Decarbonize the office: Unleash the power of digital solutions for building renovations

Decarbonizing Buildings Series: Part I

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Executive summary

Meeting global climate targets requires renovating existing buildings at an accelerated rate using financially viable strategies to reduce carbon emissions from energy demand. Given climate action urgency, it is vital to consider strategies from a whole-life carbon model that includes the embodied carbon emissions of the renovation strategies and the expected gains in operational efficiency. From a whole-life carbon perspective, digital solutions have a faster return on embodied carbon investment and can be quickly implemented with low impact on building occupancy and usability.

Introduction

The Commercial Real Estate white paper series examines the typical steps and innovative solutions in power management, energy demand reduction, and socially driven emissions reductions. The series focuses on carbon emissions from the built environment occurring between 2023 and 2050 – the key time for emissions reductions to meet global climate goals.

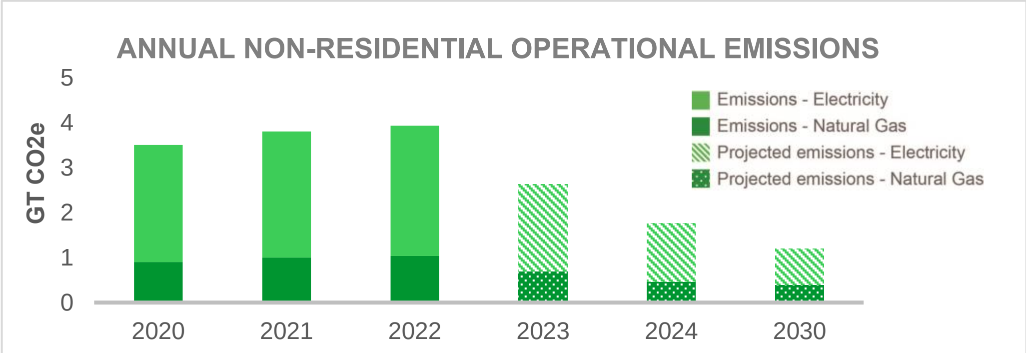
For office buildings to reduce energy demand, two primary pathways are increasing the energy efficiency of the building, to reduce overall demand, and electrification, to meet the demand with renewable energy sources. In this paper, we examine the pathway of energy efficiency:

1. **Improving the existing building stock** through envelope upgrades to improve thermal performance. This includes adding insulation (typically Expanded Polystyrene or EPS foam), upgrading windows to dual- or triple-pane glazing based on climate, and reducing infiltration rates by tightening the envelope.
2. **Upgrading building equipment** to include light sensors and power factor correction transformers.
3. **Deploying digital optimization**, including a modern building management system (BMS) controlling the HVAC system compliant with ASHRAE Guideline 36, and potential advanced enhancements to the BMS system, including AI optimization, zone-level management through Internet of things (IoT) sensor networks, and advanced lighting controls.
4. **Controls optimization**, or retro-commissioning, is the fourth typical step in increasing energy efficiency. This step is outside the scope of this paper.

Buildings are critical to achieving global greenhouse gas emissions (CO2e) targets to stay below the 1.5 C threshold of climate change. Today, buildings represent 37% of global CO2e emissions, with approximately 28% attributed to building energy consumption and an additional 9% associated with embodied carbon in building products.[1] While retrofitting buildings rather than building new structures can significantly reduce embodied CO2e emissions, operational emissions from buildings' energy consumption must reduce by 5% annually between now and 2050 to meet the emissions targets shown in **Figure 1**.[2]

Figure 1

Current emissions and projected need for carbon emissions reductions from electric and fossil fuel power sources



[1] Global Alliance for Buildings and Construction (2022) "2022 Global Status Report for Buildings and Construction," Accessed 10 May 2023. https://globalabc.org/our-work/tracking-progress-global-status-report.

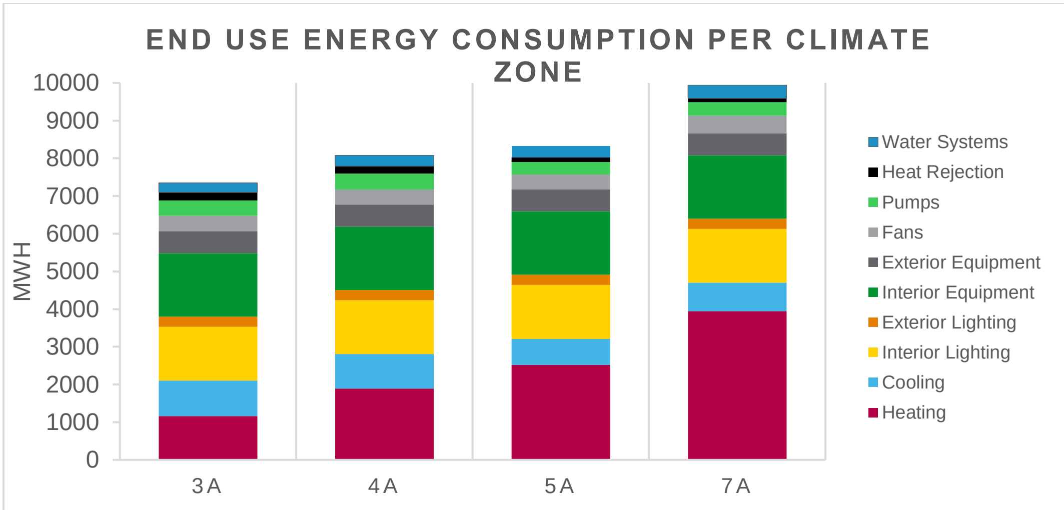
[2] International Energy Agency (2022) "Net Zero by 2050." Accessed 10 May 2023. https://www.iea.org/reports/buildings

