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Post-Occupancy Energy Efficiency Evaluation of a LEED Platinum Federal Government Facility

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POST-OCCUPANCY ENERGY EFFICIENCY EVALUATION OF A LEED PLATINUM FEDERAL GOVERNMENT FACILITY

By

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ABSTRACT

Post-Occupancy Energy Efficiency Evaluation of a LEED Platinum Federal Government Facility

By

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The purpose of this study was to gain a comprehensive understanding of the Leadership in Energy and Environmental Design (LEED$^{®}$) certification system and its relevance to Federal policies, building codes, and building standards, develop experience with whole building energy modeling, and determine the actual post-occupancy energy usage as compared with developed model and design projections. This thesis hypothesized the U.S. Green Building Council's LEED rating system compared favorably to other policies, codes, and standards in use at the time, and the U.S. Bureau of Reclamations' LEED Platinum Lower Colorado Regional Office Green Building (LCROGB), located in Boulder City, Nevada, operated at least as energy efficiently as designed. Both hypotheses were shown to be true.

Based on the design and development requirements for the 49,818 square foot LCROGB being studied, the primary building requirements addressed were the U.S. Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings, ASHRAE Standard 90.1-2007, and the LEED V2009 certification system for new construction. LEED V2009 certification requirements compared favorably by either meeting or exceeding other stated requirements.

The whole building energy simulation, QUick Energy Simulation Tool (eQUEST) Version 3.65, was used for the study, and baseline and proposed models were developed. The eQUEST results compared favorably with the designer’s simulations developed using the Hourly Analysis Program (HAP) Version 4.5. eQUEST predicted a 32.7% savings in overall energy usage, compared to the HAP 38.9% prediction.

In 2013, the LCROGB used 600,042 kWh of energy, and 60% was electrical and 40% was natural gas. This usage demonstrated high building efficiency with an Energy Use Intensity (EUI) of 41.1 kBtu/sf/yr. Following more than two years of post-occupancy operation, the LCROGB was electrically more efficient than predicted by either HAP or eQUEST, although the facility was using considerably more natural gas than predicted by the simulations. The facility design and implementation met or exceeded energy efficiency requirements established by the reviewed policies and standards.

The three objectives of the study were met. Through the literature review, study of the LEED V2009 certification system and relevant policies and standards, whole building energy model development, and analysis of a LEED Platinum facility, it was shown that earning the maximum available LEED energy efficiency points significantly contributed to the overall building efficiency of the LCROGB. With the close proximity of the facility studied and the University of Nevada, Las Vegas, several follow-on studies were recommended to further optimize building efficiency.

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I would like to thank and acknowledge the representatives of the U.S. Department of the Interior Bureau of Reclamation Lower Colorado Region, Theresa Saumier, Stacy Wade, Lance Marbut, Corey Dickson, David Palumbo, and my husband, Scott Tincher, without whom this study would not have been possible. Their interest in the study and support during the process was greatly appreciated.

I would also like to express my admiration and appreciation to my advisor and mentor, Dr. Robert Boehm. Keep on biking, Dr. B!

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LIST OF ABBREVIATIONS AND ACRONYMS

AHU	Air Handling Units
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BACnet	Building Automation and Control Network
BEAM	Building Environmental Assessment Method
bhp	brake horsepower
BMS	Building Management System
Btu	British thermal units
CBECS	Commercial Building Energy Consumption Survey
ccw	counter-clockwise
CFC	chlorofluorocarbon
cfm	cubic feet per minute
EPAct	Energy Policy Act
DDC	Direct Digital Control
deg	degree
DOE	Department of Energy
EA	Energy and Atmosphere
EERE	Energy Efficiency and Renewable Energy Office of DOE
EIA	Energy Information Administration
EISA	Energy Independence and Security Act
eQUEST	QUick Energy Simulation Tool
EUI	Energy Use Intensity
F	Fahrenheit
FAQ	Frequently Asked Questions
ft	feet
gpm	gallons per minute
GSA	General Services Administration

GUI	Graphical User Interface
h	hour
HAP	Hourly Analysis Program
HFC	hydrofluorocarbon
hp	horsepower
HVAC	Heating, Ventilation, and Air-Conditioning
ID	Innovation in Design
IECC	International Energy Conservation Code
IEQ	Indoor Environmental Quality
IESNA	Illuminating Engineering Society of North America
in	inch
k	thousands
LBNL	Lawrence Berkeley National Laboratory
LCROGB	Lower Colorado Regional Office Green Building
LEED	Leadership in Energy and Environmental Design
M&V	Measurement and Verification
MR	Materials and Resources
NBI	New Buildings Institute
NC	New Construction
n.d.	no date
NFRC	National Fenestration Rating Council
OAT	Outside Air Temperature
ppm	parts per million
PV	PhotoVoltaic
RAT	Return Air Temperature
RP	Regional Priority
SAT	Supply Air Temperature
sf	square feet
SHGC	Solar Heat Gain Coefficient
SiteEI	Site Energy Intensity
SS	Sustainable Site

TMY	Typical Meteorological Year
TSK	Tate Snyder Kimsey
USBR	United States Bureau of Reclamation, normally referenced as Reclamation
USGBC	United States Green Building Council
VAV	Variable Air Volume
VFD	Variable Frequency Drive
VLT	Visible Light Transmittance
W	Watt
WE	Water Efficiency
WT	Whiting-Turner
yr	year

Chapter 1

INTRODUCTION

The United States Federal Government, along with numerous state governments, local governments, and private companies, moved toward improving building efficiency in the early part of the 20th century. The emphasis placed on reducing energy consumption, lowering carbon emissions, conserving water, and providing environmentally friendlier facilities was a logical step for all of these entities, but was largely driven by Federal, state, and local policies, building codes and standards, and building certification systems. These policies, codes, standards, and certification systems applied to both new construction and renovations, and rarely required further energy usage analysis and verification once construction was completed. Therefore, the owners of facilities thought to be energy efficient would need to take it upon themselves to determine whether or not their facility actually was as energy efficient as designed.

Such was the case with the U.S. Federal Government's Department of the Interior Bureau of Reclamation (USBR) Lower Colorado Region located in Boulder City, Nevada. With the completion of a new office facility in 2011, USBR representatives asked the author of this thesis to compare the energy usage of the facility after occupancy with the design projections. The facility was considered state-of-the-art at the time and had been constructed in accordance with current policies, building codes, and the Leadership in Energy and Environmental Design (LEED®) certification system. The facility design and construction was awarded a LEED Platinum rating by the U.S. Green Building Council (USGBC) in 2013, the highest achievable level for this certification system.

Purpose of the Study

The purpose of this study was to gain a comprehensive understanding of the LEED certification system and its relevance to Federal policies, building codes, and building standards, develop experience with whole building energy modeling, and determine the actual post-occupancy energy usage as compared with the developed model and design projections. By meeting these objectives, the relationship between LEED certification and energy usage and efficiency was evaluated and provided to the facility owners.

This thesis hypothesized the USGBC's LEED rating system compared favorably to other policies, codes, and standards in use at the time, and the USBR's LEED Platinum facility operated at least as energy efficiently as designed.

Organization of the Thesis

Chapter 1 provides an overview of the purpose and hypothesis of the study. Chapter 2 details the review of relevant literature, summarizing the historical attributes of the project elements and key findings associated with the objectives of the study. Chapter 3 presents a detailed description of the methodologies and analyses used to conduct the study, including energy requirement comparisons, whole building energy modeling, and energy usage analysis. Chapter 4 discusses the analytical results of the study. Chapter 5 summarizes the conclusions and recommendations reached as a result of this study.

Chapter 2

REVIEW OF RELEVANT LITERATURE

The purpose of this study was to gain a comprehensive understanding of the LEED certification system and its relevance to Federal policies, building codes, and building standards, develop experience with whole building energy modeling, and determine the actual post-occupancy energy usage as compared with the developed model and design projections. A review of relevant literature was conducted in order to obtain a thorough understanding of building requirement progression in modern times, energy usage analyses conducted with respect to relevant requirements, and the status of building energy analysis programs and applicability to this study.

Terminology

In order to demonstrate energy efficiency improvements in building design, it was customary for development teams to compare two whole building energy simulations. The first simulation was typically based on the minimum requirements defined by ASHRAE Standard 90.1 and was referenced as the "baseline" model. Improvements to this model were then demonstrated by simulating the proposed design aspects of the building, including efficient heating, ventilation, and air-conditioning (HVAC) systems, windows, doors, walls, roofs, and lighting. This second model was usually referenced as the "design" or "proposed" model. The improved building performance was then computed by comparing the total energy usage estimates of the two models using the following equation:

$$\textit{Energy Efficiency Improvement} =$$

$$100*(\textit{baseline energy} - \textit{proposed energy})/\textit{baseline energy}$$

Throughout this document, the terms “baseline” and “proposed” will be used to reference these two levels of simulation. Details regarding the inputs to the baseline and proposed models developed for this study will be discussed in Chapter 3.

Background

The USBR Lower Colorado Regional Office had been headquartered in Boulder City, Nevada since 1943, following the Hoover Dam development in the 1930’s. This department was responsible for managing western U.S. water resources from southern Utah to the Mexican border and employed approximately 320 personnel in 2012. Employees had been housed in four office locations in Boulder City, and in 1985 the USBR gained title to a former Bureau of Mines’ Metallurgical Research Laboratory property to develop new facilities and consolidate personnel into two primary locations. The Bureau of Mines operated at the proposed facility location from 1941 to 1983 and hazardous chemical remediation of the property was conducted by the USBR from 2004 to 2005. Initial USBR office, maintenance, and laboratory construction at what became known as the Date Street Complex began in 2006 (“Green Building in Boulder City,” 2011).

In April 2010, the USBR awarded a design-build contract to the Whiting-Turner Contracting Company, partnered with Nevada-based Tate Snyder Kimsey (TSK) Architects, to design and construct an energy and water efficient, environmentally friendly office building. As a “green” building, the structure was designed and constructed with “environmentally sustainable methods, including efficiently using energy, water and materials while reducing building impacts on the environment through improved siting, design, construction, operations, and maintenance techniques" ("Green Building in Boulder City," 2011, p. 2).

The USBR Date Street Complex was located in the viewshed of the Boulder City Historical District which required new construction to comply with Section 106 of the National Historic Preservation Act. Since the property was historically an industrial area, the external characteristics of the structure, including size, orientation, window layout, and exterior finish, required a retro appearance similar to the original Bureau of Mines' structures ("Reclamation Building Receives," 2013). The approximately 50,000 square-foot facility was funded through the American Recovery and Reinvestment Act of 2009 (Public Law 111-5) and was commissioned in the fall of 2011. As of September 2011, the Lower Colorado Regional Office Green Building (LCROGB) was fully operational, housing approximately 170 USBR employees ("Green Building in Boulder City," 2011). The project was formally awarded a Platinum-level LEED rating in January, 2013 ("Reclamation Building Receives," 2013) by the USGBC under Project Identification Number 100004579 ("Public LEED Project Directory," 2014).

Federal Policies

The U.S. Federal Government energy policies date back even further than the Hoover Dam design and construction, as the first Federal Water Power Act took effect in 1920 and the Federal Power Commission was established this same year. Many policies associated with utilities, natural gas, atomic energy, and water were established for the next few decades, and in 1977 the U.S. Department of Energy (DOE) was created ("DOE History Timeline," 2014). The first National Energy Conservation Policy Act was passed by the U.S. Congress the following year and changed energy standards from being voluntary to being mandatory ("History of Major Energy Policy," 2014).

By 1992, interest in energy usage and conservation was building throughout the U.S., and the year included the signing of an updated Energy Policy Act (EPAct) of 1992, the formation of the Building Energy Codes Program by the U.S. DOE, and the Energy Star program was established by the U.S. Environmental Protection Agency ("DOE History Timeline," 2014). In this same timeframe, the DOE's Office of Energy Efficiency and Renewable Energy (EERE) developed the Federal Energy Management Program with the goal of analyzing energy policies and regulations and coordinating with Federal agencies to reduce energy use and help them reach Federal energy goals ("Federal Energy Management Program," 2012). In 2005, the EPAct was once again updated to encourage more energy efficiency through tax benefits, net metering, and renewable energy development ("History of Major Energy Policy," 2014). Also in 2005, the National Building Performance Initiative, led by the DOE, was created with the objective of consolidating Federal, State, and private sector policies and procedures. The goal was to move research, design, and development to higher standards, including construction materials for building envelopes and building systems, energy technology for building efficiency and automation, and overall building performance ("National Building Performance Initiative," 2005).

In 2006, the Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding was signed by 21 Federal agency representatives, including the U.S. Department of the Interior, and mandated a set of "Guiding Principles" for all new federal construction and major renovations that would require compliance with former energy policies. This was followed by the Energy Independence and Security Act (EISA) of 2007 and Executive Order 13423 that required compliance with the Guiding Principles updated in 2008. The Guiding Principles required five primary areas of compliance (Wang, Fowler & Sullivan, 2012):

1) Employ Integrated Design Principles: This included the use of collaborative planning and design with establishment of performance goals and involvement of an experienced commissioning provider.
2) Optimize Energy Performance: This included the establishment of whole building energy efficiency performance targets with new construction reducing "the energy use by 30% compared to the baseline building performance rating per the American National Standards Institute (ANSI)/American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., (ASHRAE))/Illuminating Engineering Society of North America (IESNA) Standard 90.1-2007, Energy Standard for Buildings Except Low-Rise Residential Buildings" (referenced as ASHRAE 90.1 throughout this document), (Wang, et al, 2012, p. B-5). This principle also included the EISA on-site renewable energy requirement to provide at least 30% of the hot water demand, the EPAct of 2005 measurement and verification requirements for metering and optimizing electricity and natural gas usage, and a benchmark requirement to compare the first year of actual performance data to the energy design, and demonstrate that actual energy use was within 10% of the designed usage.
3) Protect and Conserve Water: This principle included regulations for indoor and outdoor water, water processing, and the use of water-efficient products.
4) Enhance Indoor Environmental Quality: This included compliance with ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy and ASHRAE Standard 62.1-2007, Ventilation for Acceptable Indoor Air Quality for ventilation and thermal comfort, along with moisture

control, daylighting minimum requirements, use of low-emitting materials, protection of air quality during construction, and tobacco smoke control.

5) Reduce Environmental Impact of Materials: This included the use of EPA-designated products for recycled content, biobased content, and environmentally preferred products, along with waste and materials management and the elimination of ozone depleting compound use.

Building Codes and Standards

The two primary building energy codes used throughout the United States were the International Energy Conservation Code® (IECC) and the ASHRAE 90.1. The IECC was used in both the residential and commercial building industry, while ASHRAE 90.1 applied only to commercial buildings. According to the DOE's EERE ("Building Energy Codes 101," 2010), the IECC had acknowledged that compliance with ASHRAE 90.1 "qualifies as compliance with IECC" (p. 5). The purpose of these codes and standards was to define minimum energy-efficiency requirements on new and renovated buildings in an attempt to lessen the environmental impact and enhance energy and cost savings ("Building Energy Codes 101," 2010).

The original ASHRAE Standard 90 was published in 1975, and by 1999 the ASHRAE Board of Directors decided to place the standard under continual maintenance ("ASHRAE 90.1," 2013). A formal maintenance process managed comments, suggestions, inquiries, reviews, and approvals of the standard, by committee. Addenda were regularly published, and a supplement was published every 18 months and a complete standard every 3 years ("Building Energy Codes 101," 2010). The USBR LCROGB was required to be compliant with the ASHRAE 90.1-2007 edition. As of this writing, ASHRAE 90.1-2010 and -2013 had been published.

The LCROGB design and construction was also required, through the Guiding Principles, to be compliant with ASHRAE Standards 55-2004 and 62.1-2007. Both standards were first published in 1974 and 1973, respectively (Janssen, 1999). Numerous updates were published over the years, and the 2013 editions had been published as of this writing.

One additional ASHRAE standard of interest was the fairly new Standard 189, Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings. In development since 2006, the ASHRAE 189-preliminary draft was first released in 2007 (BuildingGreen.com, n.d.). Per ASHRAE ("FAQ Standard 189.1," n.d.), the standard covered "site sustainability, water use efficiency, energy efficiency, indoor environmental quality, and the building's impact on the atmosphere, materials and resources, and construction and plan for operation" (p. 1). ASHRAE ("FAQ Standard 189.1," n.d.) goes on to state:

> The U.S. DOE, through the National Renewable Energy Laboratory, has made a preliminary estimate based on Standard 189.1 as published. Applying the minimum set of prescriptive recommendations in the standard resulted in weighted average site energy savings of 27 percent when compared to Standard 90.1-2007. (p. 2)

Though the LCROGB design and construction was not required to be complaint with ASHRAE 189.1, the development of this standard indicated a continual drive to improve energy efficiency in new commercial buildings in the United States. As of this writing, ASHRAE Standard 189.1-2011 had been published.

Building Certification Systems

As the Federal Government was producing legislature and policies aimed at improving energy efficiency, and the building codes and standards were continually being updated and adopted at the State and local levels and throughout the building industry, a variety of organizations worldwide were working to develop and promote building rating and certification systems. The fundamental intent of these systems was focused on energy and water consumption and efficiency, material use, environmental impact, and indoor environmental quality associated with building design and construction. Participation in these certification systems was voluntary, but did allow awarded developers and building owners to advertise compliance with the certifying system.

One of the earliest system developments was led by the Building Research Establishment of the United Kingdom with the Building Research Establishment Environmental Assessment Methodology in 1990 (BREEAM, n.d.). This was followed by the establishment of the USGBC in 1993 who promoted sustainability in buildings through work with various firms, non-profit organizations, and the American Institute of Architects (USGBC.org, n.d.). The USGBC would develop the LEED rating and certification system that was formally launched in 1998 both domestically and internationally (USGBC.org, n.d.). In 1999, the World Green Building Council was founded with member countries including the U.S., Australia, Canada, Japan, Spain, United Arab Emirates, and the United Kingdom. Since the turn of the century, numerous certification systems around the world were launched and a few are listed below (Wang, et al, 2012):

- 2000 Australia: National Australian Built Environment Rating System (NABERS, n.d.)

- 2001 Japan: Comprehensive Assessment System for Built Environmental Efficiency (CASBEE, 2013)

- 2001 Hong Kong: Comprehensive Environmental Performance Assessment Scheme (CEPAS, 2014)

- 2004 Canada/U.S.: Green Globes^{TM} (Green Globes, n.d.)

- 2005 France: Haute Qualite Environnementale (Ecophone Saint-Gobain, n.d.)

- 2006 China: Three Star System (China Green Buildings, 2009)

- 2008 Germany: Deutsche Gesellschaft fur Nachhaltiges Bauen E.V. (DGNB, n.d.)

- 2008 U.S./International: Living Building Challenge (International Living Future Institute, n.d.)

- 2010 Japan: Building Environmental Assessment Method Plus (BEAM, 2012)

- 2010 Abu Dhabi: Estidama Pearl (Estidama, 2010)

In 2012, the U.S. Federal Government’s General Services Administration (GSA) Office of Federal High-Performance Green Buildings commissioned an evaluation of these various building rating and certification systems in accordance with the EISA of 2007. The EISA required such a review to be conducted every five years to determine systems most appropriate for government use (“Summary of Comments Received,” 2013). The study considered certification system robustness, auditor independence and availability, verification method, transparency, system maturity and usability, and national recognition within the building industry. The study discovered that none of the systems were fully aligned with Federal requirements, but recognized that the systems were useful in demonstrating that Federal goals were being met, especially with regard to the mandatory Federal Guiding Principles (Wang, et al, 2012). The two systems recommended for use by the GSA were Green Globes and LEED ("Green Building Certification System," n.d.). The remainder of this study will focus only on the LEED certification system since it relates to the LCROGB design and development under consideration.

As of 2013, the USGBC had published their 2013-2015 Strategic Plan outlining the organization's vision, goals, and strategies for upcoming years. These included expanding their interests beyond individual buildings and looking at larger built environments, making improvements to existing buildings, improving strategies to reduce building contributions to climate change, and addition of new tools, strategies, and technologies to measure building performance. The evolution and expansion of their LEED certification system played a primary role in the strategies to accomplish these visions and goals (Fedrizzi, Gottfried, & Italiano, n.d.).

LEED and Certification Studies

The continuing expansion of goals by the USGBC in 2013 seemed logical as the U.S. Energy Information Administration (EIA) at this same time reported that nearly half (47.6%) of all U.S. produced energy and approximately three-quarters (74.9%) of all U.S. produced electricity were used for operating buildings, while almost half (44.6%) of the U.S. CO_2 emissions in 2010 were due solely to buildings (Architecture 2030, 2011). The U.S. DOE took this one step further by pointing out that the Federal Government in 2012 operated over 500,000 buildings and was the U.S.'s "largest energy consumer and greenhouse gas emitter" ("Federal Energy Management

Program," 2012, p. 2). According to Hart (2009), "one of the first adopters of LEED was the U.S. GSA, which manages much of the federal government's real estate portfolio" (p. 11).

The LEED system initially supported certification for only new construction (LEED-NC), but existing buildings and commercial interior certifications were added in 2004, and core and shell certification was added in 2007 (Dirksen & McGowan, 2008). This study researched only the LEED-NC certification system.

The LEED system provided flexibility for earning points toward certification by initially crediting design and construction in several categories: sustainable site, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation and design process. Four levels of certification were offered: Certified, Silver, Gold, and Platinum (USGBC.org, n.d.).

After launching a pilot version in 1998, the USGBC began modifying the LEED system, and from 2000 to 2005 published LEED versions 2.0, 2.1, and 2.2. It was possible, however, during the early years of LEED to earn a Platinum rating and not earn any points in the Energy and Atmosphere category. To remedy this, the USGBC began requiring that a minimum of two points in the energy credit categories be earned for any buildings certified after June 2007 (Hart, 2009). By 2009, LEED V2009, sometimes referred to as LEED V3, was published. With V2009, the number of possible points available in the various credit areas had increased, and the number of points required for the four certification levels had been adjusted accordingly. As of this writing, LEED-NC V4 had been published and numerous other LEED certification programs, including schools, healthcare facilities, data centers, and many others, had been added to the program. LEED V4 also divided the sustainable site credit areas into two categories, adding the location and transportation category, along with integrative process. As with previous versions, the total number of points available had been modified. Table 1 lists the maximum points available by credit category and LEED version, and Table 2 lists the number of points required for each certification level by version (USGBC.org, n.d.). LEED-NC V2009 was the certification system used for the LCROGB design and development researched in this study.

Table 1. LEED-NC Maximum Points Awarded by Credit Category and Version.

Credit Category	V2.2	V2009	V4
Location & Transportation			16
Sustainable Site	14	26	10
Water Efficiency	5	10	11
Energy & Atmosphere	17	35	33
Materials & Resources	13	14	13
Indoor Environmental Quality	15	15	16
Innovation & Design Process	5	6*	6
Regional Priority		4*	4
Integrative Process			1
Total Base Points	69	100	110

*Excluded from total base points

Table 2. LEED-NC Point Range for Certification Levels by Version.

Certification Level	V2.2	V2009	V4
Certified	26 - 32	40-49	40-49
Silver	33 - 38	50-59	50-59
Gold	39 - 51	60-79	60-79
Platinum	52 - 69	80 or above	80 or above

As of April 2013, the USGBC’s Green Building Certification Institute reported approximately 16,888 buildings being formally LEED certified with an additional 35,930 being reported as registered (“Public LEED Project Directory,” 2014). These numbers represented buildings throughout the world, though most were located in the U.S. Of the certified buildings, only 1,067 had earned a Platinum certification level.

A limited number of comprehensive post-occupancy studies were found during the review of relevant literature with respect to these LEED-certified buildings. Hart (2009) pointed out the following:

> Performance evaluation of LEED-certified buildings inevitably lags practice. Buildings are registered with USGBC at the beginning of the design process and held to account for the version of LEED-NC in force at that time. Several years may pass after registration before a commercial building has been constructed and operated for long enough that meaningful energy performance data can be gathered. These data are not collected in the LEED-NC certification process, so researchers must rely on voluntary participation by building owners. (p. 14).

The New Buildings Institute Study

Perhaps the most significant post-occupancy study conducted to date was the “Energy Performance of LEED for New Construction Buildings” published in March 2008. This study was funded by the USGBC and was prepared by Cathy Turner and Mark Frankel of the New Buildings Institute (NBI), a non-profit organization working with the building industry to improve building efficiencies and the environment. As noted by Scofield (2009), “the NBI LEED energy consumption database comprise the largest and most complete collection of its kind . . . and it is useful to squeeze any information available from it” (p. 775).

The NBI representatives invited the owners of the 552 LEED-NC V2 buildings certified through 2006 to participate. A total of 121 owners (22%) responded to the NBI request. These participants were required to submit “one full year of measured post-occupancy energy usage data” (Turner & Frankel, 2008, p. 1). With these data, a comparison of LEED building energy use intensity (EUI) with national archived commercial building data and initial design and baseline energy models was accomplished.

EUI was a measure of the British thermal units (Btu) per building square footage (sf) per year (yr) used by each facility. The EUI included purchased energy only and did not include on-site renewable sources. The national archived data came from the Commercial Building Energy Consumption Survey (CBECS) which was to be compiled by the U.S. EIA every four years. The initial design and baseline energy models for these buildings could be submitted as part of the LEED certification process, and were mostly developed in accordance with ASHRAE 90.1-1999. Of the 121 responses, only 91 facilities had earned points based on baseline energy models, and only 2 of these had earned a Platinum rating (Turner & Frankel, 2008).

The authors sorted the data by building type and consolidated the types into medium and high energy use activities. The medium energy use activities aligned with office building usage, while the high energy use activities aligned with high process load facilities, such as laboratories, data centers, and recreation facilities. There were 100 buildings considered as medium energy and 71 of these had energy models for comparison. The authors also evaluated results based on certification level, number of energy optimization points earned, and climate zone (Turner & Frankel, 2008).

The study indicated the median EUI for the medium energy use “office” buildings was 62 kBtu/sf/yr. When certification level for these buildings was considered, the results showed median EUIs (kBtu/sf/yr) as follows: 67.4 (38 Certified buildings), 61.7 (35 Silver buildings), and 51.2 (27 Gold-Platinum buildings). The two Platinum-rated buildings had EUIs of approximately 52 kBtu/sf/yr and 71 kBtu/sf/yr, and were included with the Gold building median calculation due to the low number of Platinum buildings (Turner & Frankel, 2008).

When buildings had earned points from LEED's Energy and Atmosphere category, specifically for energy optimization, the authors showed median EUIs (kBtu/sf/yr) as follows: 77.6 (< 2 points), 63.4 (2-4 points), 61.7 (5-7 points), 42 (8-10 points). When they looked only at true office buildings earning 8 to 10 energy optimization points, the median EUI was 50 kBtu/sf/yr (Turner & Frankel, 2008).

The climate zone analysis from this report showed the medium energy usage facilities in warm to hot climates having higher median EUIs than the facilities in mixed, cool, or cold climates. The median EUI for the 18 buildings in warm to hot climates was approximately 75 kBtu/sf/yr (Turner & Frankel, 2008).

When comparing the initial design and baseline energy model results to the actual energy usage data, the authors used the following equations:

$$Proposed\ Savings = \frac{Model\ baseline\ EUI - Model\ design\ EUI}{Model\ baseline\ EUI}$$

$$Measured\ Savings = \frac{Model\ baseline\ EUI - Actual\ measured\ EUI}{Model\ baseline\ EUI}$$

For the medium energy usage buildings, the authors computed an average 25% proposed savings, which compared favorably to the computed 28% average measured savings (Turner & Frankel, 2008).

This result seemed to indicate that energy modeling results were an effective means of predicting actual energy usage. However, when the authors compared the actual measured building EUI to the model design EUI, the results were not as encouraging. When computing the ratio, Actual Measured EUI/Model Design EUI, results ranged from 0.50 (better energy performance than expected) to 2.75 (nearly three times as much energy used as predicted). The authors found similar variations when reviewing the model baseline energy predictions, based on the ASHRAE 90.1 standard. They concluded that “better feedback to the design community is needed to help calibrate energy modeling results to actual performance outcomes. Follow-up investigation into the reasons for the deviations could help improve future modeling and benchmarking” (Turner & Frankel, 2008, p. 32). Hart (2009) also suggested that “a large part of the difference between predicted and actual performance found by the NBI study of LEED-NC may be explained by operational practices, rather than design and construction deviations” (p. 16).

The NBI authors compared the LEED results with the CBECS 2003 overall national building stock average data for all building types. This was the eighth survey conducted by the EIA since 1979, which attempted to sample data from 6955 of the estimated 4.9 million commercial buildings throughout the country. Final responses and validated results came from 5215 buildings (“CBECS,” 2003). The EIA also collected data from 2007, but due to a new method of collecting data, most data were considered invalid (EPA WaterSense, 2012) and very few data were actually released for public use in 2012. The next round of CBECS data collection for the 2012 calendar year was proposed to begin in the spring of 2014 and was targeting approximately 8400 commercial buildings (“CBECS,” 2012).

Turner and Frankel (2008) did not discern the CBECS building EUI results by medium and high building energy use activities, as they had done for the LEED building results. This resulted in an average EUI of 91 kBtu/sf/yr for all buildings reported in the 2003 CBECS. They did show CBECS EUI results by building type, indicating that office buildings used an approximate average of 92 kBtu/sf/yr, compared to the medium usage median EUI of 62 kBtu/sf/yr for the LEED office buildings (Turner & Frankel, 2008).

Neither LEED data nor CBECS EUI data were sorted by building square footage in the NBI study. However, Turner and Frankel (2008) did point out the average square footage of the LEED buildings studied was approximately 110,000 sf with approximately 50% of the buildings ranging from 25,000 to 200,000 sf and a total range of under 10,000 sf to 1,000,000 sf. In comparison, the CBECS buildings had an average square footage of 14,700 sf with 73% of the buildings having less than 10,000 sf (Turner & Frankel, 2008).

Turner and Frankel (2008) concluded that LEED-rated buildings were averaging “building energy use 25-30% better than national average” . . . . and “gold and platinum buildings average EUI are 45% better than non-LEED buildings” (p. 31). These results were hard to support since direct comparisons were not achieved. Had the authors differentiated the CBECS results with respect to medium and high energy use activities and used either median values or average values from both sets of data, the results would seem more useful. Additionally, the large disparity between LEED and CBECS building square footage data highlights the need for further analysis with this building characteristic taken into account. The large variation in the building energy usage models reported by Turner and Frankel (2008) may have correlated with building square footage, again, pointing toward the need for this characteristic to have been considered in detail.

John Scofield, Professor of Physics at Oberlin College, Ohio, performed a detailed evaluation of the NBI study, presenting results at the 2009 Energy Program Evaluation Conference in Portland, Oregon. According to Scofield (2009), “it is appropriate to compare the means for the two distributions, or the medians, but to compare the mean of one with the median of the other introduces bias by compensating for skew in only one distribution” (p. 765). Scofield also points out that mean and median EUI values that were not weighted by building square footage had “no physical meaning” (p. 766). He suggested the appropriate average EUI for a site or Site Energy Intensity (SiteEI) should be computed using the ratio of total site energy used divided by the total square footage. Scofield goes on to say this “is the only physically meaningful way to calculate mean and median energy intensities for a collection of buildings of vastly different sizes” (p. 766). Reevaluating the 121 LEED buildings and all CBECS buildings, Scofield found the mean SiteEI for LEED exceeded CBECS by 41% and the median SiteEI for LEED also exceeded CBECS by 14%. This was in stark contrast to the NBI study findings.

Scofield (2009) further dissected the LEED and CBECS data to compare medium energy use activity buildings constructed between 2000 and 2003 (280 CBECS buildings). He found that LEED Certified buildings used slightly more SiteEI than comparable CBECS buildings, but Silver-rated and Gold-Platinum-rated buildings used 23% and 31% less site energy than conventional medium energy buildings. Comparing just office buildings, he found LEED buildings used 17% less SiteEI, on average, than CBECS office buildings from all years built (Scofield, 2009).

Even the founder of the LEED rating system, Robert Watson (2009), points out some of the shortcomings of the NBI study. With only 550 buildings LEED certified by the end of 2006, and most certified under the early versions of LEED V2.0 and V2.1, the number of facilities represented made it difficult to draw meaningful conclusions. Watson speculated that many of the LEED buildings were not adequately metered and, therefore, could not respond to the NBI survey. Starting with LEED V2009, all LEED certified buildings were required to report energy consumption (Watson, 2009).

Even if later versions of LEED "required" energy consumption reports, this author was concerned that once a certification was granted, there would be no apparent method for enforcing this stated requirement. As major critic of the LEED system Henry Gifford (2008) suggested:

> Only by rating buildings according to actual energy consumption can a rating system reward success, and encourage energy savings . . . . The most realistic approach would be to first award a tentative green building rating that would be subject to redaction based on actual energy use, and only issue a final rating if the utility bills show the building really is energy efficient. (p. 8).

The Regional Green Building Case Study Project

Published in 2009, the “Regional Green Building Case Study Project: A Post-Occupancy Study of LEED Projects in Illinois” analyzed 25 LEED certified buildings with respect to measured energy, greenhouse gas emissions, water, operating costs, occupant comfort, and several other characteristics. The multi-year study was conducted by the USGBC – Chicago Chapter and Center for Neighborhood Technology.

The study required a minimum of 12 consecutive months of post-occupancy energy use data for all buildings, and included new construction (NC), existing buildings, commercial interiors, and core and shell rated buildings. The square footage of the facilities ranged from 3200 to 4.2 million sf with diverse building activities. Most participating facilities certified using LEED V2.0 or V2.1 (U.S. Green Building Council, 2009).

Of the 25 buildings included in the study, 64% (16) were certified under LEED-NC. The LEED certifications for all 25 buildings were as follows: 5 (certified), 13 (silver), 3 (gold), and 4 (platinum). Of these, 9 were considered “office” buildings (U.S. Green Building Council, 2009).

For the 17 projects that provided complete sets of energy data, the median EUI was 94 kBtu/sf/yr. This value was compared to comparable mid-west region buildings from the CBECS 2003 study, and the LEED median EUI was approximately 5% lower than the CBECS median EUI of 99 kBtu/sf/yr. The EUI for the LEED buildings ranged from 30 to 138 kBtu/sf/yr (U.S. Green Building Council, 2009).

The study found that increasing LEED certification level did not correlate with increased energy performance, and thought this might have been attributable to the small sample size. The study did, however, show a trend towards reduced energy usage with increased Energy and Atmosphere – energy optimization points, which ranged from 0 to 10 (U.S. Green Building Council, 2009).

The study also made measured energy use comparisons with the initial design and baseline models. Four of the 16 projects that had completed a building energy model demonstrated that the Actual Measured EUI/Model Design EUI < 1 (operating better than predicted). Large variations in the initial design and baseline models by project, however, were demonstrated in this study. The study concluded that "design models were not a reliable indicator of performance" (p. 18) (U.S. Green Building Council, 2009).

Though this study was small in sample size, the authors did compare medians rather than mixing means and medians. The diversity in building usage and square footage, combined with the sample size, made the results have essentially no statistical significance, but this was recognized by the authors who planned to continue adding LEED projects to the database in future years (U.S. Green Building Council, 2009). The authors did provide information regarding the square footage of the various buildings studied, but neglected to weight the overall EUI to develop a SiteEI, as recommended by Scofield (2009). Including this computation may have altered the overall results.

The Green Building Performance Study

In 2011, the U.S. GSA published the "Green Building Performance" study that analyzed 22 "sustainably designed commercial" (p. 2) GSA federal buildings over the course of several years. The Pacific Northwest National Laboratory, commissioned by the GSA, analyzed energy and water use, carbon emissions, operations and maintenance, waste generation and recycling, and occupant satisfaction. The first phase of the study was completed in 2008 where 12 buildings were included. These 12 buildings were then re-analyzed in the second phase of the study to confirm consistency of the findings. At that time, an additional 10 buildings were added to the study. The objective was to evaluate the effectiveness of the Federal Policies in place for green building development (“Green Building Performance,” 2011).

Unlike the previous studies, this study evaluated only measured building performance and did not consider modeled predictions. The buildings were located throughout the U.S. and were used as either courthouses or offices. Sixteen of the buildings were LEED certified. As with previously discussed studies, 12 months of operating data were required to participate (“Green Building Performance,” 2011).

