Rapid Deployment of Energy Upgrades Through a Community-Scale Approach: Leveraging Partnerships to Achieve Equitable Clean Energy Goals

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ABSTRACT

State and local governments are key partners in advancing equitable clean energy and environmental justice. In this paper, Elevate, NREL, the City of Chicago, and the U.S. Department of Energy will present a city-scale analysis of energy efficiency potential from whole-home retrofits, including a roadmap for equitable climate action in Chicago. Using NREL's ResStock™ model and local housing characteristics data, we analyzed baseline housing characteristics and energy usage patterns for the City's entire stock of single-family and low-rise multifamily buildings. We then modeled multiple retrofit scenarios to develop cost-effective deep retrofits (with 50% or greater energy savings) that are technically achievable through the installation of heat pumps, air sealing and insulation, and other off-the-shelf technologies. Furthermore, electrification combined with energy efficiency can produce substantial cost savings in low-income communities. These findings are especially significant given Chicago's cold climate and high heating needs, suggesting that under the right conditions heat pumps could reduce energy burden rather than exacerbating it. Additionally, we will demonstrate the local application of NREL tools, discuss how this partnership advances equity by merging the various strengths of project partners, and highlight the benefits and opportunities for federal government and the national laboratory system to collaborate with community partners. This collaboration is a successful example of how partnerships can lay the groundwork to support community, state and national energy equity goals, including the Justice40 initiative, through rapid, equitable deployment of clean energy for the communities and households that need it most.

Introduction

To achieve ambitious energy, equity, and climate goals, policymakers and local and state governments need to rapidly accelerate the volume and depth of building energy efficiency retrofits, which means we need data and ways to prioritize measures within the diverse U.S. housing stock. What are the housing types best suited for significant energy savings, cost savings, and carbon emission reductions? Where are the communities that can most benefit from strengthening housing and energy security and affordability, based on their housing stock and higher energy burdens? This partnership between the U.S. Department of Energy, National Renewable Energy Laboratory (NREL), Elevate, the City of Chicago, and Commonwealth Edison (ComEd) addresses these questions and demonstrates solutions through a city-scale analysis of energy efficiency potential from whole-home retrofits, a roadmap for equitable climate action in Chicago and field demonstrations of deep retrofit packages (in progress). This work is part of a 3-year technical potential analysis and field validation study; in the current phase of the project, which began in early 2022, Elevate will install and validate selected energy upgrade packages in occupied Chicago homes. This analysis approach and partnership serves as a model for 1) understanding the housing stock and geographic priorities that are best suited for rapidly equitably scaling-up of home energy retrofit programs, 2) developing retrofit packages that can achieve at least 50% energy savings cost-effectively using commercially-available technologies, and 3) utilizing city-scale data to plan rapid deployment and implementation to advance national energy and equity goals, such as Justice40.[1] The Justice40 initiative aims to channel at least 40% of the benefits of federal investments to disadvantaged communities, meaning communities that have been marginalized, underserved, or overburdened with pollution (The White House 2021); this analysis supports Justice40 by identifying the housing types, measure packages, and neighborhoods that are most likely to achieve significant benefits from clean energy investments for underserved households.

Chicago Housing Characterization. In general, the Chicago and Cook County, IL housing stock is older, leakier, more energy intensive, and more commonly made of brick compared to the national and regional housing stock. Chicago single-family homes use over 40% more natural gas than the Midwest average[2] and are less likely to have central air conditioning: for example, only 29% of Chicago single-family homes have central air conditioning[3], compared to 76% nationally (Census Bureau 2019). Chicago housing is dominated by single-family and small multifamily buildings; taken together, single-family and 2-4 unit buildings make up 93% of the buildings and over half the housing units (52%) in the City of Chicago. These housing types are similarly predominant in many low-income neighborhoods: for example, Auburn Gresham is a community on the Southwest side with median annual household income just over $34,000, compared to the City median of just over $58,000 (CMAP 2021). Auburn Gresham is 76% single-family and 21% 2-4 unit buildings, and 85% of the 10,914 buildings in Auburn Gresham are among the five types listed below that have high potential for cost-effective energy retrofits.

Using parcel-level property tax assessor data Elevate has analyzed the distribution and energy use of Chicago buildings, and identified five building types that are both prevalent in the local stock and likely to achieve large energy savings from a retrofit (Corso, Garascia, and Scheu 2017; Scheu 2014). As shown in Table 1, these building types are older (pre-war and mid-century) and most have not previously been retrofitted, so they have high baseline energy use and significant potential for energy savings from efficiency measures. Taken together, these five home types make up 76% of the buildings and 42% of the housing units in Chicago. The rest of this analysis focuses on these five building types to take advantage of both prevalence and high energy savings potential.

