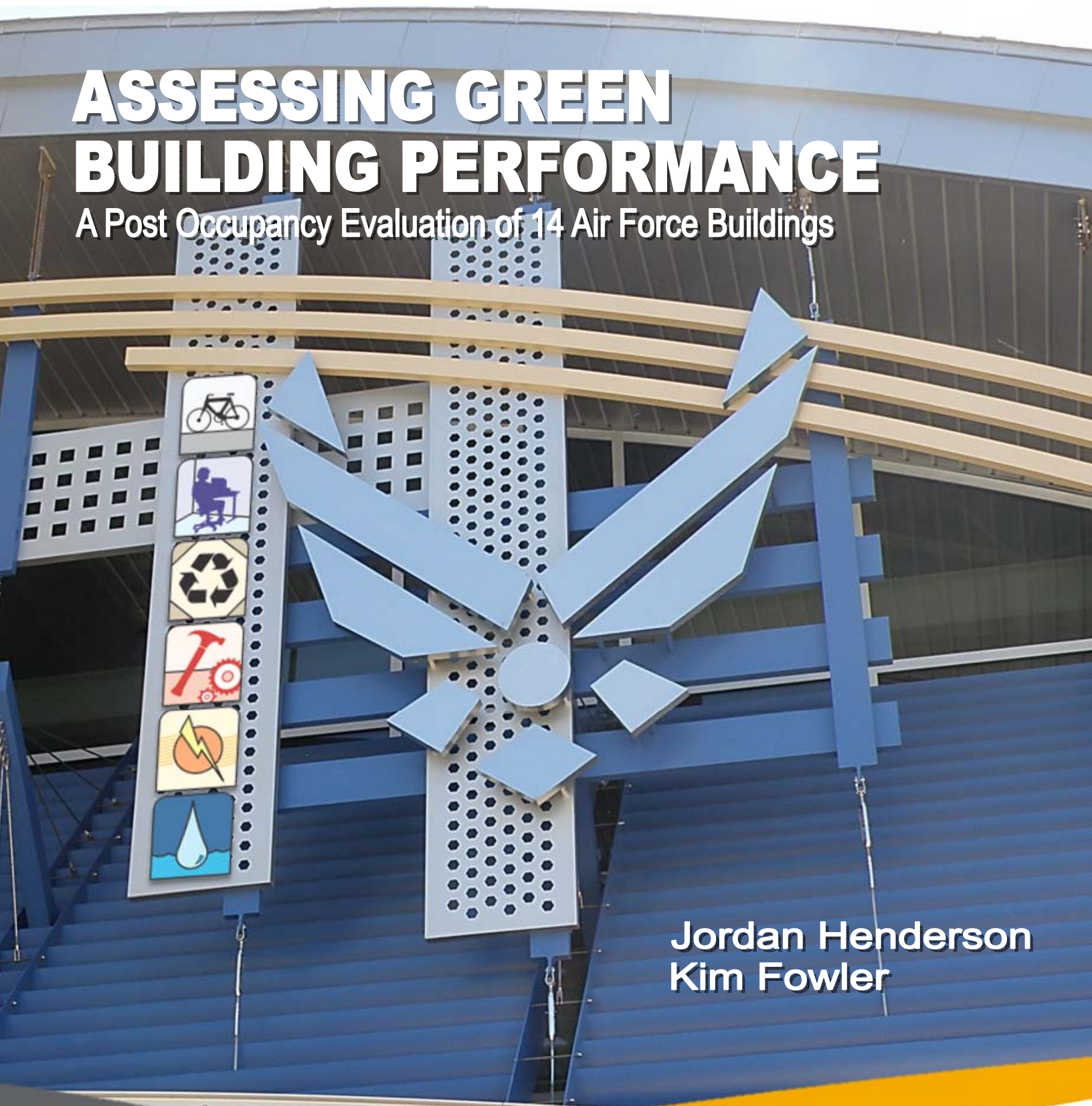
ASSESSING GREEN BUILDING PERFORMANCE

A Post Occupancy Evaluation of 14 Air Force Buildings



Jordan Henderson
Kim Fowler

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

PNNL-23426

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Assessing Green Building Performance

A Post Occupancy Evaluation of 14 Air Force Buildings

June 2014

JH Henderson
KM Fowler

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <http://www.ntis.gov/about/form.aspx>
Online ordering: http://www.ntis.gov

This document was printed on recycled paper.
(8/2010)

Assessing Green Building Performance

A Post Occupancy Evaluation of 14 Air Force Buildings

JW Henderson
KM Fowler

June 2014

Prepared for
the U.S. Air Force
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Acknowledgements

This study was conducted under the direction of Christopher Kruzel with assistance from Thomas Rech of the U.S. Air Force Civil Engineering Center (AFCEC). Jordan W. Henderson of the Pacific Northwest National Laboratory (PNNL) led the PNNL research team as the principal investigator of the study. Kim M. Fowler was co-author of the report, performed two site visits, and provided senior research support. Dan Skorski and Laura Turo contributed to the analysis effort. Additional contributing PNNL staff include Nora Wang (technical peer reviewer), and Shannon Colson (graphics). John Goins and Joan Victoria from the Center for the Built Environment (CBE) were instrumental in administration of the occupant satisfaction survey.

Because of the need for a large quantity of data for each building, the Air Force buildings' site contacts were generous with their time and data. The site contacts offered their time to host site visits, provided data for the building performance metrics, and promptly responded to our requests for clarification. Fourteen of the buildings pursued in this study lent themselves to assembling comparable data sets for analysis. The site contacts that helped make this study possible include the following:

Patrick Johnston, Base Personnel Office
David Harrell, Building 2800
Andy Hinojosa, Mission Support Center
Robert Flood, AFIT Engineering Building
Jeremy Eisenbrandt, Base Education Center
Patrick Johnston, Fire Crash Rescue Station
Ruben Ramos, Rambler Fitness Center
Robert Conklin, Weather Agency HQ
David Harrell, Consolidated Support Facility
Ruben Ramos, AFPC Admin Facility
Daniel Rohrbach, AFIT Academic Facility
Kyle Davies, McElveen MRC Library
Elias Schtakleff, Main Fire Station
Jonathan Caldwell, Tyndall Fitness Center

Thank you to these and all others that contributed to this research effort.

Executive Summary

The U.S. Air Force sustainably designed buildings investigated under this study use less energy and water, cost less to maintain, and have occupants that are satisfied when compared to their matched-pairs. Additional findings from the building performance analysis include:

- Aggregate operations costs are 15% lower than typically designed buildings
- U.S. Green Building Council Leadership in Energy and Environmental Design (LEED) Gold & Platinum rated buildings were generally top-performers

Figure S1 represents the energy, water, maintenance, and aggregate operational costs for each of the fourteen buildings investigated (six office buildings, four academic facilities, two fire stations and two fitness centers). All of the energy use intensity values for the LEED certified Air Force buildings were better than their industry baseline and outperformed their matched-pair. The top six buildings in the energy metric and four out of five of the buildings in the water metric were LEED certified. Thirteen of the fourteen buildings in this study had aggregate maintenance costs that were better than the industry baseline. The top two buildings in the maintenance cost metric were LEED-Gold certified. The buildings performing the best in all categories are shaded dark blue and located in the top-right quadrant.

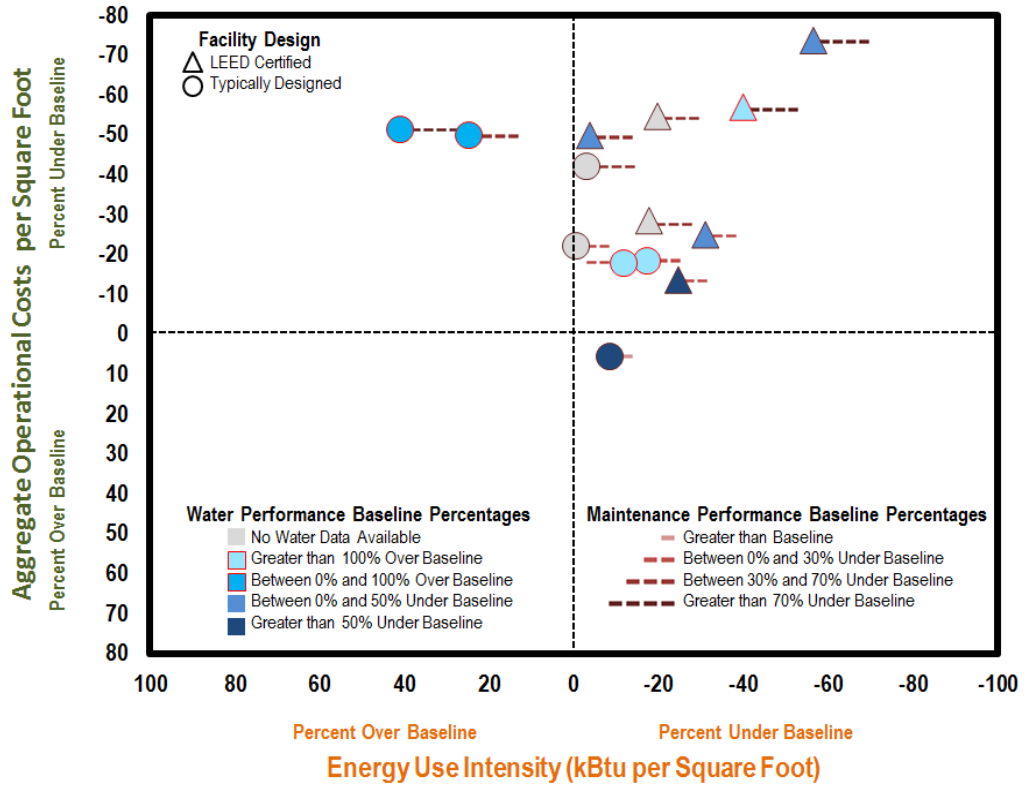


Figure S1. Energy and maintenance performance is better than the baseline for all of the LEED certified buildings.

This whole building performance measurement study uses the Building Cost and Performance Metrics: Data Collection Protocol to collect performance criteria for seven sustainably designed buildings and seven traditionally designed buildings from eight US Air Force Bases (Figure S2). The structure of this report follows the Re-Assessing Green Building Performance: A Post Occupancy Evaluation of 22 GSA Buildings study as a framework. The intent of the analysis is to inform the Air Force on how its sustainably designed buildings are performing in comparison to industry and typically designed buildings for energy, water, maintenance and operations, occupant commute, and occupant satisfaction. The baselines selected for the whole building performance analysis set the boundaries for the study findings. This study uses matched-pairs in conjunction with industry baselines for the comparative analysis. Seven of the buildings are LEED for New Construction certified (one LEED-Platinum, two LEED-Gold, three LEED-Silver, and one LEED-Certified) while the seven comparable buildings were built to typical US Air Force standards (the matched-pairs).

Figure S2. Seven sustainably designed buildings and seven traditionally designed buildings from eight US Air Force Bases are analyzed in this study.

The Air Force has been aggressively pursuing sustainable design and development for over 10 years. As of fiscal year 2011, the Air Force, who manages approximately 70,000 buildings in support of its defense mission, had over 30 LEED certified facilities, 736 LEED Silver certified homes and roughly 300 LEED registered projects. Although this study involved a small number of buildings, especially when considering the size of the Air Force portfolio, it is important to validate the correlation between and the return on investment of high performance, sustainable design to real world facility operations. LEED certification levels of the buildings in this study are shown in Table S1.

Table S1. Documentation of "green-ness" of study buildings.

Building Name	LEED Version	LEED Rating	Total points	LEED EAc1 Points	LEED WEc3 Points	LEED SSc Points
B323	N/A	N/A	N/A	N/A	N/A	N/A
B185	LEED NC 2.1	Gold	41	8	2	6
B2800	N/A	N/A	N/A	N/A	N/A	N/A
B3000	LEED NC 2.1	Silver	35	1	1	10
B2484	N/A	N/A	N/A	N/A	N/A	N/A
B667	LEED NC 2.2	Gold	40	5	2	8
B643	N/A	N/A	N/A	N/A	N/A	N/A
B646	LEED NC 2.2	Silver	34	7	2	8
B501	N/A	N/A	N/A	N/A	N/A	N/A
B827	LEED NC 2.1	Silver	34	6	2	6
B288	N/A	N/A	N/A	N/A	N/A	N/A
B4601	LEED NC 2.1	Certified	27	3	1	5
B999	N/A	N/A	N/A	N/A	N/A	N/A
B1601	LEED NC 2.2	Platinum	54	10	2	10

Table Notes

LEED-NC is LEED for New Construction and Major Renovations
EA is USGBC's Energy and Atmosphere topic area
WE is USGBC's Water Efficiency topic area
SS is USGBC's Sustainable Sites topic area

Performance metrics collected, normalized, and analyzed for the buildings include

- Water
- Energy
- Maintenance and operations

These performance metrics were chosen to evaluate the intent of sustainable design - reduced environmental impact while keeping operational costs low and occupant satisfaction high.

Building contacts provided utility bills, maintenance budgets and schedules, and supported the administration of an occupant survey. Twelve consecutive months of data were collected for each performance metric (where available) and the data were normalized using building and site characteristics. The performance data were compared to industry baselines from the U.S. Environmental Protection Agency, International Facility Management Association, Building Owners and Managers Association International, University of

California Berkeley's Center for the Built Environment, and the Energy Information Administration.

Aggregate Operational Cost is Lower in Sustainably Designed Buildings

The "aggregate operating cost" metric includes water utilities, energy utilities, general maintenance, grounds maintenance, and janitorial costs. Thirteen of the fourteen Air Force buildings performed better than the industry baseline, with one having an aggregate operating cost 6% higher baseline largely because of the building's general maintenance performance. On average, the seven LEED certified buildings have an aggregate operational cost 43% lower than industry average and 15% lower than the matched-pairs. Six of the seven buildings cost less than their respective pair as shown in Figure S3. The 1% difference in that matched-pair was due to higher total maintenance costs despite having lower energy and water costs.

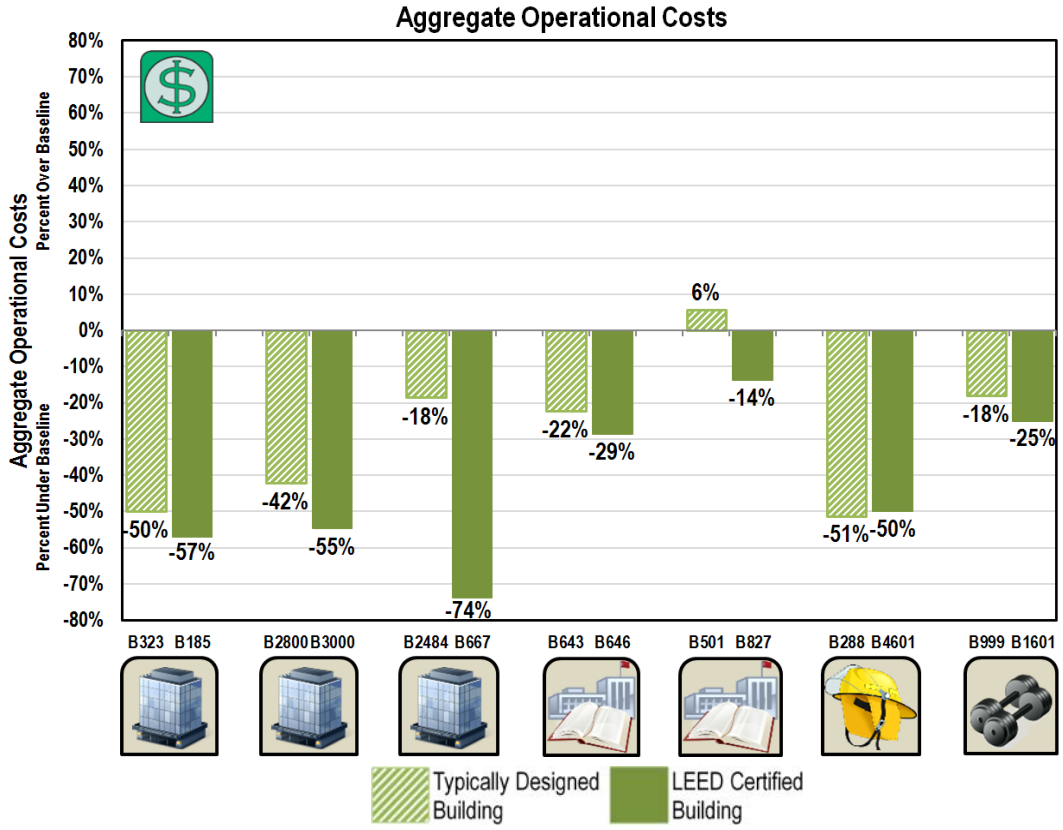


Figure S3. Aggregate operational costs are lower for most buildings.

Energy Performance is Better than Baselines and Matched-Pairs

The buildings' energy use intensity (EUI) was compared to multiple different baselines (Figure S4), with the most commonly referenced baselines being from the Commercial Building Energy Consumption Survey (CBECS) and EPA's Energy Star® 50th percentile for office buildings. In addition to comparing to industry standards, the sustainably designed buildings were also compared to their matched-pair's respective performance. The energy performance of the sustainably designed buildings in the study was on average 28% better than industry baselines and 28% better than their matched-pairs. The industry baselines included CBECS specific regional average and EPA's Energy Star 50th percentile depending on the characteristics of the buildings. More information on energy and other baselines is located in the body of the report.

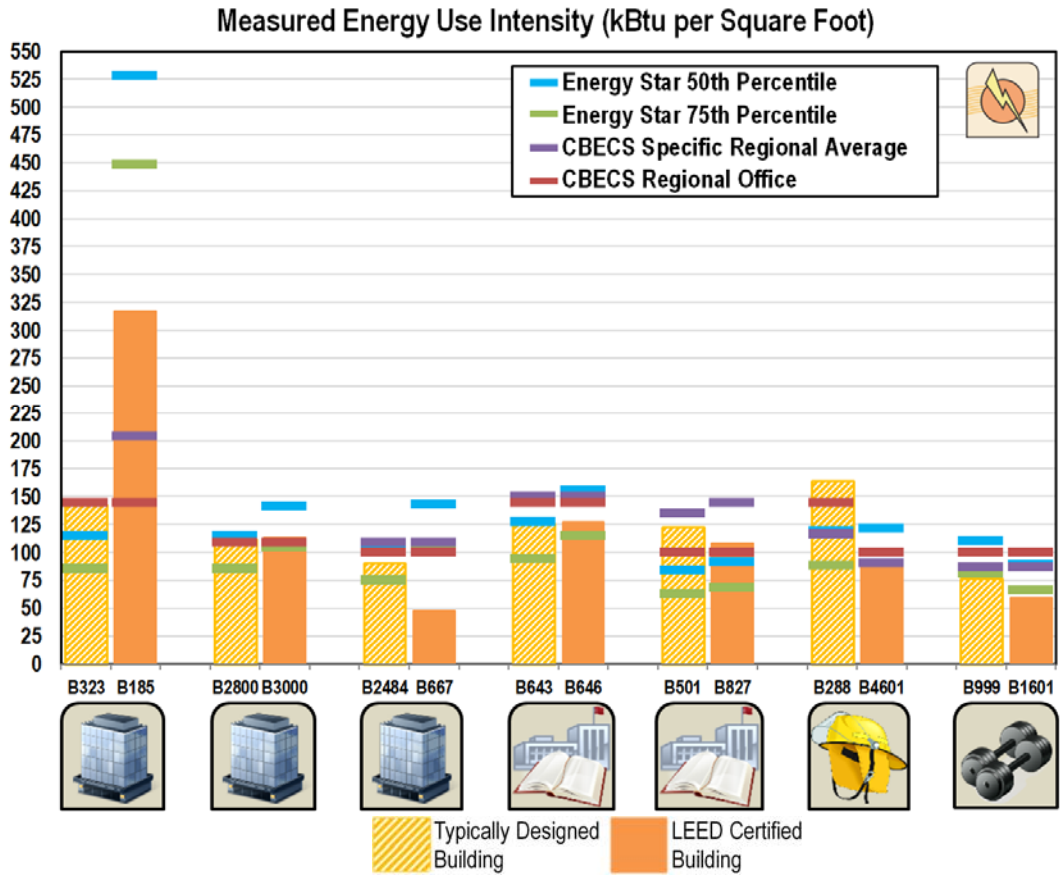


Figure S4. Energy performance of Air Force buildings is strong when compared to industry averages and typically designed Air Force buildings.

Water Use is Lower than Baseline

The common metric for assessing the water use of buildings is water use per gross square foot, also known as water use intensity (WUI). Five matched-pairs in this assessment had quality water data that could be used for this analysis. The WUI metric that four of the five sustainably designed buildings in this study use less water than the IFMA baseline (Figure S5) with the average water use 7% below the industry baseline. Of the five sustainably designed buildings with water data, three of the buildings largely outperformed their matched-pairs with two using slightly more water per square foot. The only sustainably designed building that is using more water per square foot than the industry baseline and its matched-pair has approximately 900 occupants, a two cell cooling tower with a below grade concrete basin, a coffee/sandwich shop in the foyer, and several large data centers areas with a non-typical operating schedule. The combination of these factors is assumed to contribute to the higher water use for that building. On average the sustainably designed buildings in this study use 32% less water per square foot than their matched-pairs.

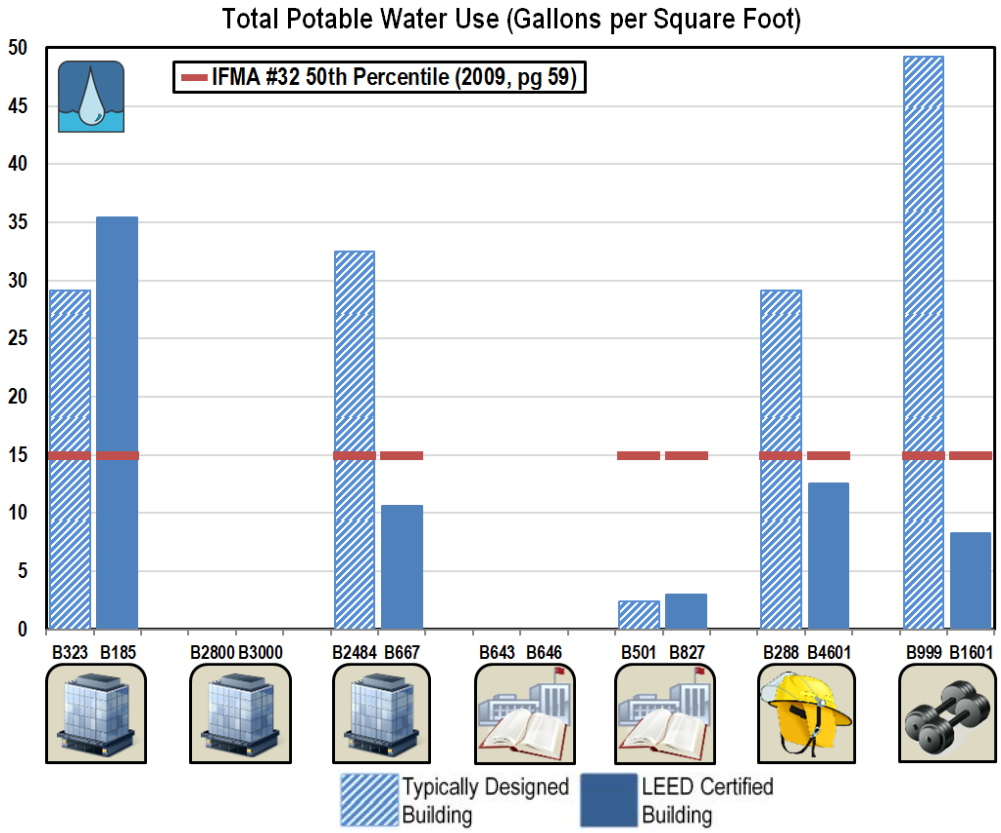


Figure S5. Green Air Force buildings use less water.

As with energy, there are multiple baselines with which the buildings' water use can be analyzed. Water cost per square foot is another metric used, with three out of the five sustainably designed buildings having lower water costs than their matched-pairs. On average, the water costs in the sustainably designed buildings were 16% less than the typical Air Force buildings in this study. The water use in these buildings was also analyzed based

on the quantity of domestic water use and the number of building occupants and visitors. This metric was examined however the comparison was erratic because of the variety of water uses in the buildings, with several buildings using more than the calculated baseline.

Occupants are Satisfied with the Buildings

This study attempted to use the Center for the Built Environment's (CBE) occupant satisfaction survey to assess the Indoor Environmental Quality (IEQ) of the selected buildings. Only six (three LEED certified and three typically designed) of the fourteen buildings in this study had at least one response. Of the buildings with responses, most had low survey response rates with the average response rate being 15%. Based on these limited responses, the occupants in the three LEED certified Air Force facilities scored higher on average with respect to building satisfaction than both their matched-pairs and the CBE 50th Percentile. Given the CBE's target of a 50% response rate, minimal analysis could be done with the survey data and these results should be considered observational.

LEED Gold & Platinum Buildings Perform Well

Figure S6 shows overall the two LEED Gold buildings and one LEED Platinum building in the study performed well in most of the key performance metrics with regards to baseline and their matched-pairs. Although water performance of the Main Weather Station HQ (B185) is above baseline, B185 is the building noted previously with the large number of occupants and visitors, small cafeteria and unique water-using operations.

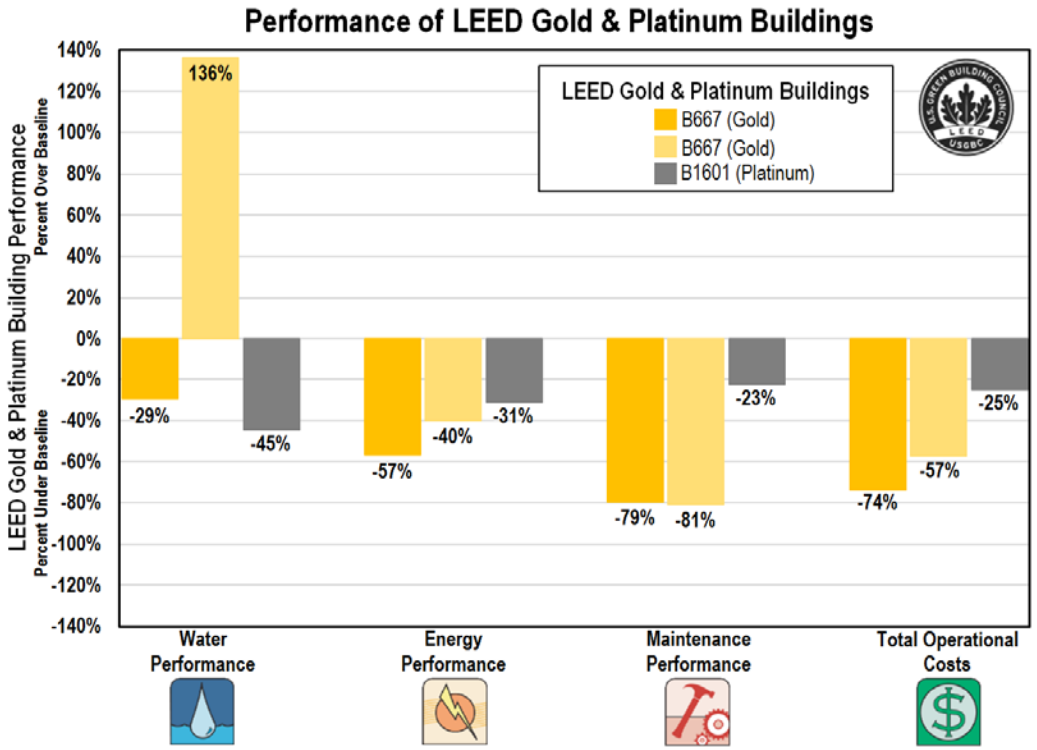


Figure S6. LEED Gold buildings show exceptional performance on all of the key performance metrics.

Do Green Air Force Buildings Perform Better?

The results from this study of fourteen buildings are generally consistent with the findings from previous studies. For individual buildings the response to the question "Do sustainably designed Air Force buildings perform better than typically designed buildings?" is still "it depends." The results from this study should not be assumed to represent all sustainably designed buildings.

When examining the average performance values for the sustainably designed buildings within this study, the aggregate operational costs are 15% lower, the energy performance is 28% better, and water performance is 32% better than the typically designed matched-pairs. Both LEED Gold buildings and the LEED Platinum building are high-performers. Given this portfolio analysis of building performance, it appears these sustainably designed buildings in the Air Force portfolio are performing well and helping the Air Force to meet its mandated goals for reduced environmental impact.

The whole building performance measurement method used in this study offers a replicable tool for assessing building performance. This portfolio analysis offers an indicative assessment of building performance, identifying major strengths and weaknesses.

A unique additive to this study was the partnership with industry experts in commissioning. All seven LEED certified buildings were given a light commissioning or facility walkthrough assessments by Jacobs Engineering. While most of the LEED certified buildings in this study have served the Air Force well, retro- or enhanced commissioning and some mechanical design changes, could allow a higher level of comfort and performance for many years into the future for these facilities. For more details on current operating conditions of individual building as well as findings, actions and recommendations, see Appendix-A (Site Summaries).

Acronyms

ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BOMA	Building Owners and Managers Association International
Btu	British thermal unit
CBE	Center for the Built Environment
CBECS	Commercial Buildings Energy Consumption Survey
CO_2	Carbon dioxide
CT	courthouse
DHS	Department of Homeland Security
DOE	U.S. Department of Energy
EAc1	Energy and Atmosphere Credit 1 (Optimize Energy Performance)
EMCS	Energy Management Control System
EUAS	Energy Usage and Analysis System
EUI	energy use intensity
ft^2	square feet
ft^3	cubic feet
FY	fiscal year
gsf or GSF	gross square feet
HVAC	heating, ventilation, and air-conditioning
IAQ	indoor air quality
IEQ	indoor environmental quality
IFMA	International Facility Management Association
kBtu	one thousand British thermal units
kw	kilowatt
kwh	kilowatt hour
LEED	Leadership in Energy and Environmental Design
LEED-NC	LEED for New Construction and Major Renovations
mBtu	one million British thermal units
$MTCO_2e$	metric tons carbon dioxide equivalent
N/A	not available
O&M	operations and maintenance
Occ	occupants
PNNL	Pacific Northwest National Laboratory
POE	Post Occupancy Evaluation
rsf or RSF	rentable square feet
U.S.	United States
Vis	visitors
VOC	volatile organic compound
WBPM	whole building performance measurement
WEc3	Water Efficiency credit 3 (Water Use Reduction)
WUI	water use intensity

Contents

Figures

Tables

Introduction

The Pacific Northwest National Laboratory (PNNL) measured the performance of seven LEED (U.S. Green Building Council's Leadership in Energy and Environmental Design) certified buildings compared to seven "matched-pairs" at different Air Force bases. Matched-pair buildings were selected based on location, building function, size, vintage, and occupancy. Previous studies have indicated that on average sustainably designed buildings use less energy and water, have lower maintenance costs, the occupants are more satisfied, and the occupant commute has lower emissions than typically designed buildings.

The Air Force, who manages approximately 70,000 buildings in support of its defense mission, has been aggressively pursuing sustainable design and development for over 10 years and in doing so has over 30 LEED certified facilities, 736 LEED Silver certified homes and roughly 300 LEED registered projects that it operates. Now that the practice of sustainable design is standard within the Air Force, it is important to determine how facilities constructed to the stringent performance criteria outlined in federal requirements and the LEED rating system compare in performance to facilities constructed to typical Air Force construction standards. The objective is for the Air Force to use the performance measurement data to inform future building designs and operations.

The U.S. Air Force engaged several key stakeholders, including its own representatives, a research team from the Pacific Northwest National Laboratory (PNNL), University of California Berkeley's Center for the Built Environment (CBE), and site building managers and engineers to measure whole building performance. In contrast to LEED-NC, which is focused on the design of new construction projects; "whole building performance measurement" (WBPM) assesses how sustainably designed buildings are actually operating. Thus, the primary intent of this WBPM study is to demonstrate the impact of investing in sustainably designed buildings, thereby enabling the Air Force to better document how its buildings are performing compared to a variety of building performance baselines and similar buildings. Ideally, the information derived from this study will be used to inform the design, construction, and operation of the Air Force's building portfolio.

USGBC membership developed the LEED® green building rating system to provide a system for defining "green buildings." The rating system is organized by five aspects of building design

- Sustainable Sites
- Water Efficiency
- Energy & Atmosphere
- Materials & Resources, and
- Indoor Environmental Quality.

LEED ratings can be achieved for new construction and major renovation (LEED-NC), existing buildings (LEED-EB), and several other building products.

Points are earned for meeting the intent of specific design criterion in each of the above categories. A LEED rating is awarded based on the total number of points earned by a building design. Prior to LEED version 3.0, LEED-NC had a total of 69 possible points. LEED version 3.0 has a 110 point scale. The buildings are rated depending on the number of points as

- Certified
- Silver
- Gold
- Platinum

Background

It is commonly recognized that a whole building, integrated design approach is essential to creating a sustainable or green building design. This design is assumed to result in optimal building performance based upon the product and equipment specifications. Several studies have documented the projected benefits of sustainably designed buildings.[1,2,3,4,5] Often these studies projected savings based on design intent or measured performance of a single metric, such as occupant productivity. The measured whole building performance of sustainably designed buildings is documented less commonly. To fully measure the operational impact of sustainably designed buildings, multiple occupant and operational measures, more than energy use, need to be considered.

Although energy modeling of a building's performance is a very useful tool during the design process, it does not always accurately predict how a building will perform. Studies have shown that although modeled data can predict average, relative performance, the models do not consistently predict actual performance of an individual building.[6,7] National Renewable Energy Laboratory (NREL) technical reports have highlighted that building energy models assume the buildings will function under ideal operating conditions, which results in measured building performance being different and typically higher than modeled energy use. NREL also estimates that when an energy simulation is calibrated to the as-built design, weather, and current operating conditions, it would generally be within 12% of the measured performance. This is one reason why more measured performance data are needed to better predict the performance of design strategies, rather than design simulations.

