Large Heat Pumps for Commercial Buildings – Untapped Savings Potential and Overcoming Barriers

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ABSTRACT

Heat pump use in large commercial buildings is an underexplored avenue for decarbonization in the United States. The necessary technology exists, but there is limited domestic knowledge of the potential applications, remaining barriers, energy and economic savings, or likely market trends. This paper reviews real world case studies of heat pump use in large commercial applications in the European Union (EU) and elsewhere from the International Energy Agency's (IEA) High Temperature Heat Pump (HTHP) Annexes. It discusses the applicability of such case studies, learnings, economics, and hurdles to large scale domestic adoption. We also cover emerging market trends, and how best commercial entities can engage with utilities and government to enable the use of heat pumps to meet decarbonization targets and reduce energy costs.

Introduction

Commercial buildings in the United States are responsible for over 6,700 TBTUs, or 6.7 quads, of total energy use and 16% of domestic carbon emissions (EIA 2018). Decarbonizing the sector is essential for mitigating the worst impacts of climate change. Electricity accounts for approximately 60% of total energy use in U.S. commercial buildings, while natural gas makes up an additional 34%, or about 2,307 TBTUs of energy use every year (DOE 2022). While this overall ratio is ostensibly indicative of progress in electrifying as compared to other sectors of the economy, de-fossilizing commercial building process heat still requires significant attention. Natural gas is the predominant fuel source in commercial buildings for such processes as space and water heating, and cooking, which combine for 53% of annual energy end use in commercial buildings. Natural gas accounts for 73% of the 2,167 TBTUs of energy used annually for space heating, while electricity accounts for only 11%. An additional 11% of U.S. commercial buildings use sources including propane and wood for space heating (DOE 2022). Natural gas is responsible for approximately 78% of commercial building hot water heating. Figure one below depicts the major fuel consumption by end use in domestic commercial buildings in 2018.

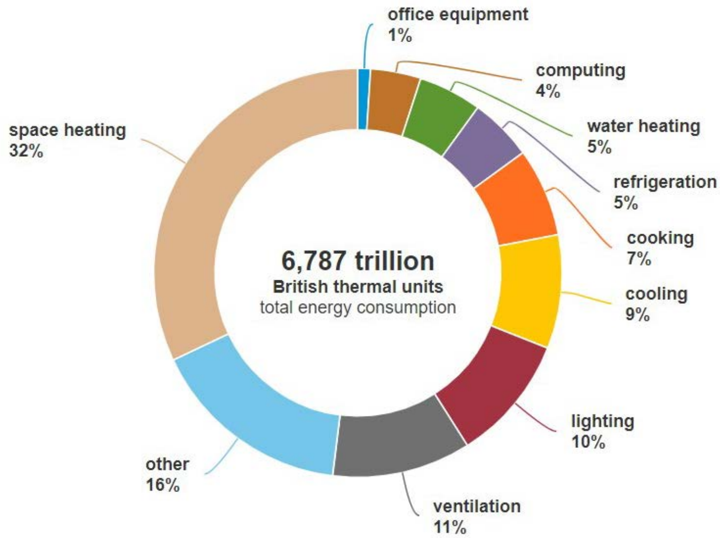

Figure 1. Major Fuel Consumption by End Use in Commercial Buildings. *Source*: EIA 2018

Large heat pumps are an important technology for electrifying buildings and reducing emissions and energy use while saving costs for end-users. These heat pumps have the potential to radically shift the above numbers, de-fossilizing the generation of hot water and comfort heat and ensuring a transition from fossil fuel based infrastructure to all-electric commercial buildings.

Heat pumps are not a new technology. They emerged as an alternative to traditional steam and natural gas process heat generation in the 1990s. However, according to Commercial Building Energy Consumption Survey (CBECS) data, heat pumps and district heating account for just over 11% of the energy consumed by heating equipment in commercial buildings in 2018 (EIA 2018). This figure means that heat pumps are underexplored and underutilized in commercial buildings, and especially in large applications where coefficients of performance (COPs) indicate efficiency improvements can be as high as three and four fold (ACEEE 2023). Heat pumps can provide simultaneous heating and cooling, and when paired with other technologies, including thermal storage, onsite renewable electricity generation, and grid decarbonization can deepen emissions and cost savings even further across a wide profile of building types (IEA 2021).

Heat pump implementation in commercial buildings at scale has been limited by a number of factors both unique to the buildings sector and cross-cutting between all heat pump applications. It is essential to examine real-world case studies of applications in order to interpret performance outcomes and inform disparate groups of stakeholders. It is also critical to discuss the measures that already exist, and those that are forthcoming that can help transform the domestic heat pump market and enable greater electrification.