Though the study provided few details with respect to the energy data analyzed, the authors found that “GSA’s LEED Gold buildings have 27% lower energy use compared to the national average” (“Green Building Performance,” 2011, p. 12). The study indicated the LEED Gold buildings had an average EUI of 62 kBtu/sf/yr compared to the CBECS weighted average from 1990 to 2003 of 88 kBtu/sf/yr. The overall EUI for all 22 buildings included in the study ranged from approximately 48 kBtu/sf/yr to 101 kBtu/sf/yr (“Green Building Performance,” 2011).

Additional Studies

The review of relevant literature also demonstrated that only a few post-occupancy studies for LEED-certified buildings had been conducted for theses and dissertations in recent years. Of note were the following, in chronological order:

“Greening Existing Buildings with LEED-EB!” by Tyson Dirksen and Mark McGowan from the Massachusetts Institute of Technology in 2008. In support of a Master of Science degree in Real Estate Development, Dirksen and McGowan reviewed trends in green building development by evaluating participants, the LEED process, and associated costs and benefits to the real estate market.

“A Quantitative Assessment of a LEED Certified Campus Building” by Steven DeArmon from Ohio State University in 2009. In support of a Bachelor of Science degree in Civil Engineering, DeArmon provided a life cycle analysis of materials associated with sustainable building construction.

“Is LEED a True Leader? Studying the Effectiveness of LEED Certification in Encouraging Green Building” by Megan Turner of Pomona College in 2010. In support of a Bachelor of Arts degree in Environmental Analysis, Turner provided an exceptional paper covering the history of LEED, some of the controversy surrounding LEED, and the Turner and Frankel NBI study. Turner concluded her paper with an energy usage overview of one campus facility. Turner (2010) concluded that “the USGBC must encourage more drastic energy efficiency measures both by the government and within its own system if it wants LEED to live up to its name” (p. 49).

“Development of Next Generation Energy Audit Protocols for the Rapid and Advanced Analysis of Building Energy Use” by Christopher Hartley of the University of California, Irvine in 2013. In support of a Master of Science degree in Engineering, Hartley provided an excellent overview of the U.S. energy policies, energy codes, utility sponsored programs, certification rating systems, and current practices in place for conducting energy analysis. Hartley then proposed a new energy collection methodology, incorporating current metering and building management systems, but requiring higher resolution, higher recording rate, limited loss data at sub-metering levels. Hartley then evaluated four local facilities using current practices compared to the proposed practices. One building, Gross Hall, was LEED-NC Platinum certified and another, LPA, was LEED-commercial interiors Gold certified. Hartley (2013) concluded that current techniques only showed seasonal variations while the proposed protocol showed variations in heating, cooling and occupancy schedules, baseline and peak energy demands, and malfunctioning equipment.

Simulation Investigation

Building system simulation had become an important and useful tool for facility designers. Referenced in Federal policies, building codes and standards, and certification systems, the requirement to develop whole building energy models and estimate energy usage prior to construction was standard practice. Typically two models were developed for certification systems, such as LEED: 1) a baseline model that met the ASHRAE 90.1 minimum requirements and 2) a design or proposed model that incorporated all energy enhancing features from the building design (U.S. Green Building Council, 2011). To help developers determine which components of a building belonged in which model, ASHRAE developed a User's Manual for the ASHRAE 90.1 Appendix G guide on developing performance rating models ("User's Manual," 2004). The two models were then compared to demonstrate the projected energy usage change for the building as designed. The LEED-NC V2009 certification system awarded Energy and Atmosphere points when the design model showed 12% to 48% improvement over the baseline model (USGBC.org, n.d.).

Beginning in the late 1950's and early 1960's, with the early development of computers, whole building simulation with hour-by-hour modeling of building behavior was of interest to design engineers and energy providers. By the late 1960's several programs had been developed by utility and energy companies, and ASHRAE formed the Task Group on Energy Requirements. This group was subdivided into three subcommittees for load calculations, system and equipment simulation, and weather data (Kusuda, 1999).

Out of the early simulation work done by both public and private groups, the U.S. DOE funded the Lawrence Berkeley National Laboratory (LBNL) to develop the first version of DOE-2 for evaluating building energy use and associated costs in 1978 (Haberl & Cho, 2004). Since the initial release of this simulation software by the DOE, the program was continually upgraded by the LBNL and James J. Hirsch & Associates. As with most robust building energy simulations, DOE-2 inputs included building design parameters, operating schedules, HVAC system configurations, utility rates, and weather data ("Building Energy Software Tools," n.d.). As of this writing, DOE-2.2 was the latest version available for use (Hirsch & Associates, n.d.).

Although DOE-2 was the best known hourly analysis program ("Energy Design Resources," n.d.), numerous other simulation programs had been developed over the years. The DOE's EERE compiled descriptions and access information for most of the whole building analysis programs available at the time of this writing. These included programs specific to energy simulation, load calculation, renewable energy, retrofit analysis, and sustainability. For energy simulation alone, 141 programs were available through the EERE website ("Building Energy Software Tools," n.d.).

The most commonly used whole building energy simulations at the time of this writing were DOE-2, EnergyPro , eQUEST, HAP, IES Virtual Environment, TRACE, and VisualDOE (U.S. Green Building Council, 2011). A brief description of each follows, and standard single license prices are shown, if provided ("Building Energy Software Tools," n.d.):

> <u>DOE-2</u>: Publicly available at no cost and developed by James J. Hirsch & Associates with collaboration from the LBNL for the U.S. DOE. A well-validated program that was considered complex and difficult for some to apply effectively ("Energy Design Resources," n.d.)
>
> <u>Energy Pro</u>: Available for purchase (variable price) and developed by EnergySoft, this program used the DOE-2.1E software.
>
> <u>eQUEST (</u>QUick Energy Simulation Tool): Publicly available at no cost and developed by James J. Hirsch & Associates, this incorporated a graphical user interface (GUI) to DOE 2.2 to simplify data entry and model development.

> HAP (Hourly Analysis Program): Available for purchase ($1195) and developed by Carrier Corporation, this Windows-based program used standard input parameters and was considered comparable to DOE-2.1.
>
> IES (Integrated Environmental Solutions) Virtual Environment: Available for purchase and developed by IES Ltd, this Windows-based program used standard input parameters, but had extensive capability for interfacing with geometrical building data. Formal training was required to use this software.
>
> TRACE (Trane Air Conditioning Economics): Available for purchase ($1995) and developed by The Trane Company, this Windows-based program used standard input parameters and formal training was recommended for new users.
>
> VisualDOE: Available for purchase ($980) and developed by Architectural Energy Corporation, this program used the DOE-2.1E software.

The initial design and baseline models developed for the LCROGB by Whiting-Turner and their associated subcontractors used Carrier Corporation's HAP software. The models developed as part of this study used James J. Hirsch & Associates' eQUEST software. This simulation package was selected since it was available at no cost, interfaced with the widely recognized DOE-2.2 software, and was considered by some to be a tool that allowed users to focus on the building input parameters without being concerned with syntax specific issues related to many of the simulation programs referenced. After evaluating several building simulation programs, Southern California Edison's Energy Design Resources group in their "Energy Design Resources Design Brief" stated, "if this will be your first attempt at developing a model, it is probably best to stick with one of the simpler, user-friendly tools, such as eQUEST" (p. 13). This author chose to take their advice.

As mentioned in earlier paragraphs, building energy modeling was not necessarily a precise predictor of actual post-occupancy energy use. Ideally, the Actual Measured EUI/Model Design EUI would be equal to 1 (unity), yet the NBI study showed a variation from 0.50 to 2.75 for the 71 medium energy use buildings that had developed energy models as part of the LEED certification process (Turner & Frankel, 2008). The U.S. Green Building Council (2009) went so far as to conclude that "design models were not a reliable indicator of performance" (p. 18).

A literature review conducted by Haberl and Cho (2004) of the Energy Systems Laboratory at Texas A&M University looked specifically at the DOE-2 simulation performance reported through various case studies. In the empirical studies (simulation results compared to experimentally measured data), 47 cases were evaluated and 33 of 47 found DOE-2 to be within 10 % of the measured data. The remaining 14 cases were within 26%. The 47 facilities had a variety of uses (offices, restaurants, schools, residencies, etc) and climate zones (Haberl & Cho, 2004).

As stated by Turner and Frankel (2008):

> The accuracy of modeling is limited not only by the inherent complexity of buildings, but also by variation in operational factors such as building schedule and occupancy, internal plug loads and weather. Therefore, most professionals in the energy modeling industry are careful to adopt caveats in their predictions or emphasize that modeling is a tool to identify relative energy performance, not to predict actual energy use. (pp. 20-21).

Through the methodologies and analyses discussed in the next chapter of this study, the simulation accuracies for the LCROGB were determined.

Chapter 3

DESCRIPTIONS, COMPARISONS, AND ANALYSES

The purpose of this study was to gain a comprehensive understanding of the LEED certification system and its relevance to Federal policies, building codes, and building standards, develop experience with whole building energy modeling, and determine the actual post-occupancy energy usage as compared with the developed model and design projections. The methodologies used and analyses performed to meet these objectives will be discussed in detail in this chapter.

Requirements Analysis

The LCROGB was the first USBR project to require compliance with the Guiding Principles, and USBR representatives had three primary concerns and considerations: 1) developers bidding on the project would be unfamiliar with the Guiding Principles and could inflate the budget to compensate for this unknown, 2) the Guiding Principles' requirements were not specific, and adhering to LEED requirements would demonstrate compliance with the Guiding Principles, and 3) many developers had LEED project experience which could be used as an evaluation factor during the selection process (USBR personal communication, March 9, 2014). Although numerous local, State, and Federal building polices, codes, and standards had to be followed throughout the construction of this facility, the Guiding Principles were of primary consideration by the USBR, and LEED was a means to show compliance.

For this study, requirements comparison focused on the U.S. Federal Government's Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings (2006, 2008), the ASHRAE Standard 90.1-2007 Energy Standard for Buildings Except Low-Rise Residential Buildings, and the LEED V2009 for New Construction and Major Renovations. Additional ASHRAE Standards, such as 55 and 62.1, were also referenced, when required. Initially, each policy or standard will be overviewed. Note that many details that were not directly applicable to this study have been intentionally omitted. A comparative analysis of the elements applicable to this study will then be provided.

Federal Government Guiding Principles

The following list of requirements was excerpted from the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings (2006), and the updated High Performance and Sustainable Buildings Guidance (2008). Some wording has been intentionally omitted, and this list should not be used as a complete set of mandates. Only the portions applicable to this study were included in this chapter. The complete listing can be found in Appendix A:

Optimize Energy Performance

Energy Efficiency Establish a whole building performance target that takes into account the intended use and occupancy. For new construction, reduce the energy use by 30% compared to the baseline building performance rating per ASHRAE 90.1-2007.

On-Site Renewable Energy Per EISA, meet at least 30% of the hot water demand through the installation of solar hot water heaters. Per Executive Order 13423, implement renewable energy generation projects on agency property for agency use.

Measurement and Verification Per EPAct of 2005, install building level electricity meters in new major construction to track and continuously optimize performance. Per EISA, include equivalent meters for natural gas, where natural gas is used.

Benchmarking Compare actual performance data from the first year of operation with the energy design target. Verify that the building performance meets or exceeds the design target.

Enhance Indoor Environmental Quality

Ventilation and Thermal Comfort Meet ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy, and ASHRAE Standard 62.1-2007, Ventilation for Acceptable Indoor Air Quality.

Daylighting Achieve a minimum daylight factor of 2% (excluding all direct sunlight penetration) in 75% of all space occupied for critical visual tasks. Provide automatic dimming controls or accessible manual light controls, and appropriate glare control.

ASHRAE Standard 90.1

The ASHRAE 90.1-2007 provided overview information (Chapters 1 through 4) and guidance for building envelopes (Chapter 5), HVAC systems (Chapter 6), water heating systems (Chapter 7), electric power distribution and metering (Chapter 8), lighting (Chapter 9), other equipment (Chapter 10), and the Energy Cost Budget method (Chapter 11). The portions of the standard applicable to this study are included as

Appendix B, and a few key excerpts are listed below. Many words, sections, and references have been intentionally omitted, and this list should not be used as an exact excerpt from ASHRAE 90.1-2007:

HVAC – Mandatory Provisions (Section 6.4)

> *6.4.2 Load Calculations* Heating and cooling system design loads for the purpose of sizing systems and equipment shall be determined in accordance with generally accepted engineering standards and handbooks.
>
> *6.4.3 Controls* 6.4.3.1 The supply of heating and cooling energy to each zone shall be individually controlled by thermostatic controls responding to temperature within the zone.
>
> 6.4.3.3 1.Systems shall have off-hour controls that can start and stop the system under different time schedules for seven different day-types per week, retain programming and time setting during loss of power for at least ten hours, and include an accessible manual override. 2. Heating systems shall be equipped with controls that have the capability to automatically restart to maintain zone temperatures above a heating set point adjustable down to 55 deg F or lower. Cooling systems that have the capability to automatically restart to maintain zone temperatures below a cooling set point adjustable up to 90 deg F or higher.
>
> 6.4.3.4 Stair, elevator shaft, outdoor air supply, and exhaust systems shall have motorized dampers.

HVAC – Prescriptive Path (Section 6.5)

> *6.5.1 Economizers* Each cooling system that has a fan shall include an economizer meeting the requirements given (not listed here).
>
> 6.5.1.1 Air economizer systems shall be capable of modulating outdoor air and return air dampers to provide up to 100% of the design supply air quantity as outdoor air for cooling. Dampers shall be capable of being sequenced and be capable of automatically reducing outdoor air intake to the design minimum outdoor air quantity when outdoor air intake will no longer reduce cooling energy usage.
>
> *6.5.2 Simultaneous Heating and Cooling Limitation* 6.5.2.1 Zone thermostatic controls shall be capable of operating in sequence the supply of heating and cooling energy to the zone.

Energy Cost Budget Method (Chapter 11)

The purpose of ASHRAE 90.1-2007 Chapter 11 was to allow an alternative to the prescriptive provisions ("ANSI/ASHRAE/IESNA," 2007). Chapter 11 provided the specific requirements for simulating the building design to meet the minimum ASHRAE 90.1 standards and provided more flexibility in design than the individual ASHRAE 90.1 chapters ("User's Manual," 2004).

In 2004, as certification systems such as LEED became more prevalently used, the ASHRAE 90.1 committee added the "Informative Appendix G Performance Rating Method" for building designs intended to exceed the basic ASHRAE 90.1 standard. Appendix G did not include requirements for ASHRAE 90.1, but provided information for demonstrating energy efficiency that exceeded the basic requirements of the standard ("ANSI/ASHRAE/IESNA," 2007).

Since the LCROGB design and energy usage was developed under the guidance of Appendix G and the prescriptive standards of ASHRAE 90.1-2007, the standards of

Chapter 11 were not included as part of this study. Appendix G is discussed further later in this chapter.

LEED V2009 for New Construction and Major Renovations

The LEED V2009 certification system included 100 base points available for accreditation, plus 6 points for Innovation in Design and 4 points for Regional Priority. As shown previously in Table 2, a minimum of 80 points were required to earn a Platinum certification with LEED V2009. The USBR LCROGB earned 83 points for a Platinum certification (“LEED Certification Project,” 2012).

The following was excerpted from the LEED V2009 for New Construction and Major Renovations (2009). The number of points possible and the number of points awarded for the LCROGB design follow each of the credit titles, parenthetically. The basic intent or requirement for each credit category is also provided. Some wording has been intentionally omitted, and this list should not be used as a complete set of guidelines. Only the portions applicable to this study were included in this chapter. The complete listing can be found in Appendix C:

Energy and Atmosphere (EA) (35 points possible/30 points awarded, complete list included in Appendix C)

EA Prerequisite 1 Fundamental Commissioning of Building Energy Systems
Verify the project's energy-related systems are installed and calibrated to perform according to the owner's project requirements, basis of design, and construction documents.

EA Prerequisite 2 Minimum Energy Performance
Establish the minimum level of energy efficiency for the proposed building and systems to reduce environmental and economic impacts associated with excessive energy use. Option 1: Demonstrate a 10% improvement in the proposed building performance rating for new buildings through a whole building energy simulation. (Options 2 and 3 not listed)

EA Prerequisite 3 Fundamental Refrigerant Management Required
Zero use of chlorofluorocarbon (CFC)-based refrigerants in new base building HVAC systems.

EA Credit 1: (19/19) Optimize Energy Performance
Option 1: Demonstrate the percentage improvement in the proposed building performance rating compared with the baseline building performance rating through a whole building energy simulation. Calculate the baseline building performance according to Appendix G of ASHRAE 90.1-2007. Points awarded vary from 1 to 19 based on savings ranging from 12% to 48%. (Options 2 and 3 not listed)

EA Credit 2: (7/8) On-Site Renewable Energy
Use on-site renewable energy systems to offset building energy costs. Points awarded vary from 1 to 7 based on percentage renewable ranging from 1% to 13%.

EA Credit 5: (3/3) Measurement and Verification (M&V)
Develop and implement an M&V plan with a period covering at least 1 year of post-construction occupancy. Provide a process for corrective action if the results of the M&V plan indicate that energy savings are not being achieved.

Indoor Environmental Quality (IEQ) (15 points possible/14 points awarded, complete list included in Appendix C)

IEQ Prerequisite 1 Minimum Indoor Air Quality Performance
Meet the minimum requirements of ASHRAE 62.1-2007 Sections 4-7.

IEQ Credit 1: (1/1) Outdoor Air Delivery Monitoring
Install permanent monitoring systems to ensure that ventilation systems maintain design minimum requirements. Configure all monitoring equipment to generate an alarm when airflow values or CO_2 levels vary by 10% or more from design values.

IEQ Credit 2: (1/1) Increased Ventilation
Increase breathing zone outdoor air ventilation rates to all occupied spaces by at least 30% above the minimum rates required by ASHRAE 62.1-2007.

IEQ Credit 6.1: (1/1) Controllability of Lighting
Increase breathing zone outdoor air ventilation rates to all occupied spaces by at least 30% above the minimum rates required by ASHRAE 62.1-2007.

IEQ Credit 6.2: (1/0) Controllability of Thermal Control
Provide individual comfort controls for 50% of the building occupants.

IEQ Credit 7.1: (1/1) Thermal Comfort – Design
Design HVAC systems and the building envelope to meet the requirements of ASHRAE 55-2004.

IEQ Credit 7.2: (1/1) Thermal Comfort – Verification
Provide a permanent monitoring system to ensure that building performance meets the desired comfort criteria as determined by IEQ Credit 7.1. Agree to conduct a thermal comfort survey of building occupants within 6 to 18 months of occupancy.

IEQ Credit 8.1: (1/1) Daylight
Options 2 and 3: Use a combination of side-lighting and/or top-lighting to achieve a total daylighting zone that is at least 75% of all the regularly occupied spaces (per list criteria), and demonstrate through records of indoor light measurements that a minimum daylight illumination level of 25 foot-candles (fc) has been achieved in at least 75% of all the regularly occupied spaces. (Options 1 and 4 not listed)

Comparative Analysis

Although compliance to numerous building codes and standards was required during the design and construction of the USBR’s LCROGB, including local, state, architectural, civil, electrical, plumbing, and structural standards, this comparative analysis focused on the U.S. Federal Government’s Guiding Principles, the ASHRAE 90.1-2007, and the LEED V2009. When analysis required, the ASHRAE 55-2004 and ASHRAE Standard and 62.1-2007 were also referenced.

Table 3 compares the design requirements specific to the energy analysis of interest to this study from these three primary sources. As shown, all three address the energy-related requirements in a comparable manner. The ASHRAE 90.1 Standard did not address benchmarking, where actual energy usage was required to be evaluated post-occupancy, and neither the Guiding Principles nor the ASHRAE 90.1 addressed a refrigerant management requirement.

Table 3. Primary Requirements Comparison.

General Requirement	U.S. Guiding Principles	ASHRAE 90.1	LEED V2009 References
Integrated Design	Use collaborative process		
Commissioning	Verify component performance and ensure design requirements met	6.7.2.3.1, 6.7.2.4 for HVAC system balancing and controls	EAp1 (commissioning), EAc3 (enhanced commissioning), IDc2 (LEED accredited professional)
Energy Efficiency	30% reduction compared to ASHRAE 90.1 baseline design	Purpose of entire document	EAp2 (10% reduction compared to baseline), EAc1 (12% to 48% reduction compared to baseline)
On-Site Renewable Energy	30% hot water demand via solar hot water heaters and renewable energy generation project on agency property	Appendix G2.4, baseline design includes backup energy source (electric or gas), while proposed design includes renewable energy source	EAc2 (1% to 13% energy costs offset by renewable), EAc6 (green power)
Measurement and Verification	Install electrical meters to track and optimize performance	6.4.1, 6.5.3, equipment verification required	EAc5 (develop and implement M&V plan)
Benchmarking	Compare actual performance data from first year with design target and verify building performance meets or exceeds target		EAc5 (provide process for corrective action if energy savings not being achieved)
Ventilation and Thermal Control	Meet ASHRAE 55-2004 and 62.1-2007 Standards	Purpose of ASHRAE Standards 55 and 62.1	IEQp1 (meet ASHRAE 62.1 requirements), IEQc1 (permanent ventilation monitoring), IEQc2 (ventilation rates 30% above 62.1 requirements), IEQc6.2 (thermal control), IEQc7.1 (meet ASHRAE 55 requirements), IEQc7.2 (permanent thermal monitoring system)
Daylighting	Minimum daylight factor of 2% in 75% of all occupied space, automatic or manual light controls and glare control	Appendix C, Methodology for Building Envelope Trade-Off Options	IEQc6.1 (lighting control), IEQc8.1 (25 fc in 75% of occupied space)
Refrigerant Management			EAp3 (zero use of CFC-based refrigerants), EAc4 (enhanced refrigerant management)

Table 4 summarizes the LCROGB design with the basic categories outlined in Table 3.

Table 4. LCROGB Comparison with Requirements.

General Requirement	Lower Colorado Regional Office Green Building (LCROGB) Complaince	LEED possible points	LEED awarded points
Integrated Design	A collaborative process was used between the Government, general contractor, architect, and engineering firms		
Commissioning	Whiting-Turner employed TMCx Solution, LLC for commissioning	3	1
Energy Efficiency	Building simulation indicated energy cost savings of 65.72%	19	19
On-Site Renewable Energy	Solar hot water heating, solar-powered exterior lighting, and on-site renewable energy generation included in design	9	8
Measurement and Verification	Energy metering installed and M&V Plan developed	3	3
Benchmarking		Part of M&V	Part of M&V
Ventilation and Thermal Control	Design compliant with ASHRAE 55 and 62.1 Standards	5	4
Daylighting	LEED analysis indicated 76.78% of occupied space met requirement	2	2
Refrigerant Management	Zero use of CFC refrigerant in design, but additional LEED credits were not pursued	2	0
Additional Requirements Unrelated to Energy Efficiency	Sustainable site , water efficiency, materials and resources, indoor environmental quality	67	46
Total points:		110	83

When commissioning the LCROGB, TMCx Solutions, LLC evaluated all commissioned equipment and ensured proper functionality, documented systems performance parameters, identified operational and design issues requiring further resolution, and provided a formal Final Commissioning Report. Systems included in the commissioning process included mechanical, lighting controls, domestic hot water, HVAC, and the Building Management System (BMS) (TMCx, 2011).

Through the whole building simulation energy efficiency evaluation, the LCROGB design team demonstrated a 65.72% energy cost savings when comparing the baseline and proposed building designs (“EA Credit 1,” n.d.). This earned the project 19 energy efficiency points in the category of Energy and Atmosphere: Optimize Energy

Performance: Credit 1, the maximum number of points available in this category. The methodologies and analyses of the whole building energy simulation are described in the simulation discussion later in this chapter.

For on-site renewable energy, the LCROGB design incorporated three renewable energy features: 1) a solar hot water heating system with natural gas backup, 2) solar-powered exterior lighting, and 3) an array of site and grid-tied photovoltaic (PV) panels to offset the facility energy costs through net metering. The combination of these renewable energy features, compared to the baseline design through the design team's whole building simulation, demonstrated an energy cost savings of 48.74% ("EA Credit 2," 2011). This earned the project 8 points in the category of Energy and Atmosphere: On-Site Renewable Energy: Credit 2.

The Maintenance and Verification (M&V) Plan developed and implemented by the LCROGB design team specified energy metering be implemented for monitoring energy usage, calibrating the whole building energy simulation, and managing overall energy usage. Energy metering was tied to the BMS and included measurements of electrical power usage for lighting, irrigation control, receptacle loads, chiller plant, air handling units (AHU), hot water pumps, elevators, whole building usage, and energy generation by the solar PV array. Meters were also installed and tied to the BMS to measure natural gas usage. Water meters were installed and tied to the BMS at several locations throughout the facility. Although an initial whole building simulation was developed by the design team to demonstrate energy savings, the M&V Plan (2011) indicated that energy and water usage data would be collected during an initial one-year period:

> Data collected during an initial one-year period will be compared with the simulations in order to calibrate the Baseline and Design models with actual occupant usage data, updated weather files . . . and heating and cooling set points by zone. Discrepancies greater than 10% will be analyzed, the cause determined, and the model re-calibrated should the cause be determined to be inaccurate input. (p. 4).

The development of the M&V Plan earned the project 3 points in the category Energy and Atmosphere: Measurements and Verification: Credit 5.

Ventilation and thermal control requirements were met in a number of ways. The mechanical ventilation system was designed to be compliant with the ASHRAE 62.1-2007 Standard, which was considered more stringent than local building codes (Yeung, n.d.). For air quality management, CO_2 sensors were installed in the facility, and specifically in densely populated areas of 25 people or more per 1000 sf. The design included an alarm system for these areas if CO_2 conditions exceeded the design set point of 700 parts per million (ppm) by 10% ("IEQ Credit 1," n.d.). The minimum outdoor air flow rates were measured at the AHUs and were required to have an accuracy of 15% of actual flow rates ("ANSI/ASHRAE Standard," 2007). To comply with the more stringent LEED IEQ Credit 2 ("IEQ Credit 2," n.d.) requirements, outdoor air ventilation rates exceeding the ASHRAE 62.1-2007 requirements by at least 30% were demonstrated using the May 2011 version of ASHRAE's 62MZ Calculation Form. This automated form was used by the design team to calculate system ventilation efficiency and required outdoor air intake volumes based on facility configurations. The results of the 62MZ calculation were provided as part of the LEED certification process to demonstrate LEED compliance.

Through the LEED credit process, the design team also demonstrated the HVAC system and building envelope were in compliance with ASHRAE 55-2004 for metabolic rates, clothing insulation, weather design conditions, and operating conditions for both heating and cooling. Thermal comfort verification was to be accomplished through thermal condition monitoring tied to the BMS and by distributing a thermal comfort survey to building occupants within 6 to 18 months of occupancy ("LEED Certification Project," 2012).

For the ventilation and thermal control requirements, the LCROGB design team earned 4 points in the Indoor Environmental Quality categories of Outdoor Air Delivery Monitoring (Credit 1), Increased Ventilation (Credit 2), and Thermal Comfort – Design and Verification (Credits 7.1 and 7.2). The team did not earn any LEED points for Indoor Environmental Quality: Thermal Control: Credit 6.2, since thermal control by individuals occupying the building was not included in the design. Thermal control was accomplished through the BMS and will be discussed in the next section of this chapter.

Lighting and daylighting requirements were met through several design features. Lighting controls were designed such that 100% of the building occupants could make adjustments to suit task needs and preferences for individuals and multi-occupant spaces ("IEQc6.1," n.d.). Daylighting design requirements were demonstrated initially through the use of a LEED provided Supplemental Daylight and Views Calculator. By inputting space type and square footage, window and skylight area and visible light transmittance value, window to floor area ratio, and skylight roof coverage percentage, the LEED tool estimated that 76.78% of all regularly occupied spaces achieved appropriate daylighting. Measurements were also taken after window and furniture installation from 30 inches above the floor and at 10 foot intervals, demonstrating the minimum daylighting illumination of 25 fc had been achieved in all occupied spaces. Glare control was also designed into the LCROGB through shades, exterior light shelves, and glazing to avoid high-contrast situations (“IEQ Credit 8.1,” n.d.). The combination of the lighting and daylighting features earned the project 2 points toward LEED certification.

Refrigerant management was the only requirement specifically addressed by the LEED certification system that was not addressed by the Guiding Principles nor ASHRAE 90.1-2007. At a minimum, LEED certification required zero use of CFC-based refrigerants in new building HVAC systems. To comply with this requirement, the LCROGB HVAC system used R-134a, tetrafluoroethane ($C_2H_2F_4$). R-134a belonged to a class of refrigerants, hydrofluorocarbons (HFC), designed to replace CFC refrigerants. HFC refrigerants did not contain chlorine or bromine, and therefore, were thought not to deplete the ozone layer (“Ozone,” 2010). Although LEED certification allowed for additional points if designers demonstrated the use of refrigerants and HVAC equipment that minimized or eliminated the emission of compounds that contributed to ozone depletion and climate change, the LCROGB design team did not attempt to earn these points through Energy and Atmosphere: Enhanced Refrigerant Management: Credit 4.

Building Design Details

The USBR's LCROGB design and construction team was formed in April 2010 and included representatives from the USBR Lower Colorado Regional Office, Whiting-Turner Contracting Company (general contractor), Tate Snyder Kimsey (architect), MSA Engineering Consultants (mechanical, plumbing, electrical), Lochsa Engineering (civil), Leslie E. Robertson Associates (structural), and numerous other subcontractors. Construction began in August 2010, and building occupancy occurred in September 2011. The National Historic Preservation Act and the Nevada State Historic Preservation Office required the LCROGB design to emulate the original Bureau of Mines' Metallurgical Research Laboratories originally on the building site. Additionally, LCROGB orientation was not optimized, as the building was required to align with other historical features at the site. Comparative photographs of the original site and building (USBR, n.d.) and the completed LCROGB (Tincher, 2013) are shown in Figures 1, 2, and 3.

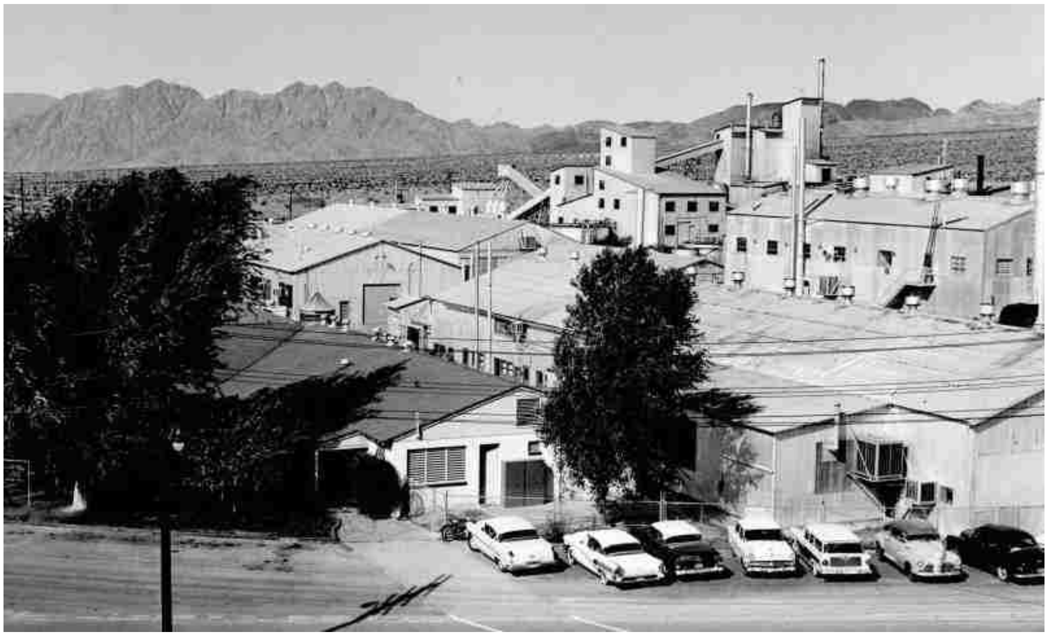


Figure 1. Original Bureau of Mines Facilities.

Figure 2. Bureau of Mines Metallurgical Laboratory.

Figure 3. USBR Lower Colorado Regional Office Green Building.

The two-story LCROGB facility was designed as office space with an overall square footage of 49,818 sf. Approximately 173 full-time equivalent employees occupied the facility that was scheduled within the BMS for occupancy from 6:00 a.m. to 6:30 p.m., Monday through Friday, excluding holidays, 250 days per year. Approximately 6% of the total square footage was unoccupied and was used for electrical rooms, fire risers, boilers, and storage. All, but the boiler room, were conditioned spaces.

Open space cubicles and individual offices comprised over 73% of the total square footage with raised ceilings on the second floor. The remainder of the facility included the following, with approximate percentage of total square footage noted: conference rooms (5%), restrooms (3%), corridors (6%), break rooms (3%), lobby (3%), storage/electrical rooms (6%), and copy rooms (1%). Figure 4 shows a portion of the second floor of the facility with raised ceiling (Tincher, 2013). Figures 5 and 6 illustrate the floor plans for the first and second floors, respectively (Valley Custom Interiors, 2011). The open spaces predominantly represented cubicle space.

Figure 4. LCROGB Interior View of Second Floor.

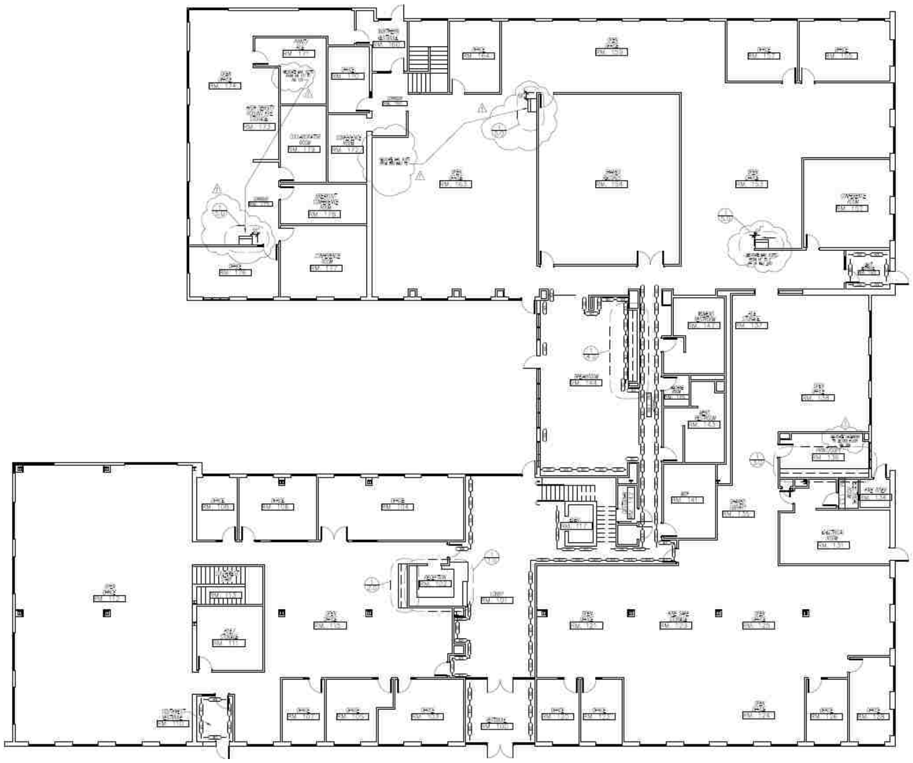


Figure 5. LCROGB First Floor Plan.

