PX-25-C073 https://doi.org/10.63044/s25amu73

A Multi-Criteria Ranking Approach for Energy Efficiency Ranking of a Cluster of Commercial Buildings

Aditya Ramnarayan
Student Member ASHRAE

Andres Sarmiento, PhD

Michael Ohadi, PhD
Fellow ASHRAE

ABSTRACT

Buildings are responsible for 30-40% of global energy consumption, making them prime candidates for improvements in energy efficiency. To this end, states across the U.S. are actively implementing building performance standards to regulate the operations of the existing building stock. However, when multiple buildings are being considered for energy performance upgrades, it can be difficult for decision-makers to determine which facility to prioritize. This study presents the development of a multi-criteria ranking tool capable of facilitating rapid, reliable, and efficient virtual energy audits. The ranking generated by this tool can be used to conduct performance analyses and identify facilities with suboptimal performance. The proposed ranking of the cluster of buildings can be used to make decisions based on key metrics such as energy use intensity (EUI), net total CO_{2e} emissions per square foot, and dollar-saving potential per square foot. By assigning different weights based on the performance of facilities relative to energy and greenhouse gas emission benchmarks from the Commercial Building Energy Consumption Survey (CBECS) and the local/regional mandates as applicable, a cumulative score is developed for a portfolio of buildings. For the case study analyzed here, the building portfolio's end-use energy data resulted in a minimum annual average energy savings potential of 1,522 terajoules (TJ) (1,442,951 MMBtu), representing a possible 45% reduction in energy consumption. This translates to approximately 567 megajoules per square meter (MJ/sq. m.) (50 kBtu/sq. ft.) over a six-year analysis period (2018-2023). As a result, this average annual energy reduction would lead to a yearly decrease in greenhouse gas (GHG) emissions of 115,249 metric tons of CO_{2e}, also a 45% reduction, equivalent to roughly 43 kilograms per square meter (kg/sq. m.) (4 kg/sq. ft.) over the same six-year analysis period (2018-2023). Furthermore, the potential annual average dollar savings is estimated at USD 26 million [~USD 10/sq. m. (~USD 1/sq. ft.)], reflecting a 40% cost reduction. Multi-criteria ranking models, such as the one presented here, are essential for identifying and prioritizing subpar building performance, facilitating targeted energy improvements, and allocating resources toward sustainability goals.

Keywords: Ranking, Energy Use Intensity, GHG Emissions, Dollar Saving Potential, Energy Efficiency, Decarbonization

1. INTRODUCTION

The built environment represents a critical focus for energy efficiency improvements, with the residential and commercial sectors in the United States accounting for approximately 27.6% of total end-use energy consumption in 2023, equivalent to about 21.7 exajoules (EJ) (20.6 quadrillion British thermal units (Btu)) [1]. This substantial energy use resulted in 561 million metric tons (MMmt) of energy-related carbon dioxide equivalent (CO_{2e}) emissions, though encouragingly, this figure represents a 6.5% decrease compared to 2022 levels [2]. Despite this positive trend, the challenge of improving building efficiency remains significant, particularly for existing structures. As buildings age, their energy performance typically deteriorates: building envelopes become less airtight, HVAC system efficiency declines, and equipment reliability

Aditya Ramnarayan is a Ph.D. Candidate in the Department of Mechanical Engineering, University of Maryland, College Park. Dr. **Andres Sarmiento** is a Research Assistant Professor at the University of Maryland, College Park. Dr. **Michael Ohadi** is a Professor and Fellow ASHRAE Member in the Department of Mechanical Engineering, University of Maryland, College Park.

diminishes [3]. The European Union estimates that at least 70% of current buildings will still be in use by 2050 [4, 5]. Likewise, projections indicate that around 80% of the buildings in the US today will remain standing in 2050 [6]. This means that the existing building stock poses an urgent challenge and a significant opportunity for energy optimization. Consequently, determining which facilities within large institutional or organizational portfolios should be prioritized for energy interventions is a crucial yet complex decision-making problem.