Barriers

Heat pumps are essentially heat recovery or transfer systems that operate on refrigeration principles of compressing and transferring heat. They're driven by electrical or mechanical energy sources and are designed such that the benefits of reusing waste heat are greater than the energy required to run them or create heat. Heat pumps often outperform efficient fossil fuel fired alternatives because they can transfer more process heat than the energy they require. They have the capacity to electrify traditionally fossil fuel powered processes, thereby reducing emissions (the impact of which is greater where grid mixes have more renewables), saving costs (due to the energy efficiency gains, reduced maintenance costs, and reduced insurance costs), and creating a host of other co-benefits.

However, there are significant barriers to the growth of the heat pump market and their more widespread use in commercial buildings. Those barriers can be grouped into those common across all heat pump types and sector applications (including industrial and residential) and those that are unique to commercial buildings. Both groups of barriers will need to be addressed by a combination of market transformation efforts and policy action in order for the technology to be able to meaningfully affect decarbonization.

<u>Barriers Common Across Heat Pump Applications:</u>

- **Economics and natural gas prices**. The initial capital required for heat pump purchase, installation, and integration is significant. The operational costs can also torpedo heat pump projects because of high electricity to natural gas price ratios at many sites.[1] Paybacks rely entirely on efficiency gains, best-fit applications, and energy prices. Many heat pump projects will depend on reducing payback timelines with effective policy, ambitious decarbonization targets that make reliance on natural gas infeasible, and the quantification of co-benefits that demonstrates the full scope of cost savings enabled by heat pumps. Some heat pump installations will also necessitate electrical upgrades and may result in more peak demand charges.
- **Supply chain issues**. Heat pump manufacturer, especially of the size and capacities of heat pumps needed for large applications, are not operating domestically at scale. This limits the ability of companies to plan for heat pump implementation and understand market timelines. It also means that there is limited vendor technical assistance and continuity available for heat pumps in the market. Codes and regulatory inconsistencies restrict importing product for pilots.
- **Workforce and technical support**. Because heat pumps are not ubiquitous, the domestic workforce that is capable of installing, inspecting and supporting heat pumps is limited. Heat pumps require the handling of high pressure refrigerants in many cases, and often require reimagining thermal loads and thermal processes after decades of boiler-based

[1] The economics of heat pump and other electric technologies are much more beneficial when compared to propane and other fuels, and the 11% of space heating energy consumption that they provide should not be ignored.

engineering. There are also behavioral challenges associated with a limited or developing workforce.

Limited real world savings. There is a lack of proven energy, greenhouse gas (GHG), and cost savings of heat pumps demonstrated by validated, domestic, public case studies. Demonstrations and support in aggregating and reporting performance data will be critical to informing and motivating both heat pump supply and demand and mitigating risk. Barriers Unique to Large Commercial Buildings:

- **Building retrofits are challenging**. The physical nature of existing buildings, and especially historical buildings, make heat pump retrofits difficult. Occupants of the buildings have to be displaced. Pipes and other infrastructure will have to be disrupted and replaced. Heat pump installations may also require shell improvements (Facility Dive 2023).
- **There are refrigerant challenges specific to buildings.** Refrigerants are the working fluids used in heat pumps' vapor compression cycle. The refrigerants typically used in heat pumps differ by efficacy, availability, and safety, among other factors. Heat pump use in commercial buildings may mean that some refrigerants are not feasible due to safety concerns and high pressures (Hoffmeister, Chen and Elliott 2024). High refrigerant uncertainty also means that both manufacturers and potential end-users are waiting for resolution before committing capital to heat pump designs and implementation projects using particular working fluids.
- **Locations limit best fits.** Heat pumps work with lower distribution temperatures, and more slowly, as compared to boilers. This means that in colder climates, applications often require particular configurations and buffer tanks (EIA 2023). Additionally, space constraints may limit some heat pumping applications.

Case Studies and Demonstrations

The barriers outlined above are not prohibitive to seizing the significant potential of heat pumps to help electrify commercial buildings. However, they mean that policy action and demonstrations of heat pumps with public facing data are critical. It is essential that potential end-users know the possible savings and efficiency improvements enabled by heat pumps in particular applications and that funding is provided to implementers during the early adoption phase of commercializing the technology.

