Industrial Revolution

Every home that is built is a representation of compromises made between different and often competing goals: comfort, convenience, durability, energy consumption, maintenance, construction costs, appearance, strength, community acceptance, and resale value. Consumers and developers tend to make tradeoffs among these goals with incomplete information which increases risks and slows the process of innovation in the housing industry. The slowing of innovation, in turn, negatively affects productivity, quality, performance, and value. This department piece features a few promising improvements to the U.S. housing stock, illustrating how advancements in housing technologies can play a vital role in transforming the industry in important ways.

A Path to 80 x 50 for Public Housing Authorities

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Abstract

Many cities now mandate large reductions in greenhouse gas emissions in residential buildings, including public housing. The authors summarize the recently released plan of the New York City Housing Authority to achieve these reductions.

States, cities, and counties have all advanced the drive to reduce emissions over many years. As of today, more than 30 states have economy-wide emissions reduction targets in place, according to Clifton et al. (2020). Billimoria et. al. (2018) and Steinberg et. al. (2017) point out that these goals, established either through legislation or executive order, typically call for reducing greenhouse gases (GHGs) 80 percent by 2050 (80 x 50) when compared with a prior benchmark (for example, 2005 levels). In parallel with this, Trumbull et al. (2019) identified 12 states; Puerto Rico; Washington, D.C.; and more than 200 cities and counties that have established goals to generate 100 percent carbon-free electricity by 2050—with some aiming for as early as 2032.

This patchwork of policies is largely a reaction to the absence of a unifying federal policy for reducing emissions. Should the federal government establish a national policy, the efforts to reduce emissions are likely to accelerate.

Abstract (continued)

Residential and commercial buildings account for 38 percent of all energy used in the United States and are responsible for 10 percent of GHG emissions. Increased efficiency and electrification—addressed through mandates and better building codes—can significantly reduce the building sector's contribution to climate change. With the trend toward decarbonization firmly established across much of the country, many buildings may soon be required to make significant reductions in energy use and emissions that will be achievable only by a transition away from fossil fuels.

New York City is uniquely affected by state and city policies to reduce GHG emissions and to meet building-specific emission reduction targets. These policies require building owners to look beyond traditional energy-efficiency measures. The New York City Housing Authority (NYCHA) recently released a detailed plan for meeting the 80 x 50 requirements with readily available technology (NYCHA, 2020). This article summarizes the NYCHA plan and includes general recommendations that other public housing authorities (PHAs) can adopt to reduce their GHG emissions significantly.

Beneficial Electrification

Beneficial electrification,[1] the replacement of fossil fuels with electricity that has been generated with low or no greenhouse gas (GHG) emissions, is generally viewed as the most cost-effective path toward the large-scale GHG reductions needed to achieve 80 x 50. A recent National Renewable Energy Laboratory (NREL) study by Steinberg et. al. (2017) found that electrification—even without a low-carbon electric grid—could reduce emissions by roughly 40 percent, but that a combination of electrification and power sector decarbonization would reduce nationwide emissions 74 percent below 2005 levels.

Generally, near-term actions to reduce emissions are less costly and far more valuable than actions taken later (IPCC, 2018). Early actions reduce the rate of increase in GHGs and help keep the increase in average global temperatures below the threshold of an increase of 1.5°C (2.7°F), above which climate consequences are projected to be more dire. Delayed action will require more extreme, and likely more costly, actions to achieve the same reductions by 2050.

Reducing energy consumption in existing buildings will require much deeper reductions than the 10–20 percent that typical energy-efficiency measures are able to deliver. The options to reduce GHG emissions generally start with relatively low-cost measures, such as upgrading lighting to LEDs, and end with major capital investments that replace one or more major building systems.

Based on the findings of Billimoria et. al. (2018), to achieve a large net reduction in GHGs, it is best to start with actions that increase energy-efficiency and the ability of the public housing

[1] The Regulatory Assistance Project, an independent non-governmental organization dedicated to accelerating the transition to a clean, reliable, and efficient energy future, suggests that electrification is "beneficial" when it meets at least one of three criteria without adversely affecting the others: (1) saves customers money long-term, (2) reduces environmental impacts, and (3) enables better grid management (Farnsworth, 2018). https://www.raponline.org/wp-content/uploads/2018/10/rap_farnsworth_shipley_ee_2.0_be_2018_sep_21.pdf

authority (PHA) and its residents to track and control how energy is used when initiating beneficial electrification at a particular building.

