Climate Solutions Series
Decarbonizing the Built Environment

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THE ISSUE
This brief is the fifth in a series on achieving net-zero global greenhouse gas emissions by 2050. The CSIS Energy Security and Climate Change Program is hosting six events that will be followed by resource briefs related to each event. For more information on the series, see our website.

THE CHALLENGE
The buildings sector emits 39 percent of global CO$_2$ emissions, 28 percent of which come from the operation of buildings and 11 percent of which come from building materials and construction.\(^1\) While the building materials and construction process are important, this brief will focus on the operational emissions of buildings. Unlike many of the other sectors that have been covered in this brief series, some of the emissions from the buildings sector could be attributed to other sectors, so the sector’s percent of total CO$_2$ emissions is not directly comparable to those of the other sectors. The emissions from purchased electricity, for example, are included in the operational emissions of buildings, and the construction and building materials that go into them are made in the industrial sector. However, as will be discussed in this brief, these are not the only emissions that come from buildings, and there are solutions that are unique to the buildings sector that can address their emissions independent of action in other sectors.

By some estimates, two-thirds of the buildings standing today will still be here in 2050, and the global building stock will double by 2060.\(^2\) In addition, according to the United Nations, 68 percent of the world’s population is expected to live in urban areas by 2050.\(^3\) This creates an urgent incentive to decarbonize the buildings we have and determine how to build net-zero carbon buildings in the future.

Decarbonizing the buildings sector looks different in advanced economies and developing countries. In advanced economies, where most of the buildings have already been built, decarbonization mostly requires retrofitting existing buildings. In developing economies, where much of the coming building stock will be built, decarbonization involves designing new buildings with net-zero carbon emissions in mind. Each has its own opportunities and challenges. This brief will address some of the opportunities for both retrofits and new construction.

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GETTING FROM HERE TO THERE
GHG emissions associated with the operation of buildings come in two categories: Scope 1 and Scope 2. Scope 1 refers
to emissions that are produced on-site, including heating and cooling systems and backup generators. Scope 2 refers to emissions from the electricity consumed on-site but generated elsewhere. Addressing them will require different interventions. Scope 1 emissions, for example, can be reduced by reducing the need for heating and cooling or switching from appliances using natural gas, propane, or oil to those using zero-carbon sources. Scope 2 emissions could be reduced by installing more energy-efficient electric systems or sourcing zero-carbon electricity.

The tension between on-site upgrades and upstream supply changes brings up an important question in decarbonizing buildings: is the goal to make every building zero-carbon or to design a zero-carbon buildings sector? A zero-carbon building, or net-zero carbon building, is one that negates as much CO\(_2\) as it emits. The World Green Building Council defines a net-zero carbon building as one that meets its annual energy demand through the use of zero-carbon sources, and any remaining emissions from that building are negated by offsets. A zero-carbon buildings sector, however, would potentially allow for more flexibility among individual buildings while maintaining net-zero emissions from the overall sector. It is important to note the difference between net-zero carbon and net-zero energy—the latter refers to generating energy that exceeds annual demand but does not necessarily mean that energy is zero-carbon. In theory, a net-zero carbon economy could also allow for some variability in emissions levels across sectors if negative emissions technologies are readily available, but that is outside the scope of this sector-specific brief.

For an individual building owner, it is easier to make changes to one building, but the upfront costs of retrofits and uncertainty about returns from those retrofits can discourage managers from making those changes. On the other hand, a systems-level approach could lower overall costs and allow for some variability in buildings with different energy needs. A hospital, for example, typically has high energy needs to power its life-saving equipment, provide heating and cooling, and establish redundant power systems in case of failure. These high energy needs may make it more difficult for the hospital to completely zero out its energy on-site. Linking the hospital with several smaller buildings that can achieve high efficiency and install on-site solar power could allow them to sell excess, zero-carbon power to the hospital to help them meet their needs. If necessary, the hospital can purchase carbon offsets to make up for any remaining emissions. Both building-level and systems-level approaches are likely to be important but will require strategic thinking by policymakers.

**TECHNOLOGY**

**Energy efficiency** is likely to be a key part of decarbonizing the buildings sector. Efficiency measures in both power and other building energy uses like heating and cooling help lower demand for carbon-intensive energy in the near-term and can make it easier to ultimately reach net-zero emissions. Many of the technology options that will be discussed in this section can be classified as energy efficiency measures when they increase the efficiency of energy use, including heat pumps, district energy systems, and passive design. Other important energy efficiency upgrades include improving the building envelope, measurement tools to provide insight into energy use, and software to optimize energy use.