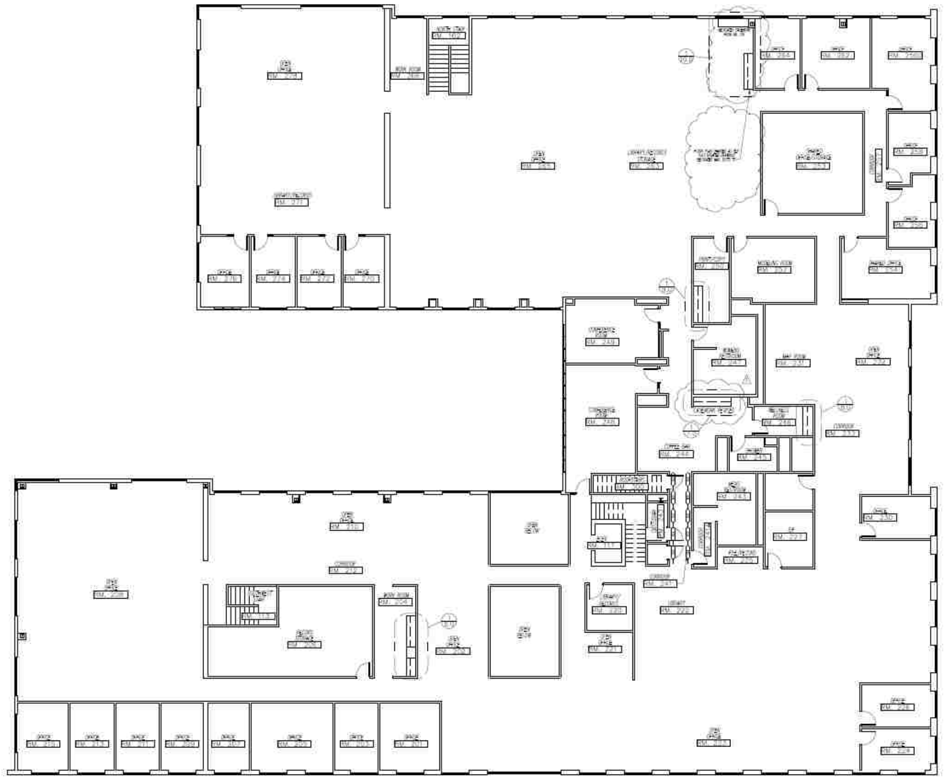


Figure 6. LCROGB Second Floor Plan.

The building faced south-south-east, rotated approximately 208.4 degrees counter-clockwise from due north. Figure 7 shows the aerial view of the finished facility (Google Earth, 2013), and Figures 8 through 11 show the elevation views from the final construction documents (Tate Snyder Kimsey (TSK), 2011, pp. A6.01-A6.02). The base floor of the entire structure was concrete slab on grade, so the facility did not have a basement level. The second level floor was also concrete.

Figure 7. LCROGB Aerial View.

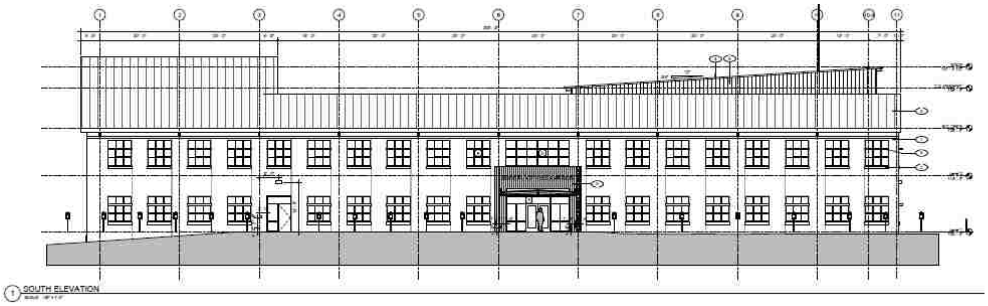


Figure 8. LCROGB South Elevation – Front of Facility.

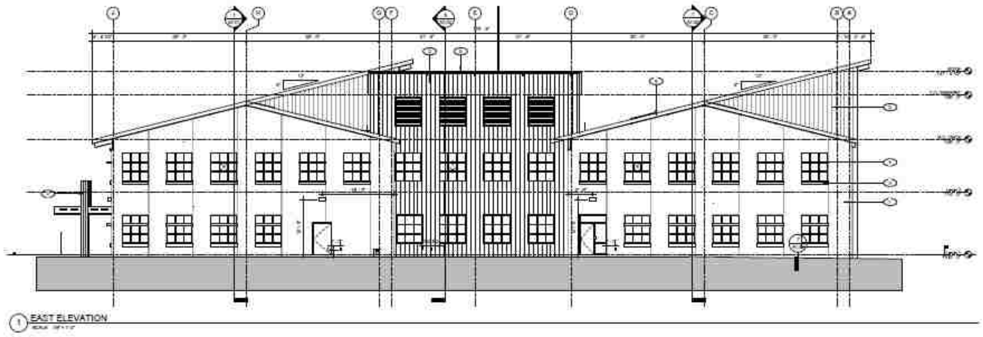


Figure 9. LCROGB East Elevation.

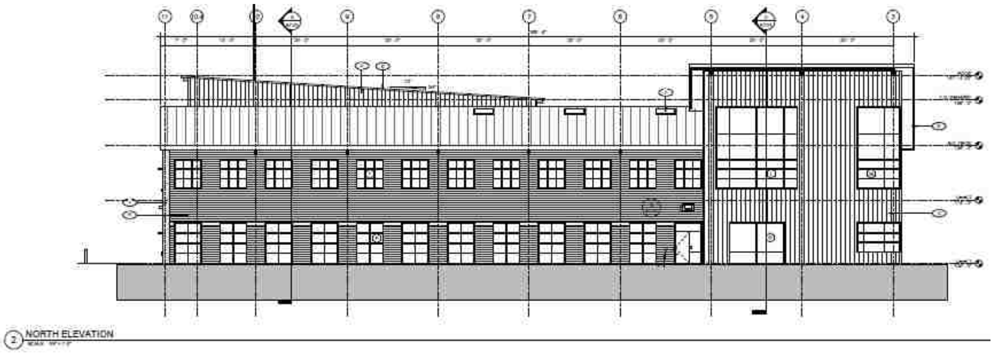


Figure 10. LCROGB North Elevation.

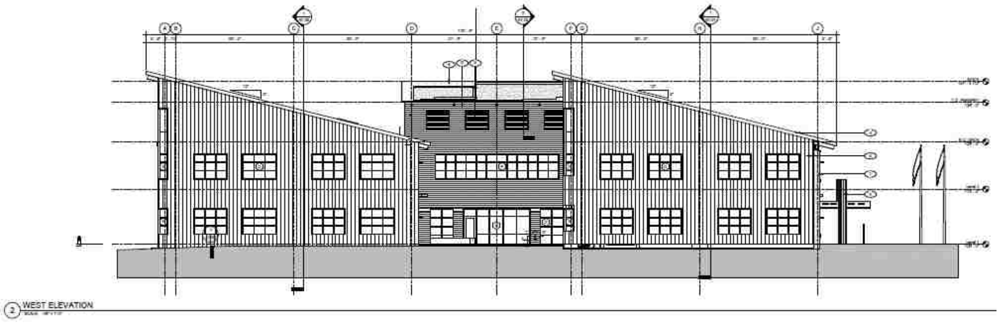


Figure 11. LCROGB West Elevation.

Building Envelope

The building had a wall area of approximately 28,367 sf, and the walls were structurally made of two basic materials: metal and concrete. The metal walls, shown in Figure 12 (Tincher, 2013) between two concrete walls and detailed in Figure 13 (TSK, 2011, p. A7.10), consisted of 1.0625-inch corrugated metal wall panel system, over 0.50-inch glass mat sheathing, over 6-inch metal studs set at 16 inch outside corner separation, with R-19 batt insulation. The interior of these walls was 0.625-inch painted gypsum board. The metal walls comprised approximately 17,928 sf or 63% of the total wall area (TSK, 2011).

Figure 12. LCROGB East-Facing Metal and Concrete Exterior Walls.

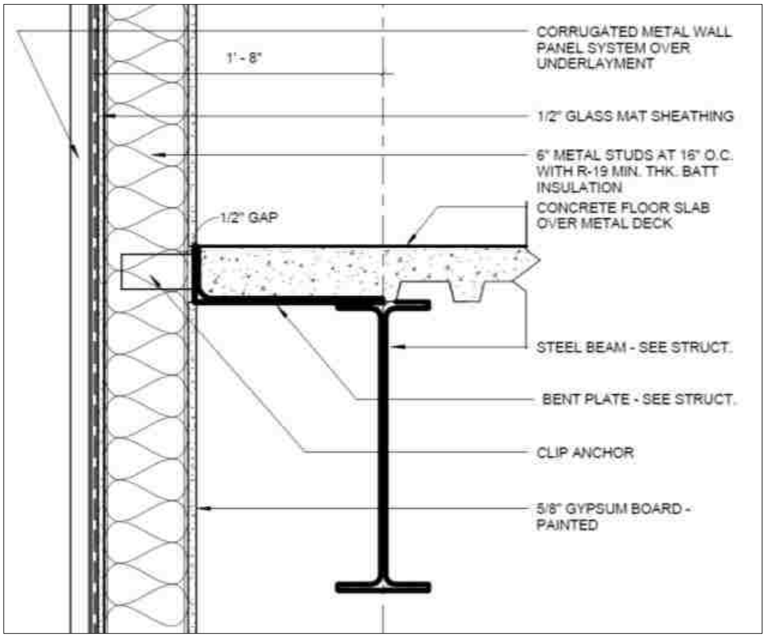


Figure 13. Metal Exterior Wall Composition.

The two-story, south facing wall and majority of the east facing wall were made of painted 14-inch cast-in-place concrete with an interior lining of 2-inch, R-19 rigid insulation covered by 0.625-inch painted gypsum board. The concrete walls comprised the other 10,439 sf or 37% of the total wall area (TSK, 2011). The south- and east-facing concrete walls and the details of the concrete wall structure are shown in Figures 12, 14 and 15, respectively (Tincher, 2013; TSK, 2011, p. A7.10).

Figure 14. LCROGB South- and East-Facing Walls With Window Light Shelves.

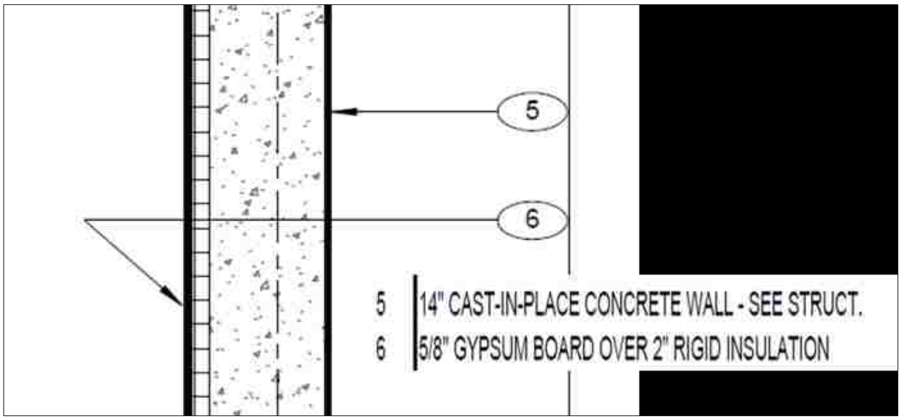


Figure 15. Concrete Exterior Wall Composition.

The LCROGB roof was predominantly standing seam metal roof system over underlayment, placed over 5-inch, R-30 rigid insulation, over metal deck. The details of this roof structure are shown in Figure 16 (TSK, 2011, p. A4.20). The portion of the roof where the AHUs were placed, as seen in Figure 7, was flat and composed of concrete over the metal deck with 5-inch, R-30 rigid insulation, covered with a single ply roof membrane system. The details of this roof structure are shown in Figure 17 (TSK, 2011, p. A4.20).

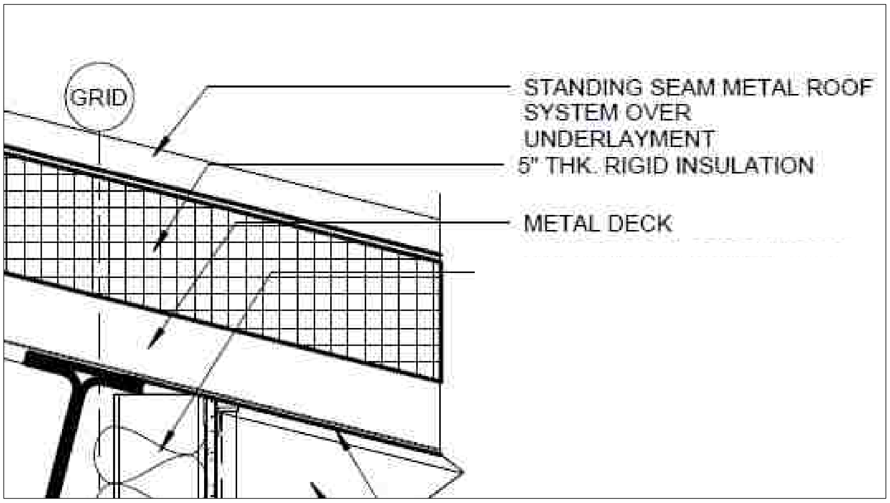


Figure 16. Metal Roof Composition.

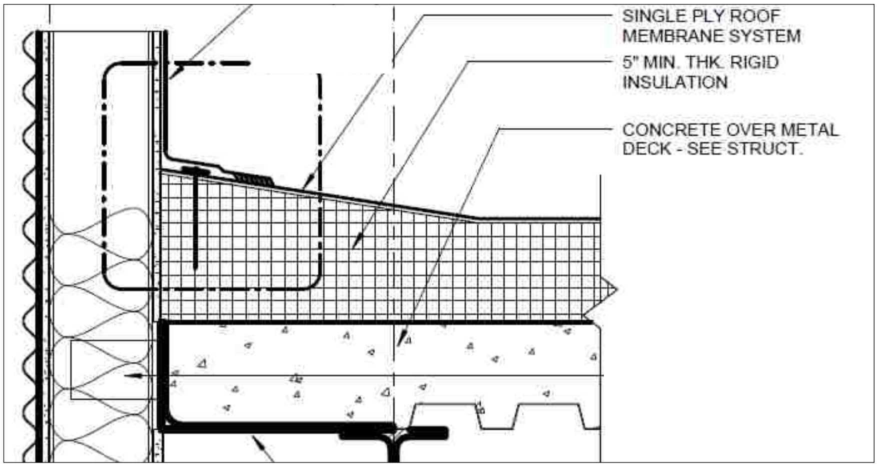


Figure 17. Flat Concrete Roof Composition.

The building had a window area of 8158 sf, resulting in a window-to-wall ratio of approximately 30% (MSA, n.d.). Numerous window sizes and configurations were used for the LCROGB structure as shown in Figures 3, 8 through 12, and 14. For the building envelope analysis portion of this study, three sizes and configurations were considered and are shown in Figures 18 through 20 (TSK, 2011, p. A2.13). These windows were all anodized aluminum framed with a thermal break and double paned, low-emissivity, glazed glass with 0.25-inch glass separated by 0.50-inch air-filled space ("Lower Colorado," 2010). The windows were assumed to have the following characteristics: solar heat gain coefficient (SHGC) = 0.28 and U-factor = 0.43 (MSA, n.d.). The south- and east-facing windows, as shown in Figures 12 and 14, also had 16-inch light shelves or sunshades projecting on the exterior of the windows. The light shelves were louvered with the intent of shading direct sunlight at work surfaces and deflecting natural light toward the ceiling and deeper into the structure.

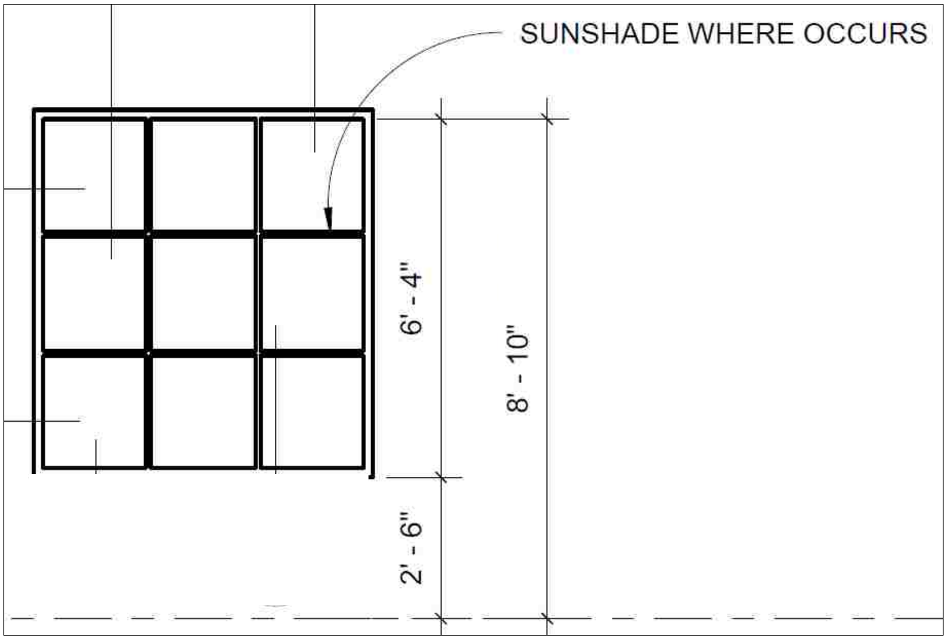


Figure 18. Standard Window Configuration.

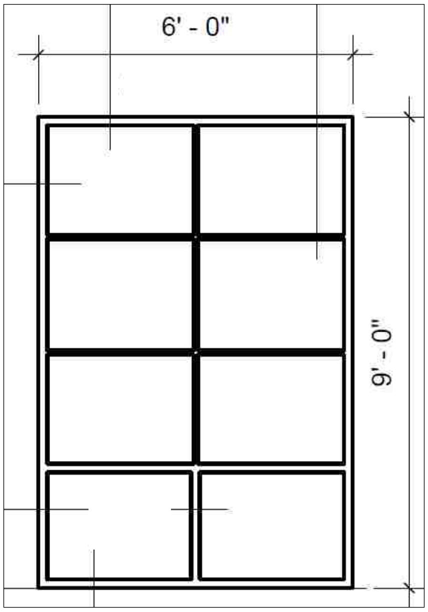


Figure 19. Elongated Window Configuration.

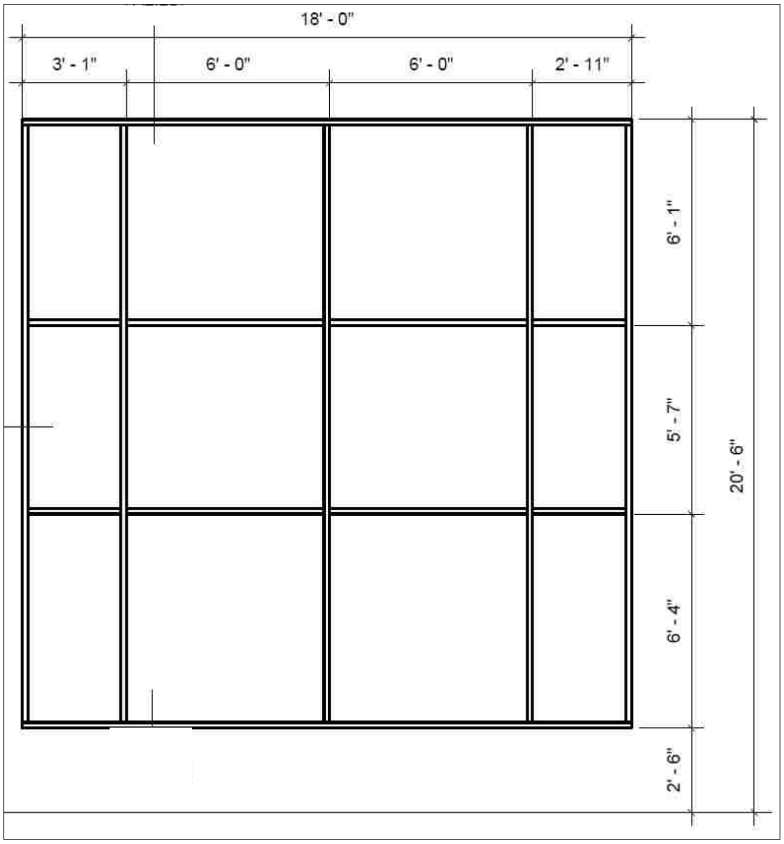


Figure 20. Large Window Configuration.

Additionally, the building had 11 skylights with SHGC = 0.29 and U-factor = 0.29 (MSA, n.d.). Six were located on the south wing of the building and five on the north wing. The first floor of the building had several 3 ft x 7 ft exterior doors, and all were anodized aluminum framed with double paned, low-emissivity, glazed glass. Although there were opaque, insulated steel doors accessing the flat roof area of the building and mechanical rooms, these were not considered in this study.

Building Management System (BMS)

The LCROGB included a BMS, installed by ABS Systems, Inc. with controls provided by Delta Controls, Inc. The BMS complied with building automation and control networks (BACnet) communications protocol and was designed to manage building operations and collect and store data. Real-time and recorded data included natural gas and water usage, lighting, solar power, and details regarding the HVAC system, including the boilers, AHUs, variable air volume (VAV) devices, central chiller plant, and cooling towers. As enhancements to the Date Street Complex and other USBR facilities located in Boulder City, Nevada were made, fiber optics allowed the LCROGB BMS to interface with many of these facilities, providing a central location for facility management information. At the time of this writing, the Date Street Complex was comprised of 10 occupied buildings.

The BMS interface allowed facility managers to monitor on-going system operation and specify various parameters to record, along with recording rates. Through the BMS screens, operators could change many of the parameters shown; however, changes to the central chiller plant had to be accomplished from inside the central plant using the Trane Tracer control system. At the time of this study, modifications to the BMS were on going and new facilities were being added to the system beyond the LCROGB. As a result, data anticipated for use in this study were limited. Figure 21 shows the main page for the BMS specific to the LCROGB. Additional information from the BMS will be provided in the following sections of this chapter.

Figure 21. Building Management System LCROGB Main Page.

Energy Loads

The major contributors to energy usage in the LCROGB were the HVAC system, lighting, and receptacle loads. Domestic hot water was provided through a solar hot water system with a backup natural gas system. The hot water system was not considered a significant contributor to the overall energy usage for this facility. The solar PV array located at the site provided energy to the various facilities located at the Date Street Complex. When energy generated by the solar installation exceeded the needs of the Date Street Complex, such as during weekend-daytime periods, the excess energy was provided to the local grid to offset energy costs. Solar energy offsets to overall LCROGB energy usage will be discussed later in this chapter.

Heating, Ventilation, and Air Conditioning (HVAC) System

The HVAC system for the LCROGB consisted of a packaged central chiller plant, cooling towers, boilers, AHUs, VAVs, BMS, associated wiring, digital controllers, pumps, fans, ducting, diffusers, filters, and piping. Figure 22 provides a general overview of the entire system, and individual components will be discussed in some detail in the following paragraphs.

Figure 22. LCROGB HVAC Overview.

The central chiller plant and cooling towers were designed to provide chilled water to the LCROGB AHUs, as well as two reconstructed buildings at the Date Street Complex, Buildings 100 and 200. These additional buildings were small in comparison to the LCROGB and were occupied in mid- 2013. The central chiller plant and cooling towers were co-located between the LCROGB and Buildings 100 and 200, and underground piping provided chilled water to the various AHUs.

Figure 23 provides a partial site overview of the Date Street Complex (TSK, 2011, p. AS1.00) with the following labels: (1) LCROGB, (2) AHUs, (3) boiler room, (4) cooling towers, (5) central chiller plant, (6) Building 100, (7) Building 200. Figure 24 shows two views of the chiller plant and cooling towers (Tincher, 2013).

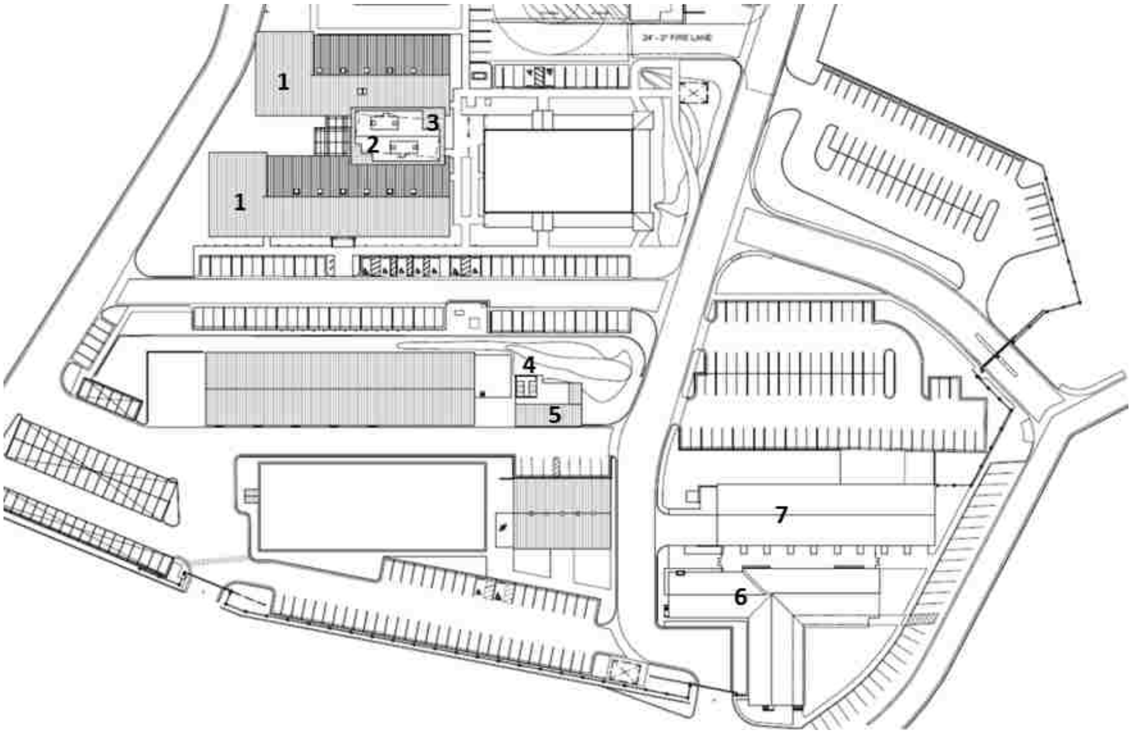


Figure 23. Date Street Complex Partial Site Overview.

Figure 24. HVAC Central Chiller Plant and Cooling Towers.

The customized central chiller plant was packaged by TAS and included Trane control systems, Paco pumps, Smardt chillers, Marley cooling towers, and a multitude of components provided by various companies including expansion valves, alarm systems, water treatment systems, piping, and insulation. Fiber optics connected the central plant data system to the LCROGB BMS.

The two Smardt WA046 water-cooled chillers operated in parallel through lead-lag sequencing, using R-134a refrigerant. Lead-lag sequencing provided automatic switching of the lead component when systems were energized. Typically only one chiller was required to cool the facilities; however, both could operate if conditions required. Each chiller had a nominal capacity of 125 tons or 439 kW (MSA, 2011a) and included a 4-pass shell and tube evaporator, 2-stage, oil-free centrifugal compressor, 4-pass shell and tube condenser, electronic expansion valve, and compressor controls (Whiting-Turner (WT), 2011). A schematic of one chiller (WT, 2011, p. 2233) and photograph (Tincher, 2013) are shown in Figure 25.

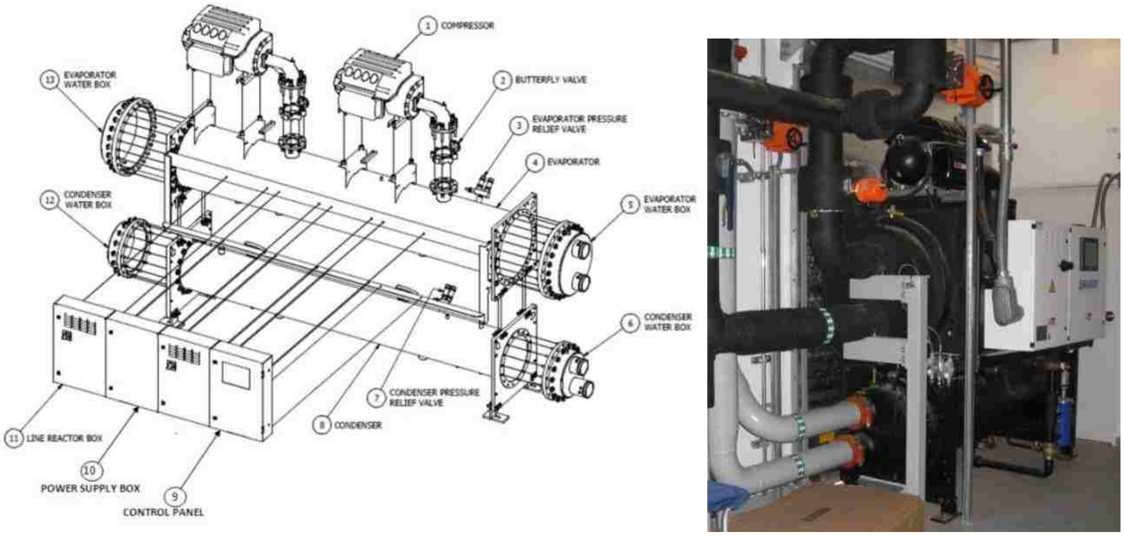


Figure 25. Smardt Chiller Schematic and Photograph.

When the chillers were operating, low pressure, condensed refrigerant entered the bottom of the evaporator or chiller where heat transferred from the water going to the AHUs to the refrigerant (design: water in: 58 deg F, water out: 42 deg F at 187 gallons per minute (gpm)) (MSA, 2011a). This heat transfer vaporized the refrigerant which was drawn to the top of the chiller by the suction of the compressor. The refrigerant then entered the compressor as a low-pressure, low-temperature superheated gas, passed through two sets of impellers to increase pressure and temperature, and exited the compressor as a high-pressure, high-temperature gas. The refrigerant then entered the top of the condenser, and heat was transferred from the refrigerant to the condenser cooling water (design: water in: 85 deg F, water out: 95 deg F at 375 gpm) (MSA, 2011a). The refrigerant then flowed through an expansion valve and re-entered the chiller to complete the cycle. Figure 26 illustrates this basic thermodynamic cycle on a pressure-enthalpy diagram (WT, 2011, p. 2267).

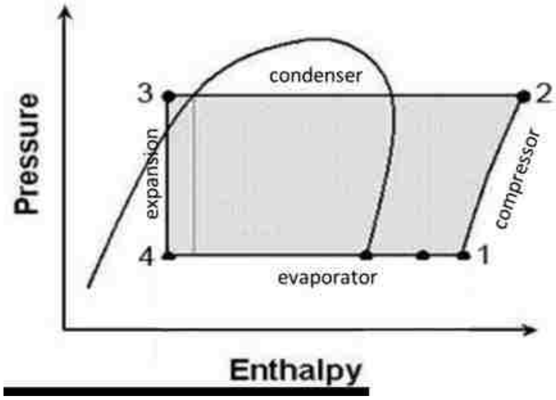


Figure 26. Smardt Chiller R-134a Pressure-Enthalpy Diagram.

The two Marley NC8401KAN cooling towers were located adjacent to the central chiller plant. The towers were combined into a single housing and operated as one unit. Water from the central plant condenser entered the top of the towers at approximately 95 deg F at 375 gallons per minute (gpm). Heat transfer occurred through evaporation to the counter air flow induced by two axial fans located at the top of the towers. Optimum air flow was 47,600 cubic feet per minute (cfm) per fan, and fan speed was controlled by variable frequency drives (VFD). Cooling water back to the condenser was supplied at approximately 85 deg F, depending on entering air wet-bulb temperature to the cooling towers. The two Paco 40707 vertical, in-line condenser water pumps were housed inside the central chiller plant, one for each chiller. Make-up condenser cooling water was provided, as required. The towers included basin heaters for outside air temperature (OAT) below 35 deg F, automatic leveling controls, and VRTX hydrodynamic cavitation treatment systems to reduce scale and corrosion build-up (MSA, 2011a).

Three Paco 20121 vertical, in-line, insulated pumps were housed in the central chiller plant for pumping the 42 deg F chilled water from the central plant to the LCROGB AHUs. Each chiller required one pump, and one stand-by pump was also integrated into the system. The chilled water was pumped through underground piping, then up to the AHUs at approximately 187 gpm (MSA, 2011a).

Chiller plant data recorded by the BMS during August, 2013, are shown in Figure 27. During occupancy on August 22 and 23, the chilled water supplied to the AHUs averaged 47 deg F, but was much closer to the designed 42 deg F over the weekend and into the next week. USBR representatives indicated adjustments were made being made to the system to accommodate for Building 100 and 200 loads on the system. The return water temperature was continually higher than the design temperature of 58 deg F, with an average value of 63 deg F during operation on August 26. Figure 27 clearly shows the system going into unoccupied mode at 6:30 p.m. each evening and a building cool down period beginning each morning at 3:00 a.m. This pattern did not persist during the weekend period when the system would have remained in unoccupied mode. Detailed BMS data were not available to determine the weekend behavior of the chiller plant.

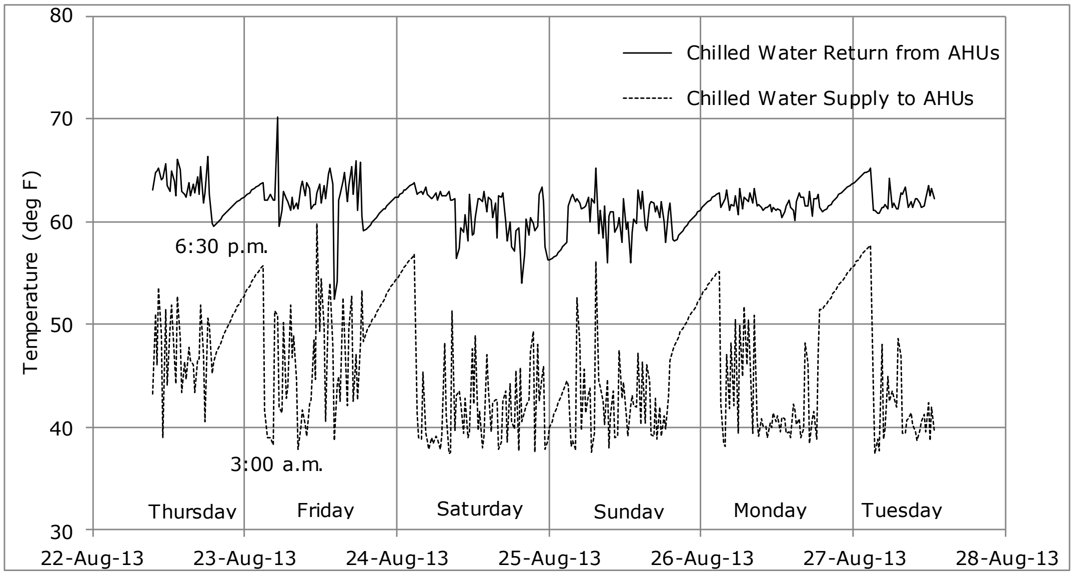
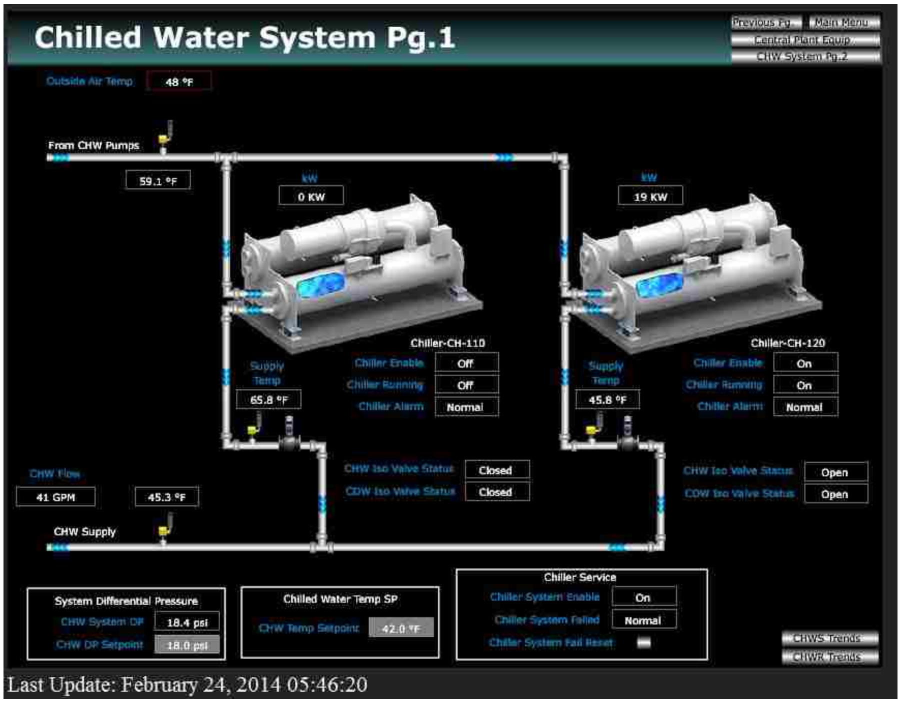


Figure 27. Chiller Plant Sample Data During August 2013.

