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Asset Management: Roof Maintenance and Facility Energy Retrofits

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ASSET MANAGEMENT:

ROOF MAINTENANCE AND FACILITY ENERGY RETROFITS

THESIS

Joseph. P DiRosario, Captain, USAF

AFIT/GEM/ENV/12-M04

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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THESIS

Presented to the Faculty

Department of Systems and Engineering Management

Graduate School of Engineering and Management

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Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering Management

Joseph P. DiRosario, B.S.

Captain, USAF

March 2012

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AFIT/GEM/ENV/12-M04

Abstract

The United States Air Force needs aggressive new techniques to compliment its asset management style control over its own real estate portfolio. Unfortunately, Air Force officials are facing budgetary issues that have been leading to degraded facilities infrastructure. Two areas of operations where opportunities can reveal themselves are roof maintenance and facility energy retrofits. Research revealed via a geospatial information systems analysis that the current state of the rooftop maintenance program was in disrepair and supported strategic sourcing as a potential solution to deficiencies. Two methodologies were also created to gauge the effectiveness of whole building retrofits and define a facility energy efficiency term to use to channel efficiency upgrade dollars. Modeling efforts further supported the need for investigation into whole building retrofitting techniques and demonstrated that they can produce at maximum 20% to 50% in annual energy savings in USAF facilities. An additional 2.0% in free synergistic efficiency gains was also found when comparing whole building retrofit projects to existing approaches. Overall, this research established there were areas for improvement in the United States Air Force asset management policies for roofing maintenance and facility retrofits suggesting paths to better management and savings.

AFIT/GEM/ENV/12-M04

Dedication

To my parents...

Acknowledgements

I am extremely grateful for the assistance of my thesis advisor, Lt. Col Peter Feng, during the course of this effort. He helped me focus the project's goals and provided constant encouragement. I also wish to thank Lt. Col William Sitzabee and Capt. Sean Chun who acted as representatives for my thesis committee and provided me with their vast knowledge. The data and expertise provided by the 88th Civil Engineer Directorate was pinnacle to the research process. Of the 88th Civil Engineer Directorate's team members, I would like to particularly express my gratitude to Robert Flood, Kevin Osborn, Forrest Dent, David Crawford, and Sloan Gragg. Each of these individuals took time out of their busy schedules to assist the endeavor, and further my research. Mr. David Perkins, head of the 88th Civil Engineer Directorate, was also vital in providing access to his organization and encouraging the free flow of information with AFIT.

Although, the research path for the project ultimately focused on WPAFB, I would also like to thank the following individuals for their contributions during the initial stage of the process: Mark Hunt, Steve White, John McDuffie, William Turnbull, James Barker, Angie Flores, Greg Noble, Dell Petersen, and Les Lambert. Additionally, both Lt. Col Matt Joganich, 28th Civil Engineer Squadron Commander, and Lt. Col Michal Holiday, 366th Civil Engineer Squadron Commander, were essential to the work by allowing direct discussions and data exchanges with their personnel. Without these individuals and their assistance, the project could never have reached an end state.

Lastly, I would like to thank my parents. They were and have always been the drivers to my success. The lessons they have taught me have encouraged me to learn,

work, and succeed. They provided advice and listened when the project reached difficult periods.

Joseph P. DiRosario

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ASSET MANAGEMENT:
ROOF MAINTENANCE AND FACILITY ENERGY RETROFITS

I. Introduction

The United States Air Force (USAF) is facing fiscal challenges which lead to a degraded facility infrastructure. Although these issues are not new, the Department of Defense(DoD) and USAF officials have had to deal with more than a decade of war, a loss of economic prowess, aging aircraft, and rising operations and modernization costs [1]. USAF civil engineers in concert with DoD directives are attempting to maximize fiscal budgets to support USAF mission priorities. This new method has been coined Asset Management which utilizes organizational levels of service, business case analysis, and risk analysis to address urgent priorities. Two priorities of USAF Civil Engineering Asset Management are roof maintenance and facility energy retrofits.

Background

Roofs are vital systems necessary for the unimpeded facility operations of building occupants [2]. Unfortunately, decreasing budgets and manning issues across the Air Force have left a number of facility systems such as roofs at risk to disrepair due to a lack of maintenance. Under the principles of asset management, the losses associated with reactive versus passive roof maintenance suggest passive approaches utilize funding more efficiently. By analyzing existing USAF roof management databases, researchers obtain an opportunity to gauge the effectiveness of their own roof preventive maintenance programs and suggest viable solutions for problem areas at minimal costs such as strategic sourcing. This technique maximizes the buying power of large organizations to streamline costs, reporting, and administrative requirements [3, 4]. With these freedoms, USAF personnel can concentrate in other areas and are given more control, responsiveness, and expertise for their roof maintenance processes.

At the same time, as the dominant energy consumer for the DoD, USAF officials also need aggressive techniques to meet energy goals and curtail consumption against rising utility costs [5]. While officials have managed to reduce facility energy intensity, energy costs have risen too sharply against the lowering of consumption levels [6]. Asset management principles demand the need to ensure that funds are properly channeled into the right facilities at the right times. Studies are needed to compare existing USAF single system efficiency upgrades to whole building retrofitting techniques. Discoveries in this area could reveal breakthrough approaches that deliver unprecedented savings in existing facilities. Large scale savings stand to aid in the energy fight. Additionally, research into a new process to determine the best way to classify facility efficiency is necessary for the proper channeling of funding and reducing energy consumption. These concepts push the USAF innovation and aid it in meeting the challenges of its own future.

Problem Statement

Knowing the existing situation, this research poses the question, is the USAF fulfilling its asset management responsibilities in the areas of roof maintenance and energy efficiency retrofitting operations? Case studies will establish the state of the USAF preventive rooftop maintenance programs through an analysis of existing database information and suggest viable options to resolve issues. Efforts will comment on a methodology to compare whole building retrofits to single system projects. Furthermore, efforts will suggest several techniques to determine the best facility efficiency term for USAF operations. Lastly, research will establish the idea that implementing whole building retrofits on existing USAF building stock yields far more energy savings then existing techniques in a series of cases studies.

Research Questions

The objectives of this research include: a detailed review of the USAF rooftop preventive maintenance program, a review of whole building retrofitting techniques, and a discussion of the best methodologies to determine a facility energy efficiency term for USAF policy. The whole building retrofitting and preventive maintenance investigations will be handled through the construction of several case studies. Benefits will be extrapolated to the USAF as a whole. Strategic sourcing and a methodology to determine facility efficiency term will only be discussed as part of the project. A discussion of the best methodology to use when comparing existing whole building retrofit projects to single system upgrades will also be established for the effort.

The following is a list of specific research questions to guide this research.

1) Should the USAF revitalize its rooftop preventive maintenance program and further investigate strategic sourcing as a viable solution?

2) What is the best methodology to enable a comparison of whole building retrofitting techniques to existing USAF approaches and to determine the best facility efficiency term?

3) What are whole building retrofit techniques?

    3.1: How do they compare to single system approaches?

3.2: What kind of synergy can be expected from a whole building perspective?

4) Can facility energy modeling software be used to simulate single systems and whole building retrofitting techniques?

4.1: How accurate can an energy model come to reality?

5) Can whole building retrofitting techniques be successfully applied to existing USAF building stock to reap major savings?

Question 1 looks to establish the current state of the USAF rooftop preventive maintenance program and suggest alternatives to improve issues. Question 2 seeks to propose a methodology for a balanced comparison of whole building retrofitting techniques to existing methods. It also seeks to provide a methodology to determine the best facility energy term. The answers to question 2 require several sub-questions be expanded upon. These are shown in chapter 3 for the purposes of being concise. Question 3 and its sub-objectives drive researchers to investigate further background on whole building retrofits and whether they would provide any tangible benefit to the Air Force should they become more main stream. Question 4 and the sub-parts support the project methodology and provide vital background on whether any savings reported in the project can be considered accurate. Lastly, Question 5 demonstrates the techniques work in existing USAF building stock.

Scope and Approach

The context of this investigation into the success of asset management policies in rooftop maintenance and energy efficiency retrofitting operations was separated into three distinct areas. First, researchers established the existing state of the USAF preventive maintenance programs through an analysis of an existing roof management database on several installations. Using an economic analysis and a detailed literature review, team members provided support for the consideration of strategic sourcing as viable solution to major deficiencies in the roofing maintenance program. Next, researchers utilized several investigative questions and an enhanced literature review to suggest the best methodology to compare whole building techniques to existing USAF approaches. This portion of the project also provided a gateway to determine the best way to classify a facility's efficiency. This was built to assist the channeling of efficiency upgrade dollars into the correct facilities at the right times. Lastly, team members utilized their pre-developed whole building analysis methodology on an existing installation in the United States. To establish a comparison between whole building retrofits and existing approaches, researchers used existing data for a case study on several facilities to construct a series of baseline models. With baseline models established, researchers launched an analysis of differences between single system and whole building retrofits. Accuracy was tested via several statistical metrics.

Significance

USAF officials are increasingly expected to innovate due to rising costs and increased expectations from the federal government. The strategic sourcing of rooftop preventive maintenance and the implementation of whole building retrofitting instead of existing methods offer a ideal ways to tackle cost reduction and improve asset management program policies for the USAF. These techniques offer real estate portfolio wide lessons for maintenance operations and energy savings.

Preview

This thesis uses the scholarly article format. The following chapters are two conference papers and an article produced from the research. The first two papers were accepted to the Western Decision Sciences Institute Forty First Annual Conference. The third paper will be submitted to the *2012 Building and Environment Journal*. These documents provide the body of this thesis and contains all the elements of research in their layout as prescribed by the conference and peer review journal. The final chapter offers a final discussion of major conclusions from the research along with pertinent findings and future research not discussed in earlier chapters.

II. Scholarly Article

Accepted to Western Decision Sciences Institute Forty First Annual Meeting

(www.wdsinet.org/)

Utilizing Strategic Sourcing to Implement Preventive Maintenance

Abstract

United States Air Force facility systems are in disrepair due to a lack of maintenance from decreasing budgets. Roofs are a facility system that is vital to performance. In this capacity, preventive maintenance programs for roofs are vital to ensuring facility performance. Reactive maintenance results in losses of $0.10 to $0.15 per square foot of roofing per year. Implementing a preventive maintenance roof program utilizes scarce funding more efficiently. By analyzing a roofing database, researchers examined Air Force roofing systems to help re-engineer its rooftop preventive maintenance program.

1. Introduction

As consistent maintenance is vital to roof performance, the first step to re-building its maintenance program is understanding the current state of roofs in the USAF. A database was acquired from Air Combat Command (ACC) to provide the basis of this case study analysis. Currently, as a solution for roofing system maintenance, the US Air Force is exploring strategic sourcing to better utilize limited DoD funding. Strategic sourcing is defined as the leveraging of buying power in a large organization to minimize overall cost expenditures in purchasing an asset or service. The roofing geospatial information system (GIS) enabled database entitled Roof Express used for the analysis provides detailed roofing inventories and condition assessments on a large variety of bases across the United States. The system serves as the most comprehensive large scale database of USAF roofing system information available to date. By examining the scope of employment of different roofing systems, the condition state of rooftops, the most common defects, and industry cost estimates involving preventive maintenance (PM), researchers answer the question, should the USAF revitalize its rooftop PM program and further investigate strategic sourcing as a viable solution?

2. Background

According to the database, public works officials were charged with supporting approximately 47 million square feet of roofing on 18 different bases for 10 separate roof systems. Table 1 showed the following roof systems within the ACC database.

Table 1. ACC Roof System Breakdown

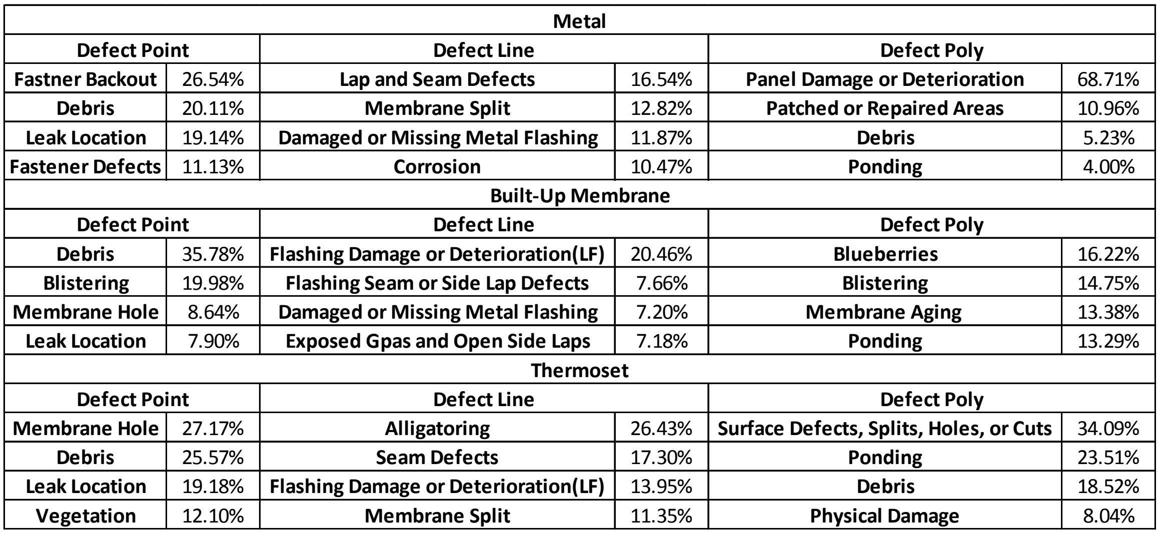
ACC Roof System Breakdown					
Metal	50.10%	**Asphault Shingle**	3.39%	**Ancillary**	0.12%
Built-Up Membrane	25.36%	**Thermoplastic**	3.33%	**Slate**	0.07%
Thermoset	11.45%	**Spray**	1.11%	**Wood Shake/Shingle**	0.02%
Modified Bitmen	4.29%	**Clay**	0.74%		

Roof systems included the following: ancillary, asphalt, built-up membrane, clay, metal, modified bitumen, spray, slate, thermoplastic, and thermoset roofs. Metal roofs were used over 50% of the time. Although metal roofs were expensive in comparison with other roof systems, their durability with low maintenance proved USAF engineers had the right mindset in initial design [7]. Researchers also determined that the average age of any sample roofing system employed regardless of type varied between 7 and 18 years. With roof systems averaging 10 to 15 years in the commercial industry, a good PM program was known to extend roofing system life by much as 40% [8]. Lastly, researchers examined Roof Condition Score (RCS) reports for the various roof systems to reveal most roofs were in good condition varying between 75-85 on the Roof Express scale. The RCS scale was an index of roof condition formulated by creators of Roof Express and the Roof Consultants Institute (RCI), Inc. RCI is an international association of professional roofing experts excelling in roof design and specification [9].

3. Research

We looked to capture the most common roof defects. The GIS database contained defects and inventory data separated into a vector based format composed of points, lines, and polygons. GIS used these formats to represent geographical features [10]. The best examples of this included the idea that a seam separation in a built-up membrane roof was best represented by a line, while a missing asphalt tile on an asphalt tile roof was best represented by a point from a geographical perspective. The information the team discovered was revealing, as database managers ensured the double counting of defects was not an issue in initial data collection procedures. Researchers concluded that a majority of the top four defects in terms of percentage of occurrence regardless of roof system or geographical categorization could have been discovered and mitigated during semi-annual maintenance inspections mandated under AFI 32-1051, Roof Systems Management. Consultations with several unbiased USAF roofing experts removed from the actual maintenance process confirmed these conclusions. Table 2 shows the defect point, line, and polygon analysis of some sample set roofs.

Table 2. Top Defect Point, Line, Polygon Incident Analysis of ACC Roofs



Metal					
Defect Point		**Defect Line**		**Defect Poly**	
Fastner Backout	26.54%	**Lap and Seam Defects**	16.54%	**Panel Damage or Deterioration**	68.71%
Debris	20.11%	**Membrane Split**	12.82%	**Patched or Repaired Areas**	10.96%
Leak Location	19.14%	**Damaged or Missing Metal Flashing**	11.87%	**Debris**	5.23%
Fastener Defects	11.13%	**Corrosion**	10.47%	**Ponding**	4.00%
Built-Up Membrane					
Defect Point		**Defect Line**		**Defect Poly**	
Debris	35.78%	**Flashing Damage or Deterioration(LF)**	20.46%	**Blueberries**	16.22%
Blistering	19.98%	**Flashing Seam or Side Lap Defects**	7.66%	**Blistering**	14.75%
Membrane Hole	8.64%	**Damaged or Missing Metal Flashing**	7.20%	**Membrane Aging**	13.38%
Leak Location	7.90%	**Exposed Gpas and Open Side Laps**	7.18%	**Ponding**	13.29%
Thermoset					
Defect Point		**Defect Line**		**Defect Poly**	
Membrane Hole	27.17%	**Alligatoring**	26.43%	**Surface Defects, Splits, Holes, or Cuts**	34.09%
Debris	25.57%	**Seam Defects**	17.30%	**Ponding**	23.51%
Leak Location	19.18%	**Flashing Damage or Deterioration(LF)**	13.95%	**Debris**	18.52%
Vegetation	12.10%	**Membrane Split**	11.35%	**Physical Damage**	8.04%

The best example of these conclusions from the table was the finding that 5%-35% of the point and polygon geographical defect categories on most roofs were associated with debris or trash. Damage to flashing and fasteners were also high percentage defect areas which could have been recorded and resolved under a regular PM program. Areas such as flashing were particularly important as industry has identified improper flashing as the cause of approximately 80% of roofing issues resulting in extensive repair or roof replacement [11]. Altogether, this evidence suggested that the current state of the USAF rooftop PM program was deficient and in need of revitalization.

Acknowledging the presence of the public works structures enlisted career field, Air Force Specialty Code (AFSC) 3E3X1, as 10th on the Air Force Personnel Center's (AFPC) stressed career field list, team members realized structures personnel were in high operational demand to build and maintain facilities at home and abroad. Structures personnel were responsible for assessing roof systems, however, due to high deployment rates there was very little continuity for personnel to continue to fulfill their traditional roof maintenance responsibilities. Logically, civilian workforce structures personnel were overly tasked with filling in for enlisted forces to meet all structural maintenance requirements on non-warfighting bases. Further compounding this issue, personnel charged with maintaining over 10 different roof systems within the sample set were not necessarily trained on every roof system or variation. These facts established a feasible line of reasoning why maintenance on roofing systems may not be completed throughout the sample set.

Using unit cost figures from across industry, the losses associated with a failure to employ preventive roof maintenance programs stand at $0.10 to $0.15 per square foot per year. Figure 1 showed a prediction of roof losses [12]:

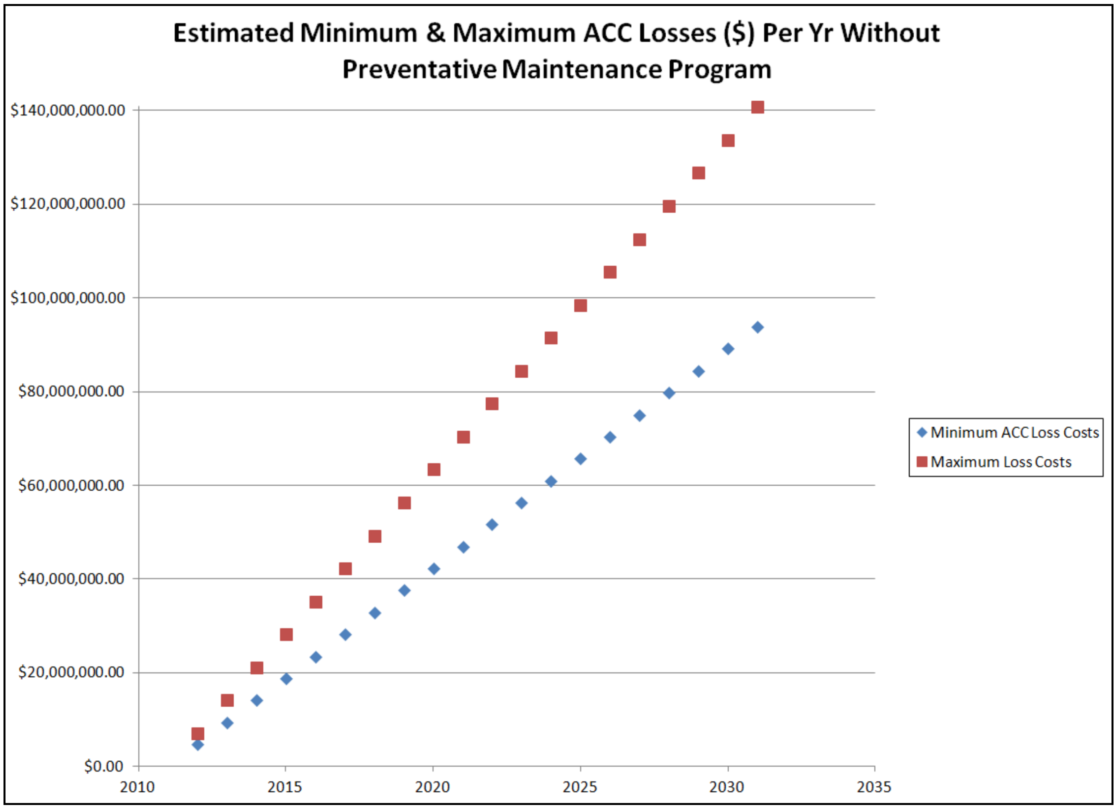


Figure 1. Estimate Minimum & Maximum Losses Per Year Without PM Program

Evidence from the analysis suggested that annual losses associated with the current direction of the sample's maintenance program would continue to rise exorbitantly over the next 20 years escalating to between $90 and $141 million dollars in the year 2031 [12]. The annual costs associated with maintaining an active PM program of any level within the sample were also determined with industry figures to be more constant. Figure 2 below showed the annual costs from three different levels of PM programs as far less than the losses from lack of maintenance [13].

