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Achieving 50% Energy Savings in Chicago Homes: A Case Study for Advancing Equity and Climate Goals

Since 2020, the National Renewable Energy Laboratory (NREL) and Elevate have collaborated to identify pathways to deep energy retrofits in Chicago's housing stock, document equity implications and co-benefits of this transition, and validate the findings by implementing retrofits in real Chicago homes. This document summarizes our analysis process to model advanced retrofit packages that lead to greater than 50% energy savings in Chicago homes. Based on these findings, we have also developed a roadmap with the City to guide implementation, and are deploying the recommended retrofit packages in real Chicago homes to realize these energy savings. This work was developed in collaboration with two key stakeholders—the City of Chicago and Commonwealth Edison (ComEd)—and funded by the U.S. Department of Energy (DOE) through the office of Energy Efficiency and Renewable Energy (EERE).

NREL's Residential Buildings team maintains the best-in-class ResStock™ energy model of the U.S. residential building stock. For this work, we calibrated ResStock to Chicago's unique local housing stock to accurately simulate energy use in Chicago homes both for current conditions and with various retrofit scenarios. We simulated a wide range of potential building retrofits covering all aspects of residential energy use and then grouped these into packages based on energy and utility bill savings. ResStock can model diverse building types and housing characteristics, so we're able to observe the range of outcomes that might occur when these upgrades are deployed across the entire housing stock. We can then estimate potential energy savings from an advanced retrofit program on Chicago's housing stock by comparing the modeled energy use before versus after a retrofit.

This novel version of ResStock, calibrated to Chicago with data from Elevate, can help City officials, ComEd, and other partners plan for community-scale decarbonization via residential retrofits. Specifically, this work contributes the following project goals:

- Develop a building retrofit prioritization strategy for Chicago single-family and 2- to 4-unit buildings
- Identify neighborhoods and home types that have the highest potential for savings from electrification
- Assess the impact of advanced building retrofits on energy use, utility bills, and CO_2 emissions at the city and building level.

Although this study is specific to Chicago, its methods and learnings are applicable across the United States. These findings are especially notable for heat pumps and electrification retrofits in cold climates.

ELEVATE

Chicago-based environmental nonprofit Elevate and the National Renewable Energy Laboratory are collaborating to identify pathways to achieve a 50% or more reduction in energy use in Chicago's housing stock.

Advanced retrofits on Chicago's older single-family and 2- to 4-unit multifamily building stock achieves the following benefits:

- >50% energy savings with technologies currently available in the market, including heat pumps
- Increased at-home cooling access, especially of central systems, usually while reducing utility bills for residents
- Reduced utility bill costs on average as electric heating replaces natural gas heating; when paired with energy efficiency, this reduces electricity usage and bill costs.

The partnership between Elevate and NREL enabled Elevate to share detailed knowledge and data on the Chicago and Cook County residential building stock with NREL to calibrate ResStock specifically for the Chicago area. With this custom version of ResStock, energy savings from advanced retrofits can be accurately estimated for the City of Chicago. During the calibration process, an emphasis was placed on the most common housing types in the city. These home types are located across the city and also are common in neighborhoods that may be defined as "disadvantaged"[1] in the Biden-Harris administration's Justice40 initiative—communities that have high energy burdens, environmental and health hazards, and socio-economic vulnerabilities.

Housing Characteristics in the City of Chicago

Homes in Chicago are generally older, leakier, less energy efficient, and more likely to be constructed out of brick compared to the national and regional housing stock. Approximately 66% of residential buildings in the City of Chicago are single-family, and 28% of buildings have 2 to 4 units. The remaining 4% are larger multifamily buildings. Most older single-family homes are heated with natural gas, and only 30% of them have central cooling systems (contrasted with 76% of single-family homes nationally). Chicago's 2- to 4-unit multifamily buildings are even less likely to have a central cooling system, with a prevalence of only 9%.[2]

Through analysis of the Cook County property tax assessor data, Elevate has identified key housing types to focus on for retrofits, which have the following attributes:

- Common in Chicago's low-income neighborhoods (i.e., 80% of the area's median income [AMI][3]), environmental justice communities, and/or communities that have historically experienced disinvestment
- High potential for realizing more than 50% energy savings
- Common in communities facing public health challenges capable of being addressed with housing improvements and increased building safety.