Scope and Approach

The scope of this WBPM study is to evaluate the impact of the Air Force's sustainably designed buildings by collecting and analyzing actual performance data from operating buildings for comparison to industry baselines and similar buildings for performance. As study collaborators, the PNNL research team was responsible for data collection, data management, data synthesis, analysis, and report development. The Air Force representatives provided building and site contacts, building data derived from existing systems and coordinated the completion of the CBE survey to assess occupants' satisfaction with their buildings. The CBE team was responsible for preparing, distributing, and summarizing the data from the building occupant satisfaction survey. The building managers and engineers hosted the site visit(s), provided data as requested, and deployed the survey. The quantity and quality of data were enhanced by the engagement of multiple stakeholders.

The selection criteria for the seven sustainably designed buildings in the study included the following:

- Buildings built or remodeled in the last 10 years that included sustainable design or energy efficiency as a key design consideration.
- Ability to collect a minimum of 12 months of operations data, at least 6 months after the building occupancy date and from a timeframe when the building is operating without major deficiencies.

- Data availability of the year 2011 (or subsequent years) with performance data for the key performance metrics.
- Occupants' willingness to participate in the CBE survey.

In addition to comparing to industry baselines, this study incorporates a matched-pair analysis of seven typically designed buildings. A building study which uses matched-pairs attempts to match each sustainably designed building with a typically designed building of comparable attributes. Basic building and site characteristics data are collected for each building in each pair of buildings to establish the pairing. The differences in relative performance between the matched buildings are then used to evaluate the performance. The buildings are matched using the following criteria:

- Be the same building type or function (e.g., office, courthouse, training center, etc.) and have similar water, energy, waste, and maintenance needs;
- Be located near each other or in similar climate zones to minimize the impact of different weather considerations over the measurement period;
- House a similar occupant type (e.g., active military, government employees, contractors, etc.), to minimize differences in policies, procedures and work ethic; and
- Have been in operation for at least 6-months and for a comparable number of years. This reduces the impacts of equipment differences.

Using the above criteria helped to narrow the Air Force portfolio of buildings to a list of seven LEED certified buildings and seven typically designed buildings for a total of 14 buildings overall. The fourteen buildings include:


Six offices/headquarters (3 matched-pairs)


Four academic facilities (2 matched-pairs)


Two fire stations (1 matched-pair)


Two fitness centers (1 matched-pair)

Site summaries for all of the buildings can be found in Appendix A.

The buildings included in the report are listed in Table 1. Throughout the report the 14 buildings are grouped in seven matched-pairs and organized by building type. There are three pairs of office buildings (six buildings), two pairs of academic facilities, one pair of fire stations, and one pair of fitness centers. The academic facilities are similar to an office building but with educational characters such as computer labs, class rooms, green rooms, laboratories and high volume of visitors.

Table 1. Air Force buildings studied

Building Name	Building Type	Air Force Base	Abbreviation
Base Personnel Office	Office Building	Offutt	**B323**
Weather Agency HQ	Office Building	Offutt	**B185**
Building 2800	Office Building	Edwards	**B2800**
Consolidated Support Facility	Office Building	Edwards	**B3000**
Mission Support Center	Office Building	Lackland	**B2484**
AFPC Admin Facility	Office Building	Randolph	**B667**
AFIT Engineering Building	Academic Facility	Wright Patterson	**B643**
AFIT Academic Facility	Academic Facility	Wright Patterson	**B646**
Base Education Center	Academic Facility	Shaw	**B501**
McElveen MRC Library	Academic Facility	Shaw	**B827**
Fire Crash Rescue Station	Fire Station	Offut	**B288**
Main Fire Station	Fire Station	Seymour Johnson	**B4601**
Rambler Fitness Center	Fitness Center	Randolph	**B999**
Tyndall Fitness Center	Fitness Center	Tyndall	**B1601**

The buildings were located at eight different Air Force Bases (Figure 1)

- Two at Edwards Air Force Base, CA
- Three at Offutt Air Force Base, NE
- Two at Randolph Air Force Base, TX
- One at Lackland Air Force Base, TX
- Two at Wright-Patterson Air Force Base, OH
- One at Seymour Johnson Air Force Base, NC
- Two at Shaw Air Force Base , SC
- One at Tyndall Air Force Base, FL

Figure 1. Study buildings by location

As stated earlier, seven of the buildings are LEED-NC certified (one LEED-Platinum, two LEED-Gold, three LEED-Silver, and one LEED-Certified) while the other seven buildings were built to typical Air Force construction standards. Photos and brief descriptions of the buildings next to their matched-pair can be found below and on the next few pages.

Offutt AFB
GSF: 101,250
Year Built: 1942
Year Renovated: 1985

Offutt AFB
GSF: 202,362
Year Built: 2008
LEED Gold

Identifying an ideal matched-pair for B185 (Weather Agency HQ) was difficult given the building's size, large data center, and unique operations as well as the limited Air Force buildings to select from. Although not a perfect match, B323 (Base Personnel Office) is also a large office building co-located on Offutt Air Force Base, with similar occupancy patterns and maintenance records. Given the differences (i.e., building vintages and the B185 data center) there will be comparison challenges.

Edwards AFB
GSF: 44,543
Year Built: 1955
Year Renovated: 2001

Edwards AFB
GSF: 48,958
Year Built: 2004
LEED Silver

Lackland AFB
GSF: 61,554
Year Built: 1996

Randolph AFB
GSF: 35,600
Year Built: 2010
LEED Gold

Wright-Patterson AFB
GSF: 52,172
Year Built: 1994

Wright-Patterson AFB
GSF: 48,446
Year Built: 2008
LEED Silver

Shaw AFB
GSF: 29,184
Year Built: 2004

Shaw AFB
GSF: 16,500
Year Built: 2007
LEED Silver

Offutt AFB
GSF: 41,375
Year Built: 2005

Seymour Johnson AFB
GSF: 43,400
Year Built: 2008
LEED Certified

Randolph AFB
GSF: 78,701
Year Built: 2007

Tyndall AFB
GSF: 72,000
Year Built: 2010
LEED Platinum

The PNNL research team collected the building and site characteristics data listed in Table 2 to normalize the building performance metrics. For example, gross interior floor area (gsf) is the total building square footage value used to estimate costs per square foot, energy use per square foot, and more. The Department of Energy (DOE) Federal Energy Management Program (FEMP) *Building Cost and Performance Metrics: Data Collection Protocol*[8], developed by PNNL, was the tool used to identify, normalize, and analyze the performance data collected for each building.

Table 2. Building and site characteristics metrics

Metrics	Characteristic
Building Specifications 	**Building Location** *address, city, state, zip code*
	Building Function *Office, Firestation, Fitness Center*
	Key Building Features *LEED checklist and design highlights*
	Building Occupancy Date *Year*
	Gross Interior Floor Area (GSF) ft^2
Occupancy 	**Operational Characteristics** $\frac{Hours}{Week}$ *# of Computers*
	Occupants and Visitors $\frac{Occupant}{Work\ Day}$ $\frac{Visitors}{Work\ Day}$
	Occupants Gender Ratio $\frac{\#\ Male\ Occupants}{\#\ Total\ Occupants}$ $\frac{\#\ Female\ Occupants}{\#\ Total\ Occupants}$
First Cost 	**Total Building Cost** $\frac{\$}{ft^2}$

Data were collected and site visits were performed for fourteen buildings under the scope of this study. Key performance metrics are provided in Table 3. The PNNL research team collected a minimum of 12 consecutive months of data and documented an industry baseline for each metric. Site and building contacts provided utility bills, maintenance budgets and schedules, and supported the distribution of the occupant satisfaction survey. The site visit process typically involved a 1 day visit to view each of the 14 buildings. A building walkthrough is performed with site personnel to

make observations based on previously collected data, collect missing/additional information, and to discuss anomalies seen in the preliminary data and building operations.

Table 3. Whole building performance metrics

Metrics	Performance Measurement	Reporting Metrics
Water 	**Total Building Potable Water Use** $\frac{gal}{year}$ $\frac{\$}{year}$	**Annual Domestic Water Use** $\frac{gal}{occupant}$ $\frac{\$}{occupant}$ $\frac{gal}{gsf}$ $\frac{\$}{gsf}$
	Indoor Potable, Outdoor, and Process Water Use $\frac{gal}{year}$ $\frac{\$}{year}$	
Energy 	**Total Building Energy Use** $\frac{Btu}{year}$ $\frac{\$}{year}$	**Annual Energy Use** $\frac{Btu}{gsf}$ $\frac{\$}{gsf}$ $\frac{Gkg\ CO_2}{year}$
Maintenance & Operations 	**Building & Grounds Maintenance** $\frac{Service\ Calls}{year}$ $\frac{\$}{year}$ $\frac{Preventative\ Maintenance}{year}$	**Annual M&O** $\frac{Service\ Calls}{Preventative\ Maintenance}$ $\frac{Maint\ \$}{gsf}$ $\frac{Grounds\ \$}{gsf}$ $\frac{Janitor\ \$}{gsf}$
Waste Generation & Recycling 	**Solid Sanitary Waste** $\frac{ton}{year}$ $\frac{\$}{year}$	**Annual Waste & Recycled** $\frac{lb}{occupant}$ $\frac{\$}{gsf}$ $\frac{\$}{occupant}$ $\frac{lb\ Recycled}{lb\ Sanitary\ Waste}$
	Recycled Material $\frac{ton}{year}$ $\frac{\$}{year}$	
Occupant Satisfaction 	**Building Occupant Self-Reported Satisfaction** $\frac{Occupant\ Rating}{Survey\ Metric}$	**Building Occupant Satisfaction** *CBE Baseline Percentile - Total Building Occupant Satisfaction*

Baseline Summary

One of the more important aspects of whole building performance measurement and assessment is selecting appropriate baselines for the basis of comparison. Ideally performance measurement data should be compared to other measured building performance data. Comparing measured values to modeled or estimated values does not offer a valid comparison, and should be avoided whenever possible. For this study, matched-pairs were used in conjunction with industry baselines to offer another basis for comparison.

Comparable industry baselines were identified for each of the metrics. The following tables are summaries of the baselines used in the study. Building specific baselines are in Table 5.

Table 4. Baseline Values and References

Metric Baseline Values and References			
	Value	Units	Source - Metric
	15.0	*Gal per ft²*	*IFMA #32 50th Percentile (2009, pg 59)*
	$0.07	*$ per ft²*	*BOMA 2008 Government Sector Total Building Rentable Area - Utility Water/Sewer*
	$2.30	*$ per ft²*	*BOMA 2010 All Sector Total Building Rentable Area - Utility (less water)*
	Varies	*$ per ft²*	*EPA Energy Star Portfolio Manager 50th Percentile*
	Varies	*kBtu per ft²*	*EPA Energy Star Portfolio Manager 50th Percentile*
	0.25	*Ratio*	*IFMA #32 Facilities less than 5 years old (2009 pg. 47) - Preventative/Total Maint.*
	0.35	*Ratio*	*IFMA #32 Facilities 5-10 years old (2009 pg. 47) - Preventative/Total Maint.*
	0.45	*Ratio*	*IFMA #32 Facilities 16-20 years old (2009 pg. 47) - Preventative/Total Maint.*
	0.47	*Ratio*	*IFMA #32 Facilities 51-100 years old (2009 pg. 47) - Preventative/Total Maint.*
	$1.07	*$ per ft²*	*BOMA 2010 All Sector Total Building Rentable Area - Repair/Maintenanece*
	$1.48	*$ per ft²*	*BOMA 2010 All Sector Total Building Rentable Area - Cleaning*
	$0.34	*$ per ft²*	*BOMA 2010 All Sector Total Building Rentable Area - Roads/Grounds*
	1.13	*Score*	*CBE 2009 Survey Average Score - General Building Satisfaction*
	1.23	*Score*	*CBE 2009 Survey Average Score - LEED General Building Satisfaction*

For the energy baseline in Table 5, the ENERGY STAR® Portfolio Manager energy use intensity value for the 50th percentile is shown. This baseline is calculated based on building characteristics gathered for each facility such as size, location, number of occupants, number of computers, hours of operation, etc. This value is used to represent the industry average energy use.

Table 5. Building Specific Baseline Values

Building Name	Energy Energy Star 50th Percentile (kBtu per SF) Energy Star 50th	Water Gallons per Occupant-Visitor Equiv FEMP WUI	Maintenance General Maintenance Cost ($/SF) IFMA 2009 #32	Maintenance Janitorial Maintenance Cost ($/SF) IFMA 2009 #32
B323	***115***	3,647	$3.16	$1.50
B185	***528***	3,750	$1.73	$1.30
B2800	***115***	3,875	$2.23	$1.59
B3000	***141***	3,923	$2.16	$1.34
B2484	101	3,855	$2.43	$1.32
B667	143	3,960	$1.73	$1.30
B643	***127***	3,434	$2.43	$1.32
B646	***155***	3,434	$1.73	$1.30
B501	84	3,750	$2.16	$1.34
B827	91	4,065	$2.16	$1.34
B288	119	3,315	$2.16	$1.34
B4601	121	3,295	$1.73	$1.30
B999	110	3,698	$2.16	N/A
B1601	89	3,750	$1.73	N/A

Report Contents and Organization

The observations for each of the key performance metrics addressed in this study are provided in the Summary Analysis section of this report. The values used for comparison include the following:

- Water use per gross square foot
- Estimated domestic water use per occupant-visitor equivalent
- Water cost per rentable square foot
- Energy Star score
- Energy use per gross square foot
- Energy cost per rentable square foot
- General maintenance cost per rentable square foot
- Grounds maintenance cost per rentable square foot
- Janitorial maintenance cost per rentable square foot
- Aggregate operational cost per square foot

General observations from the study are provided in the Conclusion section. Site-specific observations are provided in the site summaries in Appendix A.

Summary Analysis

This section is organized by metric type. First, the key building and site characteristics are provided as a reference for the analysis. Next, the building performance data are analyzed for each performance metric, with the information provided in the following order

- Water
- Energy
- Maintenance and operations

The discussion for each metric includes performance data, costs, and operational, occupant, or environmental impact, as available. The data represented in this section were provided by Air Force representatives, site contacts, and CBE. The building and site characteristics data collected for each building are used to normalize the performance metrics (Table 6). The gross square footage (gsf) is the primary building geometry characteristics used for normalizing the performance metrics. The building metrics are needed as part of the water, energy, and maintenance and operations metrics. The occupant-visitor equivalent estimates are needed as part of the water, and energy metrics. The number of computers is needed as part of the energy metric.

Table 6. Key building and site characteristics

	Building Name	Air Force Base	Building Function	Gross Square Footage	Year Built/ Renovated	Occupant - Visitor Equivalent	Weekly Operating Hours	Number of Computers
	**B323**	Offutt	Office Building	101,250	1942/1985	282	58	307
	B185	Offutt	Office Building	202,362	2008	881	63	1,500
	**B2800**	Edwards	Office Building	44,543	1955/2001	176	50	176
	B3000	Edwards	Office Building	48,958	2004	177	168	171
	**B2484**	Lackland	Office Building	61,554	1996	240	50	212
	B667	Randolph	Office Building	35,600	2010	170	60	226
	**B643**	Wright Patterson	Academic Facility	52,172	1994	341	55	132
	B646	Wright Patterson	Academic Facility	48,446	2008	362	60	230
	**B501**	Shaw	Academic Facility	29,184	2004	67	75	110
	B827	Shaw	Academic Facility	16,500	2007	35	61	82
	**B288**	Offut	Fire Station	41,375	2005	66	168	65
	B4601	Seymour Johnson	Fire Station	43,400	2008	47	168	88
	**B999**	Randolph	Fitness Center	78,701	2007	270	112	20
	B1601	Tyndall	Fitness Center	75,278	2010	138	112	19

Water

Buildings use 13.6% of all potable water in the U.S.[9] Many communities periodically experience droughts or have a decreasing availability of potable water. Tracking water use offers opportunities for identifying possible strategies for water use reduction. In addition to the resource management benefits, there is a monetary incentive to track and decrease water consumption. Industry expects that water-efficiency efforts, on average, will decrease energy use by 10-11%, lower operating cost by 11-12%, and will result in a 15% total water use reduction.[10]

The preferred water metric for comparing domestic water use (i.e., toilets, urinals, and faucets) is indoor potable water in gallons per year. The potable water use data for some buildings included a combination of domestic water use, landscape water use, and/or process water use. Very few of the Air Force buildings had the indoor domestic water separately metered and reported, thus total building water use and cost were used. In addition to water use per square foot, water use per occupant was analyzed, using the U.S. Department of Energy's Federal Energy Management Program's water use indices.[11] In this study, four of the fourteen buildings did not have metered water data. Six of the buildings have water data that included process and/or landscape water use that needed to be excluded from the water use values in order for the buildings to be fairly compared to a water use per occupant baseline. The estimation of outdoor potable water and/or process potable water use is documented in Table 7. In general the PNNL research team estimated the annual domestic water use for those buildings based on a review of monthly water use to identify a base water load.

> Domestic water consumption depends on human operation and fixed equipment efficiency. Therefore, typical indoor water consumption is best expressed as per occupant.

Table 7. Water use characteristics by building

Building Name	Water Consuming Equipment	Water Use (Gallons) Total Water	Estimated Landscape	Estimated Process	Estimated Domestic	Total Water Cost
B323	*Central Plant - Chilled Water System*	2,953,452	590,690	0	2,362,762	$4,046
B185	*Chilled Water Plant, Cooling Towers*	7,173,000	1,434,600	1,936,710	3,801,690	$9,827
B2800	*Chilled Water System*	No Meter	No Meter	No Meter	N/A	No Meter
B3000	*Chilled Water System w/ Thermal Storage*	No Meter	No Meter	No Meter	N/A	No Meter
B2484	*Central Plant - Chilled Water System*	2,000,004	400,001	0	1,600,003	$982
B667	*Central Plant - Chilled Water System*	376,850	75,370	0	301,480	$132
B643	*Chilled Water System*	No Meter	No Meter	No Meter	N/A	No Meter
B646	*Chilled Water System*	No Meter	No Meter	No Meter	N/A	No Meter
B501	-	*70,000*	No Meter	No Meter	70,000	$84
B827	*Chilled Water System*	*49,000*	No Meter	No Meter	49,000	$59
B288	*Chilled Water System*	1,206,909	241,382	325,865	639,662	$1,653
B4601	*Chilled Water System*	*544,080*	0	0	544,080	$1,157
B999	*Chilled Water System*	3,875,840	775,168	1,046,477	2,054,195	$1,354
B1601	*Chilled Water System*	625,759	0	0	625,759	$1,076

Total building water use per gross square foot includes the process water and irrigation water use. This metric shows four of the five sustainably designed buildings in this study, which have quality water data, use less water than the IFMA baseline (see Figure 2) with the average water use 7% below the industry baseline. Of the five sustainably designed buildings with water data, three of the buildings largely outperformed their matched-pairs with two of five using slightly more water per square foot. On average the sustainably designed buildings in this study use 32% less water per square foot than their matched-pairs.

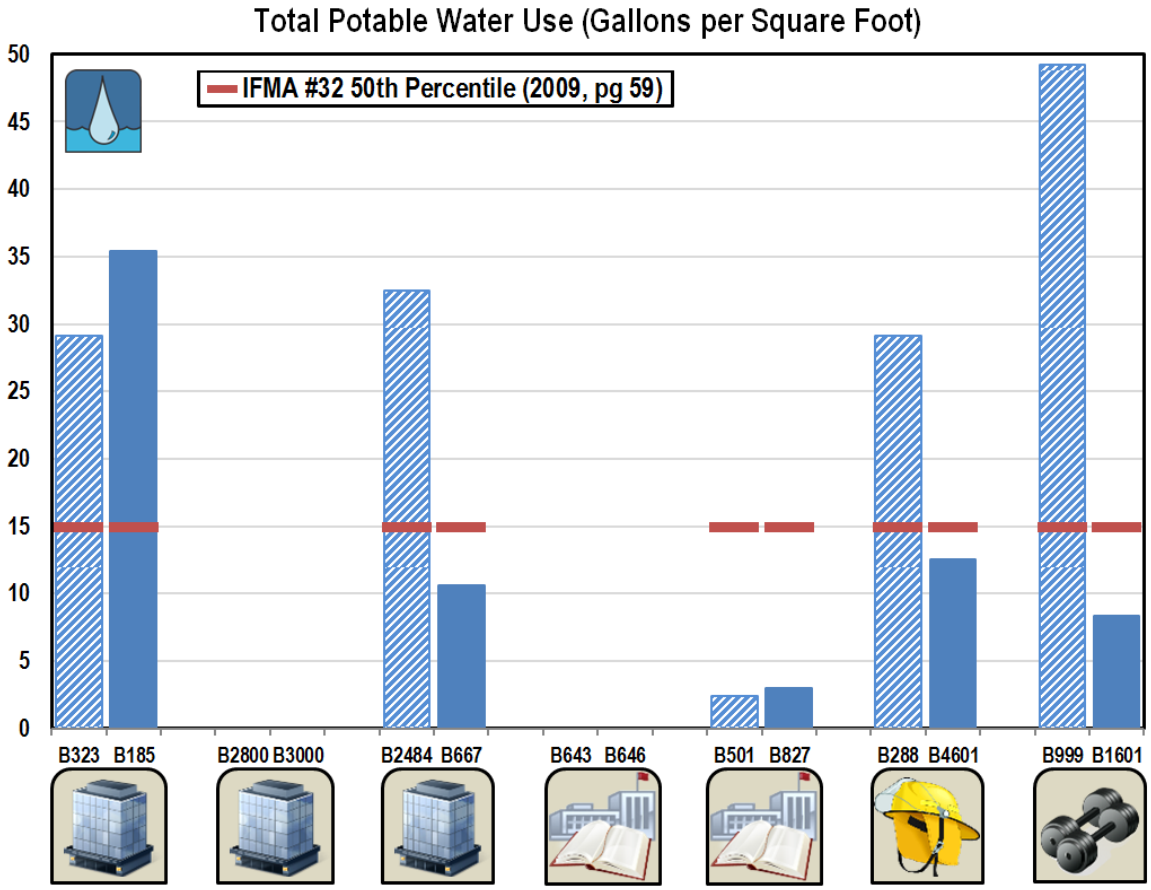


Figure 2. Water use per gross square foot

When considering the cost of water use, Figure 3 shows all of the buildings within the typical range of water cost per square foot according to the Building Owners and Managers Association baseline for the Government Sector. Water costs vary by location, which is especially noticeable when comparing the total water used per square foot with the water cost per square foot. For example, although B999 (Rambler Fitness Center, Texas) uses drastically more water per square foot than B1601 (Tyndall Fitness Center, Florida), the water utility rate at Tyndall Air Force base is almost 5 times greater than that experienced at Randolph. Low water costs decrease the likelihood of water use being a higher priority than other building operations, such as energy use and maintenance.

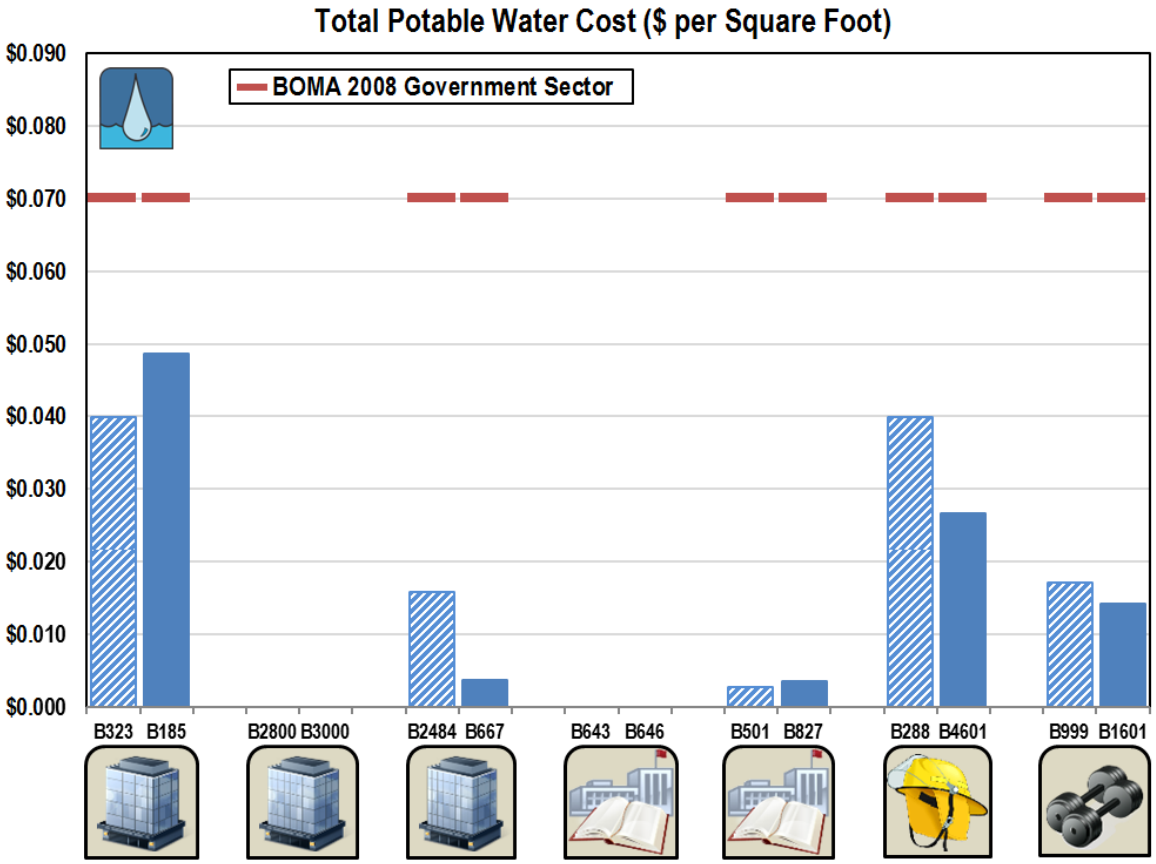


Figure 3. Water cost per square foot compared to industry baseline

Table 8 shows the values of water use and cost by building. The domestic water use was estimated given the known water uses in the buildings. The water use per occupant equivalent is unique to the building. Water use is normalized to the number of building occupants and visitors. The ratio of female-to-male occupants and the number and type of visitors provides additional detail for understanding water use.

Table 8. Water use and cost by building

	Water Performance (Gallons)						
	Building Name	Total Water	Total Water Use per Square Foot	Water Cost	Total Water Cost per Square Foot	Estimated Domestic Water Use	Domestic Water Use Per Occupant
	**B323**	2,953,452	29.2	$4,046	$0.040	2,362,762	8,379
	B185	7,173,000	35.4	$9,827	$0.049	3,801,690	4,315
	**B2800**	No Meter	N/A	N/A	N/A	N/A	N/A
	B3000	No Meter	N/A	N/A	N/A	N/A	N/A
	**B2484**	2,000,004	32.5	$982	$0.016	1,600,003	6,667
	B667	376,850	10.6	$132	$0.004	301,480	1,773
	**B643**	No Meter	N/A	N/A	N/A	N/A	N/A
	B646	No Meter	N/A	N/A	N/A	N/A	N/A
	**B501**	*70,000*	2.4	$84	$0.003	70,000	1,045
	B827	*49,000*	3.0	$59	$0.004	49,000	1,400
	**B288**	1,206,909	29.2	$1,653	$0.040	639,662	9,692
	B4601	*544,080*	12.5	$1,157	$0.027	544,080	11,576
	**B999**	3,875,840	49.2	$1,354	$0.017	2,054,195	7,608
	B1601	625,759	8.3	$1,076	$0.014	625,759	4,534

Although the water use values in Figure 4 were adjusted in an attempt to represent indoor potable water use only, it is clear that the commonly used end use distribution of water use is not representative for some of these buildings, such as B288 (Fire Crash Rescue Station), B4601 (Main Fire Station), B999 (Rambler Fitness Center), and B1601 (Tyndall Fitness Center). All of those buildings are unique building types with distinctive operations. The FEMP water use indices offer a baseline for water use per occupant. The FEMP indices do not represent water use per occupant in all building types consistently. When the Air Force buildings' water use is compared to the indices, seven of the buildings show a much greater water use per occupant than would be expected even with inefficient fixtures. It is recognized by building water use researchers that new values need to be developed.

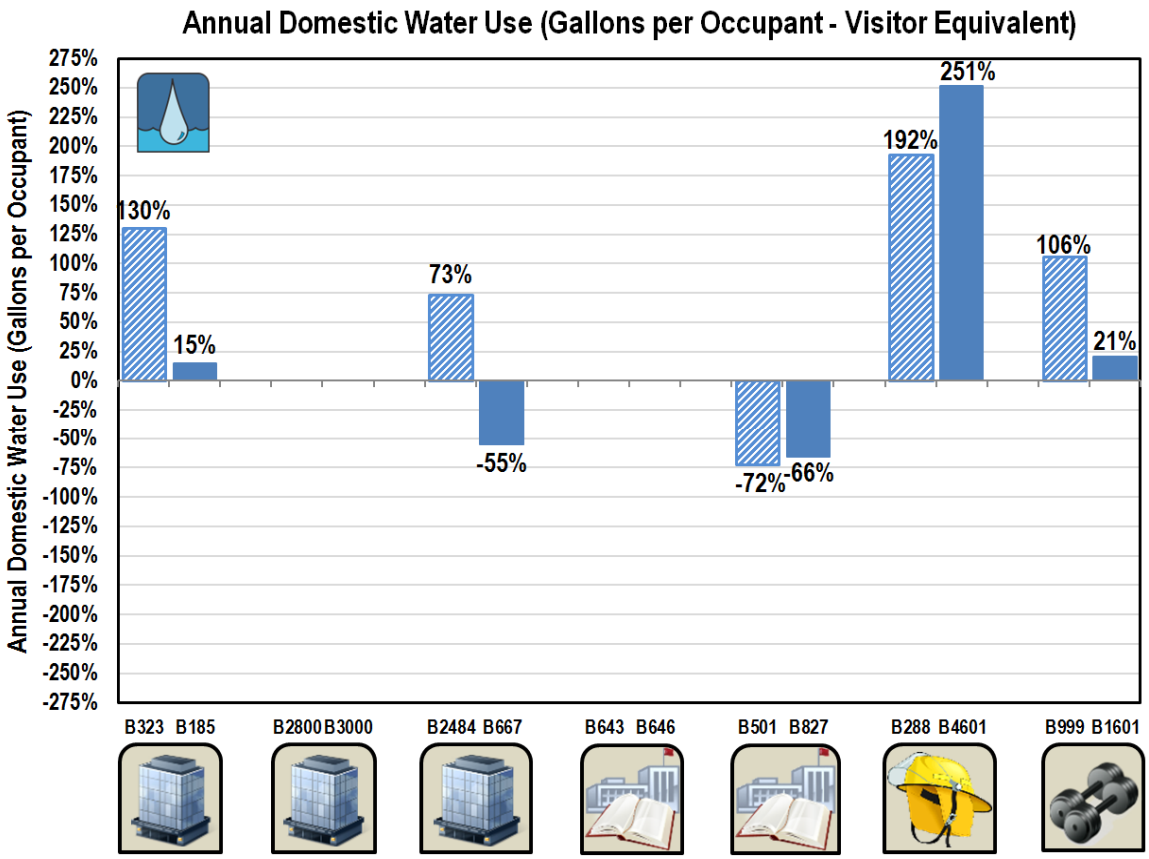


Figure 4. Water use per occupant compared to the water use baseline

The design intent of the LEED certified buildings' water use can be represented by the LEED Water Efficiency credits. Table 9 shows the number of LEED points received for water efficiency credits by each building out of the five total points available. All of the LEED buildings pursued water efficient landscaping (WEc1) and indoor water use reduction strategies (WEc3). Only one of the LEED buildings (B1601) attempted some water use reduction with innovative wastewater technologies.

LEED® Water Efficiency credit 3, Water Use Reduction, is achieved by reducing potable water use by 20% or more than a baseline design. Two WEc3 points can be achieved if potable water is reduced by 30%. An Innovation in Design point can be achieved for exemplary performance of potable water use reduction greater than 40%.

There are additional water credits that address water efficient landscaping and innovative wastewater management strategies.

Table 9. LEED Water Efficiency credits pursued

Building Name	LEED Version	LEED Rating	Efficient Landscaping WEc1	Innovative Wastewater Technologies WEc2	Water Use Reduction WEc3	Total WE Credits
B323	N/A	N/A	N/A	N/A	N/A	N/A
B185	LEED® NC 2.1	Gold	2	0	2	4
B2800	N/A	N/A	N/A	N/A	N/A	N/A
B3000	LEED® NC 2.1	Silver	1	0	1	2
B2484	N/A	N/A	N/A	N/A	N/A	N/A
B667	LEED® NC 2.2	Gold	2	0	2	4
B643	N/A	N/A	N/A	N/A	N/A	N/A
B646	LEED® NC 2.2	Silver	2	0	2	4
B501	N/A	N/A	N/A	N/A	N/A	N/A
B827	LEED® NC 2.1	Silver	2	0	2	4
B288	N/A	N/A	N/A	N/A	N/A	N/A
B4601	LEED® NC 2.1	Certified	2	0	1	3
B999	N/A	N/A	N/A	N/A	N/A	N/A
B1601	LEED® NC 2.2	Platinum	2	1	2	5

Graphically displaying the water use in comparison to the overall LEED score and total LEED WE points (Figure 5 and Figure 6) shows that water use is highly variable and there does not appear to be a strong correlation to the measured water use and the LEED credits.