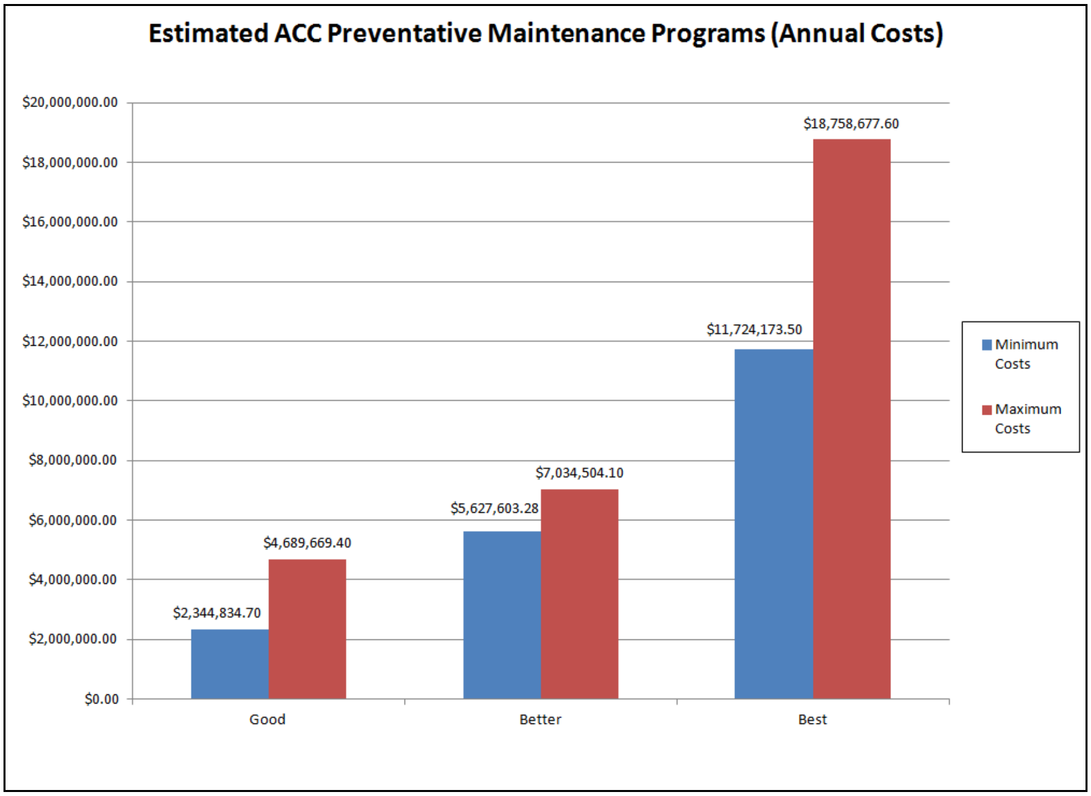


Figure 2. Estimated Annual Cost of Varying PM Program Levels

The good category included the most basic maintenance procedures such as keeping roof drains free of debris and an inspection once per year. Better maintenance programs included two inspections per year, along with minor repairs being completed and photo-documented. Inspection reports were kept on file and logs of repairs were mapped out. Lastly, the best maintenance programs completed two to four annual inspections with additional moisture scans to check for leaks. Inspection records were again updated, and a database was created for reference. Note that researchers confirmed that the better category of PM policies in Figure 3 best fulfilled USAF requirements. Overall, the results of this stage of the analysis supported the idea that roofs were financial assets and PM programs were a necessity in a time of shrinking budgets when roof replacement costs average $6 to $20 per square foot [14]. An example of the benefits of PM programs beyond mere cost figures included the work of USAF Academy engineering personnel outside of the sample set. Discovered in consultations with Roof Express personnel, USAF Academy engineering personnel reached great success with their PM programs sharply raising rooftop RCS scores across their installation. Their success coupled with evidence from the analysis clearly established that PM programs have their merits, cut costs, and maximize roof life.

With the sample's roofing inventory examined, the lack of strength in the PM program exposed, and the approximate cost differences from strengthening the program formulated, team members propose that strategic sourcing is the most viable solution to revitalizing both the sample's and all USAF rooftop PM programs at this time. Strategic sourcing can push service improvements and maximize cost reductions across all installations [4]. Installation engineers currently tend to employ reactionary procedures with no time to institute strategic initiatives aimed at reducing large scale problem areas such as flashing issues. A perfect example of this would be a strategic sourcing contractor's ability to examine and repair the 566 leaks recorded in the sample set for approximately $707,500 [3]. While providing USAF engineers with knowledge of these leak issues, a contractor could assist engineering officials in instituting policy to avoid similar problems in the future at all locations. Strategic sourcing maintenance streamlines program costs, reporting, and other administrative issues freeing USAF personnel to concentrate in other heavily needed areas. It also provides added control, convenience, responsiveness, and fully certified experts in all roof system maintenance processes [4].

Private commercial organizations such J. C. Penny and EcKerd Corporation, still in business today, have had success using the information strategic sourcing provides to make informed decisions about their roofing assets [15]. Even certain U.S. city and county governments have moved in this direction due to similar staffing and expertise issues fearing ineffective repair procedures may result in higher long term costs. Though strategic sourcing of rooftop maintenance has its merits, it is important to realize it also must be coupled with thermal scans of rooftops every three to four years and a strong roofing database management program. Thermal scans, costing between $0.01 and $0.03 per square foot of rooftop space, can help target maintenance efforts around potential leak areas [16]. This cost in combination with the budget required to employ a rooftop database management program help better secure the benefits of establishing a solid PM program.

Nonetheless, the effort clearly established the idea that with respect to the case study under investigation, roof PM programs were in need of redevelopment. As one of the most active groups of bases, the analysis clearly supported the idea that problems within the ACC sample set were most likely mirrored throughout the rest of the Air Force. Team members first ascertained the scope of the rooftop sample size, system breakdowns, age, and condition states. Participants next examined defect trends to reveal the most common roofing system problems which should have been captured and eliminated during semi-annual mandated inspections. Acknowledging the heavy personnel requirements overseas and civilian over tasking, participants supported the idea that the issue could not be resolved within the current Department of Defense military and civilian force structure. When team members appraised the costs associated with continuing a reactive roof maintenance policy, savings associated with prevention clearly surpassed reactive costs according to industry standards. Researchers further demonstrated strategic sourcing as a viable solution to the USAF PM problem by admitting its cost savings, the expertise it brings, and its success with nationwide commercial retailers. Altogether, the work established the need to reinvigorate the USAF PM program and cement strategic sourcing for further investigation as a viable solution to the task.

4. Disclaimer

The views expressed in this article are those of the authors and do not reflect official policy or position of the United States Air Force, Department of Defense, or the United States Government.

III. Scholarly Article

Accepted to the Western Decision Sciences Institute Forty First Annual Meeting

(www.wdsinet.org/)

Re-engineering USAF Energy Retrofitting Endeavors

Abstract

As the largest energy consumer in the United States Department of Defense, the United States Air Force needed a new approach to meet both federal guidance, target over-consumers, and curtail existing facility energy usage against rising energy costs. Research efforts provided merit for the wide ranging applications of whole building retrofitting techniques against single system upgrades via modeling software simulations. Investigations into facility energy efficiency classification methodologies revealed different suggestions to identify efficiency allowing officials to channel funds more accurately to the facilities most in need of renovation.

1. Introduction

The United States Air Force (USAF) was the largest energy consumer in 2010 in the U.S. Department of Defense (DoD) consuming 64 percent of total DoD energy expenditures. In terms of costs, a total of $1.06 billion dollars, 12 percent of consumption, was associated with existing facility operations [6]. Released reports documented categories of consumption below in Figure 3.

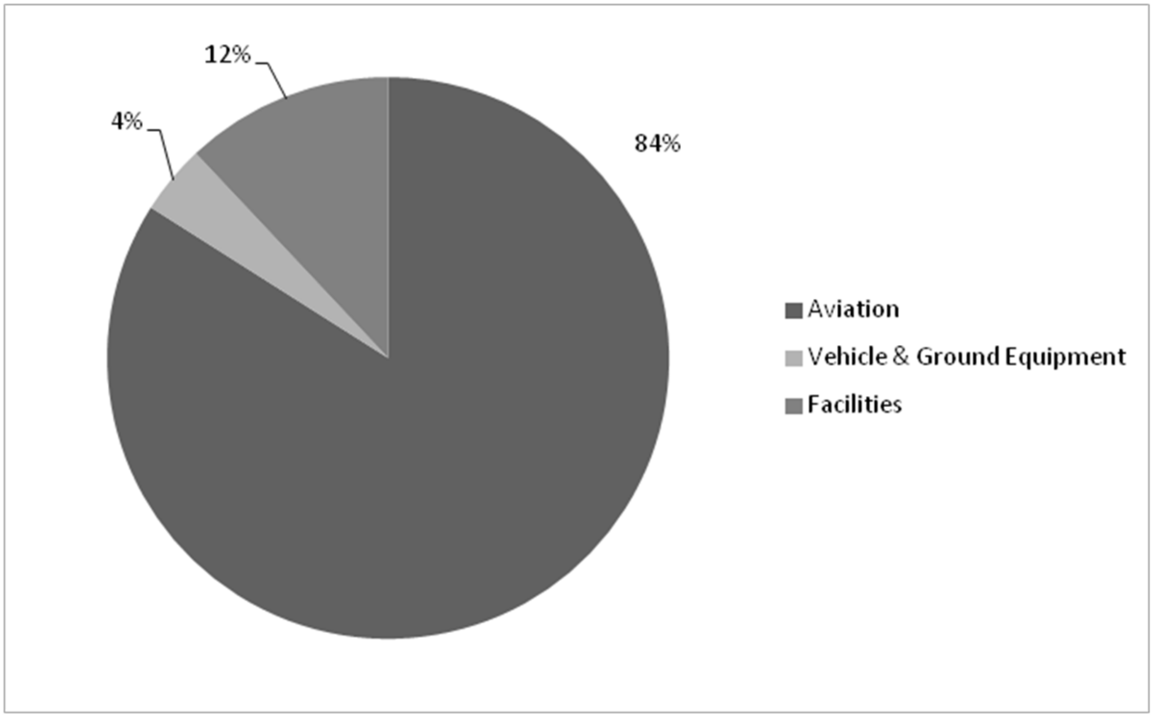


Figure 3. Air Force Energy Consumption

This figure coupled with reduction mandates and rising energy costs forced the USAF to begin aggressively searching for new energy conservation measures. Although, the USAF made significant gains in the reduction of its facility energy intensity, by cutting it by 30 percent between 1985 and 2005, energy costs have competed with reduction gains to surpass reduced consumption levels. Rising utilities costs grew between 2001 and 2007 by a total of 49 percent as an example. In response, the USAF needed an approach to meet both federal guidance, target over-consumers, and slash existing facility energy usage. A new approach was also essential to ensuring the proper funneling of energy dollars into the right facilities at the right times. By developing a classification methodology for facility efficiency and examining the whole building retrofitting techniques, researchers answered the question, should the USAF re-engineer its facility energy retrofitting program to maximize energy savings at lowest cost through a new facility efficiency classification methodology and whole building retrofitting techniques?

2. Background

Both federal and DoD guidance have forced USAF officials to increase their focus on facility energy efficiency [6]. Unfortunately, engineers cannot simply construct facilities to replace aging structures. Most older facilities were built before the advent of energy efficiency codes, and mandates for new facilities requiring energy efficiency would do little to change the environmental impact of previously constructed facilities [17]. New facilities dominated only three to four percent of the USAF physical plant in 2010 [6]. According to the USAF Energy Plan, released in 2010, existing older facilities were the primary source of energy reduction potential as new construction was restricted by low facility recapitalization rates [6]. Current projections translated this figure into a total of more than 58,047 facilities or a total of 537 million square feet as available for efficiency upgrades [18].

The USAF made strides to increase the efficiency of facilities by releasing the *Air Force Sustainable Design and Development (SDD) Policy* in 2007 and its *Air Force SDD Implementing Guidance* in 2011. However, it was crucial to remember where these documents focused their efforts. They provided additional challenges for engineers implementing policy on the installation level. Both documents addressed achieving Leadership in Energy and Environmental Design (LEED) Silver certification in new vertical construction projects and major renovations in existing facilities [19]. LEED facilities, focusing on a larger series of environmental goals, typically consume less than

25-30% of the energy of similar facilities on average [20]. The documents failed to provide a baseline for identifying underperforming facilities for LEED inspired renovations, and follow-on instructions on how to obtain mandated LEED energy points. Whole building techniques and a recommendation on a methodology for identifying facility energy efficiency provided the best solutions to these issues.

Considering industry research found that the energy use of existing facilities in the U.S. was attributed to 40% of its energy use, it was true that facility energy was a major factor in the energy use of the country and the Air Force [21]. The last quarter century resulted in a 16% increase in energy intensity in U.S. commercial facilities. These facts supported the idea that the business case for energy efficiency retrofits and the need to identify poor energy performance have increased with time [17]. Fearing the implementation of regulations to combat climate change, large property owners, such as the Department of Defense (DOD), have also recently considered the idea that it might be more cost effective to retrofit before all property owners prepare to meet standards [22]. Enduring research, pushing retrofits, has further established that property owners faced less risk in terms of exposure to changing utility costs while preserving savings for other endeavors. Other studies have indicated that efficiency efforts can enable 8-9% reductions in overall facility operating costs, and benefits can be extrapolated to $50 to $70 per square foot of facility space [23]. The benefits of a concentration in facility efficiency upgrades were seen as obvious.

Whole building retrofits involved upgrades to the energy systems of an entire facility, rather than a focus on any single one. This retrofitting approach offered an ideal way maximize energy savings on current facilities. It also provided better guidance to personnel and met guidelines set forth by US law. With research indicating most office buildings contain a potential for at least 20%-30% in cost-effective energy savings projects, the potential existed to realize expanded savings with these techniques in USAF facilities as they offer 20% to 50% in utility reduction potential [24]. However, researchers asked whether energy facility modeling software could prove itself in developing the right combination of energy efficiency upgrades to maximize savings from these techniques in a cost effective way. Confirming the application of facility energy usage modeling to document these savings, several industry simulations also documented an average of 20% savings when developing the right combination of energy efficiency conservation measures (ECMs) for certain facility types [25]. These facts documented the reasoning for concentrating on existing facilities, using whole building techniques, and employing energy modeling software to explore potential savings.

Lastly, in examining the procedure by which the Air Force classifies a facility's energy efficiency to benchmark it against other facilities, the question existed whether the process currently employed within the USAF to classify the efficiency of facilities was correct. If not, suggestions were needed to identify other alternatives. Additional answers were necessary to determine if energy efficiency terms could easily be applied to assist the Air Force in properly channeling funds to meet organizational goals. Exploration into the process of facility energy efficiency identification would empower engineering personnel to concentrate their efforts in crucial areas of existing facility inventories. By ensuring officials employed the best approach to identify energy efficiency, researchers helped leaders use the best metrics to make their decisions.

3. Research

3.1 Problem Statement

The objective of this research effort was to support re-structuring the USAF facility retrofitting program through whole building retrofitting techniques and a new term to categorize a facility energy efficiency. By establishing the benefits of these approaches, research bolstered the idea that a whole asset-centric focus far surpassed single system efficiency upgrades. Researchers also found the maximum level of accuracy for facility models in their calibration of baseline facility models for current operations.

The following list was a series of specific research and investigative questions used to guide this research effort:

1) What current guidelines, mandates, and goals do Energy Managers (EMs) and Resource Efficiency Managers (REMs) operate under to pursue facility energy savings?
2) What are whole buildings retrofit techniques and how do they compare to current USAF retrofitting methodologies?
3) What is the best term-backed program to identify a facility's energy efficiency?
4) How accurate can facility energy models be made?

Research question one defined the primary historical background on the problem of investigation seeking to expose the major legislation, guidelines, and goals of federal energy programs. Most USAF public works officials grapple with creating and completing facility energy projects. Question two was intended to address the overall benefits of whole building techniques and prove their merit to existing operations. Question three analyzed the best term-backed program to identify facility efficiency and its tangible benefits to channeling capital investment dollars. Lastly, question four, a by-product of the overall research, examined the maximum accuracy of energy models.

3.2 Methodology

Research efforts were segmented to assist in answering the effort's main research questions. To analyze the effect of whole building retrofitting techniques, research utilized facility energy modeling software to provide a scientific foundation for any achieved facility energy savings. The process of determining a classification methodology for facility efficiency was analyzed via a decision making technique called a Choosing By Advantages analysis [26]. This technique avoided the typical problems associated with unsound methods. It involved decision makers comparing different alternative courses of action by examining the advantages between alternatives rather than individual attributes. This methodology avoided the double counting associated with other approaches. This process also allowed individuals to see the most positive outcomes from an alternative. Both of these methodologies were used in industry and the scientific community in similar research endeavors.

Modeling efforts involved the application of eQuest, US Department of Energy (DOE) energy modeling software, to generate baseline and retrofitted facility models to provide the evidence of anticipated savings. Baseline models were revised through comparison to existing meter data provided by target installations. Afterwards, retrofitted facility models were developed via the guidance from a series of whole building retrofit techniques established in research and industry. By approaching models in this manner, efforts ensured maximum energy savings. The metrics of total annual electrical usage, annual natural gas usage, combined energy usage, project energy savings, upgrade project costs, return on investment, and payback period were employed in the analysis of energy. These metrics best illuminated the potential for savings, and helped measure accuracy of baseline models. Research evaluated existing computer aided design facility plans, project specifications, and meter data collected from target office type facilities on four different Air Force installations across the United States to generate models. Office-type facilities were selected to enhance the extrapolation of any future experimental results to a wider level. Target installations included facilities located on the following air force bases (AFBs): Davis-Monthan AFB (DMAFB), Ellsworth AFB (EAFB), Mountain Home AFB (MHAFB), and Wright-Patterson AFB (WPAFB). Installations were chosen as a result of recommendations from headquarters energy experts on the basis of installations with the most accurate utility data.

Targeted facilities selected for modeling were chosen through an in-depth examination of metered energy usage, structural names, and maps from all four locations. Meter data was analyzed for facilities in a period of no less than one year and reviewed to determine potential issues. A meter data issue identification scheme was required for this part of the analysis. In addition, on three of the four target installations, only facilities accounting for both total electrical and natural gas usage with fully functioning meters were included in the study. On the fourth base, WPAFB, only facilities meeting initial office type criteria were considered for study as their employment of centralized heat plant technology was not accounted for in utility meter readings. Estimations from heating factors per square foot of facility space were used to account for heating loads on WPAFB.

To answer the question of what term best exists to encompass USAF facility energy efficiency, researchers investigated both how private industry and foreign governments establish facility efficiency. Participants then compared these methods to existing USAF approaches to measuring the factor. To this end, research compared the four leading industry efficiency benchmarking programs to include: the European Performance Buildings Directive (EPBD), Energy Performance Index (EPI), Energy Star Portfolio program, and the ASHRAE Building Energy Quotient (BEQ) program. Although the initial portion of this effort was built upon an intense literature review, the actual comparison was executed via a Choosing By Advantages analysis. This alternative decision making technique served to prevent the omission of relevant facts, distortion of individual viewpoints, and double counting of advantages [26].

