Cooling Setpoint Not Met Time	0.20

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	313.83
Time Setpoint Not Met During Occupied Cooling	1219.17
Time Not Comfortable Based on Simple ASHRAE 55-2004	7918.67

Note 1: An asterisk (*) indicates that the feature is not yet implemented.

Table of Contents

[Top](#)
[Annual Building Utility Performance Summary](#)
[Input Verification and Results Summary](#)
[Demand End Use Components Summary](#)
[Source Energy End Use Components Summary](#)
[Component Sizing Summary](#)
[Surface Shadowing Summary](#)
[Climatic Data Summary](#)
[Envelope Summary](#)
[Shading Summary](#)
[Lighting Summary](#)
[Equipment Summary](#)
[HVAC Sizing Summary](#)
[System Summary](#)
[Outdoor Air Summary](#)
[Object Count Summary](#)
[Energy Meters](#)
[Sensible Heat Gain Summary](#)
[Standard 62.1 Summary](#)
[LEED Summary](#)

BUILDING ENERGY PERFORMANCE - ELECTRICITY

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - NATURAL GAS

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - ELECTRICITY PEAK DEMAND

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - NATURAL GAS PEAK DEMAND

| [Meter](#) |

Life-Cycle Cost Report

| [Entire Facility](#) |

Report: **Input Verification and Results Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2014-04-07 20:52:31**

General

	Value
Program Version and Build	EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 20:52

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=-726797 2014-04-07 20:52:31 - EnergyPlus

RunPeriod	RUN PERIOD 1
Weather File	Bozeman Gallatin Field MT USA TMY3 WMO#=-726797
Latitude [deg]	45.80
Longitude [deg]	-111.2
Elevation [m]	1349.00
Time Zone	-7.0
North Axis Angle [deg]	0.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	3551.27	850.43	957.01	855.93	887.90
Window Opening Area [m2]	5.57	0.00	5.57	0.00	0.00
Window-Wall Ratio [%]	0.16	0.00	0.58	0.00	0.00

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	3551.27	850.43	957.01	855.93	887.90
Window Opening Area [m2]	5.57	0.00	5.57	0.00	0.00
Window-Wall Ratio [%]	0.16	0.00	0.58	0.00	0.00

Skylight-Roof Ratio

	Total
Gross Roof Area [m2]	2126.75
Skylight Area [m2]	0.00
Skylight-RoofRatio [%]	0.00

PERFORMANCE

Zone Summary

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Gross Wall Area [m2]	Window Glass Area [m2]	Lighting [W/m2]	People [m2 per person]	Phg and Process [W/m2]
TZ:TZ_1_BATHROOMS	94.49	Yes	Yes	393.62	1.00	174.73	0.00	13.4549	9.29	2.1528
TZ:TZ_1_CAGE WASH	92.86	Yes	Yes	386.82	1.00	170.25	0.00	16.1459	0.01	48.4376
TZ:TZ_1_CONT CORRIDOR	138.69	Yes	Yes	577.74	1.00	554.23	0.00	16.1459	92.90	1.0764
TZ:TZ_1_CONT SUITES	188.72	Yes	Yes	786.13	1.00	234.47	0.00	16.1459	0.01	48.4376
TZ:TZ_1_CORE WORK SPACE	188.04	Yes	Yes	783.28	1.00	239.55	0.00	16.1459	0.01	48.4376
TZ:TZ_1_LOADING DOCK	142.76	Yes	Yes	594.68	1.00	260.04	0.00	13.4549	92.90	10.7639
TZ:TZ_1_MAIN CORRIDOR	462.29	Yes	Yes	1925.70	1.00	648.78	0.00	16.1459	92.90	1.0764
TZ:TZ_1_SE WORK SPACE	118.46	Yes	Yes	493.44	1.00	214.37	5.57	16.1459	0.01	48.4376

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#-726797 2014-04-07 20:52:31 - EnergyPlus

TZ:TZ_1_STAIR	30.20	Yes	Yes	125.82	1.00	106.14	0.00	16.1459	92.90	1.0764
TZ:TZ_1_SURGERY SUITE	166.31	Yes	Yes	692.79	1.00	239.01	0.00	16.1459	0.01	48.4376
TZ:TZ_1_W WORK SPACE	284.71	Yes	Yes	1185.97	1.00	485.53	0.00	16.1459	0.01	48.4376
TZ:TZ_2_MECH PENTHOUSE	219.23	Yes	Yes	757.31	1.00	224.19	0.00	13.4549	92.90	171.1828
Total	2126.75			8703.28		3551.27	5.57	15.5683	0.02	42.4491
Conditioned Total	2126.75			8703.28		3551.27	5.57	15.5683	0.02	42.4491
Unconditioned Total	0.00			0.00		0.00	0.00			
Not Part of Total	0.00			0.00		0.00	0.00			

Report: Demand End Use Components Summary

[Table of Contents](#)

For: Entire Facility

Timestamp: 2014-04-07 20:52:31

End Uses

	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Time of Peak	18-JUN-18:00	23-FEB-22:49	-	-	-	12-JUL-15:30
Heating	0.00	619693.03	0.00	0.00	0.00	0.00
Cooling	62627.27	0.00	0.00	0.00	0.00	0.00
Interior Lighting	33109.86	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	55110.13	35168.53	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	16788.19	0.00	0.00	0.00	0.00	0.00
Pumps	9359.35	0.00	0.00	0.00	0.00	0.00
Heat Rejection	5272.87	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	182267.67	654861.56	0.00	0.00	0.00	0.00

End Uses By Subcategory

	Subcategory	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Heating	Boiler	0.00	619693.03	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	62627.27	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	33109.86	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	55110.13	35168.53	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	16788.19	0.00	0.00	0.00	0.00	0.00
Pumps	General	9359.35	0.00	0.00	0.00	0.00	0.00

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 21:26:08 - EnergyPlus

Program Version:EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 21:25

[Table of Contents](#)

Tabular Output Report in Format: HTML

Building: **Building 1**

Environment: **RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797**

Simulation Timestamp: **2014-04-07 21:26:08**

Report: **Annual Building Utility Performance Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2014-04-07 21:26:08**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	22883.69	2060.52	2292.77
Net Site Energy	22883.69	2060.52	2292.77
Total Source Energy	35949.60	3237.02	3601.87
Net Source Energy	35949.60	3237.02	3601.87

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050
Other Fuel 1	1.000
Other Fuel 2	1.000

Building Area

	Area [m2]
Total Building Area	11105.78
Net Conditioned Building Area	9980.82
Unconditioned Building Area	1124.96

End Uses

	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	0.00	17533.86	0.00	0.00	0.00	0.00

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#-726797 2014-04-07 21:26:08 - EnergyPlus

Cooling	271.97	0.00	0.00	0.00	0.00	0.00
Interior Lighting	1404.61	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	2273.64	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	679.84	0.00	0.00	0.00	0.00	0.00
Pumps	617.26	0.00	0.00	0.00	0.00	0.00
Heat Rejection	102.50	0.00	0.00	0.00	0.00	2897.71
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	5349.82	17533.86	0.00	0.00	0.00	2897.71

Note: Natural gas appears to be the principal heating source based on energy usage.

End Uses By Subcategory

	Subcategory	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	Boiler	0.00	17533.86	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	271.97	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	1404.61	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	2273.64	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	679.84	0.00	0.00	0.00	0.00	0.00
Pumps	General	617.26	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	102.50	0.00	0.00	0.00	0.00	2897.71
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	140.73	0.00	0.00	0.00	0.00	0.00
HVAC	167.48	1756.76	0.00	0.00	0.00	0.29
Other	227.80	0.00	0.00	0.00	0.00	0.00
Total	536.01	1756.76	0.00	0.00	0.00	0.29

Utility Use Per Total Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	126.48	0.00	0.00	0.00	0.00	0.00

file:///C:/Users/josh.talbert/Documents/Projects/EMEC%20590%20-%20Thesis%20Project/Final%20Presentation/ALL%20CALIBRATED/2014-03-22%20LE... 2/211

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 21:26:08 - EnergyPlus

HVAC	150.51	1578.80	0.00	0.00	0.00	0.26
Other	204.73	0.00	0.00	0.00	0.00	0.00
Total	481.72	1578.80	0.00	0.00	0.00	0.26

Electric Loads Satisfied

	Electricity [GJ]	Percent Electricity [%]
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power	0.00	0.00
Net Decrease in On-Site Storage	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	5349.82	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	5349.82	100.00
Total On-Site and Utility Electric Sources	5349.82	100.00
Total Electricity End Uses	5349.82	100.00

On-Site Thermal Sources

	Heat [GJ]	Percent Heat [%]
Water-Side Heat Recovery	0.00	
Air to Air Heat Recovery for Cooling	0.00	
Air to Air Heat Recovery for Heating	0.00	
High-Temperature Geothermal*	0.00	
Solar Water Thermal	0.00	
Solar Air Thermal	0.00	
Total On-Site Thermal Sources	0.00	

Water Source Summary

	Water [m3]	Percent Water [%]
Rainwater Collection	0.00	0.00
Condensate Collection	0.00	0.00
Groundwater Well	0.00	0.00
Total On Site Water Sources	0.00	0.00
-	-	-
Initial Storage	0.00	0.00
Final Storage	0.00	0.00
Change in Storage	0.00	0.00
-	-	-
Water Supplied by Utility	2897.71	100.00
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	2897.71	100.00
Total Water End Uses	2897.71	100.00

4/14/2014

Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 21:26:08 - EnergyPlus

Comfort and Setpoint Not Met Summary

	Degrees [deltaC]
Tolerance for Zone Heating Setpoint Not Met Time	0.20
Tolerance for Zone Cooling Setpoint Not Met Time	0.20

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	898.33
Time Setpoint Not Met During Occupied Cooling	7.00
Time Not Comfortable Based on Simple ASHRAE 55-2004	8758.33

Note 1: An asterisk (*) indicates that the feature is not yet implemented.

