Opportunities for Combined Heat and Power (CHP) in the Multifamily Sector

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Executive Summary

This report was prepared for the Environmental Protection Agency's Combined Heat and Power (CHP) Partnership Program to provide a better understanding of CHP use and potential in multifamily buildings. After providing context on the multifamily building market and market trends, the report focuses on the scope and the technical and economic potential for additional CHP implementation, culminating in a discussion of the opportunities and challenges for CHP in the multifamily sector.

Multifamily buildings are attractive candidates for CHP system installation. Such buildings have significant energy costs, concurrent electricity and thermal energy demands, and power reliability and resiliency needs that, when met, enhance residents' quality of life. A well-designed CHP system can help meet these demands and, at the same time, increase the benefits of energy efficiency and avoided emissions in multifamily buildings. However, the multifamily building sector is complex, characterized by a range of different building types, sizes, and ownership structures, all of which affect CHP implementation. The CHP value proposition varies according to a variety of internal and external factors. Examples of factors that affect the CHP value proposition include building-specific design features, such as the presence of centralized and shared hot water systems; whether electricity is master-metered at the building level or direct-metered to individual units; and the market dynamics of utility energy rates, which vary considerably by geography.

Through 2017, there were 395 operational CHP systems at multifamily buildings across the country. Most of the installations are located in five key states -- New York, New Jersey, Pennsylvania, Massachusetts and Connecticut -- with the total number of installations increasing over the last decade.[1] Installations have especially increased in New York State, where targeted incentives from the New York State Energy Research and Development Authority (NYSERDA) helped spur multifamily project development. From 2008 through 2017, 65 percent of all new CHP installations in multifamily buildings across the U.S. took place in New York State, representing 88 percent of total recent CHP capacity in multifamily buildings.

CHP Market Analysis

This report estimates the potential for new CHP installations in multifamily buildings while considering optimal development size (in square feet and number of units), infrastructural characteristics such as central water heating and master- or direct-metered electricity, and different building ownership types. It analyzes the technical and economic potential for CHP in existing multifamily buildings that are large enough to support retrofitted CHP installations, encompassing both the market-rate and affordable housing sectors. Data on multifamily buildings was assembled from several sources including the U.S. Census Bureau, the U.S. Department of Energy's (DOE's) Energy Information Administration, and the

[1] U.S. Department of Energy. CHP Installation Database. Maintained by ICF. Data current through Dec. 31, 2017. https://doe.icfwebservices.com/chpdb/

Department of Housing and Urban Development (HUD).[2] Overall, the report finds significant untapped potential for CHP implementation in multifamily buildings, with potential concentrated in densely populated urban centers where energy costs are typically high.

CHP sizing for multifamily buildings is based on energy loads that vary based on building size and climate. In determining energy loads, the analysis assumes that typical lighting and building envelope energy efficiency measures, such as upgraded windows and insulation, are installed at each building. Taking likely efficiency upgrades into account, even if not yet implemented, helps avoid CHP oversizing. Three different CHP sizing strategies were considered in the analysis, and for each a rule of thumb was developed:

1. Sizing to fully utilize CHP heat for domestic hot water (DHW) loads, with thermal energy only used for water heating: ***The CHP sizing rule of thumb is 0.15 kW per thousand square feet.***
2. Sizing to average non-cooling electric loads and utilizing thermal energy for space heating and/or cooling (in addition to water heating)***: The CHP sizing rule of thumb is 0.7 kW per thousand square feet.***
3. Sizing to average electric loads for common areas only[3] (for direct-metered buildings), using thermal energy for domestic hot water (DHW) and space heating: ***The CHP sizing rule of thumb is 0.3 kW per thousand square feet of total building size.***

These three sizing strategies were then applied to U.S. multifamily buildings to develop three estimates of potential:

- **Maximum Technical Potential,** which assumes that all multifamily buildings can install a CHP system, with electricity supplied to both common areas and tenants, where CHP is sized to the average non-cooling electric load.
- **Achievable Technical Potential,** which applies percentages for central water heating and master-metered electricity, where CHP size for direct-metered buildings is limited to the average common area electric load.
- **Economic Potential**, which uses state average energy prices and CHP cost and performance parameters to evaluate economics for CHP systems with different sizing strategies, where the economic potential for CHP is based on buildings with payback periods fewer than 10 years.

The results of the market analysis are summarized in Table 1, with a breakdown by the number of buildings and the associated total CHP potential for each estimate.

[2] When evaluating energy loads and potential for CHP, assisted living buildings and additional loads from mixed-use buildings (i.e., multifamily developments with commercial retail stores on the ground level) were not included and are not considered in the analysis.

[3] Common area loads include entryways, lobbies, hallways, elevators, building operations (fans and pumps), and exterior lighting.

Table 1. Technical and Economic Potential for Multifamily CHP in the U.S.

Estimate	Number of Buildings	Total Potential (MW)
Maximum Technical Potential	71,678	4,367
Achievable Technical Potential	32,192	1,742
Economic Potential	6,493	518

In moving from the *maximum technical potential* – which assumes all multifamily buildings with 50 or more housing units can install full-building CHP systems – towards the *economic potential* for multifamily CHP – which factors in building design and energy cost savings – the number of eligible buildings with CHP potential narrows. A*chievable technical potential* is based on all buildings with central water heating systems and master-metered versus direct-metered electricity. Economic calculations for multifamily CHP are then applied to these building data sets using state average energy prices and CHP cost and performance characteristics. The results of the economic potential analysis favor large buildings in areas with high electricity prices, primarily concentrated in the Northeastern U.S. and California.

If all multifamily buildings with economic potential installed CHP systems, over 430,000 tons of carbon dioxide-equivalent emissions could be reduced on an annual basis.[4] Most of these reduced emissions would come from new potential multifamily CHP installations in New York State.

Key Takeaways for Stakeholders

This report collects information about the opportunities and challenges for CHP that are unique to the multifamily sector through a review of relevant literature and interviews with industry stakeholders. Overall, it finds that the extent of a building's resilience needs, and the presence of positive economics for CHP implementation are likely to be two key factors in determining whether a potential CHP project is an appropriate option. When both aspects are present, the ability for stakeholders to communicate a CHP system's advantages to key decision-makers associated with a potential site becomes a critical step in moving forward.

At this stage, the role of a CHP "champion" emerges as an instrumental factor in leading the project development process. Unlike other distributed generation technologies, installing a CHP system requires an understanding of different technology options and fuel choices, in addition to a having a dedicated utility contact to work through interconnection requirements. The CHP champion, whether a facility manager, board member, or other influential individual can also help discover and relate CHP best practices, especially by interacting with champions at other buildings with CHP systems.

[4] Results from economic analysis applied to EPA Energy and Emissions Savings Calculator (https://www.epa.gov/chp/chp-energy-and-emissions-savings-calculator) with modeled CHP performance characteristics and 2014 eGRID values by sub region (released 2016) for fossil fuel utility emissions.

Stakeholder interviews found that there is a need for building owners, developers, and managers in both the market rate and affordable housing sectors to understand:

- The nature and benefits of CHP, and the high level of planning and coordination required for a CHP project to achieve these benefits;
- The importance of attention to project economics and the question of who benefits, and how, from potential returns on investment; and
- The enabling role that incentive and financing programs can provide for education, awareness, and help in moving potential projects forward.

Emerging Trends

The report captures a couple of trends that have emerged over the past few years and are significant in both the CHP and multifamily sectors. The first trend is an increasing emphasis by local, state, and federal agencies on resilience planning for extreme weather events, and the important role that CHP plays as an onsite energy solution that can withstand long-duration grid outages. The second trend is a greater interest in hybrid CHP systems,[5] which combine the use of rooftop solar and storage, to achieve a cleaner, resilient energy system, and potentially improved economics, compared to stand-alone CHP systems.

The use of CHP as a solution for withstanding extreme weather events has been documented during recent environmental events.[6] Several states have evaluated CHP's ability to provide shelter-in-place benefits, leading to the inclusion of CHP in policies and plans for achieving resilience in critical facilities. Certain standalone CHP systems that are capable of "islanding" (where a generation system operating on its own, in isolation, can provide power in the absence of a functioning electrical grid) have successfully maintained critical operations during grid outages. Looking forward, CHP systems combined with renewable technologies, in a hybrid or microgrid configuration, can support delivery of additional benefits including baseload grid support and flexibility that enables greater integration of renewable resources. Such capabilities can lead to opportunities to capitalize on CHP's unique value proposition, especially as local and state clean and renewable energy policies continue to expand in size and scope. Hybrid CHP systems offer a promising strategy for balancing the need to meet multi-day resilience requirements at critical facilities with the need to minimize greenhouse gas (GHG) emissions in order to support broader emission reduction policy goals.

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[5] Hybrid CHP in this context signifies the use of CHP in combination with renewables, either at the site or as part of a microgrid or district energy system.

[6] U.S. HUD, U.S. DOE and U.S. EPA. *Guide to Using Combined Heat and Power for Enhancing Reliability and Resiliency in Buildings.* September 2013. https://www.epa.gov/chp/guide-using-combined-heat-and-power-enhancing-reliability-and-resiliency-buildings

1.0 Introduction

Combined heat and power (CHP) is an efficient way to generate both electricity and thermal energy (hot water, steam, and/or chilled water) for buildings with consistent electric and thermal requirements.[7] Historically, CHP has primarily been used by industrial manufacturing facilities, but commercial, institutional, and residential buildings can also benefit from CHP.[8]

Multifamily buildings have characteristics that make them good candidates for installing CHP systems. They have a consistent need for electricity and thermal energy to provide hot water and space conditioning for residents; they operate around the clock for the entire year; they need to have reliable power systems in the event of outages; and they tend to be in urban areas were electricity rates are likely to be high. This fit has been seen more frequently in recent years. From 2015 through 2017, among all building types, multifamily buildings have had the most CHP systems installed, as documented in the Department of Energy's CHP Installation Database.[9] These systems have primarily been installed at multifamily buildings in the Northeastern states and California.

