# THE ECONOMIC FEASIBILITY TO REDUCING ENERGY USE IN LARGE COMMERCIAL U.S. AIRPORT BUILDINGS THROUGH LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN (LEED) CERTIFICATION

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**ABSTRACT**

There is a growing movement in the U.S. (e.g., airports) to obtaining LEED (Leadership in Energy and Environmental Design) certification to reduce energy use. LEED advocates assert, on average, 25% less energy used by LEED-certified buildings compared to conventional commercial buildings. In the absence of studies regarding large U.S. LEED commercial airport buildings, a systematic quantitative review, content analysis and SWOT was performed to determine the economic feasibility of reducing energy use in airport buildings. A systematic quantitative literature review, combined with a comparison of LEED cost-benefit studies, and LEED certification objectives - to - airport facility energy requirements and U.S. government energy reduction initiatives was performed. Positive and negative (Pro/Cons) energy reduction findings were catalogued, charted, and analyzed. The findings from 1) LEED commercial building studies, 2) the LEED cost-benefit studies, and 3) the comparison of LEED certification program to large commercial U.S. airport energy requirements and trends were synthesized using a SWOT analysis. In aggregate, there was negligible correlation between commercial U.S. building LEED certification levels and energy use reduction. In spite of noteworthy findings regarding on-site energy reductions, there was insufficient evidence to suggest that LEED reduced overall (site and source) energy use. Therefore, little evidence supports the cost-effectiveness and economic feasibility to reducing energy use simply through the LEED certification process. This study presents the pros and cons in applying LEED certification to reducing energy use in commercial airport buildings.

**KEYWORDS**: airport, commercial buildings, cost/benefit, energy, LEED certification, SWOT.

## 1. INTRODUCTION

Commercial building energy use ranks among the highest costs in commercial U.S. airports (El Choufani, 2016), thus, facility energy efficiency is a high priority for airport management. Because of the large heating, cooling, lighting, and automation requirements of airport buildings - such as terminals, air control towers, hangers, parking facilities, etc., proactive management must find innovative ways to control and reduce energy use. LEED certification offers a systematic alternative to most traditional building and operational practices and asserts "25% less energy on average used by LEED buildings compared to commercial buildings" (USGBC, 2020, p. 1).

This study focuses on examining current literature involving U.S. commercial building energy trends, requirements, and performance to assess the feasibility of LEED certification to reducing energy use in large commercial U.S. airport buildings. The study includes a systematic quantitative literature review of published peer-reviewed studies examining LEED certified commercial building energy use and an analysis into LEED certification objectives and criteria, airport facility energy requirements and use, and U.S. government energy reduction initiatives to determine if LEED certification is economically feasible. The research study parameters focus on the economic feasibility of LEED certification in reducing energy use in large commercial U.S. airport buildings. Because of the scarcity of U.S. airport related LEED certification literature obtained searching the internet, and time limitation of the study (March – May 2021), a systematic quantitative online search included peer-reviewed English language literature involving U.S. LEED certified commercial building energy management studies covering the past 20 years. In addition, a comparison of LEED certification objectives and criteria to airport facility energy requirements and U.S. government energy reduction initiatives was performed to determine if LEED certification is economically feasible.

## 2. LITERATURE REVIEW

### 2.1 Commercial Building Energy

Scofield & Cornell (2018) explained the two common definitions for building energy in the U.S. are "site energy", and "source energy" (also referred to as primary energy). Site energy is the annual purchased energy used within the building's limits. Annual site energy is calculated by adding the British thermal units (Btu's) in natural gas and/or electricity fuel purchased for a 12-month period. Building site energy is typically referred to as "building energy". To determine a building's site Energy Use Intensity (EUI), annual site energy is divided by the building's gross floor area, also referred to as gross floorspace (gfs). Floor area is determined and expressed in squared meters or feet (m2 or ft2). Site EUI is expressed in Btu/ft2.

Scofield & Cornell (2018) emphasized site energy and EUI do not account for off-site energy losses associated with producing fuels and transporting them to the building site; an important distinction, because off-site energy losses must be considered in making energy policy or evaluating the total resource consumption, energy costs, and/or environmental impact of a building. They further explained off-site losses are particularly relevant to electric energy mostly generated from combustion processes at power plants running at approximately 35% efficiency. "Primary energy" is energy which can be harvested through solar, wind, natural gas, coal, hydro-power, and nuclear capability. Electricity is a secondary form of energy which cannot be harvested; it is produced from a primary source of energy (Scofield & Cornell, 2018).

## 2.2 LEED to Reducing Commercial Building Energy Use

LEED (Leadership in Energy and Environmental Design) is currently the dominant green building rating system in the world and the U.S. LEED is also the most widely used by U.S. Federal and state agencies, such as the Government Service Agency (GSA) (Pacific Northwest National Laboratory, Department of Energy, 2006; USGBC, 2020). LEED can be applied to most any building type. According to the LEED developers, the U.S. Green Building Council (USGBC, 2020), LEED is intended to provide a framework for achieving healthy, efficient, and cost-effective buildings. USGBC lists over 51,000 registered and certified U.S. commercial buildings and asserts 25% less energy on average used by LEED buildings compared to commercial buildings.

LEED energy use objectives and criteria. LEED certification is based on a scoring system allocating points (credits) to buildings from five categories: energy and atmosphere (EA), sustainable site (SS), water efficiency (WE), materials and resources (MR), and indoor environmental quality (IEQ); additionally, building projects can earn credits for "exceptional" performance or by showing innovation in design within the innovation and design process category (USGBC, 2020). Depending on the number of points earned, projects can receive a Certified (40-49 points), Silver (50-59 points), Gold (60-79 points), or Platinum (80+ points) designation after an independent, third-party verification (USGBC, 2020). One important aspect of LEED involves Commissioning, which includes verifying and documenting a building's systems and assemblies are designed as planned, installed, tested, operated, and maintained to the project requirements (USGBC, 2020).

LEED has undergone several revisions since version 1.0 debuted in 1998; the current version is v4.1. One of the most important categories, and essential to this research, is Energy and Atmosphere (EA), which covers roughly 30% of the total amount of credits (Amiri, et al., 2019). USGBC (2020) described the objective of the EA credit category is to promote better building energy performance through innovative strategies. The 11 EA categories in the rating system are listed in Table 1. While remaining focused on commissioning, green power and renewable energy, both cost and greenhouse gas emissions energy metrics were added with v4.1 in 2019; this included an energy performance metering requirement to track building consumption at least monthly for five years and report the data to the USGBC (2020).

| 0 | 0 | 0 | Energy and Atmosphere | | 33 |
|---|---|---|---|---|---|
| Y | | | Prereq | Fundamental Commissioning and Verification | Required |
| Y | | | Prereq | Minimum Energy Performance | Required |
| Y | | | Prereq | Building-Level Energy Metering | Required |
| Y | | | Prereq | Fundamental Refrigerant Management | Required |
| | | | Credit | Enhanced Commissioning | 6 |
| | | | Credit | Optimize Energy Performance | 18 |
| | | | Credit | Advanced Energy Metering | 1 |
| | | | Credit | Demand Response | 2 |
| | | | Credit | Renewable Energy Production | 3 |
| | | | Credit | Enhanced Refrigerant Management | 1 |
| | | | Credit | Green Power and Carbon Offsets | 2 |

