Cooling Down the U.S. With Maximum Heat Pump Adoption

Executive Summary

Energy Solutions veic ARUP

Acknowledgements

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Executive Summary

A Study with a Purpose

Communities in the United States (U.S.) will face pressing challenges as global temperatures rise. Demand for cooling technologies is expected to increase across much of the nation, including in temperate and cold climate zones. What can be done to ensure that cooling is widely accessible while reducing greenhouse (GHG) emissions to address climate change?

This report provides insights to inform policy and program design in the U.S. to equitably reduce emissions through the expanded adoption of heat pumps for both cooling and heating needs. By motivating stakeholders and supporting actions across a broad range of institutions and market actors — policy and equity advocates, regulators, the philanthropic community, utilities, program administrators, equipment installers, appliance manufacturers and more — we can establish effective pathways towards a sustainable future.

The research presented here quantifies the anticipated building thermal-related emissions for eight northern U.S. climate zones out to the year 2050 for eight residential and commercial building prototypes, assuming weather changes and no interventions. Potential GHG emissions mitigation strategies are evaluated in a subset of four prototypes using the vast majority of energy, with a primary focus on air-source heat pumps (including variable-speed and variable-refrigerant-flow systems) as well as weatherization, lighting efficiency, plug load controls and a range of refrigerant solutions. These technologies offer significant emissions reductions when compared to stand-alone air conditioners and furnaces, and when combined with near-clean, renewable grids, we estimate a best-case scenario of 94.5% reduction in GHG emissions below business-as-usual (BAU) conditions by 2050.

Context for Action

The U.S. has one of the highest rates of air-conditioning in the world, using nearly 392 terawatt-hours annually (EIA 2021), nearly equivalent to electricity use of California and New York combined. In March 2020, the Energy Information Administration (EIA) projections for 2050 pointed to air-conditioning as the end use with the largest projected increases in energy use.

Notably, air-conditioning demand at present is significantly lower for households in the eight northern climate zones focused on in this report compared to the U.S. average, suggesting this number will continue to increase as temperatures warm (EIA 2019). However, in BAU conditions aggregate increasing temperatures will alter both cooling and heating activity, leaving GHG emissions from the built environment almost unchanged, an insufficient reality for meeting global emissions targets.

Currently, centralized heating, ventilation, and air-conditioning (HVAC) equipment is prevalent in residences, especially in single family homes. Window and wall units are common in multi-unit buildings. In commercial buildings, packaged units are dominant for both air-conditioning and heating.

Heat pumps are commercially available products for providing efficient cooling and heating using electricity. Due to their efficiency and use of increasingly clean electricity instead of fossil fuel-based heating and electric-resistance heating, they cause dramatically lower GHG emissions even with the increased use of refrigerants. Heat pumps range in types, efficiencies, and sizes. For this report, we examined air-source heat pumps: single-speed and variable-speed (also known as variable-capacity or inverter-driven) determined by the compressor speed, and variable-refrigerant-flow (VRF) systems. The “variable” technology responds to cooling and heating

demands more efficiently and improves occupancy comfort compared to conventional single-speed furnaces and heat pumps.

Figure 1 provides a promising snapshot of heat pump adoption in the U.S., illuminating that there is significant traction.

