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Decarbonize the office: Accelerate with electrification

Building Decarbonization Series: Part III

by Efrie Escott and Mike Kazmierczak, Schneider Electric
Jay Wratten and Romeo Michael, WSP

Executive summary

A digital-first approach is the fastest path for building decarbonization and saves significant headaches in the building electrification process. Eliminating carbon emissions also requires a change in mindset from looking at the building in isolation to looking at it as an active participant in the utility grid. It is vital to proactively manage, monitor, control, and maintain building energy systems to meet the carbon reductions required to avoid the worst of the climate crisis. Digital solutions and on-site power generation are immediately beneficial for the climate and are required foundational steps for building electrification to be climate-positive.

Introduction

The Building Decarbonization 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 between 2024 and 2050 – the critical 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 the first paper of the series, *Decarbonize the office: Unleash the power of digital solutions for building renovations*, we explored efficiency improvements. In this paper, we leverage the same building modeling methods to examine the pathway of electrification:

1. **Retrofitting building systems** to become all-electric while retaining the existing distribution system as much as possible to minimize embodied carbon impacts. The upgrade includes the installation of an air source heat pump to replace a natural gas boiler and a domestic hot water upgrade to an electric heater.

2. **Generating power on-site** through photovoltaic (PV) systems covering 70% of the available roof space and an on-site battery energy storage system (BESS).

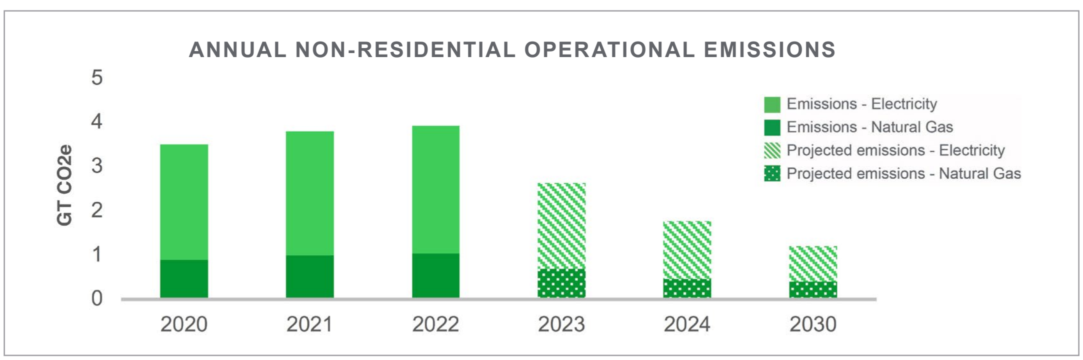
3. **Load shifting** through a flexible, grid-responsive microgrid system that avoids the peak carbon emissions in the grid and optimizes the relationship between the different power sources. In this instance, we optimize our use of the PV system and battery storage to flatten our carbon curve and reduce our annual carbon emissions.

4. **Power monitoring** as a companion to the BMS to provide a full suite of monitoring services. Although these systems offer significant fault detection and preventative maintenance against system failure, these do not have standard methods to account for carbon benefits. Therefore, we will only account for the calibration of the PV system and protection against performance decay over time across all systems in this paper.

As explored in the first paper of the series, buildings are critical to achieving global greenhouse gas emissions (CO_2e) targets to stay below the 1.5 C threshold of climate change, as they represent 37% of global CO_2e emissions.[1] While retrofitting buildings rather than creating new structures can significantly reduce embodied CO_2e emissions, operational emissions from buildings' energy consumption must also be reduced by 5% annually between now and 2050. The first milestone on this path is the 2030 emissions target shown in **Figure 1**.[2]

Figure 1

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



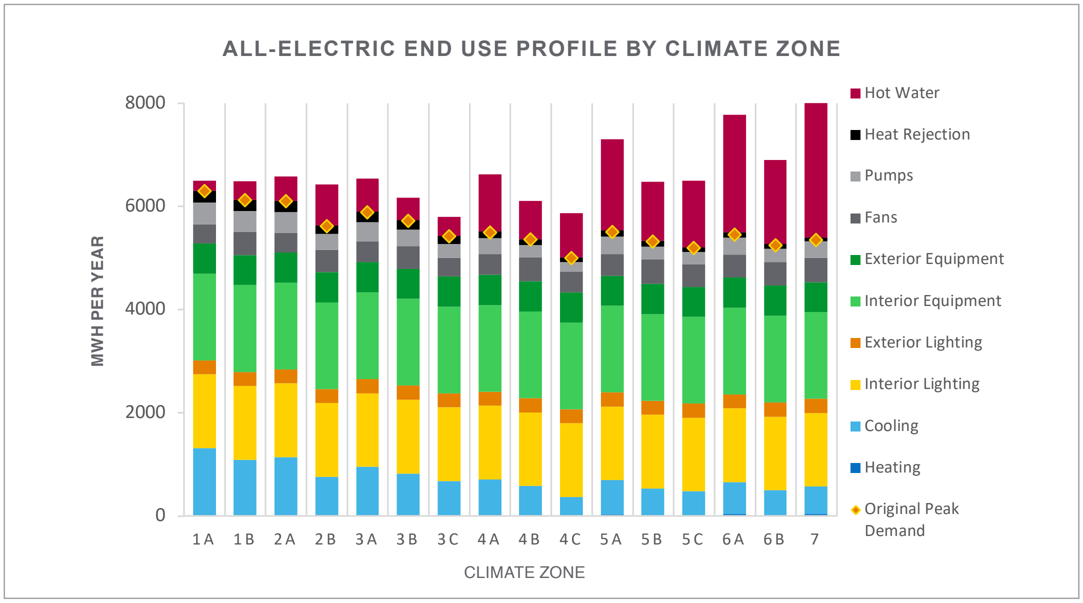
1. Global Alliance for Buildings and Construction (2022) "2022 Global Status Report for Buildings and Construction," Accessed 10 May 2023. https://globalabc.org/our-work/tracking-progress-global-status-report
2. International Energy Agency (2022) "Net Zero by 2050." Accessed 10 May 2023. https://www.iea.org/reports/buildings