The intent of this report is to make evident to multifamily building[10] owners, developers and policy makers broadly CHP benefits, opportunities and challenges. To that end, this report describes multifamily building characteristics and trends and provides an evaluation of energy consumption by building size and location. This characterization is the basis for a technical and economic screening of CHP market potential in the sector. The report is organized in the following sections:

1. **Introduction**, describing the purpose and organization of the report.
2. **CHP in the Multifamily Housing Sector**, describing multifamily building characteristics and trends and providing information on which features are best for CHP.
3. **Energy Use and CHP Sizing in Multifamily Buildings**, containing energy usage characteristics related to CHP implementation, including electric and thermal energy usage load shapes.
4. **Quantifying the Opportunities for Multifamily CHP**, providing information on the overall CHP market potential in multifamily buildings by size and state.
5. **Opportunities and Challenges for Multifamily CHP**, containing an overall evaluation of the competitiveness of CHP in the multifamily building industry.

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[7] For more information on CHP, see the EPA Combined Heat and Power Partnership website, www.epa.gov/chp

[8] U.S. Department of Energy, Advanced Manufacturing Office. *Combined Heat and Power (CHP) Technical Potential in the United States*. March 2016. https://www.energy.gov/sites/prod/files/2016/04/f30/CHP%20Technical%20Potential%20Study%203-31-2016%20Final.pdf

[9] U.S. Department of Energy. CHP Installation Database. Maintained by ICF. Data current through Dec. 31, 2017. https://doe.icfwebservices.com/chpdb/

[10] This report defines multifamily buildings as residential buildings with multiple tenants encompassing both market-rate and affordable developments that are large enough (typically more than 50-100 housing units) to support a CHP system. The definition excludes assisted living and mixed-use buildings (commercial and residential uses in a building).

2.0 CHP in the Multifamily Housing Sector

The varied and complex housing stock of the United States – comprising single-family, multi-family, and mobile home residences over diverse climate geographies – accounts for over 20% of the nation's total annual energy consumption.[11] An examination of U.S. Energy Information Administration (EIA) data shows that when compared to the three other energy-consuming sectors (industrial, transportation, and commercial buildings) the residential sector has a far greater proportion of consumption due to electrical losses from inefficient generation, transmission, and distribution than it does from primary consumption, defined as direct consumer use at the source. These losses and inefficiencies from low-voltage distribution interconnections result in a cumulative loss of over 10 quadrillion BTUs in energy annually.[12] CHP, a distributed energy resource that provides useful thermal energy and electricity near the point of consumption, holds an opportunity to address such losses, thus reducing wasted energy and expense for owners while improving the carbon footprint of the United States.

A combination of factors makes multifamily housing a potentially rich target for CHP:

- ***Inherent market opportunity.*** Two of every 10 Americans live in a unit in a multifamily building.[13] Many of these buildings contain centralized energy systems that can incorporate CHP.
- ***Coincident need for electricity and thermal energy.*** Multifamily buildings operate 24 hours a day, seven days a week, with a consistent need for both electricity, water heating, and space heating/cooling.
- ***Benefits of resilient CHP.*** CHP can allow multifamily buildings to continue operation during utility grid outages, ensuring that critical loads at multifamily buildings stay operational, adding to quality of life for tenants.
- ***Multifamily housing's disproportionately high energy use compared to other forms of existing residential construction.*** Although the dense spatial configuration of multifamily as compared with single-family housing would suggest its greater energy efficiency, the national data contradicts such an assumption. Multifamily buildings make up 18% of the total residential building stock but use 28% of the energy.[14]

The multifamily housing sector is a strong market for CHP, but it is also a complex market with many variables that can impact both a CHP system's applicability and economic viability. A multifamily building needs to be large enough for CHP to be a viable option, and hot water needs to be delivered through a

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[11] See the Energy Information Administration's summary report on "Energy Consumption By Sector," https://www.eia.gov/totalenergy/data/monthly/pdf/sec2.pdf. Accessed December 30, 2017.
[12] Ibid.
[13] O'Malley, Charlotte. "80 Percent of Americans Prefer Single-Family Homeownership". *Builder.* August 2013. http://www.builderonline.com/money/economics/80-percent-of-americans-prefer-single-family-homeownership_o
[14] Brown, Matthew and Mark Wolfe. Energy Programs Consortium. *Energy Efficiency in Multi-Family Housing, A Profile and Analysis.* June 2007. Pp. 1, 7.

centralized distribution system to efficiently utilize CHP's thermal energy through hot water delivery to building tenants. Additionally, there are two different ways that multifamily buildings can be metered for electricity, which can affect the applicable electric loads for CHP.

Multifamily buildings can either be master-metered for electricity - with bills paid by the owner and distributed through rent or condo fees – or tenant units can be individually metered for electricity, referred to as "direct metering" in this report. While CHP can be applied to direct-metered buildings, the ability for CHP electricity to be applied to tenant loads could be limited, leaving only common area loads, and limiting the potential size of the installation.

These factors can potentially limit opportunities for multifamily CHP applications and prevent a "one size fits all" solution. However, CHP has proven to be beneficial for many multifamily buildings, and installations have been increasing in recent years. The growth of CHP in the multifamily sector has resulted in a roster of effective installations, which could improve consumer confidence among the next batch of prospective adopters and bolster the credentials of solution providers. This chapter examines the complexities involved in applying CHP to multifamily buildings, describing the status and recent trends of the multifamily housing market and the factors influencing demand for and/or constraints to CHP implementation within that market.

2.1 Multifamily Building Characteristics

There are several infrastructural and ownership characteristics of multifamily buildings that can affect the suitability and viability of CHP installations, including:

- Building size
- Electricity metering
- Central water heating
- Additional building loads
- Unit ownership
- Building ownership

This section explores these characteristics of multifamily buildings and describes how they can influence the viability of CHP installations. Note that there are other characteristics that affect CHP installations, such as the socioeconomic status of residents and whether it is in a multi-building campus (either in a microgrid or district energy systems). These characteristics have not been explored in detail in this report, and are areas recommended for further analysis.

Building Size

Multifamily buildings can be characterized by the number of housing units they contain and their total square footage. Larger buildings have higher energy loads that can support commercially available and economically viable CHP systems. The U.S. Department of Housing and Urban Development (HUD) developed a toolkit for renewable energy in affordable housing, which included suggestions for CHP. The HUD toolkit recommended multifamily buildings with 100 or more housing units as the minimum size to be used as a screening mechanism for CHP viability.[15] Other data, including the energy load analysis conducted in chapter 3 of this report, suggests that buildings in the 50-100-unit size range are also viable CHP candidates, while buildings with less than 50 housing units are likely too small to support CHP.

Electricity Metering

How a multifamily building's electricity is metered to the utility can have a major impact on the likelihood of CHP installation. If a building is master-metered for electricity, then the building owner pays the electric bills and passes on the power costs to tenants as part of the rent or condo fees. In such buildings, the owner can install CHP behind the master-meter and recoup the investment through electric bill savings or pass on the savings to tenants in the form of competitively lower rents.[16] With master-metered buildings, CHP systems can be sized to full building energy loads.

If a multifamily building has electricity sub-meters installed on a by-unit basis, then each tenant unit is directly metered by the utility and is responsible for its own electric bills. This can limit the ability of CHP electricity to be delivered to each tenant. Multifamily buildings with directly metered individual units can still benefit from CHP, but the size will likely be limited to electric loads for common areas such as entryways, lobbies, hallways, and parking lots.

Central Water Heating

Large multifamily buildings have a high and near-constant need for domestic hot water accentuated by morning and evening spikes, and most are equipped with central water heaters or boilers, and often some domestic hot water storage, to deliver hot water to each tenant. When designing a large multifamily building, there is a substantial cost associated with installing individual water heaters in each unit, in addition to the associated decrease in valuable living space.[17] Therefore, most large multifamily buildings have central water heating, which allows thermal energy from a CHP system to be directly applied to water heating loads. Even when thermal energy from a CHP system is used for space heating or cooling, the system is also typically configured to provide hot water to the building year-round to maximize the operational efficiency.

Some multifamily buildings are not equipped with central water heating, instead using small individual water heaters in each dwelling unit. These buildings tend to be smaller, with owner-occupied units, and they are not configured to distribute hot water throughout the building. Multifamily buildings that do

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[15] U.S. Department of Housing and Urban Development, Community Planning and Development, *Renewable Energy Toolkit for Affordable Housing*, 2018.

[16] This would be especially likely to occur in markets experiencing increased vacancy, as energy cost savings would help enable the rent reductions necessary to keep units filled. In addition, vacant units incur increased financial exposure as owners would need to pay for energy and capital recovery costs.

[17] Hynek, Don; Levy, Megan; Smith, Barbara; Wisconsin Division of Energy Services. "Follow the Money": Overcoming the Split Incentive for Effective Energy Efficiency Program Design in Multi-family Buildings". ACEEE Summer Study on Energy Efficiency in Buildings. 2012. https://aceee.org/files/proceedings/2012/data/papers/0193-000192.pdf.

not have central water heating may find it difficult to efficiently utilize the thermal energy from CHP installations.