Quantifying energy demand

As operational energy demand is the primary driver of operational carbon emissions in existing buildings, Schneider Electric and WSP began targeting operational energy efficiency improvements. To identify whether the strategies were universally applicable across similar building types with similar building systems, we based our analysis on the 2004 NREL Large Office archetype,[3] a 12-story office building employing a traditional HVAC system common in North American office design, and looked at four ASHRAE Climate Zones, see **Figure 2**. The energy consumption profile of the baseline archetype matches the expectation for a normative office building in the United States (U.S.).

Figure 2

Energy demand profiles of the baseline 2004 Large Office archetype by Climate Zone



We identified a series of Energy Conservation Measures (ECMs) associated with each of the potential solutions proposed for an energy retrofit, with a series of physical improvements to the envelope (window upgrades, wall insulation, and roof insulation) as one category of solutions, digital optimization as a second, and a series of less-traditional approaches that emphasize power management or emerging digital technologies, as listed in Table 1. To capture the benefit of occupancy-driven controls, we simulated a custom occupancy schedule using the LBL Occupancy Tool[4] to ensure occupancy rates accurately reflect a more realistic, dynamic condition.

[3] Existing Commercial Reference Buildings Constructed In or After 1980, Accessed May 15, 2023. https://www.energy.gov/eere/buildings/existing-commercial-reference-buildings-constructed-or-after-1980.

[4] Lawrence Berkeley National Laboratory Occupancy Simulator - https://occupancysimulator.lbl.gov/.

Table 1

Breakdown of Energy Conservation Measures tested in Part 1 of the study (showing Site Demand Reduction ranges across all Climate Zones studied)

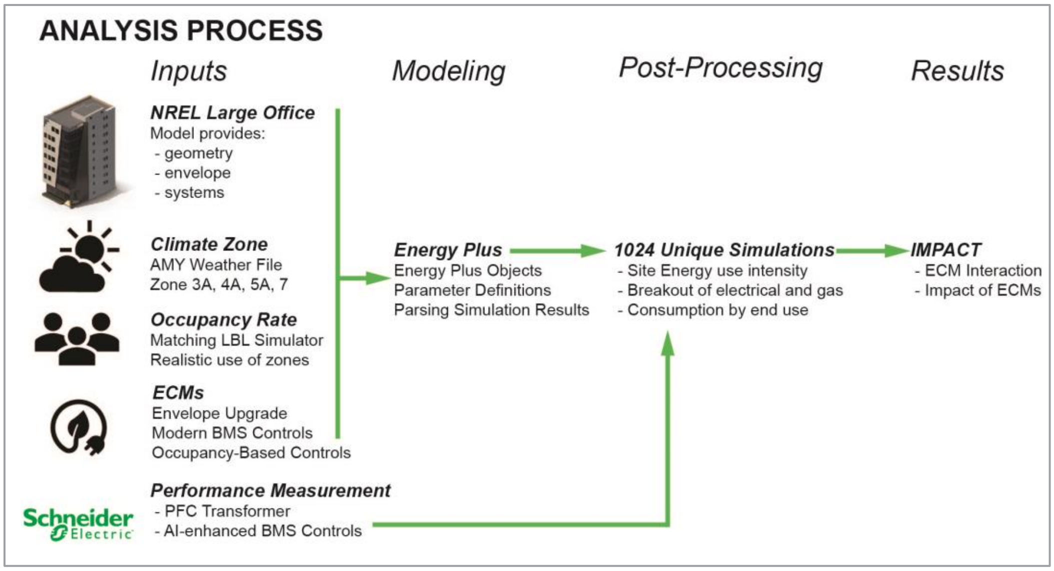
Energy Conservation Measure	Site Demand Reduction (when applied in isolation)	Implemented Solution
Occupancy-Based Lighting Setback	0.01 - 0.05%	1. Occupancy-Based Zone Controls (Reference for Performance: Connected Room Solutions)
Occupancy-Based Temperature Setback	7.2 – 10.8%	
Occupancy-Based Ventilation Rate	0.2 – 6.0%	
Daylight-Based Lighting Controls	0.6 – 2.2%	
Chilled and Hot Water Temperature Reset	0.13 – 0.20%	2. High-Quality BMS System (Reference for Performance Factors: EcoStruxure Building Operations)
VAV Controls – Duct Pressure + Supply Temp Reset	15.2 – 27.7%	
Artificial Intelligence (AI) - Enhanced Controls	8 - 16%	3. AI-Optimized BMS (Reference for Performance Factors: EcoStruxure Building Operations with AI add-on)
Power Factor Correction	19.7%	4. Power Factor Correction transformer (Reference for Performance Factors: PowerLogic PFC Capacitor)
Wall Insulation	5.2 – 19.2%	5. Envelope Upgrade
Roof Insulation		
Window Upgrade		

We conducted a study to determine if reducing fossil fuel demand for on-site use can meet 2030 targets without upgrading physical HVAC equipment. Part 2 of this series will look more deeply at electrification and associated system modifications, load shedding, and on-site energy generation from a whole-life carbon perspective.