Table of Contents

[Top](#)
[Annual Building Utility Performance Summary](#)
[Input Verification and Results Summary](#)
[Demand End Use Components Summary](#)
[Source Energy End Use Components Summary](#)
[Component Sizing Summary](#)
[Surface Shadowing Summary](#)
[Climatic Data Summary](#)
[Envelope Summary](#)
[Shading Summary](#)
[Lighting Summary](#)
[Equipment Summary](#)
[HVAC Sizing Summary](#)
[System Summary](#)
[Outdoor Air Summary](#)
[Object Count Summary](#)
[Energy Meters](#)
[Sensible Heat Gain Summary](#)
[Standard 62.1 Summary](#)
[LEED Summary](#)

BUILDING ENERGY PERFORMANCE - ELECTRICITY

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - NATURAL GAS

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - ELECTRICITY PEAK DEMAND

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - NATURAL GAS PEAK DEMAND

| [Meter](#) |

Life-Cycle Cost Report

| [Entire Facility](#) |

Report: **Input Verification and Results Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2014-04-07 21:26:08**

General

	Value
Program Version and Build	EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 21:25

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=-726797 2014-04-07 21:26:08 - EnergyPlus

RunPeriod	RUN PERIOD 1
Weather File	Bozeman Gallatin Field MT USA TMY3 WMO#=-726797
Latitude [deg]	45.80
Longitude [deg]	-111.2
Elevation [m]	1349.00
Time Zone	-7.0
North Axis Angle [deg]	0.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	18347.31	4953.56	4181.80	5009.75	4202.20
Window Opening Area [m2]	378.71	97.76	64.16	91.20	125.60
Window-Wall Ratio [%]	2.06	1.97	1.53	1.82	2.99

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	17354.36	4620.04	4018.85	4676.23	4039.25
Window Opening Area [m2]	378.71	97.76	64.16	91.20	125.60
Window-Wall Ratio [%]	2.18	2.12	1.60	1.95	3.11

Skylight-Roof Ratio

	Total
Gross Roof Area [m2]	11105.78
Skylight Area [m2]	0.00
Skylight-RoofRatio [%]	0.00

PERFORMANCE

Zone Summary

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Gross Wall Area [m2]	Window Glass Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
TZ:1ST_BATHROOMS	28.61	Yes	Yes	122.10	1.00	93.65	0.00	11.8403	9.29	2.1528
TZ:1ST_CORE LABS	228.36	Yes	Yes	974.44	1.00	280.94	0.00	16.1459	6.97	16.1459
TZ:1ST_CORRIDOR	131.55	Yes	Yes	561.35	1.00	421.41	0.00	10.7639	92.90	1.0764
TZ:1ST_MER	33.01	Yes	Yes	140.87	1.00	104.92	0.00	13.4549	92.90	10.7639
TZ:1ST_NE LABS	172.17	Yes	Yes	734.67	1.00	315.61	0.00	16.1459	6.97	16.1459
TZ:1ST_NORTH LABS	73.71	Yes	Yes	314.53	1.00	155.22	0.00	16.1459	6.97	16.1459
TZ:1ST_SE STAIR	24.15	Yes	Yes	103.07	1.00	85.84	0.00	13.4549	92.90	10.7639
TZ:1ST_SOUTH LABS	338.82	Yes	Yes	1445.80	1.00	351.17	0.00	16.1459	6.97	16.1459
TZ:1ST_SW STAIR	26.57	Yes	Yes	113.38	1.00	91.04	0.00	10.7639	92.90	1.0764
TZ2ND_AUD STAIR	40.68	Yes	Yes	173.60	1.00	123.65	0.00	12.9167	11.61	10.7639
TZ2ND_AUDITORIUM UG	286.11	Yes	Yes	1220.88	1.00	282.97	0.00	12.9167	11.61	10.7639
TZ2ND_BATHROOMS	28.61	Yes	Yes	122.10	1.00	93.65	0.00	11.8403	9.29	2.1528

file:///C:/Users/josh.talbert/Documents/Projects/EMEC%20590%20-%20Thesis%20Project/Final%20Presentation/ALL%20CALIBRATED/2014-03-22%20LE... 5/211

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#-726797 2014-04-07 21:26:08 - EnergyPlus

TZ2ND_CORRIDOR LARGE	367.30	Yes	Yes	1567.33	1.00	985.03	0.00	10.7639	92.90	1.0764
TZ2ND_EAST LAB	168.48	Yes	Yes	718.94	1.00	232.82	0.00	12.9167	11.61	10.7639
TZ2ND_LAB CORE 1	103.23	Yes	Yes	440.48	1.00	173.43	0.00	16.1459	6.97	16.1459
TZ2ND_LAB CORE 2	90.39	Yes	Yes	385.73	1.00	163.88	0.00	16.1459	6.97	16.1459
TZ2ND_MER	33.01	Yes	Yes	140.87	1.00	104.92	0.00	13.4549	92.90	10.7639
TZ2ND_NE LABS	172.17	Yes	Yes	734.67	1.00	315.61	0.00	16.1459	6.97	16.1459
TZ2ND_NORTH LABS	73.71	Yes	Yes	314.53	1.00	155.22	0.00	16.1459	6.97	16.1459
TZ2ND_SE LAB	139.82	Yes	Yes	596.64	1.00	218.51	0.00	16.1459	6.97	16.1459
TZ2ND_SE STAIR	24.15	Yes	Yes	103.07	1.00	85.84	0.00	13.4549	92.90	10.7639
TZ2ND_SW LAB	154.79	Yes	Yes	660.52	1.00	212.45	0.00	16.1459	6.97	16.1459
TZ2ND_SW STAIR	26.57	Yes	Yes	113.38	1.00	91.04	0.00	10.7639	92.90	1.0764
TZ2ND_WEST LAB 1	215.60	Yes	Yes	920.01	1.00	255.37	0.00	12.9167	11.61	10.7639
TZ3RD_AUD_BATHROOMS	45.60	Yes	Yes	171.40	1.00	122.56	0.00	12.9167	11.61	10.7639
TZ3RD_AUD_BIG AUDITORIUM	286.11	Yes	Yes	1075.54	1.00	249.29	0.00	12.9167	11.61	10.7639
TZ3RD_AUD_EAST ENTRANCE	29.31	Yes	Yes	110.19	1.00	84.78	0.00	12.9167	11.61	10.7639
TZ3RD_AUD_ENTRANCE LOBBY	149.69	Yes	Yes	562.72	1.00	209.28	0.00	12.9167	11.61	10.7639
TZ3RD_AUD_LOBBY	99.81	Yes	Yes	375.20	1.00	221.44	0.00	12.9167	11.61	10.7639
TZ3RD_AUD_MINI AUDITORIUM	172.17	Yes	Yes	647.21	1.00	197.83	0.00	12.9167	11.61	10.7639
TZ3RD_AUD_WEST ENTRANCE	40.68	Yes	Yes	152.94	1.00	108.93	0.00	12.9167	11.61	10.7639
TZ3RD_BATHROOMS	28.61	Yes	Yes	111.93	1.00	85.84	0.00	11.8403	9.29	2.1528
TZ3RD_CORE LAB	228.36	Yes	Yes	893.24	1.00	257.53	0.00	16.1459	6.97	16.1459
TZ3RD_CORRIDOR	131.55	Yes	Yes	514.57	1.00	386.29	0.00	10.7639	92.90	1.0764
TZ3RD_MER	33.01	Yes	Yes	129.13	1.00	96.18	0.00	13.4549	92.90	10.7639
TZ3RD_NE LAB	172.17	Yes	Yes	673.45	1.00	289.31	29.92	16.1459	6.97	16.1459
TZ3RD_NORTH LAB	73.71	Yes	Yes	288.32	1.00	142.28	14.88	16.1459	6.97	16.1459
TZ3RD_PLENUM	540.88	No	Yes	659.44	1.00	113.71	0.00	12.9167	11.61	10.7639
TZ3RD_SE STAIR	24.15	Yes	Yes	94.48	1.00	78.69	0.00	13.4549	92.90	10.7639
TZ3RD_SOUTH LAB	299.80	Yes	Yes	1172.69	1.00	321.91	11.68	16.1459	6.97	16.1459
TZ3RD_SW STAIR	26.57	Yes	Yes	103.93	1.00	83.46	0.00	10.7639	92.90	1.0764
TZ3RD_VESTIBULE	11.38	Yes	Yes	44.52	1.00	52.86	10.24	10.7639	92.90	1.0764
TZ4TH_BATHROOMS	28.61	Yes	Yes	111.93	1.00	85.84	0.00	11.8403	9.29	2.1528
TZ4TH_CORE LAB	228.36	Yes	Yes	893.24	1.00	257.53	0.00	16.1459	6.97	16.1459
TZ4TH_CORRIDOR	131.55	Yes	Yes	514.57	1.00	386.29	0.00	10.7639	92.90	1.0764
TZ4TH_MER	33.01	Yes	Yes	129.13	1.00	96.18	0.00	13.4549	92.90	10.7639
TZ4TH_NE LAB	172.17	Yes	Yes	673.45	1.00	289.31	24.32	16.1459	6.97	16.1459
TZ4TH_NORTH LAB	73.71	Yes	Yes	288.32	1.00	142.28	3.20	16.1459	6.97	16.1459
TZ4TH_SE STAIR	24.15	Yes	Yes	94.48	1.00	78.69	0.00	13.4549	92.90	10.7639
TZ4TH_SOUTH LAB	299.80	Yes	Yes	1172.69	1.00	321.91	24.64	16.1459	6.97	16.1459
TZ4TH_SW STAIR	26.57	Yes	Yes	103.93	1.00	83.46	0.00	10.7639	92.90	1.0764
TZ4TH_VESTIBULE	11.38	Yes	Yes	44.52	1.00	52.86	10.24	10.7639	92.90	1.0764
TZ5TH_BATHROOMS	28.61	Yes	Yes	111.93	1.00	85.84	0.00	11.8403	9.29	2.1528
TZ5TH_CORE LAB	228.36	Yes	Yes	893.24	1.00	257.53	0.00	16.1459	6.97	16.1459
TZ5TH_CORRIDOR	131.55	Yes	Yes	514.57	1.00	386.29	0.00	10.7639	92.90	1.0764
TZ5TH_MER	33.01	Yes	Yes	129.13	1.00	96.18	0.00	13.4549	92.90	10.7639
TZ5TH_NE LAB	172.17	Yes	Yes	673.45	1.00	289.31	24.32	16.1459	6.97	16.1459

file:///C:/Users/josh.talbert/Documents/Projects/EMEC/20590%20-%20Thesis%20Project/Final%20Presentation/ALL%20CALIBRATED/2014-03-22%20LE... 6/211