The Energy Information Administration's Residential Energy Consumption Survey (RECS) provides representative data that can be applied to all households across the country, including multifamily dwellings. An analysis of the latest 2015 RECS data showed that 56 percent of multifamily dwellings (with 5 or more units) in the U.S. receive hot water from a central water heater or boiler that serves multiple tenants.[18] However, larger buildings that are master-metered for electricity are more likely to use central water heating. When evaluating only buildings that are master-metered for electricity, over 81% of these multifamily dwellings were found to have central water heating.[19]

Additional Building Loads

Multifamily buildings typically consist of common areas (i.e. entryways, lobbies, hallways, elevators, parking garages, and operations spaces for boilers, HVAC equipment, and water pumps), and dwellings for tenants. Some multifamily buildings have additional spaces with specialized energy requirements, including swimming pools, fitness centers, and gymnasiums. Furthermore, in urban areas, multifamily buildings often share space with ground-level retail stores and restaurants, creating mixed-use buildings with additional energy loads that could potentially be supported by CHP. Many recent CHP installations at multifamily buildings have occurred at facilities with swimming pools and mixed uses, allowing electric and thermal outputs from CHP to be applied more consistently.

Unit Ownership

From the point of view of the occupants of multifamily buildings, there are two basic ownership types. The first is the cooperative or condominium model, where owners own either their units or shares in the building equivalent to the square footage of their units. In newer owner-occupied multifamily developments, energy systems tend to be decentralized, with each unit direct-metered for electricity and having its own contained hot water and HVAC systems. In older developments, energy systems are more likely to be centralized. In individually direct-metered or individual energy system units, unit owners can control their energy systems, and thus have the power to directly affect their energy use behavior and consequent savings.

In the second multifamily ownership type, rental units (apartments, in commercial real estate terms), this power is often absent. Rentals encompass a range of target audiences and income levels, from market-rate to affordable housing. Commonly, in multifamily market-rate rental housing, the landlord prorates whole building energy use by unit square footage and passes on the cost through rent. The owner/developer/landlord has a reduced incentive[20] to invest in efficient energy systems, since they

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[18] U.S. Department of Energy, Energy Information Administration. *2015 Residential Energy Consumption Survey*. https://www.eia.gov/consumption/residential/

[19] Ibid.

[20] In such cases, circumstances and awareness will affect an owner's willingness to invest in energy efficiency. For example, where the market will not support an increase in rents, owners may have an incentive to invest in energy efficiency, since reducing energy costs becomes one of the few ways to increase net operating income.

pass on the cost to occupants. Indeed, the reverse is true, as it is a less expensive first cost to install conventional rather than efficient central systems. Renters in these types of buildings have no incentive to save because they do not pay for energy costs directly. This energy efficiency barrier is known as “the split incentive.” This can also occur in buildings where units are owned by the tenants rather than rented, as electricity may be master-metered and included in condo fees. And in affordable or public rental housing sponsored by the Department of Housing and Urban Development (HUD), there may be an actual disincentive towards energy efficiency; under HUD guidelines, low-income tenants receive utility allowances set by historical energy cost and use – the higher the use, the greater the utility allowance. Thus, implementation of efficiency measures reduces the HUD subsidy as opposed to accruing financial savings to the party that would pay to implement the efficiency measures.

Ultimately, electricity metering and central water heating are the primary indicators of CHP applicability, but different classes of building owners – private versus public – may be more prone to overcome the split incentive and install energy-efficient systems like CHP.

Building Ownership

There is limited literature examining the role of incentives at multifamily buildings broken down by ownership type. A 2012 paper outlines findings related to the problem of split incentives by ownership type in Wisconsin.[21] It concludes that for privately-capitalized, privately-operated buildings and their owners there is little incentive towards energy efficiency since owners “bear no costs for utilities unless the property is especially inefficient.”[22] The same barrier exists for privately-capitalized, publicly-funded multifamily buildings and for publicly-capitalized, privately-operated buildings (which tend to be more recently built low-income and/or senior housing). For these ownership types, the existence of utility and government incentives for CHP may be the deciding factor in energy system retrofits.

The 2012 paper finds that publicly-capitalized, publicly-operated multifamily buildings are potentially fertile ground for energy efficiency projects. Owner-operators, usually public housing authorities with a mission to shelter residents from high housing costs, do not intend to sell their buildings to other owner-managers, and thus prioritize low operating costs and can accept longer returns on investment in energy efficient systems. These factors could be conducive to CHP implementation.

Although publicly-owned multifamily buildings may be more prone to install energy efficient systems like CHP, the economics and benefits of CHP until now have been a more attractive option to private owners of multifamily buildings. In areas of the country with high energy prices and incentives for CHP installations, such as New York City, many privately-owned multifamily buildings have been implementing CHP. Chapter 5 of this report highlights several New York City case studies in owner

[21] Hynek, Don; Levy, Megan; Smith, Barbara; Wisconsin Division of Energy Services. “Follow the Money”: Overcoming the Split Incentive for Effective Energy Efficiency Program Design in Multi-family Buildings”. ACEEE Summer Study on Energy Efficiency in Buildings. 2012. https://aceee.org/files/proceedings/2012/data/papers/0193-000192.pdf

[22] Ibid, pp. 6-142.

decision-making in favor of CHP, in which the New York State Energy Research and Development Authority (NYSERDA) provided CHP incentives and assistance to the multifamily sector. In the Brevoort residential high-rise in Manhattan, in addition to environmental and financial benefits, owner-initiated, NYSERDA-supported CHP installation has resulted in increased resiliency to storms and power outages. During Superstorm Sandy, the Brevoort, with 290 individual units, was able to maintain its energy systems to power central boilers, elevators, and all apartments; as a result, it became a community haven, doubling its normal occupancy during the storm.[23]

2.2 Multifamily Housing Trends

The multifamily housing sector is expected to grow, based on the trend of increasing urbanization. A 2015 report for CB Richard Ellis (CBRE)[24] underlines how shifting demographic trends towards smaller families (2.6-person average U.S. household size), later-in-life marriage, and lifestyle preferences for urban living are driving real estate trends in cities. The CBRE report names the top U.S. cities experiencing a double-digit increase in the pace of population growth in downtown areas (defined as within two miles of city hall) between 2000 and 2010: Chicago, New York, San Francisco, Philadelphia, and Washington, DC. In terms of multifamily housing starts, a January 2017 report by Principia Consulting[25] shows the greatest overall increases in new multifamily housing construction between 2015 and 2016 were in the Mountain region (38.5%) and the East North Central region (22.9%), and the West North Central region (10.4%).

Older multifamily buildings, constructed in the era when energy costs were comparatively inexpensive, are more likely to have central water heating and master-metered electricity, but as a general trend, multifamily buildings are moving away from central energy systems and towards distributed in-unit water heaters and sub-metered or direct-metered electricity. In this way tenants or tenant-owners become responsible for the costs of their own consumption, a reality that encourages efficient behavior. Various utilities and state governments have created incentive programs for older, master-metered buildings to install energy sub-meters. For example, NYSERDA previously offered an Energy Reduction in Master Metered Buildings (ERMM) Program to provide up to 50% of the cost of installing sub-meters in master-metered multifamily buildings with more than five units where tenants do not currently pay for their electric usage.[26]

The 2015 Renewable Energy Consumption Survey (RECS) includes data on whether electricity bills are paid by the tenant (direct-metered) or included as part of rent or condo fees (master-metered). As

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[23] U.S. Department of Energy, Better Buildings Initiative. *Combined Heat and Power for Resiliency*. May 2016. https://betterbuildingssolutioncenter.energy.gov/sites/default/files/Combined_Heat_and_Power_for_Resiliency_Organizational_Strategies_WED.pdf

[24] CBRE Global Investors. *U.S. Urbanization Trends.* January 2015.

[25] Principia. " Residential Construction: Top 10 Areas Experiencing Growth in the United States". January 2016. https://www.principiaconsulting.com/residential-construction-top-10-areas-experiencing-growth-in-the-united-states/

[26] Geberer, Raanan. "Submetering Your Building's Electricity". *The Cooperator, New York.* September 2011. https://cooperator.com/article/submetering-your-buildings-electricity/full

previously indicated, buildings that are master-metered for electricity are more likely to apply central water heating, with a correlation of over 80 percent, and master-metered buildings are also more likely to be older than those that are direct-metered. 2015 RECS data was used to estimate the percent of master-metered and direct-metered housing units for different time periods, with the results shown in Figure 1. Note that the blue bars and gray bars each add up to 100 percent, representing the distribution of current master-metered and direct-metered buildings according to year of construction.