Figures 28 and 29 show the BMS chiller plant pages. The first page shows the chilled water conditions with respect to the chillers, and the second page shows the chilled water pump and VFD conditions. These examples show the chiller plant operating in February, 2014 with OAT at 48 deg F. During this time, it was observed that AHU-2 had called for chilled water, even though the supply air temperature was 59 deg F. Detailed BMS data were not available to determine if this behavior was in accordance with the HVAC schedule of operations, and the observations were brought to the attention of USBR representatives for further investigation. Example BMS pages, were not available during summer months with high OAT.



Outside Air Temp: 48 °F

From CHW Pumps: 59.1 °F

	Chiller-CH-110	Chiller-CH-120
kW	0 KW	19 KW
Supply Temp	65.8 °F	45.8 °F
Chiller Enable	Off	On
Chiller Running	Off	On
Chiller Alarm	Normal	Normal
CHW Iso Valve Status	Closed	Open
CDW Iso Valve Status	Closed	Open

CHW Flow: 41 GPM

CHW Supply: 45.3 °F

System Differential Pressure

CHW System DP: 18.4 psi

CHW DP Setpoint: 18.0 psi

Chilled Water Temp SP

CHW Temp Setpoint: 42.0 °F

Chiller Service

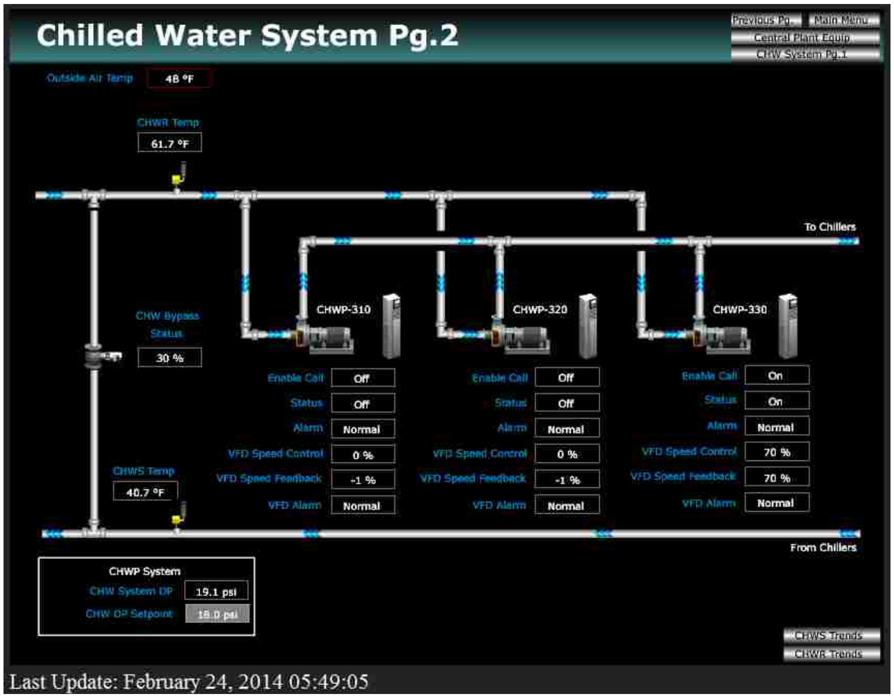
Chiller System Enable: On

Chiller System Failed: Normal

Chiller System Fail Reset

Last Update: February 24, 2014 05:46:20

Figure 28. BMS Chilled Water System Condenser Sample Page.



Outside Air Temp: 48 °F

CHWR Temp: 61.7 °F

CHW Bypass Status: 30 %

CHWS Temp: 40.7 °F

	CHWP-310	CHWP-320	CHWP-330
Enable Call	Off	Off	On
Status	Off	Off	On
Alarm	Normal	Normal	Normal
VFD Speed Control	0 %	0 %	70 %
VFD Speed Feedback	-1 %	-1 %	70 %
VFD Alarm	Normal	Normal	Normal

CHWP System

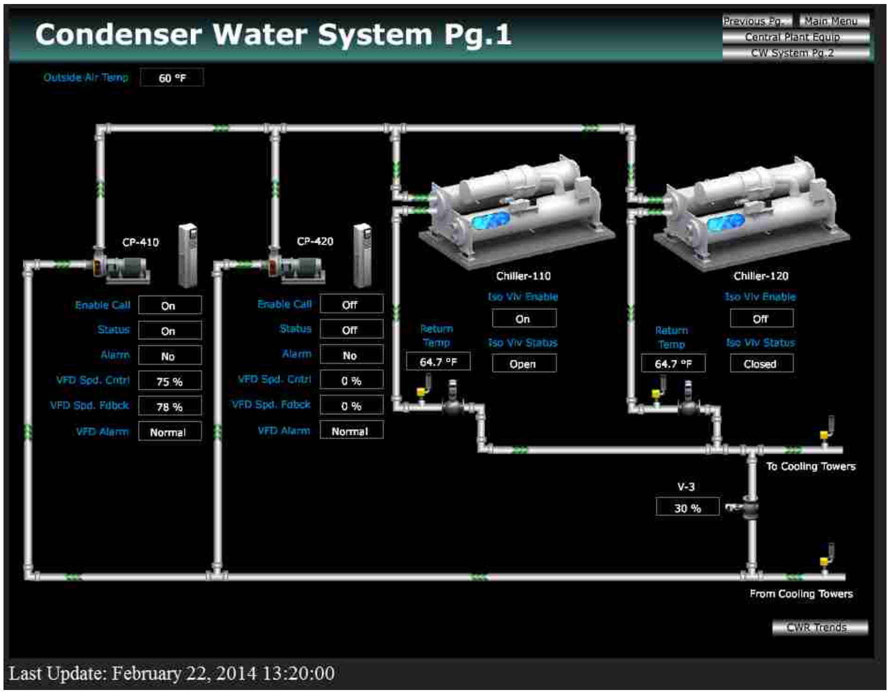
CHW System DP: 19.1 psi

CHW DP Setpoint: 18.0 psi

Last Update: February 24, 2014 05:49:05

Figure 29. BMS Chilled Water System Pump Sample Page.

Figures 30 and 31 show the condenser water side of the chiller plant. The first BMS condenser page provided the condenser, pump, and VFD conditions. Note the system was running due to AHU-2 calling for chilled water. The second page, shown in Figure 31, provided an overview of the cooling tower conditions. Cooling tower operation was not required at the time of this data capture due to the low condenser water temperature of 64.7 deg F.



Outside Air Temp: 60 °F

CP-410
Enable Call: On
Status: On
Alarm: No
VFD Spd. Cntrl: 75 %
VFD Spd. Fdbck: 78 %
VFD Alarm: Normal

CP-420
Enable Call: Off
Status: Off
Alarm: No
VFD Spd. Cntrl: 0 %
VFD Spd. Fdbck: 0 %
VFD Alarm: Normal

Chiller-110
Return Temp: 64.7 °F
Iso Vlv Enable: On
Iso Vlv Status: Open

Chiller-120
Return Temp: 64.7 °F
Iso Vlv Enable: Off
Iso Vlv Status: Closed

V-3: 30 %

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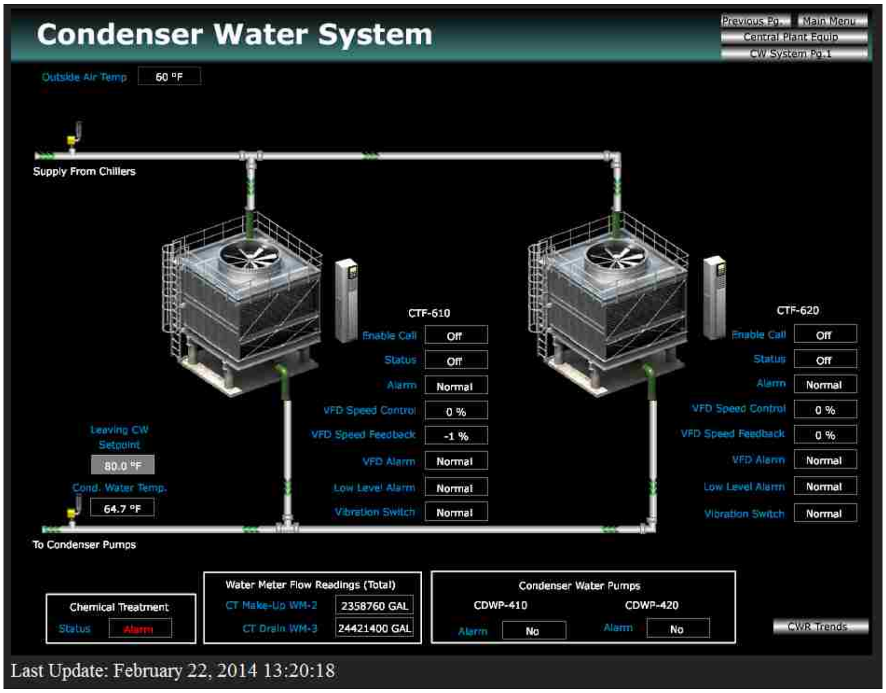
Figure 30. BMS Condenser Water System Sample Page.



Outside Air Temp: 60 °F

	CTF-610	CTF-620
Enable Call	Off	Off
Status	Off	Off
Alarm	Normal	Normal
VFD Speed Control	0 %	0 %
VFD Speed Feedback	-1 %	0 %
VFD Alarm	Normal	Normal
Low Level Alarm	Normal	Normal
Vibration Switch	Normal	Normal

Leaving CW Setpoint: 80.0 °F

Cond. Water Temp.: 64.7 °F

Chemical Treatment
Status: Alarm

Water Meter Flow Readings (Total)
CT Make-Up WM-2: 2358760 GAL
CT Drain WM-3: 24421400 GAL

Condenser Water Pumps
CDWP-410 Alarm: No
CDWP-420 Alarm: No

Last Update: February 22, 2014 13:20:18

Figure 31. BMS Cooling Tower Sample Page.

The two Trane “penthouse” AHUs, with ABS Systems, Inc. controls, were co-located on the roof of the LCROGB facility. A Trane TSCX50 AHU-1, shown in Figure 32 (Tincher, 2013), serviced only the first floor. A similar, but higher capacity Trane TSCX57 AHU-2 serviced the second floor of the LCROGB. With the raised ceilings on the second floor (reference Figure 4), designers determined this larger AHU-2 was required. Table 5 lists some of the specifications for these AHUs (MSA, 2011a).

Figure 32. AHU-1 Roof-Top Installation.

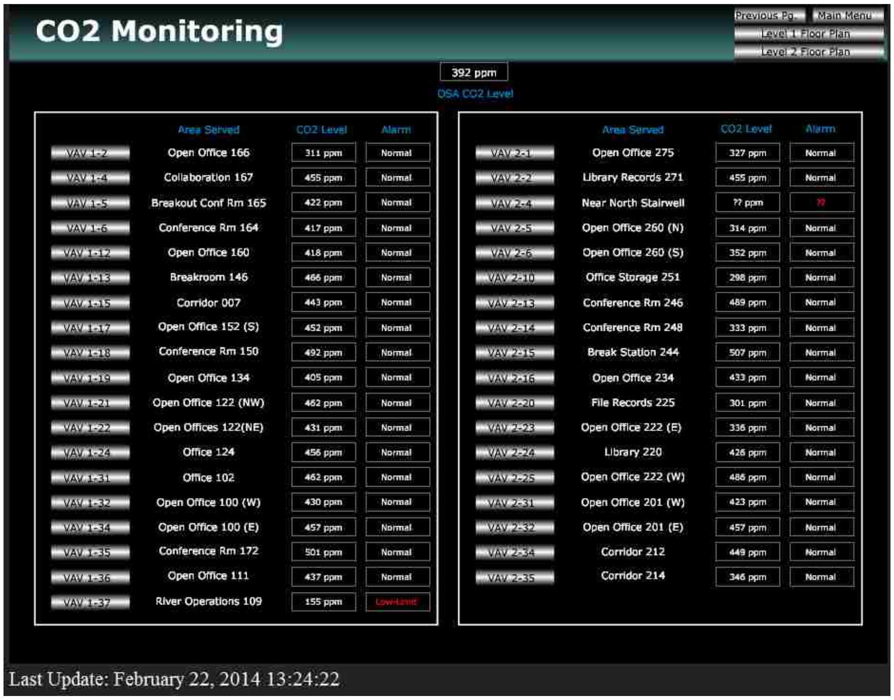
Table 5. Air Handling Unit (AHU) Specifications.

	Supply air capacity (cfm)	Supply air fan (hp)	Return air fan (hp)	Cooling coil water flow rate (gpm)	Heating coil water flow rate (gpm)
AHU-1	25,125	30	15	101	25
AHU-2	30,570	40	20	118	29

The supply and return air fans were VFD controlled and allowed the duct static pressure to remain at or slightly above 1.0 inch water column pressure to reduce infiltration within the building. The AHU exhaust dampers were also automatically modulated to maintain this positive pressure condition. The duct static pressure sensors were located approximately two-thirds of the way along the longest duct runs on each floor of the LCROGB (WT, 2011).

To reduce energy usage, each AHU was equipped with an air economizer that allowed outside air to be used for cooling the facility. The HVAC cooling mode was available when OAT was above 50 deg F. Sensors inside each AHU measured return air temperature (RAT), and an exterior sensor measured OAT. When the OAT dry bulb was less than the RAT dry bulb (cool outside air), the economizer function of each AHU modulated the outside air dampers and return air dampers to allow the cooler outside air to enter the AHUs. When the RAT was less than the OAT (warm outside air), the return air dampers were 100% open and the outside air dampers were closed or modulated for minimum required outside air flow.

The AHUs had demand ventilation control based on CO_2 sensors placed in 19 zones on the first floor and 18 zones on the second floor. During occupancy, when CO_2 levels increased, the outside air damper on each AHU was modulated to ensure CO_2 levels inside the building remained below the maximum 700 ppm set point. When indoor CO_2 levels remained low, and RAT was below OAT (warm outside air), the outside air dampers were 100% closed (WT, 2011). Figure 33 shows the BMS real-time monitoring capability for the 37 CO_2 sensors in the LCROGB.



392 ppm
OSA CO2 Level

	Area Served	CO2 Level	Alarm
VAV 1-2	Open Office 166	311 ppm	Normal
VAV 1-4	Collaboration 167	455 ppm	Normal
VAV 1-5	Breakout Conf Rm 165	422 ppm	Normal
VAV 1-6	Conference Rm 164	417 ppm	Normal
VAV 1-12	Open Office 160	418 ppm	Normal
VAV 1-13	Breakroom 146	466 ppm	Normal
VAV 1-15	Corridor 007	443 ppm	Normal
VAV 1-17	Open Office 152 (S)	452 ppm	Normal
VAV 1-18	Conference Rm 150	492 ppm	Normal
VAV 1-19	Open Office 134	405 ppm	Normal
VAV 1-21	Open Office 122 (NW)	462 ppm	Normal
VAV 1-22	Open Offices 122(NE)	431 ppm	Normal
VAV 1-24	Office 124	456 ppm	Normal
VAV 1-31	Office 102	462 ppm	Normal
VAV 1-32	Open Office 100 (W)	430 ppm	Normal
VAV 1-34	Open Office 100 (E)	457 ppm	Normal
VAV 1-35	Conference Rm 172	501 ppm	Normal
VAV 1-36	Open Office 111	437 ppm	Normal
VAV 1-37	River Operations 109	155 ppm	Low-Limit

	Area Served	CO2 Level	Alarm
VAV 2-1	Open Office 275	327 ppm	Normal
VAV 2-2	Library Records 271	455 ppm	Normal
VAV 2-4	Near North Stairwell	?? ppm	??
VAV 2-5	Open Office 260 (N)	314 ppm	Normal
VAV 2-6	Open Office 260 (S)	352 ppm	Normal
VAV 2-10	Office Storage 251	298 ppm	Normal
VAV 2-13	Conference Rm 246	489 ppm	Normal
VAV 2-14	Conference Rm 248	333 ppm	Normal
VAV 2-15	Break Station 244	507 ppm	Normal
VAV 2-16	Open Office 234	433 ppm	Normal
VAV 2-20	File Records 225	301 ppm	Normal
VAV 2-23	Open Office 222 (E)	336 ppm	Normal
VAV 2-24	Library 220	426 ppm	Normal
VAV 2-25	Open Office 222 (W)	486 ppm	Normal
VAV 2-31	Open Office 201 (W)	423 ppm	Normal
VAV 2-32	Open Office 201 (E)	457 ppm	Normal
VAV 2-34	Corridor 212	449 ppm	Normal
VAV 2-35	Corridor 214	346 ppm	Normal

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Figure 33. BMS CO_2 Monitoring Sample Page.

Figure 34 demonstrates the variation in CO_2 levels from four sensors during a two week period in February, 2014. The bottom line on the graph represents a large, open cubicle area that had been vacated during this entire time period and low CO_2 values were observed. The solid line represents the incoming outdoor air levels and the inherent fluctuation with weekly business activity and traffic in the Boulder City area is apparent. The top line on the graph represents a first floor conference room and spikes in the CO_2 levels were noted throughout the business days when the room was in use. As levels exceeded 700 ppm, outdoor air was brought into the room to bring air quality to acceptable levels of CO_2.

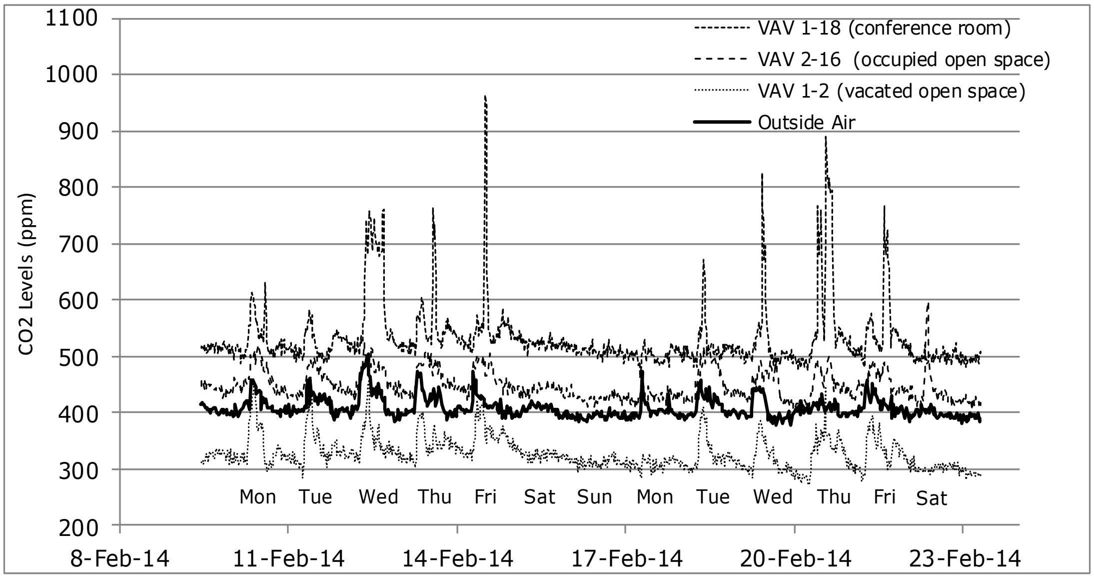


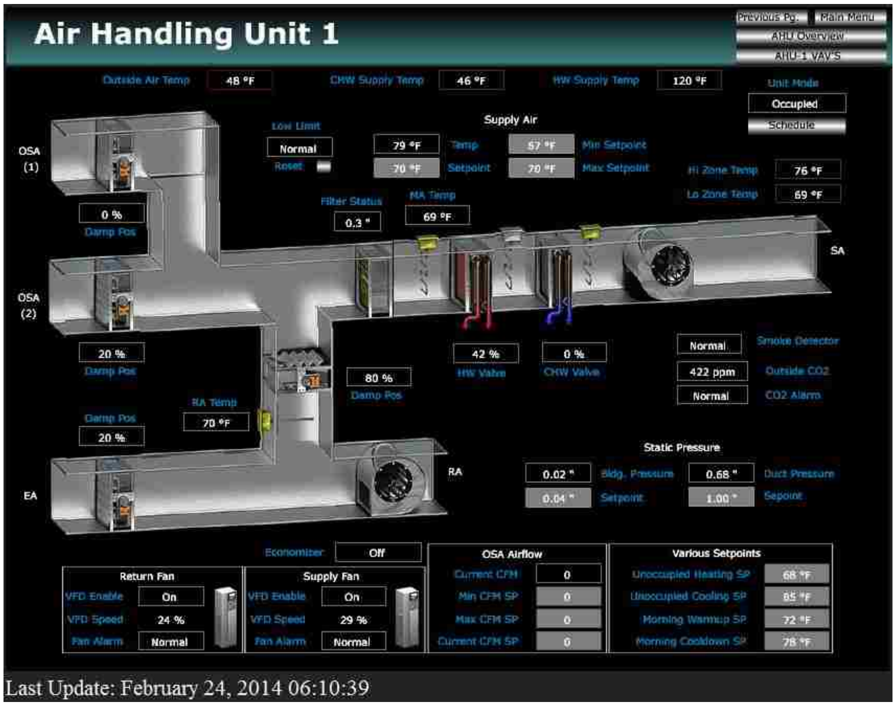
Figure 34. CO_2 Levels in Representative Rooms Versus Outside Air Levels.

During building occupancy (Monday through Friday from 6:00 a.m. to 6:30 p.m.), the adjustable supply air temperature (SAT) set point was 60 deg F when OAT was greater than 50 deg F (cooling mode). The SAT was measured inside each AHU by internal sensors. With an economizer on or off, if the SAT increased 2 deg F to 62 deg F for 5 minutes, the cooling coil water valve would modulate to maintain SAT at the set point. If the economizer was off and the SAT decreased 2 deg F to 58 deg F for 5 minutes, the heating coil water valve modulated to maintain SAT at the set point (WT, 2011).

When the building was unoccupied, the AHU supply fans were off, the outside and exhaust air dampers were closed, and the return air dampers were 100% open. If any of the facility interior zone sensors indicated temperatures greater than 85 deg F, the AHUs would begin cooling operations with a SAT set point of 60 deg F until all interior zone temperatures were below 80 deg F. The system would then go back into unoccupied mode. Similarly, if any interior zone temperature fell below 60 deg F, the AHUs would begin heating operation with a SAT set point of 85 deg F until the RAT reached 70 deg F. The system would then go back into unoccupied mode (WT, 2011).

Two minor variations in the design AHU sequence of operations were noted during system analysis and are listed below. These variations can be observed in Figure 35 showing sample BMS AHU-1 operating conditions:

- AHU-1 Supply Air Set Point: 70 deg F (vs 60 deg F)
- Unoccupied Heating Set Point (both AHUs): 68 deg F (vs 60 deg F)



Air Handling Unit 1

Outside Air Temp 48 °F
CHW Supply Temp 46 °F
HW Supply Temp 120 °F
Unit Mode Occupied
Low Limit Normal
Supply Air
Temp 79 °F
Setpoint 70 °F
Min Setpoint 57 °F
Max Setpoint 70 °F
Hi Zone Temp 76 °F
Lo Zone Temp 69 °F
Filter Status 0.3 "
MA Temp 69 °F
OSA (1) Damp Pos 0 %
OSA (2) Damp Pos 20 %
EA Damp Pos 20 %
RA Temp 70 °F
Damp Pos 80 %
HW Valve 42 %
CHW Valve 0 %
Smoke Detector Normal
Outside CO2 422 ppm
CO2 Alarm Normal
Static Pressure
Bldg. Pressure 0.02 "
Setpoint 0.04 "
Duct Pressure 0.68 "
Sepoint 1.00 "
Economizer Off

Return Fan
VFD Enable On
VFD Speed 24 %
Fan Alarm Normal

Supply Fan
VFD Enable On
VFD Speed 29 %
Fan Alarm Normal

OSA Airflow
Current CFM 0
Min CFM SP 0
Max CFM SP 0
Current CFM SP 0

Various Setpoints
Unoccupied Heating SP 68 °F
Unoccupied Cooling SP 85 °F
Morning Warmup SP 72 °F
Morning Cooldown SP 78 °F

Last Update: February 24, 2014 06:10:39

Figure 35. BMS AHU-1 Sample Page.

The HVAC heating mode was available when OAT was less than 75 deg F. Heating was provided by two Raypak XTherm H7-1005 natural gas boilers housed in a penthouse boiler room, adjacent to the AHUs. The boilers had a specified efficiency of 98%. Shown in Figure 36 (Tincher, 2013), the boilers operated through lead-lag sequencing, and each had a VFD-controlled Armstrong vertical, in-line pump with a 100 gpm capacity to pump the heated water to the AHU heating coils. When in heating mode, the boilers maintained heating water supply to the AHUs at 140 deg F. The boilers also provided heated water to the VAV system, discussed below, when reheat in zones was required (WT, 2011).

Figure 36. Raypak XTherm Boilers.

The coldest day observed during the winter of 2013-2014 occurred on February 2, 2014 when OAT reached 27 deg F. Figure 37 shows the boiler hot water supply to the AHUs during this period averaging 136 deg F, just below the hot water set point. Figure 38 shows the AHU-1 supply air to the first floor of the LCROGB oscillating around the 85 deg F set point over the cold weekend. As OAT increased on Monday and the building became occupied, supply air was no longer needed at 85 deg F to maintain room temperatures, and the supply air temperature dropped to below the 70 deg F set point. With cool overnight temperatures and prior to weekday occupancy, heated supply air was provided in the early morning hours during the weekdays shown. A sample BMS boiler system page is shown in Figure 39.

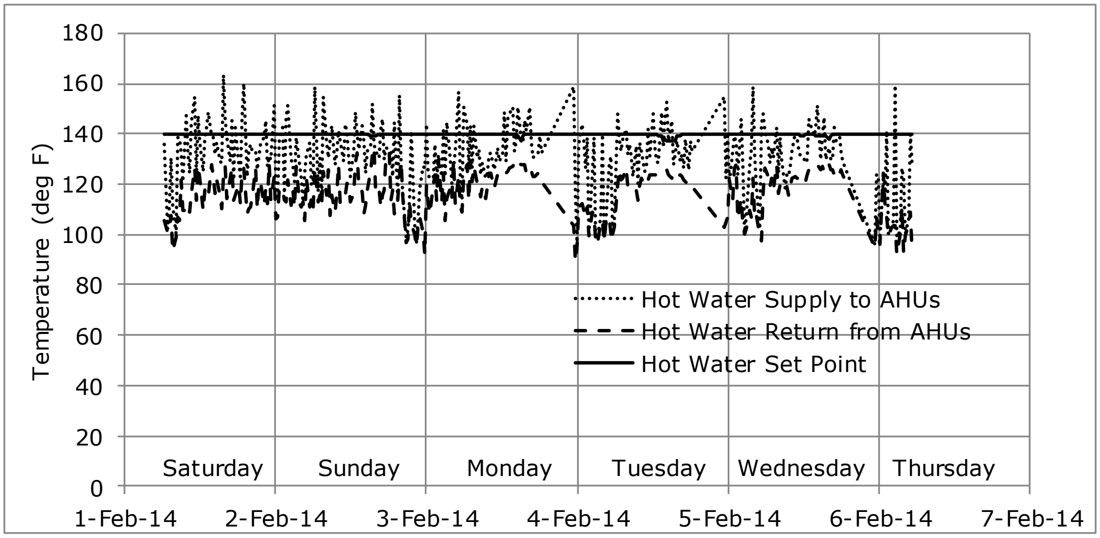


Figure 37. Boiler Activity During Cold Outside Temperatures.

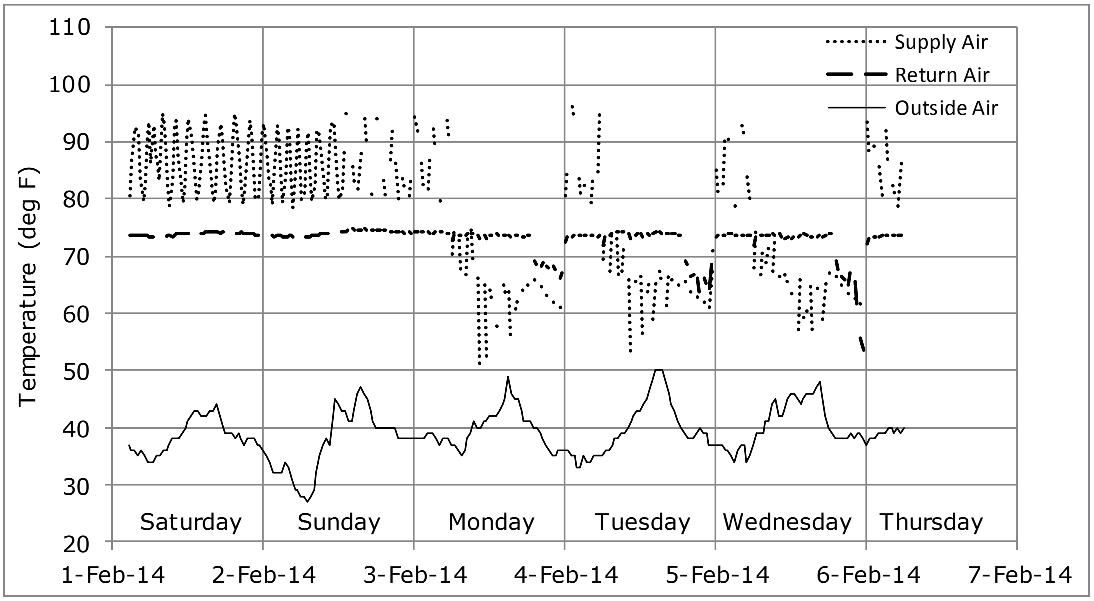
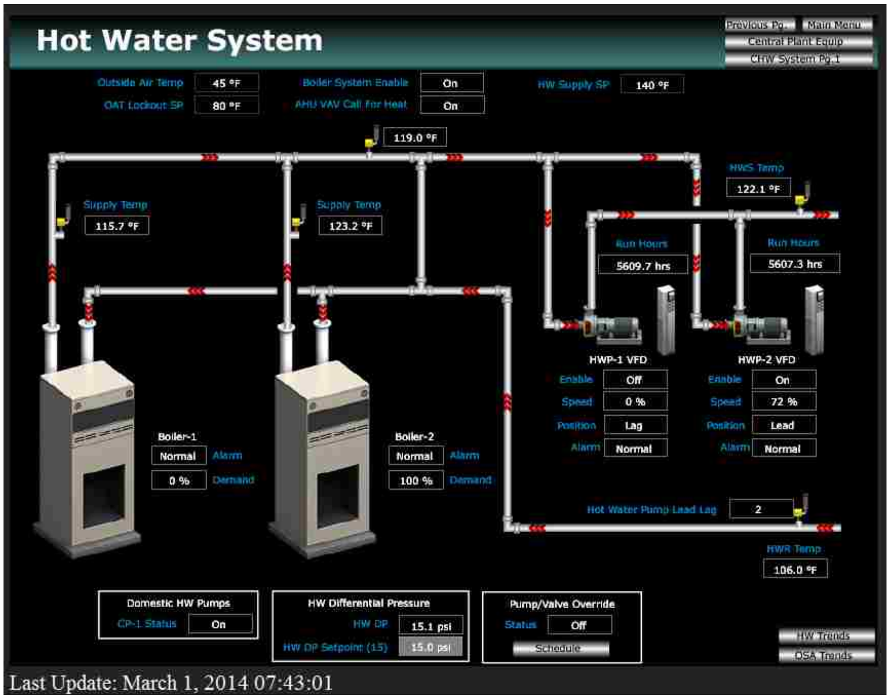


Figure 38. AHU-1 Air Temperatures During Cold Outside Temperatures.



Outside Air Temp 45 °F
OAT Lockout SP 80 °F
Boiler System Enable On
AHU VAV Call For Heat On
HW Supply SP 140 °F
119.0 °F
HWS Temp 122.1 °F
Supply Temp 115.7 °F
Supply Temp 123.2 °F
Run Hours 5609.7 hrs
Run Hours 5607.3 hrs
HWP-1 VFD: Enable Off; Speed 0 %; Position Lag; Alarm Normal
HWP-2 VFD: Enable On; Speed 72 %; Position Lead; Alarm Normal
Boiler-1: Normal Alarm; 0 % Demand
Boiler-2: Normal Alarm; 100 % Demand
Hot Water Pump Lead Lag 2
HWR Temp 106.0 °F
Domestic HW Pumps: CP-1 Status On
HW Differential Pressure: HW DP 15.1 psi; HW DP Setpoint (15) 15.0 psi
Pump/Valve Override: Status Off
Last Update: March 1, 2014 07:43:01

Figure 39. BMS Boiler System Sample Page.

The AHU supply air, whether in cooling or heating mode, was managed with a VAV flow rate system. Here, the air flow rate to each zone in the building was modulated to control the local, interior zone temperatures. There were 75 VariTrane VAV devices installed in the LCROGB, with 39 on the first floor and 36 on the second floor. All included hydronic reheat coils with heating water provided by the HVAC boilers (MSA, 2011a, MP0.03). The purpose of the reheat coils was to warm the incoming cooling supply air from the AHUs for zones requiring heating while the HVAC was operating in cooling mode. When this condition occurred and individual reheat systems were activated, the individual VAV dampers automatically adjusted to a minimum flow position to minimize the volume of cooled air being heated. The VAV reheat coils could also operate during heating mode when supply air provided to any specific zone required additional heat.

Each VAV device had a thermostat and temperature sensor mounted 4 ft 2 in from the floor on the wall in the specified zones. All thermostats were designed to be automatically set to 75 deg F during occupancy, 85 deg F when unoccupied in cooling mode, and 60 deg F when unoccupied in heating mode. As noted under the AHU discussion, the unoccupied set point had been increased to 68 deg F. Figure 40 shows zone temperature for two offices on the north-east corners of the first and second floors during the cold weather period discussed previously. Office temperatures were maintained at approximately 68 deg F during unoccupied hours, and increased to approximately 73 deg F during occupancy.

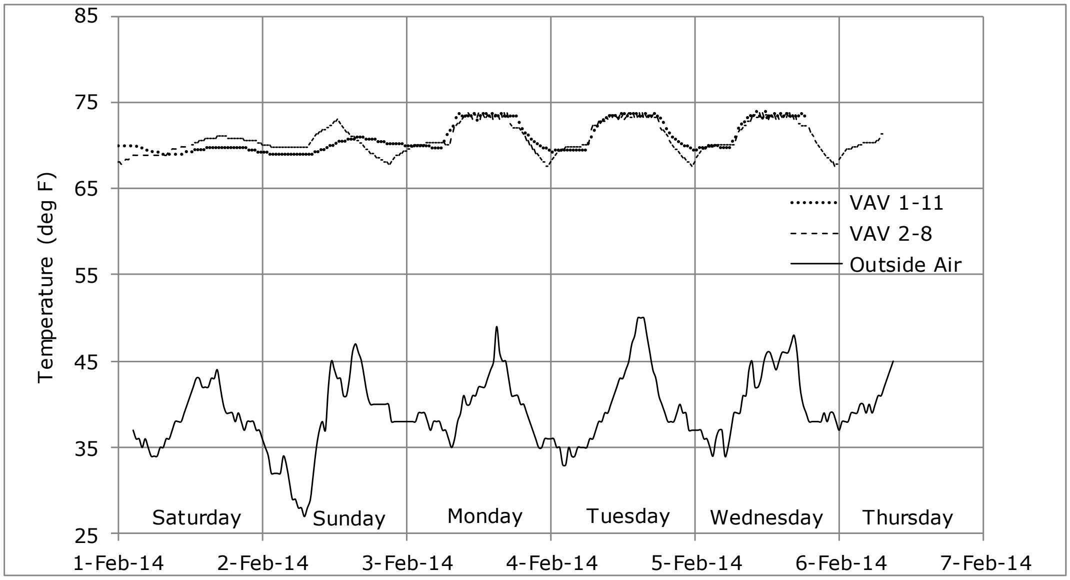
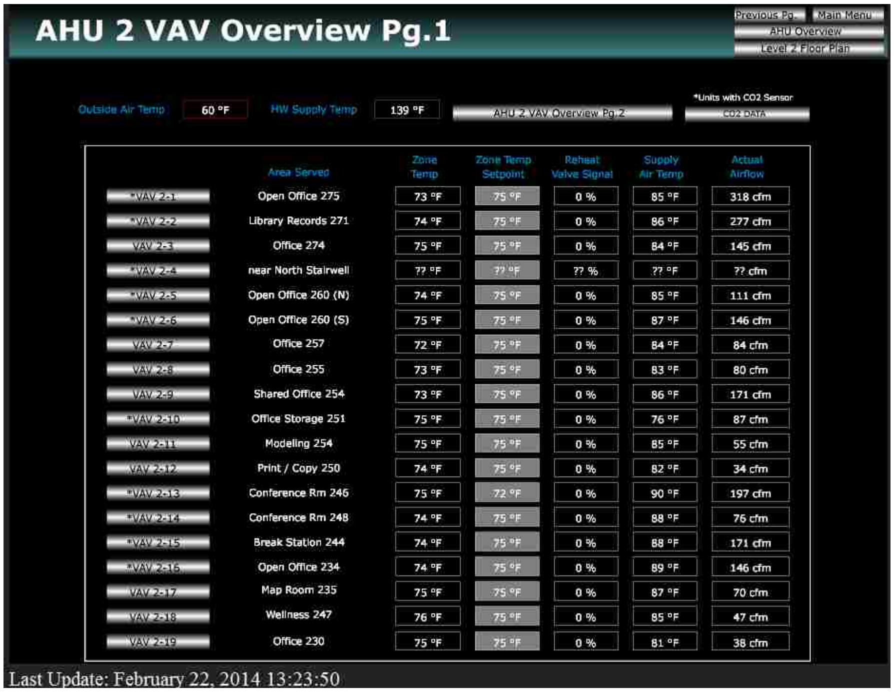


Figure 40. Zone Temperatures During Cold Outside Temperatures.