4/14/2014	Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#-726797 2014-04-07 21:26:08 - EnergyPlus										
	TZ:5TH_NORTH LAB	73.71	Yes	Yes	288.32	1.00	142.28	3.20	16.1459	6.97	16.1459
	TZ:5TH_SE STAIR	24.15	Yes	Yes	94.48	1.00	78.69	0.00	13.4549	92.90	10.7639
	TZ:5TH_SOUTH LAB	299.80	Yes	Yes	1172.69	1.00	321.91	24.64	16.1459	6.97	16.1459
	TZ:5TH_SW STAIR	26.57	Yes	Yes	103.93	1.00	83.46	0.00	10.7639	92.90	1.0764
	TZ:5TH_VESTIBULE	11.38	Yes	Yes	44.52	1.00	52.86	10.24	10.7639	92.90	1.0764
	TZ:6TH_BATHROOMS	28.61	Yes	Yes	111.93	1.00	85.84	0.00	11.8403	9.29	2.1528
	TZ:6TH_CORE LAB	228.36	Yes	Yes	893.24	1.00	257.53	0.00	16.1459	6.97	16.1459
	TZ:6TH_CORRIDOR	131.55	Yes	Yes	514.57	1.00	386.29	0.00	10.7639	92.90	1.0764
	TZ:6TH_MER	33.01	Yes	Yes	129.13	1.00	96.18	0.00	13.4549	92.90	10.7639
	TZ:6TH_NE LAB	172.17	Yes	Yes	673.45	1.00	289.31	24.32	16.1459	6.97	16.1459
	TZ:6TH_NORTH LAB	73.71	Yes	Yes	288.32	1.00	142.28	3.20	16.1459	6.97	16.1459
	TZ:6TH_SE STAIR	24.15	Yes	Yes	94.48	1.00	78.69	0.00	13.4549	92.90	10.7639
	TZ:6TH_SOUTH LAB	299.80	Yes	Yes	1172.69	1.00	321.91	24.64	16.1459	6.97	16.1459
	TZ:6TH_SW STAIR	26.57	Yes	Yes	103.93	1.00	83.46	0.00	10.7639	92.90	1.0764
	TZ:6TH_VESTIBULE	11.38	Yes	Yes	44.52	1.00	52.86	10.24	10.7639	92.90	1.0764
	TZ:7TH_BATHROOMS	28.61	Yes	Yes	111.93	1.00	85.84	0.00	11.8403	9.29	2.1528
	TZ:7TH_CORE LAB	228.36	Yes	Yes	893.24	1.00	257.53	0.00	16.1459	6.97	16.1459
	TZ:7TH_CORRIDOR	131.55	Yes	Yes	514.57	1.00	386.29	0.00	10.7639	92.90	1.0764
	TZ:7TH_MER	33.01	Yes	Yes	129.13	1.00	96.18	0.00	13.4549	92.90	10.7639
	TZ:7TH_NE LAB	172.17	Yes	Yes	673.45	1.00	289.31	24.32	16.1459	6.97	16.1459
	TZ:7TH_NORTH LAB	73.71	Yes	Yes	288.32	1.00	142.28	3.20	16.1459	6.97	16.1459
	TZ:7TH_SE STAIR	24.15	Yes	Yes	94.48	1.00	78.69	0.00	13.4549	92.90	10.7639
	TZ:7TH_SOUTH LAB	299.80	Yes	Yes	1172.69	1.00	321.91	24.64	16.1459	6.97	16.1459
	TZ:7TH_SW STAIR	26.57	Yes	Yes	103.93	1.00	83.46	0.00	10.7639	92.90	1.0764
	TZ:7TH_VESTIBULE	11.38	Yes	Yes	44.52	1.00	52.86	10.24	10.7639	92.90	1.0764
	TZ:8TH_BATHROOMS	28.61	Yes	Yes	111.93	1.00	85.84	0.00	11.8403	9.29	2.1528
	TZ:8TH_CORE LAB	228.36	Yes	Yes	893.24	1.00	257.53	0.00	16.1459	6.97	16.1459
	TZ:8TH_CORRIDOR	131.55	Yes	Yes	514.57	1.00	386.29	0.00	10.7639	92.90	1.0764
	TZ:8TH_MER	33.01	Yes	Yes	129.13	1.00	96.18	0.00	13.4549	92.90	10.7639
	TZ:8TH_NE LAB	172.17	Yes	Yes	673.45	1.00	289.31	24.32	16.1459	6.97	16.1459
	TZ:8TH_NORTH LAB	73.71	Yes	Yes	288.32	1.00	142.28	3.20	16.1459	6.97	16.1459
	TZ:8TH_SE STAIR	24.15	Yes	Yes	94.48	1.00	78.69	0.00	13.4549	92.90	10.7639
	TZ:8TH_SOUTH LAB	299.80	Yes	Yes	1172.69	1.00	321.91	24.64	16.1459	6.97	16.1459
	TZ:8TH_SW STAIR	26.57	Yes	Yes	103.93	1.00	83.46	0.00	10.7639	92.90	1.0764
	TZ:8TH_VESTIBULE	11.38	Yes	Yes	44.52	1.00	52.86	10.24	10.7639	92.90	1.0764
	TZ:BSMT_MER	386.48	No	Yes	1649.17	1.00	416.21	0.00	13.4549	92.90	10.7639
	TZ:BSMT_SE STAIR	24.15	No	Yes	103.07	1.00	85.84	0.00	13.4549	92.90	10.7639
	TZ:BSMT_STORAGE	146.88	No	Yes	626.77	1.00	286.14	0.00	13.4549	92.90	10.7639
	TZ:BSMT_SW STAIR	26.57	No	Yes	113.38	1.00	91.04	0.00	10.7639	92.90	1.0764
	Total	11105.78			43127.58		18347.31	378.71	14.4346	9.92	12.1950
	Conditioned Total	9980.82			39975.74		17354.36	378.71	14.5814	9.35	12.3821
	Unconditioned Total	1124.96			3151.83		992.95	0.00	13.1326	21.28	10.5351
	Not Part of Total	0.00			0.00		0.00	0.00			

Report: Demand End Use Components Summary

[Table of Contents](#)

For: Entire Facility

Timestamp: 2014-04-07 21:26:08

file:///C:/Users/josh.talbert/Documents/Projects/EMEC%20590%20-%20Thesis%20Project/Final%20Presentation/ALL%20CALIBRATED/2014-03-22%20LE... 7/211

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:51:32 - EnergyPlus

Program Version:EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 20:51

[Table of Contents](#)

Tabular Output Report in Format: HTML

Building: **Building 1**

Environment: **RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797**

Simulation Timestamp: **2014-04-07 20:51:32**

Report: **Annual Building Utility Performance Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2014-04-07 20:51:32**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	3807.14	1087.11	1087.11
Net Site Energy	3807.14	1087.11	1087.11
Total Source Energy	4618.72	1318.85	1318.85
Net Source Energy	4618.72	1318.85	1318.85

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050
Other Fuel 1	1.000
Other Fuel 2	1.000

Building Area

	Area [m2]
Total Building Area	3502.07
Net Conditioned Building Area	3502.07
Unconditioned Building Area	0.00

End Uses

	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	0.00	2839.06	0.00	0.00	0.00	0.00

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=-726797 2014-04-07 20:51:32 - EnergyPlus

Cooling	34.96	0.00	0.00	0.00	0.00	0.00
Interior Lighting	40.32	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	44.88	731.99	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	48.59	0.00	0.00	0.00	0.00	0.00
Pumps	53.21	0.00	0.00	0.00	0.00	0.00
Heat Rejection	14.12	0.00	0.00	0.00	0.00	384.33
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	236.09	3571.05	0.00	0.00	0.00	384.33

Note: Natural gas appears to be the principal heating source based on energy usage.

End Uses By Subcategory

	Subcategory	Electricity [GJ]	Natural Gas [GJ]	Additional Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	Boiler	0.00	2839.06	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	34.96	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	40.32	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	44.88	731.99	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	48.59	0.00	0.00	0.00	0.00	0.00
Pumps	General	53.21	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	14.12	0.00	0.00	0.00	0.00	384.33
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	11.51	0.00	0.00	0.00	0.00	0.00
HVAC	43.09	810.68	0.00	0.00	0.00	0.11
Other	12.82	209.02	0.00	0.00	0.00	0.00
Total	67.42	1019.70	0.00	0.00	0.00	0.11

Utility Use Per Total Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Additional Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	11.51	0.00	0.00	0.00	0.00	0.00

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:51:32 - EnergyPlus

HVAC	43.09	810.68	0.00	0.00	0.00	0.11
Other	12.82	209.02	0.00	0.00	0.00	0.00
Total	67.42	1019.70	0.00	0.00	0.00	0.11

Electric Loads Satisfied

	Electricity [GJ]	Percent Electricity [%]
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power	0.00	0.00
Net Decrease in On-Site Storage	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	236.09	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	236.09	100.00
Total On-Site and Utility Electric Sources	236.09	100.00
Total Electricity End Uses	236.09	100.00

On-Site Thermal Sources

	Heat [GJ]	Percent Heat [%]
Water-Side Heat Recovery	0.00	
Air to Air Heat Recovery for Cooling	0.00	
Air to Air Heat Recovery for Heating	0.00	
High-Temperature Geothermal*	0.00	
Solar Water Thermal	0.00	
Solar Air Thermal	0.00	
Total On-Site Thermal Sources	0.00	

Water Source Summary

	Water [m3]	Percent Water [%]
Rainwater Collection	0.00	0.00
Condensate Collection	0.00	0.00
Groundwater Well	0.00	0.00
Total On Site Water Sources	0.00	0.00
-	-	-
Initial Storage	0.00	0.00
Final Storage	0.00	0.00
Change in Storage	0.00	0.00
-	-	-
Water Supplied by Utility	384.33	100.00
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	384.33	100.00
Total Water End Uses	384.33	100.00

4/14/2014

Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=726797 2014-04-07 20:51:32 - EnergyPlus

Comfort and Setpoint Not Met Summary

	Degrees [deltaC]
Tolerance for Zone Heating Setpoint Not Met Time	0.20
Tolerance for Zone Cooling Setpoint Not Met Time	0.20

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	2493.50
Time Setpoint Not Met During Occupied Cooling	2555.67
Time Not Comfortable Based on Simple ASHRAE 55-2004	8720.17

Note 1: An asterisk (*) indicates that the feature is not yet implemented.

Table of Contents

[Top](#)
[Annual Building Utility Performance Summary](#)
[Input Verification and Results Summary](#)
[Demand End Use Components Summary](#)
[Source Energy End Use Components Summary](#)
[Component Sizing Summary](#)
[Surface Shadowing Summary](#)
[Climatic Data Summary](#)
[Envelope Summary](#)
[Shading Summary](#)
[Lighting Summary](#)
[Equipment Summary](#)
[HVAC Sizing Summary](#)
[System Summary](#)
[Outdoor Air Summary](#)
[Object Count Summary](#)
[Energy Meters](#)
[Sensible Heat Gain Summary](#)
[Standard 62.1 Summary](#)
[LEED Summary](#)

BUILDING ENERGY PERFORMANCE - ELECTRICITY

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - NATURAL GAS

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - ELECTRICITY PEAK DEMAND

| [Meter](#) |

BUILDING ENERGY PERFORMANCE - NATURAL GAS PEAK DEMAND

| [Meter](#) |

Life-Cycle Cost Report

| [Entire Facility](#) |

Report: **Input Verification and Results Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2014-04-07 20:51:32**

General

	Value
Program Version and Build	EnergyPlus-Windows-64 8.0.0.008, YMD=2014.04.07 20:51

4/14/2014 Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#=-726797 2014-04-07 20:51:32 - EnergyPlus

RunPeriod	RUN PERIOD 1
Weather File	Bozeman Gallatin Field MT USA TMY3 WMO#=-726797
Latitude [deg]	45.80
Longitude [deg]	-111.2
Elevation [m]	1349.00
Time Zone	-7.0
North Axis Angle [deg]	0.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	5752.61	2016.82	903.09	1929.60	903.09
Window Opening Area [m2]	292.91	129.19	0.00	150.07	13.66
Window-Wall Ratio [%]	5.09	6.41	0.00	7.78	1.51

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	5752.61	2016.82	903.09	1929.60	903.09
Window Opening Area [m2]	292.91	129.19	0.00	150.07	13.66
Window-Wall Ratio [%]	5.09	6.41	0.00	7.78	1.51

Skylight-Roof Ratio

	Total
Gross Roof Area [m2]	3527.04
Skylight Area [m2]	0.00
Skylight-Roof Ratio [%]	0.00