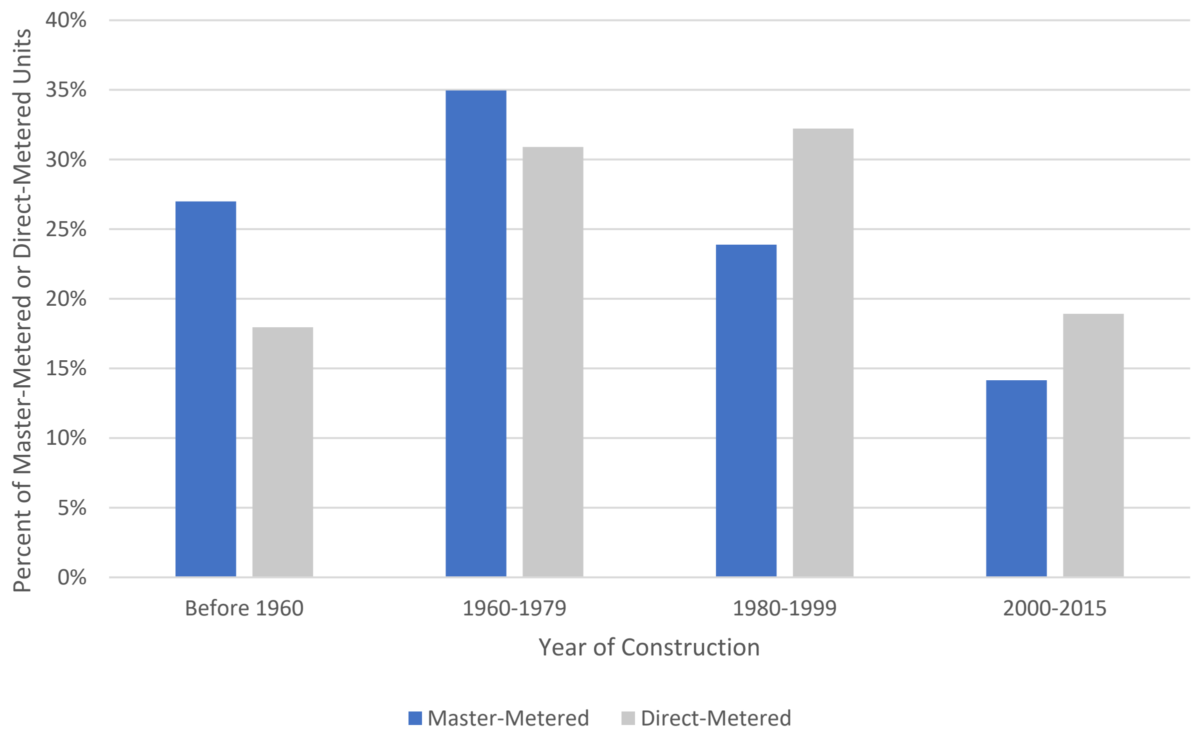

Figure 1. Year of Construction for Multifamily Units Located in Master-Metered and Direct-Metered Buildings (2015 RECS)

The data shows that while there is a clear trend of multifamily buildings shifting towards direct-metered electricity over time, master-metered electricity persists in older multifamily housing and is still being implemented in a significant percentage of newer multifamily buildings. Overall, an estimated 23 percent of multifamily dwellings are in buildings with master-metered electricity.[27] These buildings tend to be larger, and they are more likely to be publicly-owned, with low-income tenants.[28]

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[27] Ibid.

[28] Hynek, Don; Levy, Megan; Smith, Barbara; Wisconsin Division of Energy Services. "Follow the Money": Overcoming the Split Incentive for Effective Energy Efficiency Program Design in Multi-family Buildings". ACEEE Summer Study on Energy Efficiency in Buildings. 2012. https://aceee.org/files/proceedings/2012/data/papers/0193-000192.pdf.

2.3 Market Conditions Favorable For CHP

There are several market conditions that can make multifamily buildings favorable for CHP.

Metropolitan Areas

Large multifamily buildings are concentrated in metropolitan areas. In 2007, ten states accounted for almost 64% of all multifamily housing, and the top five states accounted for nearly half of all multifamily housing.[29] The Energy Programs Consortium reported in 2009 that the Northeast had only 19.8% of the nation's housing stock but 28.1% of the multifamily housing stock. The Midwest and Southeast have the lowest ratios of multifamily to total housing stock.[30] This trend has continued through 2015, and current RECS data shows that the Northeast has only 18% of the nation's overall housing stock but accounts for 26% of the multifamily housing stock.[31]

The U.S. Census Bureau tracks the number of housing units in multifamily buildings, with size categories that indicate the total number of units in the building. The largest size category, 50 or more units, provides a good indicator for potential CHP opportunities. Figure 2 illustrates which states contain the most opportunities for multifamily CHP, generally corresponding to the states with the largest population centers.

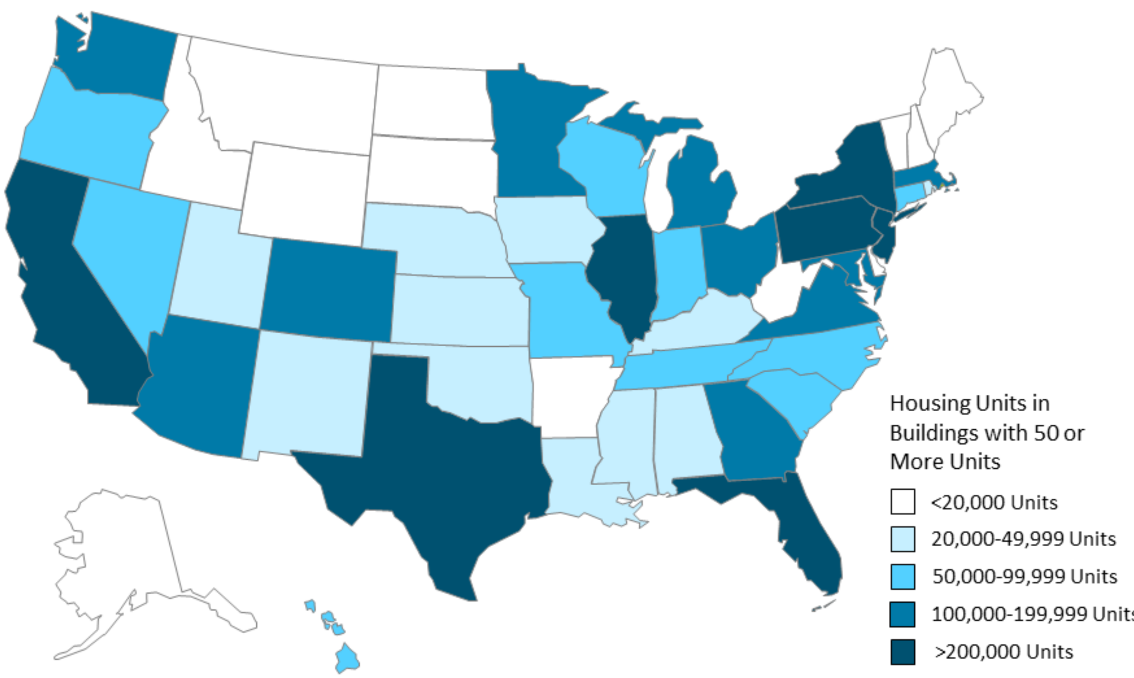

Figure 2. Housing Units in Multifamily Buildings with 50 or more Units, by State

[29] Cadmus Group. Internal white paper developed for U.S. EPA on *Energy Use and Energy Efficiency Opportunities in Multifamily Buildings.* May 5, 2017.
[30] Brown, Matthew and Mark Wolfe, Energy Programs Consortium. *Energy Efficiency in Multi-Family Housing, A Profile and Analysis.* June 2007. p. 2, 19.
[31] U.S. EIA, 2015 RECS Table HC 2.1.

New York and California are among the states that have the most opportunities for multifamily CHP, each with over 1 million housing units located in buildings with 50 or more units. These two states also have some of the country's highest energy costs, with higher costs at urban centers than statewide-average costs. Table 2 summarizes some of the major advantages and disadvantages of installing CHP in metropolitan areas, based on NYSERDA's experience in New York.

Table 2. Influence of Metropolitan Areas on Applicability of CHP

Advantages	Disadvantages
• Geographically-clustered projects facilitate "show and tell" tours for marketing to prospective customers • Project developers can "learn the ropes" with relevant agencies and develop a go-to-market strategy for project replication • A density of projects facilitates cost-effective maintenance (a technician stationed within the cluster will have reduced travel times to project sites)	• Challenge in freeing-up enough footprint space • Higher wages of trade laborers result in increased costs to construct/maintain

High Energy Costs

Where there is a higher energy cost-burden—the proportion of operating budget spent on energy costs – then there may be greater incentive to invest in energy-efficiency and systems such as CHP. A recent Cadmus Group report[32] for U.S. EPA found that while there is correlation between energy costs and energy consumption, other factors such as climate, architectural styles, and building age/configuration also influence the efficiency of the multifamily buildings and how multifamily residents utilize energy.

For potential CHP installations, electricity prices have the largest influence on economic viability. In areas with low to moderate electricity prices, it can be difficult to recover the initial investment in a CHP system. Natural gas prices, the fuel most commonly used with multifamily CHP systems, are also a significant factor. A common metric used to estimate potential for CHP is called the "spark spread" which measures the difference between utility purchased electricity and utility-purchased gas (for CHP generation). The higher the spark spread, the greater the potential for favorable paybacks from CHP installation. Using average 2017 state commercial electricity and natural gas prices from the Energy Information Administration,[33] the map shown in Figure 3 was developed to show how the commercial spark spread differs across each state.

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[32] Cadmus Group. Internal white paper developed for U.S. EPA on *Energy Use and Energy Efficiency Opportunities in Multifamily Buildings.* May 5, 2017.
[33] U.S. Energy Information Administration. "Average state prices for electricity and natural gas". Accessed March 2018.