Although a high-quality BMS system and power factor correction equipment are the optimal individual ECMs options in isolation, organizations seldom implement these strategies independently. When combined, many techniques interact in ways that are not simple to predict. We leveraged a parametric modeling approach, as diagrammed in **Figure 3,** to understand the tradeoffs, benefits, and interactions between potential strategies for the full decarbonization of a large office for Solutions 1, 2, and 5 from Table 1. Power Factor Correction and AI-Enhanced Controls were applied in the post-processing of demand data based on Schneider Electric's internal research. This process enabled the comparison of 4,096 variants of the energy model, adding each of the ECMs in different combinations to recreate every possible permutation.

Figure 3

Energy Modeling Process Diagram



Understanding energy demand reduction

When we begin to consider the results of this simulation, specific trends emerge. First of note – the PFC Transformer acts in an absolute reduction of 19.7% across the board, as it significantly reduces the difference between the apparent power (kVA) and the actual power (kW) consistently, irrespective of climate. These savings are based on the capacitor providing reactive energy at the load through the capacitor, avoiding the reactive energy consumed by the utility itself, by providing a power factor correction of 0.8 to 0.95.

For simplicity, we will start by isolating Climate Zone 7 (see Table 2), which has a baseline site energy use intensity of 214.6 kWh/m^2 with 121.9 kWh/m^2 from electricity demand and 92.74 kWh/m2 provided by natural gas. The PFC Transformer reduced energy demand to 190.62 62 kWh/m2 (97.87 kWh/m2 electricity, 92.7 kWh/m2 natural gas) after factoring it in. In isolation, the other ECMs provided the following savings:

Table 2

Energy Conservation Measures savings in isolated application, Climate Zone 7

Energy Conservation Measure	Energy Demand (kWh/m2)	Δ Electricity	Δ Natural Gas
Occupancy-Based Lighting Setback	214.43	-2.2%	+2.7%
Occupancy-Based Temperature Setback	188.06	-0.2%	-28%
Occupancy-Based Ventilation Rate	201.99	-10.2%	-0.2%
Daylight-Based Lighting Controls	213.64	-4.1%	+1.2%
Chilled and Hot Water Temperature Reset	214.21	-0.3%	+0.0%
VAV Controls – Duct Pressure + Supply Temp Reset	161.65	-9%	-45%
AI-Enhanced Controls	184.58*	-29%*	-14%*
Power Factor Correction	190.62	-19.7%	-
Envelope Upgrade	173.46	-2.3%	-41%
Baseline	**214.63**	**121.88**	**92.75**

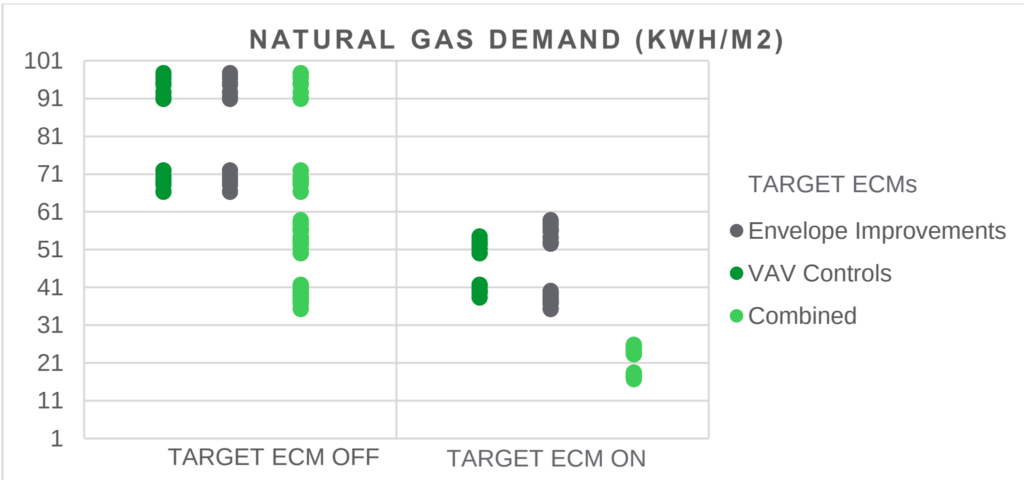
*NOTE: AI-Enhanced Controls cannot run in isolation in reality; they rely on a modern BMS system with cloud connectivity to function. Similarly, occupancy-based controls are reliant on a central BMS system. These improvements are shown in isolation for illustrative purposes only.

If these savings did not have interactions between them, such that an additional increase in savings would mean two ECMs with savings of 5% and 25% applied together would still achieve a 5% and 25% reduction, applying them simultaneously would be expected to save 42.6% of the electrical demand and 20.8% of the natural gas. However, when applying all the ECMs simultaneously, we found an overall energy demand savings of 56%, with a 22% reduction in electricity demand and an 81% reduction in natural gas. This indicates that while some of the ECMs may interact in ways that reduce the effectiveness of the electricity efficiency measures, they also interact in positive ways to reduce natural gas consumption.

Starting with the significant reduction in natural gas, we can look at the two biggest contributors to these savings – the envelope upgrade and the variable air volume (VAV) controls – and how they perform in combination with the other ECMs. **Figure 4** shows the range of performance outcomes when each is applied alone in combination with the other ECMs versus the performance of both together.