We selected five top housing types that represent over 75% of Chicago's residential building stock and 50% of Cook County's stock. The types are described in Table 1.

Community Prioritization for Advanced Retrofits

In addition to housing type, Elevate identified 20 communities prioritized by the City of Chicago for equitable investment. The intersectionality of public health, environmental justice, and wealth-building considerations prioritizes specific communities that have the most to benefit from an advanced retrofit program. In collaboration with the City of Chicago and using the context of existing priorities and programs like Resilient Chicago,[4] the INVEST South/West

1 DOE's working definition of disadvantaged is based on cumulative burden and includes data for 36 burden indicators collected at the census tract level. These burden indicators can be grouped across four categories: energy burden, environmental and climate hazards, fossil dependence, and socio-economic vulnerabilities. **https://www.energy.gov/diversity/justice40-initiative**

2 According to Elevate analysis of 2014 data from Cook County property assessor.

3 According to the U.S. Department of Housing and Urban Development **https://www.huduser.gov/portal/datasets/il/fmr98/sect8.html**

4 **https://resilient.chicago.gov/**

Prioritized Housing Types

Single-Family, Pre-1942, Brick/Masonry Construction

Single-Family, Pre-1942, Frame Construction

Single-Family, 1942–1978, Brick/Masonry Construction

2-4 Unit, Pre-1942, Brick/Masonry Construction

2-4 Unit, Pre-1942, Frame Construction

Table 1. Five Housing Types Selected as Priorities for Analysis and Retrofit Implementation

Priority Housing Type	Building Prevalence in Chicago	Mean Annual Baseline Energy Use and Cost (per unit)
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. Example photos from the Chicago Workers Cottage Initiative.

Initiative,[5] We Will Chicago,[6] and Chicago Department of Public Health's listed priorities,[7] 20 community areas were identified as priorities for climate investment, shown in Figure 1.

By focusing retrofit programs on the high-potential housing types within the priority neighborhoods, this project identifies an opportunity to reduce the energy consumption of Chicago's residential sector while realizing positive, equitable changes to Chicago neighborhoods that have historically suffered from disinvestment.

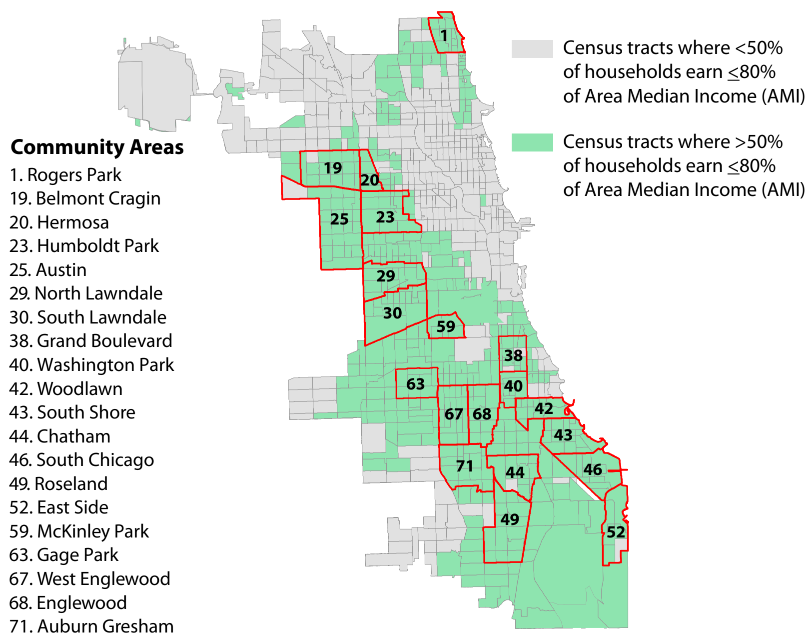


Figure 1. 20 community areas in Chicago identified for advanced retrofit programs for large energy savings, prioritized on equitable investment