Minimum performance standards and building energy codes are becoming more comprehensive and stringent across various countries, and the adoption of efficient and renewable building technologies is on the rise [7]. However, the sector needs to accelerate its efforts to align with the scenario of net zero emissions by 2050 (NZE). This decade presents a crucial turning point for implementing necessary measures to ensure that all new and existing building stock is zero-carbon-ready by 2030 [8]. One such example of climate legislation is the Climate Solutions Now Act (CSNA) enacted in Maryland, which sets some of the most ambitious climate goals in the United States, demanding a 60% reduction in emissions below 2006 levels by 2031 while also mandating reaching net-zero emissions by 2045 [9]. To meet this ambitious goal, the initiative has introduced Building Energy Performance Standards (BEPS) specifically for commercial facilities, those spanning 3,251 m^2 (35,000 square feet) or more. These standards challenge buildings to cut their net direct greenhouse gas emissions by 20% by 2030, compared to 2025, and aim for an impressive target of achieving net-zero direct GHG emissions by 2040 [10]. Starting in 2030, failure to comply with these mandates will result in significant penalties for each facility. Facilities must pay an alternative annual compliance fee of $230 per metric ton (in 2020 dollars) for every excess metric ton emitted on-site, with distinct benchmarks established for various building types [9].

In light of these stringent mandates, facility managers, owners, and policymakers must investigate and adopt effective energy efficiency measures (EEMs) that improve energy performance and contribute to the overarching goal of decarbonizing their facilities. However, when decision-makers evaluate facilities at an organizational or institutional level, it can often be challenging to identify which facility should be prioritized for energy performance enhancement. This study introduces a global, multi-criteria ranking tool capable of ranking facilities in order of their performance, serving as a blueprint for organizations and institutions to prioritize and allocate resources toward enhancing energy efficiency. This tool allows stakeholders to make informed and strategic decisions that lead to significant energy management and sustainability advancements.

The remainder of this study is organized as follows. Section 2 describes the methodology employed to develop the multi-criteria ranking, whereas Sections 3 and 4 present and discuss the results obtained using this algorithm for energy management. Section 5 concludes the study while discussing some of the study's limitations and the future work of this project to develop better energy management solutions.

2. METHODOLOGY

This study follows a three-step methodology: (i) data collection and pre-processing, (ii) data analysis and visualization, and (iii) implementation of the multi-criteria ranking algorithm. The research leverages energy data from a centralized database, EnergyCAP [11], which enables analysis of the portfolio of buildings included in this study. Due to the absence of submetering in certain facilities, campuses are evaluated in their entirety rather than on a building-by-building basis. The facilities utilized in this study align with the Maryland Building Energy Performance Standards (BEPS), underscoring the significance of committing to the State’s ambitious goals.

2.1. Data Collection and Pre-processing

To effectively identify and rank facilities with poor energy performance, the first and most crucial step is to gather end-use energy data, including detailed utility breakdowns and the associated costs of energy consumption. Utility data and bills from six fiscal years, spanning from 2018 to 2023, are collected to assess the reliability of the data and identify any anomalous values. Many facilities may not consistently update their energy utility bills, resulting in missing or incomplete values in the database. This can lead to discrepancies in energy performance evaluation. To address this issue, the software identifies missing values. It imputes data into those cells using the mean value from corresponding utility readings of the same month taken from five complete readings from previous years [12]. The analysis begins with the year 2018, as determined by Executive Order 2023 [13], signed by Governor Wes Moore, which mandates that the Maryland Department of General Services and the Maryland Energy Administration establish a goal of achieving 20% energy savings over a 2018 baseline by the year 2031. End-use energy data from approximately 2.7 million m² (~29 million sq. ft.) of facilities was harnessed as a sample set, encompassing 54 buildings and 40 campuses. Each facility's primary purpose is mapped with the Broad Category and Primary Function defined by the EnergyStar Portfolio Manager, paving the way for meaningful analysis [14].