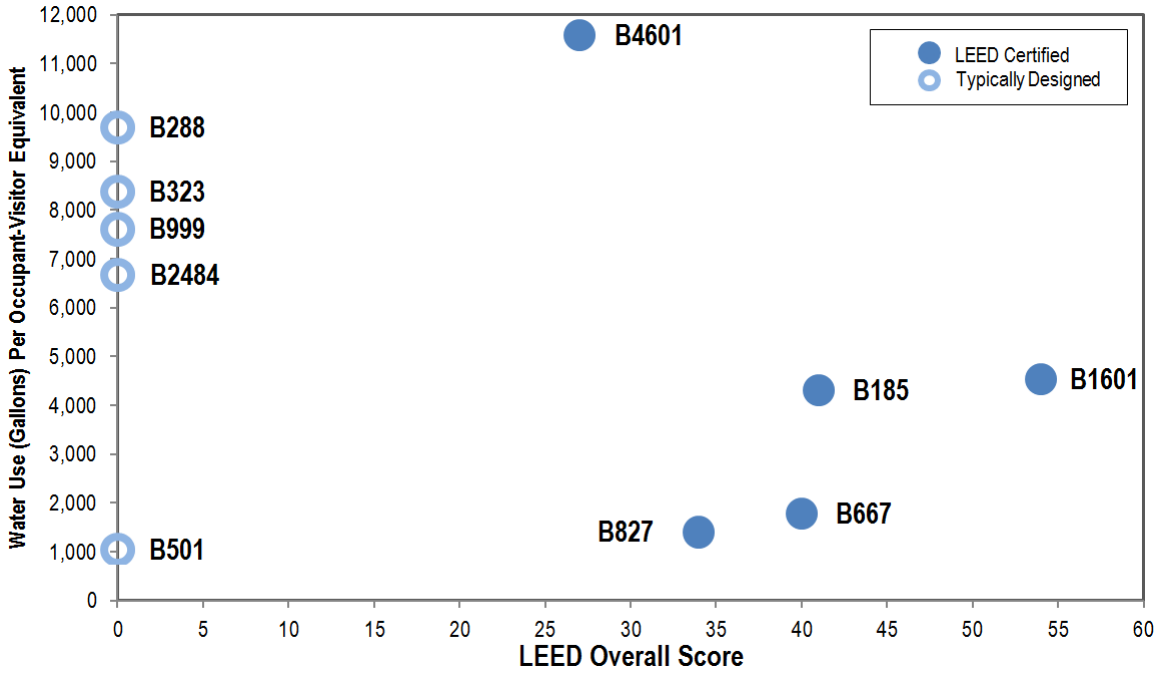


Figure 5. LEED overall score and water usage

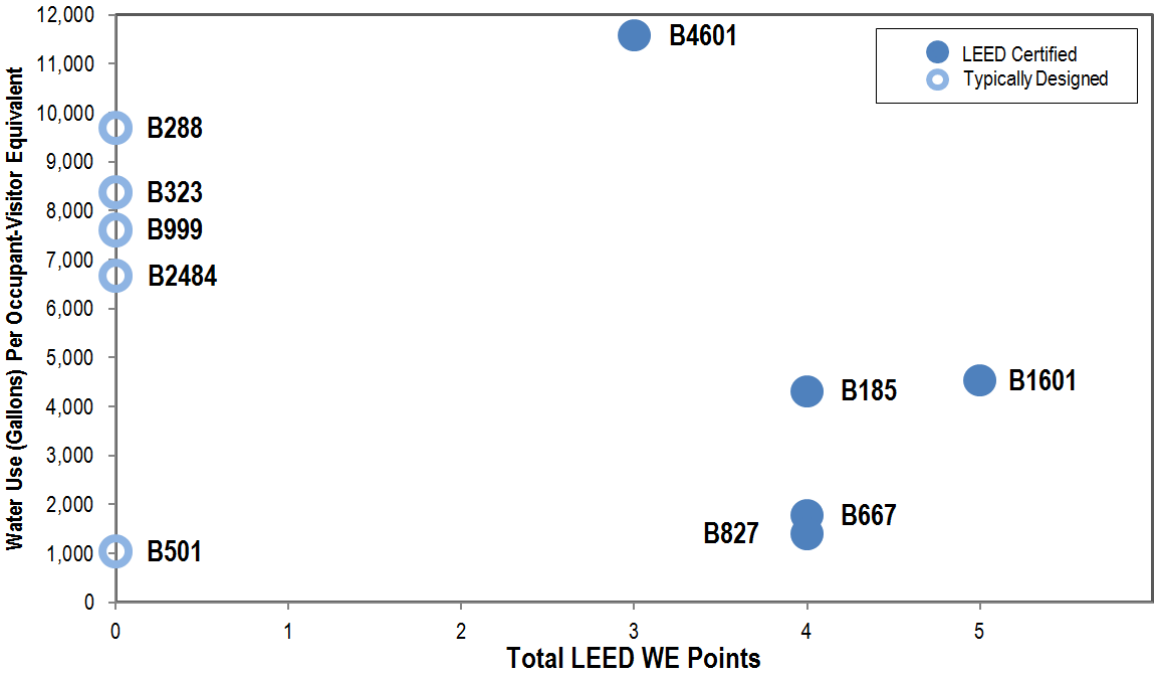


Figure 6. Total LEED WE points and water usage

When considering all of the different ways to examine water use for a building, three buildings stand out as consistently using considerably more water and having higher water costs than the others: B288 (Fire Crash Rescue Station), B4601 (Main Fire Station), and B323 (Base Personnel Office). It is recommended the cause for higher levels of water use at those buildings is investigated in the future.

Energy

Commercial buildings in the U.S. consume about 19% of the total energy.[12] Energy costs tend to be the largest utility cost for a building and with the current emphasis on global climate change there is an even greater interest to reduce energy use and modify energy sources in order to reduce the building's environmental impact.

The seven sustainably designed buildings in this study were selected because they were LEED certified. The research team chose ENERGY STAR® Portfolio Manager (referred to as Energy Star scores here forward) as a mechanism for energy comparison because it compares building energy performance to similar building types and geographic locations. Energy Star scores are relative to the buildings' energy use in the database, and the weather for a given time period and location. Other mechanisms for comparison include national and regional CBECS energy use intensity (EUI) averages, as well as average costs from BOMA and IFMA.

ENERGY STAR® Portfolio Manager is a benchmarking tool that ranks the annual energy use of a building compared to average commercial buildings data. Each building receives a score between zero and 100. Buildings with scores above 50 can be considered better than average. Buildings with scores above 75 can receive an Energy Star Buildings Label that recognizes the building as performing in the top 25% of nationwide energy performance.

The unofficial Energy Star scores for each building were calculated using the following data from each site:

- Building type
- Building location
- 12 to 24 months of energy use data
- Number of occupants
- Occupancy hours
- Number of computers

Table 10 provides a summary of the energy use and cost values for each building.

Table 10. Energy use and cost by building

	Energy Use					
Building Name	Electricity Used (kBtu)	Natural Gas Used (kBtu)	Steam Used (kbtu)	Chilled Water Used (Ton-Hr)	Total Energy Use (kBtu)	Total Energy Cost
B323	*8,563,970*	*5,946,996*	0	0	14,510,978	$121,539
B185	28,147,635	35,956,347	0	0	64,103,982	$503,416
B2800	2,389,778	*2,583,000*	0	0	4,972,778	$85,202
B3000	2,696,411	*2,841,000*	0	0	5,537,411	$48,298
B2484	3,637,823	*1,920,000*	0	0	5,557,823	$78,257
B667	758,183	202,880	0	60,318	1,684,876	$36,391
B643	*2,271,791*	0	*4,315,908*	0	6,587,699	$68,941
B646	2,164,041	0	*4,007,676*	0	6,171,717	$64,286
B501	2,133,159	1,464,432	0	0	3,597,590	$60,614
B827	1,219,449	569,364	0	0	1,788,813	$32,426
B288	*3,737,593*	*3,059,592*	0	0	6,797,184	$56,014
B4601	1,920,366	1,849,800	0	0	3,770,166	$66,591
B999	3,329,897	2,687,748	0	0	6,017,645	$72,338
B1601	3,355,784	1,270,640	0	0	4,495,072	$98,996

Although energy use by fuel type and total energy use are useful information to have when considering the overall impact of a building, they do not offer a clear picture on the efficiency of a building's energy use. To assess energy efficiency, total energy use is typically normalized to building size (gross square footage or gsf) to provide energy use intensity (EUI) value. In this study energy use was also normalized to hours of regular occupancy and the number of full-time occupant equivalents and then compared to Energy Star scores as shown in Figure 7. The figure shows that although there is a relationship between EUI and Energy Star scores, it is not a direct relationship. Note, all but one building (B999) with Energy Star scores above 69 are LEED certified facilities. All of these buildings also have greater energy utilization per hours of occupancy and number of building occupants – meaning longer operating hours and more occupants per square foot would generally increase the EUI and may be reflected as efficiency in the Energy Star scores. These graphs also show that the LEED certified buildings tend to have lower energy utilization per hours of occupancy than the typically designed buildings.

> EUI is a commonly used metric calculated when the annual energy use is divided by the total building square footage. EUI does not consider the impact of the occupants with respect to how occupant density, plug load, and operating hours may impact energy use.

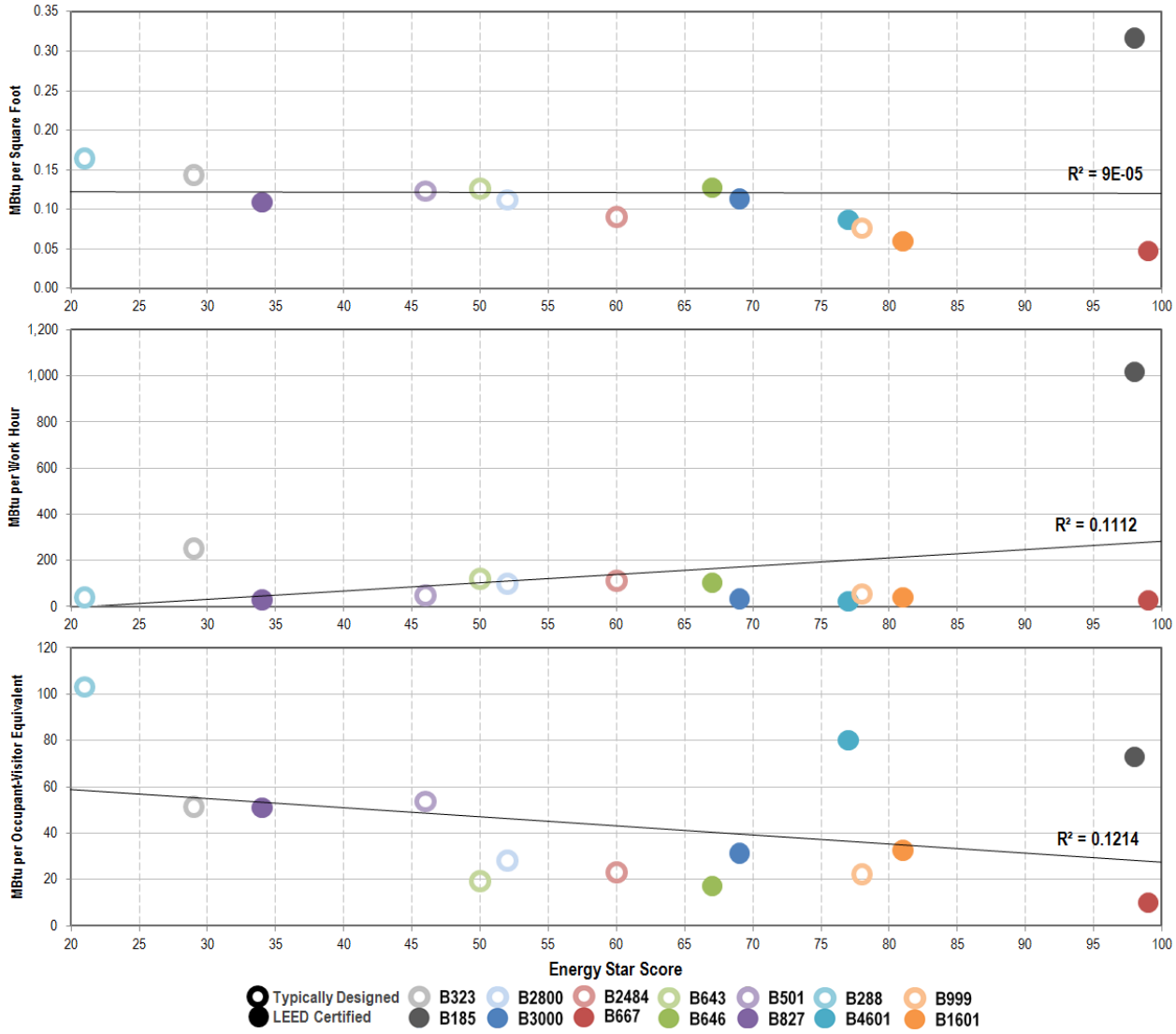


Figure 7. Energy Star score compared to energy intensity

Table 11 summarizes the EUI data available for each building. Within the table, "Energy Use Intensity" denotes the current EUI (kBtu per square foot) calculated from data provided by building contacts. "Energy Star 50th Percentile" and "Energy Star 75th Percentile" are the building-specific 50th and 75th percentile baseline values calculated within the ENERGY STAR Portfolio Manager. "CBECS Specific Regional Average" represents national average EUIs for specific building types correlated to Air Force Base locations using 2003 data.[13] "CBECS Regional Office" includes the average EUI for office buildings within specific geographic regions, correlated to Air Force Base locations. For this analysis multiple baselines were considered in order to gain a broader comparison for how the buildings were performing.

Table 11. Various EUI values of interest

Building Name	Energy Use Intensity (kBtu per SF)	Energy Star 50th Percentile	Energy Star 75th Percentile	CBECS Specific Regional Average	CBECS Regional Office
B323	143	*115*	85	144	144
B185	317	*528*	448	204	144
B2800	112	*115*	85	109	109
B3000	113	*141*	104	109	109
B2484	90	101	75	*109*	100
B667	47	143	106	*109*	100
B643	126	*127*	94	150	144
B646	127	*155*	115	150	144
B501	123	84	62	*135*	100
B827	108	91	68	*144*	100
B288	164	119	88	*116*	144
B4601	87	121	90	*90*	100
B999	76	110	81	*87*	100
B1601	60	89	66	*87*	100

In Figure 8 the buildings' EUIs are compared to the multiple baselines including the CBECS Specific Regional Average, CBECS Regional Office Average and both Energy Star 50th and 75th Percentile Baselines. Six of the seven LEED certified buildings are performing better than the Energy Star 50th Percentile Baseline and four of the seven are better than the Energy Star 75th Percentile. The one LEED certified building below the Energy Star 50th Percentile is B827 (McElveen Library) which is not a typical building type within the Portfolio Manager database. For that reason CBECS Specific Regional Average (national average EUIs for specific building types correlated to Air Force Base locations) were used for both B827 and its matched-pair, B501. In some cases the CBECS Specific Regional Averages and the CBECS Regional Office baselines are very similar and are overlapping in Figure 8 (e.g., B2800 and B3000).

CBECS is a publicly available database comprised of national survey data on U.S. commercial building energy consumption. CBECS data can be sorted by building type, age, region, size, fuel type, and various other parameters.

Twelve of the fourteen buildings in the study are performing below the selected baselines. When comparing the energy use between the matched-pairs, all of the LEED buildings are out-performing their matched-pairs by 28% on average.

The energy performance of the seven LEED certified buildings in the study was on average 28% better than the Energy Star 50th Percentile, 3% better than the Energy Star 75th Percentile, and 10% better than the CBECS Specific Regional Averages. The energy performance of the seven typically designed buildings in the study was on average 9% worse than the Energy Star 50th Percentile, 48% worse than the Energy Star 75th Percentile, and 1% better than the CBECS Specific Regional Averages.

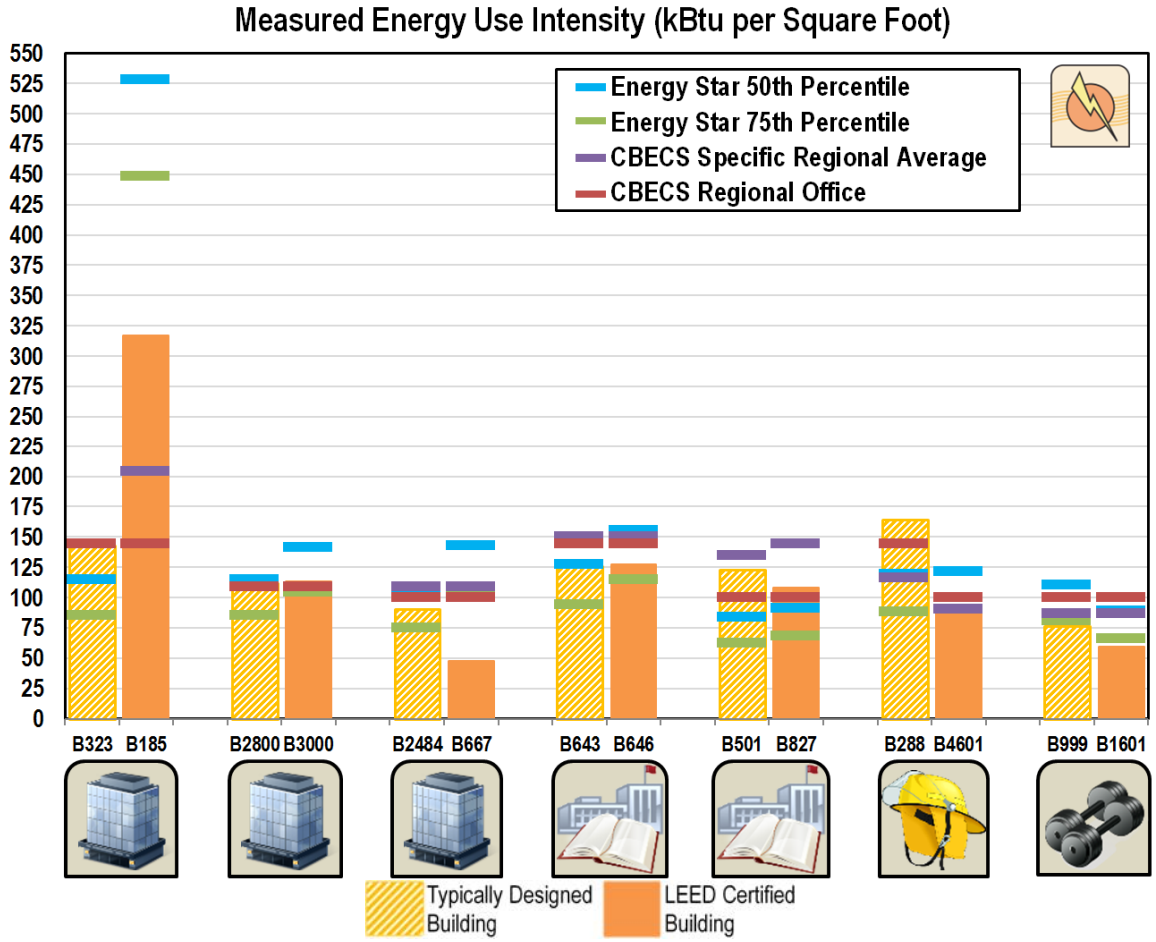


Figure 8. Study building EUIs compared to Energy Star baselines and CBECS regional EUIs

LEED® Energy and Atmosphere credit 1 (EAc1), Optimize Energy Performance, allows for up to 10 points for reducing energy consumption by 42% or more.

Table 12 provides the LEED version, LEED rating, total LEED points, EAc1 points (Optimize Energy Performance), WEc3 points (Water Use Reduction), and the estimated Energy Star scores. This table illustrates the effort of the green Air Force buildings not only reduce energy usage, but also indoor potable water use as well. Five out of the seven LEED certified Air Force building pursued a 30% reduction in indoor water use (2 points).

Table 12. "Green" design certification by building

Building Name	LEED Version	LEED Rating	Total LEED points	Optimize Energy Performance EAc1	Water Use Reduction WEc3	Energy Star Score
B323	N/A	N/A	N/A	N/A	N/A	29
B185	LEED® NC 2.1	Gold	41	8	2	98
B2800	N/A	N/A	N/A	N/A	N/A	52
B3000	LEED® NC 2.1	Silver	35	1	1	69
B2484	N/A	N/A	N/A	N/A	N/A	60
B667	LEED® NC 2.2	Gold	40	5	2	99
B643	N/A	N/A	N/A	N/A	N/A	50
B646	LEED® NC 2.2	Silver	34	7	2	67
B501	N/A	N/A	N/A	N/A	N/A	46
B827	LEED® NC 2.1	Silver	34	6	2	34
B288	N/A	N/A	N/A	N/A	N/A	21
B4601	LEED® NC 2.1	Certified	27	3	1	77
B999	N/A	N/A	N/A	N/A	N/A	78
B1601	LEED® NC 2.2	Platinum	54	10	2	81

In addition to the LEED Optimize Energy Performance credits, key energy management credits are documented in Table 13. Note that B3000 (Consolidated Support Facility) only has one point within the Optimize Energy Performance credit (EAc1) but is one of only two LEED certified buildings that pursued a point for the (additional) Enhanced Commissioning credit (EAc3) and the Measurement & Verification credit (EAc5). Enhanced commissioning and measurement and verification go beyond fundamental commissioning and are essential in ensuring and validating proper building operation.

Table 13. LEED Energy and Atmosphere Credits pursued

Building Name	LEED Version	LEED Rating	Optimize Energy Performance EAc1	Enhanced Commissioning EAc3	Measurement & Verification EAc5	Green Power EAc6
B323	N/A	N/A	N/A	N/A	N/A	N/A
B185	LEED® NC 2.1	Gold	8	0	0	0
B2800	N/A	N/A	N/A	N/A	N/A	N/A
B3000	LEED® NC 2.1	Silver	1	1	1	0
B2484	N/A	N/A	N/A	N/A	N/A	N/A
B667	LEED® NC 2.2	Gold	5	0	0	0
B643	N/A	N/A	N/A	N/A	N/A	N/A
B646	LEED® NC 2.2	Silver	7	1	0	0
B501	N/A	N/A	N/A	N/A	N/A	N/A
B827	LEED® NC 2.1	Silver	6	0	0	1
B288	N/A	N/A	N/A	N/A	N/A	N/A
B4601	LEED® NC 2.1	Certified	3	0	0	1
B999	N/A	N/A	N/A	N/A	N/A	N/A
B1601	LEED® NC 2.2	Platinum	10	0	1	1

Within the next two figures (Figure 9 & Figure 10) the full orange circles represent the LEED certified buildings and the light-orange circle outlines represent the typical Air Force buildings. Comparing the Energy Star scores to the overall LEED score (Figure 9) does not appear to offer a correlation between the measured energy use and the overall LEED scores.

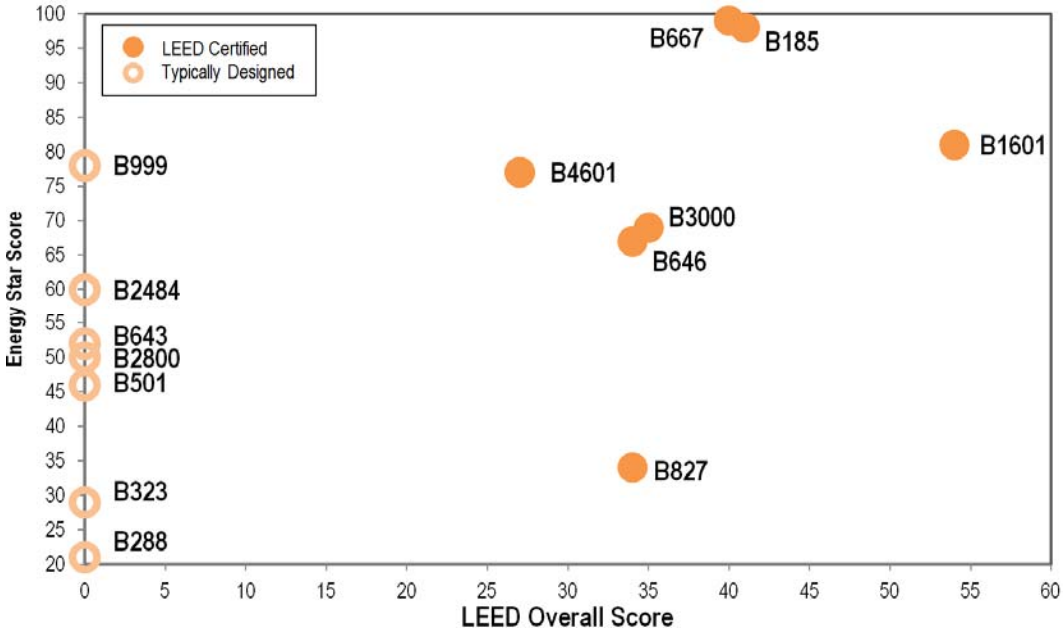


Figure 9. Energy Star rating and total LEED credits

Comparing Energy Star scores with the EAc1 (Optimize Energy Performance) points (Figure 10) shows that four of the five LEED certified buildings that had five or more EAc1 points had Energy Star scores above 66, with an average Energy Star Score of 76. The remaining two LEED certified buildings with less than five EAc1 points had an average Energy Star Score of 73.

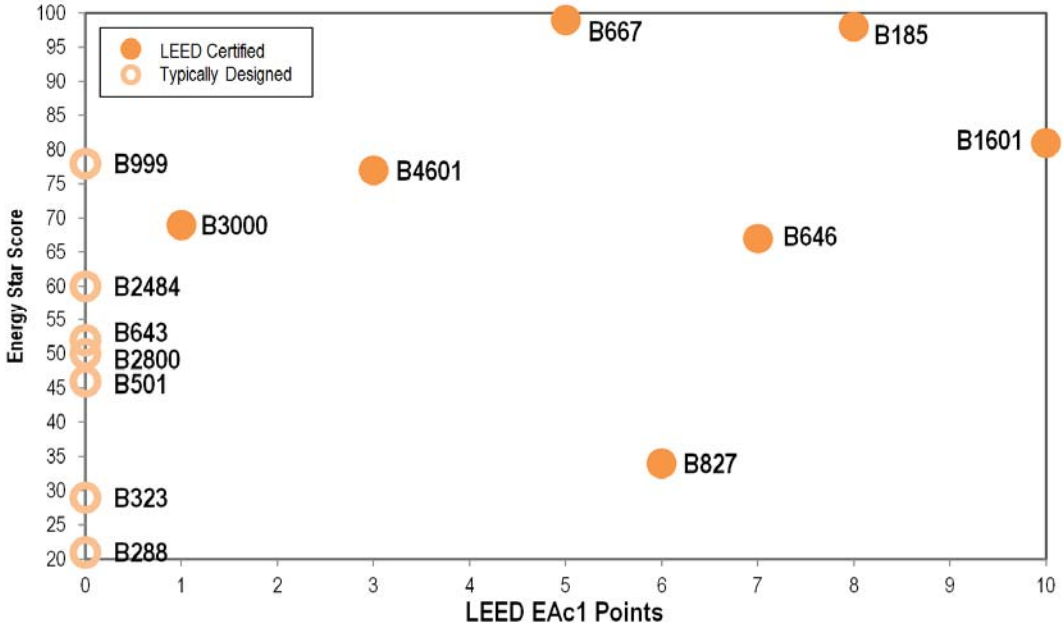


Figure 10. Energy Star rating and LEED energy credits

Figure 11 is a quad-chart showing the energy performance of all the buildings in the study in relationship to the total water use per gross square foot. The energy performance for twelve out of the fourteen buildings in this study is equal to or better than the industry average (buildings located in the two quadrants on the right). All seven of the LEED certified buildings have superior energy performance compared to industry baselines and their matched-pairs. Of the ten buildings with water data, only five have water performance (based on total use per gross square foot) that is better than the industry average (buildings in the top two quadrants). The buildings performing the best in these two metrics are those within the top-right quadrant. Three of the buildings provided water use data for the indoor, domestic water use portion only (dark blue), four of the buildings provided water use for indoor and irrigation combined (blue), three had domestic, irrigation and process water combined (light-blue), and the remaining four buildings had no water data available (grey). Note that all of the buildings within the top-right quadrant (top-performers) do not have process water included in the water performance data. Also, four out of the five buildings within the top-right quadrant are LEED certified buildings (triangles).

The next figure is referred to as a "quad chart." Performance better than the baseline by the metrics on the x and y axis are placed to the right and above the baseline lines, that is, the top right quadrant. The shape of the data point indicates the facility design and the color represents the water performance data.

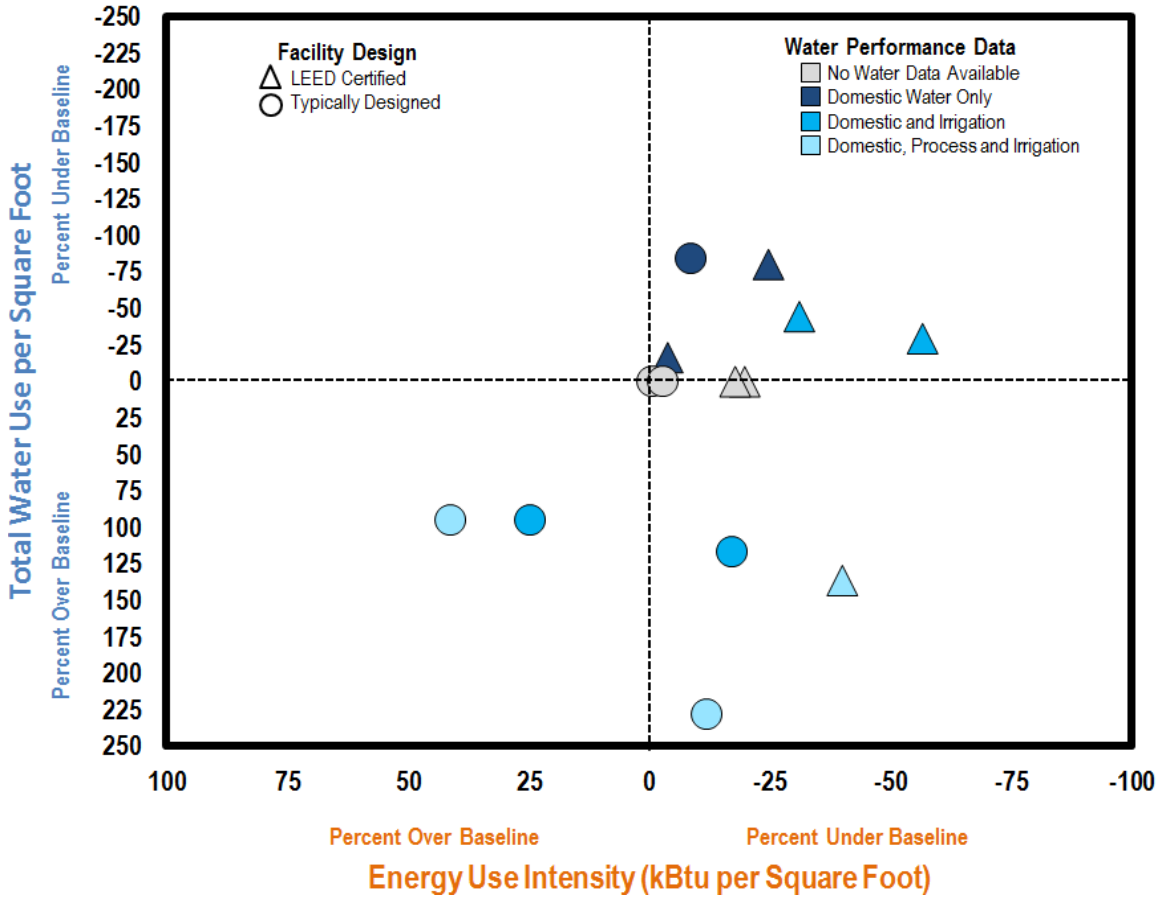


Figure 11. Energy (EUI) and water use per GSF performance

The energy-related utility costs tend to be a significant portion of a building's operating costs. Energy costs are typically expressed as cost per square foot. The baseline value for energy costs per gross square foot is based on values from EPA's ENERGY STAR Portfolio Manager 50th Percentile and BOMA.[14] The BOMA baselines shown in Figure 12 are national averages, thus location related differences in energy costs will not be representative. For example B4601 (Goldsboro, North Carolina) experiences a combined utility rate approximately double that of B288 (Offutt, Nebraska). The Energy Star 50th Percentile provides a baseline in which considers geographical location. Regardless of regional differences, the buildings with higher than average costs are worth investigating further in order to ensure everything possible is being done to reduce operating costs.

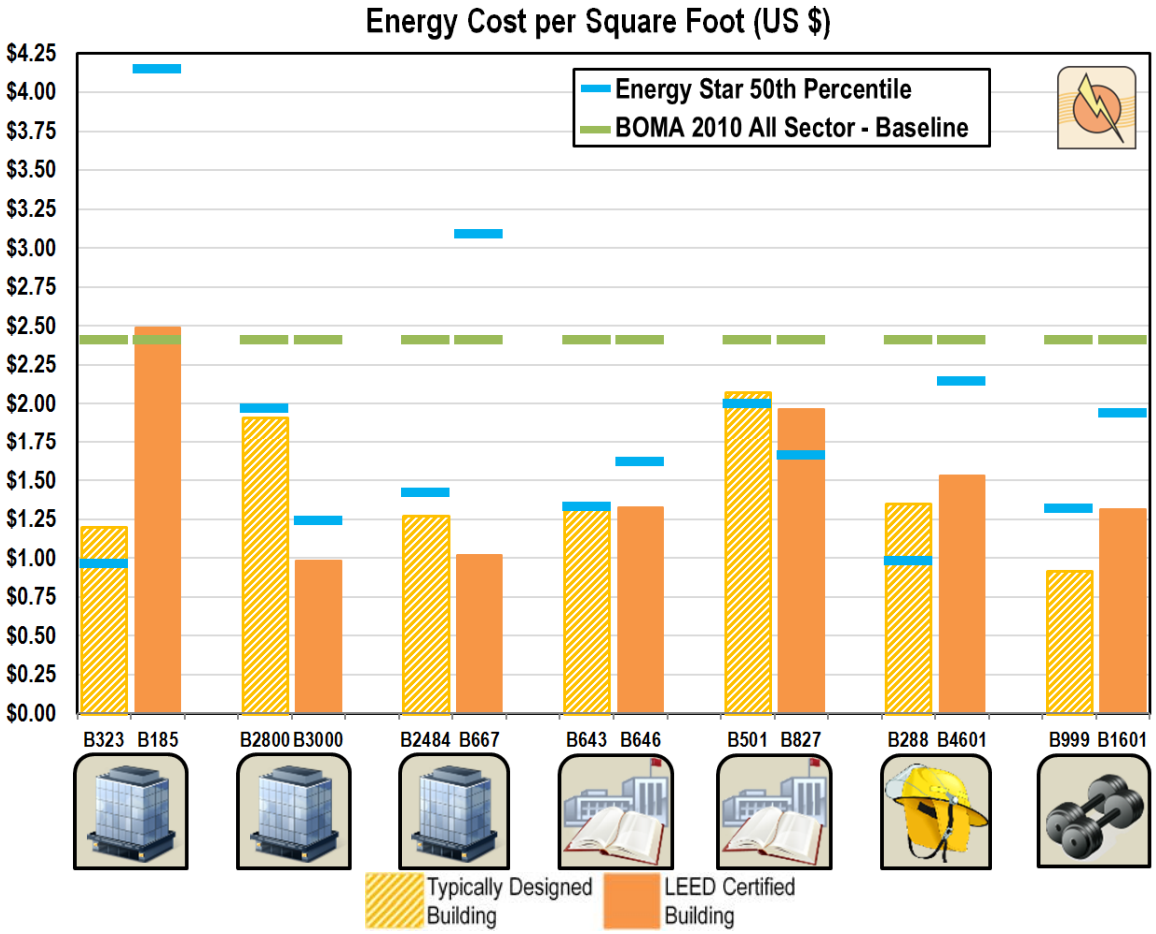


Figure 12. Energy cost per gross square foot

A key environmental impact of energy use is greenhouse gas emissions. Greenhouse gas emissions are represented as carbon dioxide (CO_2) equivalents. The CO_2 equivalents related to source energy use for the buildings in the study are calculated through the ENERGY STAR Portfolio Manager and summarized in Table 14.