Beneficial electrification may increase a building's total electric load and might require upgrading some of the existing electrical service; however, reducing in-apartment electric use will free up capacity in the building's electric infrastructure and may help postpone, perhaps indefinitely, the need for costly electrical infrastructure upgrades.

Preemptive action that building owners take may be the most cost-effective long-term solution. Early adopters can take advantage of state and utility incentives and tax credits that are available for technologies that improve energy efficiency. Utility incentives are typically designed to motivate building owners to exceed the performance requirements of their local building codes. As more cities institute mandates and increase the performance requirements of the relevant codes, buildings may need to achieve higher levels of efficiency to secure financial support from local utilities and state programs. Near-term actions may benefit from incentives today that may not be available in the future.

In-kind replacement of energy-consuming equipment is the path of least resistance but is no longer compatible with the reality of emissions reduction mandates. Replacing boilers and the like may be the most expedient way to address an urgent capital or operational need but may result in "stranded" assets—assets that are no longer useful but have a significant remaining operating life—hindering opportunities for electrification. New approaches will require different new technology, additional up-front planning and training, and new maintenance protocols.

A Practical Strategy to Meet 80 x 50

In-kind replacements of existing systems often have payback periods of 30 years or more. In the past, replacing fuel oil with natural gas was possibly a cost-effective, environmentally beneficial solution. Today, a different path must be followed; what follows is a brief summary of 10 key elements to a strategy based on NYCHA's plan.

1. Optimizing Existing Systems

The performance of mechanical systems degrades with time and must be adjusted (optimized) to its original level of efficiency. Any fossil fuel heating system that continues to operate during the transition to electrification must be optimized to achieve as much energy savings as possible until it can be replaced. The most important optimization strategies include maintaining and operating the system at maximum efficiency and sending the right amount of heat out at the right time. If optimization is pursued vigorously, it is possible to reduce energy use by 20–30 percent and even 40 percent in extremely inefficient cases. A moderate investment can achieve significant savings, help increase system uptime, and reduce heat outages.

2. Performing Preventive Maintenance and Efficient Operations

Operating and maintaining the boiler according to manufacturer instructions and best practices has a huge impact on overall energy use. Small, unnoticed changes in site or equipment conditions can result in energy waste of 10–20 percent. Efficient operation entails checking settings and taking measurements to ensure that the system is operating within its design parameters. Short-cycling of burners (analogous to stop-and-go driving) must be addressed to improve fuel “mileage.” Steam traps, zone valves, vacuum pumps, and condensate pumps must be preventively maintained rather than being allowed to fail and sit unrepaired. Small, targeted investments can yield significant savings and reduce heat outages.

3. Using Zonal/Unit-Level Controls

Ideally, each apartment and occupied space should have enough, but not too much, heat. To deliver the right amount of heat at the right time to every area, the system must be balanced (i.e., every radiator is provided the right amount of steam) and the controls must be responsive to changing conditions. In reality, many apartments receive far more heat than they need. Yet even when some apartments are overheated, others may not receive enough heat because of system imbalances. Thermostatic radiator valves or zonal controls help balance the system and reduce waste, with paybacks typically in the 5-year range.

4. Using Building Management Systems

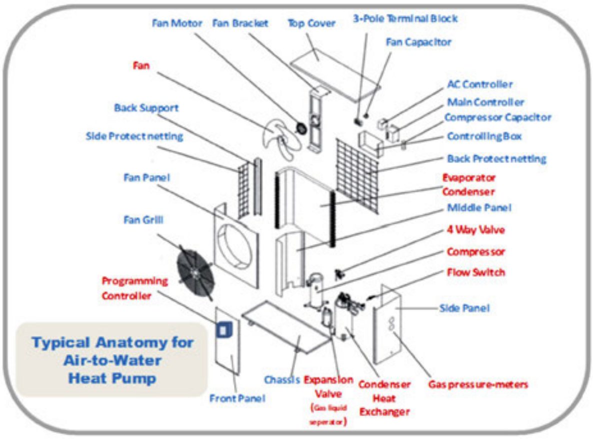
Building management systems can monitor and control building functions from a single point of access, often remotely. They are particularly important for monitoring the condition of critical building systems that drive energy use, including heating, ventilation, and air conditioning (HVAC) and lighting. Such systems, when used properly, can maximize the useful life of equipment and increase overall building efficiency at moderate cost.

5. Hydronic Conversion

Hydronic distribution systems circulate hot water instead of steam to the radiators. Building-specific hydronic systems are much more energy-efficient than campus steam systems because of higher boiler efficiency, lower circulating temperature, lower “off-cycle” losses, and no losses from campus-style distribution, among other factors. Electrification through hydronic conversion would entail replacing steam distribution systems with hot water distribution and using air-to-water heat pumps (AWHPs; exhibit 1) or ground-source heat pumps to heat the water.