Electrifying existing buildings

A building cannot decarbonize when it relies on fossil fuel combustion to heat the air and water occupants use. Therefore, one of the primary targets of advocacy and regulatory efforts is to electrify the building stock. The installation of a heat pump system typically achieves a large part of this. However, installing an all-electric building system is more complex than switching out the gas-powered HVAC and hot water equipment along with the internal rewiring and distribution system, as the conversion to an all-electric system also means increasing the electrical demand from the utility. In the all-electric office, the energy demand is driven by the hot water creation and circulation by the heat pump, plug loads ("Interior equipment"), and lighting, as shown in **Figure 2**.

Figure 2

Energy Demand profiles per climate zone after conversion to all-electric equipment



Utility connections, where the building meets the grid, are usually governed by the peak expected electrical load. Although excess capacity is included in the sizing for resilience against minor load shifts over the building lifecycle, the conversion of heating systems from natural gas to electricity frequently represents a significant shift of energy demand to that connection. Any excess capacity beyond the expected peak demand is called "headspace." Usually, unless some form of energy conservation measures are applied in conjunction with the conversion, the headroom available in the utility connection is insufficient to meet the increased electrical demand, leading to expensive retrofit of that connection and significant project delays.

Energy efficiency to enable electrification

To gain the needed headspace with minimal disruption to the building operations and on the quickest timeline, we apply the following digital upgrades to the HVAC system as energy conservation measures (ECMs)[3]:

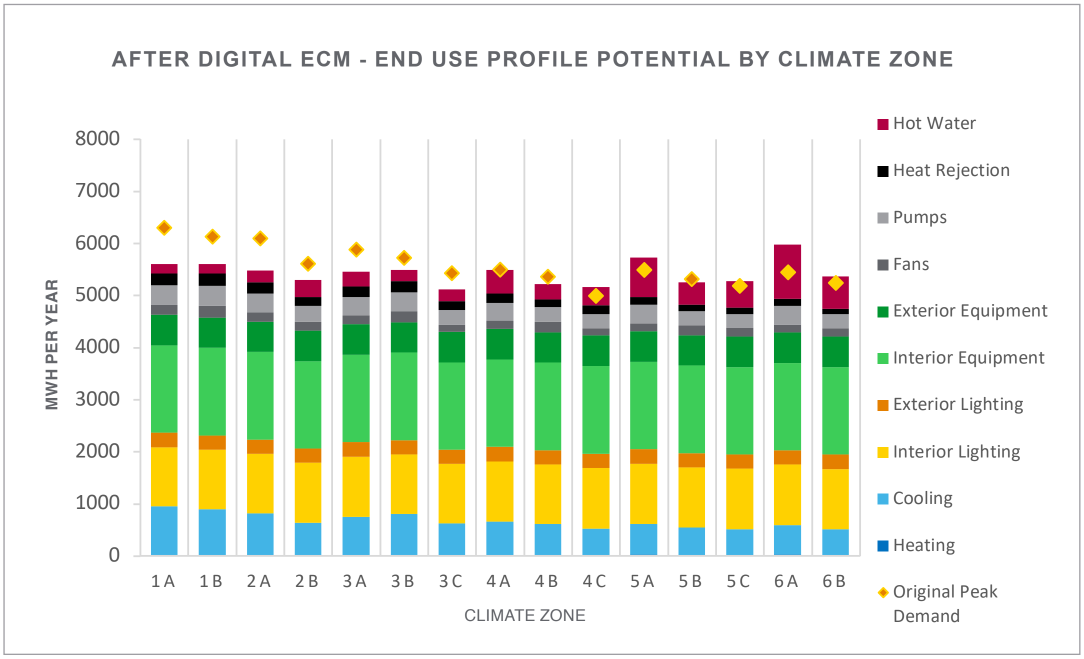
1. High-quality modernized BMS system
2. Occupancy-based zone controls

Applying the ECMs associated with digital improvements can provide the needed headspace for an all-electric conversion in many climate zones, as shown in **Figure 3.** Adding the additional ECM of a high-efficiency transformer and power factor correction from the typical office kVAr of 0.83 would provide further reductions, as shown in the difference in values between **Figure 3** and **Figure 4**.

