Executive Summary

BACKGROUND & METHODOLOGY

This report summarizes an energy modeling and life cycle cost analysis (LCCA) study designed to **provide a comprehensive roadmap and a set of most practical, impactful, and cost-effective energy conservation measures (ECMs) recommendations for the General Services Administration (GSA) to apply to their buildings across the United States in their efforts to decarbonize their building portfolio and draw their operational source energy use to net-zero**. This pursuit was driven by the goals set forth by Executive Order (EO) 14057 - Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability ***(Administration of Joseph R. Biden, Jr., 2021)*** in order to achieve a carbon pollution-free electricity sector by 2035 and net-zero emissions economy-wide by no later than 2050.

The following Federal and GSA requirements apply to GSA building stock:

- 65% carbon reduction by 2030 (Federal)
- 100% carbon pollution-free electricity by 2030 (net annual basis)
- Net-zero emissions by 2050 (Federal)
- Net-zero emission building portfolio by 2045 (GSA & Federal)
- Net-zero energy performance in 40% of designs by 2025 (GSA)
- Electrification to eliminate 90% of on-site fossil fuel construction in prospectus projects by FY 2025, 100% by FY 2030 where life-cycle cost-effective (GSA)
- Increasing existing building performance by upgrading equipment and improving energy performance metrics (GSA)
- Net-zero emissions buildings by 2030 building electrification and carbon pollution-free energy use for projects > 25,000 gsf (Federal)

The first directive for ECM selection was **electrification**, or replacement of any non-electric systems in the building to provide for electricity using renewable energy sources; in the short term, certain electricity grids across the country produce more greenhouse gas (GHG) emissions than natural gas and other fuels, but systems dependent on fuels other than electricity cannot be supplied by renewable energy sources to meet goals of net-zero energy use. Though the focus of this study was the retrofit of existing buildings, the second directive for energy conservation measures (ECMs) selection was to explore ECMs that would be applicable to all buildings across the GSA portfolio and be accessible to both retrofits and new construction projects.

Many options were explored as potential ECMs, and others that were originally part of the study were modified during the modeling and review processes to meet the needs of application to GSA projects. **Eighteen (18) ECMs were selected for this study** in the following categories:

- Non-HVAC ECMs
  - Insulation Improvements (ECM 1- 4)
  - Window Improvement or Replacement (ECM 5-7)
  - Automated Shading Addition (ECM 8)
  - Air tightness Improvement (ECM 9-10)
  - Reduced Lighting Power (ECM 11)
  - Vampire Load Management (ECM 12)

- HVAC ECMs focused on heat pump technology. (ECM 13-18)

To represent the GSA building portfolio, **three different building types were analyzed in this study, including a Land port of entry (LPOE), an Office and a Courthouse (Court)**. An existing building for each of the three building types was used to develop reference building energy models. These building energy models were created based on construction documents and geographic location for the existing buildings and were calibrated against the metered utility data to accurately represent the building's operation. These reference building models for each building type were then used to set baseline energy models and study the impact of the identified 18 ECMs for **four (4) climate zones (CZ)**, as delineated by the 2021 International Energy Conservation Code (IECC):

- CZ 2A (hot humid)
- CZ 4A (mixed humid)
- CZ 4C (mixed marine)
- CZ 7A (very cold)

The setup of these energy models spanning across 3 building types and 4 climate zones resulted in 243 energy model iterations. The results of the energy modeling studies were used to **measure site and source operational energy, operational greenhouse gas (GHG) emissions, and life-cycle cost impacts of each ECM versus the baseline models for each of the three (3) building types and four (4) climate zones**. Models reflecting a **bundle of ECMs were created for each building and climate zone by combining the lowest energy use ECMs from each ECM category** (insulation, window, automated shading, air tightness, lighting, equipment power, HVAC) into a single model. Rooftop photovoltaic (PV) systems were sized to determine available renewable energy for each building in every climate zone. The remaining gap to net-zero source energy was determined after applying the ECM bundle and the rooftop PV offset to all the baselines.

The study included **life cycle cost analysis (LCCA) over a period of 25-years for individual ECMs and ECM bundle with and without PV system, for each of the three (3) buildings in each of the four (4) climate zones**. Cost estimates from the RSMeans tool and U.S. product manufacturers for the purchasing of ECM systems, as well as the baseline replacement systems and energy cost values from the energy models were applied to 252 LCCA studies according to the life cycle costing rules of the FEMP Analysis for an Energy Project according to 10 CFR 436A. The O&M equipment costs were not included due to broad variation based on remoteness and location of a project. Aside from the cost for the rooftop renewables sized for each building in each climate zone, the scope of work excluded cost estimates for purchasing of the renewables, renewable energy credits, etc. that was required to fill the estimated gap to reach net-zero source energy and minimize operational GHG emissions.