Table 1. Rating Systems: LEED BD+C v4.1: Building Design and Construction.
Source: https://stellarfoodforthought.net/wp-content/uploads/2016/10/LEED-v4-BDC-Scorecard.png

## 2.3 Cost of LEED Certification

The LEED certification process Involves additional effort and expense (apart from traditional builds) involving project planning, registration, forms, fees, completed application submission, and more payment for reviews. The LEED application is then evaluated by a third-party credentialing and verification provider, Green Business Certification Inc. (GBCI), who provides the certification decision (USGBC, 2020). USGBC LEED Commercial Building and Design Fees are listed in Table 2. In addition, time and costs are involved in commissioning; all new construction must undergo a Fundamental Commission under the LEED rating system to ensure building energy systems are designed, constructed and calibrated to operate as planned (USGBC, 2020); these costs vary depending on the type of building, complexity of systems and building use.

Table 2. USGBC LEED Commercial Building and Design Fees.

## Building Design and Construction Fees

| Building Design and Construction Fees per Building | Silver, Gold and Platinum Level Members | | Organizational or Non-members | |
|---|---|---|---|---|
| Registration | $1,200 | | $1,500 | |
| **Precertification** | | | | |
| Flat fee (per building) | $4,000 | | $5,000 | |
| Expedited review (reduce from 20-25 business days to 10-12, available based on GBCI review capacity) | $5,000 | | | |
| **Combined Certification Review: Design and Construction** | **Rate** | **Minimum** | **Rate** | **Minimum** |
| Project gross floor area (excluding parking): less than 250,000 sq ft | $0.057 /sf | $2,850 | $0.068 /sf | $3,420 |
| Project gross floor area (excluding parking): 250,000 - 499,999 sq ft | $0.055 /sf | $14,250 | $0.066 /sf | $17,100 |
| Project gross floor area excluding parking): 500,000 - 749,999 sq ft | $0.050 /sf | $27,500 | $0.060 /sf | $33,000 |
| Project gross floor area (excluding parking): 750,000 sq ft or greater | Calculate pricing | | Calculate pricing | |
| Expedited review (reduce from 20-25 business days to 10-12, available based on GBCI review capacity) | $10,000 | | | |

Source: https://www.usgbc.org/tools/leed-certification/fees

Although empirical and projected data vary considerably, Northbridge Environmental Management Consultants (2003) determined LEED certification requirements added from 4 to 11% to a project's construction costs. Over 50% of costs were for investments in alternative systems, practices, and materials that earn points under the LEED system and go beyond standard practices. The remaining non construction, or soft costs, included incremental costs for design, documenting and verifying compliance through the commissioning process (Northbridge Environmental Management Consultants, 2003). Nyikos et al., (2012), in their analysis of cost premiums associated with sustainable facility design, construction cost, and utility data involving 160 LEED certified buildings, applied simple correlation and descriptive statistics and determined green cost premiums tend to increase on average from 2.5 to 9.4% (mean 4.1%) relative to the number of additional LEED points earned. Conversely, when evaluating the total building costs of two commercial LEED certified banks (under 5,000 ft2) with eight non-LEED bank buildings, Mapp et. al., (2011) determined the LEED building costs were within the same range as non-LEED buildings. Additionally, direct LEED certification costs were determined to be approximately 1.8% of total building costs. In investigating initial "green" premium costs of LEED-certified buildings versus conventional campus buildings (Hopkins, 2015) discovered mixed results regarding both upfront construction and full lifecycle costs when performing a cost-benefit study involving 16 higher education buildings. Although overall energy savings were reported, they found no relationship between LEED level (Gold, Platinum, etc.) and green premium costs or annual energy savings per square foot. To complicate matters, although project managers have the choice as to which criteria to select in accumulating LEED points, some government bodies, including the U.S. Navy, GAO, Maryland, New York, and Oregon, have mandated publicly funded projects apply for LEED certification. Northbridge Environmental Management Consultants' (2003) cautioned expanding certification requirements to additional districts would increase the cost of projects to the extent of exceeding potential benefits.

### 2.4 LEED Commercial Building Energy Use Studies

Peer-reviewed studies, using diverse research methods specific to U.S. commercial building energy use and LEED certification cost-effectiveness, were examined to better understand the benefits to LEED. A sample of the literature showed mixed results, often with disparate conclusions. For example, Newsham et al., (2009) re-analyzed data supplied by the New Buildings Institute and the USGBC by measuring energy use in 100 LEED certified commercial and institutional buildings and compared it to the energy use of the general U.S. commercial building inventory. They also examined energy use according to LEED certification level and energy-related credits, comparing the median EUI for the LEED buildings to the mean EUI in the national Commercial Buildings Energy Consumption Survey (CBECS) database. They concluded LEED buildings averaged 18-39% less energy ft2 than conventional buildings. Then again, 28-35% of LEED buildings used more energy than their conventional counterparts, and there was little correlation in measured energy performance of LEED buildings with their certification level, or their certified energy credits. It was concluded LEED buildings overall saved substantial energy compared to conventional buildings, but certification energy credits did not generally meet expectations.

However, Scofield (2009) was critical of Newsham et al. (2009) weighted average method in concluding LEED office building energy savings. Using a different weighted averaging method, accounting for the energy intensity of each building by gross ft2, yielded different means and significantly different conclusions. Schofield's analysis of the Newsom's et al. data focused on both on-site, and off-site energy. Schofield found both site and source energy in the same CBECS office buildings Newsham et al. examined to be statistically equivalent; there was no evidence LEED certification collectively reduced site or source energy for office buildings. While Scofield acknowledged the LEED buildings used, on average 10 -17% less site energy than comparable conventional buildings, it was argued Newsom et al.'s weighted average method for all commercial buildings, large and small, did not actually demonstrate an overarching reduction of site energy; particularly when very large office buildings used a greater amount of total commercial building energy and were less efficient than comparable conventional buildings.

In another study, Oates & Sullivan (2012) examined 25 of Arizona's 53 New Construction (LEED NC) higher education laboratory buildings to determine if they delivered expected energy performance, how they compared with non-LEED buildings, and if system or managerial variables correlated with efficiency. The study was designed around a five-page survey to facility managers or LEED consultants, the LEED credit score card, at least 1 year of energy data, and models associated with Energy and Atmosphere's (EA) Optimization Energy Performance credits. The variables were: site and source energy use, building gross ft2, and climate zones. Oates & Sullivan's results were mixed; LEED medium energy intense (MEI) buildings performed better on average than the national stock but worse than others located in similar climates. Also, the high energy intense structures performed substantially worse than national and similar climate averages, and the LEED buildings underperformed in baseline and design energy use simulations. Further, they determined there was little statistically significant energy consumption correlation. Oates & Sullivan (2012) concluded, "the LEED NC rating system's energy strategies failed to meet modeled efficiencies, highlighting a need for continued scrutiny and diligence when measuring sustainability and efficiency". (p. 1)

Kaddory et al., (2015) performed a documentary analysis of evidence related to the application of LEED building certification criteria and energy efficiency. They found 7 of 13 studies demonstrated improved energy efficiencies with LEED certified buildings; the other six studies showed some LEED buildings did not achieve significant energy efficiencies. They concluded the mixed results were largely due to research methodologies, the LEED system design, differences in occupancy reports, building energy uses, and different timeframes in construction.