The zone thermostats were not adjustable by the building occupants, but set points could be adjusted through the BMS. A sample VAV overview page for AHU-2 is shown in Figure 41. Four of these overview pages were available; two for AHU-1 and two for AHU-2. Additionally, floor plans for the first and second floors could be viewed showing all real-time zone temperatures (not shown).

Individual VAVs could be selected from the overview screens, as shown in Figure 42. In both Figures 41 and 42, the system was in unoccupied mode with a zone temperature set point of 68 deg F. In Figure 41 the zone temperature set point displayed by the BMS was 75 deg F for VAV 2-16, while in Figure 42 it was 68 deg F. This discrepancy was not resolved at the time of this evaluation. Information regarding the individual VAV devices, including air flow rates, reheat coil flow rates, locations, and related temperature and CO_2 sensor locations, are included in Appendix D (MSA, 2011a).



AHU 2 VAV Overview Pg.1

Outside Air Temp 60 °F

HW Supply Temp 139 °F

*Units with CO2 Sensor

	Area Served	Zone Temp	Zone Temp Setpoint	Reheat Valve Signal	Supply Air Temp	Actual Airflow
*VAV 2-1	Open Office 275	73 °F	75 °F	0 %	85 °F	318 cfm
*VAV 2-2	Library Records 271	74 °F	75 °F	0 %	86 °F	277 cfm
VAV 2-3	Office 274	75 °F	75 °F	0 %	84 °F	145 cfm
*VAV 2-4	near North Stairwell	?? °F	?? °F	?? %	?? °F	?? cfm
*VAV 2-5	Open Office 260 (N)	74 °F	75 °F	0 %	85 °F	111 cfm
*VAV 2-6	Open Office 260 (S)	75 °F	75 °F	0 %	87 °F	146 cfm
VAV 2-7	Office 257	72 °F	75 °F	0 %	84 °F	84 cfm
VAV 2-8	Office 255	73 °F	75 °F	0 %	83 °F	80 cfm
VAV 2-9	Shared Office 254	73 °F	75 °F	0 %	86 °F	171 cfm
*VAV 2-10	Office Storage 251	75 °F	75 °F	0 %	76 °F	87 cfm
VAV 2-11	Modeling 254	75 °F	75 °F	0 %	85 °F	55 cfm
VAV 2-12	Print / Copy 250	74 °F	75 °F	0 %	82 °F	34 cfm
*VAV 2-13	Conference Rm 246	75 °F	72 °F	0 %	90 °F	197 cfm
*VAV 2-14	Conference Rm 248	74 °F	75 °F	0 %	88 °F	76 cfm
*VAV 2-15	Break Station 244	74 °F	75 °F	0 %	88 °F	171 cfm
*VAV 2-16	Open Office 234	74 °F	75 °F	0 %	89 °F	146 cfm
VAV 2-17	Map Room 235	75 °F	75 °F	0 %	87 °F	70 cfm
VAV 2-18	Wellness 247	76 °F	75 °F	0 %	85 °F	47 cfm
VAV 2-19	Office 230	75 °F	75 °F	0 %	81 °F	38 cfm

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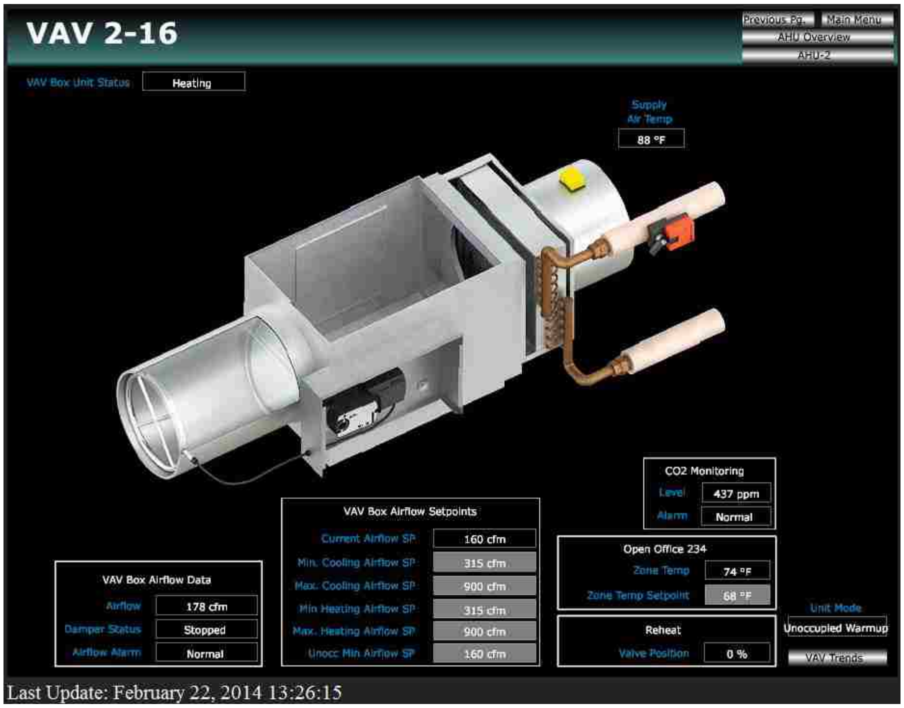
Figure 41. BMS Variable Air Volume Overview Sample Page.



VAV 2-16

VAV Box Unit Status: Heating

Supply Air Temp: 88 °F

CO2 Monitoring
Level: 437 ppm
Alarm: Normal

VAV Box Airflow Setpoints
Current Airflow SP: 160 cfm
Min. Cooling Airflow SP: 315 cfm
Max. Cooling Airflow SP: 900 cfm
Min Heating Airflow SP: 315 cfm
Max. Heating Airflow SP: 900 cfm
Unocc Min Airflow SP: 160 cfm

VAV Box Airflow Data
Airflow: 178 cfm
Damper Status: Stopped
Airflow Alarm: Normal

Open Office 234
Zone Temp: 74 °F
Zone Temp Setpoint: 68 °F

Reheat
Valve Position: 0 %

Unit Mode: Unoccupied Warmup

Last Update: February 22, 2014 13:26:15

Figure 42. BMS Individual Variable Air Volume Sample Page.

The HVAC system for the LCROGB also included six Acme exhaust fans that operated during building occupancy and on Saturdays, as scheduled through the BMS. Figure 43 shows the BMS exhaust fan page which included the fan locations. The combined exhaust fans had an estimated power requirement of 0.8kW during peak use (MSA, 2011b).

2011c).

Outside Air Temp: 60 °F

	Location / Area Served	Fan Enable	Fan Status	Ckt #
EF-1	2nd Floor File/Copy Rooms	On	On	MPL1-1
EF-2	2nd Floor Restrooms and Cust	On	On	MPL1-3
EF-3	1st Floor Breakroom	On	On	MPL1-5
EF-4	1st floor Restrooms and Cust	On	On	MPL1-7
EF-5	Print/File Rm 171	On	On	MPL1-9
EF-6	Print/Copy Rm 136	On	On	MPL1-11
EF-7	Mech. Yard Boiler Room	N/A	Off	CPL1-3

Last Update: February 22, 2014 13:33:35

Figure 43. BMS Exhaust Fan Sample Page.

For improved air quality in six miscellaneous areas, including closets that housed various support equipment for the facility, eight IEC International Environmental fan coils, independent of the primary HVAC system, were installed. The LCROGB designers estimated the combined capacity of these fans to be 4.4 tons or 15.5 kW (MSA, n.d.).

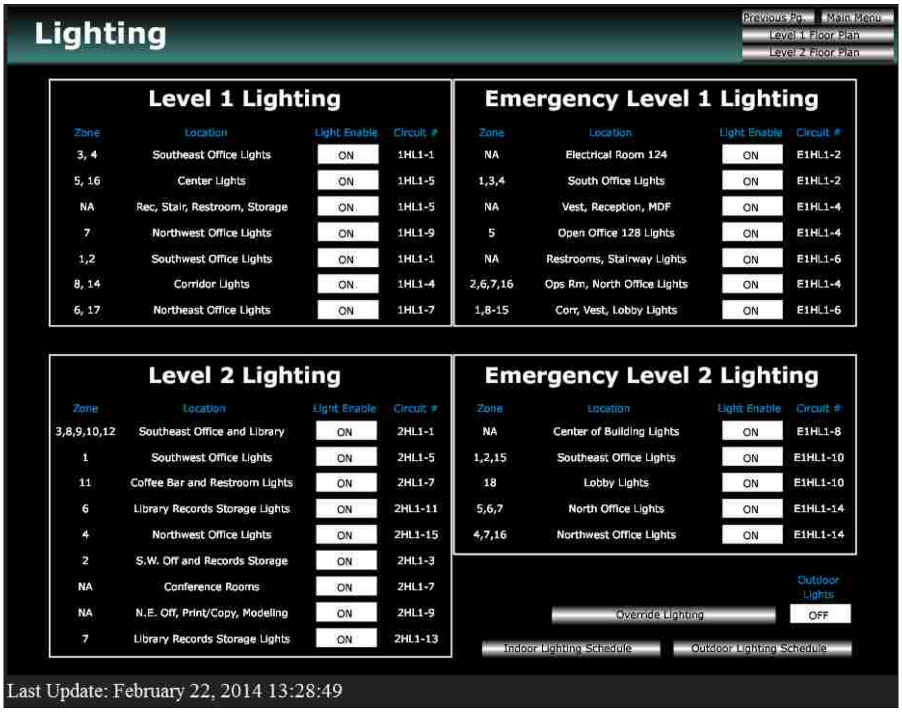
Lighting, Receptacle Loads, and Additional Loads

Fluorescent lighting was provided throughout the LCROGB, and lighting was controlled through the BMS, automatic occupancy sensors, and manual switches. Though the LCROGB had considerable daylighting through vertical windows and skylights, powered lighting did provide a sizable load toward the overall energy usage. Table 6 lists the designed indoor and outdoor lighting loads for the facility (MSA, 2011c).

Several types of lights were used including troffers (rectangular fixtures in dropped ceiling grids), down lights, strip lights, linear lights, wall sconces, and pendant or hanging lights. A ballast factor was included by the designers and is included in Table 6. This factor indicated the fractional flux of the actual fluorescent lamp when compared to use of a reference ballast. Most of the exterior lighting was solar powered and did not significantly contribute to the energy usage. Only the small amount of exterior lighting that was not solar powered is included in Table 6. An example of the BMS lighting page is shown in Figure 44.

Table 6. Lighting Installations with Total Wattage.

Light Description (indoors, unless noted)	Number of Luminaires	Watts/ Luminaire	Ballast Factor	Total Watts
2- lamp, 28W, troffer	262	56	0.82	12031.04
1-lamp, 32W, down light	12	32	0.91	349.44
1-lamp, 28W, strip	14	28	0.82	321.44
2-lamp, 28W, linear	1660 linear ft	18W/ft	0.82	24501.60
1-lamp, 24W, wall sconce	33	24	0.82	649.44
1-lamp, 28W, wall sconce	14	28	0.82	321.44
1-lamp, 54W, wall sconce	12	54	0.82	531.36
2-lamp, 28W, wall sconce	12	56	0.82	551.04
6-lamp, 40W, pendant	6	240	0.91	1310.40
1-lamp, 32W, pendant	2	32	0.91	58.24
1-lamp, 28W, pendant	5	28	0.82	114.80
1-lamp, 250W, pendant	6	250	none	1500.00
1-lamp, 42W, exterior	15	42	none	630.00
Totals:	**393** + linear ft			**42870.24**
Interior Lighting/square footage				**0.848 W/sf**
Exterior Lighting/square footage				**0.013 W/sf**



Level 1 Lighting

Zone	Location	Light Enable	Circuit #
3, 4	Southeast Office Lights	ON	1HL1-1
5, 16	Center Lights	ON	1HL1-5
NA	Rec, Stair, Restroom, Storage	ON	1HL1-5
7	Northwest Office Lights	ON	1HL1-9
1,2	Southwest Office Lights	ON	1HL1-1
8, 14	Corridor Lights	ON	1HL1-4
6, 17	Northeast Office Lights	ON	1HL1-7

Emergency Level 1 Lighting

Zone	Location	Light Enable	Circuit #
NA	Electrical Room 124	ON	E1HL1-2
1,3,4	South Office Lights	ON	E1HL1-2
NA	Vest, Reception, MDF	ON	E1HL1-4
5	Open Office 128 Lights	ON	E1HL1-4
NA	Restrooms, Stairway Lights	ON	E1HL1-6
2,6,7,16	Ops Rm, North Office Lights	ON	E1HL1-4
1,8-15	Corr, Vest, Lobby Lights	ON	E1HL1-6

Level 2 Lighting

Zone	Location	Light Enable	Circuit #
3,8,9,10,12	Southeast Office and Library	ON	2HL1-1
1	Southwest Office Lights	ON	2HL1-5
11	Coffee Bar and Restroom Lights	ON	2HL1-7
6	Library Records Storage Lights	ON	2HL1-11
4	Northwest Office Lights	ON	2HL1-15
2	S.W. Off and Records Storage	ON	2HL1-3
NA	Conference Rooms	ON	2HL1-7
NA	N.E. Off, Print/Copy, Modeling	ON	2HL1-9
7	Library Records Storage Lights	ON	2HL1-13

Emergency Level 2 Lighting

Zone	Location	Light Enable	Circuit #
NA	Center of Building Lights	ON	E1HL1-8
1,2,15	Southeast Office Lights	ON	E1HL1-10
18	Lobby Lights	ON	E1HL1-10
5,6,7	North Office Lights	ON	E1HL1-14
4,7,16	Northwest Office Lights	ON	E1HL1-14

Outdoor Lights: OFF

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Figure 44. BMS Lighting Sample Page.

The designers estimated that receptacle equipment, including computers, would demand 36.9 kilowatts (kW) (MSA, n.d.). Post-occupancy, Hi-Saver motion sensing power strips were installed at all LCROGB work stations to reduce receptacle loads. These power strips were not considered in the original design estimates. To approximate the receptacle load per square foot of office space (73% of the total square footage), the following computation was done:

$$Receptacle\ \frac{Watts}{sf} = \frac{36900\ W}{(0.73 * 49818\ sf)} \sim 1.02W/sf$$

The elevator was estimated to contribute an additional demand of 25 kW. Water pumps for facility water, unrelated to the HVAC system, were estimated at an additional 1.0 kW. A designer-estimated, combined miscellaneous load per square foot of total building space was computed for the exhaust fans, fan coils, elevator, and water pumps as follows (MSA, n.d., 2011b):

$$Miscellaneous\,\frac{Watts}{sf} = \frac{(800 + 15500 + 25000 + 1000)}{49818\,sf} \sim 0.85\,W/sf$$

Solar Photovoltaic (PV) Array

Located at the Date Street Complex, just north of the LCROGB, the USBR solar installation was developed in two phases. The first installation included 588 – 230 W panels (135.24 kW) with an estimated annual production of 240,050 kWh. The second installation included 588 – 240 W panels (141.12 kW) with an estimated annual energy production of 250,487 kWh (USBR personal communication, November 12, 2013). Combined, the solar field was anticipated to generate 490,537 kWh annually with an average 41,000 kWh per month.

The solar installations began providing power to the Date Street Complex in November 2011 and October 2012, respectively, with excess energy going to the local electrical grid (USBR personal communication, November 12, 2013). Only the first phase of the solar installation was considered for LCROGB LEED energy efficiency points, as the second solar phase was designed and installed after LEED accreditation was achieved. 100% of the first phase of the solar installation capability (240,050 kWh/yr) was considered as an offset to the LCROGB total energy usage for LEED Energy and Atmosphere credits (EA Prerequisite 2, 2012).

To evaluate the solar energy generation, the “10600_Reporting_TotalSolar _Made” parameter was evaluated from the BMS archived data. Monthly solar energy generation was computed by finding the difference between monthly totals. Computed solar energy generation since both installations were operating is shown in Figure 45. The Date Street Complex monthly electrical bills were also reviewed, and electrical solar credits were provided in January through April 2013 only, as also shown in Figure 45. The decline in solar energy generation after April 2013 and the lack of utility bill solar credits was brought to the attention of USBR representatives for further investigation.

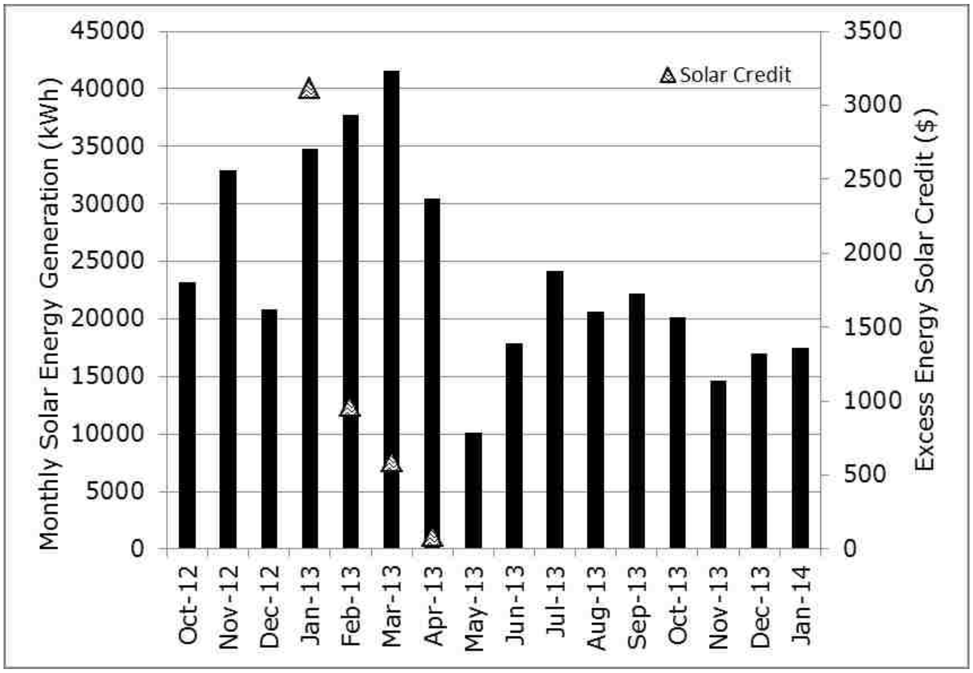


Figure 45. Date Street Complex Monthly Solar Energy Data.

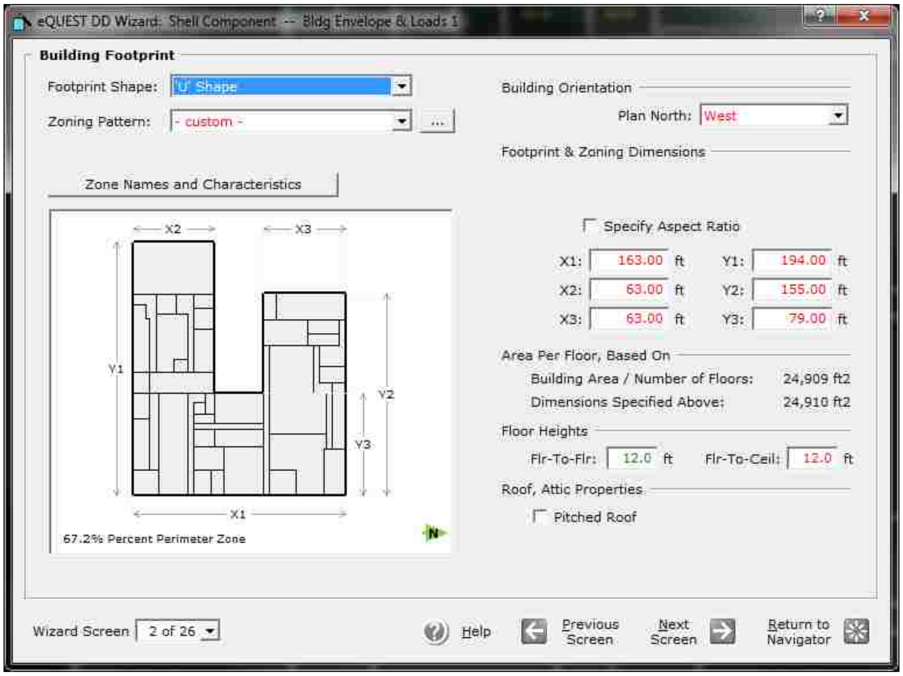
Building Energy Simulation

To earn LEED Energy and Atmosphere Credit 1 points, a 12% to 48% reduction in overall energy usage had to be demonstrated using a whole building energy simulation. The LCROGB design team demonstrated a 65.72% energy cost savings when comparing the baseline and proposed building designs (EA Credit 1, n.d.). This earned the project 19 energy efficiency points toward LEED certification, the maximum number possible. The whole building simulation was performed by MSA Engineering Consultants using the HAP Version 4.5 software (M&V Plan, 2011). The basic inputs to the HAP software and assumptions made by MSA representatives for the baseline and proposed simulations were provided to this author by USBR representatives. HAP simulations were based on the guidelines from ASHRAE 90.1 Appendix G (MSA, n.d.). A summation of the applicable ASHRAE 90.1-2007 Appendix G guidelines, as related to this study, is listed in Appendix E.

The whole building energy simulation used for this study was eQUEST, Version 3.65. This free software package provided GUIs through two basic wizards: Schematic Design and Design Development (Hirsch, 2010). The former was applicable to simple designs that included only one building envelope or shell and provided only two HVAC systems to choose from. The latter was a much more robust interface that allowed multiple shells and provided numerous HVAC systems to choose from. The Design Development wizard was used for this study.

The objective of the eQUEST simulations was to first attempt to replicate the HAP simulation energy usage results used for LCROGB LEED certification. Both a baseline and proposed simulation were developed using the HAP inputs and assumptions as nearly as possible. These two models are referenced as “eQUEST Baseline” and “eQUEST Proposed”. Secondly, the baseline and proposed eQUEST simulations were modified using details regarding final building construction and actual system operations discovered during this study. These two models are referenced as “Final eQUEST Baseline” and “Final eQUEST Proposed”. The inputs and results of the HAP and eQUEST simulations, along with comparisons to actual energy usage, will be presented later in this chapter.

To build the LCROGB simulations in eQUEST, the two floors of the building were modeled separately, and then stacked on top of each other. This allowed the zones, HVAC details, and building envelopes to vary by floor. Not all 75 zones were defined in the eQUEST simulation, but rather zones by type were grouped together. For example, offices on the same perimeter wall that actually represented several zones were grouped together to form one zone. The first and second floor dimensions and zones, as defined for all eQUEST simulations presented in this study, are shown in Figures 46 through 48. The zone descriptions provided in Appendix D can be cross-referenced to the zone names listed in Figures 47 and 48 by VAV number to eQUEST space number.


eQUEST DD Wizard: Shell Component -- Bldg Envelope & Loads 1

Building Footprint

Footprint Shape: 'U' Shape
Zoning Pattern: - custom -

Building Orientation
Plan North: West

Footprint & Zoning Dimensions
☐ Specify Aspect Ratio

X1:	163.00	ft	Y1:	194.00	ft
X2:	63.00	ft	Y2:	155.00	ft
X3:	63.00	ft	Y3:	79.00	ft

Area Per Floor, Based On
Building Area / Number of Floors: 24,909 ft2
Dimensions Specified Above: 24,910 ft2

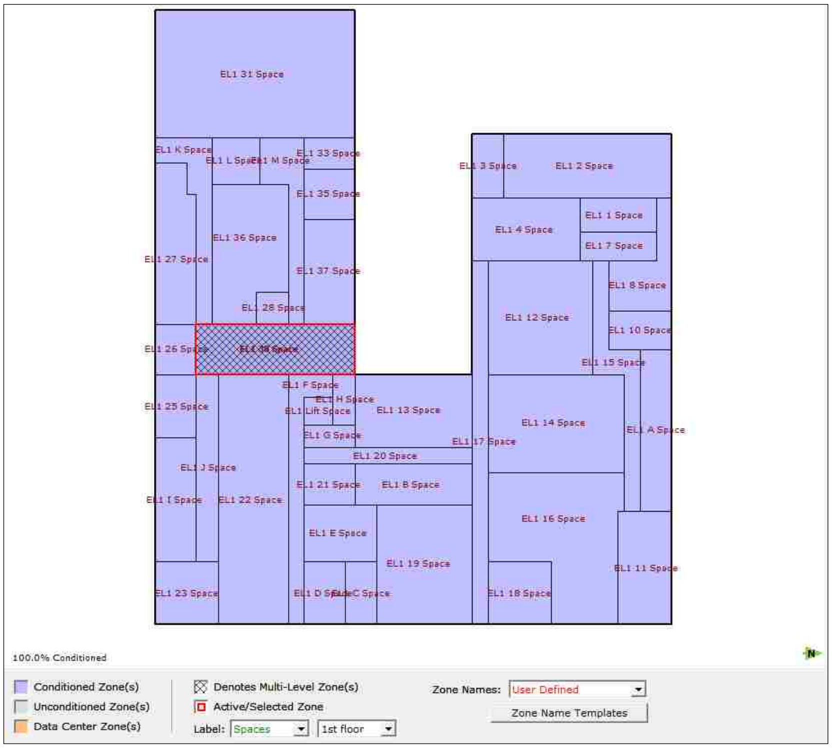
Floor Heights
Flr-To-Flr: 12.0 ft
Flr-To-Ceil: 12.0 ft

Roof, Attic Properties
☐ Pitched Roof

67.2% Percent Perimeter Zone

Wizard Screen 2 of 26

Figure 46. eQUEST LCROGB Envelope Dimensions.



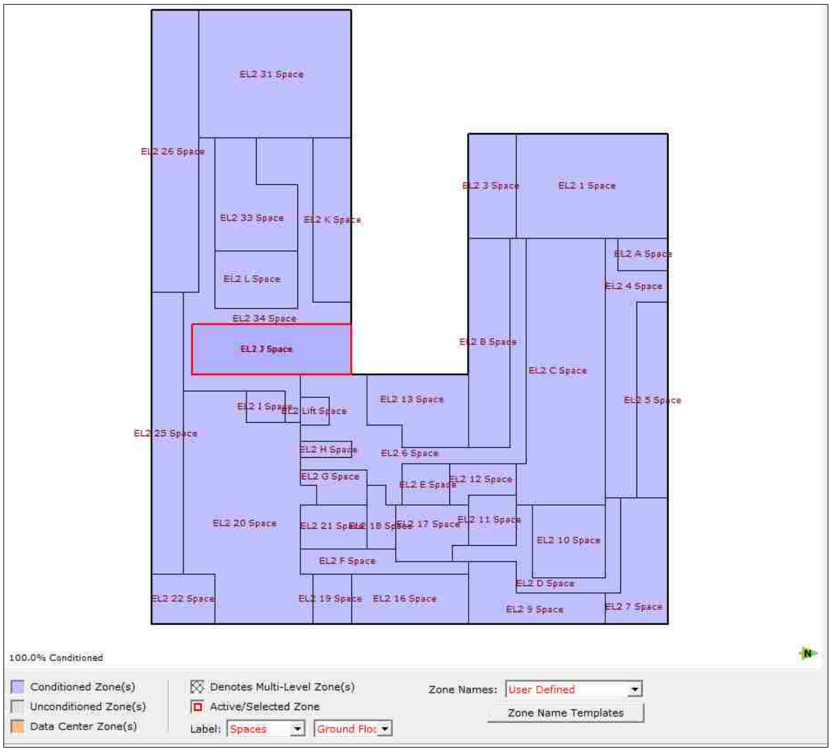
100.0% Conditioned

Zone Names: User Defined

Label: Spaces

1st floor

Figure 47. eQUEST LCROGB First Floor Zones.



100.0% Conditioned

Zone Names: User Defined

Label: Spaces

Ground Floc

Figure 48. eQUEST LCROGB Second Floor Zones.

The inputs to the eQUEST and HAP simulations are listed in Table 7. The eQUEST inputs were aligned as closely as possible to the HAP inputs, however, limitations on the choices available through the eQUEST GUIs restricted selections. For example, R-19 roof insulation was selectable, rather than R-20. The effect of this specific variance was considered negligible. Other variations are discussed later in this report. The Final eQUEST Baseline and Proposed simulations, also listed in Table 7, took into account actual building conditions, including orientation to due north, HVAC set points, as-built lighting information, and computed energy costs based on actual utility bills.

eQUEST allowed users to navigate beyond the GUI provided into a detailed interface and modify specific entries used by the program. However, if changes were then made using the GUIs, the program warned that modifications made in the detailed interface would be lost. Due to the numerous variations simulated using eQUEST, and the ease of managing these variations using the GUIs, the detailed interface was not used during this study.

Simulated HVAC system guidelines were provided in ASHRAE 90.1 Appendix G, Tables G3.1.1A and G3.1.1B. For non-residential buildings with less than 5 floors, ranging from 25,000 sf to 150,000 sf, and using fossil fuels, a “System 5 – Package VAV with Reheat”, direct expansion cooling, and hot-water gas boiler was to be simulated in the baseline models. The LCROGB designed HVAC system, simulated in the proposed HAP and eQUEST models, was defined by ASHRAE 90.1 Appendix G as a “System 7 – VAV with Reheat”, chilled water cooling, and hot-water gas boiler (ANSI/ASHRAE/IESNA, 2007).

Table 7. Inputs to Whole Building Energy Simulations.

	HAP Baseline	eQUEST Baseline	HAP Proposed	eQUEST Proposed	Final eQUEST Baseline	Final eQUEST Proposed
Occupancy[a]	6am-6pm	6am-6pm	6am-6pm	6am-6pm	6am-6pm	6am-6pm
Orientation (deg)	0	0	0	0	~30 ccw	~30 ccw
Square Footage (sf)	48252	49818	48252	49818	49818	49818
Weather[b]	Las Vegas	Las Vegas	Las Vegas	Las Vegas	Las Vegas	Las Vegas
Electricity Rates ($/kWh)	0.1081	0.1081	0.1081	0.1081	0.1070[c]	0.1070[c]
Natural Gas Rates ($/therm)	0.6721	0.6721	0.6721	0.6721	0.7057[c]	0.7057[c]
Roof	Steel R-20	Steel R-19	Combo steel/concrete R-30	Steel R-30	Steel R-19	Steel R-30
Walls	Steel R-13 + R-3.8	Steel R-13 + R-1.3	Combo steel/concrete R-19	Steel R-19 + R-1.3	Steel R-13 + R-1.3	Steel R-19 + R-1.3
Windows (30% window-wall ratio)	U=0.6, SHGC=0.25	U=0.55, SHGC=0.76	U=0.41, SHGC=0.28 + light shelf	Low e3 (U=0.29, SHGC = 0.27) + light shelf	U=0.55, SHGC=0.76	Low e3 (U=0.29, SHGC = 0.27) + light shelf
Exterior Doors	Opaque	Opaque – steel	Opaque	Opaque – steel	Glass – alum frame	Low e3 glass – alum frame
Skylights	U=1.17, SHGC=0.81	Domed, acrylic	U=0.29, SHGC=0.29	Flat, double acrylic	Domed, acrylic	Flat, double acrylic
Hot water heater (120 gal @ 135 deg F – 38 kBtuh)	η=80%	η=80%	η=98%	All solar	η=80%	All solar
Baseline Air-cooled HVAC #5[d] (per floor)	Cooling: 112 tons/2 = 56 tons (EER = 9.8) Heating: 876 kBtuh/2 =438 kBtuh (η=80%)	Cooling: 112 tons/2 = 56 tons (EER = 9.8) Heating: 876 kBtuh/2 =438 kBtuh (η=80%)			Cooling: 112 tons/2 = 56 tons (EER = 9.8) Heating: 876 kBtuh/2 =438 kBtuh (η=80%)	
Proposed Water-cooled HVAC #7[d] (per floor)			Cooling: 159 tons/2 = 79.5 tons (EER = 12-15) Heating: 1080 kBtuh/2 =540 kBtuh (η=96%)	Detailed inputs based on design[e]		Detailed inputs based on design[e]
Occupied Zone Set Point (deg F)	Cool:75 Heat: 70	Cool:75 Heat: 70	Cool:75 Heat: 70	Cool:75 Heat: 70	Cool:75 Heat: 75	Cool:75 Heat: 75
Unoccupied Zone Set Point (deg F)	Cool:85 Heat: 60	Cool:85 Heat: 60	Cool:85 Heat: 60	Cool:85 Heat: 60	Cool:75 Heat: 68	Cool:75 Heat: 68
Supply Air Set Point (deg F)	Cool:60 Heat: 85	Cool:60 Heat: 85	Cool:60 Heat: 85	Cool:60 Heat: 85	Cool:AHU-1 70/AHU-2 60 Heat: 85	Cool:AHU-1 70/AHU-2 60 Heat: 85
Economizer OAT Range (deg F)			55-75	55-75		55-75
Boiler Supply Water Set Point (deg F)	140	140	140	140	140	140
Interior Lighting (W/sf)	0.98	0.98	0.79	0.79 w/ dimming	0.98	0.848[f] w/ dimming
Exterior Lighting (W/sf)	0.24	0.24	0.024	0.024	0.24	0.013[f]
Receptacle Loads (W/sf)	1.02	1.02	1.02	1.02	1.02	1.02
Miscellaneous Loads (W/sf)	0.85	0.85	0.85	0.85	0.85	0.85

[a] Actual operating hours extended to 6:30 p.m., but only whole hour increments were available in simulations

[b] Boulder City, Nevada weather data were not available for either simulation

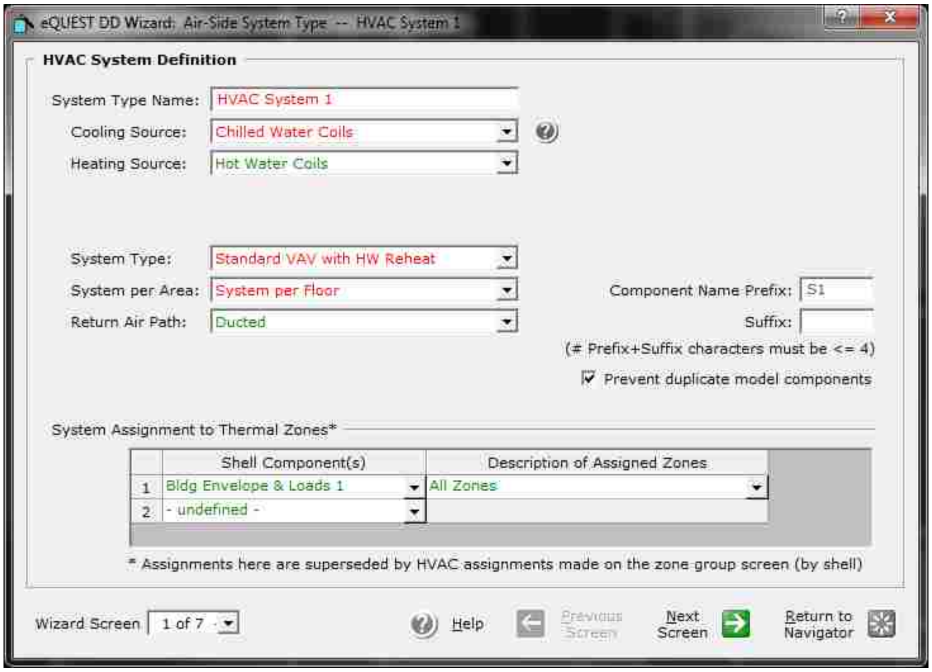
[c] Based on evaluation of actual utility bills provided by USBR representatives

[d] Per ASHRAE 90.1-2007 Appendix G Tables G.3.1.1A and B

[e] Figures 49 through 54 provide details of eQUEST Proposed HVAC system inputs

[f] Based on Table 6 values

Figures 49 through 54 provide the detailed inputs for the eQUEST Proposed HVAC system based on design documents and HAP inputs (WT, 2011; MSA, n.d.).