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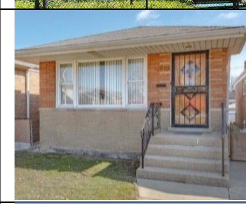
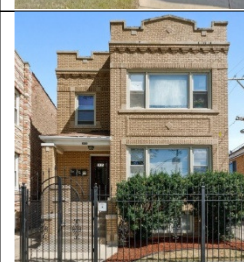
[1] More information on the U.S. Department of Energy Justice40 implementation can be found at: https://www.energy.gov/diversity/justice40-initiative

[2] Data sources: Cook county average annual therm usage of 1,411 in single-family detached homes (based on 2007 data described in Scheu et al. 2014), versus Midwest average of 990 therms (based on the 2009 Residential Energy Consumption Survey, U.S. Energy Information Administration, Table CE2.3 https://www.eia.gov/consumption/residential/data/2009/).

[3] Data source: Elevate analysis of Cook county property assessor data (2014).

Table 1. Five housing types selected as priorities for analysis and retrofit implementation, based on prevalence and high potential for energy savings.

Priority housing type	Building prevalence in Chicago	Mean annual baseline energy use and cost (per unit)	Example photo
Single-family, pre-1942, brick/masonry construction	83,028 (19.0%)	1,800 therms 10,200 kWh $3,100	
Single-family, pre-1942, frame construction	60,993 (13.9%)	1,900 therms 9,900 kWh $3,200	
Single-family, 1942-1978, brick/masonry construction	82,256 (18.8%)	1,200 therms 8,700 kWh $2,600	
2-4 unit, pre-1942, brick/masonry construction	43,812 (10.0%)	1,100 therms 7,100 kWh $2,100	
2-4 unit, pre-1942, frame construction	63,732 (14.5%)	1,100 therms 6,700 kWh $2,100	

Data sources: Elevate analysis of Cook County property assessor data (prevalence), NREL analysis using the ResStock™ analysis tool, and January 2021 utility rates for ComEd and Peoples Gas. Energy use and cost averages are rounded.

Geographic Prioritization. In addition to the housing type prioritization, the project team also identified community areas in Chicago that are aligned with City priorities for investment. This process was informed by the City's ongoing work engaging with partners and leaders in frontline communities. Led by the Mayor's Office, the City is committed to an inclusive approach and working collaboratively with communities and other partners on a variety of relevant initiatives to leverage their strengths and voices to achieve equitable clean energy goals. The historically disinvested communities shown in Figure 1 have high concentrations of low-income households, higher than average rates of asthma and other health challenges, and many of them are environmental justice communities. For example, the City of Chicago (2020a) notes that some of Chicago's most polluted communities are on the city's south and west sides, that also include many Black and Latinx neighborhoods impacted by years of racially motivated disinvestment. This project thus identified 20 community areas, shown in Figure 1, that have a high need for equitable investment and currently experience high energy costs and burdens. These communities are aligned with existing City priorities and programs, such as *Resilient Chicago* (City of Chicago n.d.), the *INVEST South/West Initiative* (Lightfoot 2017), *We Will Chicago* (City of Chicago 2020b), and Chicago Department of Public Health priorities (City of Chicago 2020a). By targeting investments in these communities, a retrofit program can advance equity by reducing energy burdens among low-income households, improving health and economic well-being, and building wealth in Black, Indigenous, and People of Color communities.