Figure 4

Comparing the two most effective natural gas conservation measures



When the VAV controls operate in combination with each of the other ECMs, we see a range of natural gas reduction from 38.25 – 76.01 kWh/m2, and for an envelope upgrade, an even larger range of reduction capability – 33.94 – 57.47 kWh/m2. When we combine the two, we observe that natural gas savings act close-to-multiplicatively. This implies that the percentage savings observed from one ECM across all other ECMs are similarly applied when the other ECM is implemented.

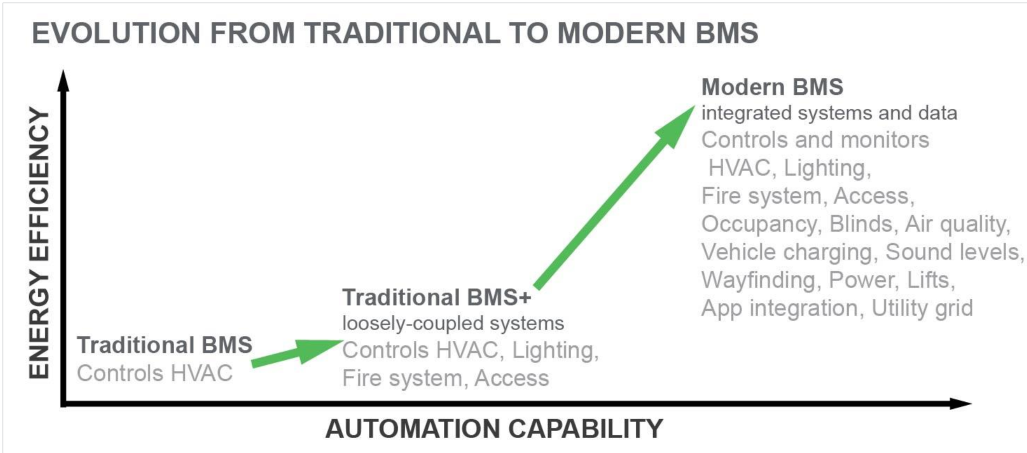
To illustrate more clearly – when we see an envelope improvement without VAV controls, natural gas consumption typically performs 37-62% better than the baseline condition. Similarly, applying VAV controls without an envelope improvement tends to perform 41-59% better than the baseline. After applying both, we see an improvement in natural gas consumption of 72-81%. In isolation, the VAV control optimization is the more realistic ECM to implement, as it has an edge in energy savings and does not carry the same installation burden associated with replacing the envelope.

As a modern BMS is required for the VAV Controls and other (non-PFC) system control ECMs to function, let's first review how a "modern" BMS is defined:

Given growing demands from the industry coupled with evolving technical capabilities, building management and control systems have become broader in scope, use more sensors, and are more tightly integrated with other smart building systems (see **Figure 5**). Modern controls take better advantage of newer IT protocols and can be software-defined, making these systems much easier to deploy, setup, and reconfigure as building needs and uses evolve over time, making the system and building more "future-proof".

Figure 5

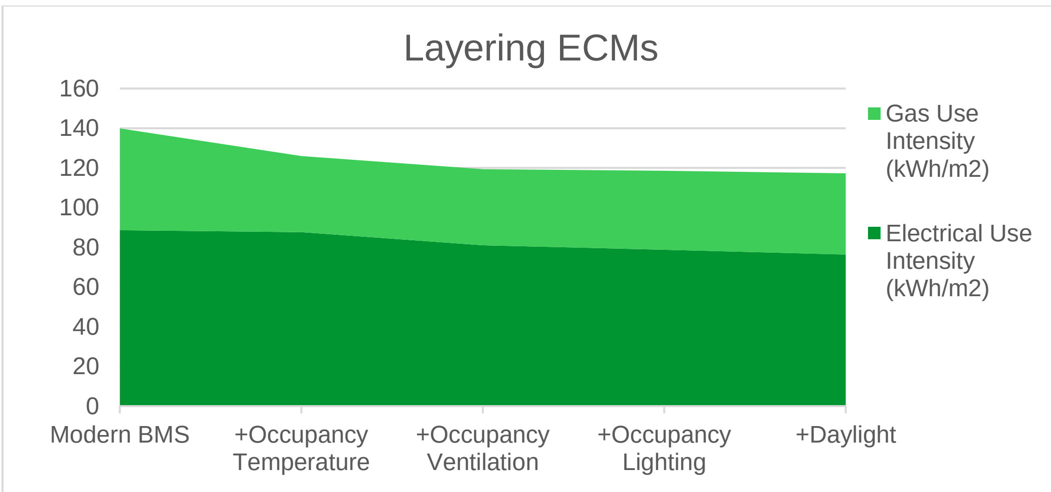
Evolution of Traditional BMS to Modern BMS (illustrative)



Accordingly, for system control ECMs, we can start with a baseline of the VAV and water reset controls to establish a realistic case. Besides the artificial intelligence (AI)-enhanced layer on top of the controls, we see a diminishing return rate with other ECM combinations after applying the occupancy-based HVAC controls, as shown in **Figure 6**.

Figure 6

Layering additional control-based ECMs on top of the BMS system



There is a clear case for the increased savings associated with HVAC Zone-based controls with occupancy sensor integration for both the temperature and ventilation. Still, the savings associated with the lighting controls will have a significantly longer return on investment, partly due to the increase in natural gas consumption associated with the loss of heat generated by the lighting equipment. This trend is unlikely to hold true in the warmer climate zones.