2.2. Ranking Metrics and Methodology

The metrics for ranking building performance must be carefully chosen for environmental impact and economic viability. Energy use intensity (EUI) is a fundamental metric for comparing buildings of different sizes and functions, providing a standardized measure of energy consumption per square foot. This metric is useful as it facilitates direct comparisons among diverse building types while accounting for differences in building size, enabling organizations to identify facilities that consume disproportionate amounts of energy relative to their spatial footprint. Furthermore, EUI benchmarks are widely established through databases like CBECS [15], providing reference points for performance evaluation across different building categories and climatic regions.

Net total CO_{2e} emissions per square foot is the selected second metric, which directly addresses the growing emphasis on decarbonization in the built environment. This metric translates on-site energy consumption to its equivalent CO_2 emissions. Accounting for on-site GHG emissions can help identify opportunities to decarbonize on-site fossil fuel consumption. Dollar saving potential per square foot was the third and final metric selected to enhance the economic dimension of the ranking system. The dollar saving potential per square foot was calculated using Equations 1 and 2, which is defined by [16], using the minimum energy savings potential. This metric plays a vital role in institutional decision-making by translating energy inefficiencies into financial opportunities, enabling organizations to prioritize their investments in energy conservation initiatives. By normalizing potential savings according to square footage, this metric identifies buildings where efficiency improvements can yield the highest return on investment, regardless of the overall size of the building.

$$MAESP\,(kBtu) = (Site\ EUI - Benchmark\ EUI)\ x\ Facility\ Area \qquad (1)$$

$$MADSP\,(\$) = \frac{MAESP\,(kBtu)}{TAEC\,(kBtu)}\ x\ Annual\ money\ spent\ on\ Energy\,(\$) \qquad (2)$$

2.2.1. Methodology

The methodology for the multi-criteria ranking system employs a progressive weighting approach based on the relative performance of facilities compared to established benchmarks. This approach is intentionally biased to prioritize buildings with significant performance gaps, ensuring a focus on facilities with the greatest improvement potential. For both EUI and total CO_{2e} emissions per square feet metrics, the methodology uses building-specific benchmarks drawn from the Commercial Building Energy Consumption Survey (CBECS) database [14] as well as state-specific emissions standards [17]. The algorithm employs a graduated weighting system that assigns increasing multipliers based on the extent to which a building's actual performance surpasses its benchmark value. This approach implements a non-linear scoring system designed to enhance the rankings of underperforming buildings while facilitating equitable comparisons among different building types. Specifically, buildings that operate within benchmark values are assigned the lowest weighting factor of 0.5. In contrast, those that surpass their benchmarks by increasingly larger margins receive progressively higher weights of 0.6, 0.7, 0.8, 0.9, and ultimately 1.0. These weights are then multiplied by their absolute values, calculated as the average from 2018 to 2023. The dollar saving potential per square foot metric uses a comparable progressive weighting system; however, instead of relying on building-specific benchmarks, it employs absolute threshold values derived from industry standards for economic viability [18, 19]. This method guarantees that buildings with a higher potential for financial improvement are given greater weight in the final ranking. The final cumulative score for each facility is calculated by summing the weighted values across all three metrics, which is then ranked in descending order, highlighting a comprehensive ranking that accounts for energy efficiency, environmental impact, and economic opportunity.

3. RESULTS

The histograms for the three main metrics—energy use intensity (EUI), total CO_{2e} emissions per square foot, and dollar saving potential per square foot—are shown in Figure 1. Our analysis included 104 buildings across 13 building types. The buildings exhibited considerable variation in energy performance metrics, with EUI values ranging from 24.19 – 10,617 MJ/m^2 (2.13 to 935 kBtu/sq. ft.) (mean = 1,293.3 MJ/m² (113.97 kBtu/sq. ft.), SD = 1,360.7 MJ/m² (119.8 kBtu/sq. ft.)). Similarly, total CO_{2e} emissions per square meter ranged from 4.52 to 1,894.33 metric tons CO_{2e}/m^2 (0.42 to 176.07 metric tons CO_{2e}/sq. ft.), and dollar saving potential ranged from 0 to 81.16 \$/m^2 (0 to 7.54 \$/sq. ft.). The weights assigned to each building within the various bins in Figure 1 are based on their respective benchmarks. This methodology utilizes six bins, each representing a distinct weight, to categorize a facility's performance and assign a corresponding score based on that performance.