RESULTS

The effectiveness of the ECMs analyzed in the study varied by building type (mainly due to the differences in the existing building conditions used to set up the baselines) and the locations. However, there were general trends seen in the energy modeling and LCCA results, as noted below:

Site Energy Trends:

- Insulation improvements had minimal impact on site operational energy savings compared to the baseline for each building in every climate zone (≤1.7% site energy savings), with the greatest impact seen in Courthouse due to the larger wall-to-floor area ratios.
- Window improvement or replacement ECMs had a more significant impact on the site energy savings (0.7-13.5% savings), with the greatest impact in CZ 7A (very cold climate) and in the Courthouse due to the highest window-to-wall area ratio (WWR).
- Automated shades had greater impact (0.8-3% savings), with the largest seen in the Courthouse building, due to the largest WWR.
- Simulated lighting and receptacle energy use optimizations had more of an impact (0.2-11.2%), with the internal heating load reduction having a greater impact in the hotter climates and less in the cooler climates, with largest impact seen in Office building.
- Air tightness had a more significant impact on energy savings (0.9-29%), with the greatest impact seen in LPOE for all climate zones and for other buildings specifically in CZ 7A (very cold).
- The HVAC ECMs had the most significant site energy savings (8.7-61.7%), and the greatest savings typically in CZ 4A (mixed humid) and CZ 7A (very cold). Of the HVAC ECMs, replacing a mixed-air system with a dedicated outdoor air system (DOAS), which decouples the ventilation from heating and cooling loads, showed the largest savings (29.7-61.7%); the air-source heat pump (ASHP) and ground-source heat pump (GSHP) DOAS systems resulted in the highest site operational energy savings across all building types.

Source Energy Trends:

- Converting the site energy usage to source energy using the national average ENERGY STAR source-to-site ratios from the ENERGY STAR Portfolio Manager Technical Reference, the non-HVAC ECMs source energy savings followed a similar trend as seen in the site energy savings.
- The HVAC ECMs resulted in source energy penalty as the all-electric HVAC ECMs required more source energy per Btu to operate than baselines, which used natural gas, steam, and propane for fuels in addition to electricity.
- While the HVAC ECMs with VAV systems resulted in negative savings in few of the climate zones (-39.4 to 13.1%); the HVAC ECMs replacing a mixed-air system with a dedicated outdoor air system (DOAS), which decouples the ventilation from heating and cooling loads, showed significant savings (8.0-37.4%). The air-source heat pump (ASHP) and ground-source heat pump (GSHP) DOAS systems resulted in the highest source operational energy savings across all building types.

Source GHG Emission Trends:

- Predicted site and source energy use from the energy modeling study was converted to operational GHG emissions using industry available fuel conversion factors. The analysis showcased that the savings of operational GHG emissions from source operational energy roughly followed the trend seen for the source energy savings.
- Out of all the non-HVAC ECMs, air tightness had the most significant impact for LPOE in all climate zones and for other buildings specifically in CZ 7A (very cold).
- Simulated lighting and receptacle energy use optimizations had a significant impact for Office and Courthouse in CZ 2A. Of the HVAC ECMs, replacing a mixed-air system with a dedicated outdoor air system (DOAS), which decouples the ventilation from heating and cooling loads, showed the largest savings (-20.9 to 26.1%) with the air-source heat pump (ASHP) and ground-source heat pump (GSHP) DOAS systems resulting in the highest source operational GHG emission savings across all building types.
- Negative operational GHG emissions savings were observed due to the negative source energy savings reported above and emission factors used for converting fuel sources to operational GHG emissions. With the grid getter cleaner and the fuel source conversion factors getting updated in the future, the negative savings specifically in the colder climate zones will switch to showcase a positive savings, resulting in operational GHG emissions minimization.

Life-Cycle Cost Analysis Trends:

- Insulation improvements ECMs either had minimal or negative lifecycle cost savings over the baseline in every climate zone except Courthouse in CZ 2A and CZ 4A. Window improvement or replacement ECMs, particularly, double pane inboard addition had a positive cost savings for all the buildings (11.8-33.9% savings), with the greatest impact seen in CZ 2A (hot humid).
- Air tightness ECMs had a more significant positive impact (<19.9%) for the LPOE and the colder climate zones for the Office and Courthouse building.
- Reduced light power density consistently showed a positive cost savings (2.6-19%), while vampire load management showed a positive impact only for the Office and Courthouse building.
- Of the HVAC ECMs, a positive cost savings is only seen for LPOE and Office building. Systems using dedicated outdoor air system (DOAS) with heat recovery (HR) for delivery of ventilation air consistently showed a better cost savings than the other VAV systems. The photovoltaic system only showed positive cost savings for LPOE and Courthouse for CZ 4A.

RECOMMENDATIONS

The results of the extensive energy modeling and LCCA study recommend both a bundle of ECMs that would provide a path to net-zero source energy for each building type across the four climate zones and recommends individual ECMs by building type that should be prioritized if the entire bundle cannot be applied. These ECMs, both included in the bundle and individually, have been selected based on their effectiveness in reducing energy consumption, their applicability to GSA's building portfolio and their cost effectiveness.