Exhibit 1

Anatomy of a Typical AWHP



AWHP: air-to-water heat pump.
Source: Iris Energy

Whether or when AWHPs that can meet the needs of buildings on the scale of a PHA will be available in the United States is unknown. Until AWHPs suitable for multifamily buildings become more widely available, electrification through hydronic conversion may require two steps: first, convert from steam to hydronic with gas-fired condensing boilers, then replace the boilers with heat pumps several years later.

The two-step approach, however, has three disadvantages. First, fossil-fueled boilers still require combustion, even if it is more efficient. Second, typical hydronic systems do not provide cooling (which, according to NYCHA [2019], is increasingly becoming a necessity because of climate change). Third, any gas-fueled system will require new gas service to the individual buildings, and continued availability of low-cost gas service is not guaranteed. Buildings that already have hydronic heat would not incur the high cost of conversion from steam.

6. Switching to Air Source Heat Pumps

Air Source Heat Pumps (ASHPs) solve several problems. They are far more reliable than steam systems and require much less maintenance. Steam and water leaks are eliminated. ASHPs permit the precise control of each room's temperature and virtually eliminate over- and underheating. Every apartment can now have air conditioning, which is critical for protecting the health and well-being of vulnerable—particularly senior—residents during hot weather which is expected to become more frequent and severe as a result of the changing climate. In a so-called multi-split installation, if one heat pump fails, only one apartment is affected—not an entire building—and because each apartment has its own system, apartment submeters can provide a feedback loop to encourage energy conservation.

Exhibit 2

Coefficient of Performance vs. Combustion Efficiency

The best heat pumps currently available are three to six times as efficient as a central steam system; how is this possible?

It is possible because heat pumps simply move heat from outdoors to in (or indoors to out for cooling), rather than create heat through combustion. Energy, usually electricity, is used to power a compressor, and this compressor takes advantage of the laws of thermodynamics to move heat from one place to another. It takes much less energy input to move heat than to create it.

The measure of a heat pump's efficiency is the Coefficient of Performance (COP). A typical high-quality heat pump has an average COP of about 2.5 to 3.0, which means that it moves 2.5 to 3.0 times as much heat energy as it uses in electrical energy.

The COP of any boiler-based system will always be less than 1.0. An inefficient steam system has a COP of about 0.3 to 0.5.

7. Building Enclosure Retrofits

Modeled savings show that a combination of exterior insulation and air-sealing can reduce heat loss from a building 50 to 80 percent; however, the cost-effectiveness of exterior insulation retrofit systems has not been well-documented. Pre-fabricated insulated masonry panels are already available, and if it can be shown that they—or systems with similar performance—have the advantage of eliminating the need for costly major repointing, the savings may make such a system worthwhile.

In addition to the direct energy reductions associated with high-performance envelopes, several other potential benefits exist:

- Once a building's heating and cooling loads have been substantially reduced, it becomes possible to install smaller and less-costly heating and cooling systems. A smaller mechanical system is less likely to require an electrical upgrade, is more likely to be able to operate on 120 volts, and will require less refrigerant.[2]
- Once ASHPs are installed in a substantial proportion of buildings, the local utility's peak electrical demand will occur in the winter. Widespread adoption of envelope retrofits will allow many more buildings to install ASHPs before the new winter peak is reached.
- Urban Green Council (2013) shows how any highly insulated building, regardless of the type of heating/cooling system, can remain habitable during an electrical service interruption longer than a building with a typical mid-century envelope. During extended cold spells, which are likely to increase in frequency, high-performance envelopes help minimize the impact of service interruptions.
- Finally, a building with a high-performance envelope could reduce GHG emissions substantially *even if it retained a fossil-fueled heating system*; if the heating load is reduced 80 percent, fossil fuel GHGs could be reduced a similar amount.

[2] Many refrigerants are extremely potent greenhouse gases, which raises the concern of refrigerant leaks. Research is being conducted to adopt more environmentally friendly alternatives, such as CO2.

8. Using Submetered Apartment Units

Research by Levinson and Niemann (2004) and Pazuniak, Reina, and Willis (2015) has established that unmetered tenants use more energy than their counterparts in individually metered apartments because they lack both the means to measure how much energy they use and the cost incentive to conserve. The U.S. Department of Housing and Urban Development (HUD, 2012) reports that master-metered utilities in public housing account for 22.3 percent of HUD's total utility expenditures. In 1996, through 24 Code of Federal Regulations (CFR) 965,[3] the Federal government required the use of individual meters for all public housing residents wherever the meters could be installed practically and affordably.