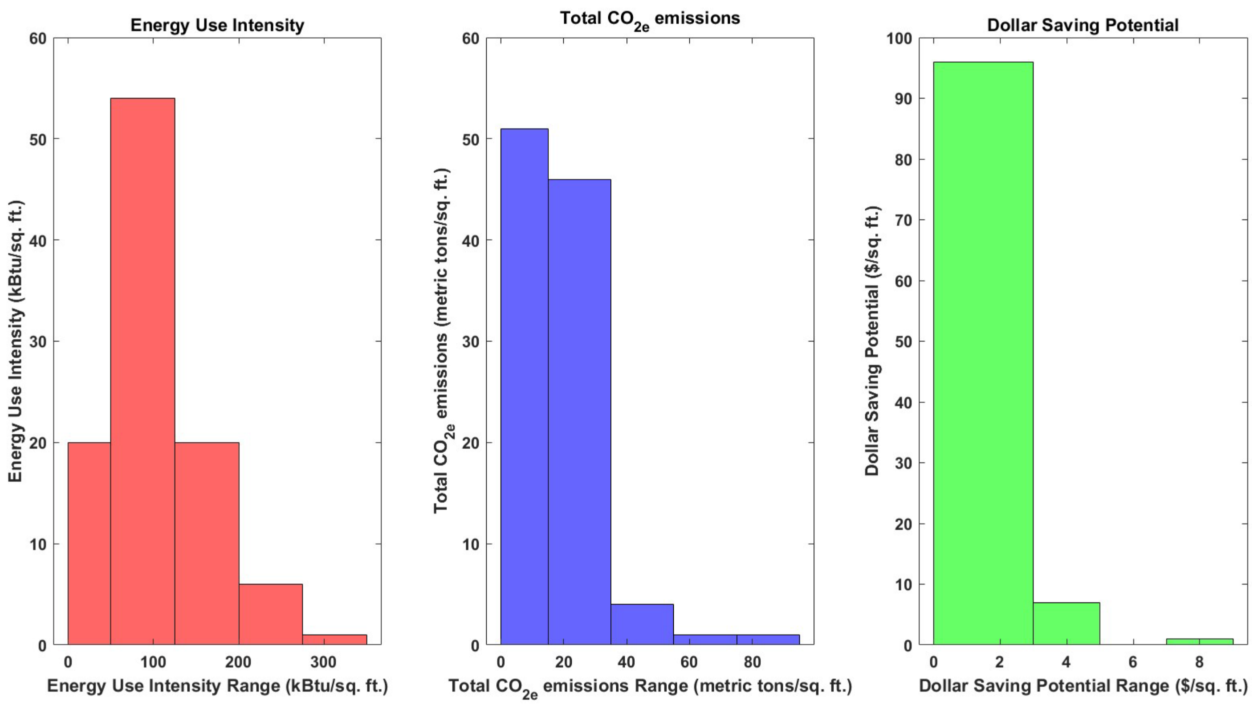

Figure 1 Histogram denoting the spread of EUI, total CO_{2e} emissions per square foot, and dollar saving potential per square foot for the cluster of buildings

Furthermore, Figure 2 shows the correlations between the three metrics in the form of a scatter plot; revealing the relationships between the three metrics. These visualizations illustrate whether buildings that perform poorly in one metric also tend to perform poorly in others, which has significant implications for prioritizing improvements. The 3D scatter plot visualizes all three dimensions simultaneously, with point colors reflecting the combined score.