Many countries are farther ahead than the US in heat pump deployment, especially in commercial buildings. IEA's HTHP annexes, which survey participating countries[2], provide a starting point for the study of commercial building applications, the potential savings, and their economics.

For example, in Annex 48[3], one of the case studies details a heat pump implemented at a cafeteria at the University of Applied Sciences in Soest, Germany. In this application, the

[2] Participating countries (Annex 48) included Austria, France, Germany, Japan, Switzerland, and the UK.
[3] Annex 48 was released in late 2020. It was intended to update HTHP knowledge with descriptions of barriers, calculation tools, and specific case studies from participating countries.

exhaust air from ventilation in the cafeteria and the waste heat of the refrigeration system (20 °C; 68 °F) operate as the heat source, and the heat pump extracts heat from the source and lifts it to a temperature of 70 to 85° C (158-185 °F) for space heating, floor heating, HVAC, and domestic hot water. The technology operates with a COP of 3.7 and with a heating capacity of 52.7 kW (180 MMBtu per hour). It also provides some simultaneous cooling as a byproduct. Compared to heat from the district heating network (from which the application would otherwise derive process heat), the heat pump in this application halves CO2 emissions, from 0.39 kg CO2/kWh to 0.2 kg CO2/kWh (or about 26 metric tons of CO2 per year) and provides operational cost savings of about 25%. (IEA 2021).

For another Annex 48 example, a water-to-water heat pump was installed in the KOKON Corporate Campus in Ruggell, Liechtenstein. The heat pump operates with a heating/cooling capacity of 341/275 kW and provides heat from a source of 7 to 10 °C (45-50 °F) to a sink of 27 to 35 °C (81-95 °F) using compressors in parallel. (IEA 2014).

Table 1 below contains the applications of high temperature heat pumps in commercial building applications from IEA's HTHP Annexes. The combination of these case studies, across multiple types of building and in various applications and temperatures indicate the efficacy and effectiveness of heat pumps to electrify commercial building heat needs thereby saving costs and reducing energy use and emissions. Successes need to be recognized and replicated in applications in the U.S. There are known domestic heat pump projects ongoing, but a serious lack of transparency into process, and ways to aggregate and interpret savings. As new designs and new applications come to market, there will need to be corresponding demonstrations. IEA's annexes provide the single largest collection of heat pump data available. Owners of commercial buildings that may be interested in heat pump applications should first investigate the data and conclusions made available through the annexes. Then they should consider the resources available through federal, state, and utility programs to mitigate costs.

Table 1. Heat Pump Applications in Commercial Buildings from IEA Annexes

Location and Application	Heat Pump Type and Capacity	COP
Strabag, Austria, multipurpose office building, space heating	Compression heat pump, 3x693 kW	4.03
Bovendeert, Netherlands, warehouse, space heating	MHP, 252 kW	N/A
Kingston Heights, UK, space heating from river water	Variable capacity heat pump, 2300 kW	N/A
Bridgford Garden Center, UK, space heating	Vapor compression, 400 kW	N/A
Bunhill, UK, space heating	Vapor compression, 1,000 kW	N/A
Aarhus, Denmark, University Hospital, heating/cooling from district heat	MHP, 6,000/8,000 kW (two stage)	4.00
Dijon, France, University of Bourgogne, space heating and cooling	MHP, 419.5/255 kW	2.6

Kokon Corporate Campus, Lichtenstein, heating/hot water supply	MHP, 341/275 kW	4.16
Soest, Germany, Cafeteria, heating/hot water supply	MHP, 52.7,39.1 kW	3.7

Overcoming Other Barriers:

Support will be needed for demonstrations and data collection of case studies like those above, however there is also urgent need for both public and private action to mitigate the other significant barriers. More investment like the Defense Production Act (DPA), which prompted significant new manufacturing investments in high-temperature heat pump manufacturing is needed in ensuring additional heat pump availability. These policies could include additional rounds of DPA funding or investment tax credits.

There needs to be additional focus on regional hubs of heat pump technical expertise that can provide both thermal analysis and technical assistance. Energy audits of buildings should look to include electrification opportunities and potential heat pump applications. Incentive and rebate programs at both the state and utility level will be key to overcoming barriers of capital. And consistent and clear refrigerant policy is essential for ensuring that end-users know what their working fluid options are, and which manufacturers are prepared to help meet them (NREL 2021 and Hoffmeister, Chen and Elliott 2024).

Anticipating Market Transformation:

Based on emerging market capacity, growing support (like the mechanisms mentioned above), and the increased visibility into case studies like those depicted by the annexes, we expect a heat pump market to grow rapidly. Figure 2 below depicts our anticipated timeline for market transformation. It includes qualitative milestones that will reflect the market's progress down a path from early adoption to early majority. Further notes on the milestones are included below (ACEEE 2023).