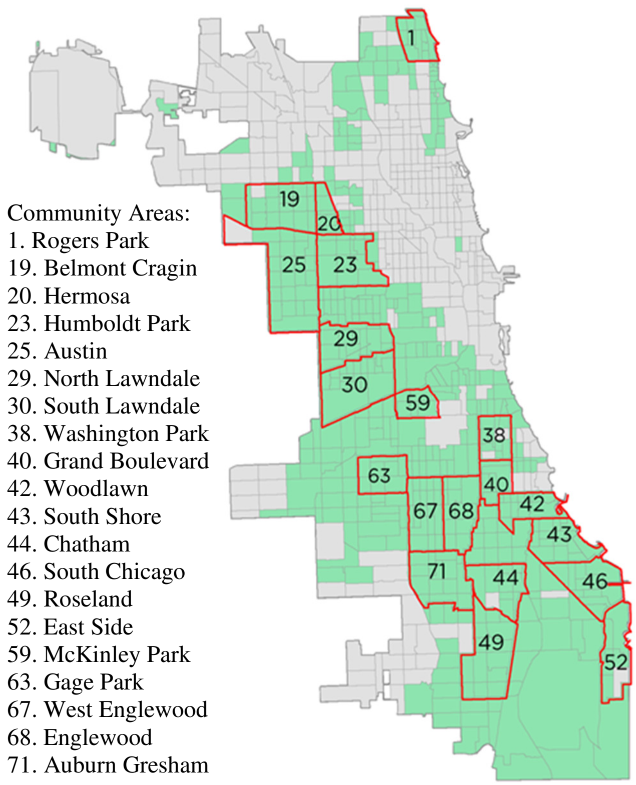


Figure 1. Map of 20 community areas identified as priorities for equitable investment. Green shading is used for census tracts where at least half of households have income <80% of the area median income for Chicago metropolitan area. *Source:* Elevate analysis of 2018 American Community Survey 5-year estimates.

In short, by focusing on prevalent housing types that are most likely to achieve large energy savings, in neighborhoods identified as priorities for equitable investment, we have a clear opportunity to achieve large-scale energy savings while supporting equity goals and helping low-income families that are energy burdened and struggling with utility bills. The rest of this analysis identifies retrofit packages that can support these goals, asses the city-wide technical potential for these retrofit packages, and presents a roadmap for rapid, equitable deployment.

Methodology

The ResStock™ analysis tool from the National Renewable Energy Laboratory (NREL) is a building stock energy model capable of constructing thousands of EnergyPlus simulations that are representative of user-specified geographies within the contiguous United States. This detailed simulation approach involves a conditional probability network of significant building characteristics developed from public and private survey data (e.g., EIA's Residential Energy Consumption Surveys, American Consumer Surveys, American Housing Survey, fuel and equipment performance data, local weather station data). This network defines the probability of any given building characteristic occurring within a building—these probabilities are conditional in that some building characteristics depend on others. For example, insulation type depends on a building's vintage, wall construction, and location.

As a physics-simulation model that uses a statistically representative distribution of building types, ResStock™ can be utilized at multiple geographic scales: PUMA, County, State, ISO-RTO territory, national, etc. Nationally, it has been used to estimate the potential electricity savings from energy efficiency upgrades to single-family homes (Wilson et al. 2017). At a state level, it was previously applied to the Texas residential sector to analyze the effects of heating system electrification (White et al. 2021). On a city scale, ResStock™ simulated the building stock of Los Angeles to analyze how efficient construction measures and appliances aid the future transition of the city to 100% clean energy (Cochran et al. 2021).

For Chicago[4], the project team calibrated ResStock™ to the local housing stock using parcel-level building data from the Cook County Property Assessor, a local infiltration study, and Elevate program data and local knowledge (Burns and Scheu 2014; Leinartas 2014; Leinartas and Stephens 2015). We compared results from baseline ResStock™ estimates to electricity and natural gas consumption in 15 single-family housing typologies identified in Scheu et al. (2014). Natural gas usage was significantly underestimated in the initial ResStock™ run – by more than 20% in most housing types. We then adjusted many ResStock™ model inputs to better represent local conditions in Chicago, for example: increased the prevalence of natural gas heating, higher infiltration rates, increased prevalence of masonry wall construction, 2-wythe brick construction replaced the default 3-wythe brick construction of pre-1978 masonry homes, and new geometries of homes were added as it is common in Chicago to have "2-flat" buildings with 2 to 4 units stacked on top of one another. The base version of ResStock™ modeled the electricity consumption of Cook County adequately, but changes were made to better represent the saturation of central air conditioners within the City of Chicago. Only 19% of housing units in the City of Chicago have central air conditioning compared to 38% of housing units in Cook County (Note: we will add a citation here during the next round of paper revisions). This split of room versus central air conditioning is updated in the version of ResStock™ calibrated to the City of Chicago.

After calibrating baseline energy use to local conditions, we used the Chicago-specific version of ResStock™ to model upgrade packages and associated outcomes such as energy savings. Individual measures within the upgrade packages are applied only to the subset of the representative sample where they can be installed. Energy savings are simply the difference between baseline and post-retrofit energy use in a given upgrade retrofit scenario. We also calculated utility bill savings using January 2021 utility rates from Peoples Gas and ComEd,

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[4] Since many of ResStock™'s data inputs are at the county level, the project team decided to implement the locally-calibrated ResStock™ for Cook County. However, the city-scale aggregation uses City of Chicago prevalence data.

which are the Chicago-area natural gas and electricity utilities, respectively. For homes that are primarily heated by natural gas, the gas rate is \$0.61658/therm with a \$45.32 monthly fixed charge and the electricity rate is \$0.1072/kWh with a \$14.28 monthly fixed charge. For homes that are primarily heated by electricity, the natural gas rate is \$0.56758/therm with a \$21.51 monthly fixed charge and the electricity rate is \$0.1262/kWh with a \$15.70 monthly fixed charge.

