Summary of Potential of artificial intelligence in reducing energy and carbon emissions of commercial buildings at scale

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INTRODUCTION

Summary by Ray Marange Climate change is accelerating, and buildings are a major contributor, responsible for 39% of U.S. primary energy use. With urbanization surging and building stock/demand expected to double by 2060, improving building efficiency is no longer optional but urgent. While AI has transformed industries such as healthcare and finance, its potential in building energy efficiency remains underexplored. AI demonstrates significant potential to reduce costs, enhance benefits, and improve safety across the building lifecycle. This study [**?**] investigates how AI can reduce energy consumption and carbon emissions in medium-sized office buildings, offering a scalable framework that could be applied globally. We will explore four key areas: **Results**, **Discussion**, **Methods**, and **Takeaways & Reflections**. The study focuses on medium-sized offices, and the results can be extrapolated to offices of any size.

AI'S IMPACT ON ENERGY AND EMISSION REDUCTIONS

Summary by Dwayne Mark Acosta

According to the 2012 U.S. Energy Information Association (EIA) survey, office buildings have the highest energy consumption among commercial types (20%), with a median energy use intensity (EUI) of 167 kWh/m^2 (EUI_{base}). In contrast, 67 verified low-energy office buildings reported a median EUI of 57 kWh/m^2 (EUI_{HEEB}). The difference between the baseline and best practice energy performance yields a technical energy efficiency saving (TEES) of 110 kWh/m^2. TEES can be improved in four categories: equipment, occupancy influence, control and operation, and design and construction.

This study focuses on medium office buildings, which comprise 70% of total office energy use. The Department of Energy's (DOE) EnergyPlus tool, defined by ASHRAE Standard 90.1, was used to simulate the annual building energy consumption of medium office buildings across four climate zones using representative U.S. cities. Both electricity and natural gas use were considered, with gas assumed to supply hot water and heating.

To estimate the TEES, a set of 23 improvement cases was developed by varying key design parameters. These include 8 cases for equipment efficiency, 9 for design and construction, and 6 for occupancy-related behavior and control. The cases, based on conservative assumptions, are summarized in Table II, and their contributions to total annual energy savings across different climate zones are illustrated in Figure 2. The results represent the maximum technical potential achievable through simulation, achieving these savings in practice may require substantial effort throughout the building lifecycle. AI technologies such as fault detection, smart sensors, robotic construction and others can help automate and streamline this process at lower cost and reduced labor.

Key Takeaway/Thoughts: Although simulation results suggest that TEES across the four categories can range from 6% to 27%, the paper assumes highly optimized performance which requires significant time, resources, and coordination across the building lifecycle. This idealized level of optimization is often difficult to achieve in practice due to real-world constraints. While AI tools may support these optimizations, their practical effectiveness is not guaranteed and remains highly dependent on a wide range of factors including data quality, user adoption, and integration with current systems.

AI'S REDUCES EMISSIONS OF BUILDINGS

Summary by David Franz

Primary focus of modeling

The paper focuses on two ways that AI can reduce the emissions of buildings.

1) By helping scale up the technologies and speed adoption by reducing the construction and labor costs;
2) By helping reduce emissions in ongoing maintenance and any new construction over the entire building's lifetime.

Scenarios simulated

The paper uses the results gained from the previous section to **simulate six scenarios**. The data is used to estimate pa-

Scenario	Energy Use (kWh/m^2)	CO_2 Emissions (kg/m^2)
Baseline	200	50
AI Optimized	150	30

TABLE I
ENERGY USE AND CO_2 EMISSIONS FOR DIFFERENT SCENARIOS.

rameters for use with complex simulation software to attempt to model the potential lifetime impact on emissions.

1) Frozen with current building efficiency;
2) BAU without AI;
3) BAU with AI;
4) Three policy-driven scenarios promoting high-efficiency energy buildings and net-zero energy buildings, and other policy implementation to achieve zero emissions by 2050.

Simulation results

The results of the simulation are shown below.

Table I shows the energy use and CO_2 emissions for different scenarios.

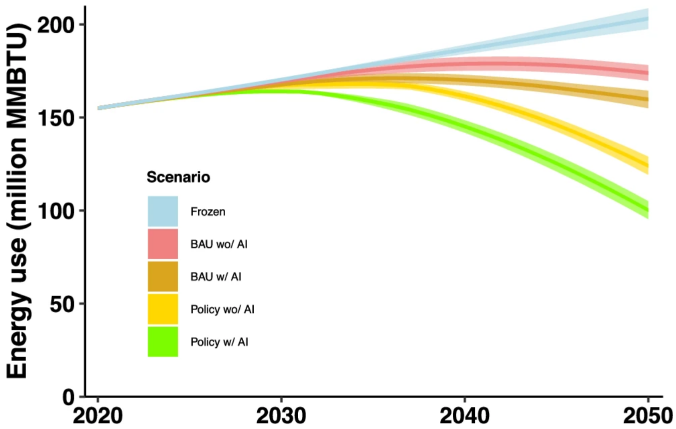

Fig. 1. Different energy use scenarios.