Digitalization is an emerging solution allowing for innovative new technologies to help boost energy efficiency and lower emissions. Software systems integrated into buildings can help coordinate supply and demand and shift energy use. Demand-side management systems can help save costs by optimizing use for when and where it is most needed, but they can also drive decarbonization by shifting energy use to times of the day when zero-carbon energy is highest in the grid mix. Buildings also have an inherent ability to store heat, which is called thermal mass, and technologies are emerging that can take advantage of this property to balance out heating and cooling to lower costs and shift power demand off of peak times.

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**Electrification** can help decarbonize the buildings sector as long as the power sector is ultimately able to decarbonize as well. Much like in transportation and in heavy industry, there are opportunities to electrify building elements, most notably space and water heating. As shown in Figure 1, 57 percent of global heating technology sales in 2019 were fossil fuel-based technologies. Another 22 percent were conventional electric heaters while the rest were
heat pumps, other heaters powered by directly renewable energy, or district energy systems. In the United States, approximately half of households use natural gas as a main source of space heating, while 25 percent use conventional electric heaters, 10 percent use heat pumps, and the remainder use fuel oil, propane, or wood. The breakdown for commercial buildings is similar. Heat pumps are an option for replacing oil or natural gas-based heating systems with those using electricity. Because they use electricity, their GHG impact depends on the carbon intensity of the grid. Air-source heat pumps move the heat from outside air to indoor spaces, and ground-source heat pumps use the residual heat from the sun in shallow earth to heat indoor air. Both systems can also cool spaces as well by moving the heat in the other direction.

Air-source heat pumps are cost-competitive with a gas furnace and air conditioner combination in many climates but particularly those with milder climates, as they become less effective as ambient temperatures decrease. However, technology has been improving, and air-source heat pumps are more efficient than gas furnaces even in cold climates. Ground-source heat pumps are currently much more expensive than traditional space heating but are much more efficient than air-source heat pumps and work at low temperatures. Dual-source heat pumps combine the best of both technologies for efficiency and a price that falls between those of the two single-source technologies.

Overall, the economics of electrifying heating and cooling are highly dependent on climate, energy needs, and whether the building is being constructed or retrofitted. In U.S. commercial buildings, an analysis by the American Council for an Energy-Efficiency Economy found about 27 percent of commercial floor space currently heated by fossil fuels could be electrified and make the investment back in under 10 years. Energy efficiency and policy interventions would change that calculus—a combination of efficiency upgrades, financial incentives, and carbon pricing would bring that to 60 percent. The economics of electrifying residential buildings are somewhat more favorable. Rocky Mountain Institute estimates that the lifecycle costs of heat pumps for heating and cooling are lower in most new construction and even some retrofits in four different regions of the United States.

District energy systems generate heat to pump water or steam from a central source to heat and cool multiple buildings or public spaces. This can, in theory, provide heating and cooling more efficiently than individual heating and cooling systems, but it can be inefficient in practice if not designed and managed appropriately. District energy systems can run on various sources, but zero-carbon thermal sources like geothermal or solar thermal would be necessary for a net-zero system. Due to their size, district energy systems are very capital-intensive projects and require integration with the areas they serve. China has the world’s largest district heating network, which covers about 9 billion square meters of space, although 90 percent of the energy in China’s district heat production comes from coal. The United States has about 500 million square meters served by district heating and 174 million by district cooling (with some overlap between the two), and the predominant fuel is natural gas. The International District Energy Association reported in 2020 that its members committed 637 new buildings around the world to district energy systems in the previous year, compared to 330 additions in 2018.