PERFORMANCE

Zone Summary

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Gross Wall Area [m2]	Window Glass Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
TZCL_0_BATHROOMS	23.23	Yes	Yes	70.79	1.00	60.39	0.00	3.2292	9.29	0.0000
TZCL_0_CORRIDOR	105.79	Yes	Yes	322.43	1.00	244.03	0.00	2.1528	92.90	0.0000
TZCL_0_EAST STAIR	18.58	Yes	Yes	56.63	1.00	55.74	0.00	2.1528	92.90	0.0000
TZCL_0_ELEV	24.53	Yes	Yes	74.76	1.00	71.23	0.00	5.3820	92.90	0.0000
TZCL_0_MER	226.68	Yes	Yes	690.93	1.00	263.84	0.00	5.3820	92.90	310.2876
TZCL_0_SOUTH LABS	166.30	Yes	Yes	506.87	1.00	203.46	0.00	3.2292	6.97	3.5521
TZCL_0_WEST STAIR	18.58	Yes	Yes	56.63	1.00	55.74	2.14	2.1528	92.90	0.0000
TZCL_1_BATHROOMS	23.23	Yes	Yes	74.33	1.00	63.41	0.00	3.2292	9.29	0.0000
TZCL_1_COLD ROOM	18.58	Yes	Yes	59.47	1.00	58.53	0.00	5.3820	92.90	0.0000
TZCL_1_CORRIDOR	105.79	Yes	Yes	338.56	1.00	256.23	3.41	2.1528	92.90	0.0000
TZCL_1_EAST STAIR	18.58	Yes	Yes	59.47	1.00	58.53	0.00	0.0000		0.0000
TZCL_1_ELEV	24.53	Yes	Yes	78.49	1.00	74.79	0.00	5.3820	92.90	0.0000

4/14/2014

Building 1 RUN PERIOD 1 ** Bozeman Gallatin Field MT USA TMY3 WMO#-726797 2014-04-07 20:51:32 - EnergyPlus

TZCL_1_LABS	166.30	Yes	Yes	532.22	1.00	213.63	28.36	3.2292	6.97	3.5521
TZCL_1_MECH AND ELEC	29.73	Yes	Yes	95.14	1.00	70.23	0.00	5.3820	92.90	0.0000
TZCL_1_NORTH LAB	178.37	Yes	Yes	570.87	1.00	226.31	37.81	3.2292	6.97	3.5521
TZCL_1_WEST STAIR	18.58	Yes	Yes	59.47	1.00	58.53	3.79	2.1528	92.90	0.0000
TZCL_2_BATHROOMS	23.23	Yes	Yes	74.33	1.00	63.41	0.00	3.2292	9.29	0.0000
TZCL_2_CORRIDOR	105.79	Yes	Yes	338.56	1.00	256.23	3.41	2.1528	92.90	0.0000
TZCL_2_EAST STAIR	18.58	Yes	Yes	59.47	1.00	58.53	3.79	2.1528	92.90	0.0000
TZCL_2_ELEV	24.53	Yes	Yes	78.49	1.00	74.79	0.00	5.3820	92.90	0.0000
TZCL_2_MECH AND ELEC	29.73	Yes	Yes	95.14	1.00	70.23	0.00	5.3820	92.90	0.0000
TZCL_2_NORTH LABS	196.95	Yes	Yes	630.33	1.00	245.82	28.36	3.2292	6.97	3.5521
TZCL_2_SOUTH OFFICES	166.30	Yes	Yes	532.22	1.00	213.63	31.51	3.2292	6.97	3.5521
TZCL_2_WEST STAIR	18.58	Yes	Yes	59.47	1.00	58.53	3.79	2.1528	92.90	0.0000
TZCL_3_BATHROOMS	23.23	Yes	Yes	70.79	1.00	60.39	0.00	3.2292	9.29	0.0000
TZCL_3_COLD ROOM	18.58	Yes	Yes	56.63	1.00	55.74	0.00	5.3820	92.90	0.0000
TZCL_3_CORRIDOR	105.79	Yes	Yes	322.43	1.00	244.03	3.41	2.1528	92.90	0.0000
TZCL_3_EAST STAIRS	18.58	Yes	Yes	56.63	1.00	55.74	3.60	2.1528	92.90	0.0000
TZCL_3_ELEV	24.53	Yes	Yes	74.76	1.00	71.23	0.00	5.3820	92.90	0.0000
TZCL_3_MECH AND ELEC	29.73	Yes	Yes	90.61	1.00	66.89	0.00	5.3820	92.90	0.0000
TZCL_3_NORTH LABS	178.37	Yes	Yes	543.68	1.00	215.54	31.51	3.2292	6.97	3.5521
TZCL_3_SOUTH LABS	166.30	Yes	Yes	506.87	1.00	203.46	31.51	3.2292	6.97	3.5521
TZCL_3_WEST STAIR	18.58	Yes	Yes	56.63	1.00	55.74	3.60	2.1528	92.90	0.0000
TZCL_4_BATHROOMS	23.23	Yes	Yes	77.87	1.00	66.43	0.00	3.2292	9.29	0.0000
TZCL_4_COLD ROOM	18.58	Yes	Yes	62.30	1.00	61.32	0.00	5.3820	92.90	0.0000
TZCL_4_CORRIDOR	105.79	Yes	Yes	354.68	1.00	268.43	3.41	2.1528	92.90	0.0000
TZCL_4_EAST STAIR	18.58	Yes	Yes	62.30	1.00	61.32	3.22	2.1528	92.90	0.0000
TZCL_4_ELEV	24.53	Yes	Yes	82.23	1.00	78.35	0.00	5.3820	92.90	0.0000
TZCL_4_MECH AND ELEC	29.73	Yes	Yes	99.68	1.00	73.58	0.00	5.3820	92.90	0.0000
TZCL_4_NORTH LAB	178.37	Yes	Yes	598.05	1.00	237.09	31.51	3.2292	6.97	3.5521
TZCL_4_SOUTH LABS	166.30	Yes	Yes	557.56	1.00	223.80	31.51	3.2292	6.97	3.5521
TZCL_4_WEST STAIR	18.58	Yes	Yes	62.30	1.00	61.32	3.22	2.1528	92.90	0.0000
TZCL_5_EAST STAIR	18.58	Yes	Yes	57.70	1.00	56.79	0.00	2.1528	92.90	0.0000
TZCL_5_MECH PENTHOUSE	546.52	Yes	Yes	1841.23	1.00	402.89	0.00	5.3820	92.90	0.0000
TZCL_5_WEST STAIR	18.58	Yes	Yes	57.70	1.00	56.79	0.00	2.1528	92.90	0.0000
Total	3502.07			11207.70		5752.61	292.91	3.6447	13.66	21.6703
Conditioned Total	3502.07			11207.70		5752.61	292.91	3.6447	13.66	21.6703
Unconditioned Total	0.00			0.00		0.00	0.00			
Not Part of Total	0.00			0.00		0.00	0.00			

Report: Demand End Use Components Summary

[Table of Contents](#)

For: Entire Facility

Timestamp: 2014-04-07 20:51:32

End Uses

						Water [m3/s]
--	--	--	--	--	--	--------------

file:///C:/Users/josh.talbert/Documents/Projects/EMEC%20590%20-%20Thesis%20Project/Final%20Presentation/ALL%20CALIBRATED/2014-03-22%20CO... 6/85

APPENDIX G

CALIBRATION LOG

OSM File Name 2014-03-13 LCL LHTZ With Space Types with HVAC DRAFT REV1												
Cooley Modelled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
93,949.99	85,177.85	95,925.91	94,430.02	98,753.38	99,160.63	104,688.32	104,461.45	97,004.18	97,740.97	93,857.87	95,989.92	
Cooley Modelled GAS (MMBth)												
1,364.11	1,241.54	1,029.81	799.87	566.55	365.98	239.70	229.97	442.34	836.38	1,124.18	1,304.95	

OSM File Name 2014-03-18 HVAC RUN CL for Calibration												
Cooley Modelled Electric Consumption (KWH)												
41,233.00	37,312.59	42,532.47	41,892.48	44,061.77	44,957.19	48,302.64	48,481.79	43,167.64	43,666.91	42,265.37	43,043.81	
Cooley Modelled GAS (MMBth)												
1,194.69	1,083.65	860.92	608.42	425.50	245.02	135.20	128.86	314.32	673.49	959.26	1,135.17	7,764.48

OSM File Name 2014-03-19 COOLEY for Calibration												
Cooley Modelled Electric Consumption (KWH)												
44,309.29	40,051.74	45,668.60	44,905.69	47,102.29	47,977.78	51,544.28	51,851.90	46,181.37	46,834.60	45,424.10	46,294.20	
Cooley Modelled GAS (MMBth)												
1,265.79	1,148.94	912.44	649.94	457.00	266.53	151.20	144.68	339.36	714.54	1,013.67	1,201.35	

OSM File Name 2014-03-21 COOLEY LAB_Calibration_REV0												
Cooley Modelled Electric Consumption (KWH)												
14,443.83	12,943.65	14,911.66	15,405.83	15,764.11	16,180.67	17,172.23	16,787.57	15,568.97	15,832.74	15,213.91	15,800.63	
Cooley Modelled GAS (MMBth)												
387.52	352.08	230.92	134.14	70.65	28.08	6.54	6.50	47.47	149.92	275.11	352.61	

Notes
 reduced occ based on metering
 reduced lights
 reduced OA
 add a CL specific Heat and Cool SP Tstat

OSM File Name 2014-03-21 COOLEY LAB_Calibration_REV0												
Cooley Modelled Electric Consumption (KWH)												
6,636.75	5,591.05	6,572.28	7,286.89	7,666.86	8,747.61	9,508.99	9,596.82	8,058.24	7,425.93	7,028.85	7,277.32	
Cooley Modelled GAS (MMBth)												
406.03	368.73	247.15	147.35	81.73	34.55	9.17	8.98	54.89	163.90	292.02	371.18	

improve fan efficiency 78 & 1.5"
 improve pump efficiency 0.99 & 30ft

OSM File Name 2014-03-22 COOLEY_Calibration_REV1												
Cooley Modelled Electric Consumption (KWH)												
6,954.62	6,236.27	7,235.50	7,546.08	7,938.08	8,973.92	10,103.21	9,863.06	8,293.99	7,702.87	7,284.69	7,569.78	
Cooley Modelled GAS (MMBth)												
524.83	473.79	357.97	241.14	166.66	106.81	78.42	76.65	132.00	266.49	404.43	492.09	

added 240MMbth for DHW per schedule M0.06 and M2.0.1
 Changed Hstat to 60/69

OSM File Name 2014-03-22 COOLEY_Calibration_REV2											
Cooley Modeled Electric Consumption (kWh)											
5,829.05	5,218.00	6,100.91	6,469.45	6,815.95	7,905.62	9,007.50	8,759.48	7,224.81	6,564.72	6,192.44	6,441.81
Cooley Modeled GAS (MMBth)											
528.77	477.24	461.48	243.86	168.85	108.37	79.62	77.76	133.70	289.47	408.11	496.13

reduced the light schedules further because of daylight harvesting
also the corridor & MER schedules had never been corrected down