Key insight

"The scenario with AI leads to a higher market share of HEEBs and NZEBs over time compared with the scenario without AI. This trend continues until the market share of net NZEBs reaches its maximum share."

The paper asserts that using AI in the ways that they propose always leads to a higher market share of efficient buildings.

Thoughts on result

The paper examines various scenarios with some amount of estimation for unknowns, so each individual simulation is unlikely to be exactly right. However, the fact that all scenarios trend in a downward direction for energy use and CO_2 emissions suggest it is highly likely that AI would have some impact on building emissions, but the current lack of data leading to necessary estimation means that the current degree of this impact is still unclear.

DISCUSSION

Summary by Mohamed Amine Benaziza

Method and Scope

The study uses a combination of engineering and energy-simulation approaches, rather than focusing on a single AI technology, to estimate how AI can boost building energy efficiency and reduce carbon emissions. While the analysis centers on a medium-sized office building, the methodology is adaptable to other commercial building types with appropriate adjustments.

Why AI Helps

AI enables data-driven modeling, which can tailor solutions to specific buildings and lower costs. This accelerates the adoption of high-efficiency and net-zero-energy buildings (HEEBs and NZEBs). The paper also notes that advanced control models, such as deep learning and reinforcement learning, could further improve accuracy in future work.

Key Analytical Structure

The paper evaluates the theoretical maximum savings achievable over a building's lifetime. It highlights that different climate zones offer varying saving potentials, but in all cases, AI can help buildings achieve these potentials at lower costs.

Quantified Impacts (US Medium Offices)

- By 2050, AI adoption alone is projected to reduce energy use and CO_2 emissions by approximately 8% compared to the "business as usual" (BAU) scenario.
- When compared to a policy-only scenario, AI provides an additional 19% in savings.
- The combination of AI, strong efficiency policies, and low-emission power generation (LEPG) could result in up to 40% less energy use and 90% less CO_2 emissions than BAU.

Limitations and Future Work

The results depend on assumptions about cost declines and adoption rates. Additionally, the methodology has not yet been tested on other building types, which may limit the generalizability of the findings.

Take-aways and Thoughts

1) **Paper's Goal:** The main contribution is not a new algorithm, but rather the demonstration that AI can make existing high-efficiency designs more affordable, thereby unlocking a larger market share for these technologies.
2) **Role of Policy:** On its own, AI delivers modest (single-digit) gains. The substantial reductions of 40% in energy use and 90% in CO_2 emissions are only achieved when AI is combined with LEPG and clear regulatory policies.
3) **Scalability:** Expanding these results to other sectors will require further investigation and the development of skilled facility management teams.

METHODS

Summary by James Thompson

APPENDIX

TABLE II
SUMMARY OF ENERGY EFFICIENCY IMPROVEMENT CASES ACROSS ALL CATEGORIES

Case	Improvements	Adjustments
Equipment Efficiency Improvements		
E1	HVAC – Cooling	+20%
E2	HVAC – Heating	+12%
E3	HVAC – Cases E1 and E2	+20%, +12%
E4	Lighting – Power density (LPD)	-15%
E5	Lighting – Power density (LPD)	-21%
E6	Equipment – Power density (EPD)	-10%
E7	Equipment – Power density (EPD)	-20%
E8	Combined – Cases E1–E7	
E9	Case E8 + Heat Pump for space heating	
Design and Construction Improvements		
D1	Orientation	East (90° rotation)
D2	Orientation	South (180° rotation)
D3	Orientation	West (270° rotation)
D4	Envelope (walls, slabs, roofs, windows)	High insulation
D5	Envelope (walls, slabs, roofs, windows)	Increased infiltration (60%)
D6	Window-to-wall ratio (WWR)	Variation 1
D7	Window-to-wall ratio (WWR)	Variation 2
D8	Window-to-wall ratio (WWR)	Variation 3
D9	Combined – Orientation, insulation, WWR	
Occupant Behavior and Control Improvements		
B1	Ventilation control	Open/close windows
B2	Lighting use	Switch on/off lights
B3	Electricity consumption	Turn off plug loads
B4	Lighting use	Dim lights
B5	HVAC	Turn on/off HVAC systems
B6	Thermostat	Adjust thermostat settings
Energy savings: Equipment = 11.5–17.3% Design and Construction = 5.9–9.1% Occupant Behavior and Control and Operation = 15–20%		

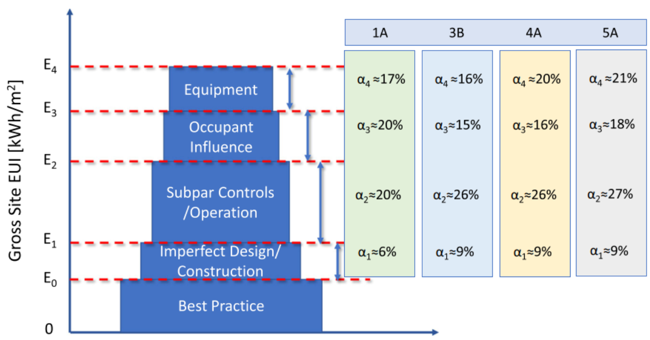

Fig. 2. Integrated building energy-saving breakdown by category and climate zone.