### 2.5 Large Hub U.S. Commercial Airports and Buildings

The Federal Aviation Administration (FAA) defines an airport as "any area of land or water used or intended for landing or takeoff of aircraft including appurtenant area used or intended for airport buildings, facilities, as well as rights of way together with the buildings and facilities" (Airport Categories; Airports, 2021, para. 1). Operationally, airports are made up of two activities, the landside and airside. Landside areas include terminal and administrative buildings, parking lots, and access roads. Airside areas include taxiways, aprons, and runways (El Choufani, 2016). Large (Hub) commercial (service) airports are publicly owned with at least 2,500 annual enplanements and scheduled air carrier services; they are designated primary airports with more than 10,000 annual enplanements and make up 1 percent or more of the annual U.S. commercial enplanements (Airport Categories: airports, 2021). According to USGBC (2017) LEED certified buildings are increasingly prominent in the transportation industry and airports. There are registered and certified airport projects in most of the states. For example, California had nearly 100 registered and certified projects in 2017. Airport and commercial buildings have similar square footage and occupancy features, including offices, car rental centers, custom facilities, hotels, retail, support centers and terminals. USGBC reported terminals as the most common projects (USGBC, 2017).

How much demand do airports place on power sources? According to (Whiteman et al., 2015) airport energy demand depends on many factors, to include: geography and terrain, infrastructure, real estate, public policy, regulatory and compliance requirements, energy costs, tax credits, ownership, safety, security, staffing issues, and many others. El Choufani (2016) estimated terminal and building services consume roughly fifty percent of electrical energy in an airport and most of the natural gas consumption because of complicated air conditioning and heating (HVAC), ventilation, and other electrical/mechanical systems.

The Airport Cooperative Research Program (2010) estimated airport terminals use the preponderance of energy for lights, ventilation, HVAC and conveyance systems; with buildings, in general, accounting for 40% of the electric energy used in the U.S. The Orlando Utilities Commission (2020) estimated an average airport uses annually roughly 20 kilowatt-hours (kWh) of electricity and 35,000 Btu's of natural gas per square foot with lights and air conditioning using 46% of the overall energy. Not surprisingly, the Orlando Utilities Commission reported energy requirements make up about 10% to 15% of an airport facilities operating budget.

Airports can effectively manage energy expenses by understanding how they are charged for energy. Utility companies charge for natural gas based on the amount delivered. On the other hand, electricity is usually charged based on consumption and demand (Orlando Utilities Commission, 2020). Consumption is based on the amount of electricity, expressed by kilowatt hours (kWh) used in a month. The demand component involves peak demand in kilowatts (kW) per month. Also, because demand charges can widely range from $2 - $20 per kilowatt based on the highest peak recorded over 12 months, managing and reducing peak demand becomes a key management objective (Orlando Utilities Commission, 2020).

Managing energy efficiency from an energy consumption and energy supply standpoint is an effective reduction strategy (Büyükbay et al., 2016). Airports have eliminated unnecessary energy consumption using basic conservation strategies. For instance, HVAC zone management based on demand times, light timers, and educating employees and tenants on energy savings behavior, such as powering down appliances and computers, turning out lights and closing doors as they leave a space (Airport Cooperative Research Program, 2010).

Airports have also been improving operational and maintenance procedures, to include optimizing existing equipment, management systems and energy facilities, installing new energy efficient HVAC and lighting systems, and using renewable energy (Ortega & Manana, 2016). Importantly, Model for improving energy use in u.s. airport facilities (2007) explained energy rates, hours of operation, climate conditions, equipment efficiency, and accuracy of control systems are key factors in estimating payback periods (recoupment of investment) and the airport's overall approach to energy management.

Consequently, renewable energy supply management has been gaining favor recently due to ideal airport site locations, reduced installation costs, technological innovation and government funding. Large commercial airports often have expansive landscapes ideal for capturing renewable energy from the sun, water, wind, and thermal heat, thus, promising to be financially worthwhile. The ACRP (2010) described how several airports have used terminal roofs and land for geothermal, solar, and wind alternative energy systems. Interest in costly solar PV has been driven by government incentives, the expanding market and financial benefits from lease payments to airports, and electricity price stabilization strategies using long term contracts (Whiteman et al., 2015). ACRP (2010) concluded the "diversity of strategies and relative costs associated with airport energy efficiency and cost reduction ensures no two airports are equal, nor will they benefit the same from any improvement" (p. 42).

### 2.6 Government Funding and Energy Policy Influence

Miller et al. (2020) explained airport operators look for additional outside funding sources to offset expensive improvement projects. Airports receive revenue from a variety of sources; each with different rules, restrictions, and approving authorities determining how funds can be used. GAO (1998) reported airport funding sources, both public and private, to finance large expenditures and capital development, primarily come from federal and state grants, passenger facility charges (PFCs), airport and special facility bonds, and airport-generated income.

Federal sponsored infrastructure funding and financing for airports is tied to the FAA managed National Plan of Integrated Airport Systems (NPIAS). The majority of grants available are, however, restricted to the FAA's Airport Improvement Program (AIP) and used mostly for "airside" operations related to aircraft, such as runways, taxiways, aprons, and navigation aids (Congressional Research Service, 2019; Miller et al., 2020). AIP funding for airport commercial building energy reduction improvements appeared restricted. Funding can also come from state and local governments in the form of full or partial (matching) grants tied-to energy payback considerations based on airport characteristics, existing energy costs, airport ownership, public sustainability policies/programs, regulations, and/or safety requirements (ACRP, 2010). Costly solar photovoltaic (PV) systems investment and payback times, for example, depend largely on suitable site locations and rebates/incentives offered by utility companies, state, and federal agencies (ACRP, 2010). For example, in 2011, an extensive interior terminal building lighting upgrade at Eastern Iowa Airport was accomplished with a grant from the Iowa Office of Energy Independence matched by local funding.

In addition to grants, airport operators have turned to alternative financing mechanisms, such as energy service companies (ESCOs) and public-private partnerships for funding large projects (Outcomes of Green Initiatives: Large Airport Experience, 2014). Growing in importance to the Federal government and the FAA are sustainable "Green" policies and programs, resulting in guidance issued for energy management in airport terminal sustainability planning, for instance. According to the FAA (2018):

> *sustainability incorporates economic, environmental, and social considerations into planning, design, construction, operations, and maintenance through a concept called the "Triple Bottom Line." High and stable levels of (1) economic growth, (2) environmental quality, and (3) social responsibility are the three pillars of sustainability. In addition to the three pillars, the airport industry adds "operational efficiency" as an equal consideration. This is called the EONS approach (economics, operations, natural resources, and social responsibility) to airport sustainability. (p. 9)*

Important features to such federal, state and local government agency sustainability initiatives include energy efficiency, conservation, renewable energy, sustainable design and construction. As an example, all 15 major airports surveyed regarding green practices (Outcomes of Green Initiatives: Large Airport Experience, 2014) reported they had a sustainability policy in place, which included energy reduction. In another case, Phoenix Sky Harbor Airport (PHX), a city owned airport, followed city policy to use LEED for new and major building construction and renovations.