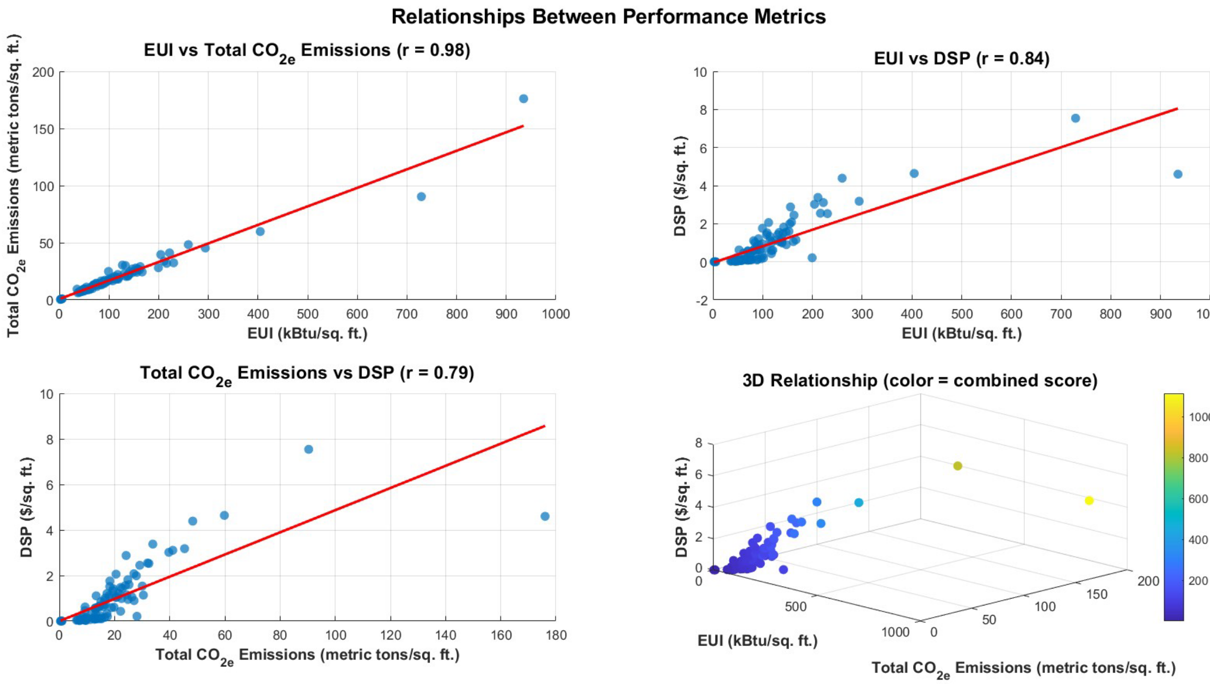

Figure 2 Correlation and combined score analysis between the three multi-criteria metrics

Using the multi-criteria ranking algorithm, the facilities in the portfolio were evaluated, and the worst-performing ones were ranked. The top 15 worst-performing facilities are displayed in Table 1. The analysis covers a timeframe of six fiscal years, from 2018 to 2023, and includes only facilities larger than 3,251 m² (35,000 sq. ft.). The top 15 worst-performing facilities shown in Table 1 help provide a starting point for improving energy performance in facilities with subpar efficiencies. Using the ranking criteria, a study by [20] investigated the energy efficiency opportunities for a public transportation maintenance facility. Through the use of energy modeling and the simulation of various scenarios incorporating a range of energy efficiency measures (EEMs), the facility demonstrated significant potential for improving its energy performance in 2022. The analysis suggests that implementing these recommendations could lead to an annual reduction of 584 metric tons in carbon dioxide equivalent (CO_{2e}) emissions, a decrease of 5,034 gigajoules (GJ) in natural gas consumption, and a savings of 1,086 megawatt-hours (MWh) in electricity usage. These improvements could translate into potential annual cost savings of approximately $162,402. This study revealed the benefits of using a prioritized approach towards energy auditing and energy efficiency improvements by showcasing quantitative and achievable savings potential to the facility manager when implementing energy efficiency retrofits.

Additionally, the multi-criteria ranking tool enabled the investigation of a cluster of university buildings in a study by [21]. By identifying the worst-performing facilities on the campus, the researchers analyzed the impact of implementing rooftop Solar PV implementation on CO_2 emissions using a comprehensive machine learning approach. The results indicated that solar PV implementation could potentially reduce the campus's CO_2 footprint by approximately 18%.