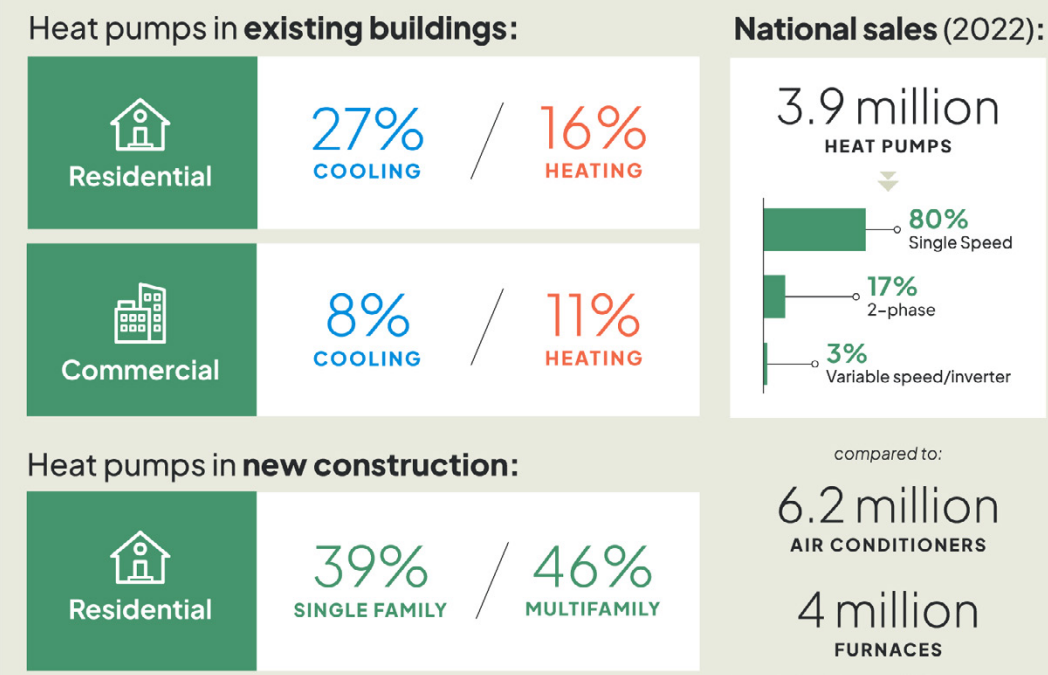

Figure 1. Current heat pump adoption in the U.S.

Sources: (EIA 2015/2020/2022; AHRI 2021; DOE 2020; NAHB 2020; Industry Interviews 2021)

We are seeing significantly higher adoption of heat pumps in new construction due to both increasing requirements of building codes that are encouraging all-electric buildings to meet climate goals and ease of installation of one versus two systems. New residential construction also can take advantage of economies of scale by ordering large numbers of units at the same time and those orders are usually well in advance of installation dates.

In existing buildings, aging HVAC systems are typically replaced upon failure in emergencies, as are some new, first-time installations, so opportunities for heat pump purchases are limited by several factors: distributor stocking, contractor proficiency, upfront costs and existing site design. All of these can present barriers to heat pump adoption. Programs and policies addressing these issues vary widely across the U.S.

While aiding consumers and businesses toward efficient, climate-friendly dual-purpose system selection is critical to GHG mitigation, investment in technology improvements in areas of cold climate performance, lower global warming potential (GWP) refrigerants and grid capabilities will bring additional benefits. Effective installation, operation and user behavior are also essential. To some extent, over-cooling buildings has become a dilemma for responsible energy management, due to behavioral norms around air-conditioning in the U.S. Further research into behavioral factors can aid in achieving GHG emissions reductions as culture, normative influences, and knowledge of alternatives all play significant roles in space-conditioning. Interventions aimed at each of these factors operate on different scales that must be considered.

Top Insights

1. Regional weather shifts across the eight climate zones evaluated will lead to **more hotter days and fewer colder days, e.g., 45 additional days above 90°F in the Cool Dry region.** The timing of extreme heat waves is difficult to forecast but cities, with their heat island effects, should be prepared.

2. Shifting to high-efficiency electric heat pumps instead of using stand-alone furnaces and air conditioners in residential buildings (single family and mid-rise apartments) and a subset of commercial buildings (medium office and strip malls), we can remove approximately **80 million metric tons of annual GHG emissions**. With additional building measures, shifts in a cleaner grid, and advanced refrigerants, reduced emissions could increase to **180 million metric tons annually**, equivalent to the electricity use emissions of Texas.

3. **Heat pump adoption is growing rapidly**, especially in new construction applications, and is now nearly equal to furnaces in sales nationally, but **barriers remain**. Variable-speed technology is still in the early adoption phase at 3% of heat pump sales.