According to Miller et al. (2020), lease agreements between airports and tenant airlines also determines the distribution of financial risks. Further, differences in local government arrangements and physical assets impact an airports' ability to raise capital. To compound matters, airports have different cash reserves, planning delays, airline competition, and limited real estate. Further, public priorities and land-use policies also influence funding matters (Miller et al., 2020).

## 2.7 Airport LEED Certification Cost-Benefit

Airport project investments involve spending capital funds and other resources to create future profits, cost savings, and/or social benefits. A worthwhile investment should result in the future benefit comparing favorably to the expenditure of resources. Chen (1996) explained economic evaluation is critical to the investment appraisal by examining, quantifying, measuring, and comparing relevant factors using monetary expression (Chen 1996). An economic evaluation helps determine a project's chances of success.

Withstanding other factors, like compliance concerns, neighbors and community, and demonstrating leadership in the community, assessing the economic feasibility of using LEED to reduce energy use requires airport management analyze the monetary costs and benefits associated with the proposed building project. However, because a detailed economic evaluation, which includes fixed costs, variable costs, depreciation, working capital, and initial capital investment etc., can be time-consuming, Chen (1996) suggested a less complicated economic evaluation could provide sufficient information to determine whether or not to proceed to the next step. One such approach involves examining cost-benefit prediction studies to understand the relationships among green costs, strategies, and the benefits achieved to determine if the extra financial benefits outweigh the costs of green applications. Another approach is by applying a Strengths, Weaknesses, Opportunities, and Weaknesses (SWOT) analysis. SWOT "allows for the creation of a plan of actions necessary for using a company's strengths and for minimizing the effect of its weaknesses in order to increase the company's opportunities and lower the risk of threats" (Kolbina, 2015, p. 76).

Khoshbakht et al., (2017) examined the cost-benefit prediction methods used in green building studies. Their literature review showed considerable variation in the cost-benefits of green building due to the different methods used in estimation. Their review of cost-benefit prediction methods combined with a SWOT analysis of data collection and analytical approaches, revealed five major methods of data collection were used: subjective and objective studies, simulations, surveys, and meta-analysis; with most lacking validity and reliability, and including different degrees of bias. Their takeaway: "much of the current cost-benefit research lacked systematic and reliable methods for data collections and analytical approach" (Khoshbakht et al., 2017, p. 176). Pham, et al., (2020), investigated the selection of LEED version 4 credits and the additional costs and challenges for sustainable building projects and found although studies have analyzed previously collected data using statistical methods and data mining techniques to build a foundation for predictions and recommendations for future LEED projects, they analyzed a limited number of attributes (LEED credits) and used old data from projects under previous LEED versions. Pham, et al., (2020) concluded the LEED New Construction version 4 (LEED-NC-V4), which replaced

LEED 2009 for all new projects, had been significantly updated with several new credits being added, thus, creating a considerable gap in applying findings of previous studies to new projects.

### 2.8 Literature Review Summary

Although specific literature was not found regarding LEED certified airport energy effectiveness, studies have been performed on U.S. commercial buildings similar in size, purpose and energy criteria to analyze LEED's cost-effectiveness. Therefore, performing a systematic quantitative literature review of LEED certified commercial building energy studies, combined with a comparison of LEED cost-benefit studies, LEED certification objectives to airport facility energy requirements, and government energy initiatives, provides insight as to the economic feasibility of applying LEED to facilities planning and operational practices in reducing airport energy use.

## 3. METHODOLOGY

A systematic quantitative literature review, combined with a comparison of LEED cost-benefit studies, and LEED certification objectives - to - airport facility energy requirements and U.S. government energy reduction initiatives was performed to test the research hypothesis it is economically feasible to reduce energy use in large commercial U.S. airport buildings through LEED certification. A SWOT analysis was applied to examine the energy use savings and economic feasibility to using LEED, thus, assisting airport managers, operators and service providers in the selection of LEED certified projects in design, build, and maintenance applications. An online search included peer-reviewed English language literature involving U.S. LEED certified commercial building energy performance studies over the past 20 years. Data relating to studies evaluating the energy performance of certified commercial buildings was entered into an excel database. Data included bibliographic information, location of the research, subject descriptions, study methods and designs, population, study variables measured, and discipline of study. Data was obtained by searching the internet for peer-reviewed English language studies concerning actual energy consumption and savings of LEED commercial buildings. Safari was used as the search engine. Initially the words peer: reviewed: LEED: energy: building: U.S. were searched through by title for the period 2010 – 2021 were screened for inclusion.

Additionally, current LEED certification objectives and requirements were compared and contrasted with airport facility energy requirements, and U.S. government energy reduction initiatives found in the literature review. Relevant literature and content from magazines, journal articles, academic papers and books were obtained accessing the internet over the period of March through May 2021. Positive and negative (Pro/Con) energy reduction findings were catalogued, charted, and analyzed. The findings from 1) LEED commercial building studies, 2) the LEED cost-benefit studies (literature review), and 3) the comparison of LEED certification program - to - large commercial U.S. airport energy requirements and trends were synthesized using a SWOT analysis to assess the economic feasibility of reducing energy use in large commercial U.S. airport buildings through LEED certification.

## 4. RESULTS

### *Systematic Quantitative Literature Review of LEED to Reducing Commercial Building Energy Use Studies*

17 peer-reviewed studies, performed between the years 2000-2021, were found concerning actual energy consumption and savings of LEED commercial buildings. Collectively, the studies involved multiple authors, from different geographic locations, and research disciplines. LEED commercial building energy use studies ranged in topics from assessments of energy use in educational buildings in Florida (Agdas et al., 2015), to office buildings in New York city (Schofield, 2013), to the application of LEED building certification criteria in determining energy efficiency (Kaddory Al-Zubaidy, 2015), and cluster analysis to evaluate the simulated energy use of 134 U.S. LEED NC office buildings (Heidarinejad et al., 2014).

The studies included a mix of different commercial building sizes from 222 sq. ft. to over 200,000 sq. ft. (Heidarinejad et al., 2014). Sample size also ranged from modeling energy use in five LEED and 13 conventional buildings (Chokor & El Asmar, 2017) to benchmarking the municipal energy data of over 551 LEED buildings across 10 major cities (Scofield et al., 2021). The complete listing of authors', study titles, subject descriptions, geographic locations, and the populations examined are displayed in Table 3.