Table 1. Summary of Key Metrics Across the Portfolio

Rank	Site Name	Area [m²] (sq. ft.)	Total CO_{2e} Emission/Sqrft [kg/m²] (kg/sq. ft.)	Dollar Reduction Potential/Sqrft [$/m²] ($/sq. ft.)	Total Energy Consumption - EUI [MJ/m²] (kBtu/sq. ft.)
1	Building #1	9,579 (103,109)	424.42 (39.43)	54.90 (5.10)	7,869.97 (692.99)
2	Building #2	6,364 (68,500)	282.88 (26.28)	52.10 (4.84)	4,354.66 (383.45)
3	Building #3	139,296 (1,499,368)	170.39 (15.83)	21.96 (2.04)	2,797.00 (246.29)

4	Building #4	7,544 (81,200)	187.83 (17.45)	27.45 (2.55)	2,674.46 (235.50)
5	Building #5	10,034 (108,000)	149.94 (13.93)	24.43 (2.27)	2,282.21 (200.96)
6	Building #6	81,764 (880,099)	179.11 (16.64)	18.08 (1.68)	2,076.09 (182.81)
7	Building #7	11,451 (123,262)	137.67 (12.79)	21.64 (2.01)	1,694.28 (149.19)
8	Building #8	3,970 (42,731)	140.58 (13.06)	11.52 (1.07)	1,686.22 (148.48)
9	Building #9	13,006 (140,000)	118.08 (10.97)	21.85 (2.03)	1,696.78 (149.41)
10	Building #10	46,417 (499,633)	113.77 (10.57)	12.06 (1.12)	1,844.42 (162.41)
11	Building #11	3,379 (36,367)	111.84 (10.39)	16.25 (1.51)	1,530.52 (134.77)
12	Building #12	18,643 (200,675)	79.55 (7.39)	8.50 (0.79)	1,558.79 (137.26)
13	Building #13	7,183 (77,318)	105.49 (9.80)	15.39 (1.43)	1,498.26 (131.93)
14	Building #14	9,941 (107,000)	116.04 (10.78)	17.87 (1.66)	1,471.70 (129.59)
15	Building #15	5,465 (58,829)	113.67 (10.56)	16.90 (1.57)	1,452.73 (127.92)

4. DISCUSSION

The results of this study emphasize the importance of using a data-driven approach to evaluate the energy performance of buildings at a portfolio level. By applying a multi-criteria ranking framework, we identified priority buildings that exhibit low energy efficiency, high GHG emissions, and significant energy cost burdens. This methodology not only streamlines the decision-making process for facility managers but also improves the effectiveness of energy efficiency programs by directing interventions to where they can have the greatest impact. Table 2 shows key performance metrics for the analyzed building portfolio. The differences in energy performance highlight the need for a focused strategy to improve efficiency.

Table 2. Summary of Key Metrics Across the Building Portfolio

Metric	Minimum	Maximum	Mean	Median	Standard Deviation
Energy Use Intensity (EUI) [MJ/m^2] (kBtu/sq. ft.)	24.19 (2.13)	10,617.79 (934.99)	1,293.87 (113.97)	1,003.87 (88.45)	1,360.03 (119.8)
Total CO_{2e} Emissions per square foot [Metric tons /m^2] (Metric Tons/sq. ft.)	4.52 (0.42)	1,894.34 (176.07)	207.14 (19.25)	162.84 (15.13)	214.10 (19.89)
Dollar Savings Potential per square foot [$/m^2] ($/sq. ft.)	0 (0)	81.16 (7.54)	10.33 (0.94)	6.24 (0.58)	13.24 (1.23)

The considerable variation in energy use intensity (EUI) values indicates that certain buildings consume significantly more energy than others. High-EUI buildings often feature outdated mechanical systems, inefficient HVAC operations, or inadequate insulation [22]. Similarly, the discrepancies in CO_{2e} emissions per square foot underscore the impact of building-level energy sourcing, as some facilities heavily depend on fossil fuel-based heating systems. Additionally, the potential for cost savings highlights the financial benefits of implementing targeted energy conservation measures, with high-cost buildings presenting substantial opportunities for economic returns through energy efficiency upgrades.