Table 14. Energy use, cost and CO_2 equivalent performance

		Energy Use Emissions		
	Building Name	Energy Use Intensity (kBtu per SF)	Energy Cost per Square Foot	Emissions ($MTCO_2e$ per SF)
	B323	143	$1.20	0.0226
	B185	317	$2.49	0.0415
	B2800	112	$1.91	0.0080
	B3000	113	$0.99	0.0081
	B2484	90	$1.27	0.0115
	B667	47	$1.02	0.0047
	B643	126	$1.32	0.0156
	B646	127	$1.33	0.0158
	B501	123	$2.08	0.0117
	B827	108	$1.97	0.0129
	B288	164	$1.35	0.0247
	B4601	87	$1.53	0.0088
	B999	76	$0.92	0.0089
	B1601	60	$1.32	0.0100

Figure 13 shows the relative baselines for each building given the energy use and utility. All but one (B827) of the seven LEED certified buildings and four of the seven typically designed buildings studied are below the industry average CO_2 equivalent emissions (Energy Star 50th Percentile). Three of the seven LEED certified buildings also have contracts to purchase green power (Table 13, EAc6), which would result in lower emissions (including B827). Emissions reductions from green power purchases are not represented in this graphic.

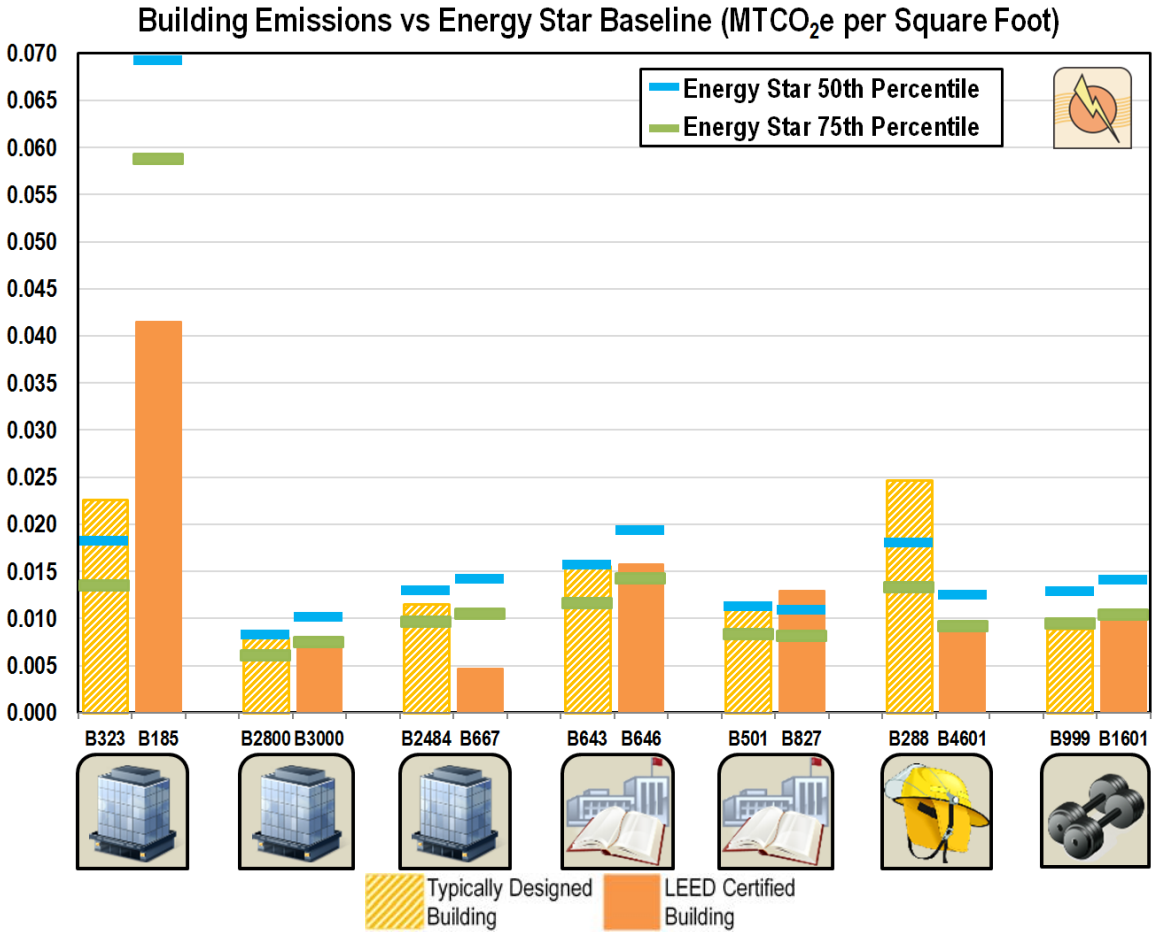


Figure 13. CO_2 equivalents compared to Energy Star baselines

On average, the LEED certified buildings in the study use less energy, have lower energy costs, and have lower carbon emissions than baseline and their matched-pairs.

Maintenance and Operations

Interdependence in building systems means that a cost effective and high-performing operations and maintenance (O&M) program may cost more in training, monitoring, and preventative maintenance, but can significantly reduce the costs of energy, water, materials, and system repair while increasing occupant satisfaction and productivity. The details provided for each building's maintenance records varied and thus, when details were not available, it was assumed that the maintenance costs represented equivalent activities to other buildings. The one year of costs provided in this study does not address the quality of work, potential regional cost differences, or the uniqueness of the year's maintenance needs, but does allow for general comparisons and observations. Additional years of maintenance records would allow for more firm conclusions. The O&M data available for each building are summarized in Table 15.

Table 15. O&M data and cost by building

Building Name	Maint. Calls / Total Maint.	Prev. Maint. / Total Maint.	General Maintenance Cost	Green Housekeeping?	Janitorial Maintenance Cost	Grounds Maintenance Cost
B323	97%	3%	$76,147	*Yes*	$83,618	N/A
B185	99%	1%	$56,791	*Yes*	$60,800	N/A
B2800	75%	25%	$27,101	*Yes*	$28,597	$8,263
B3000	88%	12%	$24,316	*Yes*	$28,596	$8,262
B2484	85%	15%	$114,004	*No*	$32,678	$35,000
B667	55%	45%	$7,046	*Yes*	$9,598	$2,204
B643	92%	8%	$63,087	*Some*	$80,303	$2,045
B646	84%	16%	$18,375	*Some*	$84,732	$1,899
B501	49%	51%	$38,073	*Yes*	$40,577	$2,545
B827	91%	9%	$22,506	*Yes*	$19,509	$2,545
B288	93%	7%	$31,756	*Yes*	$0	$0
B4601	94%	6%	$42,386	*Yes*	$7,448	$912
B999	99%	1%	$87,614	*Yes*	$342,772	$27,422
B1601	85%	15%	$24,395	*Some*	$386,000	$5,000

The baseline values for the general, grounds, and janitorial maintenance costs were collected from IFMA and BOMA resources. [15, 16] Figure 14 shows general maintenance costs per square foot. The BOMA 2010 baseline shown is a national average, whereas the IFMA 2009 baseline averages are based on the vintage of the buildings. As expected with aging facilities, the IFMA baseline costs for general maintenance escalate with increased vintage. Using the IFMA general maintenance values, thirteen of the fourteen buildings had general maintenance costs equal to or less than the baseline. When compared to their matched-pairs, all but one (B4601, Main Fire Station) of the seven LEED certified buildings had superior performance with regards to general maintenance cost per square foot. While B4601 had general maintenance cost less than its baseline, its matched-pair (B288, Fire Crash Rescue Station) had significantly lower costs. This may be attributed to B288's backlog of service orders. At the time of the site visit, there were multiple maintenance requests pending for B288, likely affecting its energy performance. For instance B4601 out-performed B288 with regards to energy by 45%.

The International Facilities Management Association (IFMA) and the Building Owners and Managers Association (BOMA) provide the main source of statistics on the state of operating commercial buildings.

Each organization publishes benchmarking reports on a variety of development, operations and maintenance topics.

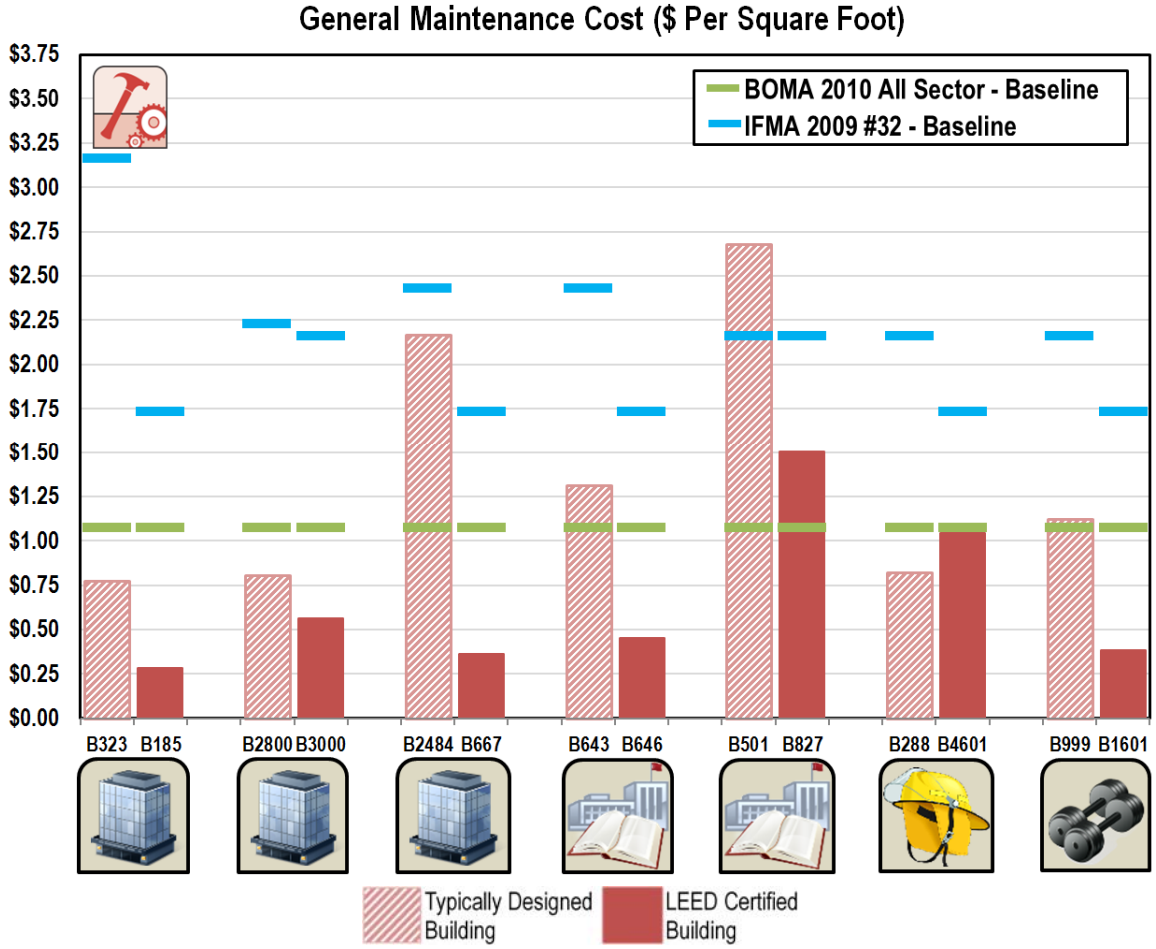


Figure 14. General maintenance cost per square foot

Figure 15 shows grounds maintenance costs per square foot. All but two of the fourteen buildings in the study fell within or below the baseline range. The building significantly above the baseline (B2484, Mission Support Center) is adjacent to the USAF Parade Grounds. Continuous upkeep in this area is likely contributing to the higher grounds maintenance costs. The three buildings at Offutt Air Force Base (B323, B185 and B288) did not have grounds maintenance cost available at the time of this study. Of the six LEED certified buildings with grounds maintenance data, all were under the baseline value. When compared to their matched-pairs, the LEED certified buildings performed 34% better.

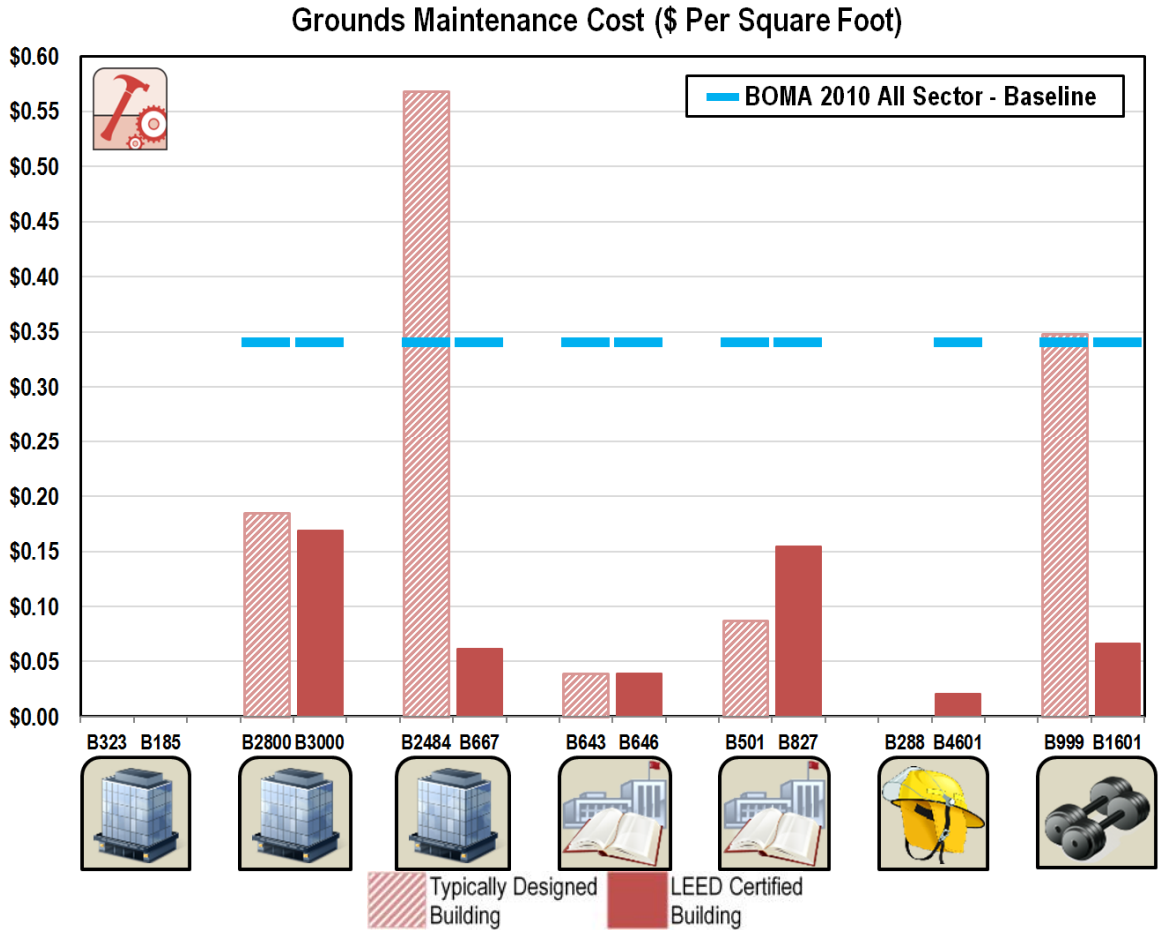


Figure 15. Grounds maintenance cost per square foot

The janitorial maintenance costs for ten of the fourteen buildings were below the baseline costs (Figure 16). The BOMA 2010 baseline shown is a national average, whereas the IFMA 2009 baseline averages are based on the vintage of the buildings. The two fitness centers (B999 and B1601) were not compared to the BOMA/IMFA baselines because their building functions are distinctively different than that of the other building types. The occupants of B288 have decided to perform their janitorial duties in-house to cut facility costs. Five of the seven LEED certified buildings had janitorial maintenance costs equal to or less than the baseline, but only three were performing better than their matched-pair. On average, the seven LEED certified buildings in this study had janitorial maintenance costs similar to that of the seven typically designed buildings. As mentioned previously, the one year of costs provided in this study does not address the quality of work, potential regional cost differences, or the uniqueness of the year's janitorial needs.

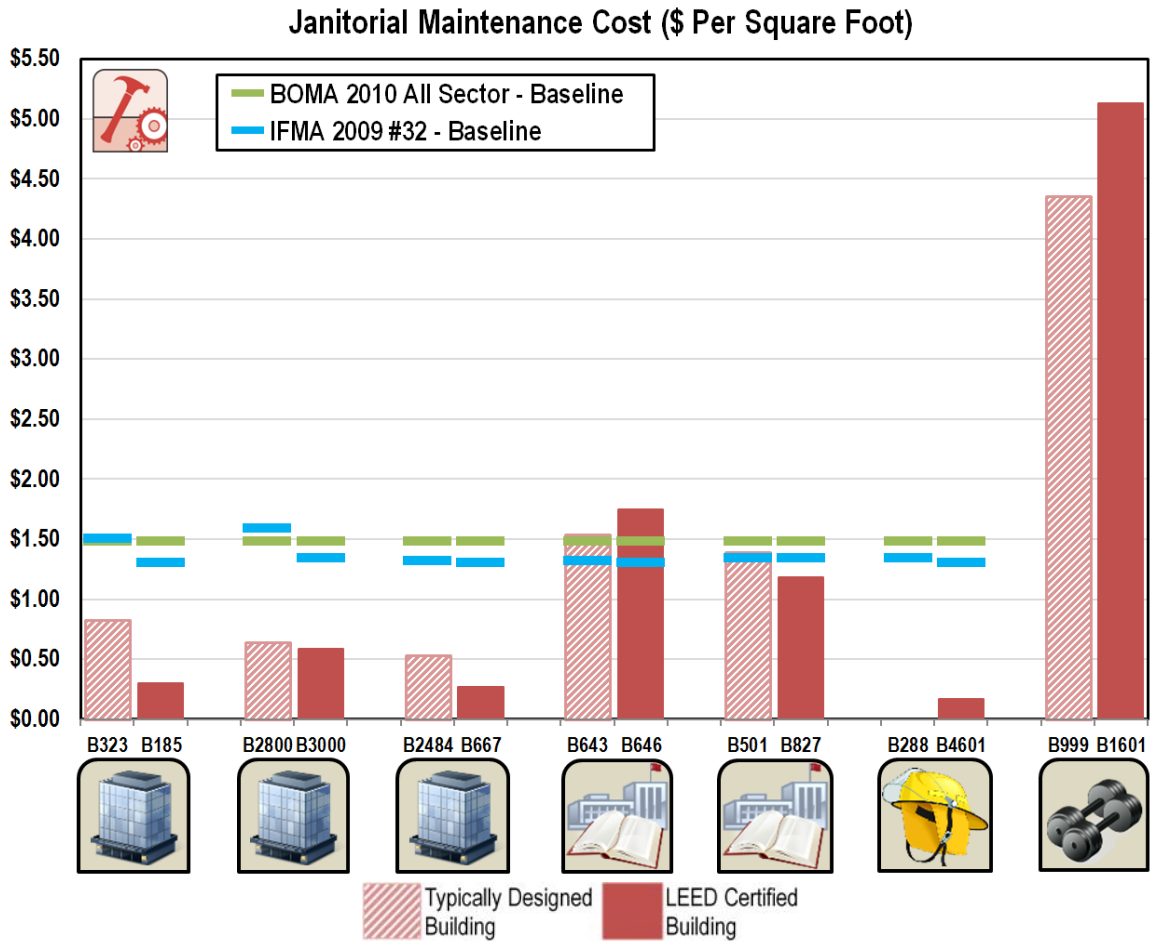


Figure 16. Janitorial cost per square foot

Multiple baselines were used to compare the total maintenance costs (Table 16).

Table 16. Maintenance cost performance against baselines

		General Maintenance ($/GSF)		Janitorial Maintenance ($/GSF)		Grounds Maintenance ($/GSF)	
	Building Name	Building Maintenance	IFMA 2009 #32 - Baseline	Building Maintenance	IFMA 2009 #32 - Baseline	Building Maintenance	BOMA 2010 All Sector - Baseline
	**B323**	$0.77	$3.16	$0.83	$1.50	N/A	N/A
	B185	$0.28	$1.73	$0.30	$1.30	N/A	N/A
	**B2800**	$0.81	$2.23	$0.64	$1.59	$0.19	$0.34
	B3000	$0.56	$2.16	$0.58	$1.34	$0.17	$0.34
	**B2484**	$2.17	$2.43	$0.53	$1.32	$0.57	$0.34
	B667	$0.36	$1.73	$0.27	$1.30	$0.06	$0.34
	**B643**	$1.32	$2.43	$1.54	$1.32	$0.04	$0.34
	B646	$0.45	$1.73	$1.75	$1.30	$0.04	$0.34
	**B501**	$2.68	$2.16	$1.39	$1.34	$0.09	$0.34
	B827	$1.50	$2.16	$1.18	$1.34	$0.15	$0.34
	**B288**	$0.82	$2.16	$0.00	$1.34	N/A	N/A
	B4601	$1.04	$1.73	$0.17	$1.30	$0.02	$0.34
	**B999**	$1.12	$2.16	$4.36		$0.35	$0.34
	B1601	$0.38	$1.73	$5.13		$0.07	$0.34

Aggregate maintenance is the summation of the general, janitorial, and grounds maintenance values. Using the aggregate general maintenance values, thirteen of the fourteen buildings had total maintenance costs less than the baselines (Figure 17). When compared to their matched-pairs, all but one (B4601, Main Fire Station) of the seven LEED certified buildings had superior performance with regards to aggregate maintenance cost per square foot.

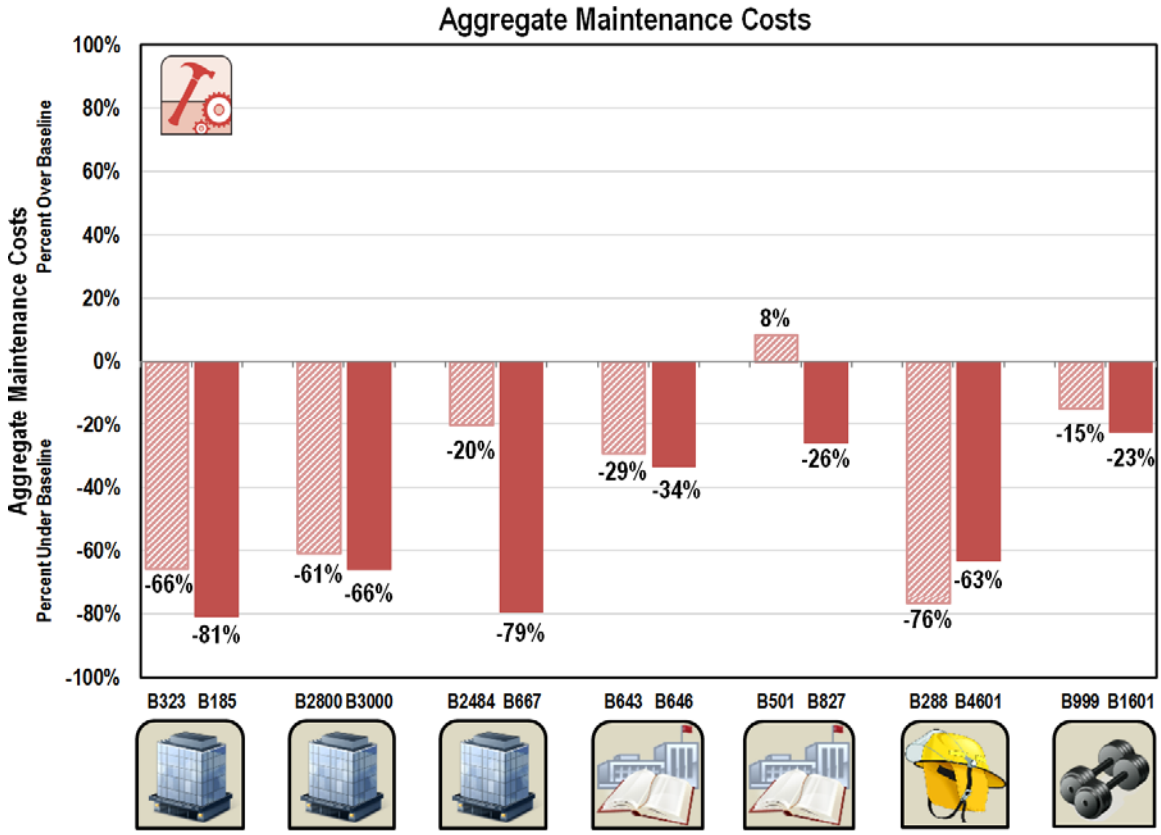


Figure 17. Aggregate maintenance cost comparison

Figure 18 represents the energy, water, and aggregate maintenance for each of the fourteen buildings investigated. All of the energy use intensity values for the LEED certified Air Force buildings were better than their industry baseline and outperformed their matched-pair. The top six buildings in the energy metric and four out of the five buildings top buildings in the water metric were LEED certified. Thirteen of the fourteen buildings in this study had aggregate maintenance costs that were better than the industry baseline. The top two buildings in the maintenance cost metric were LEED-Gold certified. The buildings performing the best in all categories are located in the top-right quadrant and are dark blue colored.

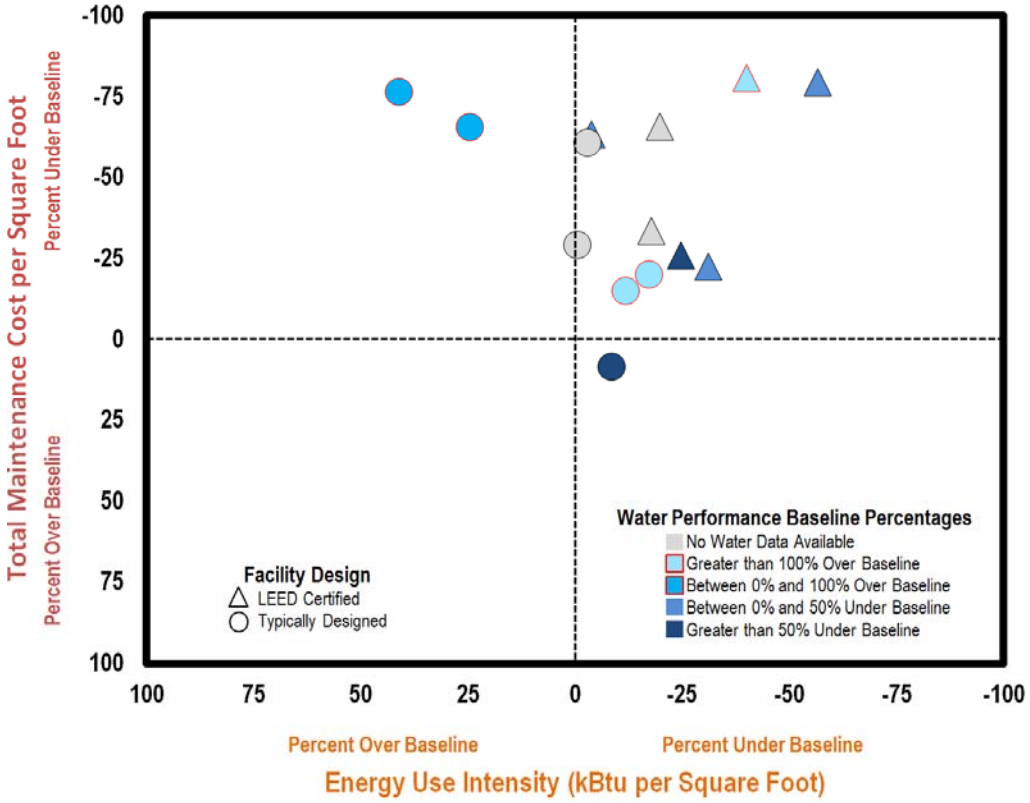


Figure 18. Maintenance performance compared to energy and water performance

Conclusions

The primary intent of this WBPM study is to evaluate the impact of the Air Force's sustainably designed buildings by collecting and analyzing actual performance data from operating buildings for comparison to industry baselines and similar buildings for performance. Ideally, the information derived from this study will be used to inform the design, construction, and operation of the Air Force's building portfolio. The PNNL research team found the data analysis illuminated strengths and weaknesses of individual buildings as well as the portfolio of buildings. This section includes summary data, observations that cross multiple performance metrics, discussion of lessons learned from this research, and opportunities for future research. Table 17 provides the cost data for each whole building performance metric.

Table 17. Total annual costs by building

		Annual Operating Costs (US $)					Aggregate Operating Cost Baseline ($/SF)	Aggregate Operating Cost ($/SF)
	Building Name	General Maintenance	Janitorial Maintenance	Grounds Maintenance	Total Water	Total Energy		
	**B323**	$78,462	$83,618	$0	$4,046	$121,539	$5.69	$2.84
	B185	$57,229	$60,800	$0	$9,827	$503,416	$7.25	$3.12
	**B2800**	$35,927	$28,597	$8,263	No Meter	$85,202	$6.13	$3.55
	B3000	$27,541	$28,596	$8,262	No Meter	$48,298	$5.08	$2.30
	**B2484**	$133,471	$32,678	$35,000	$982	$78,257	$5.58	$4.56
	B667	$12,843	$9,598	$2,204	$132	$36,391	$6.53	$1.72
	**B643**	$68,655	$80,303	$2,045	No Meter	$68,941	$5.42	$4.22
	B646	$21,888	$84,732	$1,899	No Meter	$64,286	$4.99	$3.57
	**B501**	$78,305	$40,577	$2,545	$84	$60,614	$5.91	$6.24
	B827	$24,816	$19,509	$2,545	$59	$32,426	$5.57	$4.81
	**B288**	$34,090	$0	$0	$1,653	$56,014	$4.55	$2.22
	B4601	$45,265	$7,448	$912	$1,157	$66,591	$5.58	$2.80
	**B999**	$88,369	$342,772	$27,422	$1,354	$72,338	$8.25	$6.76
	B1601	$28,832	$386,000	$5,000	$1,076	$98,996	$9.21	$6.91

The summary of annual data for each of the performance metrics is provided in Table 18. The data represent one year of measurements and are not associated with any specific design features or strategies. Individually focused post occupancy evaluation (POEs) would allow for more detailed analysis of the buildings. Examining building performance over multiple years could potentially offer a useful diagnostic tool for identifying building operations that are in need of operational changes. Investigating what the connection is between the building performance and the design intent would offer potential design guidance and possible insight into building operation strategies.

Table 18. Summary values for each performance metric

	Building Name	Gross Square Foot	Total Energy Use (kBtu)	Total Water (kGal)	Aggregate Maintenance Cost	Emissions ($MTCO_2e$ per SF)	Aggregate Operating Cost
	**B323**	101,250	14,510,978	2,953	$159,765	0.0226	$287,666
	B185	202,362	64,103,982	7,173	$117,591	0.0415	$631,272
	**B2800**	44,543	4,972,778	No Meter	$63,961	0.0080	$157,989
	B3000	48,958	5,537,411	No Meter	$61,174	0.0081	$112,697
	**B2484**	61,554	5,557,823	2,000	$181,682	0.0115	$280,388
	B667	35,600	1,684,876	377	$18,848	0.0047	$61,168
	**B643**	52,172	6,587,699	No Meter	$145,435	0.0156	$219,945
	B646	48,446	6,171,717	No Meter	$105,006	0.0158	$172,805
	**B501**	29,184	3,597,590	70	$81,195	0.0117	$182,125
	B827	16,500	1,788,813	49	$44,559	0.0129	$79,354
	**B288**	41,375	6,797,184	1,207	$31,756	0.0247	$91,758
	B4601	43,400	3,770,166	544	$50,746	0.0088	$121,373
	**B999**	78,701	6,017,645	3,876	$457,809	0.0089	$532,255
	B1601	75,278	4,495,072	626	$415,395	0.0100	$519,904

The "aggregate operating cost" metric used in this study represents the costs that were available for developing a comparative industry baseline for typical buildings. The costs include water utilities, energy utilities, general maintenance, grounds maintenance, and janitorial costs.