4. Disclaimer

The views expressed in this article are those of the authors and do not reflect official policy or position of the United States Air Force, Department of Defense, or the United States Government.

IV. Scholarly Article

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Synergy in Existing Building Retrofitting and Operations

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Abstract

As the largest energy consumer in the Department of Defense (DoD), the United States Air Force (USAF) needs a new approach to meet federal energy reduction guidance, and curtail existing facility energy usage against rising costs. Research efforts provided merit for the wide ranging applications of whole building retrofitting techniques in comparison to single system upgrades via eQuest, a U.S. Department of Energy (DOE) program, energy modeling software simulations. Accuracy of models was established via calculations of each model's mean absolute percent error, coefficient of variation of root mean square error, and normalized mean bias error (NMBE). The metrics of coefficient of variation of root mean square error and normalized mean bias error were used at the project's completion to validate models to American Society of Heating, Refrigeration, and Air Conditioning Engineer standards. While not all models met American Society of Heating, Refrigeration, and Air Conditioning Engineer standards, most case studies met pre-established mean absolute percent error criteria. Overall, results clearly support the need for further investigation into whole building retrofitting techniques and demonstrate whole building retrofits can generate at maximum between approximately 20% to 50% in annual energy savings. Electrical utility savings were the primary energy area of consideration for the study.

Keywords

eQuest

whole building retrofits

retrofits

deep energy retrofits

energy modeling

model accuracy

1. Introduction

The United States Air Force (USAF) is the largest energy consumer in the U.S. Department of Defense (DoD) consuming 64% of total DoD energy expenditures [27]. In terms of costs, a total of $1.06 billion dollars, 12 % of consumption, is associated with existing facility operations [6]. Released reports document the categorical breakdown of energy consumption below in Figure 4:

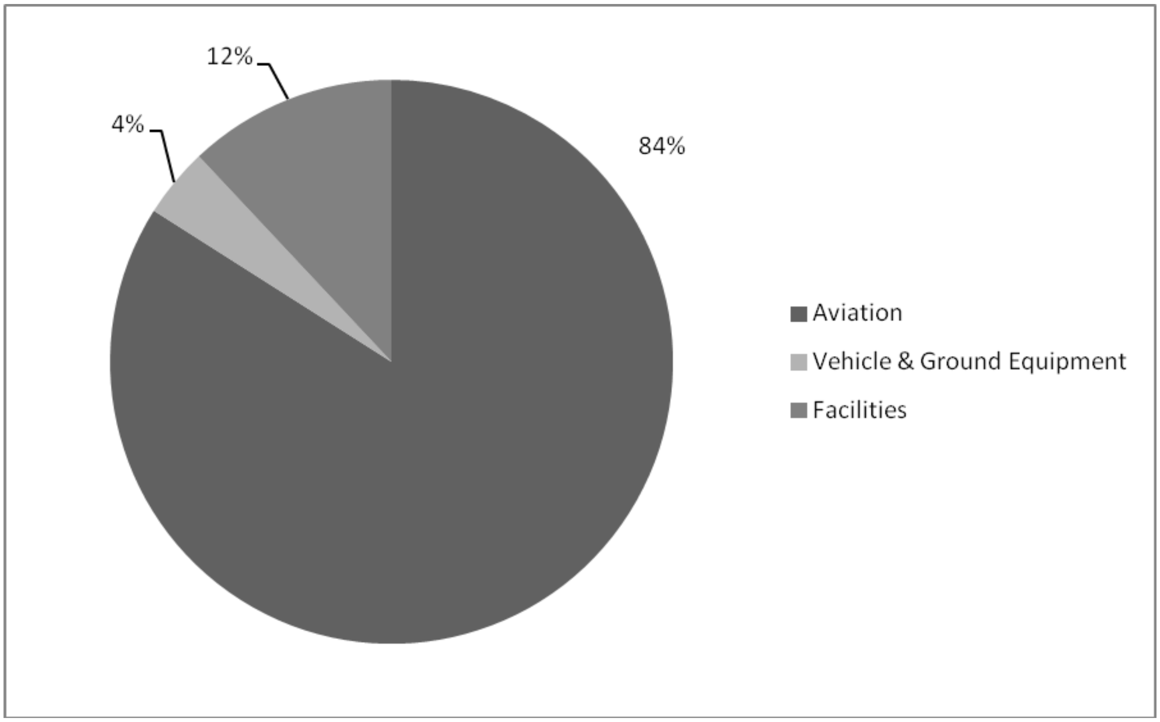


Figure 4. Air Force Energy Consumption

While USAF officials have met every federal goal related to the reduction of facility energy use since 1975, there is speculation that it will be harder to achieve the current goal established by the Energy Independence and Security Act (EISA) of 2007 which pushes reduction levels to 60% of a 1975 Air Force baseline. Energy costs have also competed with reduction gains to eliminate past successes. Between 2001 and 2007, rising utilities costs grew by a total of 49% in cost. With the expected fiscal constraints of the next two decades, research into whole building energy efficiency retrofitting techniques is pivotal to maximizing energy savings in comparison with existing USAF single system retrofit approaches. Holistic renovations ensure the proper funneling of dollars into the right facility projects to maximize the synergy in efficiency which can be achieved by upgrading an entire facility at once. By this, researchers suggest that whole building upgrades offer additional energy savings beyond that of single system approaches through their maximization of the dynamic interplay between systems.

1.1 Background

1.1.1 Whole Building Retrofits

A whole building energy retrofit offers an ideal way maximize energy savings on USAF facilities. Under the methodology, buildings are systems [28]. The technique recognizes how efficiency gains in some areas can have a direct impact on other facility systems. By optimizing this interrelation, small changes in a facility systems can flow into larger savings. A whole building or deep energy retrofit is defined as a efficiency retrofit that uses enhanced design tactics to improve overall facility efficiency and produce larger savings than conventional approaches [29]. The design process traditionally saves approximately 50% in annual energy costs, but this is not a universal standard. There are major considerations for the process involving proper timing, advanced design principles, the application of energy modeling software, facility audits, life cycle cost analysis, and metering to verify savings [28].

1.1.2 Costs & Opportunities

Air Force officials recognize that the opportunities to cut their energy intensity, energy usage per square foot, in new construction are limited by several factors [6]. Facilities infrastructure for the military has a extremely low recapitalization rate. New facilities typically also only dominate three to four percent of the USAF physical plant. As such, officials currently speculate that at least 22% of their energy intensity reductions to meet goals will originate in existing infrastructure. Most existing older facilities were built before the advent of energy efficiency codes, therefore mandates requiring efficiency in new facilities can do little to change the environmental impact of the built environment [17]. A positive aspect of this acknowledgement is that there is a well funded energy project program for Fiscal Year 2010-2015. There are overall funds to make strides in energy reduction for the 58, 047 facilities or 537 million square feet of space currently in the USAF real property inventory [6, 18]. While past investments project $2.2 billion in cost savings through the year 2015, different ideas are necessary to meet both the future fiscal constraints and goals of the military.

An example of these costs and opportunities in existing buildings is seen in the 50% of existing U.S. building stock that is due for retrofit over the next three decades [29]. That number translates into 30% of the entire U.S. commercial building stock portfolio being ripe for renovation. According to other success stories, a need for renovation is key in determining prime candidates for whole building retrofits. Drawing a analogy to the USAF real estate portfolio, engineers must imagine that there is a similar opportunity in their own building stock [6, 27]. In terms of cost, the National Academy of

Science currently speculates that the U.S. can cut 28% of its building energy consumption cost effectively by the year by 2020 and 4% more by 2030 [29]. Similar cost effective energy savings figures are also seen in European studies for office buildings with larger reductions for larger retrofit projects [24]. Unfortunately, these savings are not always easily obtainable [29]. They are predicted to require certain changes in current design, construction, and renovation processes to achieve maximum benefits. Integrative design under a whole building renovation might be the best solution.

1.1.3 Obstacles

Barriers to retrofitting exist despite the large opportunities for investment. According to the Rocky Mountain Institute (RMI), the main obstacles to increasing the prevalence of retrofits include: project financing, risk, business case analysis, first cost, split incentives, design, and tenant demand [30]. Many of these factors are seen in both the public and private sectors. An example of the financing issue is found in the idea that both financial institutions and building owners require a proof of similar successful projects before investing. This is to limit their own financial risks. Unfortunately, successful case studies are not as discussed due to owners being unwilling to share information. Further obstacles arise as most energy efficiency projects fail to provide hard evidence in terms of documented utility consumption records. These facts often result in owners investing in only the projects that are low risk, pay for themselves, and return small savings. Most building owners presently only look for Leadership in Energy and Environmental Design (LEED) program certification and smaller scale energy savings goals. Owners also view the costs of determining energy efficiency opportunities as too high. These individuals operate on a fundamental misunderstanding of integrative design and the synergies which can be created by a detailed review up front. By understanding the process, interested parties can see the potential to drastically cut the energy usage in their facilities. Lastly, a final example includes the budget required for these progressive energy modeling processes. These costly tools essentially require personnel experienced in their application to compound the benefits of unseen savings in facilities. Often times building the right experience levels requires a larger budget.

1.1.4 Benefits Beyond Energy

Deeper retrofits offer other tangible benefits to the USAF. These include: increases in building value, public relations opportunities, reduced risk, productivity, fewer sick days, higher retention rates, and lessons on integrated energy efficiency measured (EEMs) for their entire real estate portfolio [29, 31]. Several of these areas emphasize comfort for occupants and a better environmental public image. Some studies indicate that a whole building retrofit which focuses on occupant comfort and their comfort levels can actually add value in the space for building tenants due to productivity boosts.

For health benefits, a recent review of a 28-story facility renovation in Australia, obtaining 52% in energy savings, lauds a 21 to 24% decrease in reported cases of colds and flu for employees [29, 31]. These retrofits also provide lower maintenance costs and decrease liability for health issues linked to the work place. Retrofits proactively address greenhouse gas emission reductions through efficiency savings. Additionally, if greenhouse gas legislation is passed by the government, owners have insurance against the legislation's impact to energy costs. Finally, lessons provided by retrofits are useful for portfolio level energy reduction [29]. Lessons of integrated EEMs can apply for similar facility types. Using this information, Air Force officials could strategically implement retrofits in similar facility types on bases across the country.

1. 1.5 Existing Research

1.1.5.1 Initial Energy Efficiency Building Design

A notable application of energy modeling software and holistic design concepts was recently published in 2011 describing a team's efforts to pair software tools with data mining technology for the design of a Community Service Station (CESS) facility [32]. Data mining was a process which utilized machine learning and statistics to uncover patterns or concepts from datasets. Software tools for the project included the eQuest 3.63 software package and Autodesk Green Building Studio. The approach was used to simplify the large amounts of data generated from the modeling process and generate savings. Notable results for the effort included the team's discovery of the relevance of individual facility elements for overall efficiency. For example, the team determined for roofing insulation thickness was key in determining a roof's impact on energy usage. Air space in a roof's construction was also considered as important as insulation. For walls, insulation, material makeup, and airspace were the three largest factors in determining a wall's efficiency. Overall, as would be expected, HVAC options were proven to have the largest effect on annual facility operating costs in comparison to facility orientation which had the smallest impact. It is with analytical tools like these that project designers were able to make a facility more efficient and lower overall lifecycle operating costs.

1.1.5.2 Existing Energy Efficiency Building Retrofits- Hotels

Simulation technology has even been applied in the commercial hotel industry to examine the potential for efficiency improvement [25]. In 1996, European researchers released findings of their assessment of the energy efficiency retrofitting potential of 158 Hellenic hotels. The effort was a result of work to establish efficiency guidelines for future buildings and successful renovations. Researchers examined various energy conservation measures based upon the consumption in each part of the hotels. Major areas of concern included: facility operations and maintenance, alterations to building and building subsystems, and replacement of obsolete equipment.

The team's efforts uncovered several projects and energy efficiency gains which could be used in facilities for maximum savings in hotel type facilities. Researchers determined that projects adding the proper amount of thermal insulation had a payback period of 6-8 years. For windows, by employing double glazed windows and removing thermal bridges, for a savings of 6.1% in thermal energy, researchers demonstrated projects with payback periods of 4-7 years. Other discoveries included showing certain heating system efficiency upgrades could save 13% in energy for heating operations, while facility shading could save up to 30% of a facility's cooling load. Lastly, some final measures included the simulation of low heat emission fluorescent lamps and the use of ceiling fans to obtain a total 72% reduction in the cooling load of their case study facilities.

Altogether, the biggest energy take away from this effort is the 20% savings in overall energy conservation which could be achieved in hotels through the employment of various efficiency measures. While the work does not directly support whole building retrofits, it does establish that energy modeling software has been employed on other occasions to investigate energy savings potential for facilities for large paybacks. The modeling software works, but has to be applied carefully with the right input data.

1.1.5.3 Existing Facility Retrofits – Offices & Climates

Other work to expand the merits of energy modeling and the potential for energy reduction in office building types was released in 2002 by European researchers [24]. Team members assessed potential retrofit efficiency savings through modeling for various administrative building types in different climate regions across Europe. Energy efficiency measures in the study included upgrades of facility envelope, active and passive HVAC components, and building lighting. The result of the work was discoveries of common trends in the energy upgrade performance for certain facilities and that an average a cost-effective energy savings of 20-30% could be achieved in office buildings. The project predicted even greater savings for larger scale renovations. Despite the smaller scale renovations simulated, it is observations and studies like these which could prove vital to the Air Force in reducing their energy burden over the next decade and demonstrate the validity of modeling to investigate retrofit savings.

1.1.6 Modeling & Modeling Software

1.1.6.1 Issues in Energy Modeling

Although, the design principles and modeling techniques required for whole building retrofits have seen success, several issues still exist in the modeling industry that demonstrate barriers to the acceptance and use of energy models to validate projects.

These issues include: a perceived lack of credibility in results, limited critical thinking, a lack of practitioners, and low demand for modeling services [33]. Often the most important, the lack of perceived credibility is brought by low quality results, a lack of reproducibility, misguided expectations, and difficulty in assessing energy modeler backgrounds. However, these issues are not insurmountable. Organizations like the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) constantly work to establish guidelines for the accuracy of modeling results and certifications to ensure modelers are properly qualified for the services they perform [34].

1.1.6.2 Model Accuracy

There are a number of ways to measure the discrepancies for modeled processes to measured data. For facility models, the best statistical factors for measuring the accuracy for this investigation are the mean absolute percent error (MAPE) (1), coefficient of variation of the root mean square error (CWRMSE) (2), and the normalized mean bias error (NMBE) (3) for each model. MAPE is a accuracy measure for average error in a series most often expressed as a percentage [35]. In comparison, CVRMSE discusses the variation in overall pattern of the data, and NMBE produces a depiction of the variance between mean recorded and predicted data points [34]. Both NMBE and CVRMSE are also prescribed by ASHRAE guidelines for the specific purpose of ensuring accuracy in facility models. ASHRAE recommends that NMBE be within 5% of meter data, while CVRMSE should be within 15% of meter data. The formulas for all three statistical metrics are as follows in Equation 1,2, and 3 [35, 36]:

$$\text{MAPE} = \frac{1}{n}\sum_{t=1}^{n}\left(\frac{At-Ft}{At}\right) \qquad (1)$$

where

At= Actual Value

Ft = Forecast Value

$$\text{CVRMSE} = 100 * \frac{\frac{\sqrt{\sum(yi-ypre)^2}}{n-1}}{yavg} \qquad (2)$$

where

y = measured value

ypre = model predicted value

yavg = mean value of measured data

$$\text{NMBE} = 100 * \frac{\sum(yi-ypre)}{(n-p)*yavg} \qquad (3)$$

where

n = number of samples

p = P-Values (P=1)

1.1.6.3 eQuest Software

EQuest is an energy modeling software package that provides facility stakeholders with the ability to conduct energy performance analysis on a whole facility. Though its primary user is anyone involved in the design or operations of a facility, program wizards do allow some individuals with virtually no experience in energy analysis to participate in retrofitting endeavors. Strengths of the software include the capability to review the performance of entire facilities through design, and allow the energy performance evaluation of multiple design concepts. The program also allows the analysis of critical building system interactions to determine the full impact of design decisions. Limitations of the software include the inability to support Standard International (SI) units, and simplifications of ground coupled and natural ventilation models.

1.2 Problem Statement

Within the USAF energy program, the question exists as to is whole building retrofitting a better way to maximize the effect of Air Force energy funding under the expected fiscal constraints of the next decade? Research will establish the idea that implementing whole building retrofits on existing USAF building stock yields far more energy savings then a measured approach, and the advanced design practices required to facilitate the process result in a major return of energy savings for facility operations. Modeling software will also be established as an accurate predictor of holistic savings.

1.3 Research Objectives

The objective of this research effort is to provide support for the application of whole building retrofitting techniques on facilities in the USAF through their application in six different cases studies for facilities located on Wright Patterson Air Force Base (WPAFB) in Dayton, Ohio. The following is a list of specific research questions and sub-questions to guide this research:

1) What are whole building retrofit techniques?

    1.1: How do they compare to single system approaches?

1.2: What kind of synergy can be expected from a whole building perspective?

2) Can facility energy modeling software be used to simulate single systems and whole building retrofitting techniques?

2.1: How accurate can an energy model come to reality?

3) Can whole building retrofitting techniques be successfully applied to existing USAF building stock to reap major savings?

Question 1 and its sub-objectives drive researchers to investigate further background on whole building retrofits and whether they would provide any tangible benefit to the Air Force should they become more main stream. Question 2 and the sub-parts support the project methodology and provide vital background on whether any savings reported the project can be considered accurate. Lastly, Question 3 demonstrates the techniques work in existing USAF building stock.

2. Materials and Methods

2.1 Methodology

2.1.1 Case Study Selection

Research for this effort began by reviewing facility and utility meter data from several Air Force Installations across the nation. Researchers selected Wright-Patterson AFB (WPAFB) in Dayton, Ohio as the primary installation for investigation and case study selection. The location had superior meter data and facility plan libraries to aid the process of model development. The installation also was co-located with the main research institution for the study, and allowed the best chance for on location facility audits and walkthroughs. Researchers would also be allowed to conduct onsite consultations with facility occupants and operations personnel charged with maintaining facility HVAC controls. Consequently, this meant that all case studies would be subjected to the weather conditions of the Ohio Valley Central U.S. climatic region [37].

A total of six different facility case studies were selected to examine the effect of implementing a variety of single system and whole building retrofitting techniques. Six facilities were chosen on the basis of data availability and project time constraints. The two main factors of selection were data availability and the representative nature of the facility as a common USAF facility type. These criteria increased the chances of successful model construction and the extrapolation of project results. Before study inclusion, existing site conditions were assessed via on-site inspections, interviews, and facility plan analysis. Key documents for model development were determined to be: exterior and interior wall constructions, foundation details, roofing breakouts, schedules, HVAC layouts, and lighting system schematics. This information was obtained as a result of lessons learned from the project's first model construction efforts. Other important areas included walkthrough access to the facility and knowledge of its HVAC control systems. HVAC control systems familiarization was developed via consultations with CE experts and WPAFB control personnel. Facility types included buildings geared to administrative functions, academic/research operations, medical care, and child care. The facilities selected for the study are described below in Table 3:

Table 3. Case Study Descriptions

Case Study Selections	
Facility Number	Description
Building 20015	▪ Purpose: AFRL HQ Operations ▪ Facility Type: Administrative ▪ Area: 34,427 Sq Ft (3 Levels) ▪ Hrs: Mon-Fri(0700-1800 Hrs) ▪ Special Note: Contains Telephone Switch ▪ Built Date - 1941-1942
Building 20653	▪ Purpose: Materials Lab HQ ▪ Facility Type: Administrative ▪ Area: 17,269 Sq Ft (5 Levels) ▪ Hrs: Mon-Fri(0700-1800 Hrs) ▪ Special Note: Run off of a centralized chiller plant for lab complex Built Date - 1971-1972
Building 20646	▪ Purpose: AFIT Building ▪ Facility Type: Academic/Research ▪ Area: 17,949 Sq Ft (3 Levels) ▪ Hrs: Mon-Fri(0700-1700 Hrs) ▪ Special Note: LEED Silver Certified ▪ Built Date - 2006-2007
Building 20643	▪ Purpose: Civil Engineer & Services School ▪ Facility Type: Academic ▪ Area: 20,010 Sq Ft (3 Levels) ▪ Hrs: Mon-Fri(0700-1700 Hrs) ▪ Special Note: N/A ▪ Built Date - 1992-1993
Building 20675	▪ Purpose: Occupational Medicine ▪ Facility Type: Medical Care ▪ Area: 17,475 Sq Ft (2 Levels) ▪ Hrs: Mon-Fri(0700-1600 Hrs) ▪ Special Note: Contains X-Ray Room ▪ Built Date - 2001-2002
Building 20630	▪ Purpose: Child Care/Development ▪ Facility Type: Child Care ▪ Area: 46,979 Sq Ft (1 Levels) ▪ Hrs: Mon-Fri(0400-1800 Hrs) Sat-Sun (0700-1700 Hrs)

	▪ Special Note: Complex Building Geometry ▪ Built Date - 1999-2000

2.1.2 Model Creation/Calibration

2.1.2.1 Major Assumptions

Before undertaking the modeling process, researchers needed to deal with the fact that a majority of the facilities for WPAFB were uniformly fed during the winter months of the year by a centralized coal fired steam producing heat plant. Per discussions with industry experts, researchers elected to use the dynamic defaults embedded in eQuest to setup a standard boiler to act in place of the centralized plant [38]. Team members selected a forced draft steam boiler as the standard boiler for every facility supplied by the heat plant. Heating system sizing was established via eQuest automation procedures.