Table 3: Authors, titles, subject descriptions, geographic locations, and populations

| Author's & Study | Subject Description | Geography & Population |
|---|---|---|
| Agdas et al.(2015). Energy use assessment of educational buildings: Toward a campus-wide sustainable energy policy. | Energy consumption trends of 10 LEED-certified buildings and 14 non-LEED certified buildings at a major university in the US. | LEED & non-LEED campus Buildings University of Florida (UF), Gainesville, Florida, U.S. |
| Amiri et al. (2019). Are leed-certified buildings energy-efficient in practice? | Are LEED-Certified Buildings Energy-Efficient in Practice? | 26 studies of LEED-certified buildings US & canada |
| Chokor & El Asmar (2017). Data-driven approach to investigate the energy consumption of leed-certified research buildings in climate zone 2b | Investigates correlation between LEED certification and the actual energy consumption by a case study of LEED-certified research buildings in climate zone 2B from 2008-2011 | 18 buildings: 5 LEED-certified facilities and 13 non-LEED facilities. Climate zone 2B, U.S. |
| Heidarinejad et al.(2014). Cluster analysis of simulated energy use for leed certified u.s. office buildings. | Cluster analysis of simulated energy use for leed certified U.S. office buildings in 13 climate zones in the U.S., and vary in size from 222ft to ~199,999 ft | 134 U.S. LEED NC office buildings. US & canada |
| Hopkins (2015). Leed certification of campus buildings: A cost-benefit approach. | Cost-benefit analysis (LEED) buildings certified within the higher education sector | Sixteen institutions of higher education (IHEs). U.S. undisclosed locations. |
| Menassa et al. (2012). Energy consumption evaluation of u.s. navy leed-certified buildings. | Analyzed whether the 11 LEED-certified USN buildings have achieved the expected energy consumption savings | 11 U.S. Navy buildings. Undisclosed locations |
| Newsham et al. (2009). Do leed-certified buildings save energy? yes, but…. | Re-analysis of New Buildings Institute and US Green Buildings Council on measured energy use data from 100 LEED certified commercial and institutional buildings | 100 U.S. LEED certified commercial and institutional buildings. U.S. |
| Nyikos et al. (2012). To leed or not to leed: Analysis of cost premiums associated with sustainable facility design. | Analysis of cost premiums associated with sustainable facility design | 160 LEED certified buildings throughout U.S. |
| Oates & Sullivan (2012). Postoccupancy energy consumption survey of arizona's leed new construction population. | Postoccupancy energy consumption survey of arizona's leed new construction population | 25 Arizona higher education laboratory buildings. U.S. |
| McNaughton et al. (2018). Energy savings, emission reductions, and health co-benefits of the green building movement. | Energy savings, emission reductions, and health co-benefits of the green building movement | Commercial/institutional buildings; LEED buildings. Five countires & U.S. |
| Kaddory Al-Zubaidy. (2015). A literature evaluation of the energy efficiency of leadership in energy and environmental design (leed) -certified buildings. | A literature evaluation of the energy efficiency of leadership in energy and environmental design (leed) -certified buildings. | Commercial LEED certified buildings. U.S. |
| Sadatsafavi & Shepley. (2016). Performance evaluation of 32 leed hospitals on operation costs. | Performance evaluation of 32 leed hospitals on operation costs | LEED & non-LEED Hospital Buildings. Various States throughout Continental U.S. |
| Scofield, J. H. (2009). Do leed-certified buildings save energy? not really…. | Critical review of Newsham, et al., (2009) weighted average method in concluding LEED Office Buiding energy savings. | LEED certified office buildings. U.S. |
| Scofield, J. H. (2013). Efficacy of leed-certification in reducing energy consumption and greenhouse gas emission for large new york city office buildings. | Efficacy of leed-certification in reducing energy consumption and greenhouse gas emission for large new york city office buildings | LEED certified office buildings. NY U.S. |
| Scofield & Cornell. (2018). A critical look at "energy savings, emissions reductions, and health co-benefits of the green building movement". | Review of Harvard's "energy savings, emission reductions, and health co-benefits of the green building movement" methodoly. | Commercial/institutional buildings; LEED buildings. Five countries & U.S. |
| Scofield & Doane (2018). Energy performance of leed-certified buildings from 2015 chicago benchmarking data. | Energy performance of leed-certified buildings from 2015 chicago benchmarking data | Chicago, U.S. |
| Scofield et al. (2021). Energy and greenhouse gas savings for leed-certified u.s. office buildings. | Energy and greenhouse gas savings for 551 leed-certified U.S. office buildings. | 10 major U.S. cities |

A wide variety of conclusions were found regarding the effectiveness of LEED-certification in reducing commercial building energy use. Appendix A summarizes the major findings of each study. One study espoused the virtues of LEED certification. 12 studies concluded various degrees of energy savings (or not) depending on what method and variable (certification category, onsite energy, offsite-energy, and/or building characteristics, etc.) were considered; some determined although LEED buildings did not generally demonstrate energy savings, there were notable exceptions; others determined there were somewhat more advantages to LEED, depending on the particular variable. Four studies concluded there were no energy savings from LEED. The results of these three categories of LEED energy reduction findings and conclusions (Positive, Mixed, and Negative) are discussed in further detail.

*Positive LEED energy savings*: McNaughton et al., (2018) applied Harvard's Co-BE (Co-Benefits of the Built Environment) Calculator to determine (model) energy cost savings, emission reductions, and health co-benefits for six countries, including the U.S. They used data from the Green Building Information Gateway (GBIG) to estimate annual energy savings using a baseline energy use intensity (EUI) of conventional commercial/institutional buildings. EUI of LEED buildings was calculated from GBIG and compared to the benchmark to determine each fuel source's annual energy savings. Energy savings were translated into emission reductions for GHGs and pollutants. They determined energy use reductions varied significantly across different sub-regions due to floor space of LEED-certified projects and baseline energy intensity, and geographical distributions of energy reductions were different for each fuel type. They concluded an estimated 88.50 billion kWh of U.S. energy was saved from LEED-certified projects between 2000 to 2016.

*Mixed LEED energy savings*: In addition to the six studies discussed earlier in the paper (Hopkins, 2015; Newsom et al., 2009; Scofield, 2009; Oates & Sullivan, 2012; and Kaddory et al., 2015), there were an additional six studies with mixed conclusions regarding LEED certification energy savings. Amiri et al. (2019) analyzed 44 peer-reviewed article results concerning LEED energy-efficiency. Studied buildings varied in size, occupants, locations and climate zones. The results were ambiguous; 10 articles stated LEED certification indicated energy efficiency while eight papers concluded otherwise. The remaining papers did not take any position on LEED certification leading to energy efficiency. They concluded although LEED certification reduced energy use in higher levels of certification (Gold and Platinum), energy efficiency of LEED-certified buildings was questionable, particularly at lower certification levels such as Certified. They highlighted small sample sizes and different characteristics of buildings among the different studies which were crucial parameters in influencing findings.