Carbon emission reductions are estimated using long-term marginal emissions factors for CO_2 from NREL's Cambium tool (www.nrel.gov/analysis/cambium.html). This tool enables projection of electricity grid conditions across various future timeframes based on scenarios for policy and renewable energy cost. After evaluating several options for future grid scenarios, for the analysis we settled on a realistic and conservative approach by using the Mid-Case Standard Scenario for the Chicago Balancing Area, and annual long-run emissions averaged across 2028-2032. The changes in emissions from electricity use are then combined with reduced emissions from natural gas based on U.S. Environmental Protection Agency (EPA) emissions factors for residential natural gas combustion (EPA 1995).

To assess effects on air pollution emissions besides CO_2, we used the EPA's AVERT tool version 3.0 (EPA 2021). Unlike the Cambium tool, the AVERT tool only assesses avoided emissions from the state of the current electric grid. AVERT estimates changes in outdoor emissions of nitrogen oxides (NO_x), particulate matter ($PM_{2.5}$), and sulfur dioxide (SO_2) from decreases or increases of electricity generation. For upgrade packages that increase electricity usage, like electrification via heat pumps, this increase can mean higher emissions of some pollutants in the short term, however this pattern is expected the change as the electric grid gets cleaner over time. Additionally, for NO_x and $PM_{2.5}$ the short-term increases from electricity generation are offset by reduced emissions from residential natural gas combustion (EPA 1995).

Finally, thermal resilience was assessed by identifying buildings in the representative sample that did not have heating or cooling systems, and tracking their hourly temperature when outdoor weather condition began from a starting point near room temperature and rapidly increased or decreased. This was made possible because there are a small number of buildings identified in national data sources as not having heating systems, and because there are buildings without any form of air conditioning in Chicago. Solar photovoltaic (PV) potential was estimated using a Chicago Solar Potential map previously developed by Elevate and NREL (Elevate 2021). Using these data, we estimated energy generation potential of solar PV for the five housing types that are the focus of this analysis.

Upgrade Packages

Based on their energy savings and cost performance in the five home types listed above, the project team evaluated 58 individual upgrade measures from three categories: intensive fuel agnostic measures (shell or envelope improvements), like air sealing and insulation; multi-fuel measures, including heating, ventilation, and air conditioning (HVAC) and appliances (e.g. stoves and clothes dryers); and "easy" upgrades and swaps (e.g. thermostats, EnergyStar electric appliances, LEDs etc.). Some measures were also simulated at different levels or tiers such as R-49 or R-60 Attic Insulation and varying levels of equipment efficiency. We also consulted the current Chicago Energy Code to ensure envelope measures comply with minimum requirements for city building codes. From the initial assessments, we eliminated measures that were not cost effective (i.e. having high measure cost with low savings) or were only applicable in a small portion of the housing stock. For instance, windows were found to produce very low energy savings compared to their cost to install and were therefore eliminated from further analysis. Similarly, upgrade of existing electric heating systems to heat pumps was eliminated since less than 1% of the Chicago building stock currently uses electricity as the primary heating fuel.

After identifying promising measures based on individual outcomes, we combined measures into packages to take advantage of synergistic effects. For example, insulating and air sealing a home can enable installation of a lower-capacity HVAC system, and thus produce synergistic energy savings. Based on results from these package simulations, Elevate selected three upgrade packages that can produce at least 50% energy savings on average in the five home types, and also typically produce utility bill savings: comprehensive energy efficiency (EE) with upgrade to a high-efficiency HVAC system (no fuel switching); comprehensive EE with conversion to a heat pump; and full electrification which includes comprehensive EE plus conversion to a heat pump and replacement of all gas appliances to energy efficient electric appliances. More details about the measures in each package are in Table 2. Median modeled upgrade cost per housing unit[5] ranges from $6,000 to $20,000 depending on the housing type, heating system type, and upgrade package (full electrification being the most expensive). However, since these are modeled costs based on national data, and not contractor-vetted, it will be important to assess actual costs during the field validation phase of the project, which is currently in progress.

Table 2. Measures included in each of the three upgrade packages in this analysis.