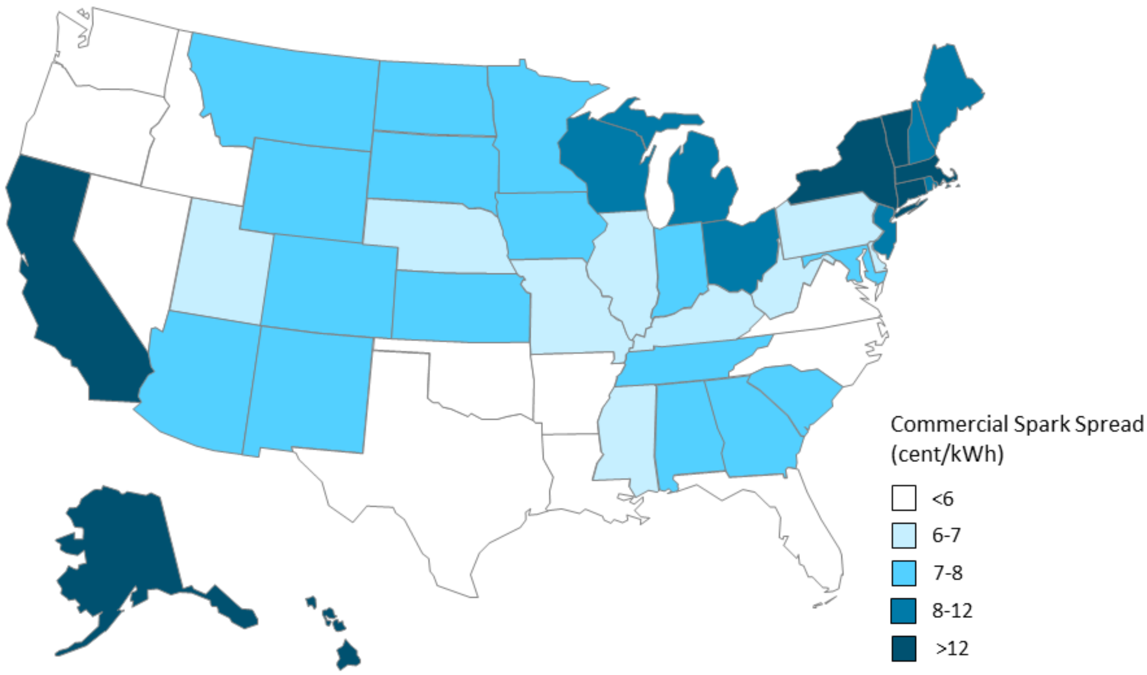

Figure 3. Commercial Spark Spread, using Average State Electricity and Natural Gas Prices

California and the Northeastern U.S. are areas with the highest spark spreads and also where the largest number of CHP installations – including for multifamily buildings – are concentrated.

Older Buildings with Central Energy Distribution

Regions of the country with older multifamily buildings with central water heating, master-metered electricity, and higher energy cost burdens due to inefficiencies are likely to make the best candidates for multifamily CHP installations. Buildings with these characteristics tend to be in dense, aging metropolitan areas, such as those along the Northeastern I-95 corridor, where large multifamily housing projects have been operating for decades.[34] This geography happens to coincide with areas with high energy prices.

Areas Interested in Lowering Greenhouse Gas Emissions

Cities, states, and regions that are looking to lower emissions through policy and financial incentives, to enhance resiliency and encourage energy efficiency, could be primary targets for multifamily CHP installations. One proxy for identifying the cities with such a policy landscape is the presence of ENERGY STAR mandatory energy use benchmarking and disclosure ordinances for multifamily buildings. Energy use disclosure cities are, typically, cities with a commitment to GHG reduction and the provision of policy incentives or disincentives for energy efficiency. Currently, local governments with benchmarking and disclosure ordinances for multifamily buildings include Seattle, Los Angeles, Denver, Kansas City, St.

[34] For example, Co-op City, in the New York City borough of the Bronx, constructed between 1965 and 1973 and with a current population of over 40,000, is the largest cooperative development in the world. See https://ny.curbed.com/2018/12/5/18126231/co-op-city-rental-apartment-prices-history-nyc, December 5, 2018.

Louis, Chicago, Austin, Atlanta, Orlando, Washington, DC, Philadelphia, New York City, Boston, Cambridge, and Portland (ME). Note that, as mentioned earlier, CBRE's top five rapidly urbanizing cities -- Chicago, New York, San Francisco, Philadelphia, and Washington, DC -- are among the local governments with energy use benchmarking and disclosure mandates. Participation in ENERGY STAR's Multifamily High-Rise (new construction) Building program is also a bellwether; its Locator[35] shows greatest concentrations of ENERGY STAR multifamily properties in New York and Philadelphia.

A recent report by Greentech Media illustrates the power of public sector incentives for implementing CHP. The report notes that multifamily residential buildings have been the fastest growing customer type in the CHP market, with a 46 percent increase in just five years, citing the reasons for owner adoption of CHP as "saving money, improving resiliency, and raising comfort." The development of small-footprint CHP technology, with public-sector incentives, has also made a difference: "a small 5- or 10-kilowatt micro CHP has a small enough footprint -- less than 4 feet wide and 2 feet deep -- to fit almost anywhere, and still provide sufficient money savings and grid security for a small multifamily building. The NYSERDA CHP Incentive Program included systems less than 50 kilowatts under its eligibility criteria."[36]

2.4 Multifamily CHP Installations

CHP systems have been generating electricity and heat in multifamily buildings for over six decades in the U.S. However, multifamily CHP applications have changed significantly in recent decades. In the 1960s and 1970s, larger CHP systems were installed as central power plants for multiple multifamily buildings, sometimes serving nearby retail establishments like shopping malls and grocery stores in district energy systems. As an example, the 20 MW Rochdale Village CHP system installed in 1962 still provides electricity, heating, cooling, and domestic hot water (DHW) to the multi-building Rochdale residential development and two shopping malls in Jamaica, Queens, New York.[37]

The Department of Energy's CHP Installation Database provides insights on the characteristics of current multifamily CHP installations throughout the U.S. Through December 2017, there were a total of 395 multifamily buildings with installed CHP systems operating in 15 different states and D.C., with a total capacity of 149 MW.[38] Many of the older mixed-use, multi-building CHP installations have shut down over time. In recent years, most multifamily CHP systems have been installed in single buildings with significantly smaller project sizes, largely due to the increase in economically viable CHP product offerings in the sub-500 kW size range.

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[35] Energy Star. "Multifamily High-Rise Building Locator". https://www.energystar.gov/index.cfm?c=bldrs_lenders_raters.nh_mfhr_certified_multifamily_units#mfhr-building-locator

[36] Shibata, Mei. "The Changing Face of CHP Customers". *Greentech Media.* May 2016. https://www.greentechmedia.com/articles/read/the-changing-face-of-chp-customers#gs.w3QdxPck

[37] U.S. Department of Energy. CHP Installation Database. Maintained by ICF. Data current through Dec. 31, 2017. https://doe.icfwebservices.com/chpdb/

[38] Ibid.

Characterizing Current Multifamily CHP Installations

An analysis of current multifamily CHP installation data shows that the vast majority of CHP sites (380 out of 395) are sized 500 kW or smaller, with large multi-building and mixed-use installations focused in the New York City area.[39] Figure 4 shows a scatter plot of 395 current multifamily CHP systems by project size and year of installation. The figure demonstrates that the majority of projects implemented since 1985 are smaller than 500 kW, and identifies some of the outliers in New York City where large multi-building installations occurred. The trend of decreasing size in multifamily CHP installations is due to a number of factors, including the move to single-building installations and an increase in smaller CHP systems product offerings.

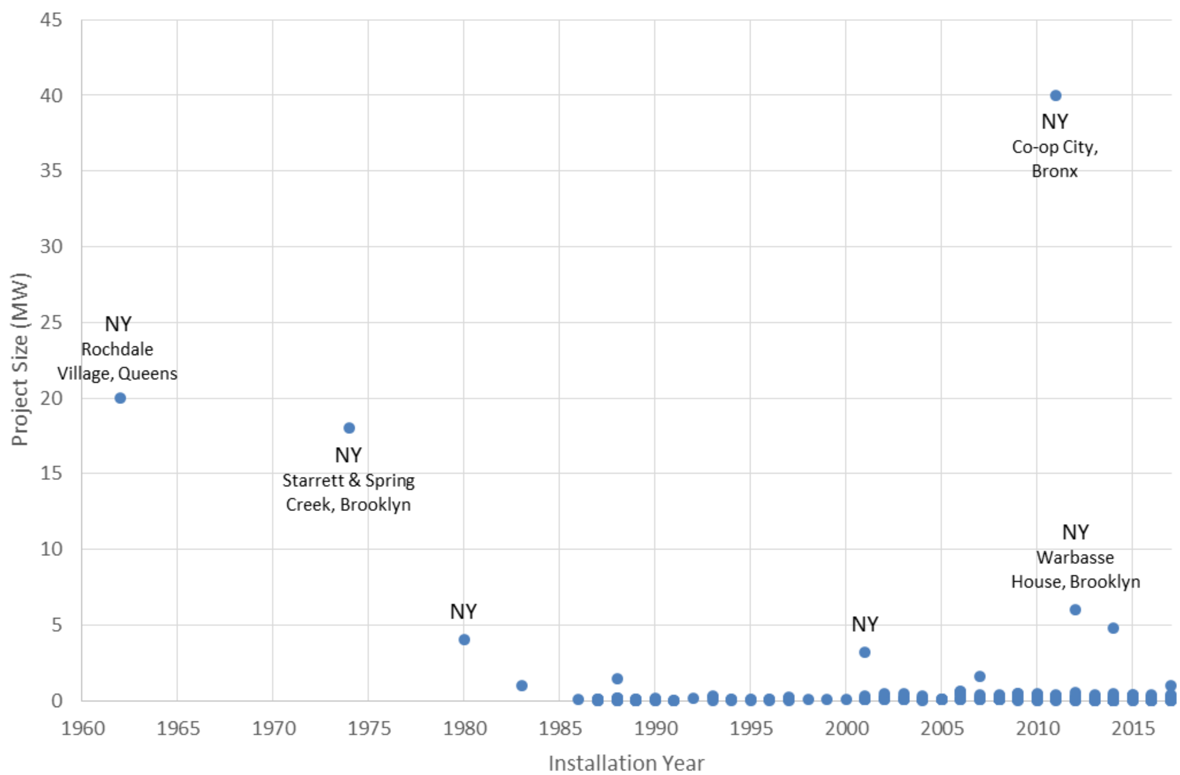

Figure 4. Scatter Plot of 395 Current Multifamily CHP Installations by Year and Project Size

Of the 395 current multifamily CHP sites, 346 use reciprocating engines, while some also incorporate microturbines, fuel cells, and other CHP technologies. Figure 5 (next page) breaks down the sites by prime mover type.[40]

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[39] Ibid.
[40] Ibid.