4. **Achieving true market transformation involves implementing solutions tailored to disadvantaged populations**, who are most at risk to climate hazards. An equitable approach to heat pump deployment requires attention to the upfront costs, baseline housing conditions, and operating costs implications beyond general market dynamics and specific to the circumstances of low-income and historically underserved households.

Other Key Findings

5. Assuming no technology change in the heating and cooling sectors, by 2050 climate change in the northern two-thirds of the U.S. will lead to an insignificant net decrease of emissions, as demand for heating falls and for cooling rises. This small change is insufficient for meeting global emissions targets.

6. When accounting for the heat pump replacement of electric-resistance heating and expansion to other commercial buildings, these emissions reductions can be even greater.

7. Single family residential buildings are responsible for the bulk of total heating and cooling emissions and therefore reductions from interventions at 70% of total building stock floorspace and approximately 80% of emissions.
8. Even with an increase in new refrigerant use, replacing all furnaces with high-efficiency heat pumps still means an overall emissions decline.
9. Recent data shows national average upfront cost savings from installation of ducted heat pumps compared to both air conditioners and furnaces: approximately 40% in new construction (RMI 2018) and 25% in retrofits (LBNL 2021; RMI 2018).
10. Variable-speed air-source heat pumps and VRF systems are superior technologies relative to single-speed heat pump technologies (comfort, emissions, peak demand reductions and utility load management). However: a) as the grid becomes more renewable, the difference in emissions caused by their use becomes less significant, and b) single-speed heat pumps when packaged together with weatherization, lighting efficiency, and plug load controls are still beneficial in terms of GHG reductions.
11. Heat pumps that use existing technology work at cold temperatures, at 5°F and below; even as their efficiencies decrease in even colder temperatures, they still function with electric-resistance back-up. They can also be supplemented by back-up non-electric heating systems, if needed. Technology advancements are and will continue to increase the efficiencies of heat pumps at ambient temperatures of 5°F and below. The reduction in very cold hours due to warming will also minimize the need for this technology; nearly half the climate zones analyzed reach and are projected to reach zero or near zero hours below 5°F.
12. The connection between building decarbonization and cooling efficiency in states' climate action and building decarbonization plans is light and nascent. Such plans primarily note increased incidence of extreme heat as rationale for climate mitigation and a need for adaptation activities such as cooling centers. Some more recent plans note the ways that a heat pump's ability to provide efficient cooling serves as a customer benefit and affects cost effectiveness as well as its potential to reduce summer electric demand peaks.

Benefits of Variable-Speed and VRF Heat Pumps

- Lower emissions (enhanced with increasing renewable grid), even when accounting for an increase of refrigerants
- One appliance versus two (most relevant when both need replacing, or for buildings without cooling)
- Lower utility bills for customers with electric-resistance heating (under current rate structures)
- Lower utility bills for customers with fossil-fuel burning heating (with deep rate reform)
- Improved occupant comfort (more consistent temperature)
- Load shifting potential

Call to Action

With a holistic market transformation approach, we have identified **30 policy and programmatic actions** to increase adoption of efficient, climate-friendly heat pumps for both cooling and heating, organized by barrier—Industry, Technology and Affordability—and then alphabetically by key groups involved. Some actions will likely involve multiple groups, in which case the primary group is listed first. The groups are:

Federal regulatory agencies + Congress

Manufacturers

Philanthropic community

Policy advocates

(should consider all the recommendations)

State regulatory agencies + state legislatures

Utilities + utility commissions

Actions for Industry Barriers

Action Reference	Who	Barrier – Detail	Action Description	Action Type	Time Horizon	Scale
A	Manufacturers Philanthropic Community	Workforce knowledge and capacity	**National education / re-branding campaign** (e.g., heat cool pumps).	Program	Intermediate: 1–3 years	National
B	Utilities (+ Regional Energy Efficiency Organizations)	Workforce knowledge and capacity	Develop a "**Heat pump Nation**": a National Heat pump installer network, education and training hour requirements of training gateway to incentives, expanding the number of contractors who have familiarity and trust in heat pumps as a solution for their customers' needs. Incorporate basic building science education on envelope improvement and system sizing to increase HVAC efficiency.	Program	Intermediate: 1–3 years	National
C	Utilities	Lack of installer value proposition	Integrate **grid flexibility enablement programs** at time of installation and/or through repair, maintenance contractors.	Program	Intermediate: 1–3 years	State Regional