HVAC System Definition

System Type Name: HVAC System 1
Cooling Source: Chilled Water Coils
Heating Source: Hot Water Coils

System Type: Standard VAV with HW Reheat
System per Area: System per Floor
Return Air Path: Ducted

Component Name Prefix: S1
Suffix:
(# Prefix+Suffix characters must be <= 4)
☑ Prevent duplicate model components

System Assignment to Thermal Zones*

	Shell Component(s)	Description of Assigned Zones
1	Bldg Envelope & Loads 1	All Zones
2	- undefined -	

* Assignments here are superseded by HVAC assignments made on the zone group screen (by shell)

Wizard Screen 1 of 7

Figure 49. eQUEST Proposed HVAC System Definition.

HVAC System Fans

System(s): 1: Standard VAV, HW Reheat
24,910 SqFt Served (67.2% perimeter)

Supply Fans

Power & Mtr Eff: 5.00 in. WG High
Fan Flow & OSA: Auto-size Flow (with 1.15 safety factor)
Fan Type: Variable Speed Drive

Return Fans

○ None ● Return ○ Relief

Power & Mtr Eff: 1.25 in. WG High
Fan Flow: Auto-size
Fan Type: Variable Speed Drive

Wizard Screen 4 of 7

Figure 50. eQUEST Proposed HVAC Fan Definition.

HVAC Zone Heating, Vent and Economizers

System(s): 1: Standard VAV, HW Reheat

Zone Heat Sources & Capacities / Delta T

Baseboards: - none -

Heat / Reheat: Hot Water 40.0 delta °F

Economizer(s) and Humidity Control

Type: Drybulb Temperature

High Limit: 75.0 °F DP Low Limit: °F

Humid. Type: - none - Max/Min: 100.0 % 0.0 %

Wizard Screen 6 of 7

Figure 51. eQUEST Proposed HVAC Heating and Economizer Definition.

Cooling Primary Equipment

Chilled Water System

CHW Loop: Head: 56.6 ft Design DT: 16.0 °F

Pump Configuration: Individual Chiller Pumps Only

CHW Loop Flow: Variable

Estimated CHW Load: 49,820 ft² Served x Size Factor: 1.20 / 400 ft2/ton = 149.5 tons.

Total Chiller Capacity by Type: Type 1: 250.0 tons Type 2: (none) = 250.0 tons.

Describe Up To 2 Chillers

	Chiller 1	Chiller 2
Chiller Type(s):	Electric Centrifugal Hermetic	- select another -
Condenser Type(s):	Water-Cooled	
Compressor(s):	Variable Speed	
Chiller Counts & Sizes:	2 Specify 125.0 ton	
Chiller Efficiency:	0.950 kW/ton	
Pump Head / Flow:	90.0 ft 187 gpm	
Pump Eff / Control:	High VSD	

Wizard Screen 1 of 3

Figure 52. eQUEST Proposed HVAC Cooling Equipment Definition.

Primary Equipment Heat Rejection

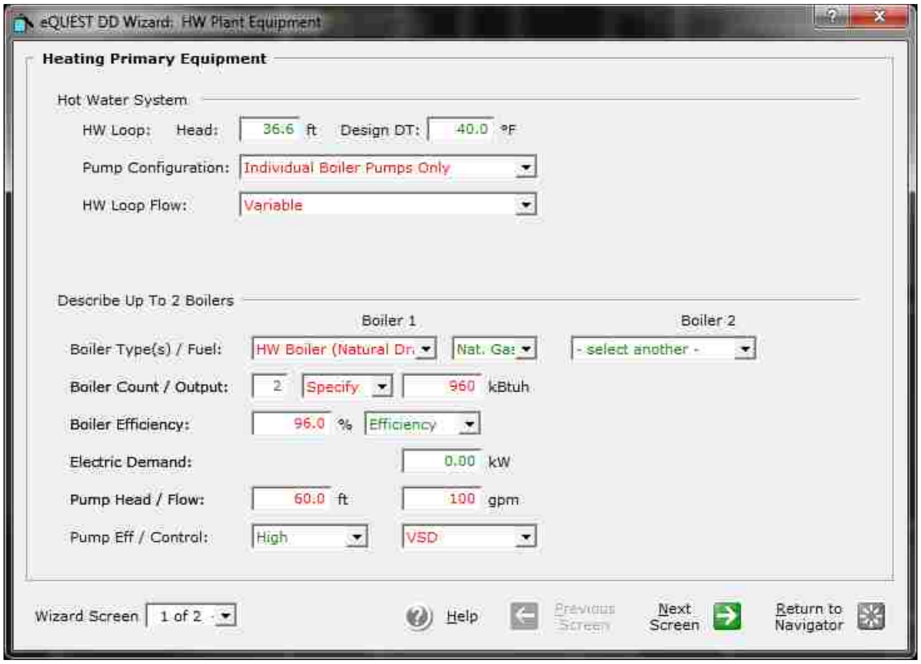
Water-Cooled Condenser / Cooling Tower

Cnd. Water Loop: Head: 61.6 ft Design DT: 10.0 °F
Condenser Pump: Head: 42.0 ft Flow: 375 gpm
Condenser Configuration: Open Tower
Temperature Control: Reset Min Temperature: 70.0 °F
Capacity Control: Variable Speed Fan
Fan Efficiency and Type: High Axial

☐ Water-Side Economizer

Wizard Screen 2 of 3

Figure 53. eQUEST Proposed HVAC Cooling Tower Definition.



Heating Primary Equipment

Hot Water System

HW Loop: Head: 36.6 ft Design DT: 40.0 °F
Pump Configuration: Individual Boiler Pumps Only
HW Loop Flow: Variable

Describe Up To 2 Boilers

	Boiler 1			Boiler 2
Boiler Type(s) / Fuel:	HW Boiler (Natural Dr	Nat. Ga:		- select another -
Boiler Count / Output:	2	Specify	960 kBtuh	
Boiler Efficiency:	96.0 %	Efficiency		
Electric Demand:			0.00 kW	
Pump Head / Flow:	60.0 ft		100 gpm	
Pump Eff / Control:	High		VSD	

Wizard Screen 1 of 2

Figure 54. eQUEST Proposed HVAC Heating Equipment Definition.

The results of the various simulations performed by both MSA Consulting Engineers using the HAP program (MSA, 2011d) and this author using the eQUEST program are provided in Table 8.

Table 8. HAP and eQUEST Simulation Results.

	HAP Baseline	eQUEST Baseline	HAP Proposed	eQUEST Proposed	Final eQUEST Baseline	Final eQUEST Proposed
ELECTRICAL (kWh/yr)						
Space cooling	145,973	291,500	58,273	123,030	440,400	158,090
Heat rejection			11,997	1,840		2,220
Pumps	7,890	200	27,282	20,880	100	31,600
Interior lighting	153,484	130,000	124,499	105,870	131,400	113,090
Exterior lighting	51,684	38,100	5,256	3,810	38,100	2070
Receptacles and Miscellaneous equipment[a]	350,796	288,900	261,895	281,090	288,900	281,090
GAS (therms/yr)						
Space heating	5,378	998	1,318	511	1,177	2,699
Domestic hot water	606	1,422	445	all solar	1,411	all solar
TOTAL ELECTRIC (kWh/yr)	709,827	748,700	489,202	536,520	898,900	588,160
TOTAL GAS (therms/yr)	5,984	2420	1,763	511	2,588	2,699
TOTAL GAS (kWh/yr)[b]	175,253	70,874	51,633	14,966	75,794	79,054
TOTAL ENERGY (kWh/yr)	885,080	819,574	540,835	551,486	974,694	667,214
ELECTRIC COST ($/yr) @ $.1081/kWh	76,732	80,934	52,883	57,998	96,182[c]	62,933[c]
GAS COST ($/yr) @ $0.6721/therm	4,022	1,626	1,185	343	1,826[d]	1,905[d]
TOTAL COST ($/yr)	80,754	82,560	54,068	58,341	98,008[c,d]	64,838[c,d]
ENERGY SAVINGS OVER BASELINE			38.9%	32.7%		31.5%
COST SAVINGS OVER BASELINE			33.0%	29.3%		33.8%

[a] Miscellaneous equipment includes exhaust fans, fan coils, elevator, and water pumps
[b] 1 kWh = 0.034145 therms (Glover, 1994)
[c] Using calculated actual rates of $0.1070/kWh from USBR utility bills
[d] Using calculated actual rates of $0.7057/therm from USBR utility bills

The eQUEST space cooling load was consistently and considerably higher than the HAP space cooling results. Alternatively, the loads due to HVAC pumps, lighting, and space heating were consistently lower when comparing the eQUEST results to

HAP. There were notable limitations to the way eQUEST simulations were developed, and this will be discussed in the next chapter. Understanding and comparing the detailed algorithms used in the HAP and eQUEST/DOE 2.2 programs was outside the scope of this study; therefore, and a true understanding of the drivers behind the differences between the results of these simulations was not pursued.

Of greater relevance to this study was the improvement to the overall energy consumption estimated by the proposed models when compared to the baseline models. Energy usage improvements of 38.9% and 32.7% over the ASHRAE 90.1 baseline were projected by HAP and eQUEST simulations, respectively. These savings were a result of improvements to the building envelope, lighting, and HVAC system. Similarly, the models estimated an average 31% reduction in energy costs with the more efficient building components.

For LEED accreditation, the expected energy generated by the first phase of the solar installation (240,050 kWh/yr) was allowed to be deducted from the LCROGB proposed energy usage, as follows:

$$\begin{aligned}&LEED\ energy\ efficiency\ improvement\\ &\qquad = 100 * (baseline - (proposed - solar))/baseline\end{aligned}$$

When this adjusted energy value was compared with the baseline model, total savings using HAP and eQUEST were 66% and 62%, respectively. Both were well above the 48% required by LEED certification to earn the maximum 19 points for energy efficiency in the Energy and Atmosphere category.

The EUIs for all simulations were also computed and are shown in Table 9. All three proposed model EUIs were below the medium energy usage building, median EUI of 62 kBtu/sf/yr and LEED gold/platinum building EUI of 51.2 kBtu/sf/yr, as computed by Turner and Frankel (2008). The LCROGB simulated EUIs were comparable to the median EUI of 42 kBtu/sf/yr demonstrated by LEED V2 buildings earning maximum energy efficiency points (Turner & Frankel, 2008).

Table 9. Simulation Energy Use Intensity (EUI) Comparisons.

	HAP Baseline	eQUEST Baseline	HAP Proposed	eQUEST Proposed	Final eQUEST Baseline	Final eQUEST Proposed
Total Energy (kWh/yr)	885,080	819,574	540,835	551,486	974,694	667,214
Total Energy (kBtu/yr)[a]	3.02×10^6	2.80×10^6	1.85×10^6	1.88×10^6	3.33×10^6	2.28×10^6
Energy Use Intensity (EUI) (kBtu/sf/yr)[b]	60.6	56.2	37.1	37.7	66.8	45.8

[a] 1 kWh = = 3.4145 kBtu (Glover, 1994)
[b] Building square footage = 49,818 sf

Also of interest were the energy savings or costs based on the type of load. Table 10 shows the estimated savings or costs, by percentage change from the baseline, when comparing each proposed model to the baseline model. For example, eQUEST Proposed usage for space cooling was compared to eQUEST Baseline usage for space cooling, as follows:

$$Energy\ change = 100 * (proposed\ usage - baseline\ usage)/baseline\ usage$$

To understand the relevance of these savings or costs, the percentage of the total energy usage for each load is also listed for each proposed model.

Table 10. Proposed to Baseline Model Energy Usage Comparisons By Load.

	HAP Savings or Costs (%)	HAP Proposed Percentage of Total Energy (%)	eQUEST Savings or Costs (%)	eQUEST Proposed Percentage of Total Energy (%)	Final eQUEST Savings or Costs (%)	Final eQUEST Proposed Percentage of Total Energy (%)
Space cooling	-60	11	-58	22	-64	24
Heat rejection	+100	2	+100	<1	+100	<1
Pumps	>+200	5	>+200	4	>+200	5
Interior lighting	-19	23	-19	19	-14	17
Exterior lighting	-90	1	-90	<1	-95	<1
Receptacles and Miscellaneous equipment[a]	-25	49	-3	51	-3	42
Space heating	-75	7	-49	3	+129	12
Domestic hot water	-27	2	-100	0	-100	0
Totals:		100		100		100

[a] Miscellaneous equipment included exhaust fans, water pumps, fan coils, and elevator loads

With the addition of a water-cooled HVAC system, significant percentage increases in pump and cooling tower (heat rejection) loads are shown in Table 10, but these had minimal impact on the overall energy usage due to the low percentage of total energy used. Of importance are the decreases in space cooling and interior lighting loads, as these averaged 39% of total energy used when including all three proposed models. The average receptacle and miscellaneous equipment energy consumption was estimated at 47% over the three proposed models. The 25% energy savings shown for HAP in this category resulted from an improvement in fan performance. The inputs to the HAP simulation that resulted in this improvement were not found in the information provided to this author. Space heating with the more efficient boilers also contributed to energy savings for the HAP and eQUEST Proposed models; however, when the actual

HVAC set points were simulated in the Final eQUEST Proposed model, the energy required for space heating increased considerably.

As previously shown in Table 7 for the Final eQUEST Baseline and Final eQUEST Proposed simulations, the actual HVAC and zone temperature set points being used at the LCROGB were modeled. After initial occupancy and use of the facility, occupant comfort levels drove adjustments to the set points (USBR personal communication, March 20, 2014). The temperature set points assumed in all other HAP and eQUEST simulations were based on the designed HVAC sequence of operations provided by the development team (WT, 2011).

For example, occupied zone temperature set points of 75 deg F for both cooling and heating modes were actually being used in the LCROGB, rather than 75 and 70 deg F as assumed in the other simulations. More critically, the unoccupied zone temperature set points of 75 deg F for cooling and 68 deg F for heating were employed in the actual building, rather than 85 deg F and 60 deg F, respectively, as assumed in the other simulations. Additionally, it was noted during system evaluation that the AHU-1 supply air set point was set at 70 deg F, while the AHU-2 supply air set point was at the original design point of 60 deg F. Trade-off simulations were run using the Final eQUEST Proposed model to estimate the impact of these and other simulation assumptions. The comparison of these individual variations to the simulations is shown in Table 11. It was assumed the occupied setting of 75 deg F was desired year round during these simulations.

Table 11. Trade-off Simulations for the Final eQUEST Proposed Model.

	Electrical Usage Change	Gas Usage Change	Total Energy Change
Final eQUEST Proposed Model	--	--	--
No building rotation	-0.3%	+3.1%	0%
Fewer zones	+0.1%	-0.7%	0%
All walls: 12-inch concrete + R-19 insulation	-0.2%	-30.1%	-3.7%
Occupied heating zone set point to 70 deg F	+0.5%	-38.7%	-4.1%
AHU-1 and -2 supply air set point reduced to 60 deg F	-1.5%	+48.2%	+4.4%
AHU-1 and -2 supply air set point increased to 70 deg F	-0.6%	-48.3%	-6.2%
Unoccupied zone set point to 85 deg F (cooling only)	-6.4%	-20.0%	-8.0%
Unoccupied zone set points to 85 deg F (cooling) and 60 deg F (heating)	-6.5%	-61.4%	-13.0%
Combined AHU-1 and -2 supply air set point to 60 deg F and unoccupied zone set points to 85 deg F (cooling) and 60 deg F (heating)	--7.8%	-56.0%	-13.5%
Combined AHU-1 and -2 supply air set point to 70 deg F and unoccupied zone set points to 85 deg F (cooling) and 60 deg F (heating)	--6.4%	-67.5%	-13.7%

As shown in Table 11, the building rotation to the actual constructed position and simulation of fewer zones per floor had essentially no impact on the overall energy usage. When the metal wall structures used in all of the eQUEST simulations were replaced entirely with 12-inch concrete walls with R-19 insulation, a savings in heating (gas) energy was observed, but this had minimal impact on total energy savings. The actual building was constructed of 63% metal walls and 37% 14-inch, insulated concrete on the south-facing and east-facing walls. This combination of walls was not simulated using eQUEST.

Also shown in Table 11, lowering the occupied heating zone set point by 5 deg F simulated a reduction in overall energy usage by approximately 4%. The AHU-1 supply air set point lowering to 60 deg F actually resulted in an increase in overall energy consumption. This was due to the increased heating requirement for the first floor. Alternatively, increasing the AHU-2 supply air set point to 70 deg F indicated a savings in energy usage of approximately 6%. Larger savings of 13%, however, came from adjusting the unoccupied cooling and heating settings to 85 deg F and 60 deg F, respectively. As shown in the last two rows of Table 11, combining the suggested unoccupied cooling and heating set points with the two different AHU supply air set points resulted in minor improvements to the 13% savings. The last row of Table 11 shows the savings estimated by the "HVAC Variation" simulation modeled in eQUEST.

Monthly comparisons of the Final eQUEST Proposed model and the HVAC Variation model, with AHU-1 and -2 supply air set points at 70 deg F and unoccupied cooling and heating zone set points at 85 and 60 deg F, respectively, are shown in Figures 55 and 56. Monthly breakdowns of energy usage by load for the HVAC Variation model are shown in Figures 57 and 58. In Figure 57, the natural gas usage has been converted from therms to kWh for comparison with electrical loads. In Figure 58, the "other" category includes pumps, heat rejection, and exterior lighting.

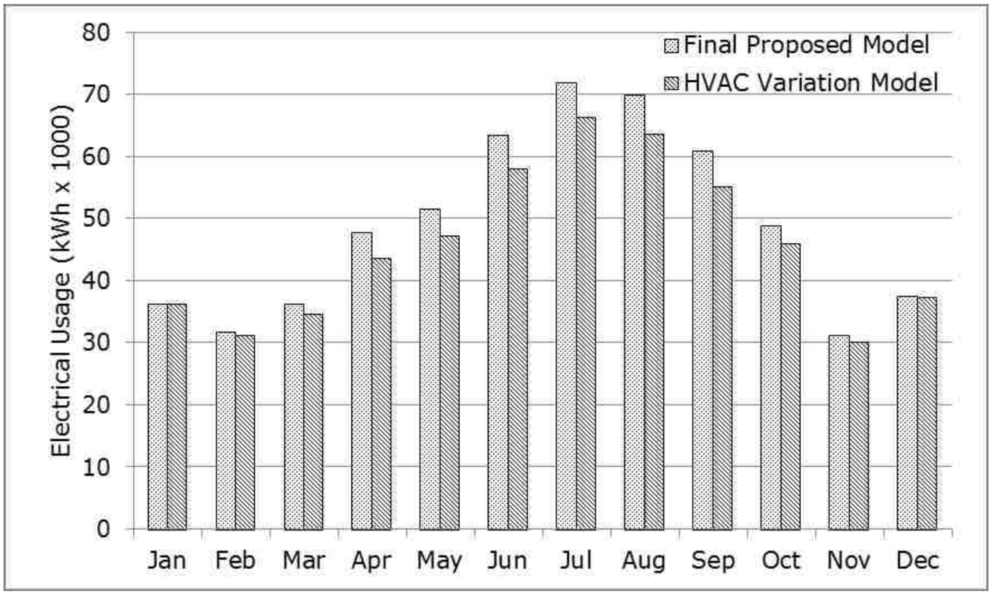


Figure 55. eQUEST Final Proposed and HVAC Variation Electrical Usage Comparison.

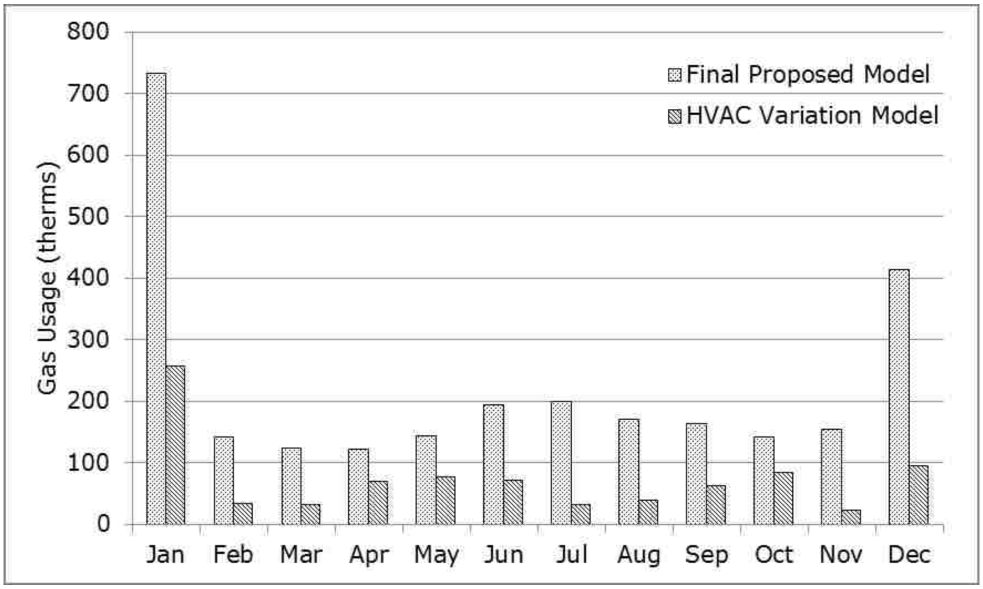


Figure 56. eQUEST Final Proposed and HVAC Variation Gas Usage Comparison.

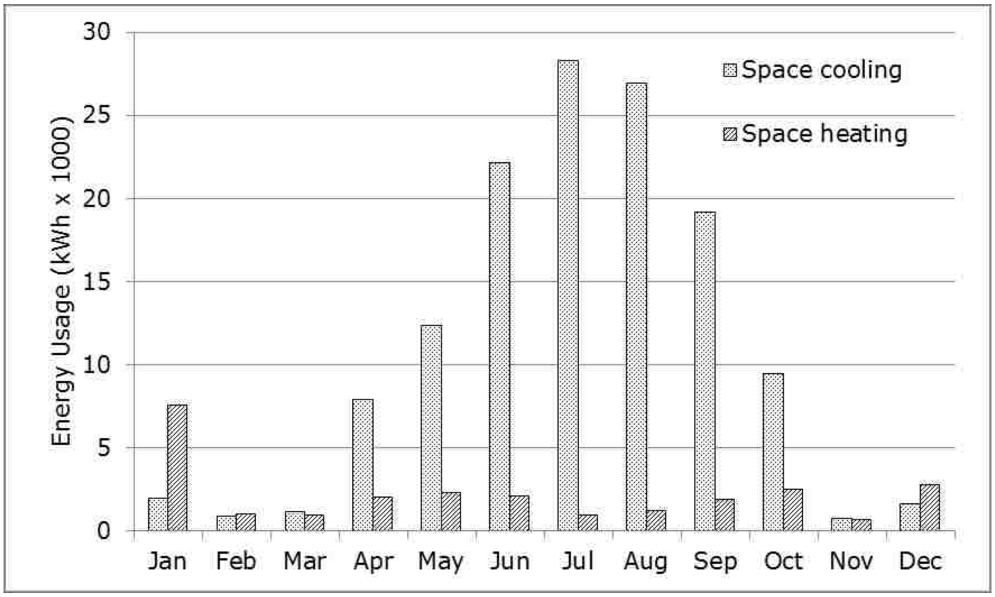


Figure 57. eQUEST HVAC Variation Energy Usage For Primary HVAC Equipment.

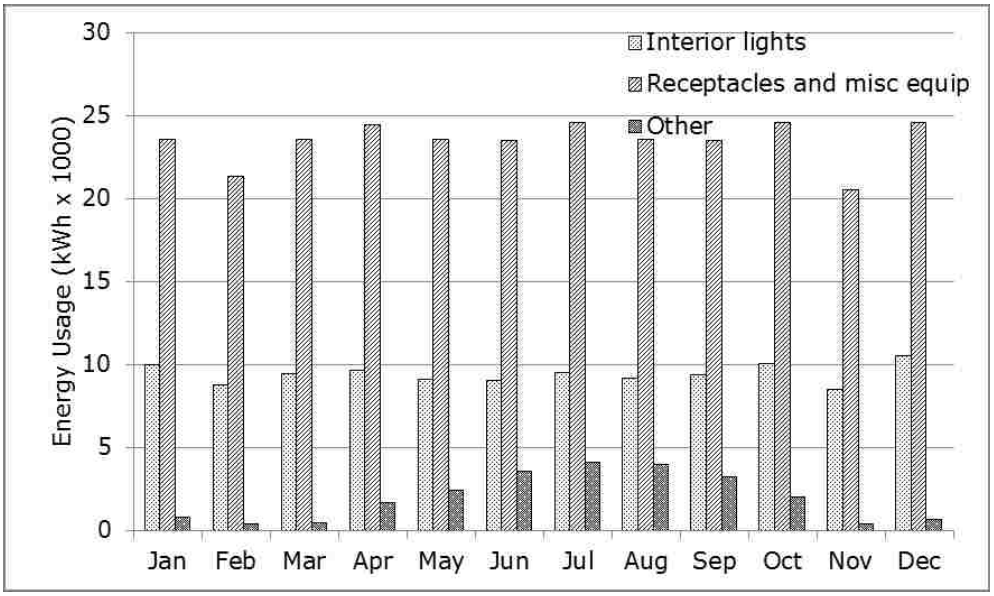


Figure 58. eQUEST HVAC Variation Energy Usage For Other Equipment.

As shown in Figures 55 and 56, altering the HVAC set points did impact the overall energy usage, as less electricity was used during the summer months and less gas was used throughout the simulated year. The detailed look at the HVAC Variation model in Figures 57 and 58 shows space cooling in the summer months and receptacle and miscellaneous equipment loads throughout the year being the dominating contributors to overall energy usage. Table 12 summarizes the percentage of usage by each type of load for the HVAC Variation model.

Table 12. eQUEST HVAC Variation Model Energy Usage by Load Type.

Load	Percentage of Overall Energy Usage
Space cooling	23.0%
Space heating	4.5%
Interior lights	19.6%
Receptacles and misc equipment	48.8%
Other (pumps, heat rejection, exterior lights)	4.1%

Energy Usage Analysis

As a final step in the analysis, the actual energy usage of the LCROGB was evaluated and compared to the simulations. The monthly electrical usage for the LCROGB was obtained from recorded BMS data starting in October, 2012. The BMS recorded cumulative usage each day at midnight, and monthly usage was computed from these data by subtracting the end of month readings. End of month dates were aligned with the electric utility bills that provided the total Date Street Complex usage and did not specify the LCROGB usage. The “Power_Total_Dashboard” BMS parameter was used for this analysis. The actual monthly and cumulative electrical usages for the LCROGB are shown in Figures 59 and 60, respectively.

In addition to the LCROGB usage, the electrical energy required to operate the central chiller plant was assessed using the Central_Plant_HW SYS TCP (13000) “HWP_KWH_TL” parameter suggested by USBR representatives. This parameter was recorded each day at midnight by the BMS beginning in late April, 2013, and indicated cumulative usage. Since the central chiller plant also provided cooling for Buildings

100 and 200 beginning in mid-2013, an estimated 4500 kWh/yr for cooling the LCROGB was assumed, based on the data available. This usage was not included in Figures 59 and 60.

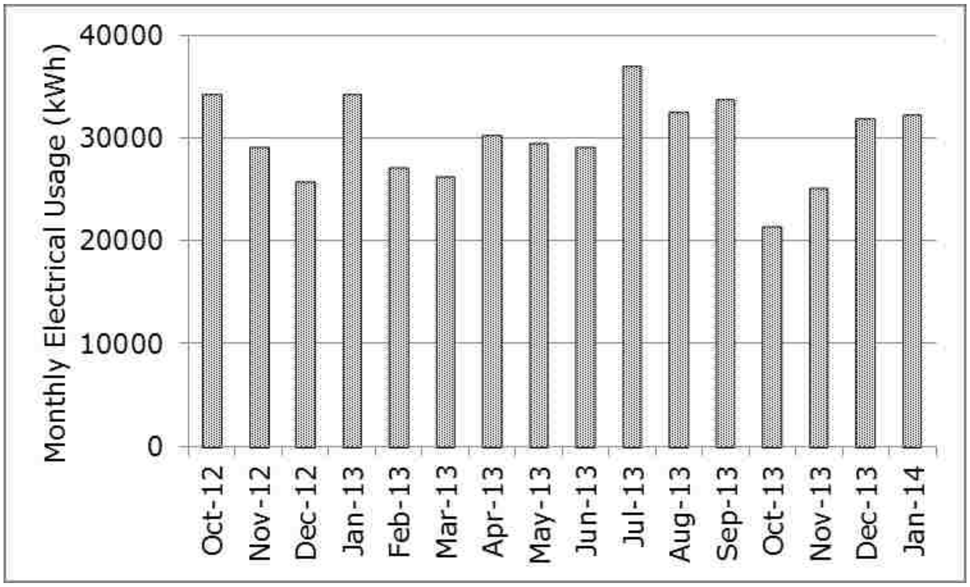


Figure 59. LCROGB Actual Monthly Electrical Usage.

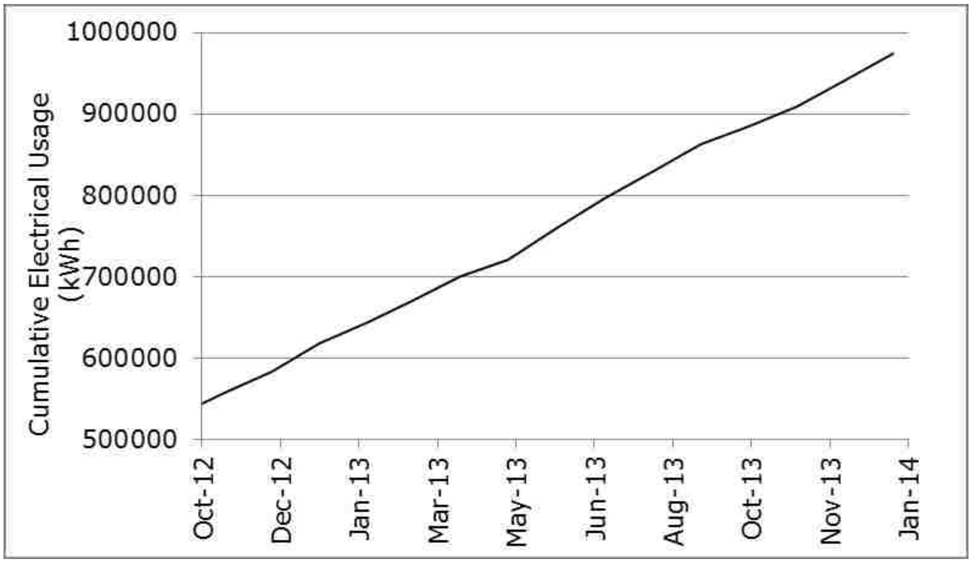


Figure 60. LCROGB Actual Cumulative Electrical Usage.

The actual monthly and cumulative natural gas usages for the LCROGB are shown in Figures 61 and 62. Here, the utility bills provided by the USBR were for the LCROGB only. Note, the LCROGB became occupied in September, 2011.

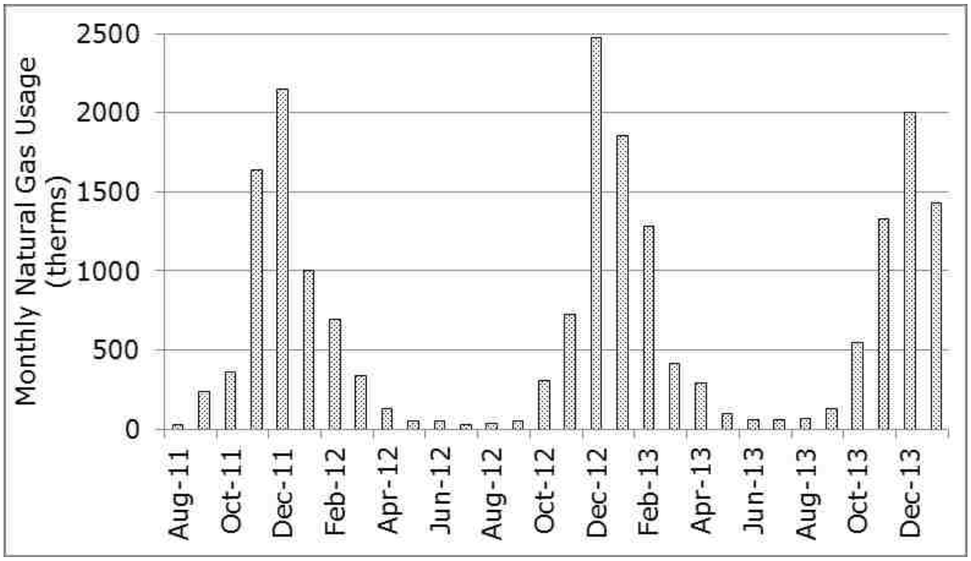


Figure 61. LCROGB Actual Monthly Natural Gas Usage.

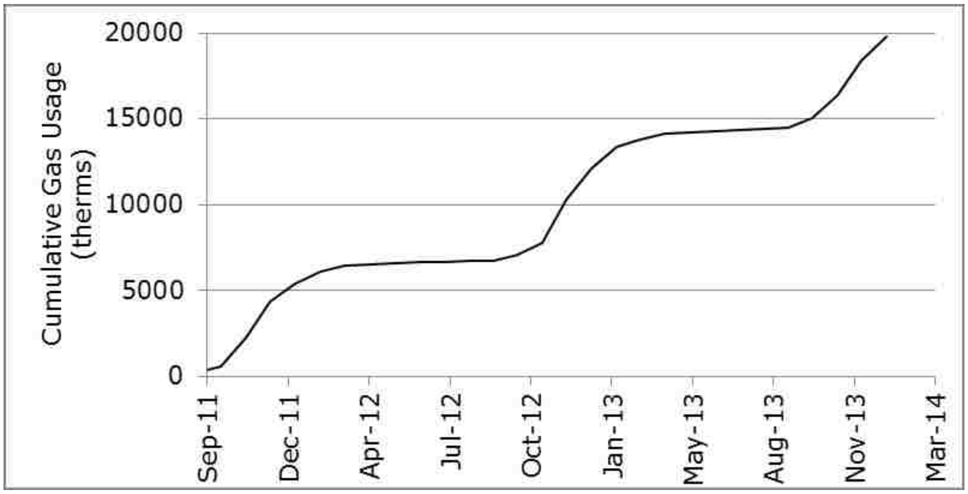


Figure 62. LCROGB Actual Cumulative Natural Gas Usage.

For the year 2013, the LCROGB used 362,262 kWh of electricity or an average 30,189 kWh per month, including the central chiller plant electrical estimate. That same year, the LCROGB used 8,119 therms (237,780 kWh) of natural gas or an average 677 therms (19,827 kWh) per month. These actual usage values and associated costs are compared to the HAP Proposed, eQUEST Proposed, and Final eQUEST Proposed simulation results in Table 13.

Table 13. LCROGB Actual Energy Usage Compared to Simulation Results.