Expanding on the costs of LEED-certification, Nyikos et al. (2012) analyzed cost premiums associated with sustainable facility design by collecting construction cost and utility data on 160 LEED certified buildings to determine if green cost premiums were justified. Variables included utility costs, energy intensity, and facility construction costs. Regarding energy conservation, LEED-NC certified buildings averaged 31% lower energy costs than conventional buildings. LEED certified buildings operating costs were also $0.70 per sf2 less than others. However, LEED cost premiums ranged from 2.5 to 9.4% with a mean of 4.1%; they determined because the median value was 30%, data more closely represented a normal distribution, thus, few statistically significant correlations among design variables. They cautioned following LEED criteria alone does not necessarily equate to cost effectiveness or successful sustainable design.

Scofield et al. (2021), applied municipal energy benchmarking data from 2016 to 10 major cities to evaluate LEED building energy and greenhouse gas savings. Annual energy use and greenhouse emissions were compared between LEED and conventional offices by city and in total. They determined mixed results; LEED offices showed 11% site energy savings but only 7% source energy and GHG emission savings. While LEED offices saved 26% in non-electric energy there was no significant savings in electric energy. Furthermore, LEED savings in GHG and source energy increased to 10% when compared with newer, non-LEED offices, but minimal correlation in savings for Existing Buildings (EB). Disappointingly, total site energy savings for LEED-NC was 11% lower than expected, and total source energy savings for LEED-EB was 81% lower than projected. Only gold-level LEED offices demonstrated statistically significant savings in source energy and greenhouse gas emissions. They concluded although there was wide variability in LEED building energy performance, LEED office buildings, on average, achieved statistically significant source energy savings and reductions in greenhouse gas emissions.

Scofield & Doane (2018) examined the energy performance of LEED buildings by applying 2015 Chicago benchmarking data; they cross-referenced the data of 132 commercial buildings, with greater than 50,000 ft2 each, with the U.S. Green Building Council's LEED project database. They applied 21 variables, including site and source energy, square footage, and different energy sources. Scofield & Doane concluded LEED buildings, in aggregate, used no less source energy than similar conventional buildings. However, they used roughly 10% less site energy than conventional buildings. Also, LEED offices demonstrated 10% lower site energy and 7% lower source energy than new conventional Chicago offices. Interestingly, no source energy was saved by any large building type.

Heidarinejad et al., (2014) applied a cluster analysis of simulated energy use in 134 new construction LEED office buildings to classify them into intensity clusters. They determined the Energy and Atmosphere Credit 1 intended to improve the energy performance of buildings has a direct correlation with the building clusters, whereby low intensity buildings benefitted from higher points. The study provided a quantitative evaluation demonstrating the disparity in energy intensities among high-performance office buildings because of unregulated internal process loads. They concluded improving assumptions and accuracy of internal process loads is required to predict energy performance in buildings. They recommended energy simulations guidelines and rating programs encourage common conservation practices for reducing internal loads for reducing total building energy use. They argued if certification energy assumptions are to be valid, unregulated process loads should be accounted for in the LEED design.

Menassa et al., (2012) performed an energy consumption evaluation of 11 U.S. Navy LEED-certified buildings by comparing their electrical use to the national averages for commercial buildings in the CBECS database. Seven of the 11 LEED buildings had electric energy savings compared to conventional Navy buildings. However, they found no direct correlation between LEED points obtained for Energy and Atmosphere (EA) and average electric savings. Navy LEED buildings consumed more electricity than the national CBECS averages. They highlighted not all buildings, new and old, had a standardized method of collecting utilities data (i.e., electric, natural gas) to provide a comprehensive set of data for analysis, thus preventing a full understanding and measure of energy performance to determine if the set metrics were achieved through LEED building design. Scofield (2013) compared 2011 energy consumption, GHG emission, and ENERGY STAR energy performance rating data for 21 LEED-certified office buildings to similar conventional building characteristics, time period, and location and climate zone to examine the effectiveness of LEED-certification in reducing energy use and GHG emissions in large New York City office buildings. Scofield determined LEED buildings, collectively, used the same amount of source energy and emitted the same amount of GHG as conventional NYC office buildings. Impressively, LEED Gold buildings showed a 20% reduction in source energy consumption and GHG emission than other buildings. However, LEED Certified and Silver buildings used more energy and emitted more

GHG than other NYC office buildings. They concluded there was no evidence LEED certification, except the Gold level, was progressing NYC any closer to carbon neutrality.

*Negative LEED energy savings*: Agdas et al. (2015) assessed the energy use of educational buildings and sustainable energy policy. Variables included energy efficiency, LEED building rating systems and sustainable energy policy. They concluded no statistically significant energy use differences were identified between certified and non-certified buildings, and the new construction LEED rating system's energy strategies failed to deliver modeled efficiencies. They highlighted the need for ongoing scrutiny and diligence when measuring sustainability and efficiency.

Chokor & El Asmar (2017) undertook a data-driven approach to examine the energy use of LEED-certified research buildings in climate zone 2B in southern California, Arizona and Texas. Eight performance models were applied to 13 non-LEED buildings, and modeled to five comparable LEED certified buildings. Variables included heating, cooling, and electricity data comparisons to actual energy consumption of the non-LEED benchmark. Results showed the failure of LEED certification in saving energy, with the average energy consumption of all LEED buildings higher than conventional buildings. Moreover, the authors showed an inconsistency in LEED building performance due to earlier defined building characteristics regarding energy performance and savings. Sadatsafavi & Shepley (2016) performed an evaluation of 32 LEED hospitals' operation costs by comparing the operation and maintenance costs of healthcare facilities of similar type, ownership, and location. The variables included energy efficiency, including on-site renewable energy. Energy clusters included Platinum, Gold, and Silver certified office buildings. They found there is still a high variability in the operation and maintenance costs of green healthcare facilities, just as there are with hospital buildings. Scofield & Cornell (2018) applied previous study findings (consensus) to critically review the Harvard group method/design assumptions used by McNaughton et al. (2018). They argued McNaughton et al. only examined LEED commercial buildings, assuming each consistently achieved the energy savings projected by the design team, and the fuel mix of LEED buildings is the same as the average of other buildings in the same region. Furthermore, many studies demonstrated buildings, on average, use more energy than design simulations. Scofield & Cornell pointed to research demonstrating LEED-certified buildings, on average, achieved little or no primary energy savings compared to conventional buildings; and any reduction in site energy is achieved through increased off-site energy use. Scofield & Cornell concluded the environmental benefits calculated by MacNaughton et al. is based on assumptions inconsistent with measured LEED building energy performance.

The Literature Review and Results provided information in determining the economic feasibility of LEED certification to reducing energy use in large commercial U. S. airport buildings by: 1) examining LEED energy performance and cost-benefit studies; 2) comparing LEED objectives and criteria to both U.S. commercial building stock and airport buildings (to include physical characteristics, purpose, location, energy requirements, and performance); and understanding government policy's effect on airport and/or LEED energy objectives, criteria, and costs.

