EXECUTIVE SUMMARY

Intelligent Building Management with Holistic Digital Lighting

ESTCP Project EW-201720

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Project: EW-201720

TABLE OF CONTENTS

Page

1.0 INTRODUCTION 1
2.0 OBJECTIVES 1
3.0 TECHNOLOGY DESCRIPTION 1
4.0 PERFORMANCE ASSESSMENT 3
  4.1 LIGHTING 3
  4.2 PLUG-LOADS 3
  4.3 HVAC 4
5.0 COST ASSESSMENT 4
6.0 IMPLEMENTATION ISSUES 5
7.0 REFERENCES 5

LIST OF FIGURES

Page

Figure 1. Office Area with New LED Lighting Systems Installed. 1
Figure 2. Office Area with Original Baseline Fluorescent Lighting Fixtures. 2
Figure 3. High-bay Area with Original Baseline Lighting Fixtures. 2
Figure 4. High-bay Area with New LED Lighting Systems Installed. 3

ACRONYMS AND ABBREVIATIONS

ACST	Advanced Connected Sustainability Technologies
AFB	Air Force Base
AIRR	Adjusted Internal Rate of Return
BEA	Business Energy Advisor
BLCC	Building Life Cycle Cost
BTU	British Thermal Unit
CERL	Construction Engineering Research Laboratory
DoD	Department of Defense
EIA	U.S. Energy Information Administration
ERDC	Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
EW	Energy and Water
HBS	Honeywell Building Solutions
HVAC	Heating Ventilation and Air Conditioning
kW	Kilowatt
kWh	Kilowatt-Hour
LED	Light-emitting diode
NIST	National Institute of Standards & Technology
OC/ALC	Oklahoma City Air Logistics Complex
SERDP	Strategic Environmental Research and Development Program
SIR	Savings-to-Investment Ratio
TLED	Tubular light-emitting diode

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1.0 INTRODUCTION

Light has a profound impact on people. Beyond basic visual needs, light also influences the health and wellness of building occupants. Light directly consumes about 30% of the energy in typical office buildings and up to 60% in typical non-refrigerated warehouse buildings (Business Energy Advisor [BEA-2016]). As many buildings in the Department of Defense (DoD) portfolio start to age, lighting retrofit projects become cost effective, but not all solutions offer the same savings. The opportunity cost of realizing only mediocre savings with an energy retrofit represents 15 to 20 years of lost opportunity.

2.0 OBJECTIVES

The objectives of this project were to demonstrate energy reductions from lighting, Heating Ventilation and Air Conditioning (HVAC), and plug-loads at Tinker Air Force Base (AFB) in Oklahoma City, OK, in both an office area (5,000 ft^2) and a high-bay area (21,000 ft^2), through a commercially available advanced lighting control system by integrating the dense sensor network from the lighting system with the pre-existing Building Management System and enable occupancy-based HVAC control.

3.0 TECHNOLOGY DESCRIPTION

This project, EW-201720, demonstrated the deep energy savings possible by going beyond simple lamp replacements and instead incorporating advanced lighting controls enabled by a fine-grained sensor network with light-emitting diode (LED) luminaires. The project developed a holistic method to lighting retrofits, applicable to both high-bay and office environments on military installations. This holistic method integrated sensed occupancy needed for the advanced lighting controls into the building automation system and optimized the HVAC control and plug-loads accordingly.

Other lighting retrofits incorporate ambient light sensors and occupancy sensors, but at a much coarser level. While those attempts need to control a zone of lighting around each sensor, this innovative approach to combine the sensor with the luminaire allows for a finer level of control which translates into deeper energy savings.

Figure 1. Office Area with New LED Lighting Systems Installed.

Phase 1: Pendant design with direct/indirect lighting (left), and Phase 2: Troffer design (right).

Figure 2. Office Area with Original Baseline Fluorescent Lighting Fixtures.