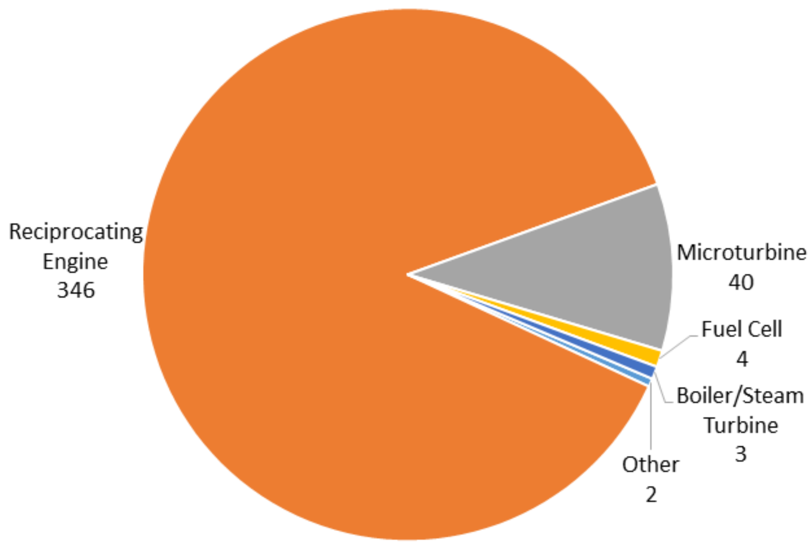

Figure 5. Current Multifamily CHP Installations by Prime Mover Type

Table 3 shows how the multifamily CHP sites are distributed by state.

Table 3. Multifamily CHP Installations: Number of Sites and Capacity by State

State	Sites	Capacity (kW)	Average Size (kW)
California	32	2,533	79
Colorado	1	70	70
Connecticut	27	3,335	124
District of Columbia	2	260	130
Idaho	1	15	15
Illinois	5	30	6
Indiana	1	135	135
Massachusetts	44	4,235	96
Maryland	2	225	113
New Hampshire	1	80	80
New Jersey	47	4,287	91
Nevada	2	140	70
New York	211	127,567	605
Pennsylvania	11	5,145	468
Rhode Island	7	927	132
Texas	1	65	65
All U.S.	395	149,049	377

Most multifamily CHP systems are in the Northeast, most prominently in New York, New Jersey, Massachusetts and Connecticut. However, there are also several systems operating in other regions, including states like California and Illinois.

Most multifamily CHP systems (216 out of 395) are under 100 kW in size. Figure 6 shows how multifamily CHP facilities are distributed by both state and CHP size range.

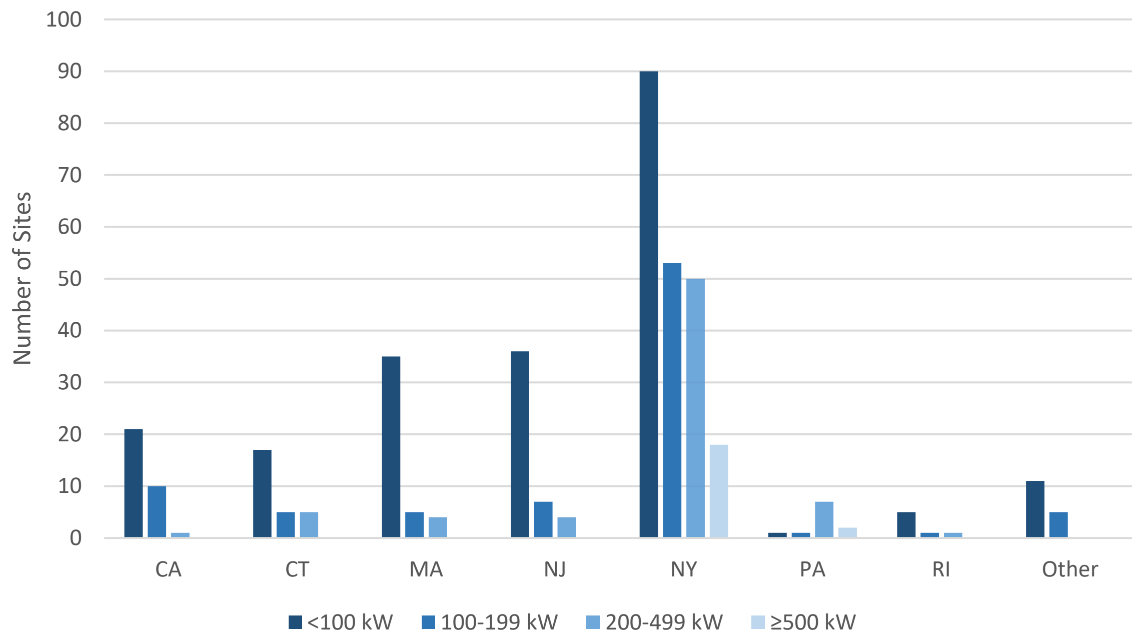

Figure 6. Multifamily CHP Systems by CHP Size Range

Trends in Recent Multifamily CHP Installations

The number of multifamily CHP installations has increased significantly in recent years. The increase reflects a rise in New York City in particular, a reflection of NYSERDA's campaign to raise awareness and incentivize the use of CHP in commercial and institutional buildings, where it made economic sense. The installations took place in buildings of all sizes where predominantly packaged systems have been installed. Figure 7 shows the number of installations and the CHP capacity additions by year, from 2008 through 2017. Each of the years from 2013 to 2017 contained more installations than any previous years. During this time, an average of 39 CHP systems were commissioned each year – more than double the average number of installations from 2008 through 2012.

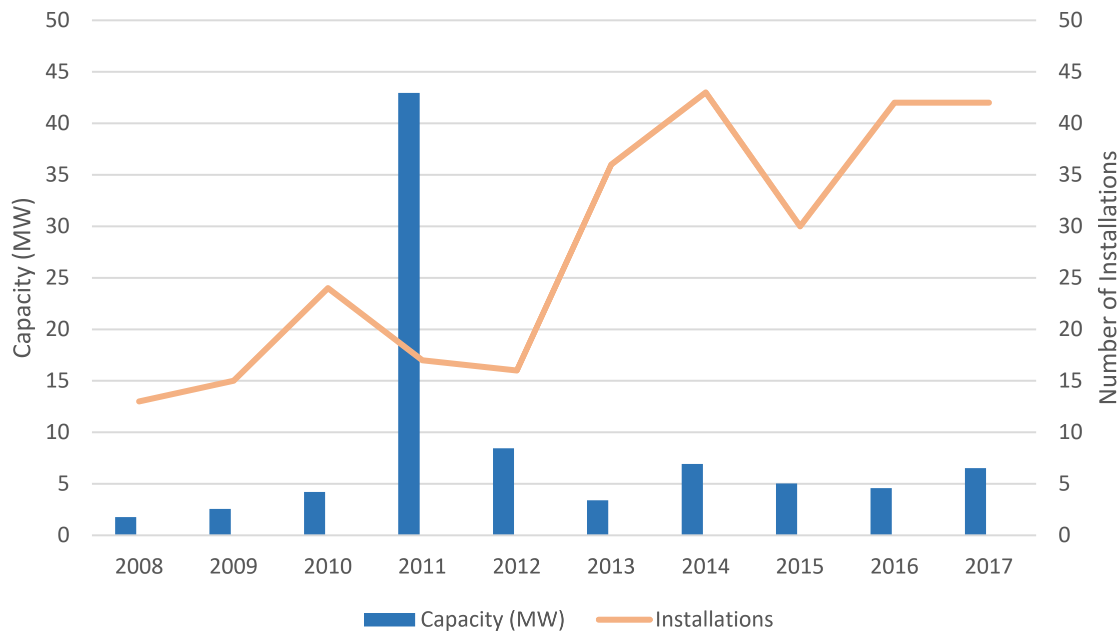

Figure 7. Recent Multifamily CHP: Number of Installations and CHP Capacity by Year

The 2011 spike in capacity came from a large 39 MW combined cycle CHP installation at Co-op City in Bronx, New York, serving multiple buildings with a central CHP plant. Otherwise most installations from 2008 to 2017 have been limited to single buildings, with 98 percent of installations sized 500 kW or smaller. Over 65 percent of sites and 88 percent of new capacity for multifamily CHP installations from 2008 to 2017 were in New York State, largely supported by incentives offered by NYSERDA.

Through its CHP Program (PON 2568), NYSERDA offered incentives for packaged CHP installations from a catalog of pre-certified CHP equipment, in addition to incentives for traditional design/build CHP systems.[41] The solicitation is currently closed, although NYSERDA maintains an online tracking system that monitors the performance of CHP installations that have taken advantage of available incentives through the CHP program.[42] This data can be used to provide details on how recent multifamily CHP systems have been sized, and how they are performing.