Renewable energy heating is another option for decarbonizing heating, particularly solar heating, hydrogen, or biogas. Solar heating is commonly used to heat water in a residential or commercial building. These heaters collect solar energy with collectors much like a
photovoltaic system, but instead of generating electricity, they pump a heated fluid through pipes to heat water for the building. Solar air heating is also available but is not a widespread technology, with only about 1 gigawatt-thermal installed around the world at the end of 2018 out of almost 500 gigawatts for all solar thermal technologies.\(^2\)

Switching out natural gas for hydrogen or biogas is a potentially viable strategy for heating that can take advantage of the existing transportation infrastructure. Hydrogen can be blended with natural gas and transported in the existing gas grid at concentrations up to 20 percent.\(^3\) However, because hydrogen has a lower energy density than natural gas, a blend of 5 percent hydrogen would only reduce natural gas consumption by about 1.6 percent.\(^4\) In addition, hydrogen does have a higher chance of igniting than natural gas, but studies have shown that blending at 20 percent has a negligible effect on safety risks.\(^5\) Biogas is a low-carbon source of methane, so it could be substituted for natural gas in home heating.\(^6\) Of course, blending low-carbon gases with natural gas at low volumes is not sufficient to achieve net-zero emissions, but this strategy can help further the transition.

Alternative cooling solutions will also be key to decarbonizing buildings. Air conditioners pose two problems from a decarbonization perspective: they use electricity, which on a carbon-intensive grid emits \(\text{CO}_2\), and they use refrigerants, the most popular of which are powerful GHGs called hydrofluorocarbons (HFCs). Fortunately, the industry has developed alternative refrigerants that have much lower global warming potential, and there is an international effort to phase out HFCs.\(^7\) While simply increasing the efficiency of air conditioners is key, alternatives exist, including evaporative coolers that extract energy from the air to evaporate water.

Evaporative coolers can save money and energy but are only effective in areas with low humidity because of the limited ability of humid air to take on more water vapor.\(^8\) Solar cooling systems also exist but are in limited use, with fewer than 2,000 installed worldwide at the end of 2019.\(^9\)

Some innovative new technology solutions are emerging as well. Solid-state cooling systems use the thermodynamics of solids rather than liquid refrigerants to transfer heat.\(^10\) These are used in other sectors, but scientists are in the early stages of determining how they can be adapted to space cooling.

**Passive design** refers to the decisions made in the design process of a new building that take advantage of the environment to control the temperature in a building without additional heating or cooling systems. This can include orienting the position of a building to increase or decrease the amount of sun heating it up, using different building materials that will absorb or reflect heat, or creating spaces that maximize airflow to naturally cool a space. Buildings designed this way may also add on-site renewable power generation such as solar panels to reduce reliance on grid electricity.

**POLICY**

To begin to understand how buildings can get to net-zero, it is necessary (although not sufficient) to understand their emissions profiles. These data are often readily available for high-income countries but are typically less available in developing countries. Benchmarking and certification for energy use and emissions are important efforts. These efforts involve tracking and reporting energy use in buildings. As of 2015, only 41 countries had benchmarking requirements for building energy use.\(^11\) Groups like the International Energy Agency are attempting to gather energy data on more countries, but it requires buy-in from governments as well as building owners.

Like in other sectors, governments can institute performance targets that buildings must meet. These are frequently implemented at the state or city level, but higher levels of government can set model regulations. In fact, the International Code Council publishes the International Energy Conservation Code every three years, and the next version is due out in 2021.\(^12\)

Some U.S. cities have historically targeted energy use for reduction, which on a grid powered by fossil fuels will reduce \(\text{CO}_2\) emissions. However, setting a target to reduce \(\text{CO}_2\) emissions themselves could allow for more flexibility as zero-carbon energy can substitute for fossil-based energy without a need to reduce overall energy use. In New York City, for example, Local Law 97 of 2019 requires most buildings larger than 25,000 square feet to reduce their emissions by 40 percent in 2030 and 80 percent in 2050.\(^13\) Building codes can also help make it easier to install efficiency upgrades, energy generation, or heating and cooling systems by making clear the standards that must be met and the process that must be followed. This, of course, depends on building codes being implemented and enforced.

Governments can also take a direct role in decarbonizing the sector and lead by example by decarbonizing the
government buildings system. In Canada, for example, the Greening Government Strategy aims to reduce Scope 1 and Scope 2 emissions from government buildings and fleets to 80 percent below 2005 levels by 2050. This includes following forthcoming net-zero building codes, requiring all new buildings to be net-zero from 2022, and using 100 percent clean electricity by 2025.