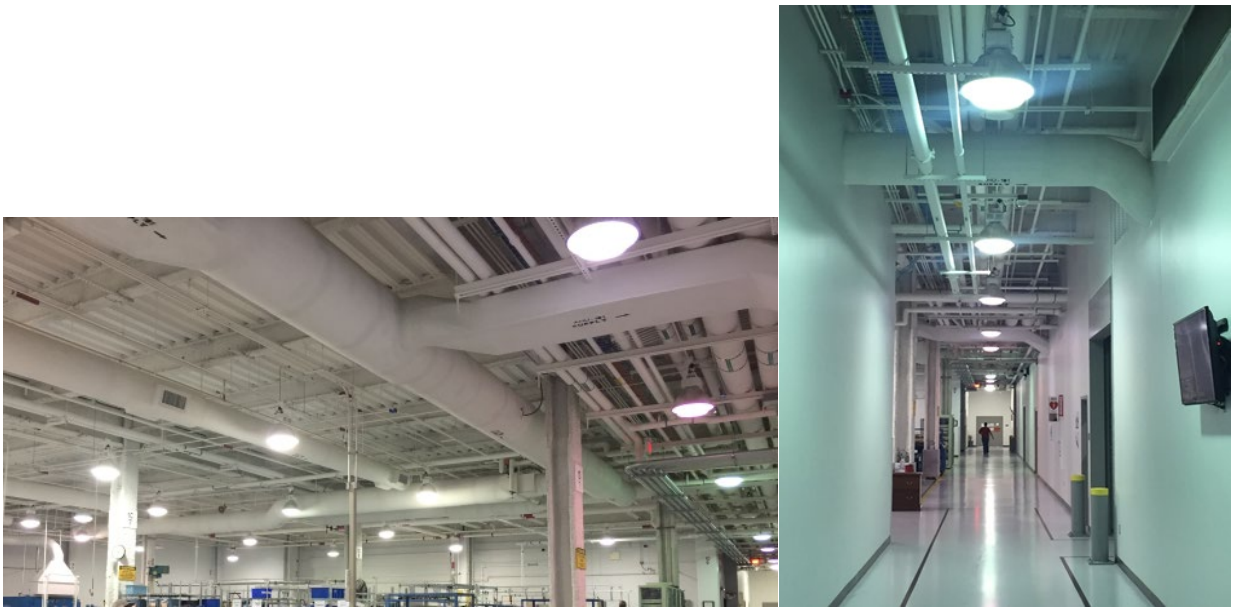

Figure 3. High-bay Area with Original Baseline Lighting Fixtures.

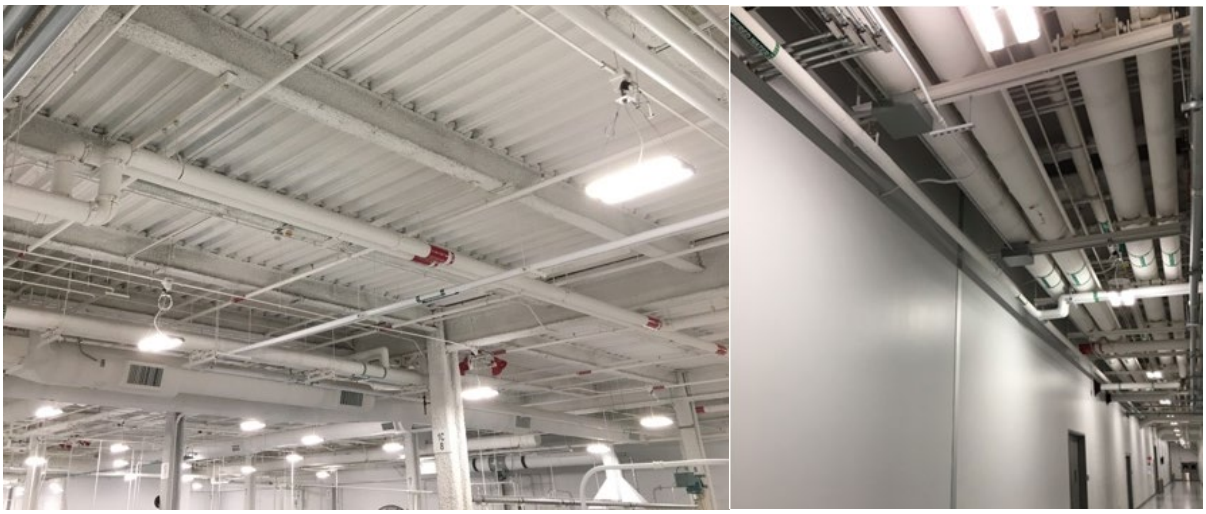

Figure 4. High-bay Area with New LED Lighting Systems Installed.

4.0 PERFORMANCE ASSESSMENT

4.1 LIGHTING

The Enlighted lighting system achieved an energy savings of 69% of baseline usage in the high-bay area over the high-bay demo period. In the office area, the pendant fixtures achieved an energy savings of 71% of baseline usage over the pendant demo period. The troffer fixtures achieved an energy savings of 67% relative to baseline usage over the troffer demo period. While the overall energy savings did not meet the target goal of 80% reduction, the savings remain notably substantial and may meet or exceed this target goal in spaces with more daylight. The lower level of energy savings achieved by troffer lights (compared to pendants lights) is explained by decreased level of occupancy-based savings for troffer lights. This was due in part to overly-sensitive occupancy sensors in the troffer demonstration. This caused troffer lights to remain powered at times throughout the night when the workspace was unoccupied, increasing energy consumption relative to the pendant lights (whose occupancy sensors were not abnormally sensitive). For further discussion, see Section 8.1.4.