Thirteen of the fourteen buildings in this study had aggregate operational costs less than the baselines (Figure 19). When compared to their matched-pairs, all but one (B4601, Main Fire Station) of the seven LEED certified buildings had superior performance with regards to aggregate operational cost per square foot. While B4601 had aggregate operational costs less than its baseline (by 50%), its matched-pair (B288, Fire Crash Rescue Station) had slightly lower costs (around 1%). When looking at individual metrics, B4601 has superior energy (by 45%) and water (by 57%) performance and higher maintenance costs (by 13%). As stated previously, the inferior maintenance performance may be attributed to B288's backlog of service orders. At the time of the site visit, there were multiple maintenance requests pending for B288 (effectively deflating actual maintenance costs).

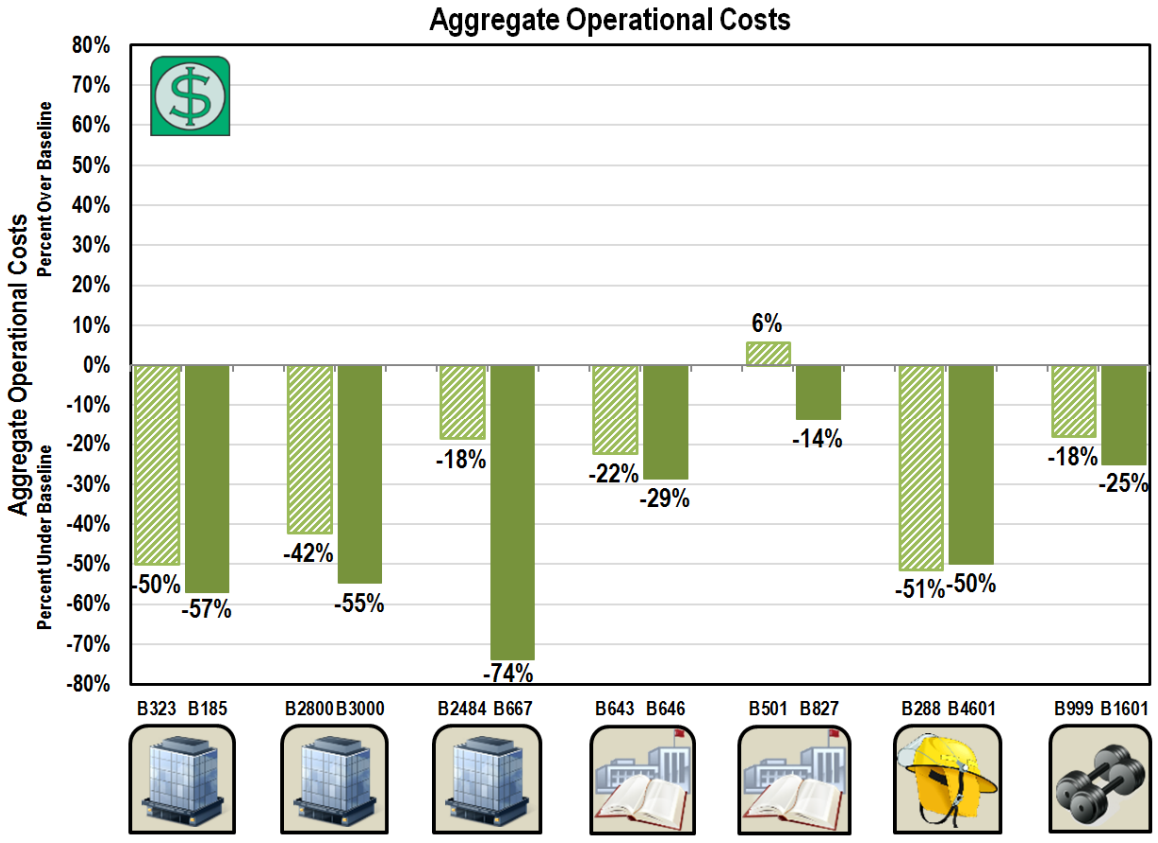


Figure 19. Aggregate operational costs compared to baseline

Given the volume of data collected and analyzed for this study, the inevitable request is for a simple answer with respect to sustainably designed building performance. As previously stated, compiling the individual building values into single metrics is not statistically valid given the small number of buildings, but it has been done to provide a cursory view of this portfolio of sustainably designed buildings (Table 19). For all metrics except janitorial maintenance cost per square foot, the averaged building performance for the seven LEED certified buildings was better than the seven typically designed buildings in this study.

Table 19. Summary performance for study buildings portfolio

Metric Description	LEED Certified Building Performance	Performance Description
Total Water Use	-32%	*Average LEED certified building performance when compared to matched pairs and the IFMA #32 (2009 pg. 59) - 50th Percentile Water Use per Square Foot Baseline*
Total Water Cost	-5%	*Average LEED certified building performance when compared to matched pairs and the BOMA 2008 Government Sector - Utility Water/Sewer Cost Baseline*
Total Energy Use	-28%	*Average LEED certified building performance when compared to matched pairs and Energy Star's 50th Percentile and CBECS Specific Regional Average Energy Use (kBtu) per Square Foot Baselines*
Total Energy Cost	-26%	*Average LEED certified building performance when compared to matched pairs and Energy Star's 50th Percentile Cost Baselines*
General Maintenance	-25%	*Average LEED certified building performance when compared to matched pairs and the IFMA #32 (2009 pg. 47) - Repair/Maintenanece Cost Baseline*
Janitorial Maintenance	0%	*Average LEED certified building performance when compared to matched pairs and the IFMA #32 (2009 pg. 37) - Janitorial Maintenance Cost Baseline*
Grounds Maintenance	-34%	*Average LEED certified building performance when compared to matched pairs and the BOMA 2010 All Sector Total Building Rentable Area - Roads/Grounds Cost Baseline*
Aggregate Operational Cost	-15%	*Average LEED certified building performance for Water, Energy, Maintenance, Janitorial, and Grounds costs per square foot compared to matched pairs and Energy Star, BOMA and IFMA baselines.*

Observations

Whole building performance measurement involves the analysis of the interaction between different metrics. Many comparisons can be made between energy, water, maintenance, and occupant satisfaction. Additional comparisons could include waste generation and commute data, but data for those metrics was not readily available.

Based on the LEED credits and Energy Star scores, it was observed that when projects had incorporated sustainable design principles from the start (e.g., LEED requirements) the overall performance of the building was better than the industry standard and respective matched-pair. Additionally, the LEED Gold & Platinum buildings performed consistently well in most metrics (Figure 20) with regards to baseline and their matched-pairs. Although water performance of the Main Weather Station HQ (B185) is above baseline, B185 is the building noted previously with the large number of occupants and visitors, small cafeteria and unique water-using operations.

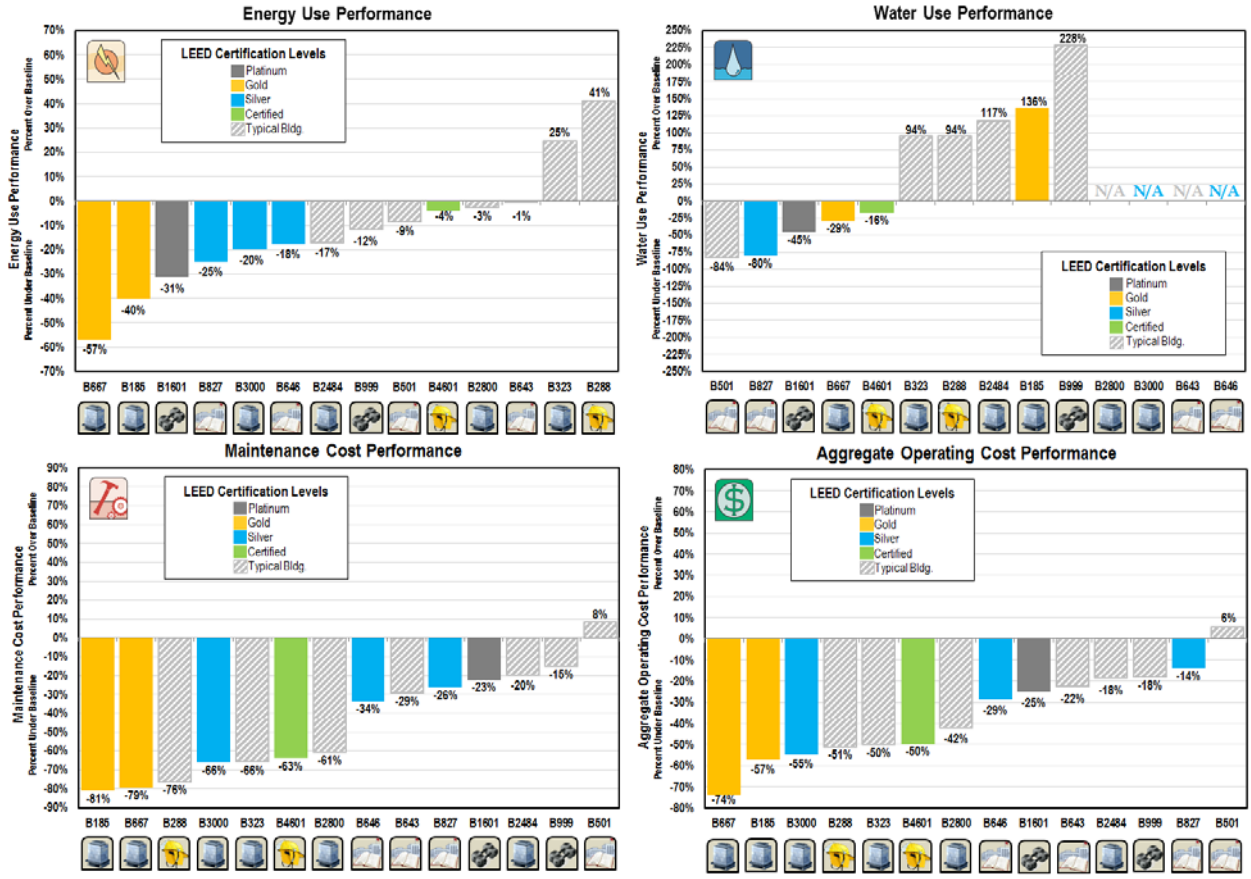


Figure 20. LEED Gold & Platinum buildings consistently perform well

Figure 21 is a quad-chart showing the energy performance of all the buildings in the study (x-axis) in relationship to the aggregate operational costs per square foot (y-axis). The energy performance for twelve out of the fourteen buildings in this study is equal to or better than the industry average (buildings in the two quadrants on the right). All seven of the LEED certified buildings have superior energy performance compared to industry baselines and their matched-pairs. Thirteen of the fourteen buildings in this study had aggregate operational costs less than the baselines (top two quadrants). The buildings performing the best in these two metrics are those within the top-right quadrant.

In addition to the axis metrics, the shape of the data point indicates the facility design (LEED certified or typically designed) and the color represents the water performance (the darker the blue, the better water performance) and the red tails indicate the total maintenance performance (the longer the tail, the lower maintenance costs). Note, all seven of the LEED certified buildings (triangles) are within the top right quadrant and have maintenance costs lower than baselines.

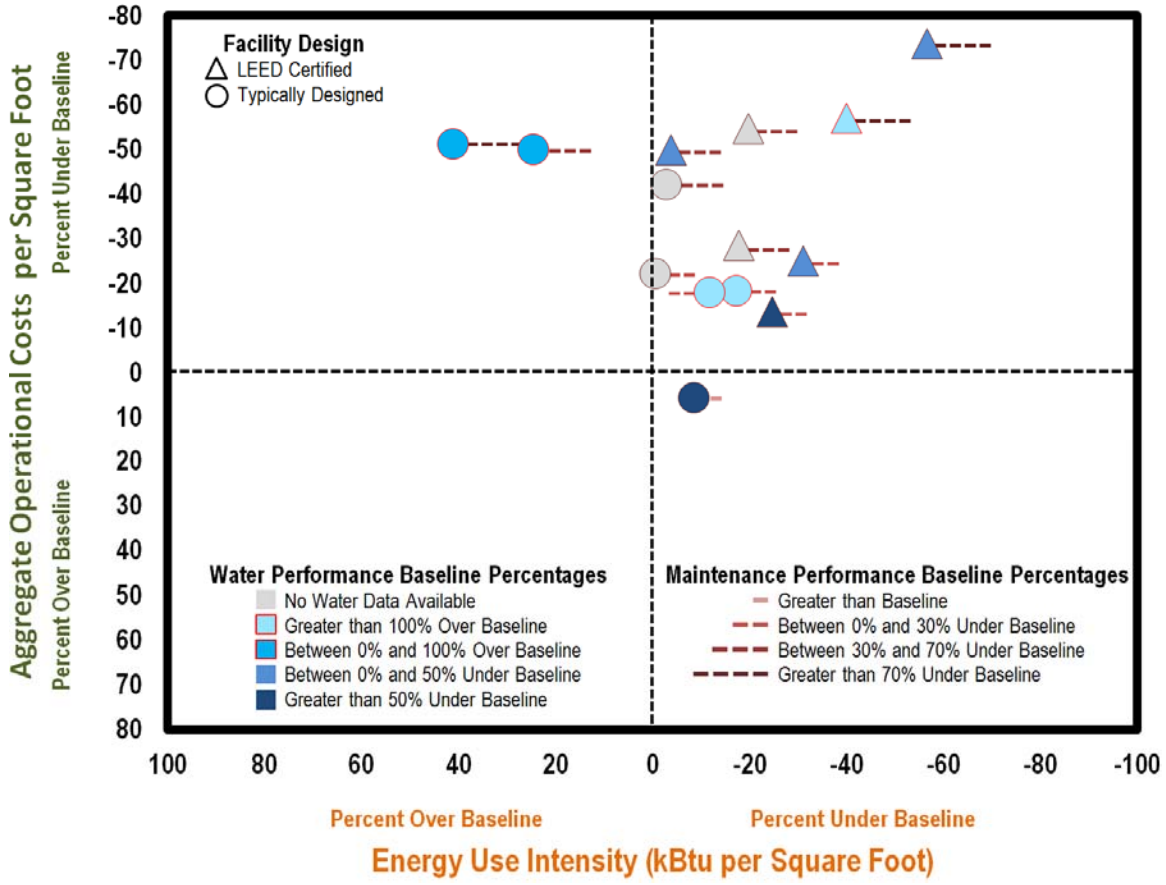


Figure 21. Aggregate operational costs compared to energy, water and maintenance performance

Figure 22 shows the aggregate operation costs by metric compared to the aggregate baselines. When looking at the portfolio, total maintenance costs on average are approximately 57% of the total operational costs. As a result, facilities with superior maintenance performance are likely to also perform well with regards to aggregate operational performance. Water costs comprise of less than 1% on average, and energy costs make up the remaining 43%. How a building is maintained and operated, largely affects the building energy performance, costs and occupant comfort and satisfaction.

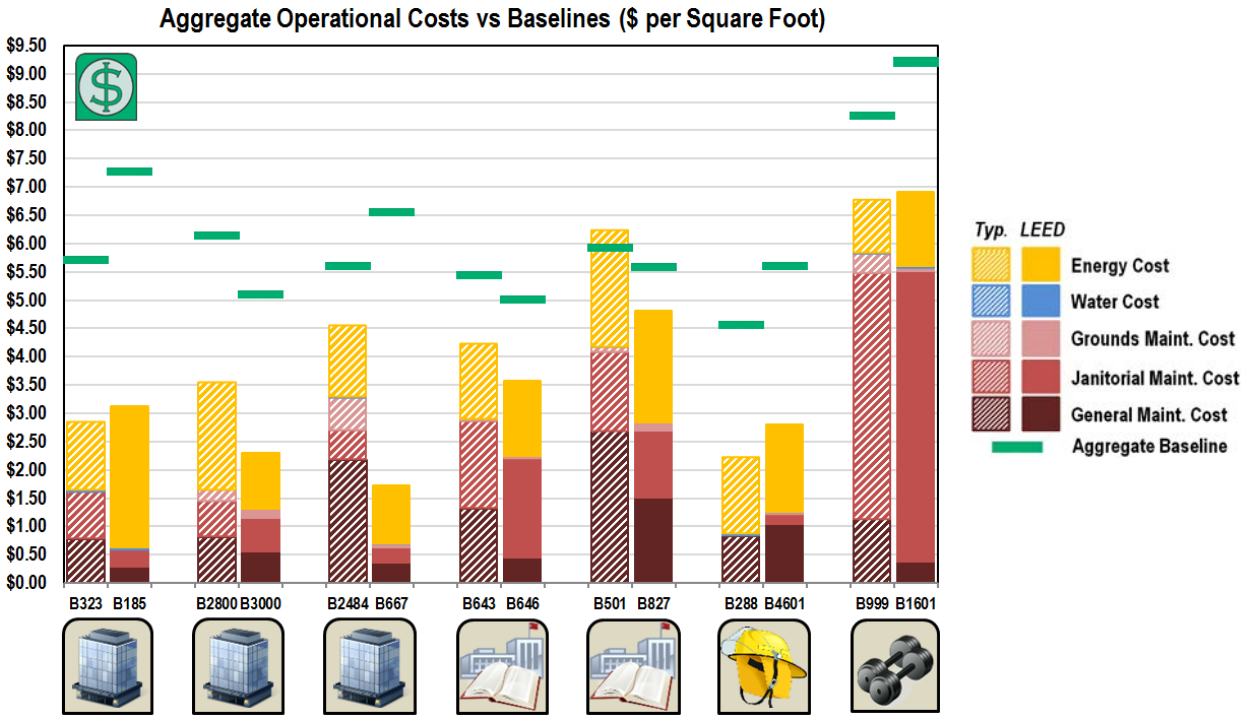


Figure 22. Aggregate operational costs by metric

A unique additive to this study was the partnership with industry experts in commissioning. All seven LEED certified buildings were given a light commissioning or facility walkthrough assessments by Jacobs Engineering. The facilities surveyed have a varying degree of system performance and comfort levels in regards to the HVAC systems serving each building. The process of constructing buildings per LEED guidelines should result in a building or facility having superior or better performing HVAC systems. The LEED process is only successful if all parties involved in the project adhere to the goals set forth with the LEED rating system and the owner's project requirements. The facilities that were surveyed have experienced some issues with HVAC system operation due to design, installation and poor commissioning practices.

Energy Management and Control Systems were a concern in all but one building (B1601, Tyndall Fitness Center). Other top issues include frequent humidity or comfort complaints, high CO_2 levels, and control dampers malfunctions. Although seven buildings is a small sample size, and the degree of severity ranged, the average number of findings from the walkthroughs seemed to reduce with the increased LEED certification levels (i.e., 7 issues for LEED Certified versus 4 issues for LEED

Platinum). For more details on current operating conditions of individual building as well as findings, actions and recommendations, see Appendix-A (Site Summaries).

Many of the issues noted may have been avoided with a more stringent approach to the development of the owner's design and construction project requirements, design review phase, construction oversight, and better functional performance testing during the commissioning phase. While the LEED process is a good approach for designing a good facility, it must be coupled with sound design, construction and operating practices for the design intent to be realized. The two most critical phases early in a building's life are during the design review process and the testing or commissioning phase after building construction has been completed. The best goals and ideas will sometimes have results that do not meet the expectations of all parties. Most of the buildings surveyed have served the Air Force well but some have fallen short in regards to HVAC and building control systems. With retro-commissioning and some mechanical design changes, the buildings currently experiencing issues can be improved to allow an even higher level of comfort and performance for many years into the future for these facilities.

Lessons Learned and Future Research Opportunities

At the time of this study, the Air Force had over 30 LEED certified facilities, 736 LEED Silver-certified homes and roughly 300 LEED registered projects that it was managing. This study includes seven of the 30 LEED certified Air Forces facilities. Although this is a respectable representation of the buildings that have been officially identified as being sustainably designed, the sample size is small, so it does not lend itself to broader inferences for the entire Air Force building stock. Nevertheless, the lessons learned may be helpful for future design, construction, and operation of Air Force buildings. Measuring the performance of more buildings will allow for a greater understanding of how sustainably designed buildings perform as a group. Based on the data collection and analysis experienced, the following includes future research opportunities and observations of the current data set.

A detailed investigation into the water use for each building is needed to determine, with any confidence, an accurate understanding of water use within sustainably designed buildings. Design estimates focus on bathroom and kitchenette fixture specifications. How much water building occupants actually use is not well understood. Plus, many buildings use water for irrigation, process water, food service, and other activities without separately metering the water use. The impact of that "other" water use is also not well understood.

Energy use and cost are the metric that is most easily and commonly examined in a more detailed fashion. Many facilities on U.S. Air Force bases are served by a central chiller or steam plant, making accurate measurement of whole building energy usage difficult, if not impossible, at times. Sub-metering all energy use data can provide insights into what aspects of the building operations are impacting energy use most significantly. In many buildings, the miscellaneous electric load is presumed to be a significant portion of the energy use, but is not well understood since it is driven by the occupants. Large electric loads associated with computing equipment, in the form of small data centers, are a growing portion of building energy use. Additional data collection and research related to the miscellaneous electric load in

buildings would identify potential opportunities for conservation and efficiency. Energy Management and Control Systems were a concern in all but one building (B1601, Tyndall Fitness Center). More consistency with energy control interfaces and devices, building automation systems, and standardized operator training would be offer a better understanding of energy use and an effective mechanism for managing the building operations.

Operations and maintenance data are being tracked by more building managers, but the quality of the data varies by building. Additionally, there is no consistent level of detail collected at each building because of the diversity of the tracking systems. This variability of data makes comparisons between buildings a challenge. Inferences from the regular maintenance and preventative maintenance ratio should be considered speculative unless the more consistent data and details are provided by all of the buildings for each metric. The ability to collect consistent data from each site is critical for building-to-building comparisons to industry baselines. It was noted that buildings with a superior maintenance program, also had lower aggregate operational costs. It was also noted that some bases were experiencing a backlog of maintenance requests due to lower than normal resource allocation. In some cases, a lower total maintenance cost per square foot also correlated with increased energy use in the facility. While most of the LEED certified buildings in this study have served the Air Force well, retro- or enhanced commissioning and some mechanical design changes, could allow an even higher level of comfort and performance for many years into the future for these facilities. How a building is maintained and operated, largely affects the building energy performance, costs and occupant comfort and satisfaction.

Waste disposal is a utility cost incurred by buildings that is an indicator of resource use by the building occupants. Although occupant waste generation is not typically seen as having a connection to a building, LEED requires recycle bins as part of the building design. This performance metric has been used in the past to investigate whether the occupants of green buildings recycle at a greater rate than an industry baseline. It was decided early on that waste disposal data would not be available at these buildings and thus this metric was not used in this study. However, during site visits it was noted that all buildings had recycling-stations and bins placed throughout the facilities. A consistent mechanism for comparing sanitary waste, and recycling, is needed.

A primary aim of sustainable design is maximizing the occupant comfort and satisfaction, while minimizing the environmental impact and costs. Indoor environmental quality (IEQ) is the commonly used term to describe the building features that directly impact the occupants. The IEQ of a workplace reflects the interaction of air, lighting, and surroundings with occupants in a holistic sense. IEQ effects include occupant health, productivity, and satisfaction. This study attempted to use the Center for the Built Environment's (CBE) occupant satisfaction survey to assess the Indoor Environmental Quality of the selected buildings. Only six (three LEED certified and three typically designed) of the fourteen buildings in this study had at least one response. Of the buildings with responses, most had low survey response rates with the average response rate being 15%. Based on these limited responses, the occupants in the three LEED certified Air Force facilities scored higher on average with respect to building satisfaction than both their matched-pairs and the CBE 50th Percentile. Given the

CBE's target of a 50% response rate, minimal analysis could be done with the survey data and these results should be considered observational. A better understanding of response rate expectations is needed, especially given CBE's goal and the study's inability to meet that goal for many of its buildings.

One of the more important lessons learned with respect to whole building performance measurement and assessment is that the baselines selected for performance comparison are what define the study findings. Ideally, performance measurement data should be compared to other measured building performance data. Comparing measured values to modeled or estimated values does not offer a valid comparison, and should be avoided whenever possible. For this study, matched-pairs were used in conjunction with industry baselines to offer another basis for comparison.

In addition to the baselines needing consistency to make the performance measurement and assessment data useful, the buildings being studied should be working properly to be representative of sustainably, or typically, designed building performance. If a building is not operating well because it has not been properly commissioned, has had an equipment failure, or occupancy settings have not been optimized, it is difficult to parse out what aspect of the performance data is related to the design rather than the insufficient operations. In this case it would be more effective to perform a detailed post occupancy evaluation to identify where changes could be made in the building to improve building performance. A more detailed study of individual buildings could be used to determine which design features offer the best value. This type of investigation may be able to show the difference between early design expectations, as-built expectations, and operations. Additionally, multiple years of data would be useful in understanding whether the performance will be maintained or if it was a 'good' or 'bad' year for the building.

The snapshot view of these sustainably designed buildings provides a valuable picture of the overall performance. Continued work to assess more buildings and to include multiple years of whole building performance data could improve the accuracy and depth of this assessment. Of course, individual buildings had higher and lower performance in various metrics, as the performance of every building whether LEED certified or typically designed depends on many factors, especially the building occupants. Nonetheless, as a portfolio of buildings, the average performance of the LEED certified Air Force buildings in this study was better than industry baselines and their respective matched-pair for almost all of the performance metrics.

Appendix A: Site Summaries

Data were collected and site visits were performed for fourteen buildings under the scope of this study. The site summaries in this appendix provide an overview for each building and offer site-specific observations. Each site summary includes the following:

- Building photo
- General building description
- Table listing building and site characteristics data
- Certification information
- Operation costs compared to baseline costs
- Table summarizing building performance data
- Jacobs Engineering – Facility Walkthrough Assessment

The site summaries are presented in the following order

Abbreviation	Building Name	Building Type	Air Force Base
B323	Base Personnel Office	Office Building	Offutt
B185	Weather Agency HQ	Office Building	Offutt
B2800	Building 2800	Office Building	Edwards
B3000	Consolidated Support Facility	Office Building	Edwards
B2484	Mission Support Center	Office Building	Lackland
B667	AFPC Admin Facility	Office Building	Randolph
B643	AFIT Engineering Building	Academic Facility	Wright Patterson
B646	AFIT Academic Facility	Academic Facility	Wright Patterson
B501	Base Education Center	Academic Facility	Shaw
B827	McElveen MRC Library	Academic Facility	Shaw
B288	Fire Crash Rescue Station	Fire Station	Offut
B4601	Main Fire Station	Fire Station	Seymour Johnson
B999	Rambler Fitness Center	Fitness Center	Randolph
B1601	Tyndall Fitness Center	Fitness Center	Tyndall

The table above shows both the official building name and the name used within the body of this report, which includes building location and type. In this appendix, each site summary is titled using the same name as the body of the report and then the official building name is used throughout the text so that the site is recognizable to those who occupy each building.

Base Personnel Office (B323)

Description

Building B323 – The Base Personnel Office is a three story facility originally building in 1942 and renovated in 1985. The interior is comprised largely of administrative spaces. The building has all exterior office space with interior corridors. The office space is largely open offices and cubicles with some private/enclosed offices. Building B323 houses the Mission Support Group and has a high volume of visitors and electronic equipment. There are approximately 200 visitors for an average visit of 45 minutes a day. The facility has approximately 6 conference rooms, 2 computer labs, 8 data centers/server closets (2 with separate HVAC systems) various lounge areas, a full size kitchen and lunch/break rooms. The facility incorporates military personnel, service, finance, LSI, medical reimbursement, American Red Cross and WIC programs.

Metrics	Base Personnel Office (B323)		
	Street Address	*705 Nelson Drive*	*Offutt*
	State & Zip Code	*NE*	*68113*
	Air Force Base		*Offutt Air Force Base*
	Building Function		*Office*
	Design Certification		-
	Year Built		*1942*
	# of Floors		*3*
	Gross Square Foot		*101,250*
	Weekly Operating Hours		*58*
	Regular Occupants		*269*
	Average Daily Visitors (FTE)		*13*
	Electronic Equipment		*307*
	Construction Cost		*$355,059*

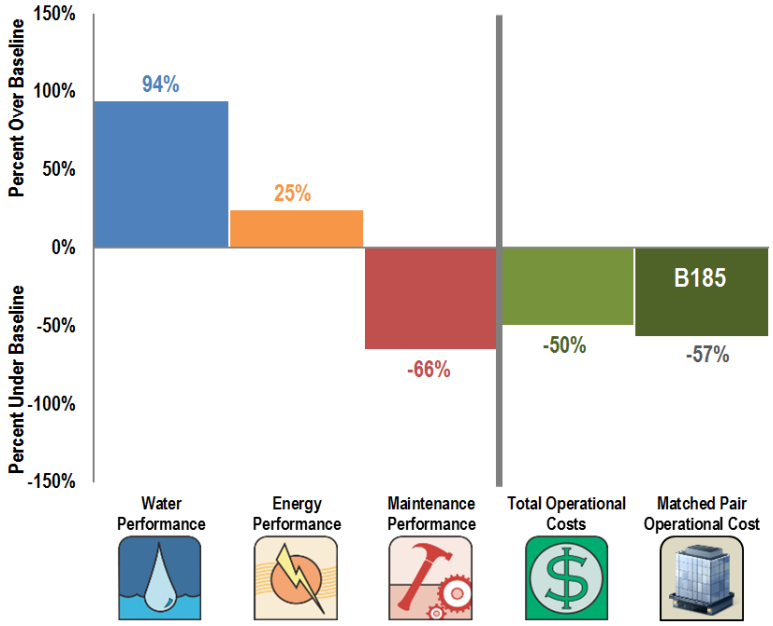
Building B323 has 59 variable air-volume cooling only terminal boxes, 57 parallel fan powered boxes with hot water reheat and 6 cabinet unit heaters, and 2 single duct variable air volume AHUs serving the building. There is no chiller in the building as the chilled water is supplied by the chilled water pumps located in an adjacent building (B304). The heating system is comprised of 3 recently replaced boilers.

Each building in the study had operational highlights and potential opportunities for improvement. Although it was not the focus of this study to investigate and/or document operational highlights and opportunities, the research team observed:

- Interior light fixtures were updated to T8s and roof perimeter lights to LEDs.
- There have been frequent thermal leakages from exterior windows accompanied by occupant comfort complaints. Commissioning the building envelope and addressing the problems will likely lead to substantial future energy savings.

Whole Building Performance

The Base Personnel Office operating costs are lower than the industry baseline for all maintenance metrics. The water and energy metrics are performing above industry standards. The maintenance performance does not include grounds maintenance costs. Overall, the building cost 50% less to operate than industry baselines and 7% more than its matched-pair.



Performance Data Summary

The research team collected, normalized, and compared whole building performance data for the Base Personnel Office to industry baselines. The following table summarizes the annual performance data collected and normalized. Outdoor water use was estimated using the "rule-of-thumb" that 20% of total water used is for landscaping.

Metrics	Annual Performance Measurements		Annual Performance Metrics	
	Water Use (gal)	*2,953,452*	Gallons per occupant	*10,473*
	Process Water Use (gal)	*0*	Water Cost per occupant	*$14.35*
	Outdoor Water Use (gal)	*590,690*	Gallons per GSF	*29.17*
	Water Cost	*$4,046*	Water Cost per GSF	*$0.040*
	Energy Star Score	*29*		
	Total Energy Use (kBtu)	*14,510,978*	Energy Use (kBTU) per GSF	*143*
	Energy Cost	*$121,539*	Energy Cost per GSF	*$1.20*
	Building Emissions ($MTCO_2e$)	*2,289*	Building Emissions per Occupant ($MTCO_2e$)	*8.12*
	General Maintenance Cost	*$78,462*	General Maint Cost per GSF	*$0.77*
	Janitorial Services Cost	*$83,618*	Janitorial Services Cost per GSF	*$0.83*
	Grounds Maintenance Cost	*$0*	Grounds Maint Cost per GSF	*$0.00*
	Quantity of Maint Requests	*167*	Ratio of Maint Requests to Total Maint Jobs	*0.91*
	Quantity of Prev Maint Jobs	*16*		

Weather Agency HQ (B185)

Description

Building B185 – The Weather Agency HQ was completed and occupied in 2008. B185 has a staff of scientists, forecasters, technicians, and operations personnel who provide weather-related products to all U.S. Army and Air Force units. AFWA does extensive computer processing using data gathered from satellites and other weather instruments. The computer center and 24-hour operations staff is located in the basement, completely below grade, for disaster protection. The headquarters also includes a daytime operations floor with a forecasting area and broadcast studio.

Metrics	Weather Agency HQ (B185)		
	Street Address	*101 Nelson Dr*	*Offutt*
	State & Zip Code	*NE*	*68113*
	Air Force Base		*Offutt Air Force Base*
	Building Function		*Office*
	Design Certification		*LEED NC 2.1 - Gold*
	Year Built		*2008*
	# of Floors		*3 levels, 1 basement and 1 penthouse*
	Gross Square Foot		*202,362*
	Weekly Operating Hours		*63*
	Regular Occupants		*800*
	Average Daily Visitors (FTE)		*81*
	Electronic Equipment		*1,500*
	Construction Cost		*$29,822,866*

The building is served by stand-alone chilled and hot water plants supplying AHUs and VAV terminal reheat units located in the under floor air distribution systems throughout the building. The HVAC system consist of (8) VAV and (5) CV AHU's. The primary air source is distributed by VAV terminal units. The perimeter terminal units utilize hot water reheat coils to maintain the space temperature. The air distribution system is unique in design by using fan powered terminal units, with VFD's to maintain a static pressure set point below the raised floor plenums. The space temperature in the zones is maintained by modulating the primary air dampers and hot water valves on the reheat coils of the terminal units. Chilled water is produced by two water cooled York chillers and is distributed by a variable primary flow arrangement. The chillers are served by a two cell cooling tower and two vertical multistage condenser water pumps. The cooling tower has a concrete basin below ground level.