OSM File Name 2014-03-22 COOLEY_Calibration_REV2											
Cooley Modeled Electric Consumption (kWh)											
4,683.83	4,194.14	4,777.61	4,912.32	5,281.47	6,495.97	7,659.46	7,427.63	5,843.91	4,951.17	4,583.34	4,770.41
Cooley Modeled GAS (MMBth)											
532.17	480.25	364.62	246.67	171.35	109.93	80.21	78.41	135.38	272.29	411.28	499.55

improve fan efficiency .85 & 1"
improve pump efficiency 0.99 & 25ft

OSM File Name 2014-03-19 LEWIS HALL for Calibration												
Lewis Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
49,647.97	44,844.75	50,314.18	49,448.07	51,584.49	50,962.25	53,594.59	53,664.51	50,626.43	51,048.93	49,090.30	50,680.23	
Lewis Modeled GAS (MMBtu)												
682.55	609.70	442.52	266.28	162.20	71.95	19.58	16.93	109.35	309.31	513.38	636.50	

Notes
less schedule
less lights
less infltr
boiler eff = 1 ~ district heat
setback tsats

OSM File Name 2014-03-20 LEWIS HALL Calibration_REV1												
Lewis Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
33,508.97	30,245.86	34,205.02	33,729.77	35,018.38	34,378.11	36,060.17	35,879.90	34,072.00	34,802.26	33,397.48	34,381.94	
Lewis Modeled GAS (MMBtu)												
437.93	390.86	266.55	148.68	80.22	31.52	8.50	8.64	53.15	175.62	318.24	403.10	

OSM File Name												
2014-03-20 LEWIS HALL Calibration_REV2												
Lewis Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
33,607.92	30,347.25	34,235.46	33,734.90	35,024.07	34,380.61	36,033.39	35,870.09	34,086.63	34,807.01	33,452.06	34,458.77	
Lewis Modeled GAS (MMBh)												
458.00	408.28	282.47	161.82	93.38	44.67	22.67	22.72	66.20	189.58	334.95	422.39	
added DHW 60 Mbh to the attic space as a space gas load												

OSM File Name												
2014-03-20 LEWIS HALL Calibration_REV2												
Lewis Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
35,287.97	31,863.50	35,888.11	35,293.34	36,546.46	35,721.38	37,269.32	37,139.36	35,420.76	36,430.45	35,040.29	36,119.88	
Lewis Modeled GAS (MMBh)												
435.96	387.83	265.55	157.50	102.24	67.06	54.31	54.28	82.55	179.76	314.38	398.95	
revised dhw no200mbh Tstart to 58/70												

OSM File Name 2014-03-19 TIETZ HALL for Calibration												
Tietz Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
35,098.65	31,695.33	37,278.78	38,814.39	41,544.50	45,353.05	51,423.97	51,753.42	43,246.74	39,792.09	37,449.71	38,640.49	
Tietz Modeled GAS (MMbh)												
1,000.46	911.41	669.91	426.12	265.06	125.77	43.21	46.25	187.78	481.16	765.32	932.44	

OSM File Name 2014-03-19 TIETZ HALL for Calibration												
Tietz Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
35,295.59	32,489.43	37,729.58	38,742.71	40,919.20	43,794.88	49,833.14	50,090.70	42,153.71	39,850.95	37,755.04	38,995.64	
Tietz Modeled GAS (MMbh)												
862.30	786.40	540.69	309.96	169.24	64.67	13.41	14.07	116.16	357.29	634.15	797.65	

OSM File Name 2014-03-19 TIETZ HALL for Calibration												
Tietz Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
48,408.99	43,723.11	50,461.30	51,327.91	54,696.86	58,591.93	67,403.75	67,813.82	56,656.94	52,745.75	49,888.33	51,505.98	
Tietz Modeled GAS (MMbh)												
838.66	765.39	519.93	295.69	160.29	61.36	12.71	13.35	110.74	340.64	612.33	772.79	

Notes
added specific Tstat schedules H68 C72

lower cool temp
increase space load

OSM File Name 2014-03-19 TIETZ HALL for Calibration											
Tietz Modeled Electric Consumption (KWH)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
60,750.85	54,871.25	63,187.70	63,676.83	67,998.92	71,884.45	81,593.83	81,967.30	69,777.77	65,445.83	61,950.25	63,945.07
Tietz Modeled GAS (MMbh)											
817.51	747.00	501.77	285.31	154.49	58.91	12.36	12.86	106.70	327.85	592.96	749.31
increase ARC load +1.5 -3.5W total											

OSM File Name 2014-03-19 TIETZ HALL for Calibration											
Tietz Modeled Electric Consumption (KWH)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
68,836.74	62,166.96	71,536.13	72,021.01	76,928.27	80,853.77	91,170.11	91,474.22	78,586.61	74,032.69	69,969.42	72,153.97
Tietz Modeled GAS (MMbh)											
804.51	736.48	489.87	276.18	149.56	56.52	11.18	11.05	103.33	317.89	580.15	734.48
ARC +1 - Total = 5W/sf											

OSM File Name 2014-03-19 TIETZ HALL for Calibration											
Tietz Modeled Electric Consumption (KWH)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
84,500.36	75,639.77	92,717.05	97,336.64	106,758.31	111,874.64	122,817.61	122,525.39	107,231.50	98,212.11	86,322.42	85,619.67
Tietz Modeled GAS (MMbh)											
712.30	656.53	497.29	385.90	377.88	359.97	371.75	371.74	362.35	407.28	538.90	647.39
Add DHW Base load reduce H SP - 66deg f increase ewall Insul											

OSM File Name 2014-03-19 TIETZ HALL for Calibration												
Tietz Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
74,912.72	67,803.34	79,509.18	81,473.31	89,680.86	95,407.03	106,523.97	106,653.81	91,269.97	83,302.29	74,927.35	75,412.64	
Tietz Modeled GAS (MMbh)												
746.43	697.35	472.31	290.98	223.53	181.35	178.94	178.91	202.98	332.19	540.11	677.83	

remove +RS Insul
DHW to 240

OSM File Name 2014-03-19 TIETZ HALL for Calibration												
Tietz Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
64,174.24	58,000.69	68,851.66	71,198.00	77,679.18	82,761.17	93,597.69	93,794.39	79,560.56	72,864.53	67,081.44	68,381.36	
Tietz Modeled GAS (MMbh)												
736.26	688.39	459.74	274.57	178.80	112.40	92.43	91.81	148.56	314.55	534.53	666.74	

add RS Insul again
dhw120
minus 0.5 W ARC elec

OSM File Name 2014-03-19 LEON JOHNSON for Calibration												
Leon Johnson Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
169,980.03	153,871.33	174,858.82	172,363.91	180,974.50	186,894.92	203,798.81	202,870.19	177,059.92	180,959.91	173,810.54	176,046.01	
Leon Johnson Modeled GAS (MMBh)												
5,255.51	4,731.93	4,039.12	2,986.28	2,120.47	1,290.00	815.98	776.28	1,610.93	3,281.08	4,409.59	5,131.82	

OSM File Name 2014-03-22 LEON JOHNSON, Calibration_REV0												
Leon Johnson Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
169,821.44	159,966.72	181,681.07	173,290.00	181,759.69	186,488.50	201,276.86	200,705.94	177,054.47	180,875.43	175,284.92	178,173.28	
Leon Johnson Modeled GAS (MMBh)												
4,531.94	4,114.20	3,148.71	2,061.33	1,212.52	569.91	273.06	234.18	859.59	2,320.61	3,605.01	4,360.48	

Notes

Add H and C SP Tstats
reduce schedule

OSM File Name 2014-03-22 LEON JOHNSON, Calibration_REV0												
Leon Johnson Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
124,532.89	112,435.81	129,532.08	130,312.25	136,039.81	141,979.72	154,973.94	153,495.92	133,320.28	135,751.92	131,668.22	133,980.39	
Leon Johnson Modeled GAS (MMBh)												
3,503.81	3,176.59	2,382.40	1,517.12	879.03	389.71	135.60	125.97	617.70	1,717.16	2,742.47	3,353.41	

Aligned schedules with meters data

OSM File Name 2014-03-22 LEON JOHNSON, Calibration_REV0												
Leon Johnson Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
118,621.46	110,894.15	123,618.34	118,009.87	124,092.54	128,258.33	139,508.11	138,666.92	121,264.33	123,188.93	119,083.12	120,857.24	
Leon Johnson Modeled GAS (MMBh)												
2,791.71	2,536.16	1,905.21	1,231.54	733.64	349.46	156.72	142.21	529.07	1,389.91	2,185.97	2,654.48	

Reduce infiltration
Reduce OA

OSM File Name 2014-04-03 MONTANA for Calibration_REV2												
Montana Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
24,165.81	21,839.28	23,878.17	22,611.80	22,901.27	21,789.72	22,248.84	22,346.73	21,984.61	23,581.66	23,300.15	24,157.89	
Montana Modeled GAS (MMBh)												
225.50	199.35	128.27	66.95	34.95	13.99	4.29	4.68	25.04	82.41	159.02	206.27	

Calibration Notes

OSM File Name 2014-04-04 MONTANA for Calibration_REV3												
Montana Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
24,152.18	21,823.74	23,924.46	22,732.47	23,224.99	22,190.20	22,840.92	22,581.58	22,332.23	23,662.19	23,280.02	24,119.11	
Montana Modeled GAS (MMBh)												
242.09	213.81	145.86	82.53	49.36	22.29	8.09	8.60	35.59	100.11	175.66	223.05	

add some cooling in presidential office spaces
increase heating setpoint 70 -> 72 deg F