2.1.2.2 Software Tools Required

For model development, researchers utilized four main software tools. AUTOCAD 2012 and Bentley Viewer (2004 Edition) were utilized for viewing drawing (DWG) and design (DGN) file types in facility plans residing within the WPAFB library. These selections were mandatory given the existing file type setup of the plan library at WPAFB. However, the use of AUTOCAD 2012 was also expanded to include assisting in space measurements required for audit calculations for model development. This was determined was done to reduce the time required for the calculation processes. EQuest software was explicitly chosen for modeling purposes due to its widespread acceptance in the federal government as a product of the DOE, its dynamic defaults to simplify user inputs, and the development wizards it offered inexperienced users. Defaults were composed of information supported by well recognized national standards such as ASHRAE 90.1. These characteristics made it a prime candidate for more active deployment in the federal government, along with minimizing any extra training required for software use. Lastly, Microsoft Excel 2007 was utilized for the purpose of calibrating and comparing model run results. It was selected by researchers for its graphical chart capabilities.

2.1.2.3 Creation Process

All site conditions of facilities were assessed via onsite inspections, consultations, and facility plans analysis. This information was used in the model construction process. A simplified view of the effort was laid out as follows:

- Project, Site, and Utility Data
- Building Footprint
- Building Envelope (Construction/Windows/Doors)
- Building Operations Schedule
- Space Allocation/Zone Group Breakouts
- Building Loads and Profiles
- HVAC/Chilled Water/Hot Water/Domestic Hot Water Systems Makeup

Researchers began the development process with inputs describing the facility's weather and the annual time period of analysis. Both the weather file for the Dayton, Ohio area and an analysis period of 2010 were selected for each model. The year 2010 was chosen due to the fact that meter data provided by WPAFB for the study was for the same year.

Model creation continued as researchers traced out the facility footprint of each building and its other levels. Construction details were then input based upon facility plans for the building envelope's material makeup and construction. As part of the building envelope, researchers also built and sited doors and windows in the program. This process occurred via the eQuest custom window/door placement option the program has as an internal component. Users could have gone with automated placement based upon the percentage of facility envelope each item type occupied, but the effect was the same. Customization adds an element of model believability for users as a graphical three dimensional model is constructed in the program.

After the initial envelopes were completed, users then proceeded to input facility operations schedules. This information was gathered from a combination of consultations with building occupants and facility controls personnel. Although occupants alone could have captured the generalized facility schedule, operations personnel responsible for running HVAC systems were thought to have a more intimate knowledge of each facility's HVAC schedule. Researchers then moved into the space audit stage of the project confirming the purpose of each area in the facilities. Areas with similar purposes were grouped according to eQuest space classification categories. These percentages for space purposes were known to be important in areas of the model where eQuest's dynamic defaults were used in place of user inputs. Some defaults, based upon ASHRAE criteria and other standards, were known to be directly linked to the function of the space. Square footage calculations for this process were made primarily in AUTOCAD to minimize audit onsite time and calculation requirements. After space audits, zone groups were assigned to areas sharing similar functions and HVAC feeds.

Researchers then targeted another round of facility audits to determine lighting and office equipment power densities, watts per square foot, by space use allocation. Facility plans and site inspections were used to verify equipment counts and wattages. Office equipment wattages were then re-verified via specification sheets or on the internet. As a good amount of office equipment products were found similar for the government, a generalized wattage scheme was established for all six facilities. Once wattages were confirmed, lighting and office equipment power densities were established for each area of the facilities. The remainder of the development process was completed through consultation of facility plans to construct facility HVAC, chilled water, and hot water systems. Inspections were used to verify onsite infrastructure where necessary.

2.1.2.4 Special Issues

Team members had difficulties in the model development of some facilities requiring certain assumptions to proceed forward. These issues were particularly present in the following facilities to include: Building 20015, Building 20675, and Building 20653. Additional assumptions were also required in some facilities to account for the effect of lighting and elevators. Specifically, both Building 20015 and Building 20675 had specialized equipment installed on their premises [22,32]. Building 20015 had also experienced a large number of retrofits since its construction increasing the difficulty of lighting audits. Furthermore, Building 20653 was run off a centralized chiller plant.

Lastly, accounting for elevator electrical consumption in all the facilities was challenging.

First, Building 20015 had a telephone switch installed in its premises. To account for the power usage, researchers assumed that the average base phone drew about 2 watts of power [39]. Therefore, serving a total of 25,000 people, the main telephone switch would draw approximately 50KWH handling all the telephone communications for base networks. This number was used in the remaining calculations for the office equipment and miscellaneous loads of the facility. In addition, the facility had also experienced a large number of retrofits since its construction which made lighting audits difficult. Considering the time constraints of the study, researchers concluded it was more convenient to assume the facility already meet ASHRAE 90.1 lighting standards. This was on the discovery of lighting upgrades being included in most of the facility renovations. Next, examining Building 20675, investigators discovered an x-ray room in the facility [40]. Using a cross section of available data on similar machines, researchers discovered that the x-ray room also would use approximately 50KWH in terms of electrical consumption.

Building 20653 required a different approach as it was run off of a centralized chilled water plant. Producing much more chilled water then the facility required, researchers knew it did not make sense to include the entire chilled water plant in the model. As such, upon observing that one of the chillers in the plant supplied almost as much chilled water as the facility would need, researchers elected to model that as the facility's sole supplier of chilled water. This was due to the loading similarities between the chiller and facility's cooling requirements. Lastly, to provide for elevator consumption requirements in facilities, researchers assumed they consumed approximately 5% of the total energy load in each facility [41]. This was accounted for in overall calculations.

2.1.2.5 Calibration Process

Model calibration was constant during and after baseline model development. Before accuracy was tested, baseline models were visually compared to existing meter data for facilities. Individual adjustments were made incrementally until baseline model annual profiles were similar to metered data. Again, it is important to note that researchers only calibrated electrical usage in their models. Unfortunately, as a centralized heat plant was used for most of the base without metering, there was nothing researchers could do to calibrate the heat energy employed by facilities in the study. The total calibration process is demonstrated below in Figure 5 for Building 20675:

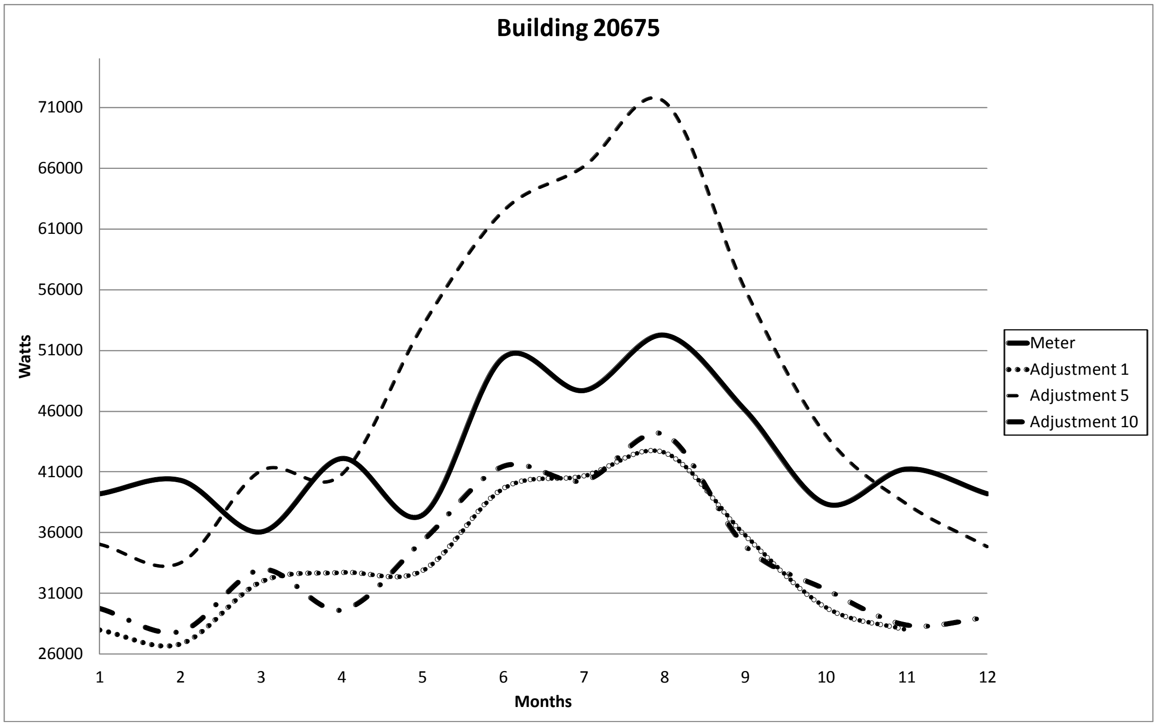


Figure 5. Building 20675 Calibration Process

After initial calibration, accuracy was checked via MAPE calculations. If MAPE values were determined to be less than 30%, a model was deemed sufficient to begin the retrofit creation and comparison process. MAPE was chosen as an accuracy tool due to its popularity as a check of error, and that it was recommended by Air Force statistics experts [36]. Two other final measures of accuracy were applied at the conclusion of the research effort to verify the suitability of the models under ASHRAE guidelines. It is noteworthy that ASHRAE standards were not the goal of the research. It was only a secondary check. Overall, accuracy checks were important to ensure consistent calibration.

2.1.3 Retrofit Initiation/Comparison

Retrofits were created in three different phases to include: single option change outs, single system retrofits, and whole building retrofits. Altogether, each step of the retrofit design process was designed to iteratively build on the last. Iteration and integration was used to push forward only the most effective options from each phase and show the best single system and whole building options.

First, in terms of single change outs, researchers investigated different materials, construction options, and equipment selections in five areas of their models to determine the best opportunities for electrical energy savings. These included building envelope, internal loads, HVAC systems, chilled water systems, and hot water systems. It should be noted that hot water systems were only investigated in terms of pump upgrades. Also, several thermostat operational strategies were tested under the HVAC section of this stage. Discovering the best change outs, team members then re-bundled options into single building system retrofit packages in eight building areas. These were geared to: roofing systems, exterior walls, floors, windows, internal loads, HVAC systems, chilled water systems, and hot water systems. After bundling, these packages were tested against baselines to determine savings. If a package failed to save money, it was left off from analysis. A whole buildings retrofit package was then built out of these single system bundles to determine the possible synergies which could arise from implementing all changes at once. Developing the combination, researchers then compared to whole building models to baselines to determine savings. Overall, the research was completed when investigators compared saving possibilities between their single and whole building retrofit packages.

2.1.3.1 Retrofit Initiation/Comparison-Specifics

Many single system retrofits were considered. For roofing, researchers examined finishing, insulation, and method of construction. In exterior walls, team members modeled the possible change out options for interior insulation. Researchers simulated different types of flooring installations to include carpet and tile on floors. Windows were reviewed in terms of glass category, glass type, frame, and different forms of shading. Lighting was examined in terms of expected power density for different area types under ASHRAE standards. Under HVAC systems, team members modeled different retrofit change strategies in thermostat management, fan power/control, and exhaust fans. The thermostat modeling process focused on the implementation of seven different set point strategies for buildings in the study [42-48]. This effort was implemented after researchers discovered a finding released by the California Energy Commission which estimated a 1% to 3% energy savings for every degree a thermostat was set above 72°F [44]. The thought was that the consideration of different set point strategies might yield similar savings. These were considered low cost or no cost retrofit possibilities for the purposes of the effort. In chilled water systems, researchers investigated for the most effective pumps, chiller types, efficiencies, and set point type approaches. Chiller efficiency changes were excluded from the rest of the process due to the high variability in maximum efficiency between different chiller types. Researchers simply wished to iterate through a range of efficiencies to gauge the area as a possibility of future research. Lastly, hot water systems were investigated for the most effective pumping approaches.

3. Results/Discussion

3.1 Accuracy

Model accuracy is important in analyzing facility retrofits. Baselines for every facility case study needed to be established and within a certain range of existing meter data for models to be considered correct. Researchers established model MAPE values of within 30% to be the primary indicator of accuracy for the effort. CVRMSE and NMBE statistical metrics were used as secondary checks on the models to determine their applications according to ASHRAE standards. A table describing the results of the analysis is listed below in Table 4:

Table 4. Baseline Model Accuracy

Building	MAPE	CVRMSE	NMBE
20675	19%	22%	21%
20646	2.3%	12%	4.8%
20643	-18%	19%	-18%
20653	-29%	36%	-29%
20630	50%	60%	58%
20015	22%	26%	25%

According to Table 4, all models with the exception of Building 20630 met pre-established MAPE criteria. Further analysis of the models revealed only Building 20646 of being capable of meeting ASHRAE standards. In looking at problems of meeting MAPE criteria, researchers took a closer look at the facility design of Building 20630. This review resulted in a determination that the gap in accuracy could be attributed to the facility's complex building geometry. Unfortunately, a review of the published literature on eQuest showed that building geometry can be difficult to model and require simplifications in facility construction [49]. These simplifications that eQuest required may explain why Building 20630 had accuracy issues.

Team members surmised that the ASHRAE accuracy gaps may be the result of limited data availability with only one year of meter data for calibration purposes. Five of six models met MAPE standards and the most accurate model met both ASHRAE and MAPE standards. Therefore, it was determined that the models positively depicted the facility trends over time. The next step was to investigate how single system retrofits affected facility energy.

3.2 Comparative Analysis

3.2.1 Percentage Improvement Ranges in Single Option Change Out Areas

Multiple single option change out scenarios were conducted for the project’s case studies. For each facility, the base model was altered to determine the effect a single change had on energy usage. For example, for building 20646, applying overhangs, reduced energy consumption between 0.23% and 0.95%. Table 5 below shows the results of these model simulations.

Table 5. Percentage Improvement Ranges From Baseline in Facility System Areas

Efficiency Savings Potential						
Building Numbers	**Building 20015**	**Building 20653**	**Building 20646**	**Building 20643**	**Building 20675**	**Building 20630**
BUILDING ENVELOPE						
ROOF						
Exterior Finish Color	0.03%-0.57%	0.01%-0.03%	0.17-0.67%	0.02%-0.05%	0.03%-0.56%	0.08%-0.8%
Exterior Insulation	N/A	0.01%-0.05%	0.03%-0.06%	0.01%-0.02%	0.01%-0.05%	0.08%-0.10%
Additional Insulation	N/A	0.01%-0.10%	N/A	N/A	0.03%	0.02%-0.07%
Construction Type	0.01%	0.03%-0.061%	0.003%-0.21%	0.001%	0.01%-0.05%	0.01%-0.09%
EXTERIOR WALL						
Interior Insulation	0.02%-0.08%	0.87%-1.5%	0.03%	N/A	0.08%-0.12%	N/A
GROUND FLOOR						
Interior Finish	0.19%-0.24%	0.02%-0.03%	0.24%-0.27%	0.01%-0.03%	0.09%	N/A
WINDOWS						
Glass Category	0.03%-3.5%	0.58%-0.91%	1.6%-3.6%	0.05%	0.04%-0.95%	0.53% to 2.7%
Glass Type	1.3%-1.5%	0.44%-0.54%	1.3%-1.5%	0.05%	0.44%-0.49%	2.3%-2.5%
Frame Type	0.02%-0.12%	0.01%-1.5%	0.05%-0.16%	0.001%-0.01%	0.01%-0.06%	2.3%-2.7%
Overhang	0.19%-0.95%	0.03%-0.05%	0.23%-0.95%	0.05%-0.06%	0.02%-0.18%	2.3%-2.4%
Fins	0.24%-0.73%	N/A	0.08%-0.33%	0.01%-0.04%	0.15%-0.41%	2.4%-2.5%
INTERNAL LOADS						
LIGHTING POWER DENSITY						
Lighting Power Density	N/A	28%	4.5%	4.0%	N/A	11%
HVAC SYSTEM						
THERMOSTAT MANAGEMENT						
Occupied/Unoccupied	1.8%-5.5%	0.79%-6.9%	2.6%-10%	0.15%-7.56%	1.3%-3.1%	0.35%-4.9%
FAN POWER/CONTROL						
Motor Efficiency	0.10%	0.04%-0.12%	N/A	0.33%	0.16%	1.6%-2.7%
Type	N/A	N/A	N/A	0.05%-0.28%	N/A	N/A
EXHAUST FANS						
Exhaust Fans	N/A	0.01%	N/A	0.78%	0.11%	2.3%-2.4%
CHILLED WATER SYSTEM						
Chiller Pump	0.09%-2.9%	0.04%-0.81%	2.3%-3.0%	0.07%-0.43%	0.03%-1.4%	1.9%-10%
Chiller Type	0.21%-6.2%	0.51%-2.9%	0.20%-4.5%	0.21%-0.25%	0.74%-1.1%	3.3% -15%
Condenser Type	1.7%-4.3%	0.89%-1.0%	N/A	0.25%	1.1%	3.3%-9.4%
Efficiency(Saving Depends On Eff)	8.8%	3.9%	2.3%-12%	0.16%-1.31%	0.54%-8.9%	4.1%-22%
Setpt Type	0.70%-1.7%	0.52%-0.53%	0.61%-1.2%	0.12%-0.23%	0.37% -1.0%	11%-12%
HOT WATER SYSTEM						
Hot Water Systems Pump	0.15%-0.19%	0.01%-0.23%	0.14%-0.17%	0.03%-0.82%	0.05%-0.29%	9.9%-11%

Engineers under fiscal or time pressure could use the information in Table 5 to focus their efforts in preparing retrofit projects. This information could also be implemented in the initial design of similar facilities. The single option change outs retrofits that produce the best energy savings are: window glass category, window frame type, light power density, chiller pump efficiency, and chiller type.