Actions for Technology Barriers

Action Reference	Who	Barrier – Detail	Action	Action Type	Time Horizon	Scale
D	Federal Regulatory Agencies (DOE*)	Emergency purchases	Require **reversing valves** on all air conditioners, thereby making them reversible heat pumps (DOE standard).	Policy	Intermediate: 1–3 years	National
E	Federal Regulatory Agencies (DOE)	Emergency purchases	Explore opportunities for **regional heat pump standards** to optimize for climatic difference beyond the existing single, national heat pump standard.	Policy	Intermediate: 1–3 years	National
F	Federal Regulatory Agencies (DOE)	Lack of realized value from variable speed	Modify the Standards Test Procedure to ensure **repeatability and reproducibility below 5°F**.	Policy	Intermediate: 1–3 years	National
G	Federal Regulatory Agencies (DOE)	Lack of realized value from variable speed	Modify the Standards Test Procedure to include **manufacturer-recommended controls** to help ensure equipment + controls are optimized to meet the performance rating.	Policy	Intermediate: 1–3 years	National
H	Federal Regulatory Agencies (EPA*)	Lack of low- and no-GWP refrigerant options	Make currently optional provisions specified for **refrigerant charge verification** in ENERGY STAR© version 6.1 for air conditioners and heat pumps a requirement in the next specification.	Policy/ Program	Intermediate: 1–3 years	National
I	Federal Regulatory Agencies (EPA)	Lack of low- and no-GWP refrigerant options	**Expand the new refrigerant-based filter** to the product finder pages for ENERGY STAR© certified Central Air Conditioner and Heat Pump Equipment.	Policy/ Program	Intermediate: 1–3 years	National
J	Manufacturers(AHRI) Federal Regulatory Agencies (EPA)	Lack of realized value from variable speed	Make the compressor type field visible in databases, or make requirement in AHRI and ENERGY STAR© to make **whether a product is variable-speed** easily findable.	Other	Short: less than 1 year	National
K	Philanthropic Community Federal Regulatory Agencies (DOE)	Emergency purchases	**Spur market transformation among manufacturers**—through technology prizes/competitions to inspire technology innovation and replace inefficient incumbent technologies for window units, particularly for multifamily renters.	Program/ Other	Intermediate: 1–3 years	National
L	State Regulatory Agencies (Building Code) State Legislatures (+IAPMO's Uniform Mechanical Technical Committee)	Lack of low- and no-GWP refrigerant options	**Change the mechanical codes to allow lower-GWP refrigerants**, including updates to certain mechanical codes (e.g., Uniform Mechanical Code) and supporting state adoption. Certain states, through both legislative and regulatory actions, are already in the process of addressing state-specific building code updates to allow the use of equipment containing low-GWP alternative refrigerants.	Policy	Short: Less than 1 year	National State