OSM File Name 2014-04-04 MONTANA for Calibration_REV3												
Montana Modeled Electric Consumption (KWH)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
24,192.39	21,861.61	24,048.87	22,932.17	23,346.08	22,514.13	23,513.12	23,708.32	22,577.44	23,862.87	23,386.07	24,186.73	
Montana Modeled GAS (MMBh)												
270.46	240.09	162.84	91.98	54.44	24.25	8.53	9.03	38.81	111.46	196.39	249.16	

double the pres office space
double the infli - leaky building

OSM File Name 2014-04-04 MONTANA for Calibration_REV3												
Montana Modeled Electric Consumption (KWH)												
Jan	29,938.29	27,062.22	29,371.33	27,863.23	May	27,889.09	27,136.33	28,502.91	28,579.17	Sep	27,254.69	28,895.86
Feb					Jun					Oct		
Mar					Jul					Nov		
Apr					Aug					Dec		
Montana Modeled GAS (MMBh)												
Jan	195.90	174.52	115.57	71.42	57.87	50.45	50.39	50.48	54.39	81.04	136.84	177.18
Feb												
Mar												
Apr												
May												
Jun												
Jul												
Aug												
Sep												
Oct												
Nov												
Dec												
Montana Modeled Electric Consumption (KWH)												
Jan	25,952.69	23,442.81	25,736.86	24,769.01	May	25,197.79	24,719.79	26,071.40	26,318.88	Sep	25,600.72	25,096.06
Feb					Jun					Oct		
Mar					Jul					Nov		
Apr					Aug					Dec		
Montana Modeled GAS (MMBh)												
Jan	260.70	232.69	157.00	88.82	55.02	35.95	30.93	30.98	46.51	105.85	188.48	240.18
Feb												
Mar												
Apr												
May												
Jun												
Jul												
Aug												
Sep												
Oct												
Nov												
Dec												
Montana Modeled Electric Consumption (KWH)												
Jan	25,158.75	22,725.64	25,013.41	24,159.95	May	24,694.59	24,365.18	25,839.46	26,043.35	Sep	24,990.16	24,343.33
Feb					Jun					Oct		
Mar					Jul					Nov		
Apr					Aug					Dec		
Montana Modeled GAS (MMBh)												
Jan	305.93	273.21	195.44	118.22	74.70	41.31	25.95	25.99	58.19	139.71	229.58	284.73
Feb												
Mar												
Apr												
May												
Jun												
Jul												
Aug												
Sep												
Oct												
Nov												
Dec												

increase infil
increase LPD 20%
add DHW load to building 200MMb/h

reduce DHW load 120Mb
reduce LPD 10%

heating setpoint adjust
dhw to 90mbh

OSM File Name 2014-04-05 CHBC Space Types												
CHBC Modeled Electric Consumption (KWH)												
Jan	23,004.39	20,787.69	22,699.48	22,058.12	21,136.16	May	24,262.17	29,631.16	Avg	27,579.88	Sep	21,388.29
Feb						Jun					Oct	22,625.53
Mar						Jul					Nov	22,610.01
Apr						Aug					Dec	23,375.37
CHBC Modeled GAS (MMBh)												
Jan	1,931.46	1,756.94	1,321.73	856.64	524.62	May	250.89	107.39	91.03	365.44	964.25	1,517.05
Feb						Jun						1,836.18
Mar						Jul						
Apr						Aug						
CHBC Modeled GAS (MMBh)												
Jan	1,893.21	1,722.04	1,278.60	814.91	482.78	May	217.03	78.60	67.42	331.03	919.70	1,474.82
Feb						Jun						1,793.86
Mar						Jul						
Apr						Aug						
OSM File Name 2014-04-05 CHBC Space Types												
CHBC Modeled Electric Consumption (KWH)												
Jan	83,279.36	75,160.47	83,226.04	79,710.06	81,584.70	May	82,614.28	89,266.00	Avg	88,635.71	Sep	79,278.86
Feb						Jun					Oct	82,463.11
Mar						Jul					Nov	81,069.01
Apr						Aug					Dec	83,110.25
CHBC Modeled GAS (MMBh)												
Jan	1,819.84	1,654.21	1,196.38	744.34	415.01	May	170.33	44.46	40.57	283.72	841.81	1,394.03
Feb						Jun						1,713.14
Mar						Jul						
Apr						Aug						
OSM File Name 2014-04-07 CHBC for Calibration.osm												
CHBC Modeled Electric Consumption (KWH)												
Jan	140,805.39	127,048.00	141,406.57	136,620.76	141,090.49	May	153,202.98	176,581.15	Avg	172,331.30	Sep	142,136.87
Feb						Jun					Oct	141,324.25
Mar						Jul					Nov	137,274.98
Apr						Aug					Dec	140,661.28
CHBC Modeled GAS (MMBh)												
Jan	3,194.38	2,896.07	2,215.68	1,431.08	816.95	May	353.35	118.60	102.97	556.72	1,607.20	2,537.42
Feb						Jun						3,084.61
Mar						Jul						
Apr						Aug						

Calibration Notes

add actual lighting schedule and lib equip at 3w/sqft

updated lights and e equip off of panel metering

corrected lab space ventilation to 8ACH

OSM File Name 2014-04-07 CHBC for Calibration.osm												
CHBC Modeled Electric Consumption (KWH)												
Jan	172,377.70	155,580.95	173,273.97	167,158.86	174,326.78	183,081.83	205,308.69	207,519.74	175,058.83	173,326.74	167,817.26	171,934.68
Feb												
Mar												
Apr												
May												
Jun												
Jul												
Aug												
Sep												
Oct												
Nov												
Dec												
CHBC Modeled GAS (MMBh)												
Jan	2,315.92	2,144.91	1,422.41	856.75	494.66	244.00	124.21	126.53	365.78	959.53	1,678.12	2,108.96

added a DHW load

OSM File Name 2014-04-07 CHBC for Calibration.osm												
CHBC Modeled Electric Consumption (KWH)												
Jan	172,377.70	155,580.95	173,273.97	167,158.86	174,326.78	183,081.83	205,308.69	207,519.74	175,058.83	173,326.74	167,817.26	171,934.68
Feb												
Mar												
Apr												
May												
Jun												
Jul												
Aug												
Sep												
Oct												
Nov												
Dec												
CHBC Modeled GAS (MMBh)												
Jan	2,315.92	2,144.91	1,422.41	856.75	494.66	244.00	124.21	126.53	365.78	959.53	1,678.12	2,108.96

improved the wall R value

OSM File Name 2014-04-07 CHBC for Calibration.osm												
CHBC Modeled Electric Consumption (KWH)												
Jan	168,708.29	152,225.01	170,607.88	165,274.02	175,628.29	185,288.94	205,720.75	210,919.30	178,472.20	171,412.85	164,319.62	168,006.25
Feb												
Mar												
Apr												
May												
Jun												
Jul												
Aug												
Sep												
Oct												
Nov												
Dec												
CHBC Modeled GAS (MMBh)												
Jan	1,503.77	1,398.83	924.24	569.55	351.46	192.97	115.46	118.19	271.04	635.38	1,085.58	1,363.19

OSM File Name 2014-04-07 Wilson REV3												
Wilson Modeled Electric Consumption (KWH)												
Jan	75,152.91	67,359.64	76,474.38	74,433.47	78,869.59	82,505.35	90,812.87	89,924.52	77,562.15	78,064.90	74,950.52	76,281.40
Wilson Modeled GAS (MMBh)												
Feb	726.69	665.70	685.70	580.25	454.38	342.72	238.87	192.40	183.28	264.93	487.37	622.57
Wilson Cooling Elec to Natural Gas												
0.00	0.00	0.00	496.16	1,211.45	2,335.78	8,816.53	16,081.31	14,031.83	5,359.08	816.59	22.86	
Cooling as MMBTU												
0	0	1.6928911	4.1334776	7.9696745	30.0819935	54.869416	47.8766142	18.2851912	2.7862119	0.07798467	0	
Actual Elec												
Jan	75,152.91	67,359.64	75,978.22	73,222.02	76,533.82	73,688.83	74,731.56	75,892.69	72,203.06	77,248.31	74,927.66	76,281.40
Actual Gas												
Feb	726.69	665.70	581.95	458.52	350.69	268.95	247.27	231.15	283.22	490.15	622.65	713.76
Calibration Notes												
reduce lights 20% add DHW load												
absorption chiller efficienc = 0.5 COP												
OSM File Name 2014-04-07 Wilson REV3												
Wilson Modeled Electric Consumption (KWH)												
Jan	67,577.13	60,580.64	70,839.60	71,846.94	78,393.21	95,602.72	118,912.73	113,788.98	83,865.11	74,278.18	69,607.35	70,850.16
Wilson Modeled GAS (MMBh)												
Feb	717.11	657.12	567.56	442.01	332.38	230.73	185.58	177.05	257.00	474.20	610.43	702.92
Wilson Cooling Elec to Natural Gas												
0.00	0.00	1,488.63	3,634.19	7,006.86	26,408.00	48,230.56	42,095.56	16,077.22	2,449.77	68.57	5.17	
Cooling as MMBTU												
0	0	0	5.1	12.4	23.9	90.1	164.6	143.6	54.9	8.4	0.2	0.0
Actual Elec												
Feb	67,577.13	60,580.64	69,350.97	68,212.75	71,386.35	69,194.72	70,682.18	71,693.42	67,787.88	71,828.41	69,538.78	70,844.99
Actual Gas												
Feb	717.11	657.12	572.63	454.41	356.28	320.83	350.15	320.68	311.85	482.56	610.67	702.94

APPENDIX H

THESIS DEFENSE PRESENTATION

EFFICIENT ENERGY MODELING:

A LOW CARBON SOURCE ENERGY ASSESSMENT OF
PROPOSED BUILDING INTERCONNECTIONS BASED ON
EMERGING MARKET MODELING TOOLS

Josh Talbert
Montana State University
April 2014

Presentation Outline

- Project Introduction
- Energy Modeling Description and History
 - Emerging Modeling Tools Discussion
- Greenhouse Gas Emission Discussion
- Model Development
- Model Calibration
 - Metering Plan
- Proposed System Analysis
- Energy Model Results
- Conclusions and Recommendations

Project Purpose

Produce calibrated energy models of campus buildings for energy consumption evaluation of proposed building energy system interconnections. Evaluate success of interconnections from a reduction in source energy greenhouse gas emission perspective.

Project Background

Basic Development

- Reached out to Kevin Amende as advisor
- Discussed my experience, skill set, and research modeling opportunities
- Kevin introduced me to Dan Stevenson
- As a group we identified a Scope of Services for value add to Facilities Services
- Project Kickoff May 16th, 2013

Personal Introduction

Joshua W. Talbert, PE, LEED-AP
Facilities Engineer
Montana State University – Bozeman

Background

Bachelor's of Science: Mechanical Engineering – 2001
Union College
Schenectady, NY

Mechanical Engineer – 2002 to 2012
Hillman/CEC: Mechanical, Electrical, and Plumbing Consulting Engineers
South Burlington, VT

LEED Accredited Professional – 2004
Vermont PE License # 9245 – 2007

Master's of Science in Mechanical Engineering Candidate – May 2014
Montana State University
Bozeman, MT

Energy Modeling

Science – Art – Black Magic

Energy-modeling is the virtual or computerized simulation of a building or complex that focuses on energy consumption, utility bills and the life cycle costs of various energy related items. It is also used to evaluate the payback of green energy solutions like solar panels and photovoltaics, wind turbines and high efficiency appliances.

Building simulation is the process of using a computer to build a virtual replica of a building. Building simulation is commonly divided into two categories: Load Design and Energy-Analysis. Building simulation for energy-analysis is commonly called: Energy Modeling.

SOURCE: EnergyModels.com

Energy Modeling

- Origins in 1970s
 - Department of Defense: Building Load and System Thermodynamics (BLAST)
 - Department of Energy: DOE-2
- 1990s continued evolution
 - Energy Plus released 1998
 - merging of DOE-2 and BLAST
 - Funded by the DOE
 - Administered by National Renewable Energy Lab (NREL)
 - eQuest: The Quick Energy Simulation Tool
 - Enhanced DOE-2 with Graphics and Wizards
 - Supported by: DOE, NREL, and James J. Hirsch & Associates
- 1994 US Green Building Council
 - Leadership in Energy and Environmental Design (LEED)

April 2012

Building Energy Simulation

10

Energy Modeling

OpenStudio Evangelist

Open Studio: is a cross platform collection of software tools to support whole building energy modeling using Energy Plus.