3.2.2 Single System & Whole Building Retrofits: A Comparative Analysis

Savings from whole building retrofit projects maximized at approximately 20% to 50% in annual electrical energy savings for several facilities. Although the range varied, the approach's savings clearly surpassed the benefits of applying a measured methodology. The results for the comparative analysis of retrofit packages in Building 20015 is listed below in Figure 6:

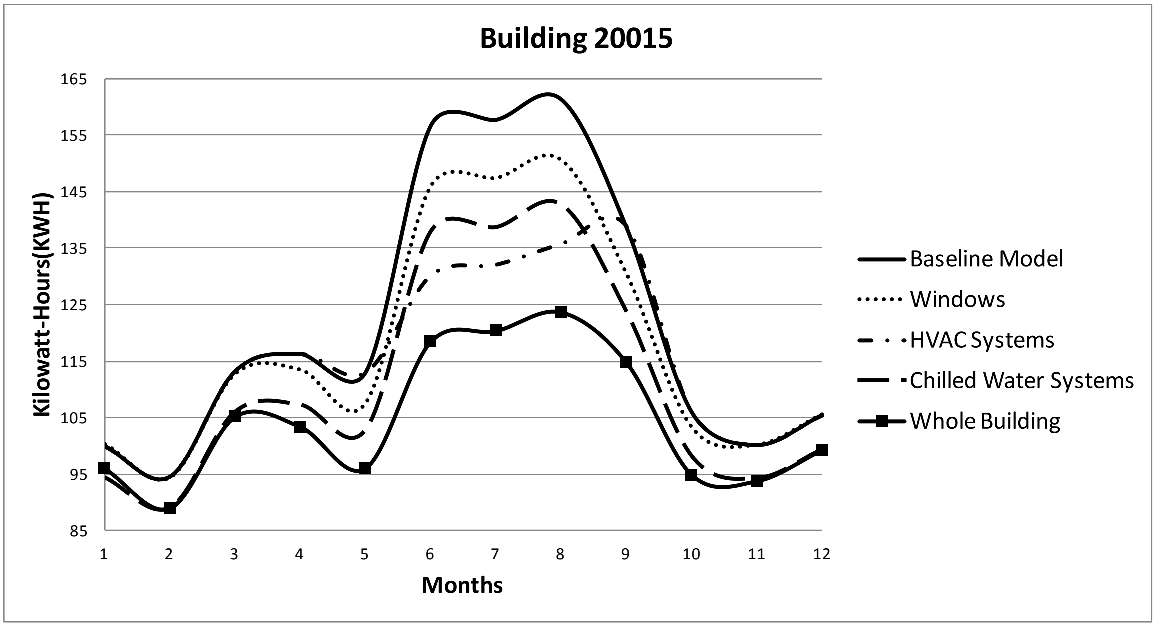


Figure 6. Single System Versus Whole Building Retrofits - Building 20015

Studies revealed that lighting, chilled water system, HVAC, and window retrofit packages were the dominant areas for obtaining single system energy retrofit savings. Chilled water systems proved to be the most effective in obtaining a 9.5% reduction from annual baseline consumption levels. Whole building retrofit modifications resulted in a savings of 17% from annual consumption figures. Constructed in the 1940s, researchers determined the information supported the benefits of deeper energy retrofits as the approach had approximately 7.0% more in possible savings than single system methods. It should be noted that researchers expected a higher improvement level due to the facility's age, but the facility was retrofit a number of times since its original construction. Project participants assumed the hypothetical efficiency gains were most likely achieved previously during these modifications.

Analysis results for Building 20643 are listed below in Figure 7:

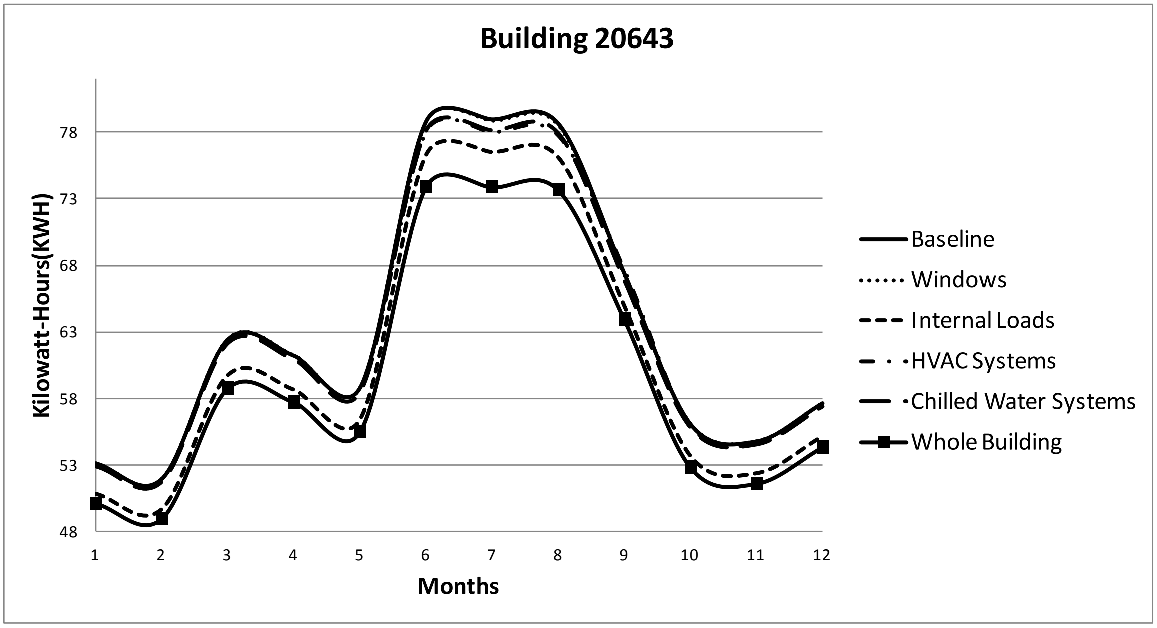


Figure 7. Single System Versus Whole Building Retrofits - Building 20643

As a more recently constructed facility, researchers expected Building 20643 to support fewer deep energy retrofit savings opportunities, while surpassing measured approaches. Overall savings from annual figures was minimal in both single system modifications and whole building approaches. However, whole building approaches still surpassed other options. Lighting, chilled water, and hot water system modifications were the primary leaders for savings in single system retrofits. Percentage reductions for these systems ranged from 0.50% to 4.0% down from annual consumption levels. Whole building retrofits maximized at a 6.3% reduction from annual figures. These results are a testament to what earlier background evidence suggested as whole building energy retrofits should be best timed when a facility is in need of total renovation.

Results from the analysis for Building 20646 are listed below in Figure 8:

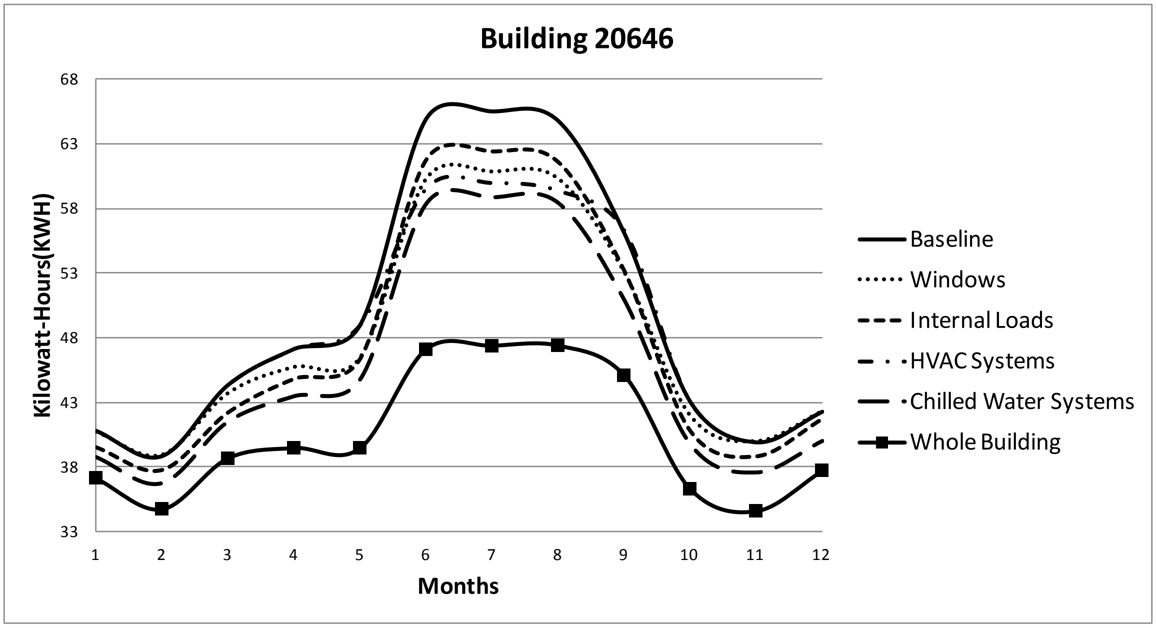


Figure 8. Single System Versus Whole Building Retrofits - Building 20646

As one of the first Leadership in Energy and Environmental Design (LEED) Silver certified facilities for WPAFB, researchers again expected Building 20646 to be another facility where overall savings would be minimal. Regardless, whole building approaches were hypothesized to still surpass measured approaches. Chilled water, lighting, and window system retrofits were the primary single system areas with the most savings benefits. These reduction opportunities ranged between approximately 3.9% and 8.6% in potential cuts to annual electrical utility consumption. In comparing these figures, whole building retrofit approaches offered at least 14% more savings than the best single system retrofit package. By renovating the entire facility, researchers believed a total of 23% in reductions from annual consumption could be achieved for the building. As a good portion of the savings resulted from lighting and chilled water system modifications, research participants suspect the project would have benefited from additional time in design. With extra effort, additional savings opportunities could have been found and possibly increased the chances of the facility achieving a higher LEED certification.

Constructed in the 1970s with few major retrofits, team members expected Building 20653 to yield massive benefits under the deep retrofit design approach. Analysis results for Building 20653 are listed below in Figure 9:

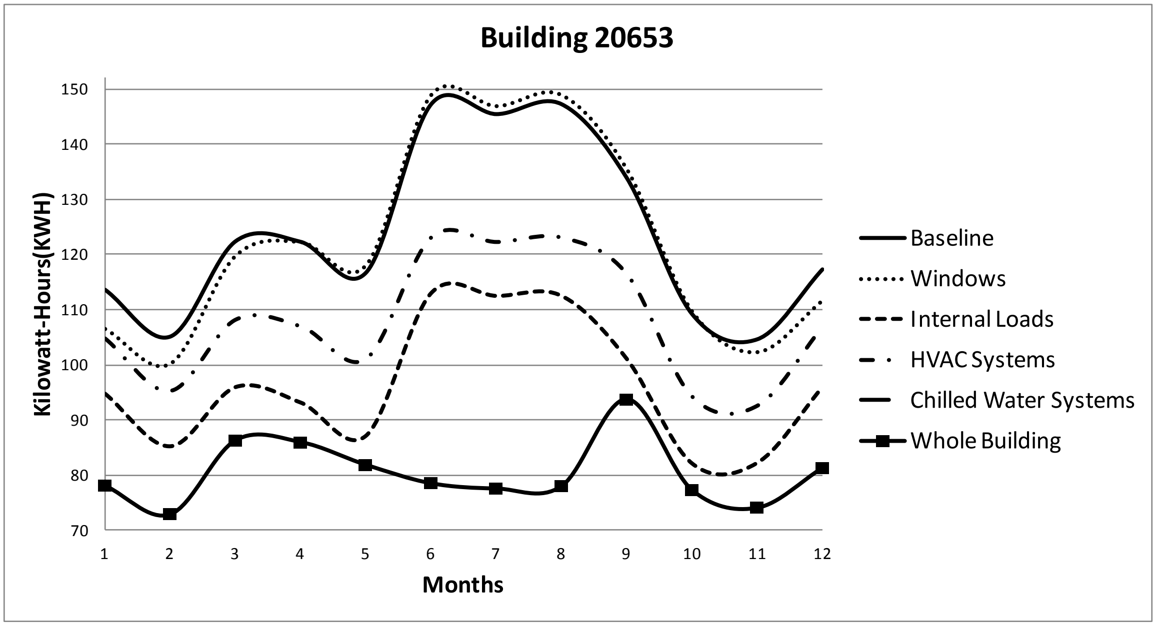


Figure 9. Single System Versus Whole Building - Building 20653

For the facility's individual systems, lighting, HVAC, and chilled water systems were the focus of most of the single system savings opportunities. ASHRAE lighting system upgrades were definitely the most effective promising approximately 29% in annual electrical savings. Meanwhile, HVAC systems only promised 15% in savings. Astonishingly, research indicated that a whole building retrofit would result in a approximate 54% reduction in annual electrical energy usage. On an individual level this surpassed the best single system modification by at least 20%. The facility serves as a perfect example of the benefits of whole building renovations and savings which can result from the synergy of an entire facility's systems. The shocking results were attributed to the lack of major renovations since construction allowing massive savings results.

Building 20675 was expected to yield few savings in both measured and whole building retrofit analysis. A breakdown of results can be found below in Figure 10:

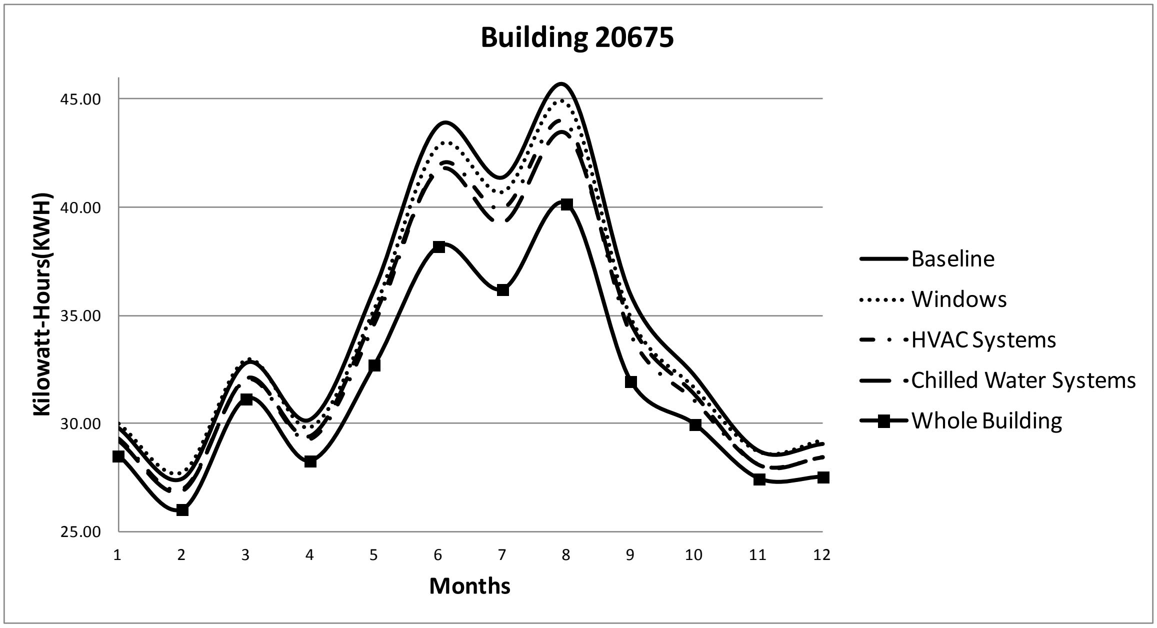


Figure 10. Single System Versus Whole Building Retrofits - Building 20675

As thought, efforts yielded minimal efficiency increases for the facility. Of the available savings opportunities, maximum single system benefit areas were found in chilled water, HVAC, and windows systems for the facility. Single system approaches were limited to no more than approximately 3.0% in annual reductions to baselines. Meanwhile, whole building retrofits brought no more than about 9.3% in electrical savings opportunities from baseline models. Altogether, the minimal benefits were attributed to the age of the facility, but whole building refinements still offered about 6.0% over the best single system upgrade.

Despite the accuracy issues, researchers still implemented the retrofit comparative analysis for Building 20630. This was done because it was hoped that information of benefit could still be extracted from the analysis. The results are listed below in Figure 11:

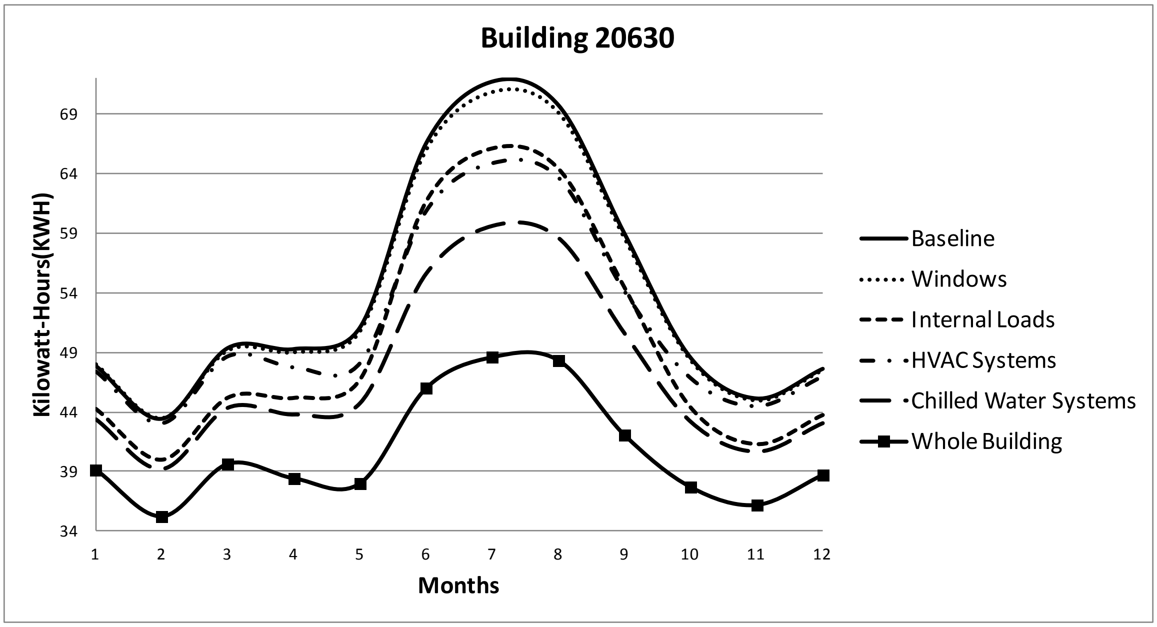


Figure 11. Single System Versus Whole Building Retrofits - Building 20630

For single system upgrades, the facility maximized its savings in chilled water, lighting, and HVAC systems. All single system retrofit packages yielded no more than 15% in energy savings from annual electrical consumption levels. Whole retrofits were maximized for the effort at 33.11% cuts from baselines. Again, researchers established another case study where holistic retrofits have yielded larger savings. Whole building modifications resulted in 15% more energy savings than the best single system measured approaches.

3.2.3 Commonalities in Analysis

Efforts revealed a number of commonalities in where savings opportunities for facility retrofits may lie and the best approaches to obtain them. Study results suggested that the top areas for obtaining electrical energy savings across all case studies were chilled water, HVAC, lighting, and window systems. These findings supported the notation that in any efficiency renovation these systems may be the core areas to consider for grouping to achieve deeper energy savings. It yielded that the idea that a synergy of efficiency increases in each could result in major paybacks. Examinations of the retrofit packages themselves produced a great deal. The most energy efficiency exterior roof finishes were shown to be mylar film and vapor low emission coatings. Floor finishes completed in ceramic stone tile were the most efficient floor coverings. Fixed insulated fiberglass window frames with metal spacers proved to be the most effective window frames. Window overhangs and fins increased savings in almost every facility. GSA and federal guideline thermostat set point strategies yielded the most effective savings in HVAC systems. ASHRAE light power density requirements were also shown to result in significant benefits. Lastly, chilled and hot water systems with variable flow and variable speed drives at premium efficiency proved to be the most efficient energy savers in facilities. This work suggested several commonalities in energy efficiency measures that could be considered after further research for implementation across the entire USAF real estate portfolio. Beyond this, the ideas could be considered during the design phase of facilities with similar functions.

3.2.4 Impacts From Analysis

Results established the idea that whole building retrofits could yield significant savings. Synergies in efficiency resulted in facilities obtaining almost 2.0% more in savings for whole building renovations when comparing to measured approaches. This was best demonstrated in Table 6 below.

Table 6. Single System Versus Whole Building Application

Building	CHW	HVAC	Windows	Roof	Ext. Walls	Floors	Lighting	HW	Single System Sum	Whole Building
20015	-9.5%	-5.8%	-3.5%	-0.65%	-0.08%	-0.23%	N/A	-0.18%	-20%	-16%
20643	-0.70%	-0.50%	-0.10%	-0.07%	N/A	-0.03%	-4.0%	-0.73%	-6.1%	-6.3%
20646	-8.6%	-2.8%	-4.0%	-0.91%	-0.03%	-0.28%	-4.5%	-0.17%	-21%	-23%
20653	-4.0%	-14%	-1.0%	-0.13%	-1.4%	-0.03%	-28%	-0.23%	-49%	-54%
20675	-3.5%	-3.3%	-1.1%	-0.41%	-0.12%	-0.09%	N/A	-0.29%	-8.8%	-9.3%
20630	-14%	-5.3%	-0.60%	-0.25%	N/A	N/A	-8.7%	-0.60%	-29%	-33%

Analysis supported the idea that on average whole building approaches surpass single system projects overtime. While not entirely significant, a synergy in efficiency was proven to exist in most cases. Reflecting upon recapitalization rates and decreasing budgets, it was clear to researchers that the applicability of the whole building techniques to DoD energy plans could be wide ranging. On the installation level, research provided a better methodology to vector Air Force Base energy efficiency programs under constrained funding environments. While whole building retrofits offered significant savings and free synergies in efficiency, USAF officials could utilize instruments such as Table 6, depicting the project results, to prescribe single system or whole building projects for the best fit for their installation. Tables describing perspective savings between techniques would allow officials to make tradeoffs between savings and levels of service for facility occupants.