5 https://www.chicago.gov/city/en/sites/invest_sw/home.html

6 https://wewillchicago.com/

7 https://www.chicago.gov/city/en/depts/cdph/provdrs/healthy_communities/svcs/healthy-chicago-2025.html

Table 2. Measures Included in Each of the Three Upgrade Packages in This Analysis

End-Use Category	Package 1: Comprehensive Energy Efficiency Upgrades, No Electrification	Package 2: Comprehensive Energy Efficiency Upgrades + Heat Pump Upgrades	Package 3: Full Electrification Upgrades
Building Envelope	• 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	• 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	• 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
Lighting and Small Appliances	• Energy-efficient LED lightbulbs	• Energy-efficient LED lightbulbs	• Energy-efficient LED lightbulbs • Heat pump clothes dryer • Induction stove
Heating, Ventilating, and Air Conditioning (HVAC)	• ENERGY STAR® 96% AFUE‡ natural gas furnace, or ENERGY STAR natural gas boiler	• High-efficiency air source heat pump, or minisplit heat pump	• High-efficiency air source heat pump, or minisplit heat pump
Water Heater	• Natural gas tankless water heater	• Natural gas tankless water heater	• Heat pump water heater

* ACH = air changes per hour, a measure of air infiltration into a home

† R-values = a higher R value means the insulation is more effective at preventing heat from entering or leaving the building

‡ AFUE = annual fuel utilization efficiency

Estimation of Energy Savings Potential From Retrofit Programs Using NREL's ResStock Analysis Tool

Of the dozen or so retrofit packages explored by Elevate and NREL, we selected three candidate packages designed to be cost-effective, code compliant, and having a high potential to reduce energy consumption. The packages vary in how much electrification is included, meaning how much of the appliances and building systems are converted from gas to electric fuel. Package 1 included energy efficiency upgrades but no electrification. Package 2 uses the same efficiency upgrades with the addition of high-efficiency heat pumps as electric heaters. Package 3 includes the same efficiency upgrades and high-efficiency heat pumps, adding in electrification of water heaters, clothes dryers, and stovetops so that no gas-fueled appliances remain in the building. These upgrade packages are further detailed in Table 2.

High-Efficiency Heat Pumps Are Major Drivers of >50% Energy Savings in Chicago

We estimated energy and utility bill savings for each package by comparing the baseline simulated energy consumption in ResStock with the energy consumption of the package. In the model, high-efficiency heat pumps (Package 2 and 3) are necessary to achieve >50% energy savings in the five selected Chicago housing types. The middle 50% (i.e., the interquartile range) for annual utility bill savings and annual energy savings for each housing type and upgrade package are shown in Table 3.

A co-benefit from electrification is the swapping of furnaces and boilers for heat pumps, which provide cooling as well as heating in the same device, increasing access to central cooling for Chicago households. Although Chicago is in a cold climate region, it has suffered from several major heat

Table 3. Annual Energy Savings and Annual Utility Savings for Each Respective Upgrade Package and Housing Type

Building Type	Retrofit Outcome Metric (per housing unit)	Package 1: Comprehensive Energy Efficiency Upgrades, No Electrification	Package 2: Comprehensive Energy Efficiency Upgrades + Heat Pump Upgrades	Package 3: Full Electrification Upgrades
Single-Family, Pre-1942, Frame	Utility bill savings	$600–$1,100	$500–$1,500	$500–$1,500
	Energy savings	41%–55%	60%–78%	64%–80%
Single-Family, Pre-1942, Brick/ Masonry	Utility bill savings	$300–$800	$200–$1,200	$200–$1,300
	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 Units, Pre-1942, Brick/ Masonry	Utility bill savings	$330–$500	$200–$800	$290–$900
	Energy savings	32%–49%	57%–74%	62%–76%
2-4 Units, Pre-1942, Frame	Utility bill savings	$170–$400	$0–$600	$90–$700
	Energy savings	15%–34%	50%–69%	56%–72%

waves. The 1995 Chicago heat wave led to 739 heat-related deaths, disproportionately affecting low-income and Black communities, and was one of the deadliest climate disasters in U.S. history.[8,9] Chicago typically experiences multiple heat waves each summer, and these are expected to become more common and more severe as climate change continues. The City of Chicago's 2022 Climate Action Plan[10] identifies extreme heat vulnerability as a significant concern and a priority to address for equitable climate action. Increased cooling in the communities highlighted in Figure 1 will decrease deaths and other health impacts during extended periods of extreme hot weather. Even with the additional cooling service in homes, the model still estimates annual utility bills savings in most homes because of the heat pumps' high efficiency.