April 2012

Building Energy Simulation

11

Energy Modeling

- Time and Data Intensive
 - Traditional modeling tools are cost prohibitive to iterative design application
- Garbage In – Garbage Out
 - “Liars figure and figures lie”
- The BIG UGLIES
 - People
 - Equipment
 - Weather
 - Infiltration

April 2012

Building Energy Simulation

12

Energy Modeling

OpenStudio Evangelist

Traditional Modeling



April 2012

Building Energy Simulation

13

Energy Modeling

Types of simulation tools – a non exhaustive list

- Manufacturer Developed
 - Carrier – Hourly Analysis Program (HAP)
 - Trane – TRACE 700
 - Mcquay – in the works
- Freeware
 - Energy Plus
 - eQuest
- Third Party Graphical User Interface (GUI) products
 - DesignBuilder
 - OpenStudio
- Built in
 - REVIT

April 2012

Building Energy Simulation

14

Energy Modeling

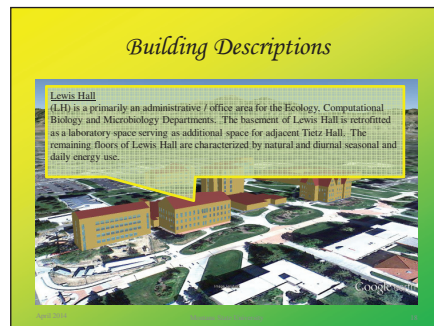
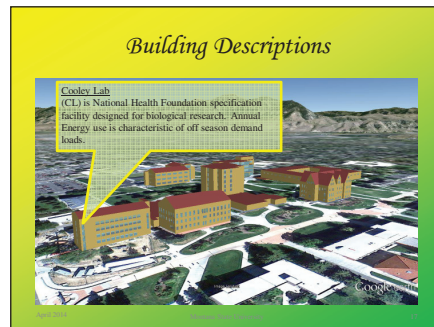
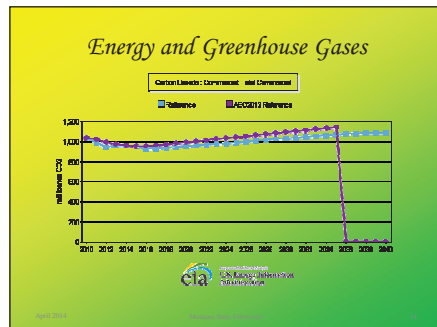
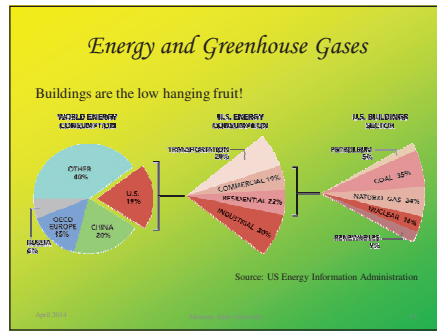
Secondary Project Purpose

Complete a ‘proof of concept’ study on utilizing OpenStudio for Energy Modeling, demonstrating significant time resource reductions.

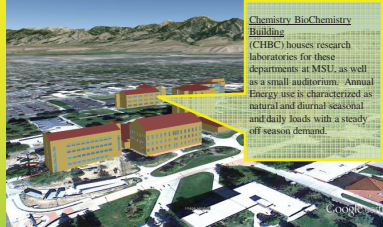
April 2012

Building Energy Simulation

15



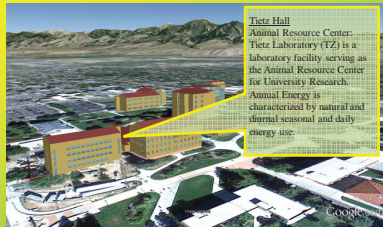
Building Descriptions



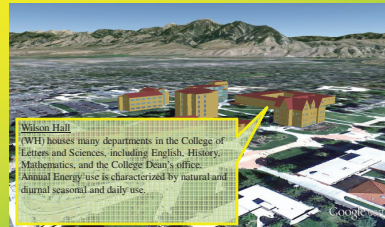
Building Description



Building Description



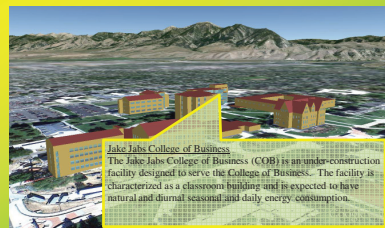
Building Description



Building Description



Building Description



Model Development

- Drawing Review
 - Obtained drawings from University Records
 - 1920 – Montana Hall
 - 2012 – Jake Jabs
 - Establish spatial programming
 - Illustrate envelope constructions
 - Identify equipment details

1/20/2014

Environ 1000 - 10000

10

Model Development

- Example Space Type Assignments



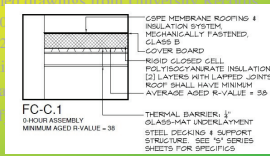
1/20/2014

Environ 1000 - 10000

10

Model Development

- Drawing Review
 - Obtained drawings from University Records
 - 1920
 - 2012
 - Establish spatial programming
 - Illustrate envelope constructions
 - Identify equipment details



Excerpt Cooky Lab AS BUILT Drawings
DWG A0.06 – Detail FC-C.1 – 2011/3/14

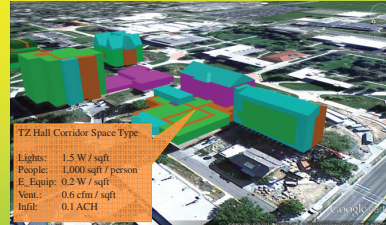
1/20/2014

Environ 1000 - 10000

10

Model Development

- Example Space Type Assignments



1/20/2014

Environ 1000 - 10000

10

Model Development

- Establish and assign Space Types
 - Space types identify and assign in how different portions of the building are used.
 - Important for representing actual programming of the facility
 - Law of diminishing Returns:
 - Model Size increases exponentially
 - Start simple → Complex
- Space Type definitions include details about:
 - Occupants
 - Lighting
 - Ventilation air flow requirements
 - Process or plug load equipment
 - Unique factors

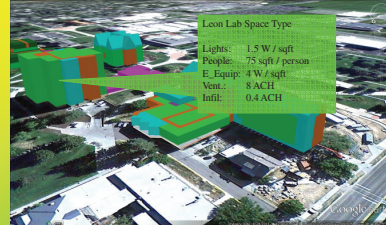
1/20/2014

Environ 1000 - 10000

10

Model Development

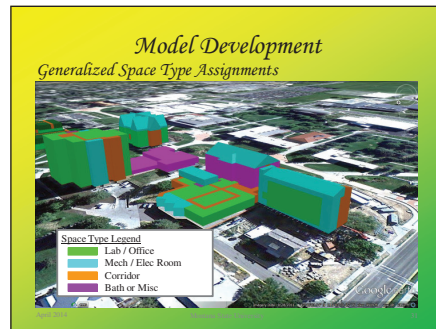
- Example Space Type Assignments



1/20/2014

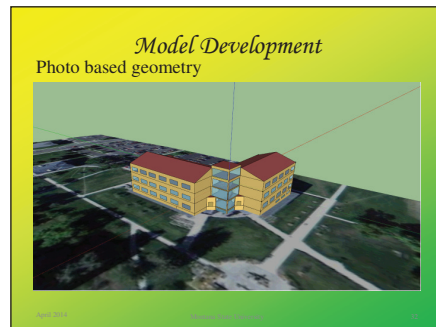
Environ 1000 - 10000

10



Model Calibration

- Why?
 - Corroboration
 - Documentation
 - Defeat *Garbage In – Garbage Out*
- Address the Big Uglys
 - Measure the Occupancy
 - Measure the Plug Loads
 - Calibrate to average utilities: addresses average weather
- Extraordinary Usage – Research Labs
 - Outside the realm of ASHRAE Supported assumptions



Model Calibration

- International Performance Measurement and Verification Protocol Option D (IPMVP: Option D)
 - Adopted by LEED for Energy Atmosphere
 - Measurement and Verification Credit 5: Compliance
 - Option D: Calibrated Simulation
 - “Calibrated” = Mean Bias Error $\pm 20\%$ when calibrated to monthly energy use.

$$MBE [\%] = \frac{\sum \frac{Error}{n}}{\sum \frac{Actual}{n}}$$

Model Development

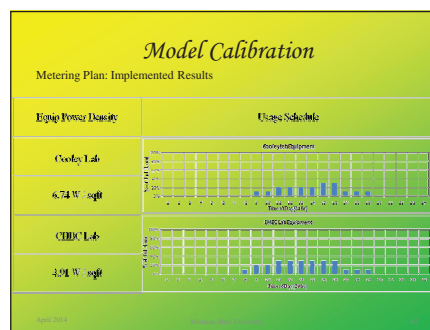
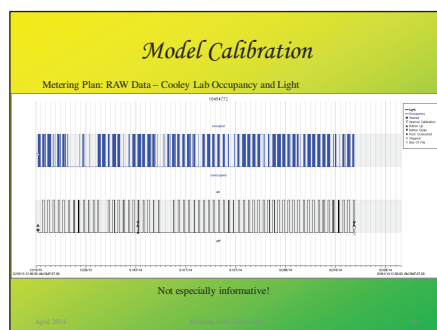
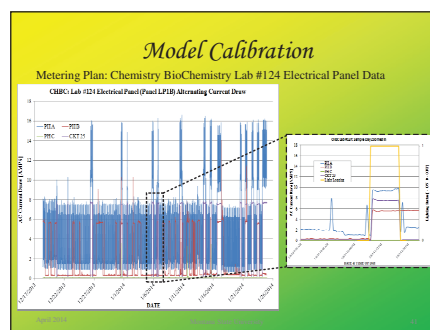
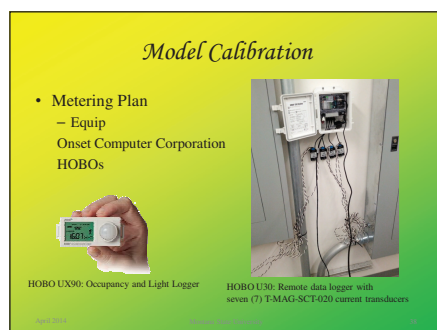
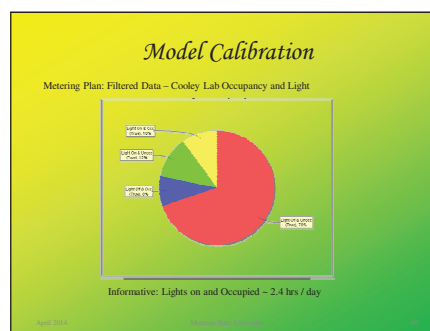
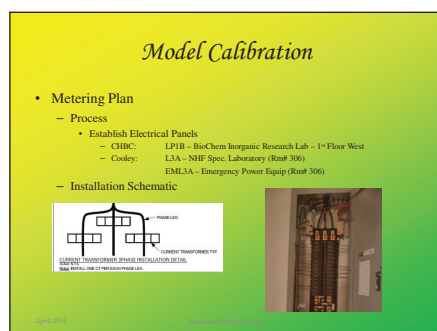
HVAC System Components