Comprehensive EE measures, no fuel switching	Comprehensive EE + heat pump measures	Full electrification measures
• Air leakage 25% reduction, with mechanical ventilator under 7 ACH50 • Attic insulation R-60 • Drill-and-fill cavity wall insulation to R-13 for frame walls • LED lightbulbs • Natural gas tankless water heater • ENERGY STAR 96% AFUE natural gas furnace, or EnergyStar natural gas boiler	• Air leakage 25% reduction, with mechanical ventilator under 7 ACH50 • Attic insulation R-60 • Drill-and-fill cavity wall insulation to R-13 for frame walls • LED lightbulbs • Natural gas tankless water heater • High efficiency air source heat pump, or Mini-split heat pump	• Air leakage 25% reduction, with mechanical ventilator under 7 ACH50 • Attic Insulation R-49 • Drill-and-fill cavity wall insulation to R-13 for frame walls • LED lightbulbs • 50 gal heat pump water heater • High efficiency air source heat pump, or Mini-split heat pump • Heat pump clothes dryer • Induction stove

Based on ResStock™ energy and bill savings for these three packages, we found that only the packages with heat pump upgrades achieved site energy savings of 50% or more in most of the five home types. Table 3 shows the interquartile range for energy and bill savings for each of the packages by housing type. Based on these results, it is clear that heat pumps are a major

[5] Modeled upgrade installation costs are based on cost factors derived from the National Residential Efficiency Measures Database (remdb.nrel.gov/).

contributor to energy savings: the 75th percentile of energy savings for the Comprehensive EE package without a heat pump upgrade ranges from 33% to 55% depending on home type, versus 69% to 78% for Comprehensive EE with heat pump upgrade. For this reason, the remainder of the analysis and city-scale technical potential will focus on the two packages with heat pump upgrades. These results also demonstrate that, when combined with energy efficiency, heat pumps and other electrification measures can produce substantial utility bill savings in the Chicago housing stock.

Table 3. Final upgrade package energy and utility bill savings by home type.

Building type	Retrofit outcome metric (per unit)	Comprehensive EE (no fuel switching)	Comprehensive EE + heat pump	Full electrification
Single-family, pre-1942, frame	Utility bill savings	\$600-\$1100	\$500-\$1500	\$500-\$1500
	Energy savings	41%-55%	60%-78%	64%-80%
Single-family, pre-1942, brick/masonry	Utility bill savings	\$300-\$800	\$200-\$1200	\$200-\$1300
	Energy savings	25%-43%	53%-75%	57%-77%
Single-family, 1942-1978, brick/masonry	Utility bill savings	\$200-\$400	\$200-\$900	\$200-\$900
	Energy savings	19%-33%	46%-69%	53%-72%
2-4 unit, pre-1942, brick/masonry	Utility bill savings	\$330-\$500	\$200-\$800	\$290-\$900
	Energy savings	32%-49%	57%-74%	62%-76%
2-4 unit, pre-1942, frame	Utility bill savings	\$170-\$400	\$0-\$600	\$90-\$700
	Energy savings	15%-34%	50%-69%	56%-72%

City-Scale Technical Potential

City-wide, the two upgrade packages with heat pumps can produce significant energy, cost, and carbon savings in the communities that need it most. Table 4 shows city-scale technical potential if the upgrade packages were installed in all 323,000 buildings from the five priority housing types.

Table 4. City-wide technical potential for energy and utility bill savings (means and inter-quartile ranges)

		Comprehensive EE + heat pump	Full electrification
Mean energy savings, mmBTUs (IQR)	City-wide	47 million (34–56 million)	50 million (37–59 million)
	Per-building	146 (106–174)	155 (116–183)
Mean utility bill savings (IQR)	City-wide	\$217 million (\$130–305 million)	\$244 million (\$160–333 million)

	Per-building	\$672 (\$401–943)	\$754 (\$495–1,030)
Mean carbon savings, metric tons (IQR)	City-wide	2.5 million (1.4–3.5 million)	2.6 million (1.4–3.7 million)
	Per-building	7.9 (4.3–11.0)	8.1 (4.3–11.4)

These results highlight the benefits of heat pumps as described in the Upgrade Packages section above: while the comprehensive package with a heat pump saves on average 146 mmBTUs per building, the same package without a heat pump only saves 83 mmBTUs. The benefits in terms of utility bills are also substantial, with savings of around 20% for the two packages with heat pump upgrades: using the average annual baseline energy cost of \$3,545 per building (based on ResStock™ modeled energy use and savings and local utility costs as described above), the packages produce bill savings of 19% (\$672) for the comprehensive EE + heat pump package and 21% (\$754) for the Full electrification package. These savings will go a long way toward helping low-income households facing energy insecurity and high energy burdens. Finally, annual carbon savings projected to future grid conditions during 2028-2032 show significant potential for support climate mitigation efforts.