3. For more on the included measures, see *Unleash the power of digital solutions for building renovations*, the first white paper in this series. Although an AI-enhanced BMS provides additional improvements that would make the headspace available across almost all regions, the technology is not yet available in all target regions.2. International Energy Agency (2022) "Net Zero by 2050." Accessed 10 May 2023. https://www.iea.org/reports/buildings

Figure 3

Energy Demand profiles per climate zone after applying digital ECMs and conversion to all-electric equipment. Zones with insufficient headroom are called out using yellow rather than orange marks for the original peak demand on the utility connection



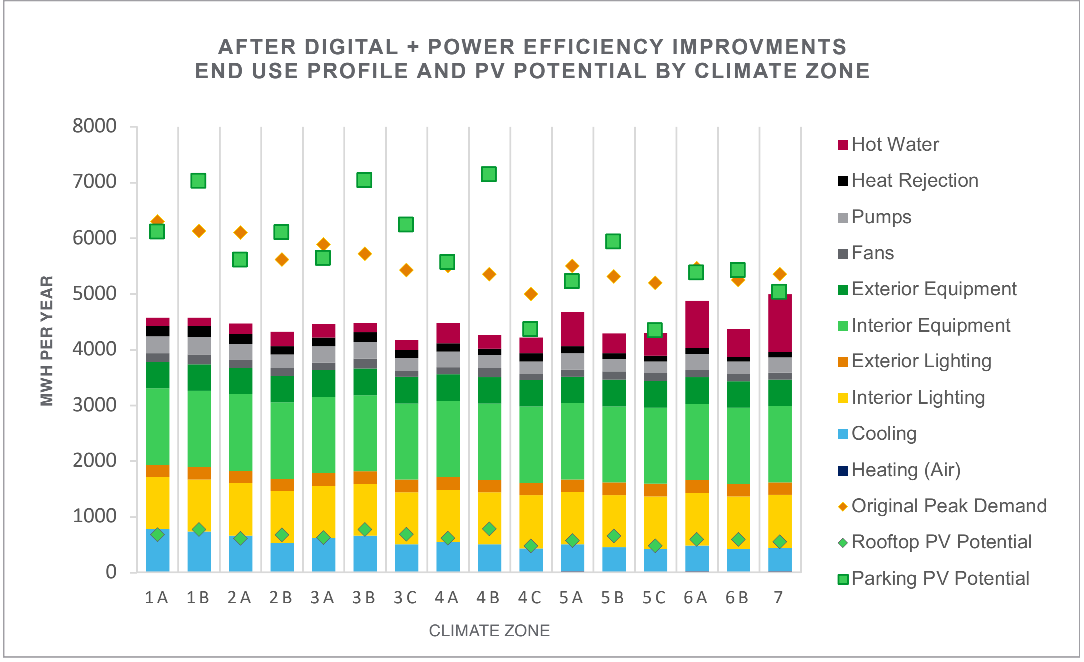
Power factor correction reduces artificial energy demand from phase distortion created by elevator motors and variable flow HVAC, and harmonic factor correction is essential in reducing the noise in the signal created by on-site power generation and battery. Power factor correction from .83 to .96 significantly reduces the building's power demand, and harmonic factor correction yields an additional 1% gain in usable energy. This reduces the utility's overall power demand and maximizes the onsite generation's usable power. As explored in the previous paper of this series, it also extends the lifetime of all connected electrical assets. This brings the retrofit well below each climate zone's existing utility connection size, as shown in **Figure 4**, even before the on-site energy is subtracted from the sum of the end uses.

The next step in building decarbonization is to install on-site power generation, typically through a photovoltaic system (PV). The benchmark building, based on ASHRAE 90.1-2004, as described in detail in the previous paper, has a rooftop area of 3680 m². After leaving space for walkways, avoiding self-shading, and keeping clear of any rooftop equipment, this leaves room for a 430 kW PV array. Including on-site surface parking sized to building code (1 parking spot per 30 m² of building gross floor area), we can add a maximum of a 3,900 kW PV array as a canopy to shade 70% of the lot.This canopy capacity is more than large enough to cover the complete building energy demand on an annual average basis, creating a Net Zero or Net Positive Energy connection to the grid, as shown in **Figure 4**.

Most building sites will have conditions between these two extremes. Depending on the size of the site-mounted PV array, the building may now achieve net-zero energy, or even energy-positive, status. A grid-connected building that produces more annual energy than it consumes is considered a "prosumer"– a citizen of the grid that is both a producer and a consumer of grid energy.

Figure 4

Energy Demand profiles per climate zone after power quality improvement reduces energy demand. Rooftop PV power generation potential hovers around 10-15% of total demand, while surface parking canopy PV frequently creates a "prosumer" condition



Although envelope enhancements require phased implementation and have a longer return on investment (ROI), a complete deep retrofit usually includes continuous exterior insulation, increased roof insulation, and an upgrade of the windows to double- or triple-pane glazing, as appropriate for the climate. With traditional building equipment, the additional energy reductions included in those enhancements reduce energy demand further and can be implemented at a future date when appropriate for the building owner. However, after a full digital retrofit has been applied to an all-electric building, there are few climate zones where making an envelope improvement has a notable benefit, as shown in **Table 1**.

Table 1

Comparison of annual energy use intensity (EUI) between the digital and digital+envelope improvement conditions

City | Climate Zone	Energy Demand Baseline (kWh/m2)	After Digital and PFC (kWh/m2)	Δ adding envelope	Roof PV Potential (kWh/m2)
Miami, FL | 1A	140.4	98.6	-0.4%	14.5
Phoenix, AZ | 1B	140.1	98.7	0.8%	16.6
Houston, TX | 2A	142.0	96.5	-0.4%	13.3
Tucson, AZ | 2B	138.7	93.3	0.3%	14.5
Atlanta, GA | 3A	141.2	96.2	1.7%	13.4
Las Vegas, NV | 3B	133.3	96.8	2.0%	16.7
San Francisco, CA | 3C	125.1	90.1	-1.2%	14.8
Baltimore, MD | 4A	143.0	96.8	1.5%	13.2
Albuquerque, NM | 4B	131.8	92.0	-1.1%	16.9
Seattle, WA | 4C	126.8	91.0	-0.7%	10.3
Chicago, IL | 5A	157.6	100.9	5.0%	12.4
Boulder, CO | 5B	139.9	92.6	0.1%	14.1
Bremerton, WA | 5C	140.3	92.9	1.2%	10.3
Minneapolis, MN | 6A	168.0	105.2	7.8%	12.8
Helena, MT | 6B	149.0	94.5	2.0%	12.9
Duluth, MN | 7	176.4	107.8	10.9%	11.9
Average (± σ)	**143.3** (± 13.3)	**96.48** (± 2.3)	**1.8%** (± 3)	**13.7** (± 2)