Other impacts included major indications of where USAF officials could concentrate their renovation efforts across their own real estate portfolios. Software package selection for the modeling process was discovered to be more important than team members originally thought. Modelers must carefully examine their case studies before choosing a software package to implement or face accuracy issues. Research also testified that obtaining statistically significant accurate computer models of facility energy usage was possible. However, researchers must be dedicated and thorough in their process. Existence and implementation of several years of meter data during calibration were thought to be pinnacle in meeting pre-established accuracy metrics and ASHRAE guidelines.

4. Conclusions

Existing buildings represent the single largest opportunity for officials to expand their energy savings opportunities. This research offers compelling evidence of a technique that can reduce energy usage for existing facilities. Recognizing tradeoffs with human comfort and cost, whole building energy retrofits demonstrate a clear energy savings advantage in any renovation against single system measured approaches. Several research case studies from the effort demonstrate approximately 20% to 50% electrical energy cuts from annual baselines. Energy retrofits also expose an approximate 2.0% synergistic benefit in raw efficiency gains from upgrading all a facility's systems at once. While this is not entirely a significant percentage, the benefit is still in addition to the 20% to 50% decreases in utility consumption. Operational energy expenditures of this level support the need for further investigation of these approaches.

Accuracy and targeting of effort is key in a whole building renovation. Statistical metrics to ensure baseline predictions are within limits are a necessity to ensure savings. Most models for the endeavor met key accuracy metric criteria, but suggest including more meter data in the calibration process to expand their compliance to ASHRAE guidelines. Additionally, while only three out of six cases demonstrate larger scale savings in comparison to single system approaches, this information is enough to suggest that the highest savings percentages are limited to the right facilities. Examinations of case study characteristics show that older facilities which have experienced fewer renovations can reach savings rates as much as 50% less than baseline usage under a whole building renovation approach.

Evidence also suggests that engineers must be sure to select the proper energy modeling platform in a renovation. Proper selections yields the most guaranteed savings for effort. Simplification of facility construction and footprint can drastically affect model accuracy. Research work further demonstrates the best systems to upgrade when under fiscal and time pressures in renovations of similar facilities. While studies prove whole building approaches clearly surpass measured methods, a commonality of chilled water, HVAC, and lighting systems is also seen as having a clear advantage across all case study facilities.

Overall, results suggest that whole building retrofits can be successfully enacted in existing USAF facilities. Evidence supports the notation that if done in the proper facility with the best energy modeling software package, unprecented savings levels can be reached. USAF officials must simply take the time to develop the expertise necessary for the process in all of their energy team members. Lessons on the best energy efficiency measure packages (EEMs) can be extrapolated across entire portfolios of real estate. The aggressive technique suggests if properly implemented officials can not only meet their goals, but can exceed them.

V. Conclusion

Chapter Overview

This chapter describes the research findings as prescribed by the questions listed in chapter one. Chapter two and three contain two conference papers that were submitted and accepted at the *Western Decisions Sciences Institute Forty First Annual Conference.* Chapter four contains a journal article will be submitted to the *2012 Buildings and Environment Journal*. All chapters communicate the prominent results of the effort. However, it is notable that due to formatting criteria established by the academic organizations and their publication, a further discussion of the results within the context of the effort's investigative questions is necessary. This discussion is vital along with the sections described in the appendices of the thesis. This chapter also entails a discussion of future research and reemphasizes the impact of results for USAF programs and goals. Finally, a summary of the thesis is presented in the last section of the effort.

Review of Findings

The review below provides a complete description of the project's findings as described by the effort's original research questions.

1) Should the USAF revitalize its rooftop preventive maintenance program and further investigate strategic sourcing as a viable solution?

   By undertaking a detailed review of a major USAF roofing management database, researchers reveal a startling discovery regarding the condition of the USAF's rooftop preventive maintenance program. Asset management policies are failing in regarding to adequate roofing maintenance. Although an extrapolation from a smaller subset of data, researchers expose the idea that the preventive roof maintenance program is in need of revitalization due to manning and funding issues. Small maintenance problems are being left unattended exposing facility infrastructure to larger problems and overall financial risk. Strategic sourcing is proposed as the most cost effective method to improve the existing program and reduce overall issues. Researchers argue that it brings added expertise to organizational roofing management and frees personnel to concentrate in other needed areas of operations.

2) What is the best methodology to enable a comparison of whole building retrofitting techniques to existing USAF approaches and determine the best facility efficiency term?

Research reveals two definitive methodologies which could be used in the comparison of whole building retrofitting techniques to existing approaches and determine the best facility efficiency term for the USAF. Comparisons required a canvas of existing USAF meter and facility plan datasets across the nation. Researchers could utilize gathered data to create baseline and retrofitted facility models to generate predictions of savings between techniques. Metrics on energy usage and cost could be a gateway of comparison between retrofit methodologies. Concurrently, throughout the project, common USAF facility types could be used as the subject of comparison to better empower findings to the USAF as a whole. Additionally, to select the best facility efficiency term for the USAF, research suggests a review of public and private organizational definitions of facility efficiency. Using these as a basis of comparison to existing USAF definitions, researchers could use a Choosing By Advantages analysis approach to eliminate the biases associated with other decision tactics.

3) What are whole building retrofit techniques?

A whole building renovation is seen as a process that implements integrated systems design practices to improve a facility's overall efficiency and obtain larger savings than conventional methods [29]. Although the process typically promises savings on the order of 50% of a facility's energy usage, that standard is not universal. Implementing the process requires the proper timing of retrofits, advanced design principles, the application of energy modeling software, facility audits, life cycle cost analysis, and metering to verify savings [28].

3.1) How do they compare to single system approaches?

Research indicates that in Air Force facilities whole building techniques clearly surpass single measured approaches in all instances. Typically, the process can obtain approximately 20% to 50% in savings from annual baseline consumption levels. Although there is a tradeoff with human comfort and expense, the techniques clearly represent an ideal approach to implementing USAF facility renovations and merit further investigation for widespread deployment in energy efficiency projects.

3.2) What kind of synergy can be expected from a whole building perspective?

Officials can expect at least approximately 2.0% in free efficiency gains when implementing a whole facility retrofit. This is seen as a result of upgrading all facility systems at once. By upgrading the independent systems together, a new systematic whole facility efficiency is achieved for operation. When looking at this effect, evidence supports the development of a efficiency term which may be linked to facility investment benefits.

4) Can facility energy modeling software be used to simulate single systems and whole building retrofitting techniques?

Energy modeling software can be successfully applied to simulate a comparison of the two approaches. However, the key is to have enough evidence to support model development. Most importantly this includes facility plans and meter data. Additionally, evidence supports a proper selection of software package is required before beginning any whole building modeling effort. Researchers believe the facility construction changes required to use their chosen product on one of their case studies resulted in a sharply degraded accuracy level of their one model. Every software package has its benefits, but care must be taken in their implementation. Lastly, it is noteworthy that while training is required to use the technology, it is by no means impossible to consider training for all USAF energy professionals in energy modeling software. Initial familiarity training and experience are all that is required for its effective implementation.

4.1) How accurate can an energy model come to reality?

Accuracy can be pre-established and met in most cases without issue. A majority of models for the effort met MAPE criteria allowing careful extrapolation of project results to broader conclusions. ASHRAE guidelines for facility models can even be held to for a holistic retrofit. Despite project limitations in meeting ASHRAE criteria for all models, further meter data was thought to be key in obtaining the required accuracy to ensure projects meet projected savings.

5) Can whole building retrofitting techniques be successfully applied to existing USAF building stock to reap major savings?

Whole building techniques can reap great success in Air Force facilities. The key to savings is widespread deployment in USAF operations. Candidates for whole building efforts need to be carefully selected at the base level. Energy minded USAF officials must become educated in the technology and criteria necessary to ensure modeled savings become reality. Facility plan libraries and meter data are of great importance and need to be maintained in this process. They are the gateways to savings of 50% or more. Research supports the idea that integrated EEM lessons for different facility types can even be obtained and deployed across the entire real estate portfolio of an organization.

Significance of Research

The world of today is more unstable than ever before. Budgets are only projected to shrink. Asset management principles in all areas of organizational operations are the gateway to employing limited funding in the best method possible. Roofing preventive maintenance stands to provide insurance against the costs of reactive care and ensure mission objectives. Strategic sourcing provides an ideal application of the buying power of the USAF to reduce costs and renew the USAF rooftop preventive maintenance program. Whole building retrofitting techniques offer keys to a potential methods of doing business which can cut operational energy expenditures. However, the key to savings is in their application. Lessons from whole building techniques can even be expanded to the design stage of facility construction. Deeper retrofits promise 50% energy reductions in Air Force facilities when implemented on the right candidates with the right tools. Accuracy of models can be established mathematically, and promise more certainty in savings than other single retrofit options. Whole building retrofitting techniques represent a revolutionary approach to meeting goals and surpassing expectations. Lastly, as established by the results of this effort's investigation, facility efficiency is a key factor in determining the overall savings from a retrofit project. A methodology to gauge facility efficiency discovered from an unbiased study of existing approaches does much to better the channeling of USAF energy program dollars. The knowledge of a facility's efficiency provides more support for where energy dollars can maximize savings. Overall, team efforts were able to establish that deficiencies were in existence for the USAF asset management of roof maintenance and facility retrofits. However, research put forth several tools and strategies that could be applied to bring about solutions.

Future Research

Research for this project focuses on revitalizing the USAF rooftop preventive maintenance program and establishing the energy based merits of whole building retrofits.. This research revealed the following future research:

- Can an accurate cost model be developed to predict the savings associated with a strategically sourced rooftop preventive maintenance program for the USAF? What impact would strategic sourcing have on enlisted personnel manning?

- After selecting a facility efficiency term for the USAF, can the term be used to successfully distribute energy project funding?
- Are whole building retrofit projects cost effective under current AFCESA funding criteria? How could criteria be relaxed to support their implementation?
- Is the accuracy of whole building models increased when using more meter data?
- Can lessons on integrated EEMs be extrapolated from whole building retrofit models of USAF facilities and implemented in similar facilities with the same success?
- When providing for human comfort and cost considerations, can projected savings levels be maintained in a whole building retrofit?
- What is the most effective energy modeling software package across all USAF facility types?

Answers to these questions can expand this research’s findings.

Summary

This research explored rooftop maintenance and facility energy retrofits. Researchers used an existing database on the condition of the roofing assets for several USAF installations to determine the organization's rooftop preventive program was in need of adjustment. Using cost analysis for those installations, researchers suggested that strategic sourcing of roofing maintenance was the most cost effective solution to the roofing issue. The concept, leveraging the buying power of larger organizations, decreases overall costs when purchasing items or services. Researchers also developed two methodologies which support the implementation of whole building retrofits.. Although only portions of the whole building methodology were eventually carried out, both approaches support future research.

In conclusion, whole building retrofitting techniques and the design processes required were implemented on six different facilities on WPAFB in Dayton, Ohio. Whole building retrofits were compared to single system renovations to determine the differences in energy savings. By understanding the benefits these techniques offered, researchers developed projects which show savings opportunities in USAF facilities. Efforts established that energy savings were possible under the right circumstances. Researchers also concluded that models could be produced which provide statistically significant evidence of savings. Free synergistic efficiency gains were determined to be available from upgrading whole facilities rather than piece by piece. Even with isolated issues, sufficient evidence was available to support the consideration of a whole building retrofitting methodology for further study.

Appendix A. Case Study Locations

Appendix B. Common Office Equipment Wattages

Table 7. Office Equipment Power Densities

Office Equipment Item	Peak Wattage(W)
Tower PC	112
Monitor	28
Labtop	23
Flatscreen TV	350
Printer	231
Copier	61
Fax	106
Radio	12
Heater	800
Shredder	400
Coffee Maker	865
Fridge	79
Microwave	22
Water Cooler	83
Toaster	800
Fan	12
Scanner	77
CD Burner	16
Battery	780
Microfridge	22
Projector	185

Appendix C. Space, Lighting, and Office Equipment Power Densities

Table 8. Building 20015

Building Number	***20015***		
Basement			
Activity Area	***Space %***	***Lighting (W/SqFt)***	***Office (W/SqFt)***
Conference Rm	6.5	1.3	2.5
Corridor	14.2	0.5	0
Mechanical/Electrical Rm	9.4	1.5	17.39
Office(General)	13.3	1.1	1.3
Office(Office Plan)	51.6	1.1	1.5
Restrooms	3.5	0.9	0
Storage(Conditioned)	1.4	0.8	0
Level 1			
Conference Rm	4	1.3	1.11
Corridor	25.1	0.5	1.76
Lobby (Office Reception/Waiting)	3.8	1.3	2.11
Copy Rm (Photocopying Equipment)	1	1.5	3.6
Mechanical/Electrical Rm	1.4	1.5	0
Office (General)	59	1.1	0.97
Restrooms	3.2	0.9	0
Storage (Conditioned)	2.5	0.8	0
Level 2			
Computer Rm(Mainframe/Server)	1.9	1.5	1.4
Conference Rm	6.5	1.3	0.96
Corridor	14	0.5	0
Kitchen and Food Preparation	0.6	1.2	10.67
Mechanical/Electrical Rm	2.1	1.5	0
Office (General)	68.7	1.1	1.17
Restrooms	3.6	0.9	0
Storage (Conditioned)	2.5	0.8	0
Penthouse 1			
Mechanical/Electrical Rm	100	1.5	0
Penthouse 2			
Mechanical/Electrical Rm	100	1.5	0

Table 9. Building 20643

Building Number	***20643***		
Level 1			
Activity Area	***Space %***	***Lighting (W/SqFt)***	***Office (W/SqFt)***
Classroom/Lecture	44.5	1.45	0.36
Mechanical/Electrical Rm	1.7	0.91	0
Corridor	15.4	1.19	1.37
Office (General)	12	1.24	2.18
Auditorium	11.7	1.87	0.23
Storage (Unconditioned)	1.2	1.11	0
Restrooms	4.5	1.18	0
Lobby (Main Entry and Assembly)	9	0	0
Level 2			
Classroom/Lecture	50.9	1.61	1.05
Restrooms	5.1	1.01	0
Corridor	15.2	0.79	0
Comm/Ind Work (Loading Dock)	1.8	0.6	0
Computer Rm (Instructional/PC Lab)	9.8	1.72	2.67
Storage (Conditioned)	4.6	0.62	0
Mechanical/Electrical Rm	3.9	1.12	0
Lobby (Main Entry and Assembly)	8.7	1.41	0
Level 3			
Office (General)	71.6	1.68	1.77
Corridor	10.6	0.94	0
Restrooms	6.2	1.01	0
Conference Rm	4.4	2.84	0.21
Dining Rm	2.6	2.36	0.88
Kitchen and Food Preparation	0.8	3.72	17.33
Mechanical/Electrical Rm	3.8	0.89	0
Penthouse			
Corridor	100	0.57	0

Table 10. Building 20646

Building Number	***20646***		
Level 1			
Activity Area	***Space %***	***Lighting (W/SqFt)***	***Office (W/SqFt)***
Classroom/Lecture	23.7	1.23	0.42
Computer Room (Instructional/PC Lab)	9.3	1.26	1.11
Corridor	17.3	0.79	1.82
Lobby (Office Reception/Waiting)	8	3.28	0.3
Mechanical/Electrical Rm	14.1	0.67	0
Office (General)	23.4	1.27	3.19
Restrooms	2.8	0.62	0
Storage (Conditioned)	1.5	2.09	0
Level 2			
Classroom/Lecture	28,2	1.16	0.41
Conference Rm	3.2	1.89	0.31
Corridor	26.4	0.64	0.19
Kitchen and Food Preparation	2.6	0.87	8.3
Mechanical/Electrical Rm	2.1	0.87	0
Office (General)	33.3	2.02	4.06
Restrooms	2.9	0.63	0
Storage (Conditioned)	1.4	2.28	0
Level 3			
Classroom/Lecture	36.9	1.19	0.36
Corridor	22.3	0.6	0.21
Kitchen and Food Preparation	0.8	1.57	18.4
Lobby (Office Reception/Waiting)	1.7	1.17	0
Mechanical/Electrical Rm	2	0.85	0
Office (General)	29.6	1.57	2.03
Restrooms	3	0.72	0
Sotrage (Conditioned)	3.8	2.06	0

Table 11. Building 20653

Building Number	***20653***		
Basement			
Activity Area	***Space %***	***Lighting (W/SqFt)***	***Office (W/SqFt)***
Comm/Ind Work (High Tech, Bio Tech)	5.9	0.53	0.57
Comm/Ind Work (General, Low Bay)	16.8	1	0
Conference Rm	0.9	2.36	4.45
Corridor	11.4	1.55	4.67
Mechanical/Electrical Rm	19.8	2.58	0
Office (General)	33.5	1.74	3.11
Restrooms	0.8	1.27	0
Storage (Confitioned)	10.8	5.39	0.16
Level 1			
Auditorium	34.1	4.83	0.66
Corridor	15.8	0.94	0
Kitchen and Food Preparation	7	6.05	9.5
Lobby (Main Entry and Assembly)	13.6	2.39	2.93
Mechanical/Electrical Rm	1.3	1.48	0
Office (General)	18	5.55	6.67
Restrooms	7.4	3.44	0
Storage (Conditioned)	2.8	2.13	0
Level 2			
Conference Rm	7.7	1.22	2.31
Corridor	20.9	1.02	0.23
Mechanical/Electrical Rm	1.3	3.14	0
Office (General)	66.1	2.56	4.04
Restrooms	2.8	2.17	0
Storage (Conditioned)	1.1	2.81	0
Level 3			
Office (General)	73.9	2.74	3.34
Corridor	17.7	0.95	0.3
Kitchen and Food Preparation	0.3	4.92	44.66
Restrooms	2.3	2.68	0
Mechanical/Electrical Rm	1.6	1.06	0
Corridor	4.2	13.18	0
Level 4			
Office (General)	79.5	2.93	3.04
Copy Room (Photocopying Equipment)	1.5	2.88	22.88
Restrooms	2.2	0.97	0
Mechanical/Electrical Rm	1.6	3.56	0
Corridor	14.3	0.82	0
Kitchen and Food Preparation	0.3	3.93	0
Storage (Conditioned)	0.7	1.54	0
Penthouse			
Corridor	100	0.5	0