Quantifying carbon emissions

Although the traditional motivation for the Commercial Real Estate market has assumed that a return-on-investment model (ROI) is based only on utility bills and maintenance savings and therefore has prioritized energy efficiency, new imperatives have emerged. With climate change reduction beginning to drive international real estate regulations, an increase in utility carbon pricing, and companies progressively adopting environmental, social, and governance (ESG) goals as a primary concern in doing business, a new focus on carbon emissions has come to the forefront. Looking through this lens, we need to update our previous analysis to account for all emissions between now and 2050. Instead of annually examining operational emissions, we must consider the total lifecycle emissions linked with the retrofit.

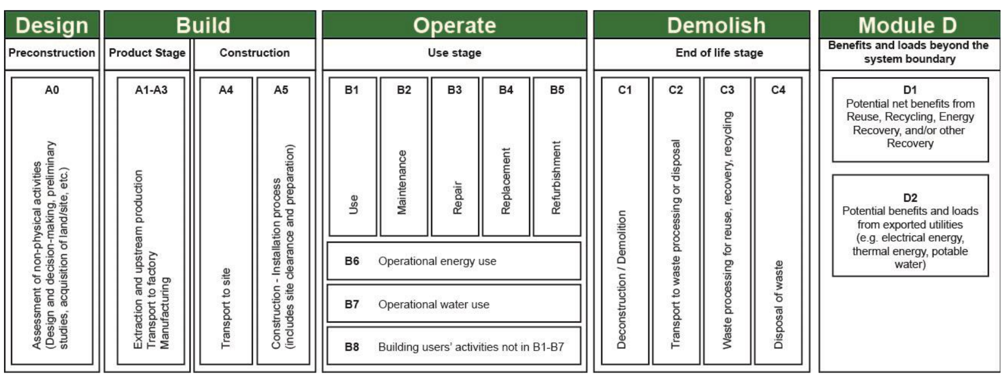
To quantify the carbon emissions, we adopted the EN 15978 framework, as shown in **Figure 7**. For operational carbon, we translated the energy consumption into carbon emissions associated with the fuel type and electric grid emissions. For embodied carbon, we included the Product Stage, Construction Process, and Use Stage for all physical additions. We include the Demolish phase of impacts for any equipment or materials we expect to replace during the 2023-2050 study period.

Calculating embodied carbon emissions

Following normative lifecycle assessment (LCA) assumptions, we discount the existing embodied carbon of the pre-existing building (before intervention) as having no upfront impacts and only count impacts during the study period. We assume the building will be in use after 2050. Therefore, we only include end-of-life (Module C) impacts for items with a reference service life shorter than the 27-year study period. We consider all applicable manufacturing (A1-3), transportation (A4), installation (A5), use phase (Module B1-5), demolition (Module C), and recycling or refurbishment (Module D) impacts for all items that we demolish, maintain, or replace during the study period from 2023-2050. Use stage energy demand (Module B6) is modeled based on predicted energy demand from the energy model and is converted into operational carbon, described in the following section.

Figure 7

The EN 15978 framework for whole lifecycle impact assessment



In the building, we use industry-typical assumptions[5] to model envelope maintenance and interior renovation cycle impacts. For an envelope upgrade, we use Polyiso roofing insulation and EPS foam board for the exterior, along with the necessary caulk and sealants, to improve the insulation rates. For window upgrades, we assume triple-glazing is used for Climate Zones 5 and 7, and double-pane glazing is used for Climate Zones 3 and 4.

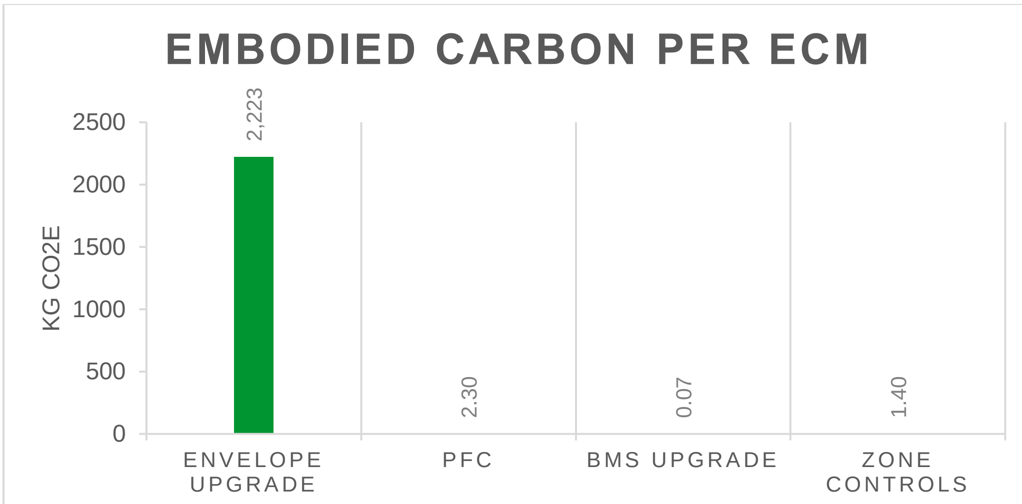
[5] For more information on assumptions, view documentation for EPiC (https://www.epic-docs.dev/c.scale-data-model/methodology) and CARE Tool (https://caretool.org/data-and-methodology/)

As generic data for power management equipment is not readily available, we use the embodied carbon and lifecycle assumptions from the product environmental profile (PEP) for a PFC low-voltage capacitor bank by Schneider Electric.[6] The assumption is a replacement rate of 15 years, which is assumed to happen once during the 2023-2050 building reference service life. The four capacitors and contactors are changed every four years, requiring six changes after the first installation period. They are assumed to follow the profile of a PFC Capacitor by Schneider Electric.[7] Finally, the four filters are changed every two years.