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If a government provides public housing, it can also be an area in which the government can take charge to decarbonize buildings. The New York City Housing Authority, for example, released a plan in 2019 that proposes electrifying space and water heating, which the agency estimates would eliminate 70-75 percent of their operational emissions if powered by zero-carbon electricity.\textsuperscript{31}

Policy can also help home or building owners access financing for building upgrades. One example of this is the Property-Assessed Clean Energy (PACE) program in the United States, which provides financing to residential or commercial property owners to install on-site clean energy such as solar photovoltaics or heating and cooling systems. The financing is then repaid over time on property tax bills.\textsuperscript{32} Because the financing is tied to the property rather than the homeowner, these programs are intended to address concerns about installing 20-year systems even if the homeowner plans to sell the house before then. It is worth noting, however, that these loans have their drawbacks, such as potentially higher interest rates than those for a home loan and federal guidelines barring homes with PACE loans from receiving mortgages from federal lending agencies.\textsuperscript{33}

In commercial and residential buildings with tenants, the incentives for upgrades are often divergent for owners and renters. If the owner of a building is responsible for making energy efficiency upgrades but the tenant sees the cost savings, there is less incentive for the owner to make the upgrades. If the tenant is responsible for making the upgrades, they may only see the benefits for a short time while they occupy the building, making it a less valuable proposal for the tenant. Designing policies that help address these incentives for both parties could drive more efficiency upgrades and zero-carbon energy installations.

**THE ROLE OF PRIVATE-SECTOR ENGAGEMENT**

In most countries, the private sector is the primary actor in the buildings space—buildings are built and often owned by private entities and the technology and equipment that provides them with energy are typically provided by private entities. Therefore, investments from private sector actors will be key to meeting decarbonization goals in the sector. Each of these groups of actors, however, has different interests and may respond to different incentives.

The developers constructing the buildings often have a strong interest in keeping capital expenditures down, so they are most interested in the lowest-cost building materials and technology that goes into the buildings. Assuming that the developer does not retain ownership of the building once it is completed, energy efficiency and other measures to lower operating costs do not benefit the builders. Successful efforts to decarbonize the buildings sector must, then, find ways to deliver benefits to the developers or risk their opposition.

For solution providers, energy efficiency and decarbonization measures typically align with their interests as they are the companies providing the enabling technologies. However, market entry can be difficult because of the relative upfront costs of their solutions, a lack of supportive policy (codes and standards, for example), lack of strong consumer demand, and pressure from their customers in the buildings sector to keep costs down. On the other hand, if the economic and policy incentives align, energy efficiency measures and cheap zero-carbon energy can help keep operating costs down for building owners.

Building owners and managers have perhaps the most direct influence of the private sector groups on the decarbonization of the sector, as they dictate the operations of their buildings. In a 2019 survey from buildings technology company Johnson Controls, building and energy managers from 11 countries expressed their plans, interests, and barriers to investing in energy efficiency and renewable energy. Energy cost savings was the most common incentive, with 79 percent of respondents indicating it was “very or extremely important” to their investment decisions.\textsuperscript{34} Reducing GHG emissions was the second most common driver at 73 percent.

The most often cited barrier to investment across all countries was a lack of funding to pay for improvements, and the second was a lack of confidence in the savings
However, these building owners appear to see more value in policy clarity and certainty—financial incentives were fourth on the list of policies deemed very or extremely important for driving their investment, with performance benchmarking, codes and standards, and owner-occupant partnerships taking first through third place, respectively.

There are clear incentives for technology providers to push for decarbonization. The interests of building managers can push them toward decarbonization as well, and there is some evidence that many plans to do so, although measures to defray the upfront costs of various enabling technologies would be necessary. Defraying the costs of technologies and low-carbon building materials could make it easier for developers to make investments in low-carbon materials and technologies.

CONCLUSION

The buildings sector is one that is deeply intertwined with other sectors, especially the power sector. Decarbonizing the built environment will require different approaches for new and existing buildings. In addition to decarbonizing the power that supplies buildings, many heating and cooling systems will need to be switched out, and energy efficiency measures will need to be pursued. New and innovative solutions that allow for much more flexibility in both supply and demand are emerging and will likely lead to greater integration between buildings and the grid. This document does not contain an exhaustive list of all technology or policy options, nor does it address building materials, but provides an overview of the potential to reduce operational GHG emissions from the sector. The private sector, which is involved in the construction and management of buildings as well as the supply of technology, will have a major role in identifying and implementing the solutions that will be needed to bring us to a net-zero buildings sector. Attempts to decarbonize the sector will need to address the various interests that each group of private sector actors has in the construction and operation of buildings.

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ENDNOTES


26 ESMAP, Primer for Space Cooling.


35 Ibid.