Table 12. Building 20675

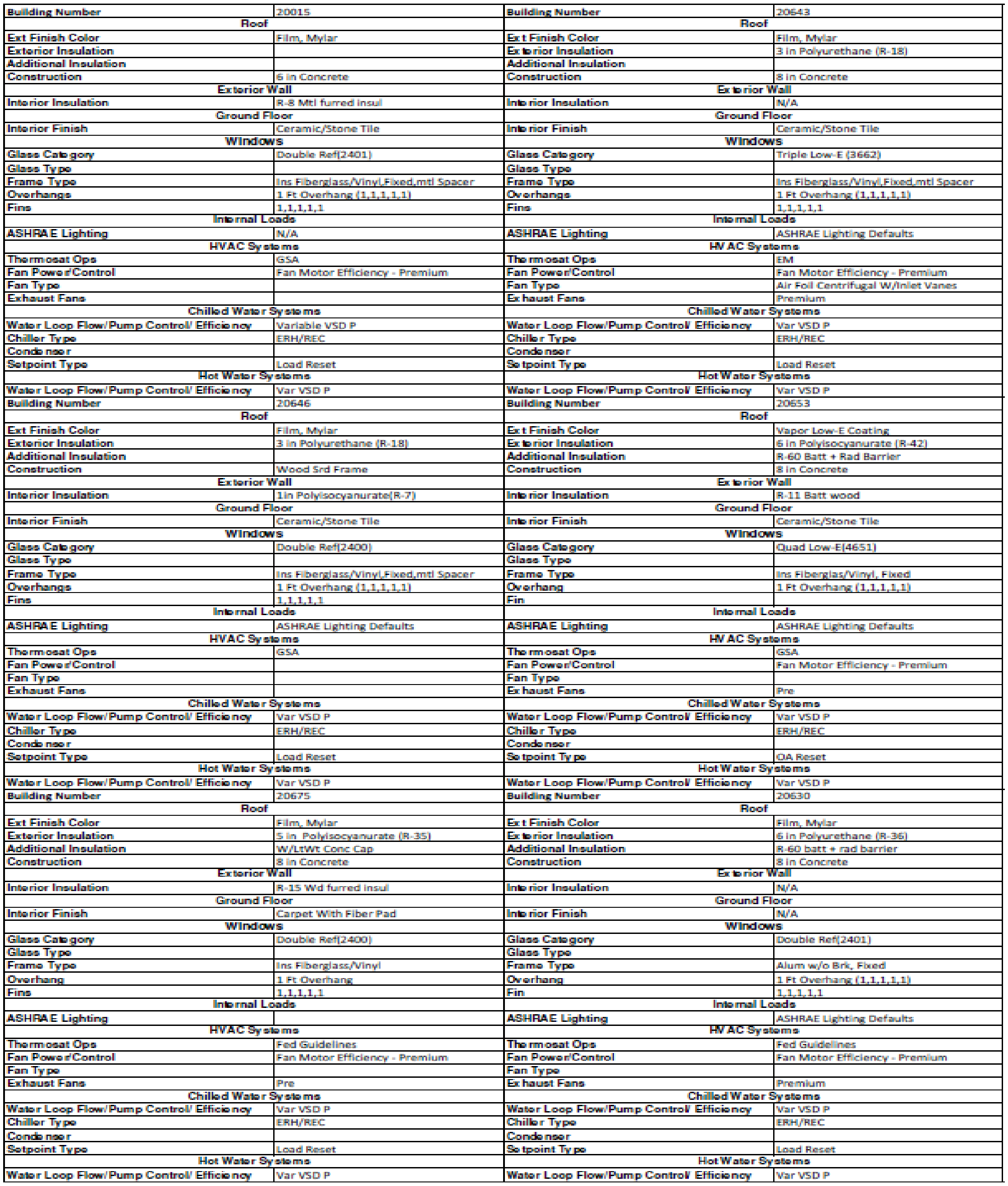
Building Number	***20675***		
1st Level			
Activity Area	***Space %***	***Lighting (W/SqFt)***	***Office (W/SqFt)***
Corridor	2.9	0.97	5.65
Kitchen and Food Preparation	1.5	1.91	4.54
Lobby (Office Reception/Waiting)	3.6	0.46	0.61
Mechanical/Electrical Rm	11.3	0.49	1.22
Medical and Clinical Care	41.4	0.64	8.06
Office (General)	28.8	1.53	1.23
Restrooms	3.6	2.84	0
Storage (Conditioned)	7	1.54	0.23
2nd Level			
Conference Rm	6.3	0.33	0.55
Corridor	40.5	0.25	0.14
Dining Area	1.2	1.77	8.89
Mechanical/Electrical Rm	2.3	1.77	0
Medical and Clinical Care	1.6	1.26	1.84
Office (General)	44.4	1.86	2.52
Restrooms	1.4	3.65	0
Storage (Conditioned)	2.3	1.34	0.28

Table 13. Building 20630

Building Number	***20630***		
1st Level			
Activity Area	***Space %***	***Lighting (W/SqFt)***	***Office (W/SqFt)***
Classroom/Lecture	62.2	1.48	0.71
Corridor	18.3	1.43	0
Kitchen and Food Preparation	4.6	1.84	0
Laundry	0.8	2.21	9.02
Mechanical/Electrical Rm	0.4	0	0
Office (General)	7.1	2.12	1.98
Restrooms	0.8	2.13	0
Storage (Conditioned)	5.8	1.8	0

Appendix D. Retrofit Package Breakdowns

Table 14. Retrofit Packages



Building Number	20015	Building Number	20643
Roof		Roof	
Ext Finish Color	Film, Mylar	Ext Finish Color	Film, Mylar
Exterior Insulation		Exterior Insulation	3 in Polyurethane (R-18)
Additional Insulation		Additional Insulation	
Construction	6 in Concrete	Construction	8 in Concrete
Exterior Wall		Exterior Wall	
Interior Insulation	R-8 Mtl furred insul	Interior Insulation	N/A
Ground Floor		Ground Floor	
Interior Finish	Ceramic/Stone Tile	Interior Finish	Ceramic/Stone Tile
Windows		Windows	
Glass Category	Double Ref(2401)	Glass Category	Triple Low-E (3662)
Glass Type		Glass Type	
Frame Type	Ins Fiberglass/Vinyl,Fixed,mtl Spacer	Frame Type	Ins Fiberglass/Vinyl,Fixed,mtl Spacer
Overhangs	1 Ft Overhang (1,1,1,1,1)	Overhangs	1 Ft Overhang (1,1,1,1,1)
Fins	1,1,1,1,1	Fins	1,1,1,1,1
Internal Loads		Internal Loads	
ASHRAE Lighting	N/A	ASHRAE Lighting	ASHRAE Lighting Defaults
HVAC Systems		HVAC Systems	
Thermosat Ops	GSA	Thermosat Ops	EM
Fan Power/Control	Fan Motor Efficiency - Premium	Fan Power/Control	Fan Motor Efficiency - Premium
Fan Type		Fan Type	Air Foil Centrifugal W/Inlet Vanes
Exhaust Fans		Exhaust Fans	Premium
Chilled Water Systems		Chilled Water Systems	
Water Loop Flow/Pump Control/ Efficiency	Variable VSD P	Water Loop Flow/Pump Control/ Efficiency	Var VSD P
Chiller Type	ERH/REC	Chiller Type	ERH/REC
Condenser		Condenser	
Setpoint Type	Load Reset	Setpoint Type	Load Reset
Hot Water Systems		Hot Water Systems	
Water Loop Flow/Pump Control/ Efficiency	Var VSD P	Water Loop Flow/Pump Control/ Efficiency	Var VSD P
Building Number	20646	Building Number	20653
Roof		Roof	
Ext Finish Color	Film, Mylar	Ext Finish Color	Vapor Low-E Coating
Exterior Insulation	3 in Polyurethane (R-18)	Exterior Insulation	6 in Polyisocyanurate (R-42)
Additional Insulation		Additional Insulation	R-60 Batt + Rad Barrier
Construction	Wood Srd Frame	Construction	8 in Concrete
Exterior Wall		Exterior Wall	
Interior Insulation	1in Polyisocyanurate(R-7)	Interior Insulation	R-11 Batt wood
Ground Floor		Ground Floor	
Interior Finish	Ceramic/Stone Tile	Interior Finish	Ceramic/Stone Tile
Windows		Windows	
Glass Category	Double Ref(2400)	Glass Category	Quad Low-E(4651)
Glass Type		Glass Type	
Frame Type	Ins Fiberglass/Vinyl,Fixed,mtl Spacer	Frame Type	Ins Fiberglas/Vinyl, Fixed
Overhangs	1 Ft Overhang (1,1,1,1,1)	Overhang	1 Ft Overhang (1,1,1,1,1)
Fins	1,1,1,1,1	Fin	
Internal Loads		Internal Loads	
ASHRAE Lighting	ASHRAE Lighting Defaults	ASHRAE Lighting	ASHRAE Lighting Defaults
HVAC Systems		HVAC Systems	
Thermosat Ops	GSA	Thermosat Ops	GSA
Fan Power/Control		Fan Power/Control	Fan Motor Efficiency - Premium
Fan Type		Fan Type	
Exhaust Fans		Exhaust Fans	Pre
Chilled Water Systems		Chilled Water Systems	
Water Loop Flow/Pump Control/ Efficiency	Var VSD P	Water Loop Flow/Pump Control/ Efficiency	Var VSD P
Chiller Type	ERH/REC	Chiller Type	ERH/REC
Condenser		Condenser	
Setpoint Type	Load Reset	Setpoint Type	OA Reset
Hot Water Systems		Hot Water Systems	
Water Loop Flow/Pump Control/ Efficiency	Var VSD P	Water Loop Flow/Pump Control/ Efficiency	Var VSD P
Building Number	20675	Building Number	20630
Roof		Roof	
Ext Finish Color	Film, Mylar	Ext Finish Color	Film, Mylar
Exterior Insulation	5 in Polyisocyanurate (R-35)	Exterior Insulation	6 in Polyurethane (R-36)
Additional Insulation	W/LtWt Conc Cap	Additional Insulation	R-60 batt + rad barrier
Construction	8 in Concrete	Construction	8 in Concrete
Exterior Wall		Exterior Wall	
Interior Insulation	R-15 Wd furred insul	Interior Insulation	N/A
Ground Floor		Ground Floor	
Interior Finish	Carpet With Fiber Pad	Interior Finish	N/A
Windows		Windows	
Glass Category	Double Ref(2400)	Glass Category	Double Ref(2401)
Glass Type		Glass Type	
Frame Type	Ins Fiberglass/Vinyl	Frame Type	Alum w/o Brk, Fixed
Overhang	1 Ft Overhang	Overhang	1 Ft Overhang (1,1,1,1,1)
Fins	1,1,1,1,1	Fin	1,1,1,1,1
Internal Loads		Internal Loads	
ASHRAE Lighting		ASHRAE Lighting	ASHRAE Lighting Defaults
HVAC Systems		HVAC Systems	
Thermosat Ops	Fed Guidelines	Thermosat Ops	Fed Guidelines
Fan Power/Control	Fan Motor Efficiency - Premium	Fan Power/Control	Fan Motor Efficiency - Premium
Fan Type		Fan Type	
Exhaust Fans	Pre	Exhaust Fans	Premium
Chilled Water Systems		Chilled Water Systems	
Water Loop Flow/Pump Control/ Efficiency	Var VSD P	Water Loop Flow/Pump Control/ Efficiency	Var VSD P
Chiller Type	ERH/REC	Chiller Type	ERH/REC
Condenser		Condenser	
Setpoint Type	Load Reset	Setpoint Type	Load Reset
Hot Water Systems		Hot Water Systems	
Water Loop Flow/Pump Control/ Efficiency	Var VSD P	Water Loop Flow/Pump Control/ Efficiency	Var VSD P

Appendix E. Synergies in Efficiency

Table 15. Summation of Measured Methods Versus Whole Building

Single System Versus Whole Building Approach			
20015			
Single System Sum	-20%	**Whole Building**	-17%
20643			
Single System Sum	-6.1%	**Whole Building**	-6.3%
20646			
Single System Sum	-21%	**Whole Building**	-23%
20653			
Single System Sum	-50%	**Whole Building**	-54%
20675			
Single System Sum	-8.8%	**Whole Building**	-9.3%
20630			
Single System Sum	-30%	**Whole Building**	-33%

Renovation

Appendix F. Calibration Graphs

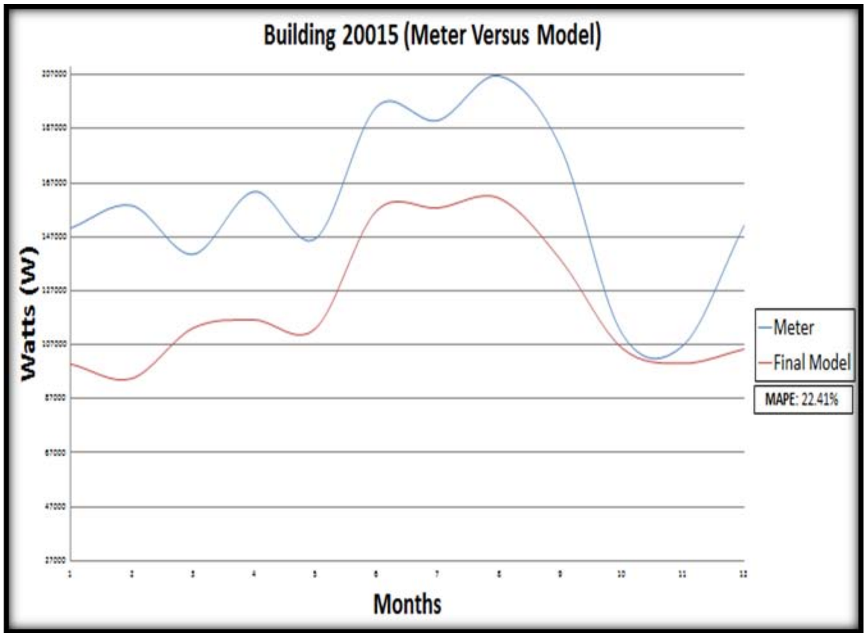


Figure 12. Building 20015 Final Baseline Calibration

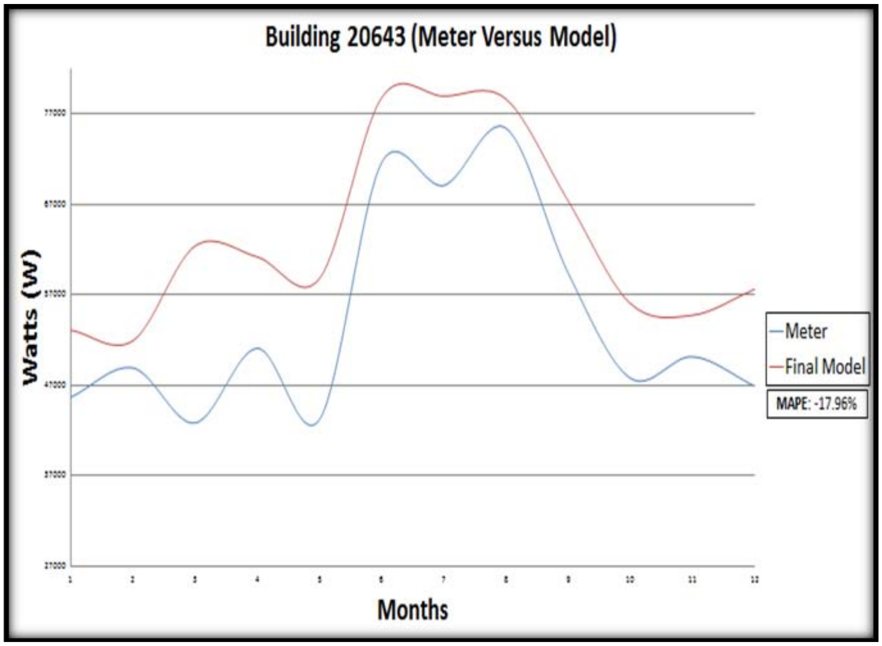


Figure 13. Building 20643 Final Baseline Calibration

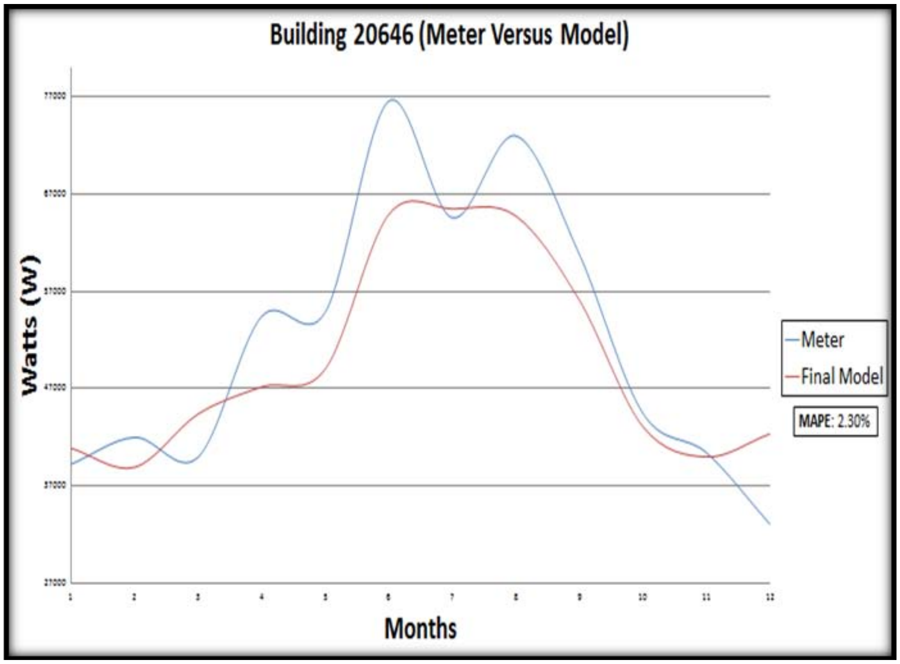


Figure 14. Building 20646 Final Baseline Calibration

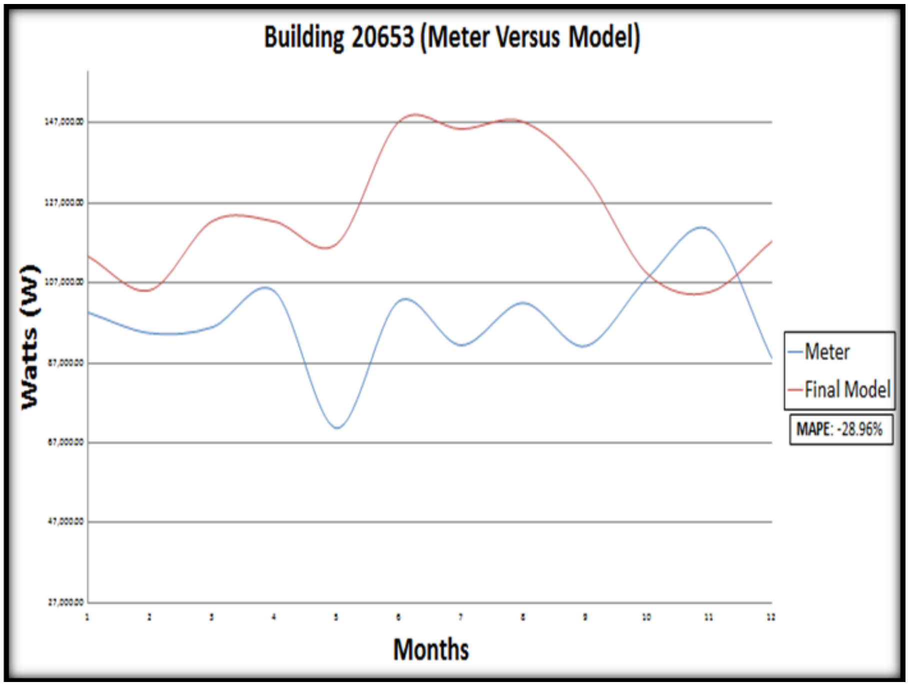


Figure 15. Building 20653 Final Baseline Calibration

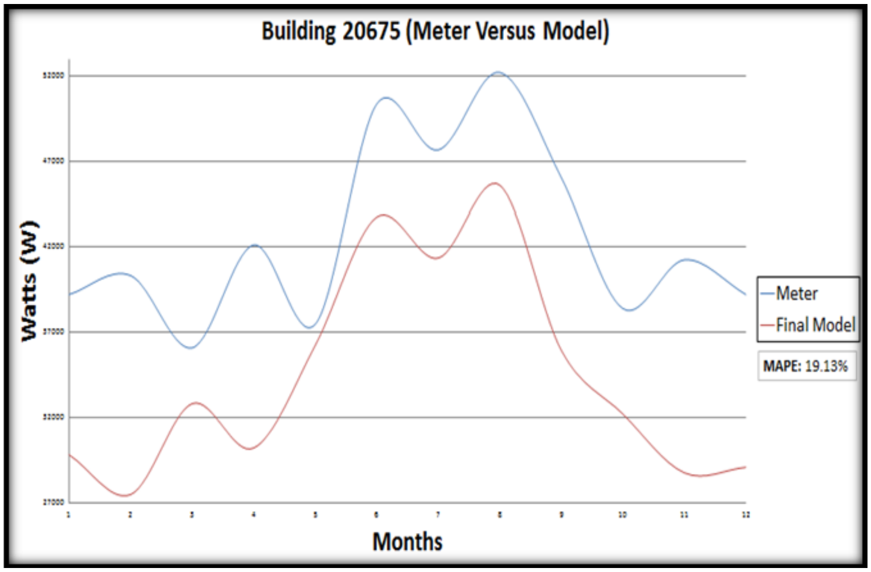


Figure 16. Building 20675 Final Baseline Calibration

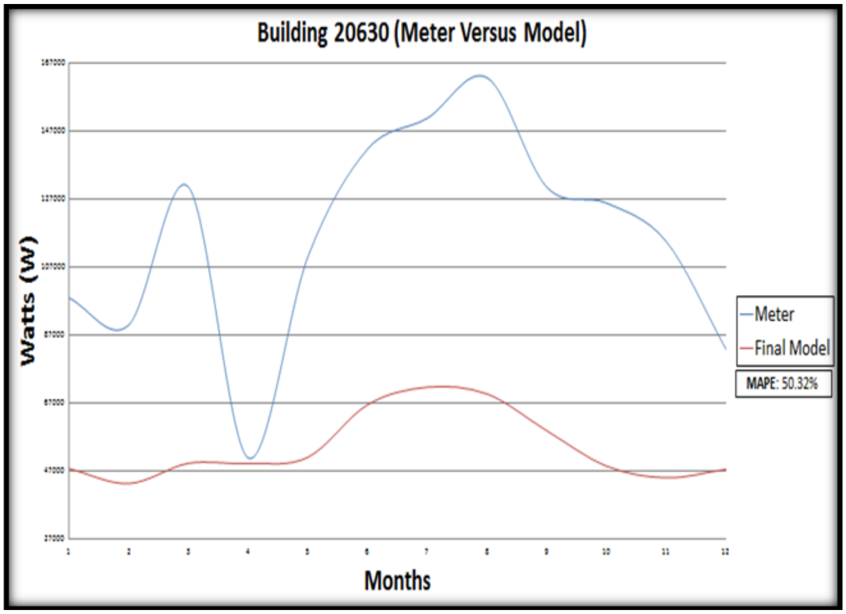


Figure 17. Building 20630 Final Baseline Calibration

Appendix G. Pictures of Models & Facilities

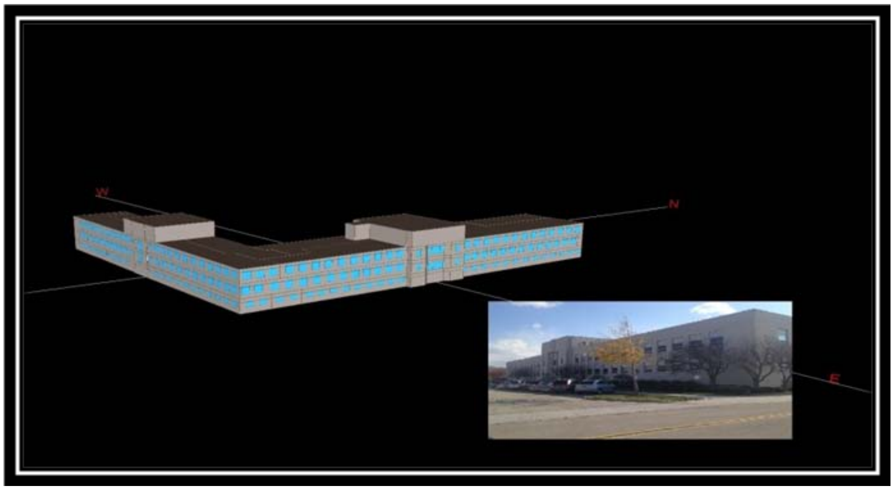


Figure 18. AFRL Research, Bldg. 20015, WPAFB (Area B)