- Variable Air Volume Air Handling Units (VAV AHU) with Reheat Coils (RHC)
- Fan Coil Units (FCU)
- Fume hoods
- Boilers
- Steam to Water Heat Exchangers
- Steam Radiators
- Liquid Chillers
- Heat Recovery Units (HRUs)
- Direct Expansion Split System Air Conditioning Units (DX)
- Pumps
- Fans

Model Calibration

Metering Plan Introduction

- Purpose: Obtain data that informs energy related variables in the building energy models.
- 2 modes of data acquisition
 - Measure laboratory equipment related electrical consumption
 - Install Current Transducers on panel electrical feeds
 - Obtain occupancy and lighting usage profiles
 - Install occupancy and light measuring equipment in corresponding lab spaces



Model Calibration

Calibrated Models

Two types of adjustments

- Cyclic
 - Weather, seasonal, or daily influenced
 - Examples
 - » Insulation R Values
 - » Temperature Setbacks
 - » Infiltration
- Periodic
 - Scheduled On/Off
 - Examples
 - » Plug Loads
 - » Lighting Levels
 - » Ventilation



Image 10/17

Image 10/17

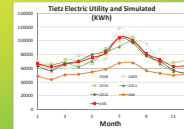
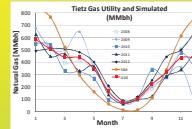
10

Model Calibration

TIETZ HALL: Calibration Step 2

Natural Gas MBE = 11%

Electricity MBE = -28%



Model Adjustments:

Reduced the cooling setpoint = 70°F
Increased the equipment intensity = 3.5 W / sqft

Image 10/17

Image 10/17

11

Model Calibration

TIETZ HALL: Initial Simulation Result

Natural Gas MBE = -44%

Electricity MBE = -46%

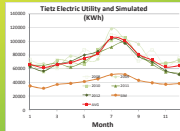
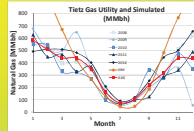


Image 10/17

Image 10/17

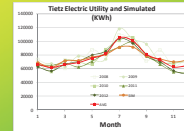
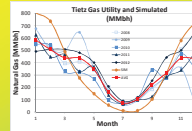
12

Model Calibration

TIETZ HALL: Calibration Step 3

Natural Gas MBE = 5%

Electricity MBE = 0%



Model Adjustments:

Increased equipment intensity: Total = 5 W / sqft

Image 10/17

Image 10/17

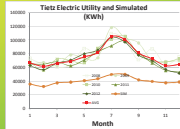
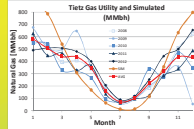
13

Model Calibration

TIETZ HALL: Calibration Step 1

Natural Gas MBE = 15%

Electricity MBE = -46%



Model Adjustments:

Added a heating temperature setback schedule

Image 10/17

Image 10/17

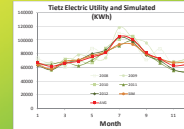
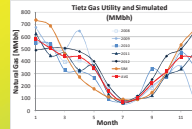
14

Model Calibration

TIETZ HALL: Calibration Step 4

Natural Gas MBE = 6%

Electricity MBE = -1%



Model Adjustments:

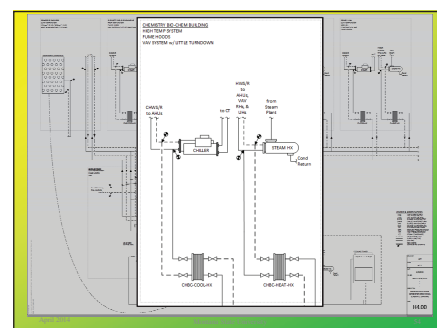
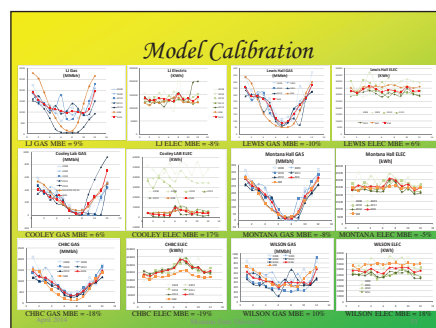
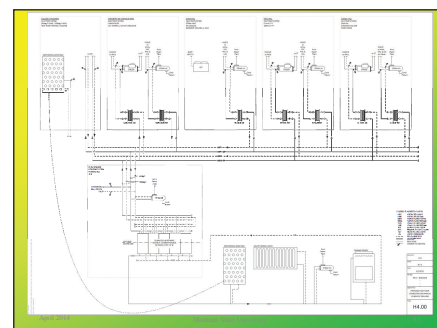
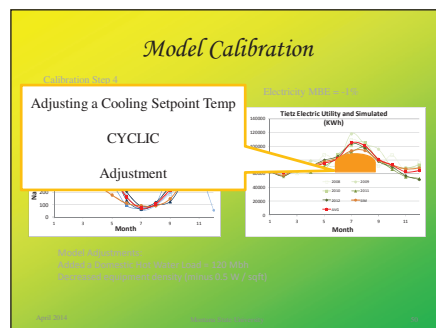
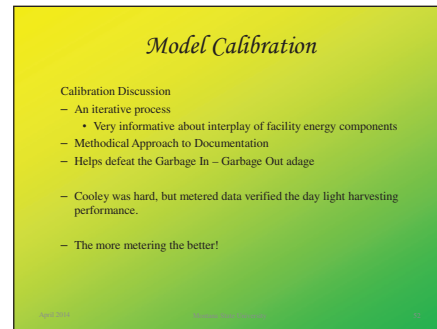
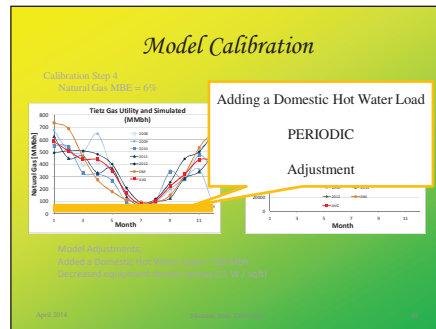
Added a Domestic Hot Water Load = 120 MWh
Decreased equipment density (minus 0.5 W / sqft)

CALIBRATED

Image 10/17

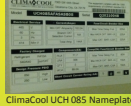
Image 10/17

15



Proposed System

Modular Heat Recovery Chillers or Central Plant Heat Pumps



ClimaCool UCH 085 Nameplate

Benefits

- Expandable and Modular
- Current: 3,400 Ton ± 400 Tons
- Room for 800 Tons
- Simultaneous Heating and Cooling
- Low Temperature Water
- Source side renewables
- R-410a refrigerant low ozone depletion factor

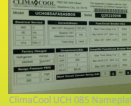


Single Chiller Module

Page 197-10 Proposed System 197

Proposed System

Modular Heat Recovery Chillers or Central Plant Heat Pumps



ClimaCool UCH 085 Nameplate

Benefits

- Expandable and Modular
- Current: 3,400 Ton ± 400 Tons
- Room for 800 Tons
- Simultaneous Heating and Cooling



Single Chiller Module

Load Side Piping Connections

Heating Water
Cooling Water
SIMULTANEOUS

Page 197-11 Proposed System 197

Proposed System

Modular Heat Recovery Chillers or Central Plant Heat Pumps



ClimaCool UCH 085 Nameplate

Benefits

- Expandable and Modular
- Current: 3,400 Ton ± 400 Tons
- Room for 800 Tons
- Simultaneous Heating and Cooling
- Low Temperature Water
- Source side renewables
- R-410a refrigerant low ozone depletion factor



Single Chiller Module

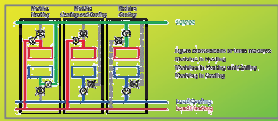
Compressors

Heating Water
Cooling Water
SIMULTANEOUS

Page 197-12 Proposed System 197

Proposed System

Modular Heat Recovery Chillers or Central Plant Heat Pumps



Schematic Operation

Page 197-13 Proposed System 197

Proposed System

Modular Heat Recovery Chillers or Central Plant Heat Pumps



ClimaCool UCH 085 Nameplate

Benefits

- Expandable and Modular
- Current: 3,400 Ton ± 400 Tons
- Room for 800 Tons
- Simultaneous Heating and Cooling
- Low Temperature Water
- Source side renewables
- R-410a refrigerant low ozone depletion factor



Single Chiller Module

Source Side Piping Connections

Page 197-14 Proposed System 197

Proposed System

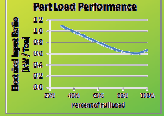
Modular Heat Recovery Chillers or Central Plant Heat Pumps

Modelled Characteristics (from ClimaCool literature)

Part Load Performance

Load	kW / Ton	EER
30%	1.1	11
50%	0.7	13
90%	0.6	20
100%	0.7	18

Part Load Performance



Page 197-15 Proposed System 197

Proposed System

Solar Thermal Component
 3,216 sqft of Solar Thermal Collector installed on the connecting roof between Leon Johnson tower and auditorium.

Analysis using PVWatts Calculator from NREL yields

536 MMBtu / year reduction in steam heating

April 2012 Leon Johnson Tower Solar Thermal 40

Project Results

	Baseline Results (Sum of Calibrated Models)	Proposed Results	% Reductions
EUI :	273.6 [kBtu / sqft / yr]	253.8 [kBtu / sqft / yr]	7.24 %
GHGe:	4941.1 [MtCO ₂ e / yr]	4237.6 [MtCO ₂ e / yr]	14.26%
		Natural Gas	69%
		Electricity	(-38%)

Source Energy Use Intensity = EUI
 Greenhouse Gas Emission Equivalent = GHGe

April 2012 Leon Johnson Tower Solar Thermal 41

Proposed System

Geothermal Wells
 52 Well Bore Field with the Jake Jabs building project.
 Source side heat sink/source for the Leon Johnson Energy Plant



1MMBtu capacity bore field; per COB Construction Documents
 Assumed to be adequate for year round heat rejection and absorption.

April 2012 Leon Johnson Tower Solar Thermal 42

Project Results

Secondary Purpose: Results Discussion
 Previous LEED Energy Modeling Projects
 Hockey Rink – Bowdoin College, ME
 Dormitory – Castleton State College, VT
 Bank Branches – Burlington, VT
 Campus Center – University of Vermont, VT

Time Estimate
 0.0091 hrs / sqft

Current Project Total Area = 439,091 sqft

Historical Time estimate = 3,995 hours

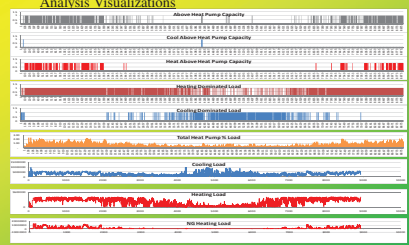
Actual project time = 1,242 hours

3.2 times faster!

April 2012 Leon Johnson Tower Solar Thermal 43

Proposed System

Analysis Visualizations



April 2012 Leon Johnson Tower Solar Thermal 44

Project Recommendations

- Metering
- Pumping analysis: variable flow vs. constant, part load performance
- Part load assessments
- Geothermal availability assessment
- Further campus interconnections
- Improved source energy for electrical grid
- Price trend analysis

April 2012 Leon Johnson Tower Solar Thermal 45