Any transition to submetering must be carefully managed. The savings potential to both the PHA and the residents can be substantial, and the residents' increased agency will give them a greater sense of control and improve their quality of life. According to the New York State Energy Research and Development Authority's (NYSERDA) Residential Electrical Submetering Manual (Hirschfeld, 1997), when submeters are installed in master-metered buildings and residents are billed for the electricity they consume, buildings reduce their kWh consumption by about 18 percent on average, and their kW demand by about 24 percent on average.

If utility allowances[4] were provided to PHA-submetered residents in the same way they are provided to their Section 8 counterparts, they would receive a rent reduction in the amount of the utility allowance. Also, they no longer would have to pay the appliance surcharge for specific energy-intensive appliances (such as air conditioners). If residents were able to reduce their electricity consumption (and thus their cost) below the amount of the utility allowance, submetering would present them with an opportunity to reduce their total monthly outlay for rent and utilities.

The latest available submeters can provide real-time information so that energy users can identify waste and adjust consumption as needed. In the future, these meters may help residents benefit from electric rates tailored to discourage consumption during peak periods.

9. Transitioning to the Networked Cooling of Apartments

Many apartment buildings are cooled with window air conditioning (AC) units. Cooling with highly efficient window ACs has the advantage of being easily deployed without capital improvements. The disadvantage is that because window ACs are rarely centrally managed, they contribute disproportionately to peak electrical demand. The demand impact of unmanaged ACs contributes to peaks that cause the most polluting "peaker" generating plants to run during times of peak demand.

AC units that can be controlled centrally and remotely—smart ACs—are fast becoming available. The NYCHA recently began a pilot project to test the costs and benefits of providing state-of-the-art, networked AC units to residents at no cost to them. Those AC units connect wirelessly to a

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[3] 24 CFR § 965 2002, https://ecfr.io//Title-24/pt24.4.965#sp24.4.965.d

[4] A resident's share of rent in federally assisted public housing may not exceed 30 percent of the household's monthly income. HUD defines gross rent to include both shelter and reasonable utility costs. HUD requires local housing agencies to set annual schedules of utility allowances that determines the resident's reasonable utility costs.

proprietary remote management system, which a building management system (BMS) monitors. Although residents retain manual control of their AC units, the BMS can remotely "modulate" the units during hot weather to ensure residents' rooms remain at a comfortable temperature while minimizing peak demand and energy costs. The networked AC units were installed in 2019, but implementation of the control system has been delayed by the COVID-19 pandemic.

10. Replacing Gas Stoves with Electric Induction Stoves

Gas stoves consume a relatively small amount of fossil fuel, but they present many problems: Gas stove combustion is very inefficient—perhaps 40 percent at best. The gas flame presents a significant fire hazard, and carbon monoxide (CO) presents an asphyxiation hazard. Some residents use the stove as a supplemental heat source, which is dangerous. Much of the gas piping is original in any given building, and as such, is subject to leaks and subsequent shutdowns of the entire gas system in the building until costly repairs are completed. Gas shutoffs may affect every apartment in an entire building or even an entire development, even if a leak is localized. The loss of gas service means residents cannot prepare meals without relying on hot plates or microwave ovens, which is annoying at best and a hardship at worst.

Electric induction stoves have been available in the United States since the 1970s, but only recently have they begun to increase their market share to a noticeable level. Unlike standard resistance electric stoves, induction units transfer heat via a magnetic field. This method of heat transfer has several advantages, including the faster heating of food, more efficient heat transfer (and thus higher energy efficiency), and a sharply reduced risk of burns or kitchen fires. If the oven is used as supplemental heat in an apartment, fire is less of a risk and asphyxiation is not a danger.

Conclusion

The road forward for many building owners will be one of increased regulation as political leaders develop long-term plans to wind down legacy fossil fuel systems. The technology exists to make this transition today, but the diversity of state requirements and building types makes it difficult to define a single path for all buildings. The options described herein represent a small subset of near-term actions available that can put building owners on the path toward efficient operation.

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Further Reading

NYCHA Climate Mitigation Roadmap: Meeting Local Law 97 through Energy Efficiency and Beneficial Electrification; https://www1.nyc.gov/assets/nycha/downloads/pdf/NYCHA-LL97-Whitepaper.pdf