4.2 PLUG-LOADS

The energy savings achieved by plug-loads over the demo period was 4% of the baseline for total plug-load energy consumption over the demo period. This did not achieve the plug-load performance objective goal of 20% energy reduction relative to baseline. The failure to meet the performance objective can be explained by the behavior of the occupants in the office space, who predominantly connected electrical appliances into uncontrolled plugs instead of occupancy-controlled plugs. For instance, energy consumption from controlled plugs during the baseline period was 17% of the total plug consumption. During the demo period, the energy consumption of controlled plugs was 6% of the total plug energy consumption. The project team notes that during the demo period, the energy consumption of uncontrolled plugs was 90% of the baseline total consumption. Hence, even if (hypothetically) controlled plugs had used no energy during the demo period, they would have achieved a savings of at most 10% of the baseline, and the savings target of 20% reduction would not have been reached.

Comparing the energy savings achieved by controlled plugs in the demo period to the baseline energy consumption of controlled plugs only, the savings is 38% of baseline. Thus, occupancy-controlled plugs achieved substantial energy savings relative to their baseline energy consumption with occupancy control disabled. Hence, the project team concludes that the primary limiting factor in realized energy savings was the limited usage of controlled plugs by the office space occupants.

4.3 HVAC

Occupancy-based control of the HVAC system achieved an energy savings of 30% of baseline consumption in the high-bay. This greatly exceeded the performance objective of 20% savings. In the office area, occupancy-based control achieved a savings of 12% of baseline. Hence, the office area did not achieve the performance objective. The project team believes this was caused by the occupancy sensors, which became overly sensitive in the office area during the second Phase of the demonstration (after May 1, 2019). The sensors intermittently detected occupancy during overnight periods when the space was actually unoccupied. This interfered with the energy savings of the HVAC system, since HVAC setbacks are not applied when occupancy is detected in a zone. The energy savings of the total system (office + high-bay areas) was 26% of the total baseline, which did meet the performance objective.

5.0 COST ASSESSMENT

The National Institute of Standards and Technology (NIST) BLCC5 tool was used to assess the costs of this demo system against a cheaper base case upgrade option (Tubular light-emitting diode [TLED] lighting retrofit only, without holistic building management). The total costs of this demo were calculated as $124,747 (with pendant light fixtures in the office area), compared to an estimated $26,000 for TLED retrofit. Assuming Oklahoma industrial energy prices*, which are quite low—$0.0524/kWh for electricity and $1.81/MMBtu for natural gas, this demo system achieves simple payback in **17 years** (assuming a 20-year study), with a Savings-to-Investment Ratio (**SIR**) of **0.93** and an Adjusted Internal Rate of Return (**AIRR**) of **2.64%. (**Discounted payback is not reached in a 20-year study.) Oklahoma energy prices have witnessed dramatic declines in the past four years due to increased domestic energy production, which decreased the cost effectiveness of the demo solution. However, the demo is quite cost effective in locales with higher energy prices: assuming California industrial energy prices* ($0.1527/kWh for electricity, $6.84/MMBtu for natural gas), simple payback occurs in 6 years and discounted payback in 7 years, with **SIR** of **2.86**, and **AIRR** of **8.53%**. Assuming average U.S. industrial energy prices* ($0.0744/kWh for electricity, $3.09/MMBtu for natural gas), simple payback occurs in **12 years** and discounted payback in **14 years**, with an **SIR** of **1.34** and **AIRR** of **4.51%**. The cost effectiveness has been impaired by extraordinary declines in energy prices. However, the system is still an attractive investment option at prevailing U.S. average energy prices, and it is very attractive assuming higher energy costs such as California energy prices, climate areas with a significant heating or cooling load, installations with abundant natural lighting for daylight harvesting, or buildings with periods of sparse or intermittent occupancy. Furthermore, energy savings could be enhanced by stricter or more aggressive configurations with smaller groups of lighting fixtures or shorter occupancy-controlled timeouts.

(*Energy prices from eia.gov as of August 2019).

6.0 IMPLEMENTATION ISSUES

Cyber security concerns caused some issues with the project. First, the approval process delayed the demonstration start date. Furthermore, cyber security constraints caused control and data issues with the HVAC system. For instance, duplicate IP addresses and network congestion disrupted the operation of HVAC control devices, resulting in data loss. The strict cybersecurity policies restricted the project team's ability to run diagnostic tools, troubleshoot communication issues, and debug faulty devices at the site, which impaired the project team's ability to promptly detect and resolve the issues. Integration of the HVAC system proved challenging due to significant mechanical defects with the HVAC system. A few smart occupancy sensors caused issues with sensitivity, with some reporting false positives, and others false negatives. Finally, the plug-load controllers also initially faced an issue with no connectivity or communications to the controller because of mismatched firmware versions. Although these issues caused delays in the project, or reduced the effective demonstration period, ultimately all issues were addressed and resolved.

7.0 REFERENCES

Business Energy Advisor – Managing Energy Costs in Warehouses. 2016.
https://fpl.bizenergyadvisor.com/warehouses