*DOE = Department of Energy EPA = Environmental Protection Agency

Actions for Technology Barriers, continued

Action Reference	Who	Barrier – Detail	Action	Action Type	Time Horizon	Scale
M	State Regulatory Agencies	Emergency purchases	Explore opportunity for **NOx standards through air quality** regulators (example: California Air Quality Management District to adopt with 14 n/j rule to align with South Coast for interim reductions).	Policy	Intermediate: 1–3 years	State
N	State Regulatory Agencies	Lack of realized value from variable speed	Require **tests of capacity and total static pressure** to within original equipment manufacturer specs on install.	Policy	Intermediate: 1–3 years	National State
O	State Regulatory Agencies (California Air Resource Board, Regional Greenhouse Gas Initiative) Federal Regulatory Agencies (EPA) Congress	Lack of low- and no-GWP refrigerant options	**Include refrigerants in existing carbon markets and create federal carbon market** for reclamation and destruction of high-GWP refrigerants.	Policy	Intermediate: 1–3 years	National State Regional
P	State Regulatory Agencies (Appliance Standards and Building Code Agencies) State Legislatures	Lack of realized value from variable speed	**Adopt grid flexibility standards** to develop the market for grid flexible HVAC solutions (enable the full benefits of variable-speed technology to be captured).	Policy	Intermediate: 1–3 years	State
Q	Utilities (+ Local governments)	Emergency purchases	Implement programs for **new temporary heating/cooling units** that can serve as emergency purchases while heat pumps are sized, installed, etc.	Programs	Intermediate: 1–3 years	State Regional Local
R	Utilities Manufacturers (+ Software developers)	Lack of realized value from variable speed	**Improve modeling** of variable-speed heat pumps in standard modeling software to account for accurate gains in efficiency.	Other	Intermediate: 1–3 years	National
S	Utilities Philanthropic Community	Lack of realized value from variable speed	Invest in **third party test lab capacity** for cold climate heat pumps.	Program/ Other	Intermediate: 1–3 years	National
T	Utilities (+ Regional Energy Efficiency Organizations)	Lack of realized value from variable speed	Develop **contractor training** on how to use published data to properly size heat pump equipment in colder climates.	Program	Intermediate: 1–3 years	State National

Actions for Affordability Barriers

Action Reference	Who	Barrier - Detail	Action	Action Type	Time Horizon	Scale
U	Federal Regulatory Agencies (The Federal Housing Finance Agency)	High upfront costs	Incorporate **heat pump replacement costs** in **green mortgage and refinancing**.	Policy	Intermediate: 1–3 years	National
V	Philanthropic Community	High upfront and operational costs	**Develop roadmap to address cost barriers** —What investment? Who pays? How do we unlock it? (e.g., unlock includes health and safety value from NOx reductions).	Other	Short: Less than 1 year	National
W	Utilities Federal Regulatory Agencies (DOE)	High upfront costs	**Establish national or regional upstream incentive program** featuring: • Extra incentives for variable-speed systems • Limitation-free installation qualification • Free-installs for industry participants • Extra incentives for Low-GWP refrigerants and leak-tight installation verification • Exclude EER requirements which make it less difficult for variable-speed / inverter technology or include a tradeoff between EER and grid connectivity.	Program	Intermediate: 1–3 years	National
Y	State Regulatory Agencies Utilities	High upfront costs	Coordinate **group purchasing power** of heat pumps.	Program / Other	Intermediate: 1–3 years	State Regional Local
Y	Utility Commissions	High operational costs	Enable **deep energy rate reform** (e.g., reducing the electricity rate base, marginal cost rates), essential to pull in private capital and build an industry, like the rooftop solar industry.	Policy	Intermediate: 1–3 years	State
Z	Utility Commissions	High upfront costs	Expand **Tariff On-bill Financing**.	Policy	Intermediate: 1–3 years	State

Action Reference	Who	Barrier – Detail	Action	Action Type	Time Horizon	Scale
AA	Utility Commissions State Regulatory Agencies	High upfront and operational costs	Properly **evaluate, quantify and unlock non-energy benefits** of heat pumps into state/utility policy (e.g., cap + trade funds, cost-effectiveness tests, health + safety funding mechanisms). Ensure those metrics are included in policy decision-making.	Policy	Intermediate: 1–3 years	State
BB	Utility Commissions Federal Regulatory Agencies (Department of Health and Human Services)	High upfront and operational costs	**Modify energy assistance programs** offered by utilities as well as the **federal Low-Income Home Energy Assistance Program** (LIHEAP) to incentivize electrification and cover cooling costs.	Policy / Programs	Intermediate: 1–3 years	National
CC	Utility Commissions	High upfront costs and operational costs	**Promote fuel switching for low-income households** through comprehensive programs that address health and safety measures as well as weatherization and appliance efficiency measures.	Programs	Intermediate: 1–3 years	National
DD	Utility Commissions State Legislatures	High upfront costs	**Modify incentive policy to eliminate barriers to stacking and braiding of federal funding**, including for electrification and heat pump deployment.	Policy	Intermediate: 1–3 years	State

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