As adding on-site solar is ana significant financial investment similar in magnitude tothat is typically only slightly lower than the cost of upgrading the building envelope, it can be necessary to consider which is of higher value. from an energy and carbon efficiency perspective. Adding rooftop solar can reduce utility energy demand by 9%-15% for an all-electric building, with an average improvement of slightly under 14%. On the other hand, upgrading the building envelope compared to those built to code in 2004 can hurt energy performance in five climate zones (1A, 2A, 3C, 4B, and 4C) – and typically only improves performance by around 2%. Only in Climate Zone 7 does the improvement associated with upgrading the envelope exceed the gainenergy demand reduction provided by rooftop solar (10.9% for envelope versus 10.1% for solar). However, on-site energy potential provides additional carbon conservation measures by enabling load-shifting on the utility that envelope performance does not.

When installing on-site solar, two additional system upgrades should be considered. The first is the installation of a microgrid with a battery to optimize the use of on-site power and the connection to the grid. This enables a grid-responsive connection for power demand shifting, the carbon benefits of which are discussed below. The second is a power monitoring system, which can typically increase the performance of a PV system, battery, and heat pump by approximately 3%-5% and will provide protection against performance decay of the building, power, and PV systems over time.[4] This protection typically provides a 5%-30% energy performance benefit, with a typical benefit of around 12% over the lifetime of the building.5 We assume ainclude the power management system benefits to increase the PV output potential in the carbon modeling performed below when modeling a typical year, but do not include the additional capabilities of load shedding, heat pump load shifting with smart pre-heating, or load “shimmying” where small windows of 15-minutes or less shift power demand away from peak grid demand conditions.

Quantifying carbon emissions

After all of these digital energy efficiency, power management, rooftop solar, and electrification measures are applied, we see an average total energy reduction (in MWh/year) of approximately 60% compared to the original reference natural gas building.

One of the primary motives for electrifying the building stock is to decarbonize the built environment. Although the energy reductions shown in the section above would also significantly reduce the carbon footprint and the energy costs, the annual cuts in energy demand by 20%-40% through ECMs and the offset of 10%-17% by onsite power generation do not tell the full carbon story.

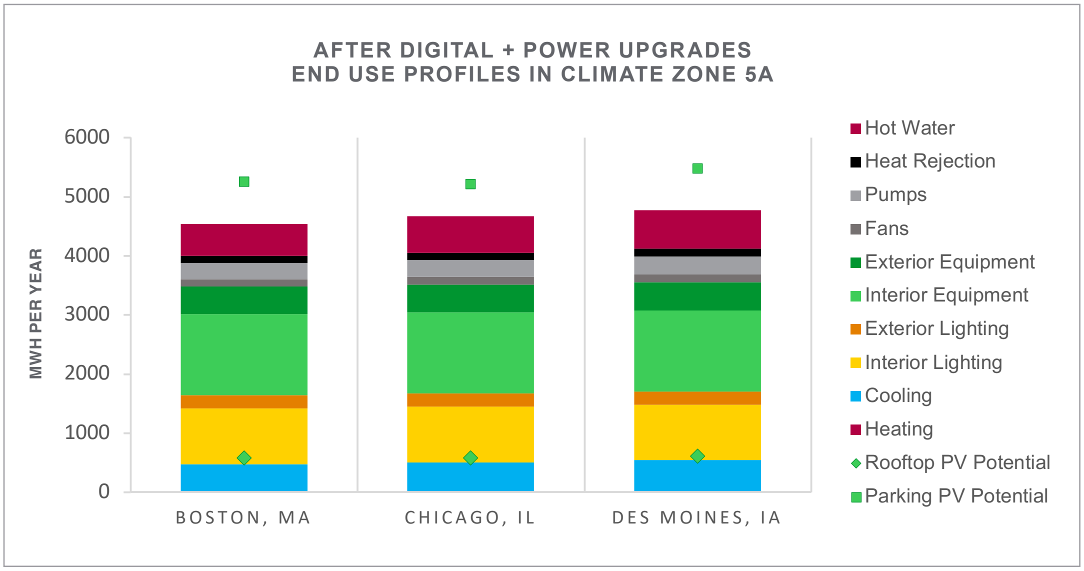
The full carbon picture requires a more in-depth understanding of carbon emissions rates from the utility grid. We will compare three US cities within Climate Zone 5A to illustrate the implications better. As shown in **Figure 5**, the end-use profiles for the energy demand after the digital and power improvements have been applied and the ability to generate solar power result in very similar net EUI figures across all zones, with an EUI of 83, 84, and 90 for Boston, Chicago, and Des Moines.

4. Based on aggregate data from Power Advisor software.

5. Katpamula and Fernandez, “*Improving Commercial Building Operations through Building Re-tuning™: Meta-Analysis*,” Pacific Northwest National Laboratory, published as a PDF, September 21, 2020.