## 5. DISCUSSION

The LEED commercial building energy use studies consisted of a substantial range of topics, methods, sample sizes, and variables resulting in divergent, and mostly inconclusive, determinations; one study was positive, the large majority (12) were mixed, and four studies concluded there was no energy savings from LEED-certified commercial buildings. Trends identified included the lack of a standardized, systematic collection method with actual energy usage data; many studies relied on surveys, simulations and literature reviews. Second, while there was evidence of "Gold" certified building effectiveness, in aggregate, there was scant correlation with LEED certification levels of commercial U.S. buildings reducing energy use as designed. Lastly, in spite of considerable findings in site energy reductions, there was insufficient evidence to suggest LEED reduced overall (site and source) energy use.

Two cost-benefit prediction studies examined the relationships among green costs, strategies, and performances to determine if the financial benefits outweighed the costs of sustainability applications. Both studies concluded the variations in methods of estimation, data collection, and analysis made it difficult to determine the cost-effectiveness and economic feasibility of using LEED-certification. Khoshbakht et al., (2017) examined the cost-benefit prediction methods used in green building studies and found there was considerable variation in the cost-benefits of green building because of different methods used in estimation. They also found most studies demonstrated poor validity and reliability, with varying degrees of bias. They concluded most cost-benefit research was deficient in applying systematic and reliable methods of data collection and analysis. Pham, et al., (2020), compared the LEED version 4 with the additional costs and challenges for sustainable building projects and determined previously collected data, used for predicting and recommending future LEED projects, only analyzed limited attributes (LEED credits) applying old data from previous LEED versions. They concluded the updated version made it difficult to apply the findings of previous studies to new projects.

According to the review of literature, airport buildings possess similar square footage and occupancy features as commercial buildings (USGBC, 2017), and energy requirements depending on the energy costs, geographic location, terrain, real estate, public policy, regulatory and compliance requirements, tax credits, ownership, safety, security, and occupant behavior (Whiteman et al., 2015). Airport buildings have similar energy demands as benchmark commercial buildings; with terminals and buildings consuming roughly fifty percent of electrical energy and most of the natural gas because of complicated air conditioning and heating (HVAC), ventilation, and other electrical/mechanical systems (El Choufani, 2016; Orlando Utilities Commission, 2020). Akin to other commercial building operators, airport managers focus on energy efficiency from a consumption and energy supply standpoint (Büyükbay et al., 2016) by applying basic conservation strategies and modern operational and maintenance procedures. Similar in practice to commercial buildings found throughout the U.S., airport building efficiencies also come from measures to improve and optimize existing equipment, management system and energy facilities, adding energy efficient HVAC and lighting, and through renewable energy.

LEED energy strategies can be applied to most any building type, with the Energy and Atmosphere (EA) credit covering roughly 30% of the total amount of LEED credits. The objective of EA being to promote better building energy performance through innovation. LEED certified buildings have become increasingly prevalent in airports (USGBC, 2017). The cost of LEED certification involves additional effort and expense, with costs varying depending on the type of building, complexity of the systems and building use; this holds true with airport projects. There are also similarities as to how airports manage and fund energy projects by applying a variety of methods, including commercial loans, municipal bonds, grants and self-generated income. However, funding unique to airports include specific federal and state grants, passenger facility charges (PFCs), and airport and special facility bonds (GAO, 1998). Airport operators also use alternative financing schemes like energy service companies (ESCOs) and public-private partnerships, for funding large projects (Outcomes of Green Initiatives: Large Airport Experience, 2014). Federal and FAA sustainability policies, programs, and funding restrictions impact economic, environmental, and social considerations given to airport design, construction, operations, and energy management; all factors which can influence airport energy project decisions dependent on rebates and financial incentives offered by utility companies, state, and federal entities (ACRP, 2010). Lastly, use-and-lease agreements between airports and tenant airlines can impact financial risk, and local government arrangements and the status of physical assets can affect an airports' ability to raise capital. To summarize and illustrate these complexities, and the feasibility in achieving airport energy reduction using LEED, a Strengths, Weaknesses, Threats, and Opportunities (SWOT) analysis is provided in Figure 2.

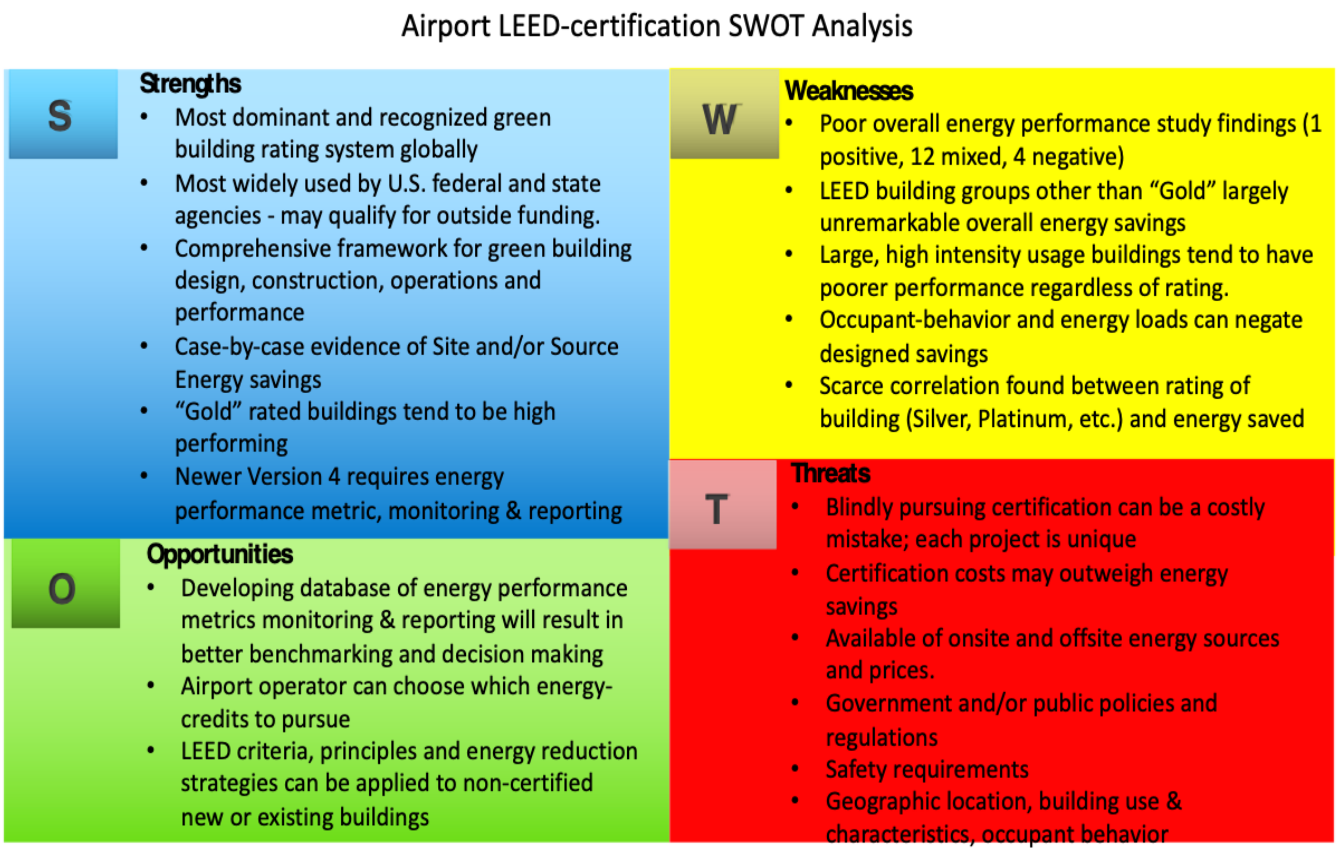


Figure 2. Strengths, Weaknesses, Threats, and Opportunities (SWOT) analysis chart