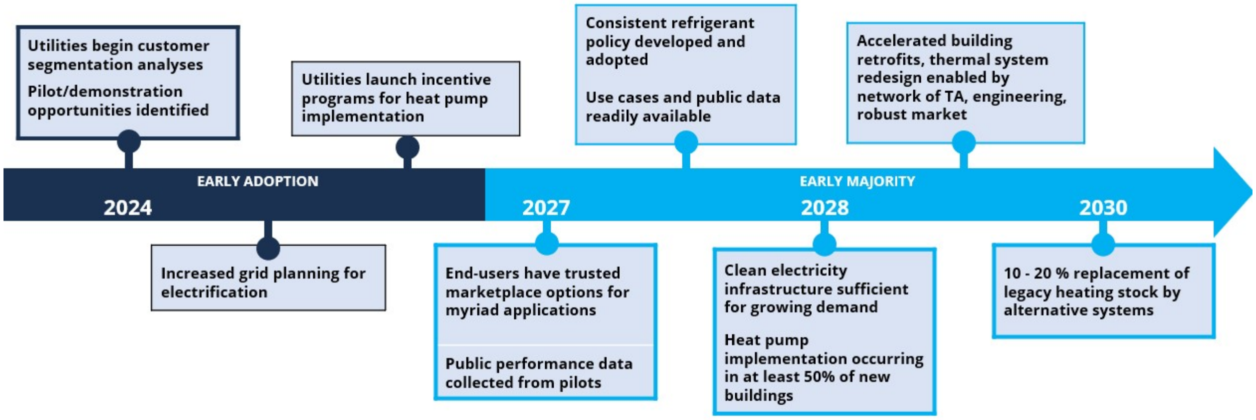

Figure 2. Qualitative Milestones for Heat Pump Market Development 2024-2030. *Source*: ACEEE.

- The utility perspective and participation in electrification is essential. Both electric and gas utilities need to evaluate the status of various building types and best fit applications for heat pumps based on the age of buildings, energy prices, climate, codes, and more. A segmented analysis of opportunity will help ensure that the scope of emerging demand can be communicated to DOE and the heat pump manufacturers. It will also help utilities understand the likely increase in electricity demand, and plan infrastructure growth accordingly.
- As clarified in the sections above, it is critical that domestic pilots and demonstrations of heat pumps occur in various building types and applications and that public data is collected and distributed. This will help inform both heat pump supply and stoke additional demand. Groups of pilots and demos could be run through various jurisdictions or authorities, including DOE.
- One of the most significant indicators of market growth will be heat pump interest being met by multiple bids by trusted manufacturers.
- Heat pump implementation occurring in at least 50% of new buildings and replacing 10-20% of additional heating stock are targets that will reflect significant progress in the market, the deployment of new heat pump options, and certainly successful and well documented pilots and demonstrations.

Conclusions

The ability of heat pumps to electrify commercial building heating needs is significant. Despite technology readiness, movement in the market is slow. There are many transformational actions to mitigate the various barriers that have hampered historical progress, including product availability, awareness, and workforce expertise. The historic price advantage of natural gas has reduced motivations to look at heat pumps as an alternative.

As discussed above, the Defense Production Act and presence of installation incentives are already motivating expansion of domestic production beginning to address product availability.

One of the most difficult hurdles has been the lack of domestic case studies and documented public facing savings, which both raises awareness and build workforce experience with the technology. IEA's High Temperature Heat Pump Annexes provides an example of a collection of case study application results from real-world heat pump installations in commercial buildings. The case studies demonstrate the efficacy and long-term economics and feasibility of the technology. Such learnings need to be replicated domestically to ensure confidence in the nascent heat pump market.

We anticipate the intersection of multiple factors, including the drive to decarbonize, developing heat pump technology, understanding of co-benefits, and utility interest to motivate significant heat pump market growth. These efforts will need to be complemented by policies to provide attractive electricity rates and incentives reflecting the benefits that decarbonization provides to the grid and the economy as a whole.

Heat pumps will be able to offset and displace much of the reliance on natural gas and other fossil fuels for commercial building heating needs. This opportunity will only deepen with the development of other technologies and heating sources including district heat, thermal storage, and others. It is critical that potentially interested end-users investigate the data available, and the emerging resources that can be leveraged to mitigate initial capital costs for their applications.

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