The ranking methodology inherently accommodates variations in building typology by benchmarking against suitable peer groups. Energy-intensive facilities, such as hospitals, are assessed using typology-specific benchmarks [9, 15] that normalize expectations for energy consumption and emissions. This approach ensures that rankings remain impartial to critical infrastructure or high-energy-use buildings, thereby facilitating a fair "apple-to-apple" comparison of performance across a diverse array of building types.

The developed multi-criteria ranking unveiled an impressive potential for energy savings over a six-year period, with a minimum annual average of 1,522 terajoules (TJ) (equivalent to 1,442,951 MMBtu) — a remarkable projected 45% reduction in energy consumption. This translates to approximately 567 megajoules per square meter (MJ/sq. m.) (50 kBtu/sq. ft.) during the analysis period from 2018 to 2023. As a result, this average annual energy reduction would lead to a significant yearly decrease in GHG emissions of 115,249 metric tons of CO_{2e}, about 43 kilograms per square meter (kg/sq. m.) (4 kg/sq. ft.), reflecting the same inspiring 45% reduction. Furthermore, the potential annual average dollar savings is estimated at USD 26 million, roughly ~USD 10/sq. m. (~USD 1/sq. ft.), representing a transformative 40% cost reduction. The data presents a significant opportunity to enhance energy performance and realize substantial cost savings within facilities. This software is an indispensable global tool for conducting fast, reliable, and efficient virtual energy audits. Moreover, it empowers organizations with advanced capabilities for data-driven decision-making and optimization, enabling them to effectively achieve their goals and comply with their respective state and federal regulations.

5. CONCLUSIONS

This study investigates a multi-criteria ranking custom-built tool designed to streamline the evaluation and prioritization of buildings for energy efficiency improvements. By integrating key performance indicators such as EUI, GHG emissions per square foot, and potential dollar savings per square foot, this tool provides a data-driven framework for virtual energy audits. Furthermore, by virtue of ranking a cluster of buildings, resource allocation for energy audits and energy efficiency improvements in a portfolio has been made possible. This study inspects a portfolio of 104 buildings comprising 2,694,188 m^2 (~29 million sq. ft.). The results demonstrate that a targeted approach to energy efficiency interventions can significantly reduce costs and carbon emissions and enhance operational efficiency. A key takeaway from this research is that not all buildings require the same level of intervention. By establishing a weighted ranking system, decision-makers can strategically allocate resources to facilities exhibiting the highest inefficiencies, thereby maximizing the impact of energy efficiency investments. The flexibility of this ranking tool allows it to be customized to fit the specific sustainability and financial goals of different organizations.

While this global ranking tool for multi-criteria evaluation offers a significant opportunity for organizations and institutions to identify facilities with underwhelming energy performance, certain limitations need to be addressed to ensure robust global scalability. A sensitivity analysis is essential to determine the appropriate weights for outlier facility performance, taking into account the relevant benchmarks for each metric. For instance, the dollar savings potential per square foot metric utilized in this study lacks predefined benchmarks at the state and federal levels and by building type. An economic analysis is also needed to assess how energy efficiency retrofits impact the financial viability of energy efficiency improvements, drawing insights from existing case studies. Lastly, financial incentives and regulatory policies shoud be incorporated into the ranking metrics to assist policymakers and building owners in aligning with energy codes and carbon reduction targets.

ACKNOWLEDGMENTS

The authors would like to thank the Office of Energy Sustainability within the State of Maryland's Department of General Services for their support of this project.

NOMENCLATURE

HVAC – HEATING, VENTILATION, AND AIR CONDITIONING

CSNA – CLIMATE SOLUTIONS NOW ACT

BEPS – BUILDING ENERGY PERFORMANCE STANDARDS

GHG – GREENHOUSE GAS

EEM – ENERGY EFFICIENCY MEASURES

CBECS – COMMERCIAL BUILDING ENERGY CONSUMPTION SURVEY

EUI – ENERGY USE INTENSITY

MAESP – MINIMUM ANNUAL ENERGY SAVING POTENTIAL

MADSP – MINIMUM ANNUAL DOLLAR SAVING POTENTIAL

TAEC – TOTAL ANNUAL ENERGY CONSUMPTION

REFERENCES

[1] Frequently Asked Questions (faqs) - U.S. Energy Information Administration (EIA). https://www.eia.gov/tools/faqs/faq.php?id=86&t=1

[2] U.S. Energy Information Administration - EIA - independent statistics and analysis. EIA. https://www.eia.gov/environment/emissions/carbon/

[3] Aksoezen, M., Daniel, M., Hassler, U., & Kohler, N. (2015). Building age as an indicator for energy consumption. Energy and Buildings, 87, 74-86.