Figure 5

Energy demand profiles and PV generation potential in three case study cities located in Climate Zone 5A



Even with all ECMs applied, large, multi-story buildings cannot meet their energy demand by installing rooftop PV alone (as shown in **Figures 4** and **5**). While the increasing rate of decarbonization in the grid will contribute to the overall decarbonization of the building footprint by 2050, a building may become a net-zero carbon building before the grid fully decarbonizes without being a net-zero energy building. Dynamically by only using grid energy when the grid is clean and offsetting the grid energy with on-site PV when the grid is dirty. The benefits of dynamically optimizing the utility grid connection to minimize carbon emissions of energy from the utility and to offset maximum emissions when using on-site energy sources, isare demonstrated through marginal emissions accounting. In our example cities below, we will assume we have no site-hosted PV system, and we are attempting to achieve net-zero carbon through efficiency measures and only a rooftop PV array (the worst-case scenario).

Understanding carbon accounting with marginal emissions

Carbon emissions associated with the utility grid are not static. When estimating emissions, the most used metric is the annual emission factor for that grid – assuming that all users of the electrical grid get a proportional share of the emissions from each generation plant feeding the utility connection to the site. In a consequential accounting method, which uses marginal emission factors, we can use time-based emissions from the utility to determine when different power plants are caused to ramp up production to meet the increased demand for power. When shifting the electrical demand of a building to reduce peak loading, we can align the power demand from the building to a time when the grid carbon emission rate is low (as the dirtier power plants are offline).

When calculating a building's carbon impact using marginal emissions, we can reduce the building's footprint and offset emissions within the grid and account for the carbon benefits of our PV system. This requires us to track two numbers – the emissions associated with our electricity use (the Carbon Footprint) and the emissions the building would have made if we had not shifted the load (the Baseline). The difference between the two is the Avoided Carbon Emissions.

Baseline — Carbon Footprint = Avoided Carbon Emissions

If the carbon footprint of the building decreases to be lower than the avoided emissions, the building retrofit is considered carbon neutral. However, this does not mean the building is carbon-neutral, which requires a carbon footprint to be less than or equal to zero.

As a simplified example:

A building has an annual power demand of 100 kWh per m^2.

Its utility has two primary sources of power:
1. 50% from wind (0 $kgCO^2e/kWh$)
2. 50% coal (1 $kgCO^2e/kWh$)

A “dumb” building without grid-responsive demand will pull an annual average emission rate of 0.5 $kgCO^2e/kWh$ from the grid for a carbon footprint of 50 $kgCO^2e/m^2$ per year and zero avoided emissions.

However, the math looks different if the building has smart, grid-responsive technology that allows it to shift its load when the grid is powered by 100% wind energy. The carbon footprint is now 100 kWh * 0 kg CO^2e/kWh = 0 kg CO^2e

This means we avoided 50 $kgCO^2e$, and the building is carbon neutral.

Comparing grid emissions across geography

With our case study locations, we are isolating several of the key factors that influence building performance – we are remaining within one climate zone (so similar number of heating and cooling degree days) and implementing identical digital and power management technologies to make our office building smarter and more efficient. However, the case study cities are in places with radically different grid emission factors, as shown in the average carbon emission factor map in **Figure 6**. This means there is a significant difference in the buildings’ abilities to achieve net-zero carbon emissions, as the carbon load from the necessary grid energy is location-based.

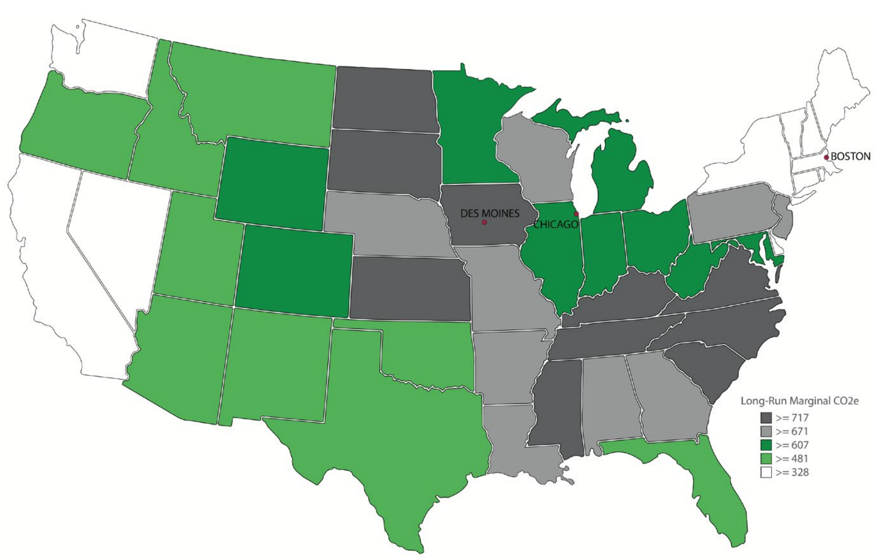


Figure 6

Long run annual average marginal carbon emissions by state in 2022. Measured in kg CO^2e/MWh

Looking at annual average emissions (**Figure 6**), we expect Boston to have the lowest carbon emissions, followed by Chicago, with the largest emissions coming from Des Moines. However, comparing the expected marginal emissions of the grid in the year 2030 on an hourly basis (**Figure 7**), we also see significant differences in carbon intensity over the time of day and season. In Chicago, daylight hours experience a lower rate of grid carbon emissions, indicating that solar is a driving force behind the decarbonization of the grid. Loads should be managed to consume resources during the day, with the on-site PV charging batteries to manage night loads that cannot be shifted, as the grid at night has the highest carbon emissions factor found in any location. Massachusetts has a less obvious split for optimization, with a larger blend of renewables contributing to the grid mix, indicating a need for a more active grid connection management strategy. Iowa falls into a middle case, with a stronger reliance on solar power. Still, there are certain times of day and days of the week when solar is unreliable and/or peak loads on the grid make marginal emission rates higher, and a significantly larger percentage of power comes from wind power. Hence, the overall grid intensity is lower.