For other types of air pollution, with the current electric grid these retrofit packages will reduce both NO_x and $PM_{2.5}$ pollution from electricity generation. NO_x emissions would be reduced by 3 million pounds per year for full electrification or 2.3 million pounds for comprehensive EE + heat pump, while $PM_{2.5}$ emissions would be reduced by 180,000 pounds per year for full electrification and 260,000 pounds per year for comprehensive EE + heat pump. Due to the current reliance on coal and other dirty generation fuels in the PJM interconnection territory that includes Chicago, SO_2 emissions would increase in the short term with both packages. However, we would expect SO_2 emissions to decrease over time as the electric grid gets cleaner. Given the long lifespan of most of the measures in these upgrade packages, we anticipate a net reduction in SO_2 emissions for the lifetime of the retrofits.

In terms of solar potential, if solar PV were included in all feasible buildings as part of these packages the technical potential is over 2.2 billion kWh annually. This would offset 30% of the post-retrofit electricity use for buildings receiving the full electrification package, or 36% for the comprehensive EE + heat pump package. In terms of thermal resilience, upgraded brick and frame homes were found to maintain healthy temperatures for longer without the HVAC system, including both cooler temperatures in summer and warmer temperatures in winter. These retrofits would therefore improve thermal resilience and help protect against future heat waves, thus addressing climate adaptation as well.

Community scale outcomes are broadly consistent with the city-scale outcomes. In particular, the 20 low-income communities identified in the Introduction as priorities for equitable investment have slightly greater prevalence of the pre-1942 homes that stand to benefit the most from a retrofit, so the energy savings, utility bill savings, and other benefits from these retrofits would be even greater in those communities. By targeting a retrofit program to these communities, significant benefits can be achieved both in terms of energy savings and climate outcomes, and in terms of reducing energy burdens and ensuring the benefits of energy upgrades reach those who need it most.

Retrofit Roadmap

These results indicate that the technical potential for energy savings, bill savings, and other benefits from deep energy and electrification retrofits in Chicago is substantial. However, achieving this potential is a separate question. In parallel with this analysis, the City of Chicago is working collaboratively with communities and other partners on a variety of relevant initiatives described above to leverage their strengths and voices to achieve equitable clean energy goals. The City's commitment to a more inclusive approach is led by the Mayor's Office. Their approach is to work in partnership with frontline leaders and values-aligned technical partners to identify and define key environmental policy priorities, and the City provided input to incorporate community perspectives into the project's process for identifying geographic priorities. So, the Chicago Retrofit Roadmap project with NREL and Elevate was done alongside several policy and community engagement building decarbonization and equity initiatives, including: the 2022 Chicago Climate Action Plan (CAP)[6], recommendations put forth by the Chicago Building Decarbonization Policy Working Group[7], and the Chicago Recovery Plan[8]. The City has invested three years coordinating with communities and local, regional, and national stakeholders to advance these initiatives.

Historically, the decarbonization solutions have excluded the voices of frontline community members and discussion of solutions has been limited to those that carry specific technical expertise. However, community members are best equipped to understand their community's assets, challenges, and needs. Chicago's inclusive approach aims to right this wrong. The City understands that the lived experience of our frontline leaders is essential to developing policy outcomes that support the health and resiliency of our communities, particularly those most vulnerable to climate change and environmental harm.

One central approach of the CAP is to prioritize energy efficiency on the path to citywide electrification. The City can use the equitable investment in retrofits and electrification to address the socio-economic disparities borne from discriminatory real estate and financial policies. For building decarbonization, the co-design process and the transition to equity in practice through implementing deep energy upgrades and beneficial electrification will further refine the City's environment and sustainability agenda to advance a just and equitable climate future for the City of Chicago and its communities.

Through the Chicago Recovery Plan, the City of Chicago is investing $188 million in meaningful, substantive, and justice-oriented climate projects that will provide the City's underserved communities with resilient infrastructure and green workforce development opportunities. This represents the largest one-time climate investment in the City's history, and

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[6] The City of Chicago 2022 Climate Action Plan sets goals that support more inclusive and equitable distribution of benefits. It is structured around 5 pillars: 1) Increase access to utility savings and renewable energy, prioritizing households; 2) Build circular economies to create jobs and reduce waste; 3) Deliver a robust zero-emission mobility network that connects communities and improves air quality; 4) Drive equitable development of Chicago's clean-energy future; and 5) Strengthen communities and protect health.

[7] The Recommendations Report of the Chicago Building Decarbonization Policy Working Group will be released Spring 2022.