	LCROGB Actuals for 2013	HAP Proposed	eQUEST Proposed	Final eQUEST Proposed
Total Electric (kWh/yr)	362,262	489,202	536,520	588,160
Total Gas (therms/yr)	8,119	1,763	511	2,699
Total Gas (kWh/yr)[a]	237,780	51,633	14,966	79,054
Total Energy (kWh/yr)	600,042	540,835	551,486	667,214
Electric Cost ($/yr)	38,762[b]	52,883	57,998	62,933[b]
Gas Cost ($/yr)	5,730[c]	1,185	343	1,905[c]
Total Cost ($/yr)	44,492[b,c]	54,068	58,341	64,838[b,c]

[a] 1 kWh = 0.034145 therms (Glover, 1994)

[b] Using calculated actual rates of $0.1070/kWh from USBR utility bills

[c] Using calculated actual rates of $0.7057/therm from USBR utility bills

None of the simulations provided comparable results to the actual LCROGB energy usage. Both HAP and eQUEST estimated much higher electricity usage and much lower natural gas usage than the building actually required. Whole building energy simulations were considered best used for comparing proposed designs with baseline requirements and were not considered valid for making projections of actual building performance (Turner & Frankel, 2008; U.S. Green Building Council, 2009).

The actual EUI for the LCROGB is shown in Table 14, along with the proposed simulation EUI results. Turner and Frankel (2008) compared actual EUI to model design or proposed EUI (actual EUI/proposed EUI) to estimate the accuracy of whole building energy models. This actual-to-design ratio would ideally be 1.0, if the simulation accurately represented the post-occupancy building. Values less than 1.0 would indicate better energy performance than expected, and values greater than 1.0 would indicate poorer performance than expected. The actual EUI/proposed EUI ratios are also shown in Table 14.

Table 14.Actual Energy Use Intensity (EUI) Comparison With Simulations Results.

	LCROGB Actuals for 2013	HAP Proposed	eQUEST Proposed	Final eQUEST Proposed
Total Energy (kWh/yr)	600,042	540,835	551,486	667,214
Total Energy (kBtu/yr)[a]	2.05 $x10^6$	1.85 $x10^6$	1.88 $x10^6$	2.28 $x10^6$
Energy Use Intensity (EUI) (kBtu/sf/yr)[b]	41.1	37.1	37.7	45.8
Actual EUI/Proposed EUI Ratio		1.11	1.09	0.90

[a] 1 kWh = = 3.4145 kBtu (Glover, 1994)
[b] Building square footage = 49,818 sf

The actual EUI of 41.1 kBtu/sf/yr was below the medium energy usage building, median EUI of 62 kBtu/sf/yr and LEED gold/platinum building EUI of 51.2 kBtu/sf/yr, as computed by Turner and Frankel (2008). The LCROGB actual EUI was essentially the same as the median EUI of 42 kBtu/sf/yr demonstrated by LEED V2 buildings earning maximum energy efficiency points (Turner & Frankel, 2008). The actual-to-proposed EUI ratios were all fairly close to 1.0, but this did not necessarily indicate the simulations closely modeled the actual building performance. In fact, all three models over-estimated electrical usage while under-estimating natural gas usage.

Turner and Frankel (2008) also proposed that a representative way of computing measured energy savings was to compare the actual EUI to the modeled baseline EUI using the following equation:

$$Measured\ Savings = \frac{Model\ baseline\ EUI - Actual\ measured\ EUI}{Model\ baseline\ EUI}$$

Using the EUI values shown in Tables 9 and 14, the HAP, eQUEST, and Final eQUEST baseline simulations resulted in LCROGB measured energy savings of 32.2%, 26.9%, and 38.5%, respectively.

Comparing the LCROGB actual energy usage to the Date Street Complex solar installation indicated that 100% of the LCROGB electrical usage (362,262 kWh) would be offset by an annual solar energy generation of 490,537 kWh, and approximately 82% of the total LCROGB energy usage (electrical and natural gas) would be covered. The first phase of the solar installation was anticipated to offset all LCROGB electrical usage. Based on the actual electrical usage observed in 2013, approximately 66% of the usage would be covered by the first installation.

Chapter 4

RESULTS AND DISCUSSION

The purpose of this study was to gain a comprehensive understanding of the LEED certification system and its relevance to Federal policies, building codes, and building standards, develop experience with whole building energy modeling, and determine the actual post-occupancy energy usage as compared with the developed model and design projections.

Requirements Comparison Results

The LEED V2009 certification system for new construction awarded points based on design considerations for energy and atmosphere, as well as design elements pertaining to sustainable sites, water efficiency, materials and resources, indoor environmental quality, innovation in design, and regional priority. To earn a platinum LEED certification, at least 80 points had to be earned across the various categories, and the LCROGB earned 83 points to achieve this highest rating.

LEED V2009 certification requirements compared favorably to the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings and the ASHRAE Standard 90.1-2007. For energy efficiency, the Guiding Principles required a 30% improvement when comparing the proposed design to the ASHRAE 90.1 baseline design. LEED required only a 10% minimum improvement, but awarded additional points when 12% to 48% improvements were demonstrated through whole building energy simulations. Nineteen points were achievable in the LEED energy efficiency category, and the LCROGB earned this maximum value by demonstrating nearly 66% improvement.

LEED certification requirements also aligned with the Guiding Principles in promoting on-site renewable energy, daylighting, requiring means for measuring and verifying post-occupancy building performance, and benchmarking performance after the first year of occupancy. No apparent mechanism existed to verify performance measurement and benchmarking occurred, and it was solely up to the facility owners to follow-up on this requirement. LEED requirements met or exceeded the Guiding Principles in the areas of ventilation and thermal control and refrigerant management. Of all the standards, only LEED required zero use of CFC-based refrigerants. The LCROGB met this requirement by using R-134a HFC-based refrigerant.

Building Energy Simulation Results

The whole building energy simulation, eQUEST Version 3.65, was used for this study and was developed using the inputs and assumptions used by the designers and actual system measurements taken during system certifications (MSA, n.d.; WT, 2011). The results of the eQUEST simulations were intended to confirm the energy savings predicted by the LCROGB design team using the HAP Version 4.5 software. Energy savings were predicted by comparing baseline simulations based on ASHRAE 90.1-2007 Appendix G guidelines to proposed simulations incorporating the designed building envelope, HVAC system, and additional loads.

During the development of the eQUEST simulations, some limitations were encountered, as listed below. Only the eQUEST building creation GUIs were used for this study, and a limited number of selections for the building envelope, HVAC system, and other loads were available. Modifications to these selections could have been attempted using the eQUEST detailed interface, but this was considered beyond the scope of this study. The impact of these simulation limitations on the overall energy usage was not investigated during this study, but most were thought to have minimal impact on the overall results. Unless noted, it was not known how the following issues were dealt with in the HAP simulations:

1) The exterior walls were modeled using only the metal systems as described earlier in this study. The simulation variation using all 12-inch concrete with R-19 insulation showed little variance from the all metal configuration. In HAP, the designers modeled the individual walls using either the metal or concrete structure. It was not known whether or not HAP modeled the actual 14-inch concrete wall thickness, which was limited to 12 inches in the eQUEST GUI.

2) The roof material was modeled with some accuracy, but the roof configuration was not. The LCROGB had three different pitch configurations ranging from 0 deg (flat) to 25 deg. To allow skylights to be incorporated, a flat roof was selected for the entire building, as shown in Figure 63.

3) Due to the flat roof simulation, roof access doors were not modeled.

4) Interior walls were not modeled in detail. A basic wall model of uninsulated, wooden studs covered with painted gypsum board was used throughout.

5) The ceilings on each floor were not modeled accurately. For the first floor, a 12-foot high, gypsum board ceiling was assumed without a plenum between floors. eQUEST documentation cautioned against incorporating a plenum due to complications with running the simulation (Hirsch, 2010). For the second floor, a flat 14-foot high, gypsum board ceiling was assumed, when the actual building had a vaulted ceiling with exposure to the roof steel deck.

6) The large 18 ft x 20.5 ft windows on the second floor of the LCROGB were restricted to a 14 ft height due to the limitation of the second floor ceiling.

7) For all windows, differences between the HAP and eQUEST U-factor and SHGC values existed. For the baseline simulations, eQUEST used a slightly lower U-factor (more resistant to conductive heat transfer) than HAP, and a much higher SHGC allowing in solar radiation (good in winter, poor in summer). For the Proposed eQUEST models, “low e3” windows were selected, with, again, a lower U-factor than HAP, but a comparable SHGC.

8) As shown in Figure 63, the window light shelves on the south-facing (shown) and east-facing (not shown) walls were automatically placed at the top of the windows by eQUEST, rather than below the first pane as on the actual building. The light shelves in eQUEST were also simulated as solid features, rather than being louvered.

9) The motion sensing power strips incorporated at all work stations in the LCROGB were not simulated.

10) Typical meteorological year (TMY) hourly weather data were used by both the HAP and eQUEST simulations. In both programs, weather data for Las Vegas was used, as Boulder City weather files were not included with the basic software. The impact of the weather differences between these two locations was not determined as part of this study.

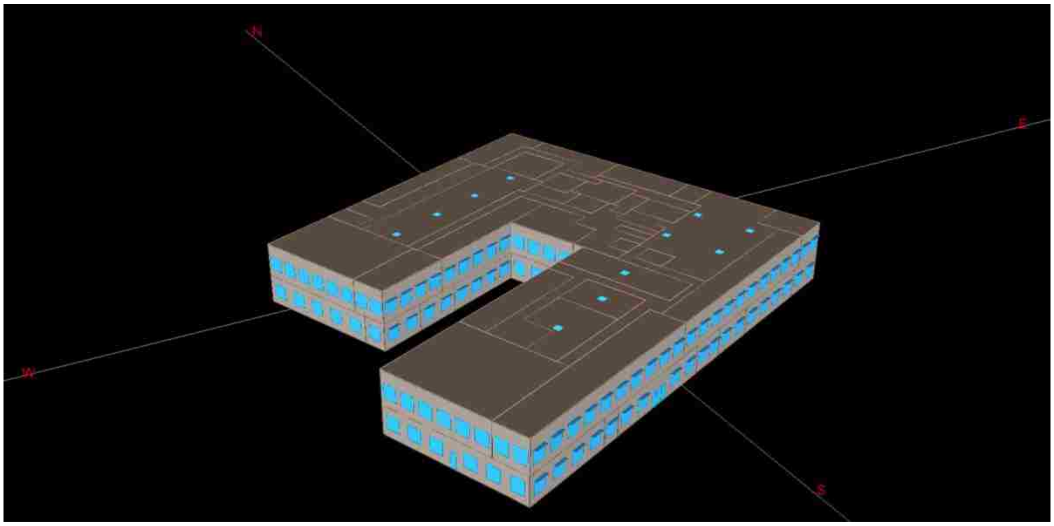


Figure 63. Final eQUEST Proposed Model Envelope Depiction.

The eQUEST simulation overall results compared favorably with the HAP results. eQUEST predicted a 32.7% savings in overall energy usage, compared to the HAP 38.9% prediction. With the additional energy savings allowed by LEED certification from the first phase of the solar installation, HAP and eQUEST predicted savings of 66% and 62%, respectively. Both energy estimates exceeded the LEED-required 48% savings to earn the maximum 19 points in the Energy and Atmosphere category.

The eQUEST EUI of 37.7 kBtu/sf/yr also compared favorably to the HAP EUI of 37.1 kBtu/sf/yr. The Final eQUEST Proposed simulation that incorporated the actual building orientation, HVAC set points, and design lighting load had a much higher EUI of 45.8 kBtu/sf/yr, though still below representative values found during the literature review.

The largest energy savings between the baseline and proposed models for both HAP and eQUEST came from space cooling with a water-cooled HVAC system, space heating with more efficient boilers, automated interior lighting, and incorporation of solar water heating. The largest simulated energy consumers were the combined receptacle and miscellaneous equipment loads accounting for essentially 50% of the consumed energy. Space cooling and heating and interior lighting accounted for approximately 20% each. Cooling towers, HVAC pumps, and exterior lighting were considered minor consumers of energy. Although the LCROGB BMS was thought to have the capability of recording the various building electrical loads, these data were not available for comparison to the simulations during this study.

Variations to the Final eQUEST Proposed model suggested that additional savings could be achieved by lowering the occupied heating zone temperature set point from 75 deg F to 70 deg F, raising the AHU-2 supply air set point from 60 deg F to 70 deg F, and setting the unoccupied cooling and heating zone temperature set points from 75 deg F and 68 deg F to 85 deg F and 60 deg F, respectively. The simulated combination of all but the lowering of the occupied heating zone temperature set point resulted in a predicted 13.7% additional savings in energy usage.

Energy Usage Comparison

In 2013, the LCROGB and central chiller plant used 600,042 kWh of energy, and 60% was electrical and 40% was natural gas. The total cost for this energy was $44,492. This usage demonstrated an EUI of 41.1 kBtu/sf/yr, well under the Turner and Frankel (2008) computed medium usage building median of 62 kBtu/sf/yr. A fully operational solar installation generating approximately 490,000 kWh per year or an average 41,000 kWh per month of energy would have exceeded the annual and monthly LCROGB electrical usage.

The HAP and eQUEST Proposed models resulted in actual-to-proposed EUI ratios of 1.11 and 1.09, respectively. Although Turner and Frankel (2008) considered this a possible indicator of reasonable energy models, the HAP and eQUEST Proposed simulations respectively predicted 35% and 48% higher electrical usage than the actual LCROGB. The natural gas usage in both models did not compare at all with the actual usage.

Haberl and Cho (2004) showed that DOE-2 simulations estimated energy usage within 10% to 26% of actual energy usage. The eQUEST Proposed model estimated a total energy usage 8.1% less than the actual LCROGB, due to the low natural gas predictions. When the actual operating conditions of the LCROGB were incorporated into the model (AHU-1 supply air = 70 deg F, AHU-2 = 60 deg F, occupied cooling and heating = 75 deg F, unoccupied cooling = 75 deg F, unoccupied heating = 68 deg F), eQUEST overestimated the total energy usage by 11% and decreased the actual-to-proposed EUI to 0.90. The simulation continued to significantly underestimate the actual natural gas usage, and the cause for this was not determined.

Following more than two years of post-occupancy operation, the LCROGB was electrically more efficient than predicted by either HAP or eQUEST. Although the facility was using considerably more natural gas than predicted by the simulations, an actual EUI of 41.1 kBtu/sf/yr demonstrated considerable efficiency. The facility design and implementation met or exceeded energy efficiency requirements established by the Guiding Principles, ASHRAE 90.1, and the LEED V2009 certification system.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to gain a comprehensive understanding of the LEED certification system and its relevance to Federal policies, building codes, and building standards, develop experience with whole building energy modeling, and determine the actual post-occupancy energy usage as compared with the developed model and design projections. By meeting these objectives, the relationship between LEED certification and energy usage and efficiency was evaluated and provided to the facility owners.

This thesis hypothesized the USGBC's LEED rating system compared favorably to other policies, codes, and standards in use at the time, and the USBR's LEED Platinum facility operated at least as energy efficiently as designed. Both hypotheses were shown to be true.

Conclusions

The three objectives of this study were met. As a result of the literature review and thorough investigation of the LEED certification system, LCROGB LEED credit forms, Federal Guiding Principles, and ASHRAE Standard 90.1-2007, a comprehensive understanding of LEED v2009 and the relevance to the standards with respect to energy efficiency was achieved. The LEED V2009 requirements met or exceeded most requirements in the other policies and standards.

Earning a LEED V2009 certification, whether Silver, Gold, or Platinum, did not guarantee a newly constructed office building would be energy efficient. However, when LEED energy efficiency points were earned in the Energy and Atmosphere category, buildings tended to be efficient, as demonstrated through the New Buildings Institute study (Turner & Frankel, 2008), Regional Green Building Case study (U.S. Green Building Council, 2009), and this study.

The second objective, to gain experience with whole building energy modeling, was met through the development of the eQUEST Version 3.65 LCROGB simulations. Development of the simulations required extensive study and investigation of the LCROGB design specifications, operations and maintenance manuals, as-built design documents, LEED credit forms, BMS archived data, discussions with USBR representatives, several tours of the LCROGB facility, and initiation into the use of the eQUEST software. Only the Design Development graphical interface was used during the study. To become proficient at using eQUEST required use of the detailed interface and was considered beyond the scope of this study.

The eQUEST simulated energy results were comparable to the designer's HAP results and proved useful in demonstrating energy costs and savings through variations to the simulation inputs. Whole building energy models were the standard for showing energy efficiencies in design by comparing proposed and baseline models. As pointed out by Turner and Frankel (2008), the Regional Green Building Case Study (U.S. Green Building Council, 2009), and through the development of the eQUEST models, building complexities, system operations, internal loads, local weather, and numerous assumptions made during the development of models could easily skew results. Considerable dedication to energy modeling would be required to gain confidence in producing reliable results.

The final objective, to determine the actual post-occupancy energy usage and compare the results with the simulations, was also met. The LCROGB proved to be considerably more efficient in electrical consumption than the HAP design simulations and the eQUEST simulations developed in this study. Both HAP and eQUEST did a poor job of estimating the natural gas usage of the facility, and due to the low estimates from both simulations, the overall simulated energy usage was lower than the actual values. Regardless of this finding, the LCROGB was found to be efficient, with an EUI of 41.1 kBtu/sf/yr, and worthy of the LEED Platinum certification.

Recommendations

The LCROGB was a state-of-the-art facility located within close proximity of the University of Nevada, Las Vegas. This LEED certified facility was one of only 1,067 buildings world-wide that had earned a Platinum rating ("Public LEED Project Directory," 2013). This study only scratched the surface of investigating the energy efficiencies of the LCROGB, and further studies by UNLV students and faculty are recommended.

The LCROGB BMS was under development during this study. The system was thought to have artificial intelligence capability and could be automated to become more efficient over time. The LCROGB BMS was also the repository for energy data from numerous USBR facilities located in Boulder City. A study of the entire BMS capability and full understanding of the system is recommended.

Some HVAC system behavior was observed during this study that warranted further investigation. A detailed study of the HVAC system when all relevant BMS data are being recorded is recommended.

The weather data used for all LCROGB simulations was the TMY Las Vegas data set. Boulder City TMY data were becoming available at the time of this study, and a UNLV weather station could be placed at the Date Street Complex to further investigate the weather effects on whole building energy models.

The Date Street Complex solar installation was under investigation by USBR representatives as a result of this study. This photovoltaic system provides opportunities for studies in several areas associated with solar energy.

Figure 64. LCROGB LEED Platinum Award.

APPENDICES

APPENDIX A

Guiding Principles for Federal Leadership in High Performance and Sustainable Building Summary

The following was excerpted from the U.S. Guiding Principles ("Federal Leadership," 2006; "High Performance," 2008). Some wording has been intentionally omitted, and this list should not be used as a complete set of principles:

I. Employ Integrated Design Principles

Integrated Design	Use a collaborative, integrated planning and design process.
Commissioning	Employ commissioning practices tailored to the size and complexity of the building and its components in order to verify performance of building components and systems and help ensure that design requirements are met.

II. Optimize Energy Performance

Energy Efficiency	Establish a whole building performance target that takes into account the intended use and occupancy. For new construction, reduce the energy use by 30% compared to the baseline building performance rating per ASHRAE 90.1-2007.
On-Site Renewable Energy	Per EISA, meet at least 30% of the hot water demand through the installation of solar hot water heaters. Per Executive Order 13423, implement renewable energy generation projects on agency property for agency use.
Measurement and Verification	Per EPAct of 2005, install building level electricity meters in new major construction to track and continuously optimize performance. Per EISA, include equivalent meters for natural gas, where natural gas is used.
Benchmarking	Compare actual performance data from the first year of operation with the energy design target. Verify that the building performance meets or exceeds the design target.

III. Protect and Conserve Water

Indoor Water	Employ strategies that, in aggregate, use a minimum of 20% less potable water than the indoor water use baseline calculated for the building.
Outdoor Water	Use water efficient landscape and irrigation strategies to reduce outdoor potable water consumption by a minimum of 50% over that consumed by conventional means.
Process Water	Per the EPAct of 2005, when potable water is used to improve a building's energy efficiency, deploy lifecycle cost effective water conservation measures.
Water-Efficient Products	Specify EPS's WaterSense-labeled products or other water conserving products, where available.

IV. Enhance Indoor Environmental Quality

Ventilation and Thermal Comfort	Meet ASHRAE Standard 55-2004, Thermal Environmental conditions for Human Occupancy, and ASHRAE Standard 62.1-2007, Ventilation for Acceptable Indoor Air Quality.
Moisture Control	Establish and implement a moisture control strategy for controlling moisture flows and condensation.
Daylighting	Achieve a minimum daylight factor of 2% (excluding all direct sunlight penetration) in 75% of all space occupied for critical visual tasks. Provide automatic dimming controls or accessible manual light controls, and appropriate glare control.
Low-Emitting Materials	Specify materials and products with low pollutant emissions.
Protect Indoor Air Quality during Construction	
Environmental Tobacco Smoke Control	Implement a policy and post signage indicating that smoking is prohibited within the building and within 25 feet of all building entrances, operable windows, and building ventilation intakes during building occupancy.

V. Reduce Environmental Impact of Materials

Recycled Content	Specify products meeting or exceeding the Environmental Protection Agency’s recycled content recommendations.
Biobased Content	For USDA-designated products, specify products with the highest content level per USDA’s biobased content recommendations.
Environmentally Preferable Products	Use products that have lesser or reduced effect on human health and the environment over their lifecycle when compared with competing products or services that serve the same purpose.
Waste and Materials Management	Incorporate adequate space, equipment, and transport accommodations for recycling in the building design.
Ozone Depleting Compounds	Eliminate the use of ozone depleting compounds during and after construction where alternative environmentally preferable products are available.

APPENDIX B

ASHRAE Standard 90.1-2007 Excerpts

The following was excerpted from the ASHRAE 90.1-2007 (ANSI/ASHRAE/IESNA, 2007). Many words, sections, and references have been intentionally omitted, and this list should not be used as an exact excerpt from ASHRAE 90.1-2007:

I. Building Envelope – Mandatory Provisions (Section 5.4)

5.4.1 Insulation – Shall comply with 5.8.1	5.8.1.1 The rated R-value shall be clearly identified 5.8.1.2 Shall be installed in accordance with manufacturers recommendations 5.8.1.5 Shall be installed in a permanent manner 5.8.1.7 Exterior insulation shall be covered with a protective material
5.4.2 Fenestration and Doors – Procedures described in 5.8.2	5.8.2.1 The U-factor, SHGC, and air leakage rate for all manufactured fenestration products shall be determined by a nationally recognized accreditation organization. 5.8.2.2 All manufactured fenestration products shall have a permanent name plate listing U-factor, SHGC, and air leakage. 5.8.2.3 The U-factor and air leakage rate for all manufactured exterior doors shall be identified on a permanent name plate. 5.8.2.4 U-factors shall be determined in accordance with National Fenestration Rating Council (NFRC) 100. 5.8.2.5 SHGC for the overall fenestration area shall be determined in accordance with NFRC 200. 5.8.2.6 Visible light transmittance (VLT) shall be determined in accordance with NFRC 200.
5.4.3 Air Leakage	5.4.3.1 The building envelope shall be sealed, caulked, gasketed, or weather-stripped to minimize air leakage. 5.4.3.2 Air leakage for fenestration and doors shall be determined in accordance with NFRC 400.

II. Building Envelope – Prescriptive Building Envelope Option (Section 5.5)

5.5.1	For a conditioned space, the exterior building envelope shall comply with the nonresidential requirements for the appropriate climate. (not listed here)
5.5.2	If a building contains any semiheated space or unconditioned space, then the semi-exterior building envelope shall comply with the requirements for the appropriate climate. (not listed here)
5.5.3 Opaque Areas	For all opaque surfaces except doors, compliance shall be demonstrated by either minimum rated R-values of insulation or maximum U-factor for the entire assembly. 5.5.3.1 All roofs shall comply with the insulation specified. (not listed here) 5.5.3.2 All above-grade walls shall comply with the insulation values specified. (not listed here) 5.5.3.4 All floors shall comply with the insulation values specified. (not listed here) 5.5.3.6 All opaque doors shall have a U-factor no greater than specified. (not listed here)
5.5.4 Fenestration	Compliance with U-factors and SHGC shall be demonstrated for the overall fenestration product.

III. HVAC – Mandatory Provisions (Section 6.4)

6.4.1 Minimum Equipment Efficiencies – Standard Rating and Operating Conditions	6.4.1.1 Equipment shall have a minimum performance at the specified rating conditions (not listed here).
6.4.2 Load Calculations	Heating and cooling system design loads for the purpose of sizing systems and equipment shall be determined in accordance with generally accepted engineering standards and handbooks.
6.4.3 Controls	6.4.3.1 The supply of heating and cooling energy to each zone shall be individually controlled by thermostatic controls responding to temperature within the zone. 6.4.3.3 1.Systems shall have off-hour controls that can

	start and stop the system under different time schedules for seven different day-types per week, retain programming and time setting during loss of power for at least ten hours, and include an accessible manual override. 2. Heating systems shall be equipped with controls that have the capability to automatically restart to maintain zone temperatures above a heating set point adjustable down to 55 deg F or lower. Cooling systems that have the capability to automatically restart to maintain zone temperatures below a cooling set point adjustable up to 90 deg F or higher. 6.4.3.4 Stair, elevator shaft, outdoor air supply, and exhaust systems shall have motorized dampers.
6.4.4 System Construction and Insulation	6.4.4.1 Insulation required by this section shall be installed in accordance with industry-accepted standards. All supply and return ducts and piping shall be thermally insulated. 6.4.4.2 Ductwork shall be sealed in accordance the given criteria (not listed here).

<ins>IV. HVAC – Prescriptive Path (Section 6.5)</ins>

6.5.1 Economizers	Each cooling system that has a fan shall include an economizer meeting the requirements given (not listed here). 6.5.1.1 Air economizer systems shall be capable of modulating outdoor air and return air dampers to provide up to 100% of the design supply air quantity as outdoor air for cooling. Dampers shall be capable of being sequenced and be capable of automatically reducing outdoor air intake to the design minimum outdoor air quantity when outdoor air intake will no longer reduce cooling energy usage.
6.5.2 Simultaneous Heating and Cooling Limitation	6.5.2.1 Zone thermostatic controls shall be capable of operating in sequence the supply of heating and cooling energy to the zone.

6.5.3 Air System Design and Control	Each HVAC system having a total fan system motor nameplate horsepower (hp) exceeding 5 hp shall meet the provisions as follows. 6.5.3.1 Fan system design conditions shall not exceed the allowable fan system motor nameplate hp or fan system brake hp (bhp) given (not listed here). This includes supply fans, return fans, and exhaust fans. 6.5.3.2 Variable air volume (VAV) with static pressure sensors used to control fans shall be placed in a position such that the controller set point is not greater than one-third the total design fan static pressure, except for systems with direct digital control (DDC) of individual zone devices reporting to the central control panel, static pressure set point shall be reset based on the zone requiring the most pressure.
6.5.4 Hydronic System Design and Control	HVAC hydronic systems having a total pump system power exceeding 10 hp shall meet the provisions as follows. 6.5.4.1 Pumping systems that include control valves designed to modulate or step open and close as a function of load shall be designed for variable fluid flow and shall be capable of reducing pump flow rates to 50% or less of the design flow rate. 6.5.4.2 When a chilled-water plant includes more than one chiller, provisions shall be made so that the flow in the chiller pant can be automatically reduced, correspondingly, when a chiller is shut down. When a boiler plant includes more than one boiler, provisions shall be made so that the flow in the boiler plant can be automatically reduced, correspondingly, when a boiler is shut down.

APPENDIX C

LEED V2009 Requirements and Points Awarded

The following was excerpted from the LEED V2009 for New Construction and Major Renovations (2009). The number of points possible and the number of points awarded for the LCROGB design follow each of the credit titles, parenthetically. The basic intent or requirement for each credit category is also provided. Some wording has been intentionally omitted, and this list should not be used as a complete set of guidelines:

Minimum Program Requirements:

1. Must comply with environmental laws
2. Must be a complete, permanent building or space
3. Must use a reasonable site boundary
4. Must comply with minimum floor area requirements of 1000 sf
5. Must comply with minimum occupancy rates of 1 full-time equivalent occupant
6. Must commit to sharing whole-building energy and water usage data for at least 5 years
7. Must comply with a minimum building area to site area ratio of at least 2%

I. Sustainable Sites (SS) (26 points possible/15 points awarded)

SS Prerequisite 1	*Construction Activity Pollution Prevention*	
SS Credit 1: (1/1)	*Site Selection*	Avoid development of inappropriate sites and reduce the environmental impact from the location of a building on site.
SS Credit 2: (5/5)	*Development Density and Community Connectivity*	Channel development to urban areas with existing infrastructure, protect greenfields, and preserve habitat and natural resources.
SS Credit 3: (1/1)	*Brownfield Redevelopment*	Rehabilitate damaged sites.
SS Credit 4.1: (6/0)	*Public Transportation Access*	Locate near public rail stations or bus stops.

SS Credit 4.2: (1/1)	*Bicycle Storage and Changing Rooms*	Provide secure bike racks and/or storage within 200 yards of a building entrance for 5% or more of all building users. Provide shower and changing facilities in the building for 0.5% of full-time equivalent occupants.
SS Credit 4.3: (3/3)	*Low-Emitting and Fuel-Efficient Vehicles*	Option 1: Provide preferred parking for low-emitting and fuel-efficient vehicles for 5% of the total vehicle parking capacity of the site. (Options 2, 3, and 4 not listed)
SS Credit 4.4: (2/2)	*Parking Capacity*	Option1: Size parking capacity to meet but not exceed minimum local zoning requirements. Provide preferred parking for carpools and vanpools. (Options 2 and 3 not listed)
SS Credit 5.1: (1/0)	*Protect or Restore Habitat*	
SS Credit 5.2: (1/1)	*Maximize Open Space*	Promote biodiversity by providing a high ratio of open space to development footprint.
SS Credit 6.1-2: (2/0)	*Stormwater Design*	Limit disruption of natural hydrology and pollution of natural water flows
SS Credit 7.1: (1/0)	*Heat Island Effect – Nonroof*	Reduce heat islands to minimize impacts on microclimates and human and wildlife habitats.
SS Credit 7.2: (1/1)	*Heat Island Effect – Roof*	Reduce heat islands to minimize impacts on microclimates and human and wildlife habitats. Use roofing materials with a solar reflectance index (SRI) of 78 for low-slope, 29 for steep-slope with the following requirement: $\frac{\text{Roof area meeting SRI}}{\text{Total roof area}} \text{X} \frac{\text{SRI installed}}{\text{Required SRI}} \geq 0.75$
SS Credit 8: (1/0)	*Light Pollution Reduction*	Minimize light trespass from the building and site, reduce sky-glow to increase night sky access and impact from lighting on nocturnal environments.

II. Water Efficiency (WE) (10 points possible/10 points awarded)

WE Prerequisite 1	*Water Use Reduction*	Employ strategies that in aggregate use 20% less water than the water use baseline calculated for the building (not including irrigation).
WE Credit 1: (4/5)	*Water Efficient Landscaping*	Reduce potable water consumption for irrigation by 50% from a calculated midsummer baseline case. Use captured rainwater, recycled wastewater, recycled graywater for irrigation.
WE Credit 2: (2/0)	*Innovative Wastewater Technologies*	Reduce potable water use for building sewage conveyance by 50% through the use of water-conserving fixtures or nonpotable water.
WE Credit 3: (4/5)	*Water Use Reduction*	Employ strategies that in aggregate use less water than the water use baseline calculated for the building (not including irrigation).

III. Energy and Atmosphere (EA) (35 points possible/30 points awarded)

EA Prerequisite 1	*Fundamental Commissioning of Building Energy Systems*	Verify the project's energy-related systems are installed and calibrated to perform according to the owner's project requirements, basis of design, and construction documents.
EA Prerequisite 2	*Minimum Energy Performance*	Establish the minimum level of energy efficiency for the proposed building and systems to reduce environmental and economic impacts associated with excessive energy use. Option 1: Demonstrate a 10% improvement in the proposed building performance rating for new buildings through a whole building energy simulation. (Options 2 and 3 not listed)
EA Prerequisite 3	*Fundamental Refrigerant Management Required*	Zero use of chlorofluorocarbon (CFC)-based refrigerants in new base building HVAC systems.

EA Credit 1: (19/19)	*Optimize Energy Performance*	Option 1: Demonstrate the percentage improvement in the proposed building performance rating compared with the baseline building performance rating through a whole building energy simulation. Calculate the baseline building performance according to Appendix G of ASHRAE 90.1-2007. Points awarded vary from 1 to 19 based on savings ranging from 12% to 48%. (Options 2 and 3 not listed)
EA Credit 2: (7/8)	*On-Site Renewable Energy*	Use on-site renewable energy systems to offset building energy costs. Points awarded vary from 1 to 7 based on percentage renewable ranging from 1% to 13%.
EA Credit 3: (2/0)	*Enhanced Commissioning*	Execute additional activities after systems performance verification is completed.
EA Credit 4: (2/0)	*Enhanced Refrigerant Management*	Use refrigerants and HVAC equipment that minimize or eliminate the emission of compounds that contribute to ozone depletion and climate change.
EA Credit 5: (3/3)	*Measurement and Verification (M&V)*	Develop and implement an M&V plan with a period covering at least 1 year of post-construction occupancy. Provide a process for corrective action if the results of the M&V plan indicate that energy savings are not being achieved.
EA Credit 6: (2/0)	*Green Power*	Engage in at least a 2-year renewable energy contract to provide at least 35% of the building's electricity from renewable sources.

IV. Materials and Resources (MR) (14 points possible/8 points awarded)

MR Prerequisite 1	*Storage and Collection of Recyclables*	Provide an easily-accessible dedicated area for the collection and storage of materials for recycling for the entire building.
MR Credit 1.1-2: (4/0)	*Maintain Existing Walls, Floors, Roof, and Interior Nonstructural Elements*	

MR Credit 2: (2/3)	*Construction Waste Management*	Recycle and/or salvage nonhazardous construction debris.
MR Credit 3: (2/0)	*Materials Reuse*	Use salvaged, refurbished, or reused materials.
MR Credit 4: (2/2)	*Recycled Content*	Use materials with recycled content.
MR Credit 5: (2/2)	*Regional Materials*	Use 10% to 20%, based on cost, building materials or products that have been extracted, harvested, recovered, or manufactured within 500 miles of the project site.
MR Credit 6: (1/0)	*Rapidly Renewable Materials*	Use 2.5%, based on cost, rapidly renewable (made from plants) building materials and products.
MR Credit 7: (1/1)	*Certified Wood*	Used 50%, based on cost, wood-based materials and products.

V. Indoor Environmental Quality (IEQ) (15 points possible/14 points awarded)

IEQ Prerequisite 1	*Minimum Indoor Air Quality Performance*	Meet the minimum requirements of ASHRAE 62.1-2007 Sections 4-7.
IEQ Prerequisite 2	*Environmental Tobacco Smoke Control*	Prohibit smoking in the building and on property within 25 feet of entries, air intakes, and operable windows.
IEQ Credit 1: (1/1)	*Outdoor Air Delivery Monitoring*	Install permanent monitoring systems to ensure that ventilation systems maintain design minimum requirements. Configure all monitoring equipment to generate an alarm when airflow values or CO_2 levels vary by 10% or more from design values.
IEQ Credit 2: (1/1)	*Increased Ventilation*	Increase breathing zone outdoor air ventilation rates to all occupied spaces by at least 30% above the minimum rates required by ASHRAE 62.1-2007.
IEQ Credit 3.1-2: (2/2)	*Construction Indoor Air Quality Management Plan*	Develop and implement an IAQ plan for the construction, pre-occupancy phases, and after all finishes have been installed.

IEQ Credit 4.1-4: (4/4)	*Low-Emitting Materials*	All adhesives, sealants, paints, coatings, flooring systems, composite woods, and agrifiber products must comply with the stated criteria.
IEQ Credit 5: (1/1)	*Indoor Chemical and Pollutant Source Control*	Design to minimize and control the entry of pollutants into buildings through entry ways, exhaust systems, and ventilation.
IEQ Credit 6.1: (1/1)	*Controllability of Lighting*	Provide individual lighting controls for 90% of the building occupants.
IEQ Credit 6.2: (1/0)	*Controllability of Thermal Control*	Provide individual comfort controls for 50% of the building occupants.
IEQ Credit 7.1: (1/1)	*Thermal Comfort – Design*	Design HVAC systems and the building envelope to meet the requirements of ASHRAE 55-2004.
IEQ Credit 7.2: (1/1)	*Thermal Comfort – Verification*	Provide a permanent monitoring system to ensure that building performance meets the desired comfort criteria as determined by IEQ Credit 7.1. Agree to conduct a thermal comfort survey of building occupants within 6 to 18 months of occupancy.
IEQ Credit 8.1: (1/1)	*Daylight*	Options 2 and 3: Use a combination of side-lighting and/or top-lighting to achieve a total daylighting zone that is at least 75% of all the regularly occupied spaces (per list criteria), and demonstrate through records of indoor light measurements that a minimum daylight illumination level of 25 fc has been achieved in at least 75% of all the regularly occupied spaces. (Options 1 and 4 not listed)
IEQ Credit 8.2: (1/1)	*Views*	Achieve a direct line of sight to the outdoor environment via vision glazing between 30 inches and 90 inches above the finish floor for building occupants in 90% of all regularly occupied areas.