Paired with energy efficiency upgrades, high-efficiency heat pumps save almost double the amount of energy as the same building without the heat pump upgrade. This also leads to a 20% reduction in energy cost, from $3,545 to $2,836 per building annually. This reduction is due to the heat pumps' high efficiency and the savings realized by going from two utility bills to one, particularly by eliminating the monthly fixed gas fees for natural gas in Chicago.

Advanced retrofit packages with heat pumps have the potential to reduce Chicago's CO_2 emissions by 2.5 million metric tons per year—the equivalent of 500,000 cars taken off the road!

8 Cusick, Daniel. 2020. "Chicago Learned Climate Lessons from Its Deadly 1995 Heat Wave." Scientific American. **https://www.scientificamerican.com/article/chicago-learned-climate-lessons-from-its-deadly-1995-heat-wave1/**

9 Thomas, Mike. 2015. "Chicago's Deadly 1995 Heat Wave: An Oral History." Chicago Magazine. **https://www.chicagomag.com/Chicago-Magazine/July-2015/1995-Chicago-heat-wave/**

10 City of Chicago. 2022a. Climate Action Plan. **https://www.chicago.gov/city/en/sites/climate-action-plan/home.html**

Table 4. City-Wide Technical Potential for Annual Energy and Utility Bill Savings: Means and Inter-Quartile Ranges (IQR)

		Package 2: Comprehensive Energy Efficiency + Heat Pump	**Package 3:** 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 CO_2 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)

If these two top packages (Package 2 and 3) are deployed in all 323,000 Chicago buildings from the five selected housing types, there would be significant energy savings, bill savings, and CO_2 savings, as shown in Table 4. CO_2 savings are based on emissions factors from NREL's Cambium Tool.[11] These long-term CO_2 emissions factors were selected to reflect a cleaner electric grid as more electricity is produced from renewable and other clean sources, which would represent what the grid will look like once these advanced retrofit packages are fully implemented in Chicago.

In addition to CO_2 savings, other air emission reductions result from these advanced upgrade packages. Using the U.S. Environmental Protection Agency's AVERT tool—which models pollutant emissions based on the current makeup of the electric grid (unlike the NREL Cambium tool)—harmful emissions of both nitrogen oxides (NO_x) and particular matter ($PM_{2.5}$) produced as a by-product of burning fossil fuels for electricity generation are reduced by all three packages. City-wide, Package 2 reduces NO_x emissions by 2.3 million pounds per year and $PM_{2.5}$ emissions by 180,000 pounds per year.

These city-wide potential outcomes can be applied to the 20 low-income communities in Figure 1. In most cases, the energy and utility bill savings will be more impactful in these communities due to relatively higher numbers of the pre-1942 housing types identified by this study.

How This Analysis Is Applicable Across the United States: Recommendations and Implementation

This analysis demonstrates that under the right circumstances, advanced retrofits with energy efficiency upgrades and electrification with heat pumps can reduce utility costs and produce >50% energy savings in older vintage homes in Chicago, reduce CO_2 emissions, add necessary cooling, and remove indoor air quality hazards like NO_x pollutants. Because these older vintage homes are also prevalent in communities with historic disinvestment and/or low-income populations, these retrofit packages can improve the energy, health, and financial well-being in Chicago neighborhoods where inequities have persisted for decades.