Hot water is produced by three condensing natural gas boilers and is distributed to the building from a primary/secondary pumping arrangement. The building has several large data center areas that are served by Data Air units. The Data Air units are DX cooling with glycol dry-coolers located outside. The data center units are equipped to provide a free-cooling cycle when ambient conditions are low enough to use the free-cooling mode of operation. The building has several large exhaust fans that serve Mechanical, UPS Distribution and Battery rooms. The building HVAC systems are controlled by Honeywell DDC controls using the BACnet communication protocol. The BAS system uses time of day scheduling in some areas, hot water reset and discharge air reset for the AHU's. Space temperature setpoints are range limited to 3.0°F +/- the normal setpoints for cooling

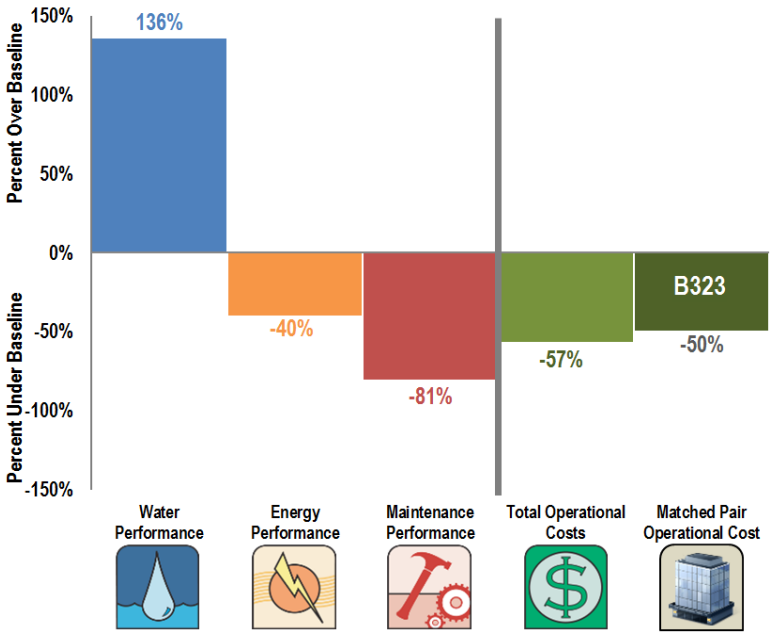
and heating in each zone. The building utilizes a free-cooling mode of operation between the dates of April 5th to May 5th as determined by the Offutt AFB operating guidelines.

Certifications

Certified: 26-32 points, **Silver:** 33-38 points, **Gold:** 39-51 points, **Platinum:** 52-69 points

Whole Building Performance

The Main Weather Station HQ operating costs are lower than the industry baseline for all metrics except water. The maintenance performance does not include grounds maintenance costs. Overall, the building cost 57% less to operate than industry baselines and 7% less than its matched-pair.



Performance Data Summary

The research team collected, normalized, and compared whole building performance data for the Main Weather Station HQ to industry baselines. The following table summarizes the annual performance data collected and normalized. The facility uses water-cooled chillers for its air-conditioning system; therefore, the cooling tower water use was estimated using the "rule-of-thumb" that 27% of total water use is process water. Outdoor water use was estimated using the "rule-of-thumb" that 20% of total water used is for landscaping.

Metrics	Annual Performance Measurements		Annual Performance Metrics	
	Water Use (gal)	*7,173,000*	Gallons per occupant	*8,142*
	Process Water Use (gal)	*1,936,710*	Water Cost per occupant	*$11.15*
	Outdoor Water Use (gal)	*1,434,600*	Gallons per GSF	*35.45*
	Water Cost	*$9,827*	Water Cost per GSF	*$0.049*
	Energy Star Score	*98*		
	Total Energy Use (kBtu)	*64,103,982*	Energy Use (kBTU) per GSF	*317*
	Energy Cost	*$503,416*	Energy Cost per GSF	*$2.49*
	Building Emissions ($MTCO_2e$)	*8,395*	Building Emissions per Occupant ($MTCO_2e$)	*9.53*
	General Maintenance Cost	*$57,229*	General Maint Cost per GSF	*$0.28*
	Janitorial Services Cost	*$60,800*	Janitorial Services Cost per GSF	*$0.30*
	Grounds Maintenance Cost	*$0*	Grounds Maint Cost per GSF	*$0.00*
	Quantity of Maint Requests	*96*	Ratio of Maint Requests to Total Maint Jobs	*0.97*
	Quantity of Prev Maint Jobs	*3*		

Jacobs Engineering – Facility Walkthrough Assessment

Findings, Actions & Recommendations

1. **Finding:** During the site survey the building was operating in a very negative pressure condition as referenced to the ambient outside pressure. The building has experienced building pressure issues since it was completed, according the facility manager. There have been some attempts to correct this problem from a previous survey and report performed in 2010 for the building. The air lock security doors located on the ground level offer some isolation for the large pressure difference and help prevent high wind noise from occurring most of the time.
    a. **Recommendation:** The TAB report for the building when completed needs to be reviewed in detail. A study needs to be performed to insure the building design and air flows are correct for the current way the building is operated and configured. All supply and return air ducts should be traversed and measurements taken again to verify the actual CFM being delivered for each AHU is correct.
    b. **Recommendation:** Verify the minimum CFM setpoints for the VAV terminal units is equal to or slightly greater than the general bathroom and equipment room exhaust. The building has several large exhaust fans that move large amounts of air.
    c. **Recommendation**: Verify the original design incorporated a building pressurization control scheme to maintain the building in a slight positive pressure during normal operation. The building should maintain a positive pressure of 0.015 inches W.C. to prevent infiltration of cold or warm air and prevent dirt and dust from entering the building.

2. **Finding:** The SCIF area is still experiencing problems meeting the cooling demand for the space. It has been determined previously the return air path is not adequate for the area and there has been a work order issued to address this problem. During the site visit on May 24th, 2012 it was discovered that AHU-7 was operating at a minimum speed of 15 HZ on the supply fan VFD. The return air fan was in alarm and not operating. The DDC controls indicated an alarm condition for AHU-7 at the local DDC control cabinet but the alarm was not received at the EMTS operator work station.
    a. **Recommendation:** Investigate the cause of the alarm condition for AHU-7 supply and return air fans.
    b. **Recommendation:** Set up trend logs for AHU-7 to monitor the discharge static pressure, discharge air temperature and supply and return fan status.
    c. **Recommendation:** Correct issues between the building local DDC controls and the EMTS operator control room to provide EMTS operators the ability to properly monitor and control the building.

3. **Finding:** After AHU-7 supply fan was brought back online in bypass for the supply fan the brake horsepower was calculated using the average phase to phase voltage and phase currents. The brake horsepower for the supply fan was approximately 16.5 BHP at the time of measurement. The sheaves and belts for AHU-7 can be adjusted to increase the units supply air volume up to the design full motor horsepower rating of 20 HP. This will increase the amount of available airflow and static pressure for AHU-7. The supply fan motor has a service factor rating of 1.15, which will allow the motor to be fully loaded to 20 HP without adverse heating or problems.
    a. **Recommendation:** Adjust the sheaves and belts to increase the BHP for the supply fan for AHU-7 to 20 BHP. Take both the supply and return air fan motor readings at 60 HZ while operating together with all access doors closed and clean filters.
    b. **Recommendation:** Perform an actual duct traverse of the supply air duct downstream of AHU-7 and below the mechanical room floor in the ceiling area on the 3rd floor. The duct traverse needs to be performed in straight run of ductwork away from any bends or transitions to achieve accurate results and readings.

4. **Finding:** During the sight survey and review of the previous commissioning report it was noted that all AHU cooling coils are not designed for 100 percent of the supply air CFM. The AHU's are equipped with bypass dampers between the return air path and the suction side of the supply fans according to site personnel. The cooling capacity for the chilled water coils in each AHU should be sized for full CFM flow rates at peak cooling demand.
    a. **Recommendation:** Review and verify the design intent for the AHU's with bypass (return air) dampers.
    b. **Recommendation:** Review the sequence of operations and control for the bypass dampers as currently configured. Make changes to operate per the design intent.
    c. **Recommendation:** Verify chilled water coil capacity at 100 percent supply air CFM.

5. **Finding:** The site personnel in CE do not have the software tools required to access the Honeywell system and make changes and adjustments, as needed, to insure the proper operation of the building. During the interview with EMTS personnel and operators it was noted that they have not been trained on the new Honeywell system to allow them to have full access and capabilities to operate and maintain the system. This puts the Air Force at a disadvantage with the Honeywell system. Currently site personnel are only able to make

simple changes, without engaging the vendor. This creates a very difficult and expensive approach to operating and maintaining the DDC control system in building 185.

a. **Recommendation:** Provide training needed to allow Air Force personnel to maintain and operate the DDC control system independently from the controls vendor and provider.
b. **Recommendation:** Provide the tools and software required for site personnel to access, program and manage all functions of the DDC control system.

6. **Finding:** At the time of the site survey the HVAC systems in building B185 were not able to be seen from the EMCS front end located at the HVAC shop. There are IT issues currently that prohibit site personnel from accessing building B185 remotely. After interviewing CE personnel it appears a problem has been ongoing and is still present regarding communication between building controllers and the EMCS operator work station. The HVAC systems and control for B185 are dependent on reliable communication between the local DDC controllers and the EMCS operator work station.
    a. **Recommendation:** Correct communication issues with the DDC controls by retro-commissioning the system, updating controllers with firmware and software of the latest versions available to improve the system performance and integrity.

Summary

The HVAC systems for Building B185 need to be retro-commissioned completely. A design review should be performed to insure the current operation and occupancy is in line with the original design intent for the HVAC systems serving the building. A very close look at the air systems for the building is needed to find out if system modifications are needed or system operating parameters need to be adjusted to improve the buildings comfort and performance. By bringing the building pressure under control and maintaining a slight positive pressure of 0.015 inches W.C., the energy use for the building should be reduced by minimizing the amount of outside air infiltration into the building. With a few modifications to the HVAC systems and DDC controls the buildings performance, comfort, energy usage and efficiency can be improved to a level that will yield a greater satisfaction for the Air Force and occupants of the building as well as reduce energy consumption.

Building 2800 (B2800)

Description

Building B2800 – The Base Procurement Office is a single-story, CMU facility originally building in 1955 and renovated in 2001. The renovation encompassed a complete gutting and remodeling of the interior and exterior. The interior ha comprised of approximately 80% open space concept, operable windows, 4 conference rooms. The facility is split between 2 sides, one with typical cubicles whereas the other side is more of an open bay concept. The office has minimal visitors with civilian employees, contracting officers, and financial management personnel.

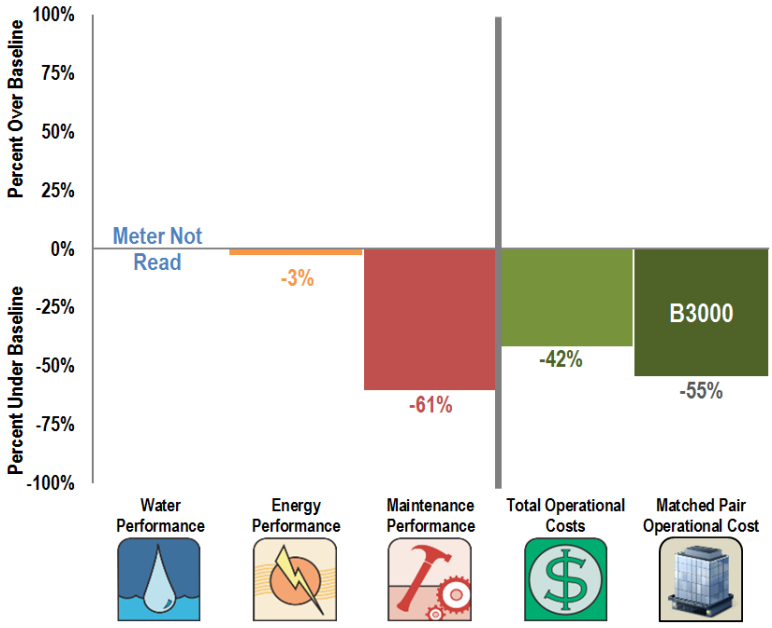
Metrics	Building 2800 (B2800)		
	Street Address	*5 South Wolfe Ave*	*Edwards*
	State & Zip Code	*CA*	*93523*
	Air Force Base		*Edwards Air Force Base*
	Building Function		*Office*
	Design Certification		-
	Year Built		*1955*
	# of Floors		*1*
	Gross Square Foot		*44,543*
	Weekly Operating Hours		*50*
	Regular Occupants		*176*
	Average Daily Visitors (FTE)		*0*
	Electronic Equipment		*176*
	Construction Cost		*$2,684,264*

The scope of work related to the exterior renovations included: installation of all new utility services including medium voltage electrical service, water, gas, communications, data, and sewer. Work also included major landscaping which created a courtyard entrance. Paths and gardens were created while still maintaining the desert motif. The entire existing concrete masonry building received an energy efficient EIFS (exterior insulation finishing system) finish.

Interior renovations included: complete gutting which involved asbestos and lead abatement, seismic modifications to the existing building structure, installation of all new mechanical, electrical, communications, data, fire detection and fire protection systems. The new HVAC system included a new chiller, boiler, and fan coil units. An entirely new plumbing system and restroom configuration was installed which involved concrete floor removal and replacement, the installation new water piping and waste lines. The new interior electrical system included installation of power distribution, and lighting panels throughout the building. The new communications and data systems involved tying into the street utilities and installing a 600 pair copper communications cable and fiber optics to various communications/data rooms throughout the building. An entirely new fire detection/reporting system was installed throughout the building to ensure occupant safety. Previously, the facility had not been protected with fire sprinklers. This project included the installation of a new fire main, riser, and distribution system to protect the building from fire. The new floor plan configurations required the installation of framing and gypsum board partitions, new frames/doors, and hardware, and interior finishes throughout.

Whole Building Performance

The Base Procurement Office operating costs are lower than the industry baseline for all metrics. There is no water performance data. Overall, the building cost 42% less to operate than industry baselines and 13% more than its matched-pair.



Performance Data Summary

The research team collected, normalized, and compared whole building performance data for the Base Procurement Office to industry baselines. The following table summarizes the annual performance data collected and normalized.

Metrics	Annual Performance Measurements		Annual Performance Metrics	
	Water Use (gal)	*No Meter*	Gallons per occupant	*N/A*
	Process Water Use (gal)	*No Meter*	Water Cost per occupant	*N/A*
	Outdoor Water Use (gal)	*No Meter*	Gallons per GSF	*N/A*
	Water Cost	*No Meter*	Water Cost per GSF	*N/A*
	Energy Star Score	*52*		
	Total Energy Use (kBtu)	*4,972,778*	Energy Use (kBTU) per GSF	*112*
	Energy Cost	*$85,202*	Energy Cost per GSF	*$1.91*
	Building Emissions ($MTCO_2e$)	*355*	Building Emissions per Occupant ($MTCO_2e$)	*2.02*
	General Maintenance Cost	*$35,927*	General Maint Cost per GSF	*$0.81*
	Janitorial Services Cost	*$28,597*	Janitorial Services Cost per GSF	*$0.64*
	Grounds Maintenance Cost	*$8,263*	Grounds Maint Cost per GSF	*$0.19*
	Quantity of Maint Requests	*69*	Ratio of Maint Requests to Total Maint Jobs	*0.21*
	Quantity of Prev Maint Jobs	*265*		

Consolidated Supported Facility (B3000)

Description

Building B3000 – Consolidated Support Facility received the LEED Silver rating and certification in 2007 three years after the building construction phase was completed. The building has 48,958 square feet of conditioned space and a multi-purpose facility that serves a variety of critical base mission support groups including the Base Wing Command group.

Metrics	Consolidated Support Facility (B3000)		
	Street Address	*5 North Seller Ave*	*Edwards*
	State & Zip Code	*CA*	*93523*
	Air Force Base		*Edwards Air Force Base*
	Building Function		*Office*
	Design Certification		*LEED-NC Silver*
	Year Built		*2004*
	# of Floors		*2*
	Gross Square Foot		*48,958*
	Weekly Operating Hours		*168*
	Regular Occupants		*161*
	Average Daily Visitors (FTE)		*16*
	Electronic Equipment		*171*
	Construction Cost		*$10,683,617*

The building is served by a single stand-alone 155 ton Trane (nominal) air-cooled chiller and 1,020,000 BTUH hot water plant both located in a separate building. The chilled water system is of the thermal storage type utilizing (6) Calmac Ice Storage Tanks to provide chilled water during the peak demand hours of operation between 12:00 noon and 6:00 PM. The chilled and hot water plant serve (2) VAV air handling units located on the second floor. The air handling units supply air to (62) VAV terminal units located throughout the building on the first and second floors. The building perimeter is served by VAV fan powered terminal units, with reheat coils to maintain the space temperature. The space temperature in the zones is maintained by modulating the VAV terminal unit primary air dampers and hot water valves on the reheat coils. Chilled water is produced by the Trane air-cooled chiller in the off peak hours, at 45.0°F between 7:00 AM to 11:45 AM. During the ice tank charge mode, the air-cooled chiller supplies low temperature brine solution to the Calmac ice storage tanks to recharge the ice tank farm. Chilled water is pumped throughout the system by (2) 20 HP chilled water pumps rated at 260 GPM @ 130 Feet TDH. The chilled water piping configuration is variable primary to the building. The chilled water pump speed is controlled by maintaining a differential pressure setpoint at each AHU located on the second floor. Hot water is produced by (2) Lochinvar condensing natural gas boilers and is distributed to the building from a primary/secondary pumping arrangement serving the VAV terminal unit reheat coils. The secondary hot water pumps (2) are rated at 5 HP at 68 GPM @ 95 Feet TDH.

The building HVAC systems are controlled by two different DDC control systems that have been integrated together. The chilled water plant is controlled by Trane DDC controls that sequence the chilled water pumps, chiller and thermal storage system. The main building HVAC equipment is controlled by Alerton DDC controls using the native BACnet protocol. The EMCS system uses

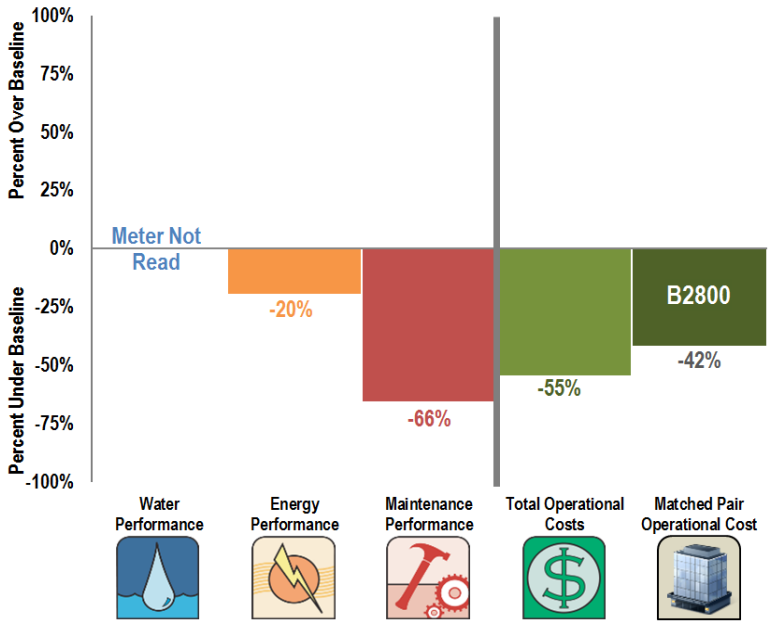
time of day scheduling in most areas. Space temperature setpoints ranges are limited to 2.0°F +/- the normal setpoints for cooling and heating in each zone. The building utilizes an outside air economizer cycle when ambient conditions are below 55.0 °F. The DDC control system uses an occupied/unoccupied night set up and set back scheme set at 65.0 and 85.0°F respectively.

Certifications

Certified: 26-32 points, **Silver:** 33-38 points, **Gold:** 39-51 points, **Platinum:** 52-69 points

Whole Building Performance

The Consolidated Support Facility operating costs are lower than the industry baseline for all metrics. There is no water performance data. Overall, the building cost 55% less to operate than industry baselines and 13% less than its matched-pair.



Performance Data Summary

The research team collected, normalized, and compared whole building performance data for the Consolidated Support Facility to industry baselines. The following table summarizes the annual performance data collected and normalized.

Metrics	Annual Performance Measurements		Annual Performance Metrics	
	Water Use (gal)	*No Meter*	Gallons per occupant	*N/A*
	Process Water Use (gal)	*No Meter*	Water Cost per occupant	*N/A*
	Outdoor Water Use (gal)	*No Meter*	Gallons per GSF	*N/A*
	Water Cost	*No Meter*	Water Cost per GSF	*N/A*
	Energy Star Score	*69*		
	Total Energy Use (kBtu)	*5,537,411*	Energy Use (kBTU) per GSF	*113*
	Energy Cost	*$48,298*	Energy Cost per GSF	*$0.99*
	Building Emissions ($MTCO_2e$)	*396*	Building Emissions per Occupant ($MTCO_2e$)	*2.24*
	General Maintenance Cost	*$27,541*	General Maint Cost per GSF	*$0.56*
	Janitorial Services Cost	*$28,596*	Janitorial Services Cost per GSF	*$0.58*
	Grounds Maintenance Cost	*$8,262*	Grounds Maint Cost per GSF	*$0.17*
	Quantity of Maint Requests	*70*	Ratio of Maint Requests to Total Maint Jobs	*0.19*
	Quantity of Prev Maint Jobs	*291*		

Jacobs Engineering – Facility Walkthrough Assessment

Findings, Actions & Recommendations

1. **Finding:** During the site survey it was noted that the combustion gas stacks for both of the Lochinvar boilers had severe oxidation and corrosion forming on the double wall metal fittings above the boilers. It appears the boilers have been operating at low water temperatures below 140.0°F at times; which are a contributing factor that causes high vapor condensation rates and acidic conditions in combustion gases for natural gas fired units. The flue materials used do not appear to be a high enough quality to prevent the corrosion from forming. In many condensing boiler applications stainless steel flue materials are recommended to insure the longevity of the combustion exhaust systems for condensing boilers.
    a. **Recommendation:** Maintain a minimum of 140.0°F return hot water temperature to the Lochinvar boilers.
    b. **Recommendation:** Consult the manufactures product literature and installation guidelines for the proper installation and approved materials for this type of condensing boiler.

2. **Finding:** The DDC control loop modulating the VFD speed for chilled water pump # 2 was hunting, when observed during the survey. The VFD frequency was witnessed to be changing approximately 5-6 HZ in a rhythmic fashion.
    a. **Recommendation:** Investigate the cause of the unstable operation. Verify the DP transmitter sensing lines are properly connected in the chilled water system to measure a stable differential pressure and are not affected by turbulence from fittings or control valves.
    b. **Recommendation:** Verify the control parameters for the PID loop controlling the pumps speed, are correct and the proportional and dead bands are adequate to prevent a hunting condition.
    c. Recommendation: Set up trend logs for the DP transmitters so the differential pressure for each AHU can be monitored for stable operation after corrections are made.

3. **Finding:** During the review of the TAB report that was provided the following was noted.
    a. **Page 36-** Chiller test performed on March 14th, 2011. The test data for the Trane air-cooled chiller indicates a chiller capacity of 151.7 tons when producing chilled water at 44.0°F LWT.
    b. **Page 36-**Chiller test performed on March 14th, 2011. The test data for the Trane air-cooled chiller indicates the same chiller capacity of 151.7 tons when producing a leaving brine temperature of 24.0°F LWT.
    c. The chiller capacity cannot be the same for both conditions at the same flow rate. The chiller capacity at the lower 24.0°F temperature would generally be 35 percent lower for the same machine. The flow rate (flow meter) and temperature sensors need to be calibrated and checked for accuracy. The chiller needs to be retested to verify the correct capacity at both conditions. The chiller should be tested with an ambient temperature in the 100-105.0°F range for producing 44.0°F LWT. When producing low temperature brine in the 22-24.0°F range the ambient temperature should be around 75.0-80.0°F (night time) to produce accurate test results.
    d. No reference to outside air temperatures were noted in the test results on page 36.

e. The pressure drop through the machine should have some variance when flowing water through the building piping system under normal chiller operation and when bypassing the building and charging the ice tank farm. The pressure drop through the Calmac tanks is generally higher than the normal ΔP and the flow rate through the chiller in many cases would be lower.
f. While performing testing for a chiller in the field the design conditions should be set up to allow for an accurate test of the machines capacity or output. The ambient conditions for normal chilled water temperatures and ice tank charge modes are quite different and should be considered when testing and balancing.

4. **Finding:** At the time of the site survey and interview with site personnel, it was noted that the DDC controls for the building have been replaced since the building received the LEED Silver certification. As explained and noted during the survey and interview there were many issues and deficiencies regarding the original Trane EMCS system utilizing the LON communication protocol for the facility. The main building HVAC equipment is now controlled by an Alerton DDC control system using the BACnet protocol and appears to be functioning correctly at this time.
    a. **Recommendation:** Develop a solid control specification for future projects.
    b. **Recommendation:** Develop solid functional test procedures to be used during commissioning.
    c. **Recommendation:** Include testing of communications during functional testing, such as; verifying field controller addresses, communication failure scenarios, global point failures, and fail safe conditions for the building HVAC equipment during network failures or interruptions.

Summary

The HVAC systems for building B3000 at this time seem to be operating very well. Based on discussions with site personnel the replacement of the original HVAC building controls with the Alerton BACnet system has corrected the problems first experienced in the building. The operations staff and personnel at Edwards AFB have a tremendous amount of knowledge and capability to maintain and operate the HVAC and EMCS system for building 3000. The lessons learned with the EMCS system and problems experienced has allowed base personnel in CE to understand how to address and deal with future new building construction or existing building renovations in regards to HVAC and EMCS systems. One item that may be of benefit is in regards to the chiller capacity tested during the TAB phase. As noted above the chiller capacity shown in the TAB report is questionable based on the flow rate and ΔT given in the report. It would be of value to have the chiller tested at design conditions for both the chilled water mode of operation at 44.0°F LWT and during the ice tank charge mode. The chiller capacity during ice charge mode should be significantly lower and in the range of 30-35 percent less tonnage or capacity. The benefit of the thermal storage system to the Base's electrical peak demand window is not fully understood. Utility bills and rate structures were not provided at the time of the survey to analyze the total benefit regarding the shift in peak demand to off peak hours of operation. According to site personnel, the Base has a very low energy rate structure with the current electric energy contract.

Mission Support Center (B2484)

Description

Building B2484 – The Mission Support Center is comprised of 50% open cubicles and 50% private offices. The facility has 2 stories with a full basement, operable windows, approximately 6-8 conference rooms, and 1 courthouse. Daylighting strategies are employed in main hallway and foyer and there are vestibules on both main entrances. The mechanical equipment was retro-fitted in 2010 with new controls tied into the EMCS with variable frequency drivers which have significantly reduced the thermal comfort complaints.

Metrics	Mission Support Center (B2484)	
	Street Address	*1701 Kenly Ave* *San Antonio*
	State & Zip Code	*TX* *78236*
	Air Force Base	*Lackland Air Force Base*
	Building Function	*Office*
	Design Certification	-
	Year Built	*1996*
	# of Floors	*3*
	Gross Square Foot	*61,554*
	Weekly Operating Hours	*50*
	Regular Occupants	*150*
	Average Daily Visitors (FTE)	*90*
	Electronic Equipment	*212*
	Construction Cost	*$8,563,389*

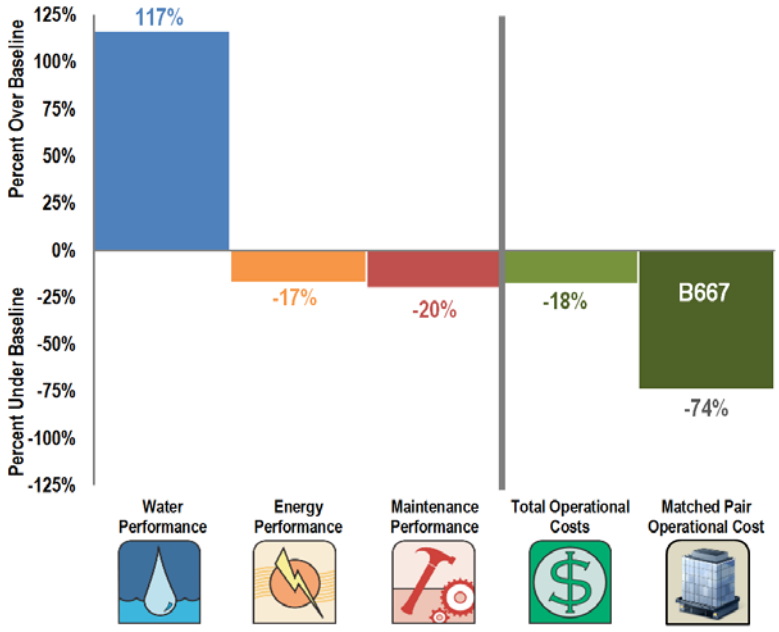
The building is fed by a well and does not have a water meter. There was a 2010 survey to calculate water indoor water use. The occupants consist of command support, safety, legal, military equal opportunity (MEO), tax post, and public affairs personnel. The facility is also adjacent to the USAF Parade Grounds and therefore has frequent daily visitors.

The building has 2 air handler units (1 for each floor), 2 chillers (150 ton) running on lead/lag times, return air by a central plenum, 1 100% outdoor air unit which is used for winter only, and 1 stand-alone unit for command post. The indoor temperature is set at a constant 72 degrees Fahrenheit and the EMCS is managed from the main shop.

Recent projects include: interior renovation and sound proofing the courtroom, major pipe leakage causing ceiling and floor damage, servers have been consolidated into a separate building, and future automatic parking lot lighting controls.

Whole Building Performance

The Mission Support Center operating costs are lower than the industry baseline for all metrics except water. Overall, the building cost 31% less to operate than industry baselines and 40% more than its matched-pair.

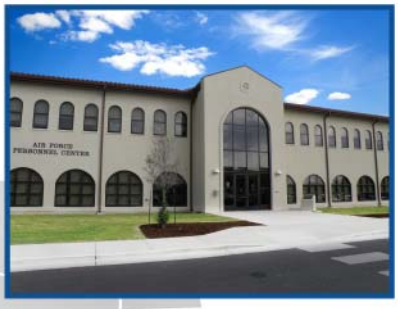


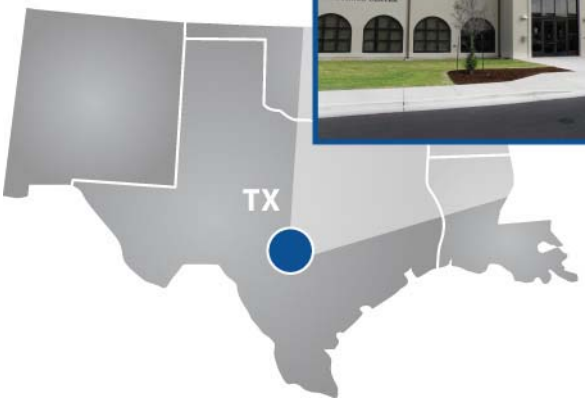
Performance Data Summary

The research team collected, normalized, and compared whole building performance data for the Mission Support Center to industry baselines. The following table summarizes the annual performance data collected and normalized. Outdoor water use was estimated using the "rule-of-thumb" that 20% of total water used is for landscaping.

Metrics	Annual Performance Measurements		Annual Performance Metrics	
	Water Use (gal)	*2,000,004*	Gallons per occupant	*8,333*
	Process Water Use (gal)	*0*	Water Cost per occupant	*$4.09*
	Outdoor Water Use (gal)	*400,001*	Gallons per GSF	*32.49*
	Water Cost	*$982*	Water Cost per GSF	*$0.016*
	Energy Star Score	*60*		
	Total Energy Use (kBtu)	*5,557,823*	Energy Use (kBTU) per GSF	*90*
	Energy Cost	*$78,257*	Energy Cost per GSF	*$1.27*
	Building Emissions ($MTCO_2e$)	*710*	Building Emissions per Occupant ($MTCO_2e$)	*2.96*
	General Maintenance Cost	*$133,471*	General Maint Cost per GSF	*$2.17*
	Janitorial Services Cost	*$32,678*	Janitorial Services Cost per GSF	*$0.53*
	Grounds Maintenance Cost	*$35,000*	Grounds Maint Cost per GSF	*$0.57*
	Quantity of Maint Requests	*112*	Ratio of Maint Requests to Total Maint Jobs	*0.84*
	Quantity of Prev Maint Jobs	*22*		

AFPC Administration Facility (B667)





Description

Building B667 – The AFPC Administration Facility was completed and occupied in 2010 and received a LEED Gold rating for construction. The building has 35,600 square feet of conditioned space. The two story office building has middle corridors, and elevator and 2 computer labs with approximately 28 computers within each lab. The facility is approximately 80% open office space with a large entrance window and vestibule with auto-dimmers and daylight strategies throughout.

Metrics	AFPC Admin Facility (B667)		
	Street Address	*1430 5th St West*	*Randolph*
	State & Zip Code	*TX*	*78150*
	Air Force Base		*Randolph Air Force Base*
	Building Function		*Office*
	Design Certification		*LEED NC 2.2 - Gold*
	Year Built		*2010*
	# of Floors		*2*
	Gross Square Foot		*35,600*
	Weekly Operating Hours		*60*
	Regular Occupants		*170*
	Average Daily Visitors (FTE)		*0*
	Electronic Equipment		*226*
	Construction Cost		*$9,352,500*

The buildings HVAC system is served by chilled water from a central plant located on Base. Chilled water is pumped with (2) pumps controlled by VFD's set up to maintain a ΔP of 14 PSID across the supply and return lines. Hot water is produced by a single Lochinvar Knight condensing boiler. The chilled and hot water systems serve (2) VAV air handling units that supply VAV terminal units located on the first and second floors. The VAV terminal units that serve the perimeter of the building have hot water reheat coils. The space temperature in the zones is maintained by modulating the terminal unit primary air dampers and hot water valves on the reheat coils. A single energy recovery unit (ERU-1) serves both VAV AHU's with outside air and utilizes an energy recovery wheel to lower the enthalpy of the entering air feeding both AHU's.