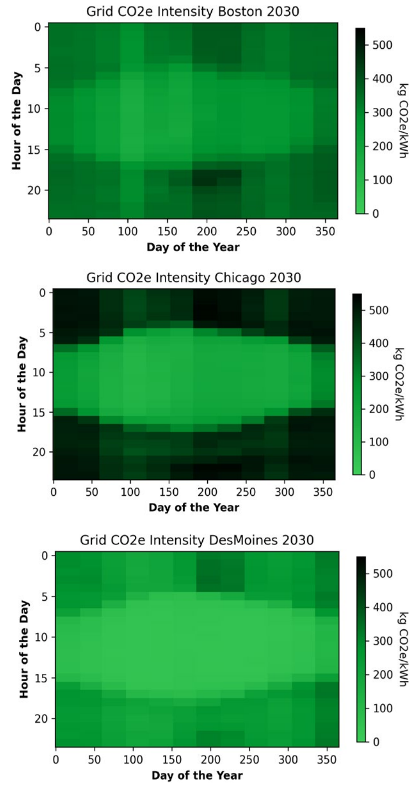


Figure 7

Long run marginal carbon emissions by state in 2030. Measured in kg CO2e/MWh

In all cases, by 2050, the emissions rates will shift so that seasonality – and the associated energy loads for heating or cooling – will be a much stronger influencing factor (**Figure 8**). Although the day-to-night variance pattern still exists in each grid, in the shoulder seasons of spring and fall, the difference between daytime and nighttime grid emissions values have significantly less variation. In such a condition, a smart grid management system must incorporate predictive weather forecasting into the load management plan to determine when batteries should be charged and how loads should be managed in conjunction with a smart building heating and cooling HVAC system. In determining optimal battery sizing for a grid-responsive building, we must optimize for lifecycle emissions – net operational emissions and embodied carbon.

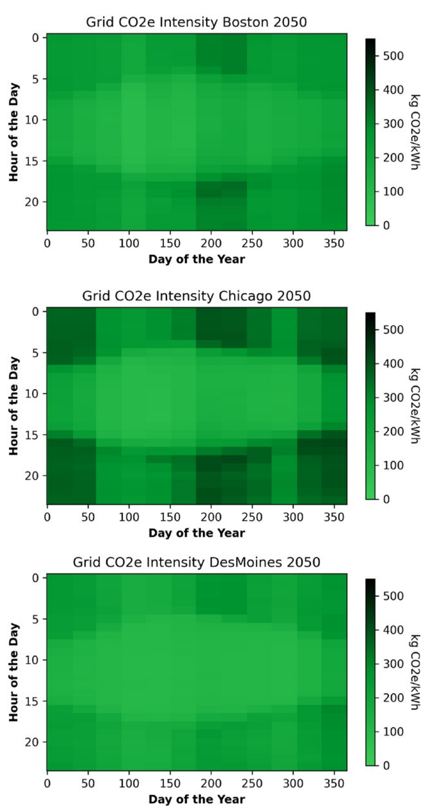


Figure 8

Long run marginal carbon emissions by state in 2050. Measured in kg CO2e/MWh

Calculating the net operational carbon emissions

To calculate the average annual impacts of a building retrofit using marginal grid emissions, we need to use the emissions that reflect the impact duration for comparison against the baseline. This requires using “long-run” marginal emissions factors, which average the expected changes in fuel sources within the grid, averaging the carbon emissions (CO^2e per kWh) over the study period, with a starting date in 2024 and a target date of 2050. Because these emissions will be compared against the total embodied carbon emissions of the materials and manufacturing of the implemented ECMs, we include both the power plant combustion and the pre-combustion impacts to reflect the full lifecycle carbon impacts of the energy.[6]

In the baseline case, we take our optimal improvement of all-electric buildings featuring the full list of digital and power ECMs. In Climate Zone 5A, the envelope upgrade also improves our energy performance by 5%, so we include an increased thermal performance of the opaque wall surfaces, roofs, and windows. Finally, we subtract the output of the PV array from the building energy demand, leading to an annual EUI of 81.6, 85.1, and 84.6 for Boston, Chicago, and Des Moines, respectively. If we use average annual carbon emission figures, this would be a carbon footprint of 25.1, 41.5, and 22.5 kg CO^2e/m^2 for our baseline values.

In a non-responsive, all-electric, efficient building without the ability to respond to changes within the grid, time-based emission modeling yields lower annual values of 18.3, 21.2, and 14.5 kg CO^2e/m^2 for Boston, Chicago, and Des Moines. This is because electrical demands tend to peak during daylight hours when the demand is offset directly by the on-site PV generation and when the grid is already at its lowest carbon emission factors due to the solar power generation in the utility grid.