The comparison of the ECMs on an embodied carbon basis is shown in **Figure 8**. For specific information on embodied carbon data sources, see **Appendix A**.

Figure 8

Sum of embodied carbon emissions per ECM in Climate Zone 7 over the Reference Study Period



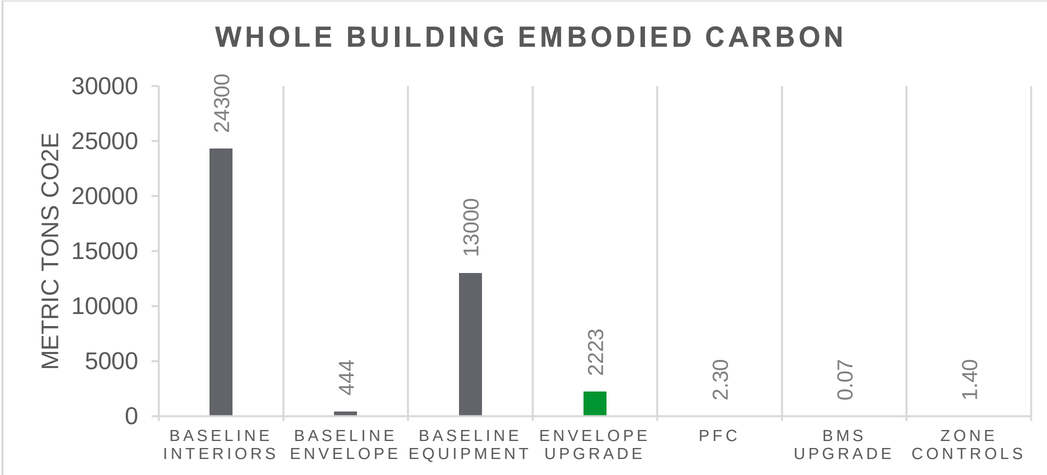
The cycle of interior renovations is by far the largest contributor to ongoing environmental impacts. Suppose we remove the interior fit-out and finishes replacement that is expected on a 10-year cycle for typical office interiors. In that case, the next largest contribution to embodied carbon is replacing the HVAC equipment itself, assumed to happen approximately every 15 years, and assumed to have happened most recently in 2019. Even though power factor correction can reduce this impact by approximately 3% by extending the lifetime of the HVAC assets, the HVAC replacement is still orders of magnitude higher than any other embodied carbon impact, as shown in **Figure 9**.

[6] Schneider Electric, "Product Environmental Profile: VarSet Low voltage capacitor bank1306063EN_V1," https://www.se.com/ww/en/download/document/ENVPEP1306063EN/

[7] Schneider Electric, "Product Environmental Profile: PowerLogic PFC," https://www.se.com/ww/en/download/document/ENVPEP1612005EN/

Figure 9

Sum of embodied carbon emissions for the whole building in Climate Zone 7 over the Reference Study Period