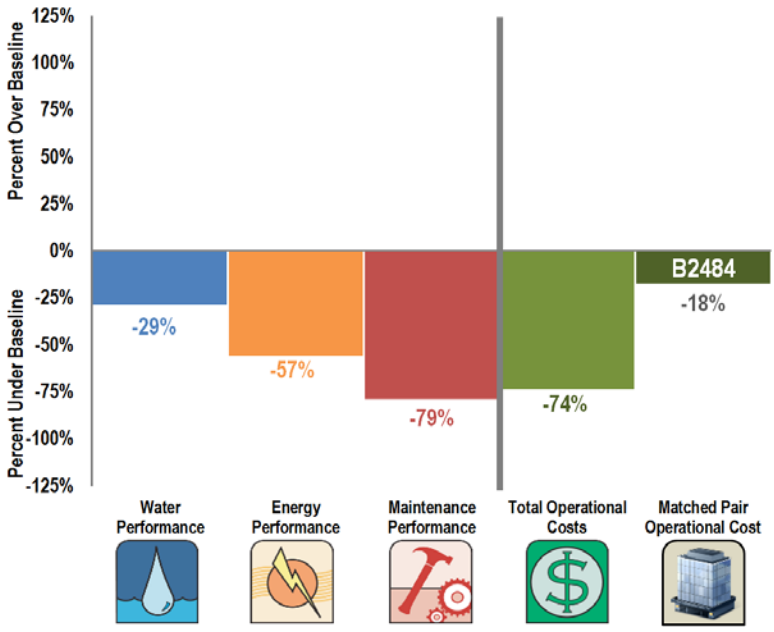
The building HVAC systems are controlled by a Johnson DDC control system (JCI) using the N2 communication protocol. The EMCS system uses time of day scheduling that operates the building from 6:00 AM to 6:00 PM. Space temperature setpoints ranges are limited to 3.0°F +/- the normal setpoints for cooling and heating in each zone.

Certifications

Certified: 26-32 points, **Silver:** 33-38 points, **Gold:** 39-51 points, **Platinum:** 52-69 points

Whole Building Performance

The AFPC Administration Building operating costs are lower than the industry baseline for all metrics. Overall, the building cost 71% less to operate than industry baselines and 40% less than its matched-pair.



Performance Data Summary

The research team collected, normalized, and compared whole building performance data for the AFPC Administration Building to industry baselines. The following table summarizes the annual performance data collected and normalized. Outdoor water use was estimated using the "rule-of-thumb" that 20% of total water used is for landscaping.

Metrics	Annual Performance Measurements		Annual Performance Metrics	
	Water Use (gal)	*376,850*	Gallons per occupant	*2,217*
	Process Water Use (gal)	*0*	Water Cost per occupant	*$0.77*
	Outdoor Water Use (gal)	*75,370*	Gallons per GSF	*10.59*
	Water Cost	*$132*	Water Cost per GSF	*$0.004*
	Energy Star Score	*99*		
	Total Energy Use (kBtu)	*1,684,876*	Energy Use (kBTU) per GSF	*47*
	Energy Cost	*$36,391*	Energy Cost per GSF	*$1.02*
	Building Emissions ($MTCO_2e$)	*166*	Building Emissions per Occupant ($MTCO_2e$)	*0.98*
	General Maintenance Cost	*$12,843*	General Maint Cost per GSF	*$0.36*
	Janitorial Services Cost	*$9,598*	Janitorial Services Cost per GSF	*$0.27*
	Grounds Maintenance Cost	*$2,204*	Grounds Maint Cost per GSF	*$0.06*
	Quantity of Maint Requests	*33*	Ratio of Maint Requests to Total Maint Jobs	*0.72*
	Quantity of Prev Maint Jobs	*13*		

Jacobs Engineering – Facility Walkthrough Assessment

Findings, Actions & Recommendations

1. **Finding:** During the site survey the building had some occupied zones with CO2 levels above the designed 800 PPM setpoint. Investigation into the operation of the AHU's and ERU found that the sequence of operations and AHU configuration was not set up to allow for increased outside air flow rates when the CO2 levels increased above the CO2 setpoint value of 800 PPM. The Johnson Controls sequence of operation indicates the highest zone CO2 value is to take control of the outside air damper, in the ERU, to allow for higher outside air flow into the mixed air plenum of the AHU's. This sequence of operations was not implemented in the JCI system or controls for the AHU's.
    a. **Recommendation:** While onsite this issue was brought to the attention of the EMCS operators. While onsite Richard Garcia in the EMCS shop consulted with a JCI representative and made changes to the program to include the CO2 control algorithm to allow the outside air damper to open and reduce CO2 levels.

2. **Finding:** During the site survey it was noted that AHU 1 and 2 do not have a control damper located in the return air duct to modulate in unison with the outside air damper in an opposing fashion. Without a control damper the outside air flow rate required to meet the CO2 set point for the building will be difficult to achieve. An increase in negative pressure in the outside air duct is needed to draw in more air into the suction side of the supply fan.
    a. **Recommendation-A:** Install a motorized control damper in the return air duct of each unit to work in conjunction with the outside air dampers.

3. **Finding:** During the site survey it was noted the current ERU-1 operation brings the supply and return air fans on at a fixed VFD speed of 30 HZ. The ERU is not being allowed to increase or decrease the outside and relief air flow rates in response to the needed outside air flow rates required to maintain the space CO2 levels in times of high occupancy. It appears the ERU control sequence is incomplete and does not accommodate all modes of operation for AHU-1 and 2 during times of low and high CO2 levels in the conditioned spaces.
    a. **Recommendation:** Modify the existing control scheme to allow the supply and return air fans to ramp up to meet the ventilation requirements to maintain the space CO2 set point of 800 PPM. Example; start the ERU supply and return air fan at 30 HZ when enabled, allow the fan speed to increase in response to high space CO2 levels from 30 HZ to 60 HZ as needed to maintain space CO2 setpoint.

4. **Finding:** During the site survey it was noted the chilled water supply temperature sensor was not reading correctly on the Onicon BTU Flow Meter located in the main mechanical room. The BTU values and readings are not valid in the meter at this time.
    a. **Recommendation:** Investigate and repair faulty chilled water supply temperature.

Summary

The HVAC systems for Building B-667 Administration appear to be in good working order in regards to space temperature and comfort levels. As noted above the control strategies and configuration for the AHU's and ERU unit need to be reviewed and modified to allow the HVAC systems to maintain the desired CO2 set point of 800 PPM, per the sequence of operations. This can be accomplished rather easily with some modifications to the existing control schemes and the installation of a return air damper in each return air duct for AHU-1 and 2. Based on the interview with site operating personnel the building has been trouble free and has performed quite well.

AFIT Engineering Building (B643)

Description

Building B643 – The AFIT Engineering Building, known as Thomson Hall, was built in 1994, is comprised of 3 stories with 52,172 square feet. Approximately 80% of the floor space serves as a Civil Engineering School and/or Professional Continuing Education. This portion consists of multiple class rooms, mechanical systems learning laboratories, broadcast studio for distance learning, and an auditorium. The rest of the floor space consists of 10% plans and programs and 10% financial management. The facility has significant daylighting, an open foyer at the entrance, and interior corridors with perimeter classrooms and office space.

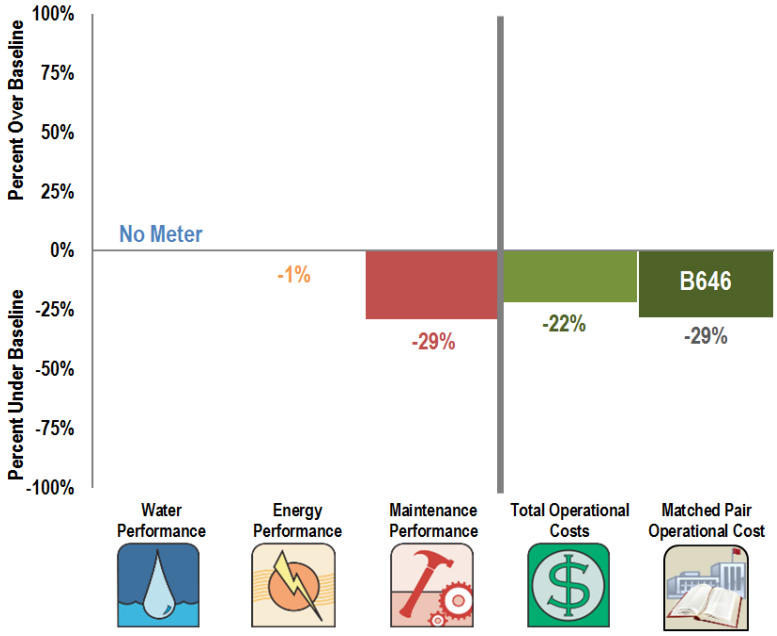
Metrics	AFIT Engineering Building (B643)		
	Street Address	*2920 Hobson Way*	*Dayton*
	State & Zip Code	*OH*	*45433*
	Air Force Base	*Wright Patterson Air Force Base*	
	Building Function	*Academic Facility*	
	Design Certification		-
	Year Built		*1994*
	# of Floors		*3*
	Gross Square Foot		*52,172*
	Weekly Operating Hours		*55*
	Regular Occupants		*54*
	Average Daily Visitors (FTE)		*287*
	Electronic Equipment		*132*
	Construction Cost		*N/A*

The occupants consist of civilian and active military personnel with 29 faculty and 25 full time staff members. The school admits approximately 90 students and guest speakers per day with the average class duration being three weeks. Being an engineering school, there is an abundance of electronic equipment: 2 computer labs with 25 desktop computers each, 5 televisions, 5 vending machines, broadcast studio, and laboratory equipment. The facility does not have a data center or server closet.

The building experiences extreme HVAC control issues. Compressors are frequently being replaced and dampers continuously cause problems with building efficiency. Replacements of HVAC systems are being investigated.

Whole Building Performance

The AFIT Engineering Building operating costs are lower than the industry baseline for all metrics. There is no water performance data. Overall, the building cost 22% less to operate than industry baselines and 7% more than its matched-pair.



Performance Data Summary

The research team collected, normalized, and compared whole building performance data for the AFIT Engineering Building to industry baselines. The following table summarizes the annual performance data collected and normalized.

Metrics	Annual Performance Measurements		Annual Performance Metrics	
	Water Use (gal)	*No Meter*	Gallons per occupant	*N/A*
	Process Water Use (gal)	*No Meter*	Water Cost per occupant	*N/A*
	Outdoor Water Use (gal)	*No Meter*	Gallons per GSF	*N/A*
	Water Cost	*No Meter*	Water Cost per GSF	*N/A*
	Energy Star Score	*50*		
	Total Energy Use (kBtu)	*6,587,699*	Energy Use (kBTU) per GSF	*126*
	Energy Cost	*$68,941*	Energy Cost per GSF	*$1.32*
	Building Emissions ($MTCO_2e$)	*812*	Building Emissions per Occupant ($MTCO_2e$)	*2.38*
	General Maintenance Cost	*$68,655*	General Maint Cost per GSF	*$1.32*
	Janitorial Services Cost	*$80,303*	Janitorial Services Cost per GSF	*$1.54*
	Grounds Maintenance Cost	*$2,045*	Grounds Maint Cost per GSF	*$0.04*
	Quantity of Maint Requests	*89*	Ratio of Maint Requests to Total Maint Jobs	*0.85*
	Quantity of Prev Maint Jobs	*16*		

AFIT Academic Facility (B646)

Description

Building B646 – The AFIT Academic Facility is used mainly for classroom instruction and continuing education. The building has office areas that are occupied 100 percent of the time during normal operating hours while classrooms have intermittent occupancy throughout the year. The building has approximately 48,446 square feet of condition area. Half of the floor space consists of office space for the AFIT Command Section as well as the Center for Systems Engineering, whereas the other half is comprised of classrooms, conference rooms, and 6 computer labs. The facility has 2 vestibule entryways with the main entryway leading to a vaulted ceiling, open foyer with large windows for daylighting. The general building layout consists of interior hallways with exterior classrooms and private office space.

Metrics	AFIT Academic Facility (B646)		
	Street Address	*2920 Hobson Way*	*Dayton*
	State & Zip Code	*OH*	*45433*
	Air Force Base	*Wright Patterson Air Force Base*	
	Building Function	*Academic Facility*	
	Design Certification	*LEED NC 2.2 - Silver*	
	Year Built	*2008*	
	# of Floors	*3*	
	Gross Square Foot	*48,446*	
	Weekly Operating Hours	*60*	
	Regular Occupants	*36*	
	Average Daily Visitors (FTE)	*326*	
	Electronic Equipment	*230*	
	Construction Cost	*$9,600,000*	

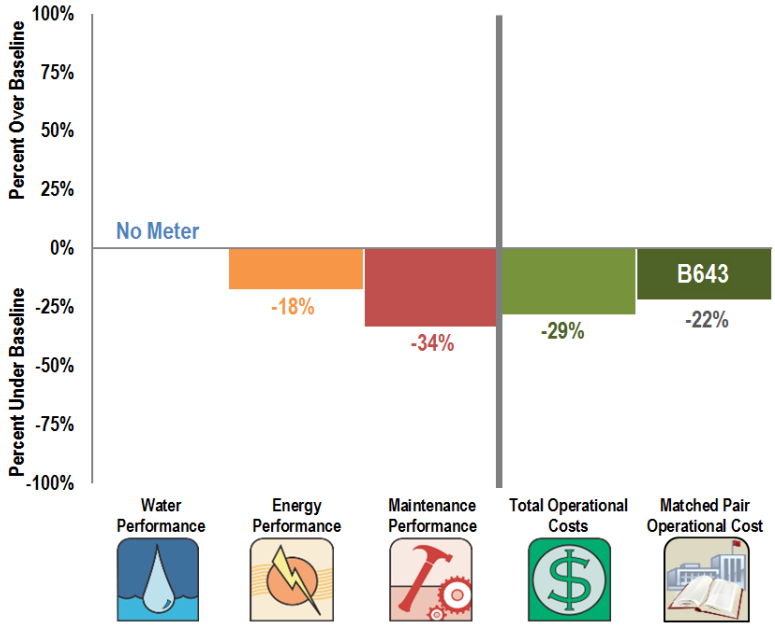
The HVAC system for the building consists of one large VAV AHU located on the ground level and 67 VAV terminal units. The air handling unit is served by a single, 200 ton York air-cooled chiller located next to the building. The chilled water system consists of one primary and secondary pumps piped in a de-coupler piping arrangement. The building is heated by hot water coils in the VAV terminal units located throughout the building. The building hot water source is derived from a tube and shell heat exchanger located in building B640 next to B646. Hot water is pumped by two hot water pumps configured in a lead/standby arrangement. The building has Staefa TALON DDC controls using the LON communication protocol. The DDC control system utilizes reset schedules for both the heating hot water system and for the discharge air temperature of the VAV air handling unit.

Certifications

Certified: 26-32 points, **Silver:** 33-38 points, **Gold:** 39-51 points, **Platinum:** 52-69 points

Whole Building Performance

The AFIT Academic Facility operating costs are lower than the industry baseline for all metrics. There is no water performance data. Overall, the building cost 29% less to operate than industry baselines and 7% less than its matched-pair.



Performance Data Summary

The research team collected, normalized, and compared whole building performance data for the AFIT Academic Facility to industry baselines. The following table summarizes the annual performance data collected and normalized.

Metrics	Annual Performance Measurements		Annual Performance Metrics	
	Water Use (gal)	*No Meter*	Gallons per occupant	*N/A*
	Process Water Use (gal)	*No Meter*	Water Cost per occupant	*N/A*
	Outdoor Water Use (gal)	*No Meter*	Gallons per GSF	*N/A*
	Water Cost	*No Meter*	Water Cost per GSF	*N/A*
	Energy Star Score	*67*		
	Total Energy Use (kBtu)	*6,171,717*	Energy Use (kBTU) per GSF	*127*
	Energy Cost	*$64,286*	Energy Cost per GSF	*$1.33*
	Building Emissions ($MTCO_2e$)	*765*	Building Emissions per Occupant ($MTCO_2e$)	*2.11*
	General Maintenance Cost	*$21,888*	General Maint Cost per GSF	*$0.45*
	Janitorial Services Cost	*$84,732*	Janitorial Services Cost per GSF	*$1.75*
	Grounds Maintenance Cost	*$1,899*	Grounds Maint Cost per GSF	*$0.04*
	Quantity of Maint Requests	*51*	Ratio of Maint Requests to Total Maint Jobs	*0.85*
	Quantity of Prev Maint Jobs	*9*		

Jacobs Engineering – Facility Walkthrough Assessment

Findings, Actions & Recommendations

1. **Finding:** During the interview with facility EMTS personnel, it was noted the building experiences problems with the Staefa TALON control system often with communications from the local building controllers to the JACES in the Niagara Tridium platform. When these problems do occur the operators at the EMTS operator station are not alerted or receive any type of Alarms to indicate the problem(s). This creates problems with the HVAC systems operating in modes or at setpoints that are not correct for the building. WP AFB personnel have been dealing with these problems and issues since the building was completed.
    a. **Recommendation:** The problems and issues with the Staefa LON DDC control system are neither new nor isolated to the problems in B646. The issues with LON and DDC controllers plague many buildings and facilities with sophisticated DDC control systems today. To understand and develop a long lasting solid solution would require a study to be performed that will identify all the known problems currently being experienced. These need to be broken down and identified as the following; software, firmware and hardware issues. A well-defined scope and sequence of operations for B646 needs to be developed by a consultant very familiar with newer DDC control systems and WP AFB operations. Any money or time spent without a detailed plan, scope or sequence of operations will result in continued failures and frustration with the building performance and operation.

2. **Finding:** During the site visit and survey of building B646, it was noted for AHU-1 the outside and relief air dampers were closed 100 percent.

a. **Recommendation:** Verify the minimum outside air damper position is being maintained by the DDC control system during the occupied mode.
b. **Recommendation:** Verify the CO2 control algorithm is set up correctly for the building to allow for proper ventilation.
c. **Recommendation:** Verify the relief air dampers are tracking correctly with the outside air dampers and building static pressure transmitter to maintain a slightly positive pressure in the building during occupied times.

3. **Finding:** Hot water pump No. 2 was operating when the building hot water system was disabled.
    a. **Recommendation:** Verify the correct operation for HWP-2.

4. **Finding:** During the sight survey and interview it was noted the Commandants Conference room was warm earlier in the morning during a meeting. Building personnel indicated this has been an ongoing problem for the Commandants Conference room.
    a. **Recommendation:** Verify the room temperature sensor reading and value match the value indicated at the EMTS operator control station.
    b. **Recommendation:** Verify the minimum and maximum CFM values for the VAV terminal units serving a room of this size.
    c. **Recommendation:** Review the design criteria for the room and compare it the way the conference room is actually being used.

Summary

The HVAC mechanical systems for Building B646 have been operating satisfactorily according the facility manager, Dan Rohrbach, for the most part. There have been issues as noted above that need to be addressed in the recommendations above. The building design and use of chilled and hot water systems have provided a higher level of building performance and reliability as compared to similar buildings located adjacent. Once the issues with the building DDC control system have been addressed and corrected, the HVAC systems should provide many years of good operation. The buildings overall level of comfort and indoor air quality will improve considerably once the outside air flow rates can be delivered consistently to maintain a higher level of air exchanges and lower CO2 levels. Once the communication issues between the building DDC controllers and JACES have been resolved, the EMTS operators at WP AFB will be able to track and monitor the building performance more closely and minimize any comfort issues the building may have or experience in the future.

Base Education Center (B501)

Description

Building B501 – The Base Education Center, also known as the Spratt Education Center, is comprised of 2 stories, a large open, day-lit foyer, and two wings (the East and West wing). The school was built in 2004 and has 29,184 square feet.

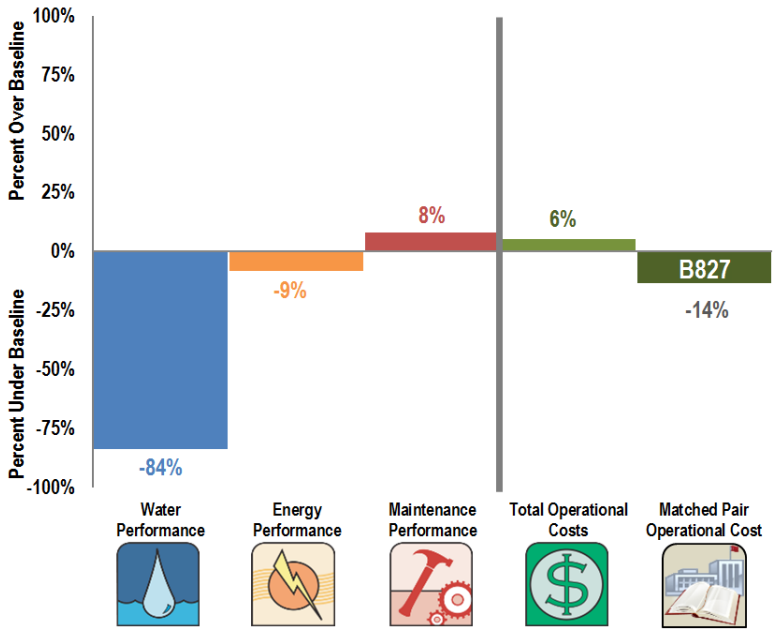
The Spratt Education Center provides education counseling, CCAF advisement, commissioning opportunities, tuition assistance, GI Bill, CLEP (College Level Examination Program) and DANTES (The Defense Activity for Non-Traditional Educational Support) examinations, and testing. The East wing is primarily used for Airman Leadership School and testing. The West wing has school classrooms on the second floor and education services and 5 college administration offices on the bottom floor.

Metrics	Base Education Center (B501)	
	Street Address	*398 Shaw Drive* *Sumter*
	State & Zip Code	*SC* *29152*
	Air Force Base	*Shaw Air Force Base*
	Building Function	*Academic Facility*
	Design Certification	-
	Year Built	*2004*
	# of Floors	*2*
	Gross Square Foot	*29,184*
	Weekly Operating Hours	*75*
	Regular Occupants	*20*
	Average Daily Visitors (FTE)	*47*
	Electronic Equipment	*110*
	Construction Cost	*$4,436,359*

The occupants consist of civilian, and retired and active military personnel with 47 faculty or full time staff members. The school admits approximately 375 students and guest speakers per day with the average duration of 1 hour. Being an engineering school, there is an abundance of electronic equipment: computer labs, 110 computers, 15-20 televisions, 4 vending machines, and laboratory equipment. The facility has 1 data center/server closet located on the lower level of the East Wing. The server closet does not have a dedicated HVAC unit and frequently gets very warm.

Whole Building Performance

The Base Education Center operating costs are lower than the industry baseline for all metrics except maintenance costs. Overall, the building cost 6% more to operate than industry baselines and 20% more than its matched-pair.



Performance Data Summary

The research team collected, normalized, and compared whole building performance data for the Base Education Center to industry baselines. The following table summarizes the annual performance data collected and normalized. Water use was estimated from a site water audit.

Metrics	Annual Performance Measurements		Annual Performance Metrics	
	Water Use (gal)	*70,000*	Gallons per occupant	*1,045*
	Process Water Use (gal)	*No Meter*	Water Cost per occupant	*$1.25*
	Outdoor Water Use (gal)	*No Meter*	Gallons per GSF	*2.40*
	Water Cost	*$84*	Water Cost per GSF	*$0.003*
	Energy Star Score	*46*		
	Total Energy Use (kBtu)	*3,597,590*	Energy Use (kBTU) per GSF	*123*
	Energy Cost	*$60,614*	Energy Cost per GSF	*$2.08*
	Building Emissions ($MTCO_2e$)	*341*	Building Emissions per Occupant ($MTCO_2e$)	*5.09*
	General Maintenance Cost	*$78,305*	General Maint Cost per GSF	*$2.68*
	Janitorial Services Cost	*$40,577*	Janitorial Services Cost per GSF	*$1.39*
	Grounds Maintenance Cost	*$2,545*	Grounds Maint Cost per GSF	*$0.09*
	Quantity of Maint Requests	*49*	Ratio of Maint Requests to Total Maint Jobs	*0.59*
	Quantity of Prev Maint Jobs	*34*		

Library (B827)

Description

Building B827 – The McElveen MRC Library, located on Shaw Air Force Base, received a LEED Silver rating for the construction and design of the facility. The Library has 16,500 square feet of conditioned space. The facility was completed and the library was occupied in 2008. The facility is a single story, open floor plan, day-lighted, library with a coffee shop, children learning center, multiple computer labs, conference rooms and other office area. The library provides access to essential information for the Air Force mission; it supports military and voluntary off-duty education programs as well as other personal needs for Air Force people.

Metrics	McElveen MRC Library (B827)	
	Street Address	*400 Shaw Ave* *Sumter*
	State & Zip Code	*SC* *29152*
	Air Force Base	*Shaw Air Force Base*
	Building Function	*Academic Facility*
	Design Certification	*LEED NC 2.1 - Silver*
	Year Built	*2007*
	# of Floors	*1*
	Gross Square Foot	*16,500*
	Weekly Operating Hours	*61*
	Regular Occupants	*10*
	Average Daily Visitors (FTE)	*25*
	Electronic Equipment	*82*
	Construction Cost	*$4,241,966*

The building HVAC system is comprised of one VAV air handling unit serving 25 VAV terminal reheat units for the conditioned spaces. The VAV reheat terminal boxes and air handling units are served by a single Raypack hot water boiler located in the mechanical room. The chilled water system has a single nominal 55 ton Carrier air cooled chiller located outside. The facility is connected to the base wide Energy Management System. This facility has Barber Coleman Network 8000 DDC controls controlling the HVAC systems and is integrated into the Niagara Tridium system that serves the base. The chilled water system is constant volume primary only pumping with a lead and standby pump arrangement. The heating hot water system is a primary\secondary system with a lead\standby pumping arrangement. The DDC control strategies for the library include the following; Time of Day Scheduling, Time Override, Night Set Up and Set Back, Space Temperature Setpoint Limits and Hot Water Reset schedule.

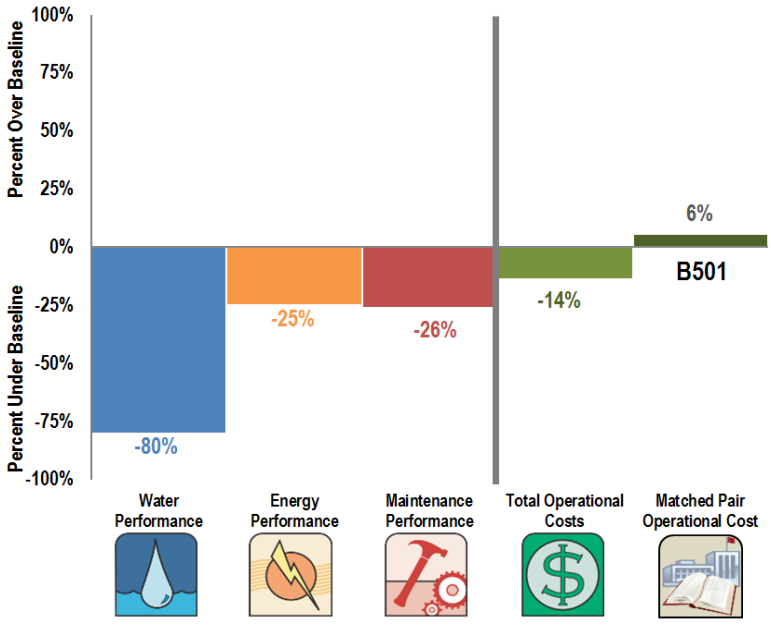
A LEED follow up survey and post construction commissioning phase was performed in 2009 according to the site facility operators. The follow up retro-commissioning activities included both changes and adjustments to the DDC control system and test and air balance activities. Documentation for the commissioning that was performed was not available at the time of this study.

Certifications

Certified: 26-32 points, **Silver:** 33-38 points, **Gold:** 39-51 points, **Platinum:** 52-69 points

Whole Building Performance

The McElveen MRC Library operating costs are lower than the industry baseline for all metrics. Overall, the building cost 14% less to operate than industry baselines and 20% less than its matched-pair.



Performance Data Summary

The research team collected, normalized, and compared whole building performance data for the McElveen MRC Library to industry baselines. The following table summarizes the annual performance data collected and normalized. Water use was estimated from a site water audit.

Metrics	Annual Performance Measurements		Annual Performance Metrics	
	Water Use (gal)	*49,000*	Gallons per occupant	*1,400*
	Process Water Use (gal)	*No Meter*	Water Cost per occupant	*$1.68*
	Outdoor Water Use (gal)	*No Meter*	Gallons per GSF	*2.97*
	Water Cost	*$59*	Water Cost per GSF	*$0.004*
	Energy Star Score	*34*		
	Total Energy Use (kBtu)	*1,788,813*	Energy Use (kBTU) per GSF	*108*
	Energy Cost	*$32,426*	Energy Cost per GSF	*$1.97*
	Building Emissions ($MTCO_2e$)	*213*	Building Emissions per Occupant ($MTCO_2e$)	*6.09*
	General Maintenance Cost	*$24,816*	General Maint Cost per GSF	*$1.50*
	Janitorial Services Cost	*$19,509*	Janitorial Services Cost per GSF	*$1.18*
	Grounds Maintenance Cost	*$2,545*	Grounds Maint Cost per GSF	*$0.15*
	Quantity of Maint Requests	*31*	Ratio of Maint Requests to Total Maint Jobs	*0.53*
	Quantity of Prev Maint Jobs	*27*		

Jacobs Engineering – Facility Walkthrough Assessment

Findings, Actions & Recommendations

1. **Finding:** During the interview with facility personnel it was noted that CO2 levels measured and sensed in the return air duct for the AHU consistently remain above setpoint. The outside air damper position was indicating 100.0 % open with an outside air flow rate of 830 CFM. The outside air flow rate setpoint is 2230 CFM for the system. At the time the survey was performed the CO2 reading was 1124 PPM.
    a. **Recommendation:** Verify the air filters for SF-2 located on the roof are clean and not plugged or dirty.
    b. **Recommendation:** Verify the belt is in place and good for the outside air fan SF-2.
    c. **Recommendation:** Verify the EBTRON outside air flow station is reading correctly by comparing reading to a duct traverse test for the OA duct serving AHU-1.
    d. **Recommendation:** Verify that OA damper is opening 100 percent when commanded by the DDC control system.

2. **Finding:** During the site survey it was noted that the building does not have a relief air fan, damper or path to relieve the building pressure.
    a. **Recommendation:** Investigate the possibility to install a relief air fan on the roof to relieve the building pressure and maintain a positive building static pressure of .015 inches W.C. during the occupied mode.

3. **Finding:** During discussions with the EMS operators it was noted the supply air for AHU-1 is not being reset by the EMS system automatically. At the time of this survey the supply air temperature setpoint was manually adjusted to 60.0°F. At this time it was very humid outside and the humidity level inside the library appeared to be high. There are six portable De-Humidifiers located in the library to address the high humidity levels. The supply air

temperature should be reset automatically to prevent the problems with high humidity in the conditioned spaces. A reset schedule that will automatically adjust the supply air setpoint will help to alleviate the humidity problem in the library.

a. **Recommendation:** Set up a reset schedule to reset the supply air temperature from 55.0°F to 60.0°F.

4. **Finding:** During the survey and walk through at the library it was noted that two of the space temperature values indicated on the LCD display for the thermostats were reading ~ 2.5°F lower than the reading taken with a digital thermometer. If the space temperature readings are incorrect the VAV terminal boxes will not open to allow the correct air flow into the space to meet the cooling demand for the areas served.
    a. Recommendation: Perform a calibration and test procedure for the thermostats serving the VAV reheat terminal boxes in the Library. Verify the thermostat values measured are within +/- 1.0°F of a calibrated test instrument.

5. **Finding:** The outside air and return air dampers are not mechanically linked so the OA damper opens when the return air damper is closing or vice-versa. The opposite action and control for the dampers is done electronically through the DDC controller serving the AHU. These dampers must operate in opposing fashion so the outside airflow rate can be increased to meet the CO2 setpoint for the system when CO2 levels increase as measured by the duct mounted CO2 sensor.
    a. Recommendation: Verify the action for the outside and return air dampers are opposite. Verify the dampers respond in a linear and proportional fashion when being controlled from the DDC controller.

Summary

The HVAC mechanical systems for Building- 827 the Library appear to have met most of the expectations of the Air Force based on the interview with the facility operators and staff. The overall building comfort was within expectations for a newer facility such as this. The CO2 levels indicated on the EMS graphics indicate the possibility of a low ventilation air exchange rate for the conditioned spaces. This may be attributed to the low outside CFM values shown on the EMS system graphics. The outside air damper, outside air supply fan (SF-2) and EBTRON air flow station needs to be checked for proper operation and calibration. Once it is determined that these components are functioning as designed then CO2 levels can be monitored for a period to see if the building is actually achieving the air exchange rate and ventilation required to maintain CO2 levels to setpoint. The thermostats in the building need to be calibrated and verified that temperatures being measured are accurate. If the thermostats are not accurate the VAV terminal units may not deliver the amount of air needed to meet the cooling demand in the conditioned spaces. The high humidity levels noticed in the Library may be mitigated once the thermostat calibrations are performed and the supply air temperature for AHU-1 is being maintained at the proper discharge air temperature automatically via a new programmed reset schedule.

Based on what was witnessed and observed during the mechanical systems survey it appears that a building relief fan is needed to insure the proper ventilation rate is being achieved for the Library on a consistent basis. A relief fan will also help to maintain a slightly positive pressure for the building that will reduce infiltration of warm or cold air and dirt, dust and other unwanted contaminants from entering the building.

Fire Crash Rescue Station (B288)

Description

Building B288 – The Fire Crash Rescue Station was constructed in 2005 and is 41,375 square feet in size. The station has an all civilian department that consist of two shifts and an administrative division that operates out of two districts comprising of approximately 62 occupants. Every firefighter is a certified firefighter/EMT/Hazmat Technician.