The tracked NYSERDA multifamily CHP installations range from 70 to 500 kW in size, covering buildings from 6 to 42 stories tall. On average, 40 percent of the total electricity needs for these buildings is served by CHP. All the CHP installations apply thermal energy to DHW loads, and over half also utilize thermal energy for space heating. Twelve percent of the systems employ an absorption chiller for space

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[41] New York State Energy Research and Development Authority (NYSERDA). Combined Heat and Power Program, CHP Catalog, PON 2568 Attachment A. http://nyserda.ny.gov/PON2568

[42] New York State Energy Research and Development Authority (NYSERDA). Distributed Energy Resources Integrated Data System. https://der.nyserda.ny.gov/

cooling loads. Although there are several different thermal utilization options, due to variable loads, some of the heat from CHP systems cannot be used by the buildings, with about 70 percent of the available thermal being utilized on average. [43]

Modular installations with multiple packaged CHP systems have been a recent trend for commercial buildings. For a majority of NYSERDA-tracked multifamily CHP installations, multiple CHP units are installed in parallel. In a multi-unit system, one or more of the CHP units can shut down during periods of low demand, allowing the other unit(s) to operate more efficiently. From the tracked NYSERDA multifamily CHP installations, 60 percent have more than one CHP unit, with 18 percent consisting of three, four, or five units.

As more multifamily CHP systems are installed, and more operational data is collected, the NYSERDA tracking system will continue to be a valuable resource for insights on the multifamily CHP market, including successful CHP sizing and deployment strategies relative to multifamily building characteristics and energy loads.

[43] Ibid

3.0 CHP Applicability in Multifamily Buildings

Data on multifamily buildings and energy use was analyzed to determine CHP applicability in multifamily buildings and develop the following tools and analysis:

- A decision tree – a visual representation of CHP "go/no-go" considerations – for CHP installation.
- An evaluation of energy loads and CHP sizing strategies for multifamily buildings across different sizes and climates.
    - Electric and thermal load profiles are modeled for several building sizes across different climate zones to determine how energy loads are related to building size and climate. The analysis does not take socio-economic characteristics into consideration.
    - The effect of energy efficiency measures (lighting, windows, and insulation) is included in the modeling to properly size CHP systems to energy-efficient buildings and avoid potential oversizing.
    - Resulting electric and thermal load profiles are evaluated to understand how CHP systems can be applied to effectively serve these loads.
- Recommended rules of thumb for general CHP sizing strategies in multifamily buildings.

The decisions and rules of thumb from the modeling exercise form the basis for the sizing strategy and other assumptions used to estimate the total technical and economic potential for CHP in the next chapter (Chapter 4).

3.1 Decision Tree for CHP Installations at Multifamily Buildings

There are several different strategies for multifamily CHP sizing, and the appropriate strategy depends on site characteristics and economic considerations. As previously discussed, CHP applicability for multifamily buildings can depend on the building size, the type of water heating, and the way that tenant loads are metered for electricity. CHP may not be applicable for buildings that are too small or buildings that lack central water heating. The decision tree in Figure 8 was used to determine when CHP is applicable, and how CHP systems can be sized for different multifamily buildings based on their electric and thermal characteristics.

The decision tree and rules of thumb for CHP sizing are based on a systematic multifamily building load profile analysis that was conducted for modeled buildings across the United States. The following sections summarize the methodology and findings of this analysis, starting with the underlying data and assumptions.

Figure 8. Decision Tree for CHP in Multifamily Buildings

3.2 CHP Multifamily Buildings Modeling

For multifamily buildings that are good candidates for CHP installation, a key step in the implementation process is to consider typical energy loads based on climate zone and building size attributes. The Energy Information Administration's Residential Energy Consumption Survey (RECS) contains data on multifamily dwellings, including building materials and characteristics. This data was used to model typical household and building properties for multifamily buildings in different locations across the country. Representative buildings from the RECS survey were chosen for each of the five different U.S. climate zones defined by the American Institute of Architects (AIA), based on total heating degree days (HDD) and cooling degree days (CDD) throughout the year.[44]

[44] Cooling Degree Days (CDD) are defined as the number of degrees that daily average temperatures are above 65° F, while Heating Degree Days (HDD) indicate the number of degrees that daily average temperatures are below 65°

Multifamily building loads were modeled with the publicly available eQUEST tool, which is based on DOE2 building simulation data.[45] Buildings were modeled based on size attributes, household characteristics and building materials found in representative RECS data points for each of the climate zones. Electric and thermal load profiles were developed for mid-rise (5-floor) and high-rise (10-, 20-, and 30-floor) buildings using these building characteristics. For multifamily building attributes that were not represented in RECS data, default values from the eQUEST tool were used.

Buildings were modeled with both typical values and energy-efficient values for lighting, windows, and insulation efficiency to determine the effect of energy efficiency (EE) measures on building loads. A facility considering CHP may also consider implementing EE measures, and this can potentially affect the appropriate CHP system size. If a facility owner opts to install CHP before implementing other energy efficiency measures, they may be advised to consider potential future energy load reductions from EE when determining the size of the CHP system.

To determine the effect of typical EE measures, buildings were modeled with a lower lighting power density (0.5 W/sq ft), double low-E tinted windows with ½ inch of air separating ¼ inch glass, and wall and roof insulation values recommended by the DOE for the given climate zones.

Overall, the effect of these energy efficiency measures was to reduce total electricity consumption by around ten percent, along with some reductions in space heating requirements. Table 4 shows how the electricity consumption levels change for multifamily buildings located in different climate zones. There are larger total savings in hotter climates because of energy efficiency measures on building cooling loads.

Table 4. Effect of Energy Efficiency Measures on Total Building Electricity Consumption

Climate Zone	Before EE (kWh/sq ft)	After EE (kWh/sq ft)	Percent Change
1 (cold)	7.0	6.4	8.9%
2	7.3	6.7	8.2%
3 (moderate)	7.2	6.6	9.1%
4	7.8	6.9	11.5%
5 (hot)	8.1	7.1	11.9%

F. Zone 1 is less than 2,000 CDD and greater than 7,000 HDD. Zone 2 is less than 2,000 CDD and 5,500-7,000 HDD. Zone 3 is less than 2,000 CDD and 4,000-5,499 HDD. Zone 4 is less than 2,000 CDD and less than 4,000 HDD. Zone 5 is 2,000 CDD or more and less than 4,000 HDD. More information and a map of the climate zones are available at https://www.eia.gov/consumption/residential/maps.php.

[45] U.S. Department of Energy. eQUEST, the Quick Energy Simulation Tool, version 3.65. April 2016, http://www.doe2.com/equest/

For this analysis of multifamily building loads and CHP sizing, all the modeled energy loads were calculated with energy efficiency measures in place. While multifamily building owners that are considering CHP may or may not be implementing energy efficiency measures, load reduction with EE measures is built in to the load profiles used for CHP sizing in this analysis. This conservative sizing strategy will avoid the oversizing of CHP systems for building owners that have either implemented EE already or are considering doing so in the future.

3.3 Energy Loads for Multifamily Buildings

Electricity loads at multifamily buildings can be highly variable from hour to hour, but 24-hour load shapes follow a predictable pattern. Loads tend to be highest during the morning and evening hours, and lowest in the hours after midnight. The same pattern is seen with domestic hot water (DHW) loads, as the demand for both electricity and hot water generally coincide with tenant activity schedules. Except for seasonal space heating and cooling loads, electricity and DHW loads for multifamily buildings tend to stay relatively consistent throughout the year.[46]

To illustrate the seasonal variation in energy loads for multifamily buildings, monthly electricity and heating loads for an energy-efficient 20-floor high-rise apartment building in Baltimore, Maryland (located in Zone 3, a moderate climate) were generated in eQUEST to represent a typical multifamily building with seasonal space heating and cooling loads. The monthly consumption values in Figure 9 show that except for space cooling and space heating loads, energy consumption totals for multifamily buildings remain steady from month to month.

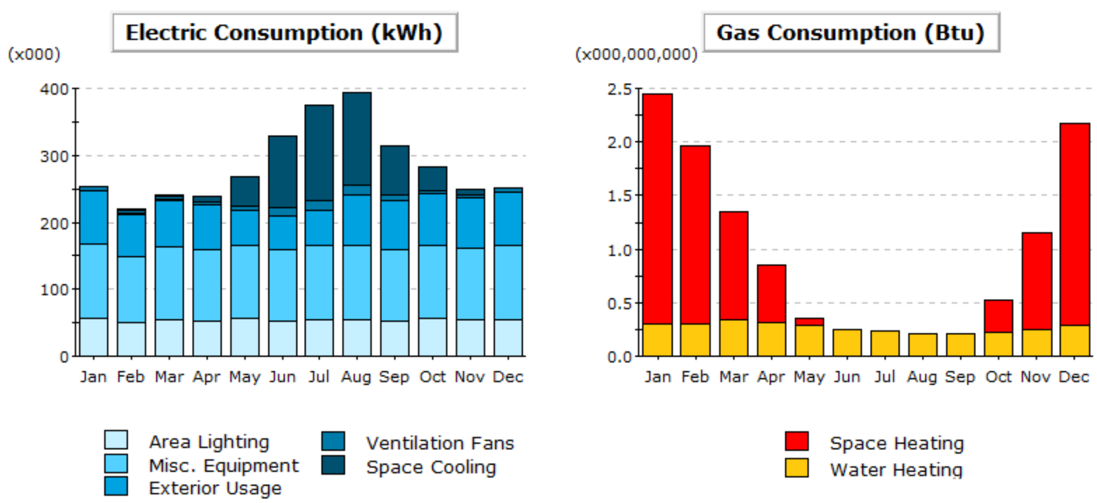

Figure 9. Electricity and Gas Consumption for Example 20-Floor Multifamily Building

[46] If electric heat pumps and/or resistance heating are used for space heating, the associated electric loads can be high during the cold winter months. This analysis assumes that gas-fueled boilers or furnaces are used for space heating.