Using an intelligent microgrid, we can significantly reduce carbon emissions when the building becomes grid-responsive by aligning our battery charging time to the grid's hours with the lowest emissions factors and running the building's systems off the battery when the grid has peak carbon emissions intensity. To demonstrate the benefits, we must identify an optimization function to compute time-based emissions for a grid-responsive building. The basic parameters are the following:

1. **A battery energy storage system** (BESS) has an 86% roundtrip efficiency (useful energy output/useful energy input) and has an expected capacity factor of 16.7% (for a 4-hour system). Batteries are typically optimized at around 25% of PV's mean daily production; we will assume this battery size.

2. **In an all-electric building,** we can run any percentage of the overall load from the PV or battery sources when the marginal carbon emission rate of the grid is extremely high.

3. **Certain end-use loads** can be shifted to "charge" during hours with lower carbon emissions. This can include the heat pump system or EV charging. However, the benefits of load-shifting with the battery are the only ones included below, to simplify the algorithm.

Improvements from baseline emissions (where no retrofit has been done) are shown in **Table 2**. As seen in the "Efficiency + Electrification + PV" column, we see a lower reduction in building carbon (kg CO^2/year) than the overall change in site energy use intensity (EUI), which was approximately 60%. This is because grid electricity is currently more carbon-intensive during the hours of use in each case study location than burning natural gas on-site. Straight efficiency measures (as discussed in the first White Paper: *Decarbonize the office: Unleash the power of digital solutions for building renovations*) are more effective in cutting carbon emissions than electrification alone, given the current carbon intensity of the grid. However, if sufficient on-site PV can be added to meet electrical demand, the all-electric building can achieve net-zero emissions in a way that a natural gas-fueled building cannot.

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6. Gagnon, Pieter, Brady Cowiestoll, and Marty Schwarz. 2023. "*Long-run Marginal Emission Rates for Electricity - Workbooks for 2022 Cambium Data.*" NREL Data Catalog. Golden, CO: National Renewable Energy Laboratory. Last updated: January 18, 2023. DOI: 10.7799/1909373.
7. Mongird, Kendall, Vilayanur Viswanathan, Jan Alam, Charlie Vartanian, Vincent Sprenkle, and Richard Baxter. "*2020 Grid Energy Storage Technology Cost and Performance Assessment.*" USDOE, December 2020. https://www.energy.gov/energy-storage-grand-challenge/downloads/2020-grid-energy-storage-technology-cost-and-performance.

Table 2

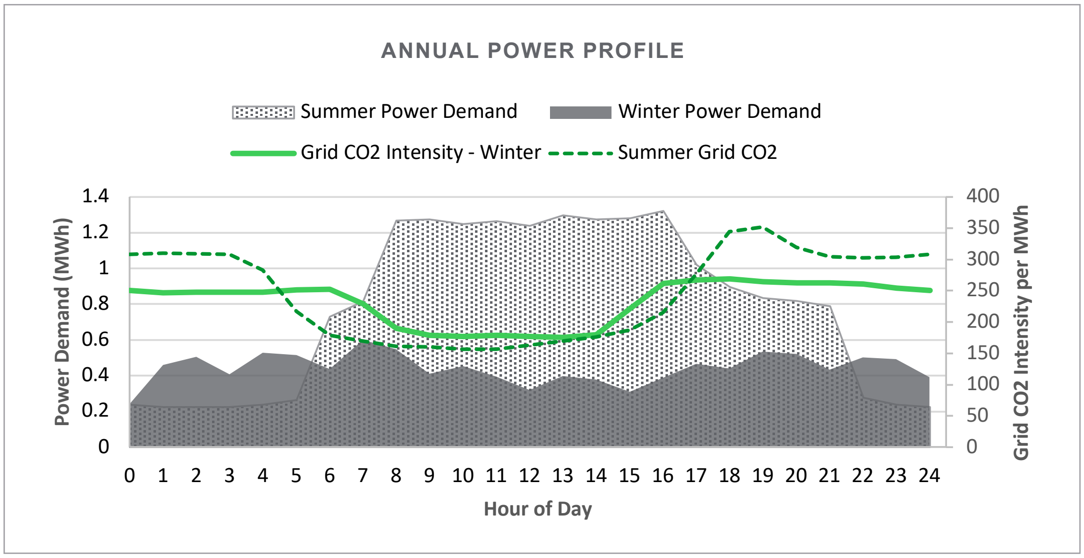
Comparison of carbon footprints across scenarios using hourly marginal emissions rates

City	Baseline Emissions (kg CO2e/m2/year)	Baseline + PV (kg CO2e/m2/year)	Efficiency +Electrification + PV (kg CO2e/m2/year)	Improvements + Load Shift (kg CO2e/m2/year)
Boston, MA	26.1	24.0 (-7.9%)	17.7 (-32.1%)	16.6 (-36.4%)
Chicago, IL	31.6	29.5 (-6.5%)	21.5 (-31.9%)	20.0 (-36.8%)
Des Moines, IA	22.1	20.4 (-7.7%)	14.0 (-36.5%)	13.5 (-39.1%)
Average	**26.6**	**24.6** (-7.4%)	**17.9** (-32.7%)	**16.7** (-37.3 %)

As shown in Boston (**Figure 9**), some electricity demand within the optimized building frequently occurs during peak grid emissions intensity, especially in the winter when the facility demand curve is almost flat. In the summer months, the peak demand is during the cleaner hours of the grid, but a significant load still occurs during the peak carbon emissions hours in the evening. We avoid additional emissions when we shift the time when that electrical demand occurs.