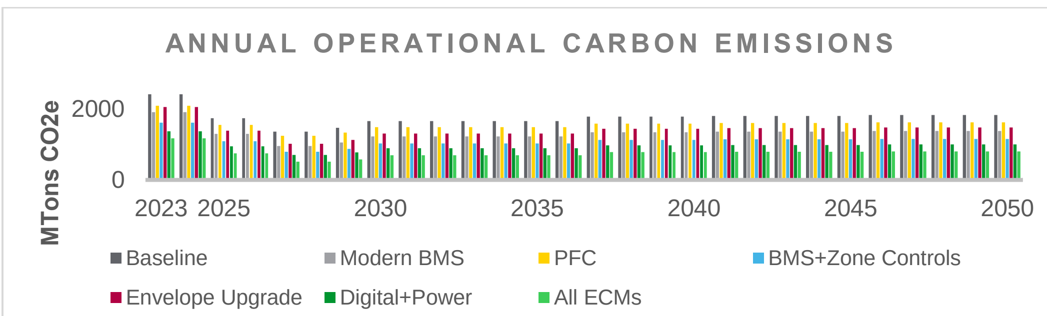


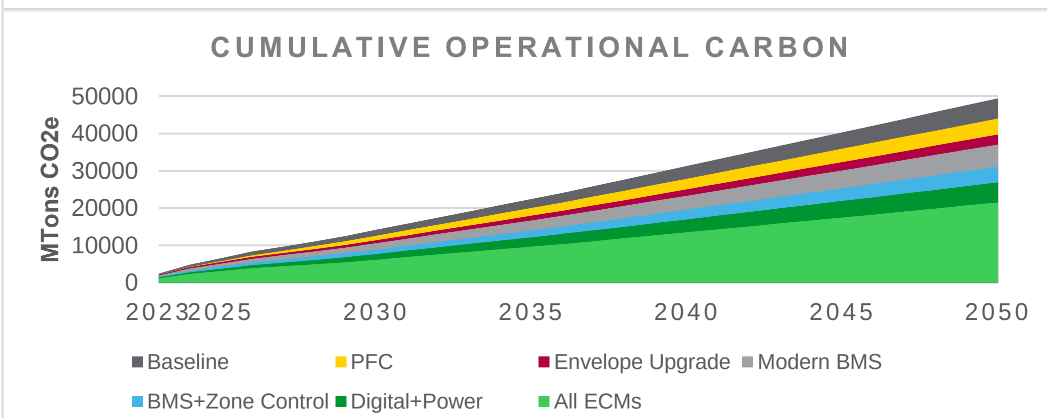
Calculating operational emissions

To understand how embodied carbon contributions operate over the building lifecycle, we need to compare them against lifecycle operational carbon savings. By combining combustion and pre-combustion factors based on site use demand, we can calculate the expected operational emissions associated with the energy demand, both electric and natural gas. We use the GWP100 AR6 emissions factors[8] to coordinate with the embodied emissions, with mid-case grid decarbonization projections for the electricity.[9] We use the U.S. average use rate of 0.228 kg CO2e per kWh for natural gas emissions.[10] The results are shown in **Figures 10** and **11**.

Figures 10+11

Annual and Cumulative Operational Carbon Emissions per scenario in Climate Zone 7





[8] The Global Warming Potential (GWP) is a measure used to assess the impact of different greenhouse gases on global warming over a specific timeframe, typically 100 years. GWP100 refers to the Global Warming Potential value calculated over a 100-year period.

[9] Gagnon, Pieter; Cowiestoll, Brady; Schwarz, Marty (2023): Long-run Marginal Emission Rates for Electricity - Workbooks for 2022 Cambium Data. National Renewable Energy Laboratory. 10.7799/190937 (Data set used: Annual marginal rates, lrmer_co2e; Emission: CO2 Equivalent, combined combustion+pre-combustion. 30 year evaluation period, starting 2023, without discount rate; mid-case scenario)

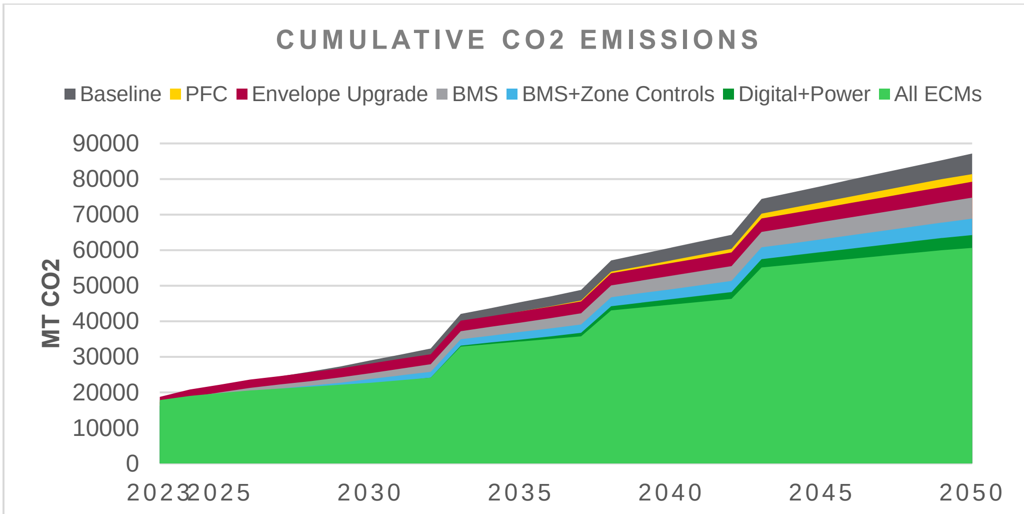
[10] https://portfoliomanager.energystar.gov/pdf/reference/Emissions.pdf

These emissions are best understood when we place them within the whole lifecycle framework, which allows for an understanding of the payoff period of carbon savings from an operational versus embodied perspective. For simplicity, we compared the most realistic permutations of the solutions (see **Table 1**) within Climate Zone 7 for the cumulative emissions rates (operational + embodied carbon):

- the baseline
- adding a modern BMS system
- adding power factor correction
- adding BMS + zone-level controls
- upgrading digital and power only (BMS + Zone Controls + PFC)
- upgrading the envelope
- adding all ECMs (BMS + Zone Controls + PFC + Envelope Upgrades)

Figure 12

Cumulative lifecycle (embodied + carbon) emissions per scenario.



In evaluating the options, as shown in **Figure 12**, we can see the importance of the embodied emissions (in particular, the jumps occurring on the interior's fit-out cycle) in the whole carbon lifecycle. We can also observe that, while the best option is to use all available ECMs, most of the best-performing options rely entirely on the digital improvements associated with the BMS system upgrade due to its low embodied carbon.

Prioritizing carbon reduction efforts

Energy is not equivalent to emissions

When considering the total lifecycle carbon emissions, the key metric is the Return on Carbon (ROC) value – the number of years it takes to save an equivalent value of operational carbon as was "invested" in the embodied carbon. For digital solutions, this occurs within the first year of implementation. For the PFC Transformer, it takes almost the full four years of operations for carbon savings to manifest. For the envelope upgrade, the carbon saved takes nearly seven years to equal the carbon invested. On the other hand, the implemented improvements for the "Digital + Power" version cover the embodied carbon "sink" after the first year and a half.