[8] The Chicago Recovery Plan is funded by ARP. City agency partners include the Department of Housing, Department of Buildings, Department of Planning and Development, and Department of Assets and Information Services. Specifically, Chicago's Department of Housing, as part of its commitment to providing safe, secure, and sustainable housing, is advancing its Home Repair Program, which will help income-qualified owners of 1-to-4 unit residential properties with critical health and safety repairs to help these homes to be electrification-ready.

can accelerate neighborhood-level resilience and climate mitigation while driving equitable co-benefits for the communities that need them most. Of the $188 million climate related investments in the Chicago Recovery Plan, $46 million is being directly invested in energy and equity projects. These initiatives are defined by equitable building decarbonization, electrification, and weatherization. Two of these five investments will be specifically for improving Chicago's existing residential housing stock, including $15 million for retrofitting low- and moderate-income housing and $6 million toward retrofitting affordable multifamily buildings. These projects will be executed within 5 years.

These investments are a first step toward the City's goal of retrofitting 20% of residential buildings with 4 or fewer units by 2030 and 50% by 2050, with the intent to focus on low-to-moderate income households (City of Chicago 2022). This means that the city and its partners aim to upgrade over 82,000 homes in less than 8 years. For context, as shown in Table 5, there are 126,000 existing 1-4 unit homes in the 20 priority community areas, and 110,000 of them are also among the five housing types focused on here with high potential for energy savings. As shown in Table 6, the city could achieve 80% of its retrofit goal for 2030 by concentrating on homes in just seven low-income community areas.

Table 5. Building counts for 1-4 unit buildings in the 20 priority community areas listed above, versus the City of Chicago.

	Total residential buildings	Single-family detached buildings		2-4 unit buildings	
	#	#	%	#	%
Priority community areas total	133,406	77,818	58.3%	45,637	34.2%
Chicago total	438,054	274,072	64.9%	123,563	28.2%

Data source: Elevate analysis of Cook County Property Assessor data.

Table 6. Building counts in seven priority community areas with high prevalence of buildings from the 5 types in this analysis.

Community Area	# of buildings from the five housing types
Auburn Gresham	9,080
Austin	13,970
Belmont Cragin	10,634
Humboldt Park	7,072
Roseland	10,233
South Lawndale	7,161
West Englewood	7,597
Total	65,747

Data source: Elevate analysis of Cook County Property Assessor data.

Discussion

In the context of the City of Chicago, widespread deployment of heat pumps, especially when combined with basic envelope improvements, is a potentially viable approach to achieving deep energy savings in the residential sector without increasing utility bills. For the packages modeled, addition of a heat pump with insulation, air sealing, and other measures produced bill savings in 84-98% of the households modeled in ResStock™, depending on the intensity of the retrofit. However beneficial heat pumps might be towards reducing energy bills in Chicago, there remains multiple barriers, primarily the high upfront cost, particularly for whole-home mini-split heat pump systems, which lead to long pay-back periods in many cases. Heat pump and other retrofit costs are currently in flux, and the ongoing field validation work for this project will help to better enumerate the local equipment and labor costs for installing deep energy retrofits. Different levels of local, state or federal intervention could potentially help to overcome this barrier to heat pump adoption.

There are several existing local conditions within Chicago that make heat pumps plus energy efficiency a viable approach to upgrades. The natural gas utility for the City of Chicago (Peoples Gas) has higher fixed charges than the surrounding Nicor utility service territory, primarily due to constraints in the natural gas distribution network, with the fixed charges anticipated to increase substantially in the coming years to support ongoing maintenance and upgrades of the constrained network (ICC 2016). This high natural gas cost can make electric technologies, such as heat pumps, more attractive from a cost perspective, particularly if the household can remove all natural gas technologies (i.e., complete electrification) and avoid the fixed gas charge. Another contributing factor is that the housing stock of the City of Chicago is substantially older, leakier, and more poorly insulated than much of the housing in cold climate regions in the U.S., leading to greater opportunities for improvement in the thermal energy performance than in areas where the baseline stock is better performing. That being said, there are large swaths of buildings in cold climates throughout the U.S. that are quite old and leaky, and natural gas, propane and heating oil costs are continuing to increase, so there are likely other areas where the savings from installing and operating a heat pump might be similar.