Figure 9

A comparison of the time of power demand versus the carbon intensity of the grid



In computing the net operational carbon, we combine the improvement in the "Improvements + Load Shift" (ILS) carbon footprint and add on top the avoided grid emissions from the pre-load shift ("Efficiency + Electrification + PV = EEPV) version of the building to calculate the total carbon benefits of the renovation, per the following equation:

ILS Footprint – (EEPV-ILS) = Net CO2e

- Boston net CO^2 = 15.4 kg CO^2e/m2/year = 40% net improvement
- Chicago net CO^2 = 18.4 kg CO^2e/m2/year = 42% net improvement
- Des Moines net CO^2 = 12.9 kg CO^2e/m2/year = 42% net improvement

For buildings looking to achieve net-zero without the ability to install sufficient PV outside of the building footprint, reductions can be achieved by targeting the biggest remaining contributors to the energy demand:

1. Reducing the interior lighting power density by upgrading to LEDs over fluorescents (an expected end-use demand improvement of approximately 25%) saves about 1.5 kg CO2e/m2 in our case study climate zone. Similar improvements can be made to exterior lighting power density, resulting in an additional 1% improvement to the building footprint.

2. Installing smart meters and smart shutoff connections for nonessential plug loads when the building is unoccupied can reduce interior equipment loads. This improvement is expected to save an average of 4% of building energy demand and approximately 1 kg CO^2e/m^2 from the overnight shutoff.

3. Elevator motor demands primarily drive exterior equipment loads. The exterior equipment load can be reduced by 24% with an elevator upgrade, creating an overall carbon reduction of 4.2%.

4. Other interior equipment loads can benefit from load shifting similar to the one modeled above, where battery charging and discharging was associated through building occupant actions, such as running dishwashers or other equipment during low carbon hours, reducing the carbon emissions by 2%-5% per kWh shifted.

Considering embodied carbon emissions

The previous paper, "*Unleash the power of digital solutions for building renovation*," demonstrated the significant embodied carbon savings from a digital-first approach. In this chapter, we have added the on-site PV, supporting equipment, batteries, and heat pump infrastructure.

The on-site PV and associated infrastructure, assumed to be replaced every 20 years, are expected to have a carbon payback of approximately one year and account for approximately 0.48% of annual lifecycle emissions.[8]

With its Li-ion battery system, the BESS has a much shorter lifespan of eight years, an embodied carbon load of 1,700 kg CO^2e per lifecycle, and a significantly larger footprint.[9] Over the 26 years before the 2050 deadline, the BESS will have an embodied carbon impact of close to 30% of the total embodied impact of the building. The carbon payback based on operational carbon saved is not achievable within the lifespan of the BESS. However, as battery components improve to avoid the carbon hotspot of the Li-ion cathode, the payback will significantly improve. An extension of the service life to 10 years also reduces the embodied impact by 20%, a potential benefit of coupling the BESS to the ongoing power monitoring system.

Prioritizing carbon reduction efforts

Energy is not equivalent to emissions.

The largest immediate reduction in carbon emissions can be achieved through digital energy efficiency and power management retrofits for buildings. Converting an existing building to an all-electric HVAC system is a vital step on the decarbonization roadmap. Still, it must be timed carefully to avoid unnecessary utility carbon emissions increases in the short term. For buildings unable to host an on-site PV array large enough to meet the power demands for the building, immediate energy efficiency reductions should be taken with a plan to upgrade the building systems to all-electric as the grid carbon reduces in the next 3-5 years (or when BESS technology has improved to store more energy on-site with a reduced embodied carbon load.)

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. The ROC for BESS systems and insulation increases in electric buildings are never achieved within the key period before 2050.

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8. De Wild-Scholten, M.J. "*Energy payback time and carbon footprint of commercial photovoltaic systems,*" Solar Energy Materials and Solar Cells, vol 119 (2013): 296-305.
9. Sadhukhan, J; Christensen, M (2021): An In-Depth Life Cycle Assessment of Lithium-Ion Battery for Climate Impact Mitigation Strategies. Energies. 10.3390/en14175555

On-site energy storage using BESS technologies is not a carbon-smart solution until either Li-ion battery systems can significantly reduce their embodied carbon footprint through service life extension or until reliable battery technology can leverage a lower-carbon material.

However, grid-responsive technologies matter, as flattening peak energy demand and load shifting are critical to accelerating the pace of future-proof retrofits of buildings and achieving grid decarbonization at the utility scale. New PV systems of the scale necessary to meet the demand of large buildings must interact intelligently with the utility grid. Furthermore, as building technologies increase their intelligence as part of the grid-responsive Internet of Things (IoT), microgrid technologies will be vital to the decarbonization story.

Becoming a citizen of the grid

To accelerate the rate of decarbonization in the built environment, building owners and operators must begin to consider the impact of their building beyond the boundary of their site. Grid carbon intensity, grid capacity to meet demand, and meter-side utility connection sizing requirements are key limitations on the rate of electrification; digital technologies and power management solutions are the most carbon-effective way to improve building efficiency and operate a building with a smaller burden on the aging grid infrastructure.

The next paper of this series will broaden the decarbonization story to outline important characteristics in the decarbonization story for buildings located in different regions around the world based on climate, building system types, and building size.

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 reduce carbon emissions radically.

Mike Kazmierczak, Schneider Electric: Mike Kazmierczak is CMO and VP of the 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.

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 clients can readily implement, with clear alignment to the organization's people, business, and technology needs.

Romeo Michael, PE, CEM, 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, 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

Whitepaper: The Path to Net Zero Buildings: 3 steps to turn sustainability ambition into action

Whitepaper: Decarbonize the Office: Unleash the power of digital solutions for building renovations