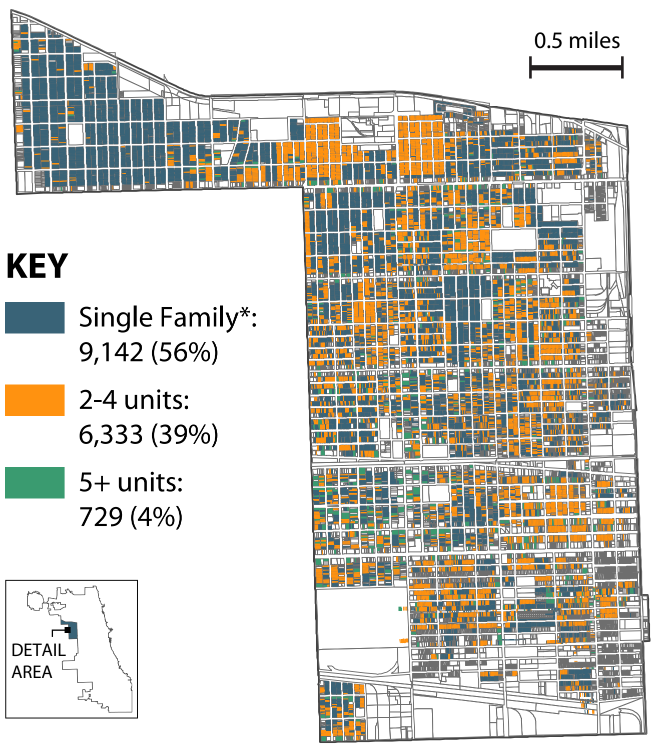
Implementation of these retrofits in Chicago neighborhoods requires coordination between the City of Chicago, community leaders, and technical partners. In terms of technical potential, retrofitting 30,000 buildings per year would mean that all homes in Table 1 would be retrofitted by 2035. A neighborhood-based strategy focusing on the 20 priority community areas discussed above could achieve large numbers of retrofits quickly while advancing equity; for example, in just seven of those community areas there are over 65,000 buildings from the five housing types. At

11 **https://www.nrel.gov/analysis/cambium.html**

the time of release of this case study, the City of Chicago is directly investing $46 million from the Chicago Recovery Plan into energy and equity projects.[12] Approximately half of this amount is reserved for retrofits in single-family and multifamily buildings. This investment is the first step to retrofitting all five housing types highlighted by this study.

Although this analysis focused on Chicago, its findings are notable for various cities/regions in the United States with high baseline gas use, colder climates, and relatively older vintage households. As such, this analysis makes the following recommendations for retrofit programs to reduce energy consumption and utility bills across the county:

- Identify housing types with the highest potential for improvement in energy savings and utility bill savings. Homes with high infiltration levels and old vintages are likely to be chosen. For example, in Chicago these home times are: pre-war single-family masonry construction, pre-war single-family frame construction, midcentury single-family masonry construction, pre-war 2- to 4-unit masonry construction, and pre-war 2- to 4-unit frame construction.
- Package high-efficiency heat pumps with improvements to the building envelope (e.g., increase roof insulation, reduce drafts and air leaks) to optimize energy and bill savings and reduce risk of death from heat waves or cold snaps.
- Consider modifying utility rates for all-electric homes, or a low-income rate, to help consumers further save on utility bills and decrease stress on the electric grid.



Community Area Profile. *Excludes single-family attached homes.
Photo from Elevate analysis of Cook County Property Assessor data, 2014. Accessed from City of Chicago Data Portal.

Along with these recommendations, it is important to note other takeaways that are helpful to municipal governments planning to undergo similar retrofit programs. For this case study, collaboration between technical experts, community-based organizations, and City officials was integral in successfully modeling the effects of a retrofit program. Significant time and resources were invested in sharing knowledge about the local building stock with all stakeholders. This knowledge could then be translated to identify household types with greatest savings potential, help NREL model Chicago's residential buildings, and help retrofit contractors understand the opportunities in the housing construction types.

For further information on the methods used in this case study, see NREL's home page for the **ResStock Analysis Tool**. For any questions or information about Chicago's housing stock or its advanced retrofit efforts, use Elevate's **project page**.

12 City of Chicago. 2022b. Chicago Recovery Plan. **https://www.chicago.gov/city/en/sites/chicago-recovery-plan/home.html**

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