## 6. CONCLUSIONS

There was insufficient evidence revealed in the Systematic Quantitative Review to suggest it is economically feasible to reduce the energy use of large U.S. commercial buildings simply through LEED-certification. Furthermore, economic feasibility studies concluded the variations in methods of estimation, data collection, and analysis made it difficult to determine the cost-effectiveness and economic feasibility of using LEED-certification. As evidenced by LEED certified buildings increasing prevalence in airports; and by comparing airport commercial building physical characteristics, energy demand, occupancy, usage, and management approaches to U.S. commercial buildings, it was demonstrated LEED studies can prove useful in determining LEEDs' application and effectiveness in airports. Airport operator practices are also comparable in managing and funding building energy projects; However, alternative financing schemes, like energy service companies (ESCOs) and public-private partnerships, offer unique opportunities to fund (and possibly offset) large LEED-certified energy project costs. Complicating matters, Federal and FAA sustainability policies, programs, and funding restrictions are fluid and can positively (or negatively) impact considerations given to airport design, construction, operations, and energy management from an economic, environmental, and/or social standpoint; all factors which can create uncertainty as to the economic feasibility of applying LEED to airport energy projects. Is it economically feasible to reduce energy use in large U.S. commercial airport buildings through LEED certification? It depends; because of the large differences in scope and scale of airport projects, building characteristics, available energy sources, geography and climate, funding, and changing political, social, and economic conditions, airport managers considering the LEED approach need closely evaluate and apply each energy criteria based on their unique situation and not accept LEED certification claims at face value.

## 7. RECOMMENDATIONS

The aviation management and environmental design fields would benefit from future airport-specific LEED-certified building energy performance studies. Importantly, the application of a standardized quantitative method, using historical and/or real-time metered data to compare building performances, would provide a more accurate measure of factors, such as the age and size of buildings, load usages, climatic zones, and occupant-behavior, leading to improved energy performance strategies for certified and non-certified commercial buildings.

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Appendix: Systematic Quantitative Literature Review Findings Summary

| Author | Major Finding | Support LEED Energy Savings |
|---|---|---|
| Nyikos et al. (2012) | LEED-NC certified buildings incur an average of 31% lower energy costs than non-LEED buildings, however, correlation analysis suggests there are very few statistically significant correlations among the design variables. Blindly following LEED criteria may not be the most cost effective or successful sustainable design approach | Mixed |
| Oates & Sullivan (2012) | On average, Arizona's LEED NC medium energy intense (MEI) buildings performed better than the national average yet worse than buildings located in similar climates. Arizona's high energy intense (HEI) structures performed considerably lower than national and similar climate averages. The LEED NC sample underperformed both design and baseline energy use simulations. Little Energy consumption correlation | Mixed |
| Scofield et al. (2021) | In aggregate, LEED offices demonstrated 11% site energy savings but only 7% savings in source energy. LEED offices saved 26% in non-electric energy but demonstrated no significant savings in electric energy. The total measured site energy savings for LEED- NC was 11% lower than projected. Only LEED offices certified at the gold level demonstrated statistically significant savings in source energy compared with non-LEED offices. | Mixed |
| Scofield & Doane (2018) | No source energy saved by any large building type. Offices, on aggregate however, saved 10% site and 7% source energy. | Mixed |
| Agdas et al.(2015) | No statistically significant energy consumption differences were observed between certified and non-certified buildings | Negative |
| Chokor & El Asmar (2017) | The average energy consumption of all LEED buildings is higher than that of non-LEED buildings. | Negative |
| Sadatsafavi & Shepley (2016) | No source energy saved by any large building type. Offices, on aggregate however, saved 10% site and 7% source energy. Analysis showed that there is still a high variability in the operation and maintenance costs of green healthcare facilities | Mixed |
| | | |
| Scofield, J. H. (2009) | Newsham et al. offer no evidence that LEED-certification has collectively lowered either site or source energy for office buildings. However, LEED buildings use an average 10 -17% less site energy than comparable non-LEED buildings. | Mixed |

| | | |
|---|---|---|
| Scofield & Cornell (2018) | The environmental benefits of LEED buildings calculated by MacNaughton et al. have questionable value because they are based on assumptions that are inconsistent with measured LEED building energy performance. | Negative |
| Heidarinejad et al. (2014) | Improving assumptions, accuracy, and granularity of internal process loads is necessary to accurately predict energy performance in buildings. Energy simulations guidelines and rating programs should consider allowing and promoting common techniques for reducing internal loads as valid methods for reducing total building energy use | Negative |
| Menassa et al. (2012) | 7 of the 11 LEED-certified buildings had electric energy savings compared to their non-LEED counterparts. However, there is no direct correlation between LEED points obtained for Energy and Atmosphere and average electric savings for the corresponding buildings. Also, the majority of sampled LEED-certified buildings actually showed more electricity consumption than the national averages | Mixed |
| Scofield, J. H. (2013) | Collectively, LEED buildings use the same amount of source energy as other NYC office buildings. However, LEED Gold buildings showed a 20% reduction in source energy consumption. LEED buildings at the Certified and Silver level actually use more energy than other NYC office buildings. | Mixed |
| McNaughton et al. (2018) | The energy use reductions vary significantly across different sub-regions, largely related to the floor space of LEED-certified projects and baseline energy intensity. The geographical distributions of the energy use reductions are different for each fuel type. Estimated 88.50 billion kWh U.S. energy savings from LEED-certified projects between 2000 to 2016. | Yes |
| Amiri et al. (2019) | Results are contradictory; out of 44 reviewed articles, ten articles state that LEED certificate indicates energy efficiency while eight papers stated the opposite conclusion. The rest of the papers did not take any stand. | Mixed |
| Hopkins (2015) | Mixed results from both an upfront construction cost and full lifecycle perspective. No relationship between LEED level and green premium/sf. Also, no relationship found between LEED level and energy savings per square foot per year. However, annual energy savings were reported by all surveyed. | Mixed |
| Newsham et al. (2009) | On average, LEED buildings used 18-39% less energy per floor area than their conventional counterparts. However, 28-35% of LEED buildings used more energy than their conventional counterparts. Further, the measured energy performance of LEED buildings had little correlation with certification level of the building, or the number of energy credits achieved by the building at design time. | Mixed |
| Kaddory Al-Zubaidy (2015) | 7 of the 13 studies showed improved energy efficiencies associated with a LEED certified building; the other 6 studies showed some LEED buildings did not achieve significant energy efficiencies. | Mixed |

Note: Positive major findings highlighted in green color. Negative findings highlighted in black color.

## AUTHOR'S BIO

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