While the overall trend remains the same as in the energy analysis – implementing all the ECMs is better than any other solution; digital tends to outperform physical improvements on a 1:1 basis – the systems that reduce natural gas demand save more carbon on a per kWh basis than the solutions that only save electricity. From a carbon perspective, the envelope upgrade outperforms the PFC transformer over the building lifecycle because it primarily reduces natural gas consumption driven by the heating load.

Additionally, the diminishing returns of adding each occupancy-based control are not as evident from a carbon perspective. Instead, there is a neutral benefit to adding daylight-based controls. The increased demand for natural gas for heating, which carries more CO2e per kWh, counterbalances the carbon reduction linked with electricity savings. Occupancy-based controls for the HVAC system provide notable advantages by reducing the reliance on natural gas for heating and minimizing electricity usage for cooling and ventilation fan power during summer. While occupancy-based lighting controls offer more benefits than daylight controls, they don't contribute significantly to carbon emissions reduction as do HVAC controls. This is because the LED-based lighting system minimizes heating or cooling demands and does not require high electrical power consumption.

Prioritize digital solutions

When facing today's global challenges and the aggressive carbon reductions needed to meet science-based targets for carbon emissions, we must prioritize the measures with a low embodied carbon emissions rate, a fast return on the upfront carbon emissions, and a low operational emissions profile. It is necessary to use solutions operating across various building typologies and climate zones and promptly implement them throughout the current building environment.

For building retrofits, this means prioritizing the digital solutions, which are faster to implement, lower in upfront carbon, and more effective from a long-term lifecycle carbon perspective. While complete envelope retrofits and building systems are necessary to achieve full building decarbonization, updating an old BMS is the most effective first step. The next meaningful step is improving the building envelope, although this intervention can take longer to implement and decreases payoff in warmer climates.

The next paper of this series continues down the path of full building decarbonization by examining best practices for sourcing green energy, managing power profiles against the marginal carbon emissions rate of the grid, and full building electrification.

About the authors

Efrie Escott, AIA, LEED BD+C, LCACP, LFA, Schneider Electric – Efrie promotes strategies to accelerate the decarbonization of the built environment as the Sustainability Transformation Leader for Schneider Electric's Digital Energy Division. With a career focused on climate action in the built environment, Efrie has developed tools, authored international standards, published peer-reviewed research, and lectured internationally to radically reduce carbon emissions.

Mike Kazmierczak, Schneider Electric – Mike Kazmierczak is CMO and VP Decarbonization Office, for the Schneider Electric Digital Energy Division, where he is responsible for developing the global decarbonization strategy and marketing to accelerate the digital transformation of power management and sustainable buildings through innovative, trusted, and open solutions. Mike has over a decade of experience in energy management, automation, and sustainability in markets including data centers, industrial automation, and buildings.

Brook Potter, Schneider Electric – Brook leads Sustainability initiatives for Schneider Electric's Digital Buildings Division and ensures that Schneider's products deliver outcomes that support decarbonization. He brings over 15 years of experience leading product management for global software offers that help AECO professionals develop and operate commercial buildings that are more sustainable, achieve higher operating potential, and deliver transformative experiences for occupants.

Jay Wratten, WSP – Jay leads WSP's Property and Buildings Innovation Advisory Services team, which focuses on creating portfolio and enterprise-wide strategies for Owners, Operators, and Tenants of the built environment. Within this context, Jay leads a team that develops strategies that can be readily implemented by clients, with clear alignment to the organization's people, business, and technology needs.

Romeo Michael, PE, WSP – Romeo, an experienced lead building performance consultant and energy modeler, collaborates with building owners, architects, and design teams to enhance a building's energy performance, spanning from schematic design to construction. With expertise in energy management and sustainability, he excels in managing the measurement and verification of energy savings derived from site upgrades.

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Resources

[The Path to Net Zero Buildings: 3 steps to turn sustainability ambition into action](#)
White Paper

Appendix A

Embodied carbon impact table

Table 3

Embodied Carbon Impact Table

Item	Reference Service Life	Module A (GWP, kg CO2e)	Module B, excluding B6 (GWP, kg CO2e)	Module C (GWP, kg CO2e)	Module D (GWP, kg CO2e)
PFC	15 yr	1263.8	-	38.4	-
PFC Capacitor	4 yr	21.9	-	0.476	-
Interiors	10 yr	8000	-	100	-
Envelope Maintenance	20 yr	-	222	-	-
HVAC Equip. Baseline	15 yr	6000	-	500	-
Window Upgrade[11]	30 yr	740	1.6	6.5	-
EPS Insulation[12]	75 yr	1297	0	5.24	-
Polyiso Insulation[13]	40 yr	250	232	8	-
Extension of HVAC Equip.	+5 yr		(-200)		
BMS Zone Control (per zone)	10 yr	38.68	-	0.14	-
BMS Upgrade[14]	10 yr	22.9	-	0.24	

[11] https://www.environdec.com/library/_?Epd=11993

[12] https://www.insulfoam.com/wp-content/uploads/2016/08/EPS-Insulation-EPD.pdf

[13] https://cdn.ymaws.com/www.polyiso.org/resource/resmgr/health&environment/epd_2020_roof_insulation_eng.pdf

[14] https://www.se.com/us/en/product-range/62111-ecostruxure-building-operation/#documents