Beyond the cost savings, heat pumps offer a significant benefit not present with other heating systems: the ability to provide both heating and cooling from the same equipment. Although Chicago is located in a cold climate region (Climate Zone 5), climate change is increasing the intensity and frequency of extreme heat events which can have devastating impacts on human morbidity and mortality when residents don't have access to cooling at home. For example, the 1995 heat wave in Chicago is still well-known for its high mortality, especially in low-income and Black communities (Klinenberg 2002), and more recently year three seniors died during a heat wave early in the season in May 2022 (Schuba 2022). The impacts of not having access to cooling are further exacerbated in communities with disproportionate rates of asthma, lung disease, heart disease and other co-morbidities, which include most of the 20 priority communities targeted in this project. A co-benefit of installing heat pumps is expanding access to energy efficient cooling technologies at home. Furthermore, our analysis shows that even with the additional cooling service (and the necessary electricity to operate heat pumps in warm months) total utility bills do not typically increase overall because of the efficiency of the heat pump units and the associated envelope improvements. In the City of Chicago, increasing access is a significant health and equity issue as only 23% of buildings have central cooling. Although many households have some form of window or room air conditioning unit, the vast majority only partially cool spaces or might not consistently achieve indoor comfort targets during warm months. Some households, especially low-income households, don't have air conditioning at all or can't afford to use it. Adding in heat pumps could help protect vulnerable populations during heat events and is a pathway to "future-proof" the building stock against future heat waves.

In this project, a crucial factor in being able to accurately interpret the ResStock™ results was the calibration of the model to local data. As mentioned in the Methodology above, using the regional default assumptions significantly underestimated the amount of natural gas consumed in Chicago homes. Digging into the physical drivers of this discrepancy, it became clear that the default data for ResStock™, which is often based on data that aggregates large regions together, was not appropriately representing the wall types, infiltration, or heating system fuel distributions. Had these not been updated in the base model, the upgrade packages applied in ResStock™ would have underestimated energy consumption across HVAC technologies and underestimated the value of energy efficiency improvements in the energy transition.

The partnership between the City and Elevate was built on a shared vision, mission, and strategy related to equitable building decarbonization. Specifically related to advancing climate justice and equitable outcomes for low-income, overburdened Chicagoans, the project's community prioritization model closely matches the priorities of Chicago's recovery plan criteria. Utilizing publicly available data, the City seeks to invest climate recovery plan funding in communities that are particularly vulnerable to the effects of climate change as well as communities that shoulder the greatest energy burden. The technical expertise of DOE, NREL, and Elevate was used to jumpstart implementation plans for the City, while the City's involved helped ensure alignment with existing priorities and implementation plans. Elevate also partnered with ComEd, the local electric utility, who added technical support and discussion of implementation regarding a broad range of energy efficiency measures. Their continued insight will be relied upon, particularly when the findings of this project move from demonstration to broader scale implementation.

Recommendations

This analysis demonstrated that, under the right conditions, heat pump and electrification retrofits can significantly reduce energy consumption in some of Chicago's most prevalent home types, thereby reducing utility bills. In turn, these findings represent an opportunity to reduce energy burden with intentionality in Chicago's frontline communities where disproportionate inequities across numerous socioeconomic metrics have persisted for decades. Other studies have found the potential for increases in utility bills arising from heat pumps (e.g. Walker, Less, and Casquero-Modrego 2022), and future research should reconcile these findings by examining the conditions in which electrification and heat pumps can reduce versus exacerbate energy burdens. Some possibilities include:

- Housing characteristics with high potential for energy savings from efficiency measures
- Packaging heat pumps with other measures (e.g., envelope improvements such as air sealing and insulation, appliance upgrades including all-electric appliances in locations where maintaining gas service for non-heating appliances has a high fixed cost)
- Pricing or rate conditions, including fixed versus per-kWh charges, time of use or other variable rates, and/or other rate structures that may be combined with demand response enabled systems and controls
- Integrating heat pumps with installation of solar photovoltaic system

Future research should investigate these and any other possibilities to identify conditions in which heat pumps and electrification generally reduce energy costs and burdens. This research will be important for ensuring that heat pump retrofit programs reach the households that can benefit from them, without harming households that may face higher costs.

This partnership represents a model for rapidly scaling up equitable climate action that could be readily replicated in other cities and regions. By combining the research strengths of NREL and DOE with Elevate's program implementation experience and the on-the-ground knowledge and planning work already underway by the City of Chicago, this collaboration helped connect detailed and accurate modeling results with local implementation planning processes. In this example, research from DOE and the national labs informed, and was informed by, local knowledge and municipal planning work. The contributions of all partners in this project supported a granular, accurate, and locally-tailored analysis that laid the groundwork for early implementation to advance the City of Chicago's energy equity goals. The partnership also supported local calibration of NREL's national tool to the unique Chicago housing stock, which enabled more accurate estimates for energy, bill, and carbon savings. We recommend that other cities develop similar partnerships to identify building types and/or neighborhoods most suitable for achieving the largest benefits, and thus support planning work to advance local and national climate and equity goals.

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