[4] European Commission. (2005). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Healthier, Safer, More Confident Citizens: a Health and Consumer Protection Strategy: Proposal for a Decision of the European Parliament and of the Council Establishing a Programme of Community Action in the Field of Health and Consumer Protection 2007-2013 (text with EEA Relevance). Office for Official Publications of the European Communities.

[5] Bell, M. (2004, September). Energy efficiency in existing buildings: the role of building regulations. In Proceedings of Construction and Building Research (COBRA) Conference (pp. 7-8).

[6] For net-zero cities, we need to retrofit our older buildings. here's what's needed. World Economic Forum. (2022). https://www.weforum.org/stories/2022/11/net-zero-cities-retrofit-older-buildings-cop27/#:~:text=Around%2080%25%20of%20the%20buildings,retrofit%20them%20for%20energy%20efficiency.

[7] Evans, M., Roshchanka, V., & Graham, P. (2017). An international survey of building energy codes and their implementation. Journal of cleaner production, 158, 382-389.

[8] IEA (2023). Tracking Buildings 2023.

[9] The Maryland Climate Solutions Now Act (2022), Maryland Department of Environment (MDE)

[10] Maryland Building Energy Performance Standards. Maryland Department of the Environment. (n.d.). https://mde.maryland.gov/programs/air/ClimateChange/Pages/BEPS.aspx

[11] Energy Management Analytics & Sustainability Data Solution Boalsburg: ESG reporting software. EnergyCAP, https://www.energycap.com/

[12] Zhang, Z. (2016). Missing data imputation: focusing on single imputation. Annals of translational medicine, 4(1).

[13] Governor Moore Signs Executive Order Doubling Maryland's Energy Conservation Goal through State Government Greenhouse Gas Reductions; Press Releases—News; Office of Governor Wes Moore: Annapolis, MD, USA, 2023

[14] ENERGY STAR Portfolio Manager, https://portfoliomanager.energystar.gov/

[15] How the 1-100 energy star score is calculated. ENERGY STAR. https://www.energystar.gov/buildings/benchmark/understand_metrics/how_score_calculated

[16] Ramnarayan, A., A. Sarmiento, A. Gerami and M. Ohadi (2023). An energy consumption intensity ranking system for rapid energy efficiency evaluation of a cluster of commercial buildings. 2023 ASHRAE Transactions 129(2): 602-611.

[17] Department of Energy (DOE). (n.d.). Building performance standards. Building Performance Standards | Building Energy Codes Program.

[18] Copiello, S. (2021). Economic viability of building energy efficiency measures: A review on the discount rate. AIMS ENERGY, 9(2), 257-285.

[19] Galiano-Garrigós, A., González-Avilés, Á., Rizo-Maestre, C., & Andújar-Montoya, M. (2019). Energy efficiency and economic viability as decision factors in the rehabilitation of historic buildings. Sustainability, 11(18), 4946.

[20] Higgins, J., Ramnarayan, A., Family, R., & Ohadi, M. (2024). Analysis of Energy Efficiency Opportunities for a Public Transportation Maintenance Facility—A Case Study. Energies, 17(8), 1907.

[21] Zargarzadeh, S., Ramnarayan, A., Castro, F. d., & Ohadi, M. (2024). ML-Enabled Solar PV Electricity Generation Projection for a Large Academic Campus to Reduce Onsite CO2 Emissions. Energies, 17(23), 6188.

[22] Lucchi, E. (2024). Energy performance indicators for air-conditioned museums in tropical climates. Buildings, 14(8), 2301.

[23] ASHRAE. 2005. ASHRAE Handbook—Fundamentals. Atlanta: ASHRAE.