VI. Innovation in Design (ID) (6 points possible/6 points awarded)

ID Credit 1: (5/5)	*Innovation in Design*	Achieved through any combination of the Innovation in Design and Exemplary Performance paths provided (not listed here).
ID Credit 2: (1/1)	*LEED Accredited Professional (AP)*	At least 1 principal participant of the project team shall be a LEED AP.

VII. Regional Priority (4 points possible/0 points awarded)

RP Credit 1: (4/0)	*Regional Priority*	Has environmental importance for a project's region.

APPENDIX D

Variable Air Volume Device Information

Variable Air Volume (VAV)	Associated Room Number	Maximum Air Flow Rate (cfm)	Minimum Air Flow Rate (cfm)	Reheat Coil Heating Water Flow Rate (gpm)	Sensors Associated with VAV c = CO_2, T = temp
1-1	File/Print 171	200	70	1	T
1-2	Open 174	1400	490	2	c T
1-3	Office 176	500	175	1	T
1-4	Conf 179	170	60	1	c T
1-5	Conf 178	170	60	1	c T
1-6	**Conf 177**	**550**	**195**	**1**	**c T**
1-7	Office 170	125	45	1	T
1-8	Corridor 175	350	125	1	T
1-9	Conf 172	160	60	1	T
1-10	Office 164	250	90	1	T
1-11	Office 155	480	170	1	T
1-12	Open 163	1650	580	2	c T
1-13	Corridor 151	1400	490	2	c T
1-14	Records 154	700	245	2	T
1-15	Corridor 156	1200	420	2	c T
1-16	Open 153	400	140	1	T
1-17	Open 153	600	210	1	c T
1-18	Conf 152	600	210	1	c T
1-19	Open 138	1200	420	2	c T
1-20	Corridor 151	950	335	2	T
1-21	Storage 123	1020	360	2	c T
1-22	Open 127	500	175	1	c T
1-23	Office 128	380	135	1	T
1-24	Office 126	890	315	2	c T
1-25	Office 122	650	230	1	T
1-26	Vestibule 100	370	130	1	T
1-27	Office 103	370	130	1	T
1-28	Reception 102	580	205	1	T
1-29	Office 105	260	90	1	T
1-30	Office 107	560	200	1	T
1-31	Office 117	880	310	2	c T
1-32	Open 112	1250	440	2	c T
1-33	Office 108	220	80	1	T
1-34	**Open 112**	**1040**	**365**	**2**	**c T**
1-35	Conf 106	410	145	1	c T
1-36	Open 115	880	310	2	c T
1-37	Ops 104	830	290	2	c T
1-38	Lobby 101	620	220	1	T
1-39	Office 157	360	130	1	T
Totals:		25,125	8,850		

Variable Air Volume (VAV)	Associated Room Number	Maximum Air Flow Rate (cfm)	Minimum Air Flow Rate (cfm)	Reheat Coil Heating Water Flow Rate (gpm)	Sensors Associated with VAV c = CO_2, T = temp
2-1	**Open 278**	**1800**	**630**	**2**	**c T**
2-2	Records 271	1600	560	2	c T
2-3	Office 274	750	265	2	T
2-4	Open 265	2100	735	2	c T
2-5	Open 205	1200	420	2	c T
2-6	Open 205	1250	440	2	c T
2-7	Office 262	540	190	1	T
2-8	Office 260	450	160	1	T
2-9	Office 254	920	325	2	T
2-10	Storage 253	850	300	2	c T
2-11	Office 252	300	105	1	T
2-12	Print 250	200	70	1	T
2-13	Conf 248	850	300	2	c T
2-14	Conf 249	450	160	1	c T
2-15	Break 244	980	345	2	c T
2-16	Open 232	900	315	2	c T
2-17	Maps 231	400	140	1	T
2-18	Wellness246	260	90	1	T
2-19	Office 230	240	85	1	T
2-20	Records 225	800	280	2	c T
2-21	IDF 227	890	315	2	T
2-22	Office 224	390	140	1	T
2-23	Open 223	900	315	2	c T
2-24	Library 222	960	340	2	c T
2-25	Open 223	1300	455	2	c T
2-26	Office 201	280	100	1	T
2-27	Office 203	260	90	1	T
2-28	Office 205	420	150	1	T
2-29	Office 213	1040	365	2	T
2-30	Office 215	450	160	1	T
2-31	**Open 208**	**1600**	**560**	**2**	**c T**
2-32	Open 208	1700	595	2	c T
2-33	Storage 206	600	210	1	T
2-34	Corridor 212	1600	560	2	c T
2-35	Corridor 214	900	315	2	c T
2-36	**Office 276**	**440**	**155**	**1**	**T**
Totals:		30,570	10,740		

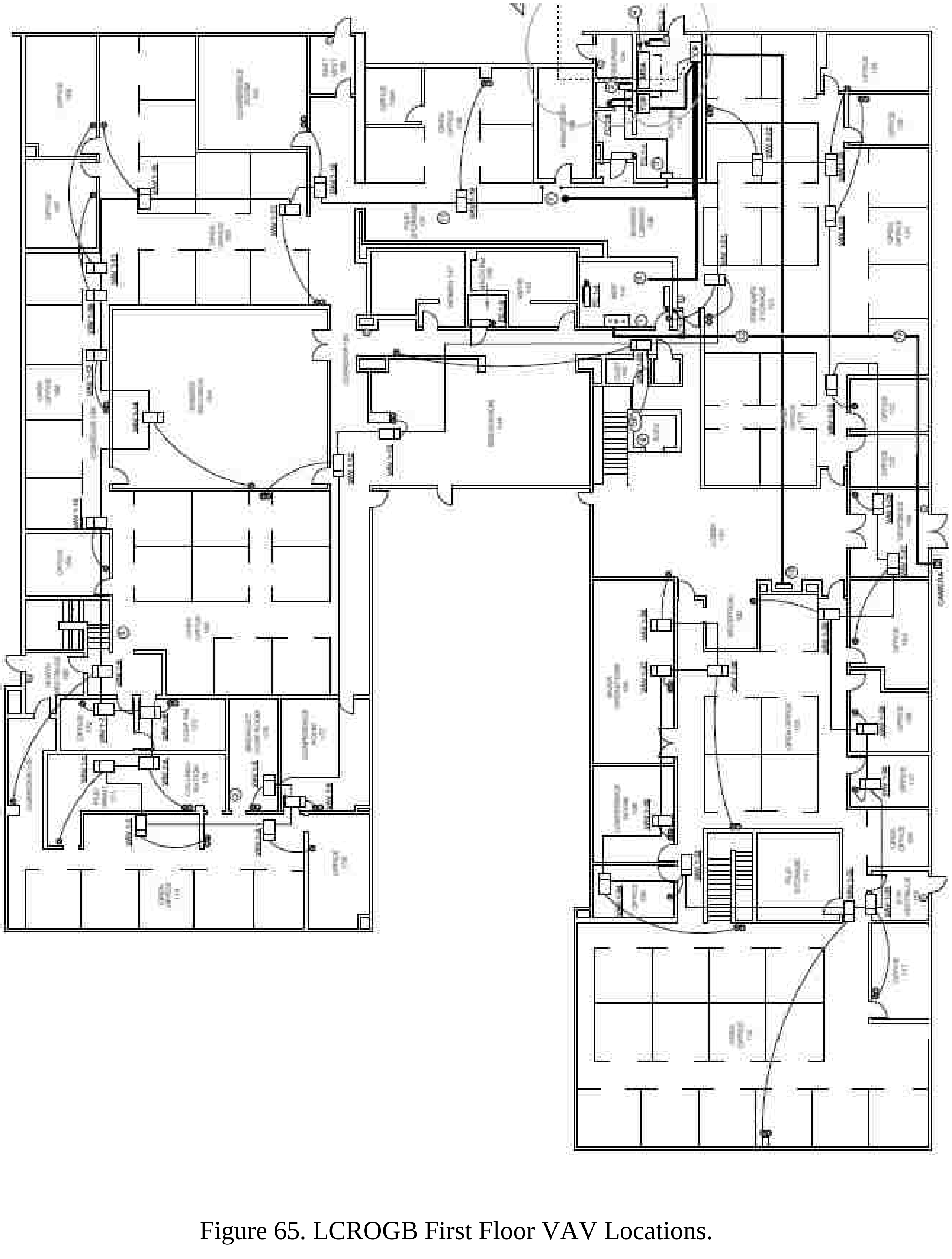


Figure 65. LCROGB First Floor VAV Locations.

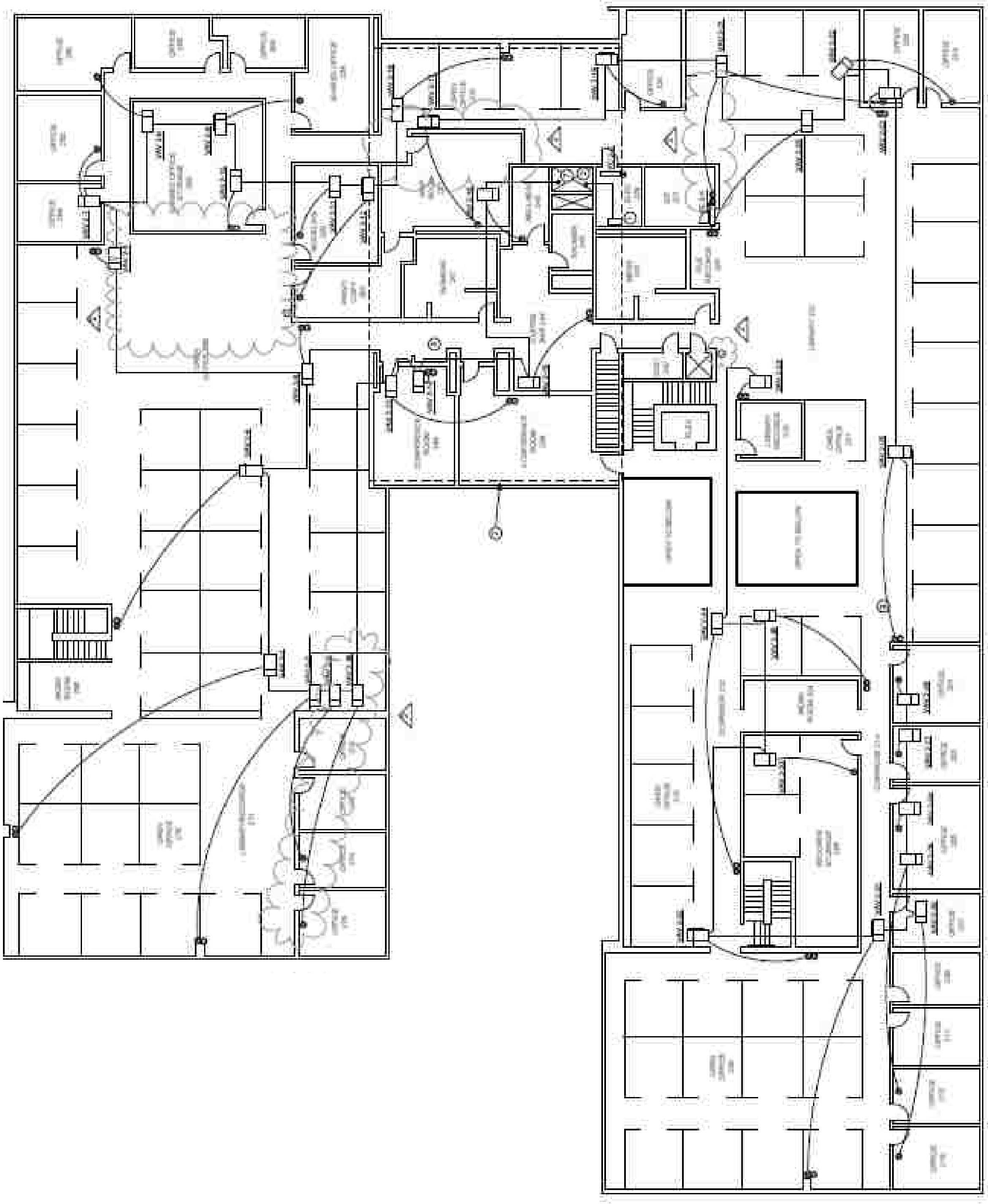


Figure 66. LCROGB Second Floor VAV Locations

APPENDIX E

ASHRAE 90.1-2007 Appendix G Summary

The following was excerpted from the ASHRAE 90.1-2007 Appendix G (ANSI/ASHRAE/IESNA, 2007). Many words, sections, and references have been intentionally omitted, and this list should not be used as an exact excerpt from ASHRAE 90.1-2007:

Informative Appendix G Performance Rating Method

G1.2 Performance Rating	Percentage Improvement = 100 X (Baseline building performance – Proposed building performance)/Baseline building performance 1. Both the proposed and baseline building performance shall include all end-use load components, such as receptacles and process loads. 2. Neither the proposed nor baseline building performance are predictions of actual energy consumption or costs for the proposed design after construction. Actual experience will differ from these calculations due to variations such as occupancy, building operation and maintenance, weather, energy use not covered by this procedure, changes in energy rates between design of the building and occupancy, and the precision of the calculation tool.
G2.1 Performance Calculations	The proposed and baseline building performance shall be calculated using the same simulation program, weather data, and energy rates.

G2.2 Simulation Program	The simulation program shall be a computer-based program for the analysis of energy consumption in buildings, such as DOE-2, BLAST, or EnergyPlus. The simulation program shall be approved by the rating authority and shall have the following modeling abilities. G2.2.1 a) 8760 hours per year, b) hourly variations in occupancy, lighting power, HVAC system operation, etc, c) thermal mass effects, d) 10 or more thermal zones, e) part-load performance curves for mechanical equipment, f) capacity and efficiency correction curves for mechanical heating and cooling equipment, g) air-side economizers with integrated control, h) baseline building design characteristics as specified (not listed here). G2.2.2 Ability to either directly determine the proposed and baseline building performance or produce hourly reports of energy use by energy source. G2.2.3 Capable of performing design load calculations to determine required HVAC equipment capacities and air and water flow rates for both proposed and baseline designs.
G2.3 Climatic Data	The simulation program shall perform the simulation using hourly values of climatic data, such as temperature and humidity from representative climatic data, for the site in which the proposed design is to be located.
G2.4 Energy Rates	Annual energy costs shall be determined using either actual rates for purchased energy or state average energy prices published by DOE's EIA for commercial building customers.
G3.1.1 Baseline HVAC System	HVAC systems in the baseline building design shall be based on usage, number of floors, conditioned floor area, and heating sources as specified. (Note: System 5 – Packaged VAV with Reheat – required based on non-residential, 5 floors or less, and 25,000 to 150,000 sf)

G3.1.2 General Baseline HVAC System Requirements	G3.1.2.1 All HVAC equipment shall be modeled at the minimum efficiency levels. G3.1.2.2 The equipment capacity shall be oversized by 15% for cooling and 25% for heating. Unmet load hours for proposed or baseline design shall not exceed 300 hours, and unmet load hours for the proposed design shall not exceed the baseline unmet load hours by more than 50 hours. G3.1.2.3 If the proposed HVAC system has a pre-heat coil, the baseline design shall be modeled with a pre-heat coil. G3.1.2.4 Supply and return fans shall operate continuously whenever spaces are occupied and shall be cycled to meet heating and cooling loads during unoccupied hours. G3.1.2.5 Minimum outdoor air ventilation rates shall be the same for proposed and baseline designs, except when modeling demand-control ventilation in the proposed design. G3.1.2.6 Outdoor air economizers shall be included in baseline design for HVAC System 5 based on climate zone. (Note: Climate Zone 3b corresponded to the LCROGB location) G3.1.2.7 The high-limit shutoff shall be a dry-bulb switch with set point temperature of 75 deg F for climate zone 3b.
	G3.1.2.8 Supply airflow rates for the baseline design shall be based on a supply-air-to-room-air temperature difference of 20 deg F or the required ventilation air, whichever is greater. If return fans are specified in the proposed design, the baseline design shall also be modeled with fans serving the same functions and sized for the baseline system supply fan air quantity less the minimum outdoor air, or 90% of the supply fan air quantity, whichever is larger. G3.1.2.9 System fan electrical power for supply, return, and exhaust (excluding fan-powered VAV devices) shall be calculated for System 5 as: P = bhp X 746/Fan Motor Efficiency (from Chapter 10)

G3.1.3 System-Specific Baseline HVAC System Requirements (System 5 guidance listed)	G3.1.3.2 The boiler plant shall use the same fuel as the proposed design and shall be natural draft. Boiler plant shall be modeled as having two equally sized boilers (> 15000 sf) and shall be staged as required by load. G3.1.3.3 Hot-water design supply temperature shall be modeled as 180 deg F with return temperature as 130 deg F. G3.1.3.4 Hot-water supply temperature shall be reset based on outdoor dry-bulb temperature using the given schedule (not listed here). G3.1.3.5 The baseline design hot-water pump power shall be 19 W/gpm. G3.1.3.6 Piping losses shall not be modeled in either the proposed or baseline designs for hot or chilled water. G3.1.3.12 The air temperature for cooling shall be reset higher by 5 deg F under the minimum cooling load conditions. G3.1.3.13 Minimum volume set points for VAV reheat devices shall be 0.45 cfm/sf of floor area served or the minimum ventilation rate, whichever is larger. G3.1.3.15 VAV system supply fans shall have variable-speed drives.

REFERENCES

ANSI/ASHRAE/IESNA Standard 90.1-2007 Energy Standard fro Buildings Except Low-Rise Residential Buildings I-P Edition. (2007). American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ANSI/ASHRAE Standard 55-2004 Thermal Environmental Conditions for Human Occupancy. (2004). American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ANSI/ASHRAE Standard 62.1-2007 Ventilation for Acceptable Indoor Air Quality. (2007). American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Architecture 2030. (2011). *Architecture 2030 Will Change the Way You Look at Buildings.* Downloaded January 22, 2014 from http://architecture2030.org/the_problem/buildings_problem_why.

ASHRAE 90.1. (2013). Retrieved January 29, 2014 from http://en.wikipedia.org/wiki/ASHRAE_90.1.

BEAM. (2012). Retrieved January 22, 2014 from http://www.beamsociety.org.hk/en_about_us_2.php.

BREEAM. (n.d.). Retrieved January 22, 2014 from http://www.breeam.org.

Building Energy Codes 101: An Introduction. (2010). U.S. Department of Energy Energy Efficiency & Renewable Energy.

Building Energy Software Tools Directory. (n.d.). U.S. Department of Energy Energy Efficiency & Renewable Energy. Retrieved August 24, 2013 from http://apps1.eere.energy.gov/buildings/tools_directory/subjects.cfm/pagename=subjects/pagename_menu=whole_building_analysis/pagename_submenu=energy_simulation.

BuildingGreen.com. (n.d.). Retrieved January 29, 2014 from http://www.buildinggreen.com.

CASBEE. (2013). Retrieved January 22, 2014 from http://www.ibec.or.jp/CASBEE/english.

CEPAS. (2014). Retrieved January 22, 2014 from http://www.bd.gov.hk/english.

China Green Buildings. (2009). Retrieved January 22, 2014 from http://chinagreenbuildings.blogspot.com.

CBECS: Commercial Buildings Energy Consumption Survey. (2003). U.S. Energy Information Administration. Retrieved January 29, 2014 from http://www.eia.gov/consumption/commercial/data/2003.

CBECS: Commercial Buildings Energy Consumption Survey. (2012). U.S. Energy Information Administration. Retrieved January 29, 2014 from http://www.eia.gov/consumption/commercial.

DGNB. (n.d.). Retrieved January 22, 2014 from http://www.dgnb.de/en.

Dirksen, T. H., McGowan, M. D. (2008). *Green Existing Buildings with LEED-EB!*. (Master’s Thesis, Massachusetts Institute of Technology, 2008).

DOE History Timeline. (n.d.). Energy.gov Office of Management. Retrieved 22 January, 2014 from http://energy.gov/management/office-management/operational-management/history/doe-history-timeline.

EA Credit 1: Optimize Energy Performance. (n.d.). Included in TSK LEED Submittal Data provided by USBR representatives on September 19, 2013.

EA Credit 2: On-Site Renewable Energy. (2011). Included in TSK LEED Submittal Data provided by USBR representatives on September 19, 2013.

EA Prerequisite 2: Minimum Energy Performance. (2012). Included in TSK LEED Submittal Data provided by USBR representatives on September 19, 2013.

Ecophone Saint-Gobain. (n.d.). *The Ecophon acoustic solutions as part of the Green Building Certification Systems.* Retrieved January 22, 2014 from http://www.ecophon.com/en.

Energy Design Resources Design Brief: Building Simulation. (n.d.). Southern California Edision. Retrieved October 27, 2013 from http://energydesignresources.com/resources/publications/design-briefs/design-brief-building-simulation.aspx.

EPA WaterSense. (2012). *WaterSense and Energy Star Stakeholder Meeting Summary: Encouraging Strategic Water Management in the Commercial Sector*. Retrieved January 29, 2014 from http://www.epa.gov/watersense/docs/ws-es_ci_meetingsummary_100212_final_508.pdf.

Estidama. (2010). Retrieved January 22, 2014 from http://estidama.org.

FAQ Standard 189.1. (n.d.). ASHRAE. Retrieved January 25, 2014 from https://www.ashrae.org/resources--publications/bookstore/standard-189-1.

Federal Energy Management Program. (2012). U.S. Department of Energy Energy Efficiency & Renewable Energy. Retrieved January 25, 2014 from energy.govnode782456programsustainable_principles.html.

Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding. (2006). U.S. Federal Government. Retrieved January 25, 2014 from wbdg.org__pdfs__sustainable_mou.pdf.

Fedrizzi, S. R., Gottfried, D. A., Italiano, M. (n.d.). *U.S. Green Building Council 2013-2015 Stratigic Plan.*

Gifford, H. (n.d.). *A Better Way to Rate Green Buildings.* Retrieved January 22, 2014 from http://www.energysavingscience.com.

Glover, T. J. (1994). *Pocket Ref.* Sequoia Publishing, Inc. Littleton, Colorado.

Google Earth Imagery. (2013). Retrieved February 14, 2013 from earth.google.com.

Green Building Certification System Review.(n.d.) General Services Administration. Retrieved January 22, 2014 from http://www.gsa.gov/portal/content/ 131983?utm_source=OGP&utm_medium=print-radio&utm_term= gbcertificationreview&utm_campaign=shortcuts.

Green Building in Boulder City. (2011). U.S. Department of the Interior Bureau of Reclamation. Retrieved August 30, 2013 from http://www.usbr.gov/lc/region/ programs/greenbuilding/factsheet.pdf.

Green Building Performance: A Post-Occupancy Evaluation of 22 GSA Buildings. (2011). General Services Administration Public Buildings Services. Retrieved February 1, 2014 from http://www.gsa.gov/portal/content/103961.

Green Globes. (n.d.). Retrieved January 22, 2014 from http://www.greenglobes.com/ about.asp#history.

Haberl, J. and Cho, S. (2004). *Literature Review of Uncertainty of Analysis Methods (DOE-2 Program)*. Energy Systems Laboratory, Texas A&M University. Retrieved November 8, 2013 from http://repository.tamu.edu.

Hart, D. M. (2009). *Don't Worry About the Government? The LEED-NC 'Green Building' Rating System and Energy Efficiency in U.S. Commercial Buildings*. Industrial Performance Center Massachusetts Institute of Technology.

Hartley, C. A. (2013). Development of Next Generation Energy Audit Protocols for the Rapid and Advanced Analysis of Building Energy Use. (Master's Thesis, University of California, Irvine, 2013).

High Performance and Sustainable Buildings Guidance (Final 12/1/08). (2008). U.S. Federal Government. Retrieved January 25, 2014 from http://www.wbdg.org/pdfs/hpsb_guidance.pdf.

Hirsch, J. J. & Associates. (n.d.) *Welcome to DOE2.com: The Home of DOE-2 Based Building Energy Use and Cost Analysis Software.* Retrieved November 8, 2013 from http://www.doe2.com.

Hirsch, J. J. & Associates. (2010). *eQUEST Introductory Tutorial, version 3.64.*

History of Major Energy Policy Landmarks. (2014). PennState College of Earth and Mineral Sciences Department of Geography. Retrieved January 22, 2014 from https://www.e-education.psu.edu/geog432/node/116.

IEQ Credit 1: Outdoor Air Delivery Monitoring. (n.d.). Included in TSK LEED Submittal Data provided by USBR representatives on September 19, 2013.

IEQ Credit 2: Increase Ventilation. (n.d.). Included in TSK LEED Submittal Data provided by USBR representatives on September 19, 2013.

IEQc6.1_CurrentReviewComments. (n.d.). Included in TSK LEED Submittal Data provided by USBR representatives on September 19, 2013.

IEQ Credit 8.1: Daylight and Views – Daylight. (n.d.). Included in TSK LEED Submittal Data provided by USBR representatives on September 19, 2013.

International Living Future Institute. (n.d.). Retrieved January 22, 2014 from https://ilbi.org.

Janssen, J. E. (1999). *The History of Ventilation and Temperature Control.* ASHRAE Journal, September, 1999.

Kusuda, T. (1999). *Early History and Future Prospects of Building System Simulation.* International Building Performance Simulation Association. Retrieved November 8, 2013 from http://www.ibpsa.org/proceedings/BS1999/BS99_P-01.pdf.

LEED Certification Project Review Report. (2012). Boulder Canyon Operations Office Project ID: 1000004579. Green Buildings Certification Institute. Included in TSK LEED Submittal Data provided by USBR representatives on September 19, 2013.

LEED V2009 for New Construction and Major Renovations. (2009). U.S. Green Building Council. Retrieved January 22, 2014 from http://www.usgbc.org/node/1731022?return=/credits/new-construction/v2009

Lower Colorado Regional Office Green Building Specification Revisions. (2010). U.S. Department of the Interior Bureau of Reclamation. Included in As-Built Data provided by USBR representatives on February 14, 2013.

Measurement and Verification Plan. (2011). Included in TSK LEED Submittal Data provided by USBR representatives on September 19, 2013.

MSA Engineering Consultants. (n.d.). *EAp2_EAp2 Section 1.4 tables-REV1*. Included in TSK LEED Submittal Data provided by USBR representatives on September 19, 2013.

MSA Engineering Consultants. (2011a). *Boulder Canyon Operations Office – As-Built Mechanical*. Included in As-Built Data provided by USBR representatives on February 14, 2013.

MSA Engineering Consultants. (2011b). *EAp2_Building_Input_Data_REV1*. Included in TSK LEED Submittal Data provided by USBR representatives on September 19, 2013.

MSA Engineering Consultants. (2011c). *EAp2_20090810_9_lighting_forms-REV1*. Included in TSK LEED Submittal Data provided by USBR representatives on September 19, 2013.

MSA Engineering Consultants. (2011d). *EAP2_Building Simulation Report-REV1*. Included in TSK LEED Submittal Data provided by USBR representatives on September 19, 2013.

NABERS. (n.d.). Retrieved January 22, 2014 from http://www.nabers.gov.au.

National Building Performance Initiative. (2005). Legal Information Institute Cornell University Law School. Retrieved January 22, 2014 from http://www.law.cornell.edu/uscode/text/42/16193.

Ozone. (2010). U.S. Environmental Protection Agency. Retrieved February 10, 2014 from http://www.epa.gov/ozone.

Public LEED Project Directory. (2013). U.S. Green Building Council. Retrieved January 29, 2014 from http://www.usgbc.org/LEED/Project/CertifiedProjectList.aspx.

Reclamation Building Receives Top Sustainability Rating. (2013). U.S. Department of the Interior Bureau of Reclamation. Retrieved January 29, 2014 from http://www.usbr.gov/lc/region/feature/LEEDcertification.html.

Scofield, J. H. (2009). *A Re-examination of the NBI LEED Building Energy Consumption Study.* 2009 Energy Program Evaluation Conference, Portland, Oregon (pp. 764-777).

Summary of Comments Received During the 60-Day Public Comment Period on Green Building Certification Ssytems Review. (2013). U.S. General Services Administration. Retrieved January 22, 2014 from http://www.gsa.gov/portal/mediaId/180471/fileName/Executive_Summary_of_GBCS_Comments_(3).action.

Tate Snyder Kimsey (TSK) Architects. (2011). *Lower Colorado Regional Office Green Building As-Built Drawings.* Included in As-Built Data provided by USBR representatives on February 14, 2013.

Tincher, T. Photographs. (2013). With USBR permission, taken during tours of facility.

TMCx Solutions, LLC. (2011). *Final Commissioning Report.* Included in TSK LEED Submittal Data provided by USBR representatives on September 19, 2013.

Turner, C. and Frankel, M. (2008). *Energy Performance of LEED for New Construction Buildings.* New Buildings Institute, Vancouver, Washington.

Turner, M. M. (2010). *Is LEED a True Leader? Studying the Effectiveness of LEED Certification in Encouraging Green Building*. (Undergraduate Thesis, Pomona College, 2010).

User's Manual for ANSI/ASHRAE/IESNA Standard 90.1-2004: G. Building Performance Rating Method. (2004). ASHRAE. Retrieved November 8, 2013 from http://web.cecs.pdx.edu/~sailor/CoursePages/ME422_Spr09/ASHRAE90_1Appendix_G.pdf.

USBR Historical Photographs. (n.d.). Provided by USBR representatives on February 14, 2013.

USGBC.org. (n.d.). Retrieved January 22, 2014 from usgbc.org.

U.S. Green Building Council. (2009). *Regional Green Building Case Study Project: A post-occupancy study of LEED projects in Illinois.* Center for Neighborhood Technology. Retrieved August 24, 2013 from http://www.cnt.org/resources/regional-green-building-case-study-project-a-post-%C2%90occupancy-study-of-leed-projects-in-illinois.

U.S. Green Building Council. (2011). *Advanced Energy Modeling For LEED: Technical Manual v2.0 September 2011 Edition.*

Valley Custom Interiors, Inc. (2011). Level – 1 and 2 Floor Plans, Sheet No. 0.1 and 0.2, Arch/I.D. Ref: A1.21 and A1.22. Included in As-Built Data provided by USBR representatives on February 14, 2013.

Wang, N., Fowler, K. M., & Sullivan, R.S. (2012). *Green Building Certification System Review*. U.S. Department of Energy document PNNL-20966.

Watson, R. (2009). *Green Building Market and Impact Report 2009.* Greener World Media.

Whiting-Turner (WT). (2011). *Operation and Maintenance Manuals.* Included in As-Built Data provided by USBR representatives on February 14, 2013.

Yeung, B. (n.d.). *IEQ Credit 2: Minimum Indoor Air Quality Performance.* MSA Engineering Consultants. Included in TSK LEED Submittal Data provided by USBR representatives on September 19, 2013.

CURRICULUM VITAE

Theresa Tincher

EDUCATION:

MS, 2014, Mechanical Engineering, University of Nevada Las Vegas
MA, 2004, Education: Curriculum and Instruction (Mathematics Specialization), California State University, Sacramento CA
BS, 1984, Mechanical Engineering, California State University, Northridge CA
AS, 1981, Preparatory Engineering, Antelope Valley College, Lancaster CA

WORK HISTORY

JBA CONSULTING ENGINEERS, Las Vegas, Nevada

Project Management Office Intern (Jan 2014 – present)

Assisting with implementation of project management policies and procedures and use of new project tracking software

UNIVERSITY OF NEVADA LAS VEGAS, Academic Success Center, Las Vegas, Nevada

Graduate Assistant (Aug 2012 – Dec 2013)

Responsible for managing and assisting staff of approximately 75 subject-matter tutors and desk managers servicing UNLV students enrolled in math, science, engineering, business, and foreign language courses.

ARIZONA WESTERN COLLEGE, Yuma, Arizona

Faculty - Engineering and Mathematics (Jan 2006 – June 2012)

Taught mostly on-campus, and continued on-line when husband’s work transferred to Boulder City, Nevada in January, 2009.

Lead Engineering Advisor (Aug 2007 – Dec 2008)

Advised students enrolled at AWC and continuing on to major universities about opportunities in engineering, course requirements, transfer credits, and student internships. Established student internship program between AWC and local business partners.

Mathematics Tutor (Aug 2004 – Dec 2004)

Data Analyst and Technical Writer/Editor

While at AWC, acted as primary analyst and supporting writer/editor for both the Student Success Center and Mathematics Department 6-year Program Reviews provided to AWC's upper administration.

U.S. ARMY YUMA PROVING GROUND, Yuma, Arizona

Senior Systems Engineer (Consultant) – EC III Inc. (Jan 2006 - Sep 2006)

Senior Systems Engineer – EC III Inc. (Jan 2005 - Jan 2006)

Supported a variety of U.S. military tests for airborne systems. Duties included managing test programs, data analysis, technical writing, editing, and briefing. Resigned from full-time employment after first year to return to teaching. Continued to maintain clearances to consult on a part-time basis at YPG through EC III Inc while teaching at AWC.

CALIFORNIA STATE UNIVERSITY, Sacramento, California.

Associate Faculty – Engineering and Mathematics (Sep 2002 - Jul 2004)

Resigned to relocate with husband's job.

Mathematics Tutor (while obtaining master's degree) - (Sep 2001 - Sep 2002).

Master's thesis involved analyzing and documenting educational backgrounds from nearly 1000 college freshmen.

BALL AEROSPACE & TECHNOLOGIES CORP., Sacramento, California

Operation Manager. (Feb 1995 - Sep 2001)

Managed the local division of Ball Aerospace consisting of approximately 40 engineers, mathematicians, scientists, and administrators working on a variety of U.S. and Australian Department of Defense programs. Major responsibilities included day-to-day operation management, long and short term planning and marketing, contract negotiation, management of all operation finances and personnel issues, progress reporting to upper management located in Ohio and Colorado, and continuing with necessary engineering assignments, including data analysis and technical writing and briefing. Successfully led corporate effort to open new operations in Australia in 1996 that reported directly to me for two years. With local base closure, led team in developing new client base and technical expertise. Resigned from Ball Aerospace to begin master's degree and pursue new career in teaching math and engineering at the college level.

Lead Systems Engineer. (Apr 1991 - Feb 1995)

Led teams of engineers and scientists in integrating, flight testing and evaluating flight control and navigation systems in U.S. and Australian military aircraft. Responsibilities included coordination of all planning and execution of tasks, effectively communicating with flight crews, maintenance crews, flight coordinators, and all levels of management, conducting and overseeing detailed data analyses, and documenting engineering findings in technical publications and briefings. Effort led to promotion into management.

AIR FORCE FLIGHT TEST CENTER, Edwards Air Force Base, California

Flight Test Engineer (civilian). (Dec 1984 - Mar 1990)

Specialized in flight testing digital flight control systems on U.S. Air Force aircraft and developing aerodynamic models for new aircraft. Required skills in engineering and communication, including both technical writing and briefing. Resigned to bicycle tour and relocate to Sacramento CA.

Engineering Cooperative-Work Education Program. (Dec 1980 - Dec 1984)

While obtaining first engineering degree, worked on design requirements for liquid and solid propulsion systems for launch/satellite systems at the USAF Rocket Propulsion Lab. Job involved data analysis, technical writing, and briefing.

SKILLS:

Exceptional communication, team building, and organizational skills.
Specialist in technical writing and editing.
Extensive experience with data collection and analyses.
Computer skills include Microsoft products, database management, MathCad, EES

PROFESSIONAL AWARDS, NOMINATIONS, AND AFFILIATIONS:

Arizona Western College
  2008 Teacher of the Year Nomination by colleagues – withdrawn due to my relocation to NV
Ball Aerospace & Technologies Corp./Systems Engineering Division
  1996 “National Manager of the Year”
Air Force Flight Test Center
  1988 Scientific and Engineering Excellence Award (“civilian engineer of the year”)
ASME Member
ASHRAE Member