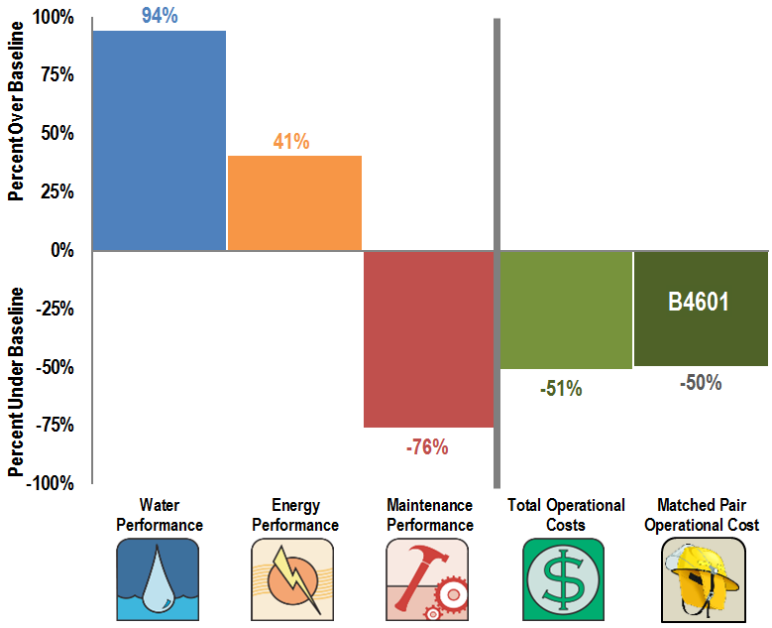
Metrics	Fire Crash Rescue Station (B288)		
	Street Address	*911 Garland Street*	*Offutt*
	State & Zip Code	*NE*	*68113*
	Air Force Base		*Offutt Air Force Base*
	Building Function		*Fire Station*
	Design Certification		-
	Year Built		*2005*
	# of Floors		*2*
	Gross Square Foot		*41,375*
	Weekly Operating Hours		*168*
	Regular Occupants		*62*
	Average Daily Visitors (FTE)		*4*
	Electronic Equipment		*65*
	Construction Cost		*$13,139,100*

The station responds to structural fires, EMS, Special Rescue, and Aircraft Emergencies (ARFF). The station operate 3 engines, 1 heavy rescue, 1 75 foot quintuple combination pumper, 1 tanker, 4 ARFF vehicles, 1 Rapid Intervention Vehicle, Hazmat unit w/decontamination trailer, specialized rescue trailer (trench and collapse rescue), 2 foam trailers, 1 boat, 1 air trailer, 1 water boom trailer (used to dam and divert hydrocarbons from waterways (rivers/streams), 1 gator, 1 fire prevention/inspection vehicle and 2 command vehicles.

The facility also contains a small fitness center with 3 cardio machines, a sauna, administration support area with 10 private offices and an enclosed Fire/Police Dispatch Center. The single data center/server closet has a dedicated HVAC unit (split Liebert). The occupants are admittedly very active in maintaining and adjusting the mechanical systems where possible.

Whole Building Performance

The Fire Crash Rescue Station operating costs are lower than the industry baseline for maintenance and higher than industry baselines for both water and energy performance. The Fire Crash Rescue Station does not pay for janitorial or grounds maintenance. Overall, the building cost 51% less to operate than industry baselines and 1% less than its matched-pair.



Performance Data Summary

The research team collected, normalized, and compared whole building performance data for the Fire Crash Rescue Station to industry baselines. The following table summarizes the annual performance data collected and normalized. The facility uses water-cooled chillers for its air-conditioning system; therefore, the cooling tower water use was estimated using the "rule-of-thumb" that 27% of total water use is process water. Outdoor water use was estimated using the "rule-of-thumb" that 20% of total water used is for landscaping.

Metrics	Annual Performance Measurements		Annual Performance Metrics	
	Water Use (gal)	*1,206,909*	Gallons per occupant	*18,286*
	Process Water Use (gal)	*325,865*	Water Cost per occupant	*$25.05*
	Outdoor Water Use (gal)	*241,382*	Gallons per GSF	*29.17*
	Water Cost	*$1,653*	Water Cost per GSF	*$0.040*
	Energy Star Score	*21*		
	Total Energy Use (kBtu)	*6,797,184*	Energy Use (kBTU) per GSF	*164*
	Energy Cost	*$56,014*	Energy Cost per GSF	*$1.35*
	Building Emissions ($MTCO_2e$)	*1,024*	Building Emissions per Occupant ($MTCO_2e$)	*15.52*
	General Maintenance Cost	*$34,090*	General Maint Cost per GSF	*$0.82*
	Janitorial Services Cost	*$0*	Janitorial Services Cost per GSF	*$0.00*
	Grounds Maintenance Cost	*$0*	Grounds Maint Cost per GSF	*$0.00*
	Quantity of Maint Requests	*14*	Ratio of Maint Requests to Total Maint Jobs	*0.09*
	Quantity of Prev Maint Jobs	*142*		

Main Fire Station (B4601)

Description

Building B4601 – The Main Fire Station, located on Seymour Johnson Air Force Base, received a LEED Silver rating for the construction and design of the facility. The fire station has 43,400 square feet with approximately 60% being conditioned spaces. The facility was completed and occupied in 2006.

Metrics	Main Fire Station (B4601)		
	Street Address	*4601 Jabarra Ave*	*Goldsboro*
	State & Zip Code	*NC*	*27531*
	Air Force Base	*Seymour Johnson Air Force Base*	
	Building Function	*Fire Station*	
	Design Certification	*LEED NC 2.1 - Certified*	
	Year Built	*2008*	
	# of Floors	*1*	
	Gross Square Foot	*43,400*	
	Weekly Operating Hours	*168*	
	Regular Occupants	*30*	
	Average Daily Visitors (FTE)	*17*	
	Electronic Equipment	*88*	
	Construction Cost	*$5,543,500*	

The building HVAC system is comprised of two VAV air handling units serving 18 VAV terminal reheat units for the conditioned areas. The VAV reheat terminal boxes and air handling units are served by a single Raypack hot water boiler rated at 630 MBH. The chilled water system has a single nominal 50 ton York air cooled chiller located in an equipment yard separate from the building. The facility is connected to the base wide Energy Management System. This facility has Barber Coleman Network 8000 DDC controls controlling the HVAC systems. The chilled and hot water systems are constant volume primary only pumping with a lead and standby pump arrangement. The building has a security center located in it now that was not part of the original design this area is served by supplemental DX mini-split systems in the raised floor area. The truck bays have infrared direct fired gas heaters located adjacent to the truck bay doors located on the north and south side overhead doors. There are numerous small hot water Hydronic unit heaters that serve the shop areas and the mechanical mezzanine area.

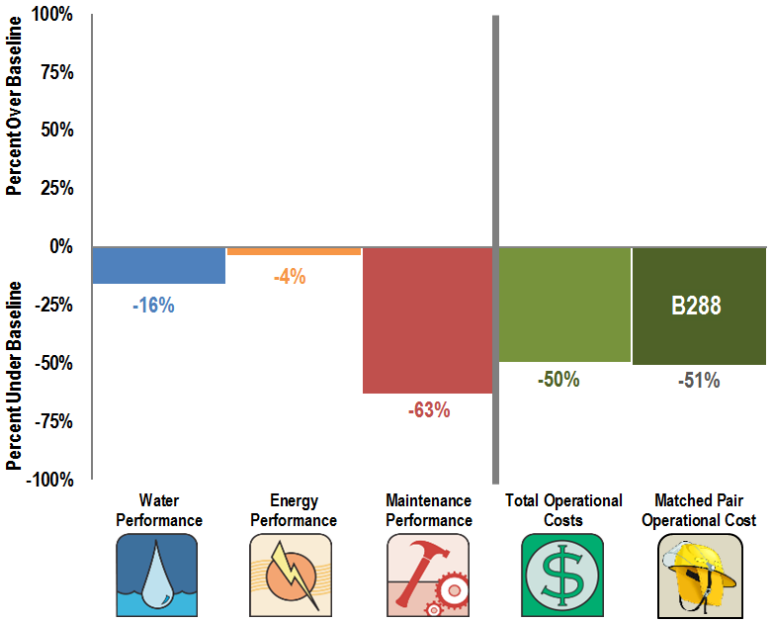
The facility has undergone a phase of retro-commissioning at the beginning of the year. There were several Energy Conservation Measures (ECMS) that were performed relating to the building automation system and test and air balance of the systems. These measures have not been validated at this time and will require more operational hours to determine if the retro-commissioning measures were successful in reducing energy cost and improving comfort levels. It appears that the energy savings modeled in the retro-commissioning report were very aggressive for a 24/7 operating building and were well below the actual usage as indicated from the energy bills.

Certifications

Certified: 26-32 points, **Silver:** 33-38 points, **Gold:** 39-51 points, **Platinum:** 52-69 points

Whole Building Performance

The Main Fire Station operating costs are lower than the industry baseline for all metrics. The Main Fire Station pays very little for janitorial and grounds maintenance. Overall, the building cost 50% less to operate than industry baselines and 1% more than its matched-pair.



Performance Data Summary

The research team collected, normalized, and compared whole building performance data for the Main Fire Station to industry baselines. The following table summarizes the annual performance data collected and normalized.

Metrics	Annual Performance Measurements		Annual Performance Metrics	
	Water Use (gal)	*544,080*	Gallons per occupant	*11,576*
	Process Water Use (gal)	*No Meter*	Water Cost per occupant	*$24.62*
	Outdoor Water Use (gal)	*No Meter*	Gallons per GSF	*12.54*
	Water Cost	*$1,157*	Water Cost per GSF	*$0.027*
	Energy Star Score	*77*		
	Total Energy Use (kBtu)	*3,770,166*	Energy Use (kBTU) per GSF	*87*
	Energy Cost	*$66,591*	Energy Cost per GSF	*$1.53*
	Building Emissions ($MTCO_2e$)	*383*	Building Emissions per Occupant ($MTCO_2e$)	*8.15*
	General Maintenance Cost	*$45,265*	General Maint Cost per GSF	*$1.04*
	Janitorial Services Cost	*$7,448*	Janitorial Services Cost per GSF	*$0.17*
	Grounds Maintenance Cost	*$912*	Grounds Maint Cost per GSF	*$0.02*
	Quantity of Maint Requests	*38*	Ratio of Maint Requests to Total Maint Jobs	*0.84*
	Quantity of Prev Maint Jobs	*7*		

Jacobs Engineering – Facility Walkthrough Assessment

Findings, Actions & Recommendations

1. **Finding:** During the interview of facility personnel it was noted that when the building experiences a problem with the HVAC system that shuts down all cooling the building warms up very quickly. This is due mainly to the very large unconditioned space above the lay in ceiling in the office and administration areas of the.
    a. **Recommendation:** The installation of insulation batts above the lay in ceiling would increase the thermal heat barrier and reduce the heat gain between the unconditioned space above the ceiling and the conditioned spaces below.
    b. **Recommendation:** Install one or more small exhaust fans to increase the ventilation rate in the attic and lower the attic space temperature.

2. **Finding:** Chilled water pump No. 1 was locked out at the local motor starter and valved off from the chilled water system. The insulation was removed from the pump housing and volute. It appears that this pump has a leaking mechanical seal and needs to be repaired. In this configuration there is not a standby pump in the event pump No. 2 should experience a failure.
    a. **Recommendation:** Replace the leaking mechanical seal and re-insulate the chilled water pump.
    b. **Recommendation:** Verify the chilled water system is maintaining a positive pressure consistently and the makeup water pressure regulator is set correctly. If the PRV station is set to high it will cause the chilled water system pressure to be higher than needed. The closed loop chilled water pressure regulator should be set to maintain a positive pressure at the chilled water pumps that is 3-4 PSIG higher than the standing static pressure of the system with the chilled water pumps not operating.

c. **Recommendation:** Verify the chilled water system pressure relief valve is not leaking and causing the system to lose pressure and make-up water.

3. **Finding:** Hot water pump No. 2 has a leaking mechanical seal and needs to be repaired.
    a. **Recommendation:** Replace the leaking mechanical seal.
    b. **Recommendation:** Verify the hot water system is maintaining a positive pressure consistently and the makeup water pressure regulator is set correctly. If the PRV station is set to high it will cause the hot water system pressure to be higher than needed. The closed loop hot water system pressure regulator should be set to maintain a positive pressure at the hot water pumps that is 3-4 PSIG higher than the standing static pressure of the system with the hot water pumps not operating.
    c. **Recommendation:** Verify the hot water system pressure relief valve is not leaking and causing the system to lose pressure and make-up water.

4. **Finding:** The TAB report furnished at the time of the survey has some information that does not appear to be correct for exhaust fans SF-1, SF-2 and SF-3. The nameplate HP shown in the TAB report does not line up with the actual voltage and amperage values recorded in the TAB report. The actual HP values are not recorded but based on the voltage and amperage readings given for 120 volt single phase motors the BHP values are significantly higher than the design values shown; .5 and .125 HP.
    a. **Recommendation:** Verify the CFM values are correct for the exhaust fans.

5. **Finding:** In the retro-commissioning report that was given it was noted in section 2.12.3.2 Control Changes to allow a supply air reset from 55.0°F to 65.0°F with a change in outside air temperature from 80.0°F to 55.0°F respectively. This may create some issues with humidity control if the supply air temperature is allowed to control this high.
    a. **Recommendation:** Minimize reset to control supply air from 55.0°F to 60.0°F.
    b. **Recommendation:** Provide a humidity sensor and input to override the reset schedule in the event the humidity reaches a predetermined level.

6. **Finding:** In the retro-commissioning report that was given in was noted in section 2.12.3.2 that the minimum OA setpoints for AHU-1 and AHU-2 were set to 15% and 12% respectively. During the site survey AHU- 2 was at 0 CFM of outside air flow. This was indicated at the local EBTRON LCD display and the damper actuator for the outside air damper. This may be the result of fumes from the flight line and truck bays entering the conditioned spaces when the unit is bringing in a lot of outside air during economizer mode.
    a. **Recommendation:** Verify why the OA damper and minimum airflow settings are set up to allow the outside air damper to close 100 percent.

7. **Finding:** It was noted that many of the system points and parameters are not being trended at this time by the EMCS system. EMCS systems are a great source for system troubleshooting and the evaluation of HVAC system performance.
    a. **Recommendation:** Set up trend logs for space temperatures in zones and areas that are heavily impacted by high occupancy. Also include zones or exposures of the North, East, South and West sun during the summer and winter. Set up trends for AHU supply temperature, chilled water and hot water supply temperature, CO2 levels, OA damper positions and outside air temperature. By monitoring these points and performing a periodic review and analysis will increase the Air Forces' ability to

better understand and determine if the building will continue to meet the goals set forth by LEED building initiatives.

Summary

The HVAC mechanical systems for Building- 4601 the Main Fire Station appear to have met the expectations of the Air Force based on the interview with the facility operators and staff. The overall building comfort was well within expectations for a newer facility such as this. The CO2 levels indicated on the EMCS graphics indicate an acceptable level of ventilation is being introduced into the conditioned spaces with CO2 levels ranging from 423 to 420 PPM. The space temperatures noted throughout the facility ranged from 70.0 to 73.0°F. The energy use does not appear to be too high for a facility that is used 24/7 year round but is still being reviewed at this time and compared to like facilities. One of the easiest ECM measures that could be put into place was recommended in the previous retro-commissioning report to add insulation above the lay in ceiling tiles of the conditioned spaces. This will not only improve comfort and help to reduce energy cost but will also add a layer of sound proofing to the occupied spaces as well.

A design study needs to be performed to determine the load and needs for the security area that was added to the facility after construction. Since this is a critical operation for the base it will require expertise in this area and scope of work to develop the best solution for the base.

Fitness Center (B999)

Description

Building B999 – The Rambler Fitness Center, located on Randolph Air Force Base, has 78,701 square feet of conditioned space. The facility was completed and occupied in 2007. The 1 story Rambler Fitness Center has a covered entry way with a vestibule and incorporates a gymnasium with three full size basketball courts, an elevated and padded 1/8 mile indoor jogging track with T5 lighting, a juice bar, saunas, and a large vaulted ceiling exercise area with over 120 cardio vascular equipment. The juice bar has 1 double door freezer, 1 double door fridge, coffee machine, flat screen TV, 2 small fridges and a smoothie machine.

Metrics	Rambler Fitness Center (B999)		
	Street Address	*1751 1st Street East*	*Randolph*
	State & Zip Code	*TX*	*78150*
	Air Force Base		*Randolph Air Force Base*
	Building Function		*Fitness Center*
	Design Certification		-
	Year Built		*2007*
	# of Floors		*1*
	Gross Square Foot		*78,701*
	Weekly Operating Hours		*112*
	Regular Occupants		*20*
	Average Daily Visitors (FTE)		*250*
	Electronic Equipment		*20*
	Construction Cost		*$14,900,000*

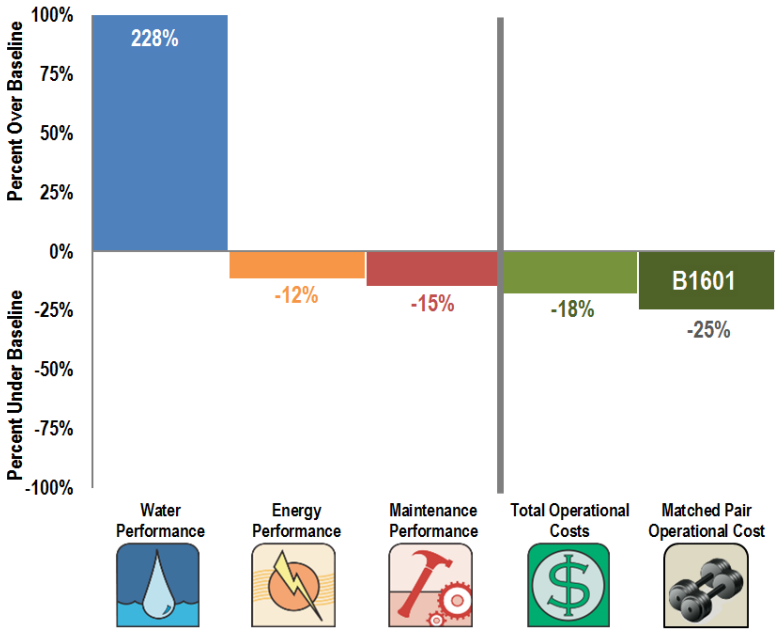
The fitness center has about 2000 visitors per day for an average duration of 1 hour and has approximately 25 flat-screen televisions and over 120 pieces of cardio vascular equipment.

A separate section of the facility includes a Health and Wellness Center where they provide fitness assessment testing, cooking classes, aqua massage therapy and other health wellness education programs. Other amenities include three racquetball courts, cycling room with a large projection screen, 24 foot climbing wall, and two large group exercise rooms, 1 aqua massage bed, 2 ice machines, 2 ovens, 2 dishwashers and a set of washer and dryers.

The facility has 1 small server closet in the main office and 1 large server/communication room on the perimeter. Both rooms have their own water cooled unit. The main HVAC systems and lighting are essentially on 24 hours a day, 7 days a week. After hours of operation, cleaning staff are in the facility all night. There are ventilation issues throughout the facility that causes frequent portable fan usage (approximately 20 through the facility).

Whole Building Performance

The Rambler Fitness Center operating costs are lower than the industry baseline for all metrics except water. Overall, the building cost 18% less to operate than industry baselines and 7% more than its matched-pair.



Performance Data Summary

The research team collected, normalized, and compared whole building performance data for the Rambler Fitness Center to industry baselines. The following table summarizes the annual performance data collected and normalized. The facility uses water-cooled chillers for its air-conditioning system; therefore, the cooling tower water use was estimated using the "rule-of-thumb" that 27% of total water use is process water. Outdoor water use was estimated using the "rule-of-thumb" that 20% of total water used is for landscaping.

Metrics	Annual Performance Measurements		Annual Performance Metrics	
	Water Use (gal)	*3,875,840*	Gallons per occupant	*14,355*
	Process Water Use (gal)	*1,046,477*	Water Cost per occupant	*$5.01*
	Outdoor Water Use (gal)	*775,168*	Gallons per GSF	*49.25*
	Water Cost	*$1,354*	Water Cost per GSF	*$0.017*
	Energy Star Score	*78*		
	Total Energy Use (kBtu)	*6,017,645*	Energy Use (kBTU) per GSF	*76*
	Energy Cost	*$72,338*	Energy Cost per GSF	*$0.92*
	Building Emissions ($MTCO_2e$)	*700*	Building Emissions per Occupant ($MTCO_2e$)	*2.59*
	General Maintenance Cost	*$88,369*	General Maint Cost per GSF	*$1.12*
	Janitorial Services Cost	*$342,772*	Janitorial Services Cost per GSF	*$4.36*
	Grounds Maintenance Cost	*$27,422*	Grounds Maint Cost per GSF	*$0.35*
	Quantity of Maint Requests	*223*	Ratio of Maint Requests to Total Maint Jobs	*0.85*
	Quantity of Prev Maint Jobs	*40*		

Tyndall Fitness Center (B1601)

Description

Building B1601 – Tyndall Fitness Center, located on Tyndall Air Force Base, received a LEED Platinum rating for the construction and design of the facility. The Fitness Center has 72,000 square feet of conditioned space. The facility was completed and occupied in August 2010.

The fitness center has a large open foyer/entrance area illuminated with large windows and daylight strategies. The Fitness Center incorporates an open floor plan with a gymnasium, 7 administrative offices, two full size basketball courts, 3 racquetball courts, 2 saunas, a large vaulted ceiling exercise area with over 62 cardio vascular equipment and a private family exercise area. A separate section of the facility includes a Health and Wellness Center with 4-5 offices where they provide fitness testing, cooking classes, and other health wellness education programs.

Metrics	Tyndall Fitness Center (B1601)		
	Street Address	*1601 Mississippi Rd*	*Panama City*
	State & Zip Code	*FL*	*32403*
	Air Force Base		*Tyndall Air Force Base*
	Building Function		*Fitness Center*
	Design Certification		*LEED NC 2.2 - Platinum*
	Year Built		*2010*
	# of Floors		*2*
	Gross Square Foot		*75,278*
	Weekly Operating Hours		*112*
	Regular Occupants		*19*
	Average Daily Visitors (FTE)		*119*
	Electronic Equipment		*19*
	Construction Cost		*$19,000,000*

The building's HVAC system has four VAV air handling units, these serve VAV terminal reheat units located throughout the building for the conditioned spaces. A single CAV AHU serves the Health and Wellness Center of the building. The central cooling and heating plant consist of two air-cooled chillers; 1-65 ton and 1- 125 ton magnetic bearing compressor machines. These are located outside separate from the building. The chilled water system has two primary pumps and one secondary pump that serve the AHUS. The small air-cooled chiller has a heat recovery tube bundle to supplement the domestic hot water system. The small chiller is the base load machine normally. A single hot water heating boiler serves the AHUS and VAV reheat terminal boxes. The heating hot water system has a single primary and secondary pump that serve the AHUS and VAV reheat terminal boxes.

The Fitness Center is connected to the base wide Energy Management System. This base has a Siemens Apogee DDC control system. The DDC control strategies for the Fitness Center include the following; Time of Day Scheduling, Time Override, Night Set Up and Set Back, Space Temperature Setpoint Limits, Hot Water Reset schedule and Supply Air Reset based on VAV cooling demand. The facility is also served by a Photo Voltaic solar array with a capacity of 30 kW to supplement the building electrical loads. A solar hot water collector array is also located on the roof and will supplement the domestic hot water system on sunny days. The solar hot water system loop is isolated from the potable hot water loop through a plate and frame heat exchanger located in the

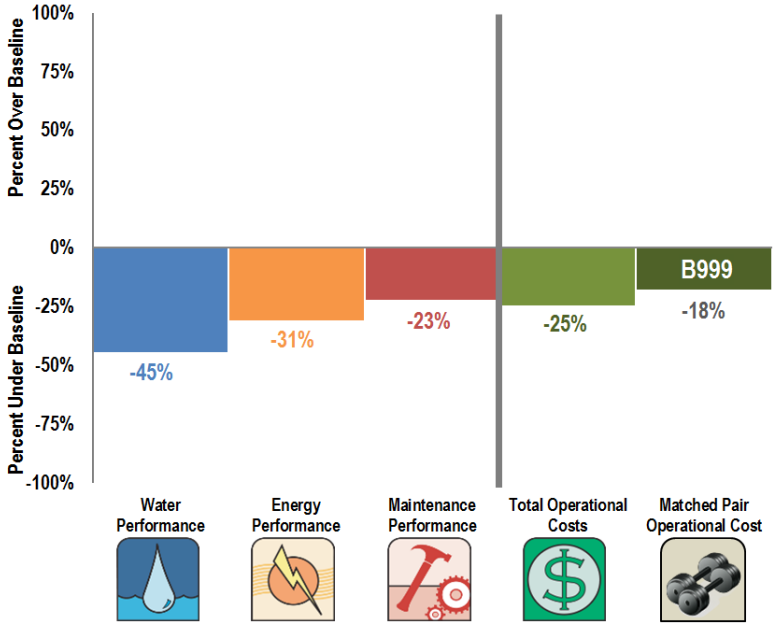
first floor boiler mechanical room. Hot water generated by the solar panel array is not stored in a tank battery currently at this time.

Certifications

Certified: 26-32 points, **Silver:** 33-38 points, **Gold:** 39-51 points, **Platinum:** 52-69 points

Whole Building Performance

The Tyndall Fitness Center operating costs are lower than the industry baseline for all metrics. Overall, the building cost 25% less to operate than industry baselines and 7% less than its matched-pair.



Performance Data Summary

The research team collected, normalized, and compared whole building performance data for the Tyndall Fitness Center to industry baselines. The following table summarizes the annual performance data collected and normalized.

Metrics	Annual Performance Measurements		Annual Performance Metrics	
	Water Use (gal)	*625,759*	Gallons per occupant	*4,534*
	Process Water Use (gal)	*0*	Water Cost per occupant	*$7.80*
	Outdoor Water Use (gal)	*0*	Gallons per GSF	*8.31*
	Water Cost	*$1,076*	Water Cost per GSF	*$0.014*
	Energy Star Score	*81*		
	Total Energy Use (kBtu)	*4,495,072*	Energy Use (kBTU) per GSF	*60*
	Energy Cost	*$98,996*	Energy Cost per GSF	*$1.32*
	Building Emissions ($MTCO_2e$)	*753*	Building Emissions per Occupant ($MTCO_2e$)	*5.46*
	General Maintenance Cost	*$28,832*	General Maint Cost per GSF	*$0.38*
	Janitorial Services Cost	*$386,000*	Janitorial Services Cost per GSF	*$5.13*
	Grounds Maintenance Cost	*$5,000*	Grounds Maint Cost per GSF	*$0.07*
	Quantity of Maint Requests	*148*	Ratio of Maint Requests to Total Maint Jobs	*0.82*
	Quantity of Prev Maint Jobs	*32*		

Jacobs Engineering – Facility Walkthrough Assessment

Findings, Actions & Recommendations

1. **Finding:** During the interview with facility personnel it was noted that CO2 levels measured and sensed in the conditioned spaces consistently reach alarm levels above the 800 PPM setpoint. Refer to the table below for the design airflow for the AHUS serving the building. The building is scheduled to operate with 12,480 CFM of outside airflow. The current configuration for the building has a total exhaust CFM airflow rate of 4950 CFM from the mechanical schedules. The building will be operating in a pressurized state with values shown in the table. The building does not currently have a relief air fan(s) or path to relieve the outside air trying to be brought into the building from the AHUS. The AHUS will not bring in the schedule CFM with the suction side of the fans in the AHUS and return air ducts pressurized above the design conditions. This can be seen and verified by reviewing the operating conditions and system parameters from the graphic pages for each AHU at the EMS operator work station.

AHU Name	Supply Air CFM	Outside Air CFM
Lockers	5410	440
Weights	17,000	4210
Exercise	10,500	3390
Gym	13,000	4440
HAWCS	3400	N/A
Total CFM	**49, 310**	**12, 480**

Exhaust Fans	Exhaust CFM
Locker Room, Toilets and Elevator Room	**4950**
Difference in Outside Air and Exhaust Air CFM	**7530**

a. **Recommendation:** Design and install a building relief air system to address the positive pressure for the building.
b. **Recommendation:** Install a building pressure sensor to measure the building static pressure in relation to the outside. Use this value as an input to the DDC control system to vary the speed of the new relief air fan to maintain a positive pressure of .015 inches W.C. in the building during occupied times.

2. **Finding:** During the site survey it was noted in the weight room area the humidity appeared to be high for this area. This can also be verified from the return air humidity levels measured by the duct mounted humidity transmitter for the AHU. At the time of the survey the return air humidity level was at 58.0 to 60.0 % RH.

    a. **Recommendation:** At the AHU maintain a supply air temperature between 52.0 to 55.0 °F consistently. Allow the chilled water coil to flow more water by lowering the supply air setpoint. This may require the VAV reheat terminal boxes to perform a higher amount of reheat but will help insure the humidity level and ventilation rate is being met. The chilled water coils in the AHUS do not perform well when the flow rate in the coils is reduced below 70 percent of the designed flow rate. A reduce chilled water flow rate will create a laminar flow condition in the coil. In certain parts of the coil the sensible and latent heat will not be removed adequately resulting in a blended discharge air stream with high moisture content.

3. **Finding:** During the survey and walk through it was noted the chilled water supply temperature to the AHU coils was between 46.0 and 48.0 °F. With the chilled water supply temperature entering the coils this warm the ability for the chilled water coils to remove moisture from the air is greatly reduced.
    a. **Recommendation:** To improve comfort and lower humidity levels the chilled water supply temperature should be maintained at the design condition of 44.0 °F. By maintaining the correct chilled water supply temperature and supply air setpoint will prevent future problems of mold and mildew forming on cold and moist surface areas.

4. **Finding:** While surveying the Weight room it was noted that the air appeared to be stagnated to some degree. The sensible temperature appeared to be acceptable but the space seemed to suffer from a low air exchange rate and higher level of humidity. During the interview with the base facility operators it was determined that changes had been made to the min/max airflow rates for the VAV reheat terminal boxes. This was apparently done to improve the outside air flow rate in the AHUS. This can also be attributed to the fact the building does not have a relief air fan and system.
    a. Recommendation: After the relief air problems have been addressed above item 1. , perform a test and air balance of the VAV reheat terminal boxes. Adjust the min/max values to the design air flow rates per the mechanical schedules.
    b. Recommendation: Maintain a consistent operation of the heating hot water system and temperature to allow the VAV reheat terminal units to function correctly. During some hours of operation in the summer reheat may be needed in some zones.

Summary

The HVAC mechanical systems for Building- 1601 fitness Center appear to have met most of the expectations of the Air Force based on the interview with the facility operators and staff. The overall building comfort and satisfaction as reported by Lou South the facility manager was very good. The Air Force seems to be very pleased with this facility being the first LEED Platinum building on the Tyndall Air Force Base. The findings and recommendations given above will provide an even greater level of comfort and operation for the facility. The recommendations made above will help to insure the longevity of the overall building and mechanical systems and maintain the energy cost within the LEED and the government energy use guidelines.

Appendix A: References

[1] GSA. 2004. *GSA LEED™ Cost Study*. Accessed: September 2007. http://www.wbdg.org/

[2] Heerwagen, J. 2001. *Do Green Buildings Enhance the Well Being of Workers?* Environmental Design+Construction. 3(4):24-30. Accessed August 2007. http://www.edcmag.com/CDA/ArticleInformation/coverstory/BNPCoverStoryItem/0,4118,19794,00.html

[3] Matthiessen, LF. 2004. *Examining the Cost of Green*. Greenbuild 2004 International Conference and Expo Proceedings, Portland, Oregon. http://www.dladamson.com/Attachment%20Files/Research/The%20full%20report.pdf

[4] Matthiessen, LF and P Morris. 2007. *The Cost of Green Revisited*. Davis Langdon, San Diego, California. http://www.davislangdon.com/USA/Research/ResearchFinder/2007-The-Cost-of-Green-Revisited/

[5] U.S. Department of Energy (DOE). 2003. *The Business Case for Sustainable Design in Federal Facilities*. Interagency Sustainability Working Group, Federal Energy Management Program (FEMP), Washington, DC. http://www.eere.energy.gov/femp/techassist/sustainability.html#business

[6] Torcellini, P, S Pless, M Deru, B Griffith, N Long, and R Judkoff. 2006. *Lessons Learned from Case Studies of Six High-Performance Buildings*. NREL/TP-550-37542. National Renewable Energy Laboratory (NREL), Golden, Colorado.

[7] Diamond, R, M Opitz, B Von Neida, and S Herrera. 2006. *Evaluating the Energy Performance of the First Generation of LEED-Certified Commercial Buildings*. Published in the Proceedings of the 2006 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, Washington DC, August, 2006. LBNL-59853. Accessed June 2007. http://epb.lbl.gov/homepages/Rick_Diamond/LBNL59853-LEED.pdf

[8] Fowler, KM, EM Rauch, AR Kora, JE Hathaway, AE Solana, and KL Spees. 2009. *Whole Building Cost and Performance Measurement: Data Collection Protocol*, Revision 2.0. PNNL-18325, Pacific Northwest National Laboratory, Richland, Washington. http://www1.eere.energy.gov/femp/pdfs/pnnl15217.pdf

[9] USGBC. 2012. "Green Building Facts." US Green Building Council website. Accessed: June 2014. http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1720

[10] McGraw Hill Construction. 2010. Green Outlook 2011: Green Trends Driving Growth.

[11] DOE FEMP. 2007. "Federal Water Use Indices website." Accessed: May 2010. http://www1.eere.energy.gov/femp/program/waterefficiency_useindices.html

[12] Energy Information Administration (EIA). 2012. *Annual Energy Review 2011*. Accessed: June 2014. http://www.eia.doe.gov/

[13] EIA. 2007. "Table C12. Consumption and Gross Energy Intensity by Year Constructed for Sum of Major Fuels for Non-Mall Buildings, 2003." Accessed: October 2007. http://www.eia.doe.gov/emeu/cbecs/contents.html

[14] BOMA International. 2010. *International Experience Exchange Report*. BOMA International, Washington, DC.

[15] International Facility Management Association. 2009. *Operations and Maintenance Benchmarks*, *Research Report #32*. IFMA, Houston, Texas.

[16] BOMA International. 2010.

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

U.S. DEPARTMENT OF
ENERGY

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)

www.pnnl.gov