Pathway to Net-Zero Source Energy

For modernization and new construction projects that intend to move towards **electrification** and attain **net-zero source energy**, the building energy usage should be reduced by first incorporating efficient building energy efficiency measures and then renewables should be added to offset the remaining building energy use.

- Out of 18 ECMs explored in this study, the project team recommends bundling the highest site energy savings ECMs from each of the studied ECM categories, even when the ECMs individually may not have a positive energy cost savings over the 25-year LCCA. The following ECMs are recommended to be bundled together for each of the studied buildings to reduce the building energy use to attain the net-zero source energy goal: **Roof and Wall Insulation improvement, Quad-pane Window Replacement** for all except Office building in CZ 2A and 4C. (**Double-pane inboard addition** for office CZ 2A hot humid and CZ 4C mixed marine), **Automated shades addition, Air tightness Improvement , Reduced light power density, Vampire Load Management** and upgrading the HVAC system to an **Air-Source Heat Pump with electric boiler(s) for supplemental heat or/and backup heat, DOAS w/energy recovery and demand-controlled ventilation (DCV)**. The bundles as analyzed in the study showed a source energy savings ranging between 35-49% across the three building types and four climate zones.

- Next, **renewables** should be added to offset the remaining building energy use and attain net-zero source energy. For this study, only rooftop PV was studied to offset the building energy use, The bundles with the rooftop PV addition showed a source energy savings ranging between 35-54% across the three building types and four climate zones. The overall reduction allowed by rooftop PV was constrained by the studied building layout and climate zone, hence resulting in source energy savings ranging between 35-54% for the ECM bundles with rooftop PV for the three building types in the four climate zones. When using the study on an individual project for guidance, additional renewable measures beyond rooftop PV such as offsite PV generation and purchased renewable energy credits should be explored to attain the net-zero source energy goal.

NOTE:
The results from energy modeling, cost estimate, and LCCA studies will vary for different buildings, building types, locations, and regional demographics. The analysis and results from this study should be looked at more for the trends they reveal rather than exact results to be expected when applied to a specific modernization and new construction project. The study is meant as a guide for assistance in selection of potential ECMs and the cost to implement them based on the closest building type and climate zone to those modeled in the study. Each project utilizing these study results should apply their own feasibility study, energy modeling and life cycle cost analysis to confirm the impacts for their specific building conditions and location.

Prioritization of Energy Conservation Measures

If a modernization project precludes the implementation of the entire bundle of ECMs and select ECMs are to be chosen for implementation, it is recommended that the following **cost-effective ECMs be prioritized in the order listed below** for operational GHG emission minimization and reduction in building energy use to attain the **net-zero energy goal** for each of the three buildings. HVAC ECM should be prioritized if electrification is the goal during modernization.

LPOE

- **HVAC ECMs: Air-source heat pump (ASHP) with a dedicated outdoor air system (DOAS) and Energy Recovery (ER)** (Initial investment ranging ~ $15/gsf -$23/gsf across the four climate zones)
- **Non-HVAC ECMs: Air tightness** (Initial investment costs ~$4/gsf), Wi**ndow improvement or replacement,** particularly, double pane inboard addition for CZ 7A (Initial investment costs ~ $5/gsf), **Reduced Light Power** Density for CZ 2A (Initial investment costs ~$7/gsf)

Office

- **HVAC ECMs: Air-source heat pump** (ASHP) **with a dedicated outdoor air system** (DOAS) **and Energy Recovery** (ER) (Initial investment ranging ~$10/gsf -$13/gsf across the four climate zones) or Water-source heat pump (WSHP) with a dedicated outdoor air system (DOAS) and Energy Recovery (ER) (Initial investment ranging ~$8/gsf -$10/gsf across the four climate zones)
- **Non-HVAC ECMs: Vampire Load Management Density** (Initial investment costs ~$0.65/gsf), Air tightness for CZ4A, CZ4C and CZ 7A (Initial investment costs ~$0.60/gsf), Reduced Light Power Density for CZ2A (Initial investment costs ~$4/gsf), **Window improvement or replacement**, particularly, double pane inboard addition for CZ7A (Initial investment costs ~ $2/gsf)

Courthouse

- **HVAC ECMs: Water-source heat pump** (WSHP) **with a dedicated outdoor air system** (DOAS) **and Energy Recovery** (ER) (Initial investment ranging ~$14/gsf -$16/gsf across the four climate zones)
- **Non-HVAC ECMs: Window improvement or replacement**, particularly, double pane inboard addition for CZ4A, CZ 4C and CZ7A (Initial investment costs ~ $5/gsf), **Reduced Light Power Density** for CZ2A, CZ 4A, CZ 4C (Initial investment costs ~$7/gsf), **Air tightness** for CZ7A (Initial investment costs ~$0.75/gsf), **Vampire Load Management Density** for CZ 2A (Initial investment costs ~$0.65/gsf), **Insulation Improvements** for CZ 2A and CZ 4A ((Initial investment costs ranging ~$0.40/gsf -$1/gsf across the four climate zones)