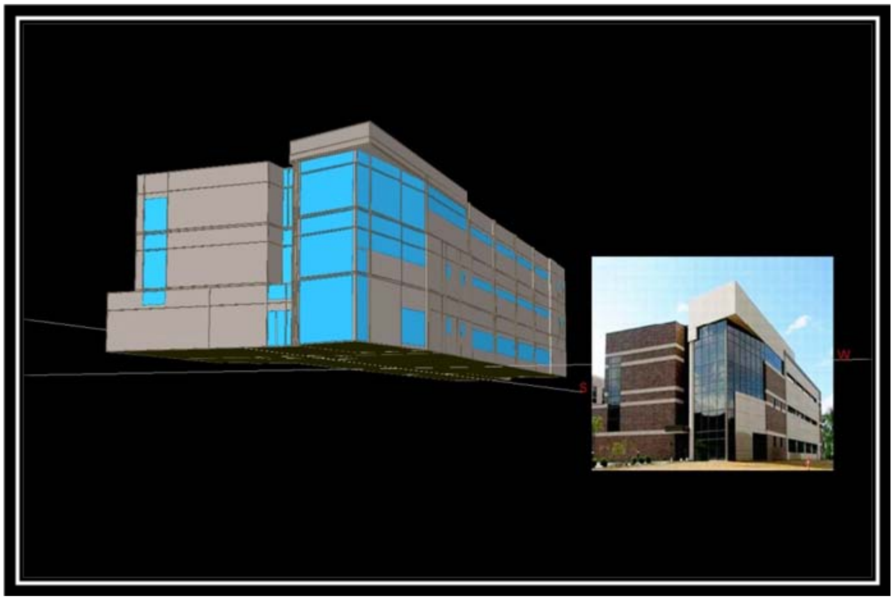


Figure 19. AFIT, Bldg. 20646, WPAFB (Area B)

Figure 20. AF Materials Lab, Bldg. 20653, WPAFB (Area B)

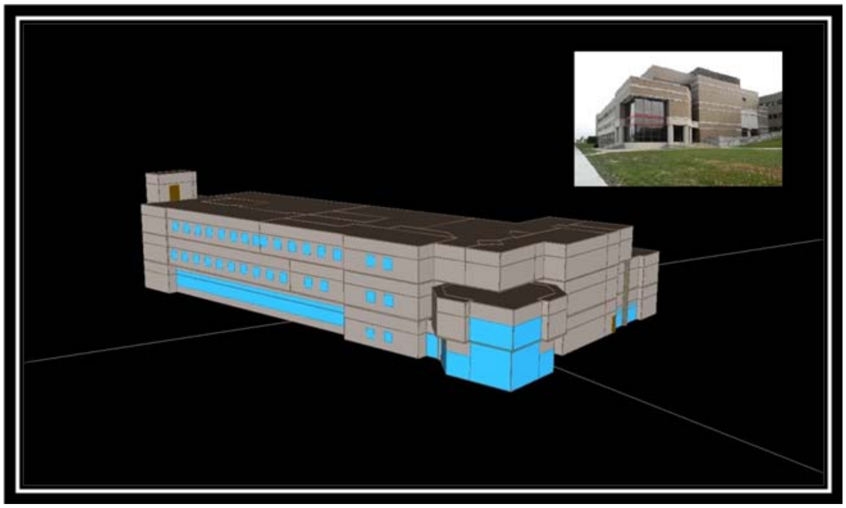


Figure 21. Civil Engineer & Services School, Bldg. 20643, WPAFB (Area B)

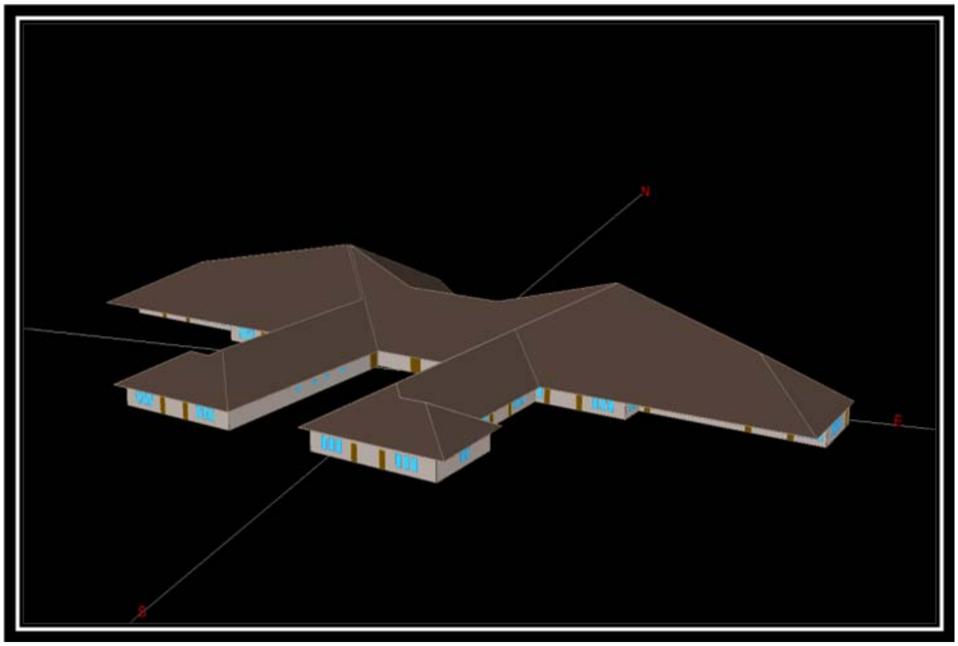


Figure 22. WPAFB CDC, Bldg. 20630, WPAFB (Area B)

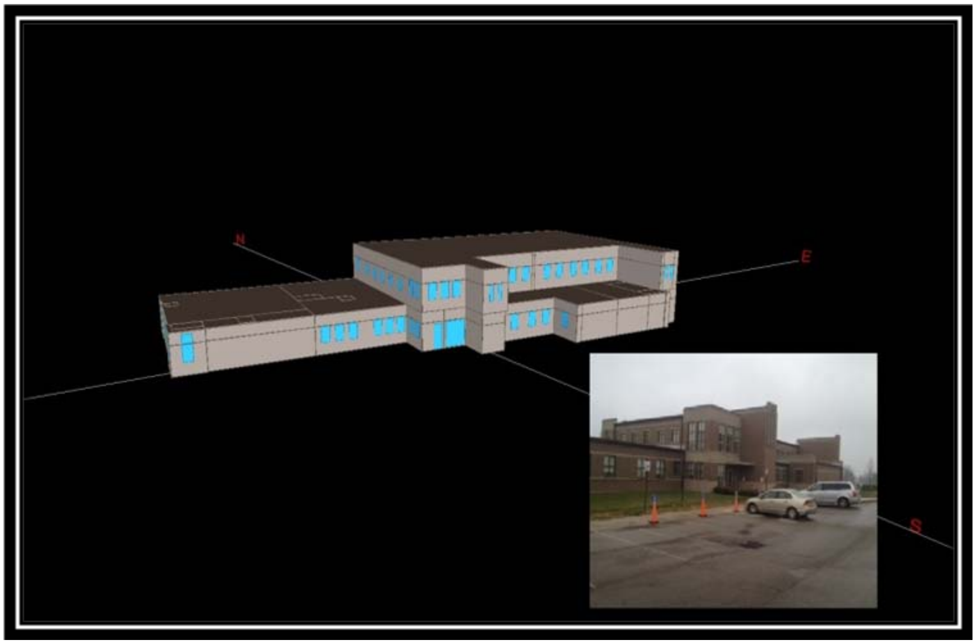


Figure 23. Occupational Medicine, Bldg. 20675, WPAFB (Area B)

Appendix H. Success Stories - Whole Building Retrofits

There are a number of success stories which can be lauded to support whole building retrofits and the integrative design process. Upgrade projections in a recent retrofit effort for the Empire State Building under a whole building design process have revealed approximately 38% in savings [50]. This was far more than the traditional 15-20% expected for single system approach over time. The U.S. General Services Administration's (GSA) work on the Byron G. Rogers Federal Office Building and U.S. Courthouse in Denver, Colorado was also projected to reduce facility consumption by 70% each year [51]. The structure was 620,000 square feet and provided space for 11 federal agencies. Even the Center for EcoTechnology's (CET) renovation of 100 year old, 60,000 square foot, facility into a non-profit recycled construction materials retail establishment to save 60% in energy costs was a prime example of the benefits of the holistic retrofit process [52]. The work was completed in partnership with Columbia Gas of Massachusetts. Furthermore, a recent report issued by the New Buildings Institute (NBI) on 49 different U.S. buildings achieving 40% reductions in energy usage endorsed deeper retrofits as achievable and profitable [53]. These ideas have even taken off in the housing industry. National Grid's, a Massachusetts utility company, Deep Energy Retrofit (DER) pilot program is slashing homeowner energy costs to 85% less than a typical home [54]. Although these cases vary in scope, they clearly demonstrated the validity of whole building retrofit ideas and that success can be achieved for maximum benefit.

Appendix I. Existing Guidance to Engineers

I.1 Existing Guidance for Engineers

Energy use for existing facilities is a major factor in overall energy consumption for both the United States and the Air Force. Recent studies have indicated that in the U. S. alone energy use for existing facilities is attributed to 40% of its consumption levels [21]. Acknowledging its role, both the federal government and DoD have issued guidance on reducing both existing facility and overall energy consumption. It is through a review of this guidance that the benefits of whole building retrofits and operations become evident to aiding both the DoD and government in their quest for energy savings.

I.1.1 Government Setting The Path

Some of the earliest legislation released by the federal government to deal with energy issues can be traced to Executive Order (E.O.) 13123 authorized in 1999. Signed into effect by President Clinton, the measure spurred energy efficiency in federal buildings, increased renewables, and slashed greenhouse gas emissions [55]. Numerous measures were enacted over several years, but one of the most significant was the Energy Policy Act (EPAct) of 2005. This measure impacted the DoD resulting in the following: revisions to energy reduction goals, the creation of Renewable Energy (REC) purchase goals, a reauthorization of Energy Savings Performance Contracts (ESPCs), mandates in the government to purchase ENERGY STAR designated products, and revisions in green building standards [56]. A last provision included a requirement for advanced metering in facilities. After EPAct, later improvements were made to its goals by the National

Defense Authorization Acts (NDAA) of 2007 and 2008 [57]. These alterations required the DOD to boost their renewable energy generation capacities through REC purchases or power plant developments on federal property. Further measures to improve existing federal energy goals were mandated by President Bush in 2007 when E.O. 13423 was signed into action [58]. These efforts spurred efficiency improvement requirements for the federal government and its operations.

Despite all of the above, the most significant piece of legislation is universally considered the Energy Independence and Security Act (EISA) of 2007[59] . The legislation's main purpose was to re-establish energy goals and amend the National Energy Conservation Policy Act (NECPA). Provisions in the act included: federal facility based energy reduction goals, facility benchmarking, performance standards for new construction and renovations, utility metering, ESPCs, energy efficient product procurement, Office of Management and Budget (OMB) reporting, reduced petroleum use, and increased alternative fuel use. Specifically, in terms of reduction goals for federal facilities, the law required the government move toward obtaining an 2.0% reduction in energy intensity of real property between FY 2006 and FY 2015 for a total of 30% in cuts. Federal agencies were now formally required to track energy usage for all facilities that constitute at least 75% of the agency’s facility energy usage. For new construction and major renovations, construction proposals for new federal facilities were now required to estimate energy performance from project design, and provide descriptions of for energy efficiency measures included in the facility. Both sustainable design principles and highly efficient lighting were also mandated for federal projects. Renovations of facilities were now expected to be highly energy efficient and life cycle cost effective. Lastly, federal agencies were also instructed to develop a process to review decisions on capital energy investment projects to ensure minimum requirements were met.

These mandates and legislative acts were the main drivers behind the USAF push to increase their energy efficiency in facilities and reduce overall consumption. They resulted in the Air Force making large improvements in the overall way they conducted operations. Several interdepartmental USAF policies arose from these efforts to lead the organization to success. Unfortunately, with these lofty goals, the current costs of energy, and an endlessly decreasing DoD budget, the USAF has to re-approach their current methodology for pursuing savings.

I.1.2 The Air Force Response To The Challenge

An analysis of the policies released by the USAF in response to federal energy legislation provides a detailed perspective on the USAF's view of their current energy addiction, previous reduction efforts, and possible future courses of action.

I.1.2.1 The USAF Infrastructure Energy Strategic Plan(2008/2010)

The USAF Infrastructure Energy Strategic Plan was one of the first attempts to formalize Air Force energy policy [60]. Released in 2008, the document was drafted in response of the need to limit energy related national security risk, reduce strain on U.S. infrastructure systems, and respond to global warming. Some of its tenants included:

reducing costs by 20% by 2020, reducing energy intensity by 3.0% per annum, decreasing water use by 2.0% per annum, increasing renewables to specific targets, cutting ground fuel use by 2.0% per annum, and increasing alternative fuel use by 10% per annum. Within these goals, the plan was structured around four pillars which included: improving current infrastructure, improving future infrastructure, expanding renewable energy sources, and managing costs. Moving toward a USAF wide cut in energy intensity of 30% by FY2015, the plan targeted large efficiency improvements of the USAF physical infrastructure and real estate with an aid of a positive return on investment. Enablers to goal facilitation included: planning, programming, budgeting, decision management, and energy awareness.

An update of the plan was released in 2010 describing many of the same goals and policies [6]. However, this version also championed the progress that made by the Air Force in their energy reduction efforts of the past, while guiding officials towards existing infrastructure to gain the remaining savings needed to meet USAF objectives. As a unique addition, this version also described in great detail the increasingly dire situation officials were faced with in terms of rising energy costs and goal expectations. Savings generated by all past reduction efforts were being decimated with a rise in the average unit cost of energy. It was due to issues like these that the publication called for aggressive tactics.

I.1.2.2 The USAF Energy Plan

The Air Force Energy Plan was released in 2009 to provide a common operating point for personnel on energy policy and operations [27, 61]. The plan was built on three pillars of equal importance which include: reduced energy demands, increased energy supplies, and execution of a culture change. These pillars were designed to provide appropriate guidance for energy management personnel within the Air Force. Overall, this document was primarily geared towards reducing all forms of Air Force energy usage rather than solely infrastructure.

I.1.3 USAF Energy Project Funding

A look at the financial requirements for project funding under USAF policy reveals officials are clearly not geared to whole building concepts [62]. Looking at achieving maximum paybacks on projects, the criteria strains innovation in the pursuit of energy savings looking for the quickest return on investment. Basic qualifications for energy projects mandate a savings to investment ratio (SIR) greater than one and a simple payback (SPB) period of less than ten years. More requirements are in place for upgrades to individual systems testifying to a current USAF mindset which must be altered to respect creativity.

Appendix J. Facility Energy Modeling-Background

Facility modeling brings a facility's location, square footage, volume, purpose, performance, cost, construction scheduling requirements, and occupancy together for the purpose of simulating a facility's systems and make predictions about its behavior [17]. Software can analyze the effect of any design change to make inferences on its effect on overall annual energy consumption. With these capabilities, modeling is moving beyond new construction to allow engineers to examine both financial and environmental criteria for renovation projects. This allows owners and operators to obtain a better understanding of their property and its daily operations. With these facts, architects and engineers can project alternatives to current systems which maximize energy savings. Modeling is moving toward enabling and optimizing the planning process for many efforts.

Appendix K. Modeled Thermostat Set Point Strategies

Table 16. Thermostat Set Point Strategies

Thermostat Strategy	Description
SRP Net	▪ Winter: - Occupied/Unoccupied -Heating:65°F/60°F -Cooling: 68°F/65°F ▪ Summer: -Occupied//Unoccupied -Heating: 78°F/80°F -Cooling: 80°F/80°F
Federal Guidelines	▪ Winter/Summer -Occupied/Unoccupied -Heating: 68°F -Cooling: 78°F
WPAFB	▪ Winter/Summer -Occupied/Unoccupied -Heating: 70°F -Cooling: 76°F
Thermal Comfort	▪ Winter/Summer - Occupied/Unoccupied -Heating: 70.7°F/67.1°F -Cooling: 73.4°F/78.8°F
General Services Administration	▪ Summer - Occupied/Unoccupied -Heating: 74°F -Cooling: 78°F
Energy Star Portfolio	▪ Winter/Summer:

	- Occupied/Unoccupied -Heating: 70°F/62°F -Cooling: 85°F
Energy Conservation & Building Management Strategies	▪ Winter: - Occupied/Unoccupied -Heating: 68°F/55°F -Cooling: 72°F/55°F ▪ Summer: -Occupied//Unoccupied -Heating: 74 °F/85°F -Cooling: 78°F/85°F

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14. ABSTRACT

The United States Air Force needs aggressive new techniques to compliment its asset management style control over its own real estate portfolio. Unfortunately, Air Force officials are facing budgetary issues that have been leading to degraded facilities infrastructure. Two areas of operations where opportunities can reveal themselves are roof maintenance and facility retrofits. Research revealed via a geospatial information systems analysis that the current state of the rooftop maintenance program was in disrepair and supported strategic sourcing as a potential solution to deficiencies. Two methodologies were also created to gauge the effectiveness of whole building retrofits and define a facility energy efficiency term to use to channel efficiency upgrade dollars. Modeling efforts further supported the need for investigation into whole building retrofitting techniques and demonstrated that they can produce at maximum 20% to 50% in annual energy savings in USAF facilities. An additional 2.0% in free synergistic efficiency gains was also found when comparing whole building retrofit projects to existing approaches. Overall, this research established there were areas for improvement in the United States Air Force asset management policies for roofing maintenance and facility retrofits suggesting paths to better management and savings.

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