Comparing electric loads to thermal loads for multifamily buildings shows considerable variation over a 24-hour period. Figure 10 and Figure 11 (next page) show the average hourly electric loads and average hourly heating loads, respectively, during winter for the modeled 20-floor high-rise building in Baltimore. Electric loads are distinguished by common area loads (including external lighting and building operations), tenant loads, and cooling loads, which are not present in winter months. Heating loads are separated by DHW and space heating loads.[47]

Figure 12 (next) and Figure 13 (page 28) show the average hourly electric loads and the average hourly heating loads, respectively, during summer months for the 20-floor Baltimore high-rise. Although space heating is not required during these months, thermal energy from the CHP system can potentially be applied to the building's cooling loads.

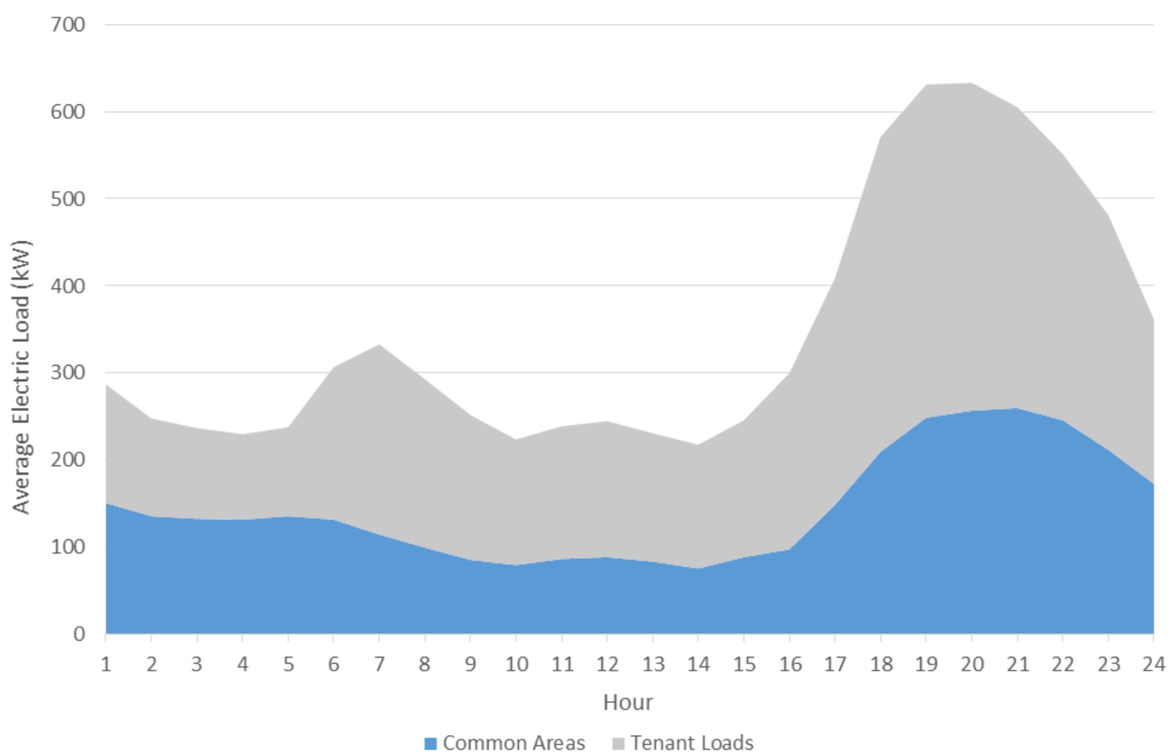

Figure 10. Winter Average Hourly Electric Loads for 20-Floor Multifamily Building in Baltimore, MD

[47] Common area electricity loads were estimated from exterior lighting, pumps/fans, and total indoor lighting loads multiplied by the percentage of common area floor space. The remaining non-cooling building loads were attributed to tenant loads in the eQUEST building models.

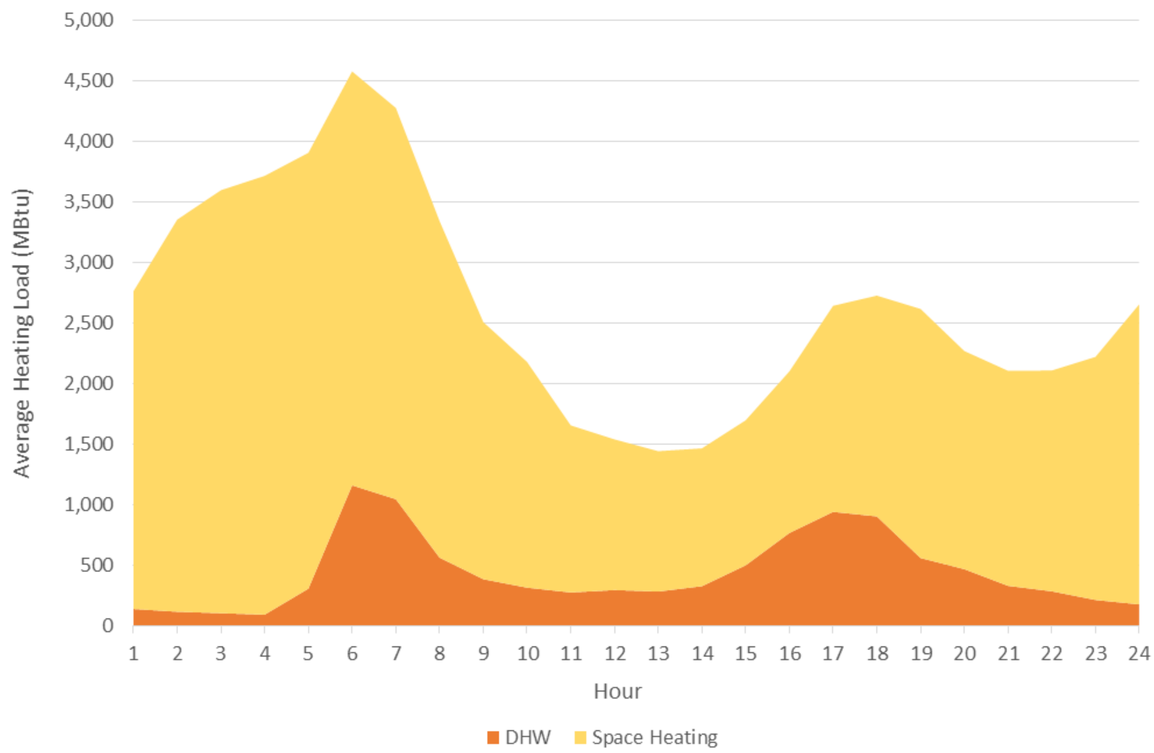

Figure 11. Winter Average Hourly Heating Loads for 20-Floor Multifamily Building in Baltimore, MD

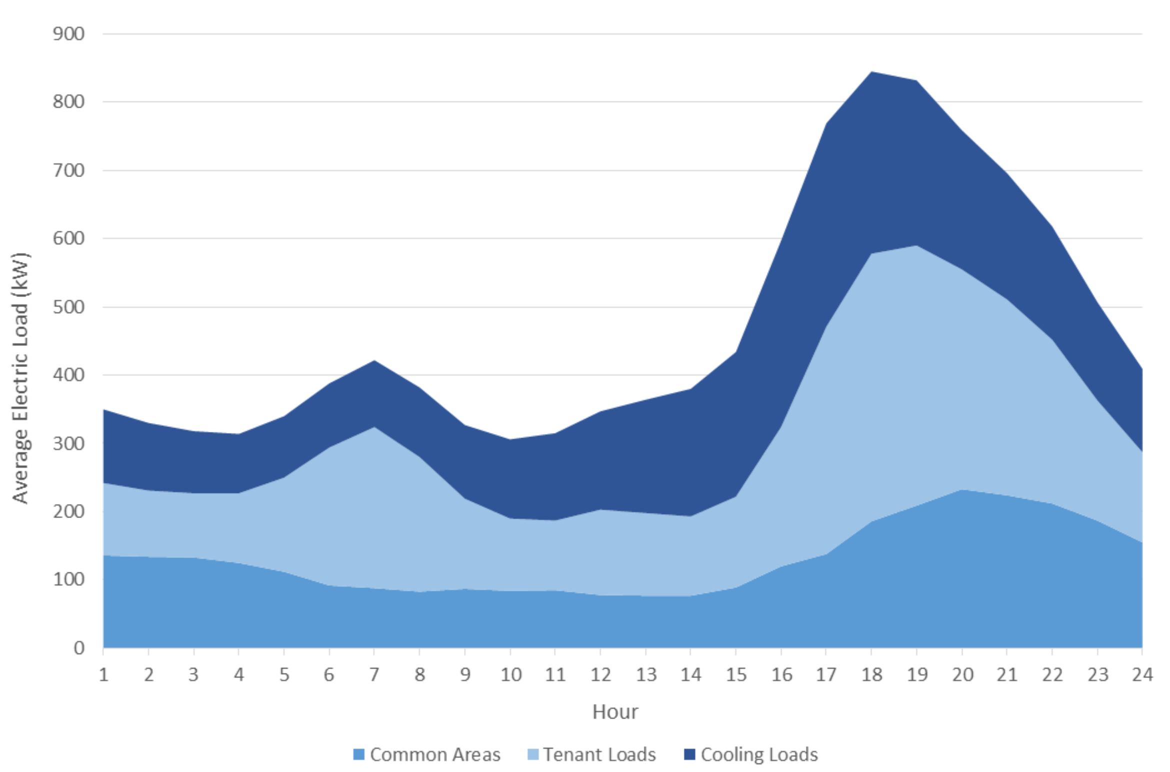

Figure 12. Summer Average Hourly Electric Loads for 20-Floor Multifamily Building in Baltimore, MD

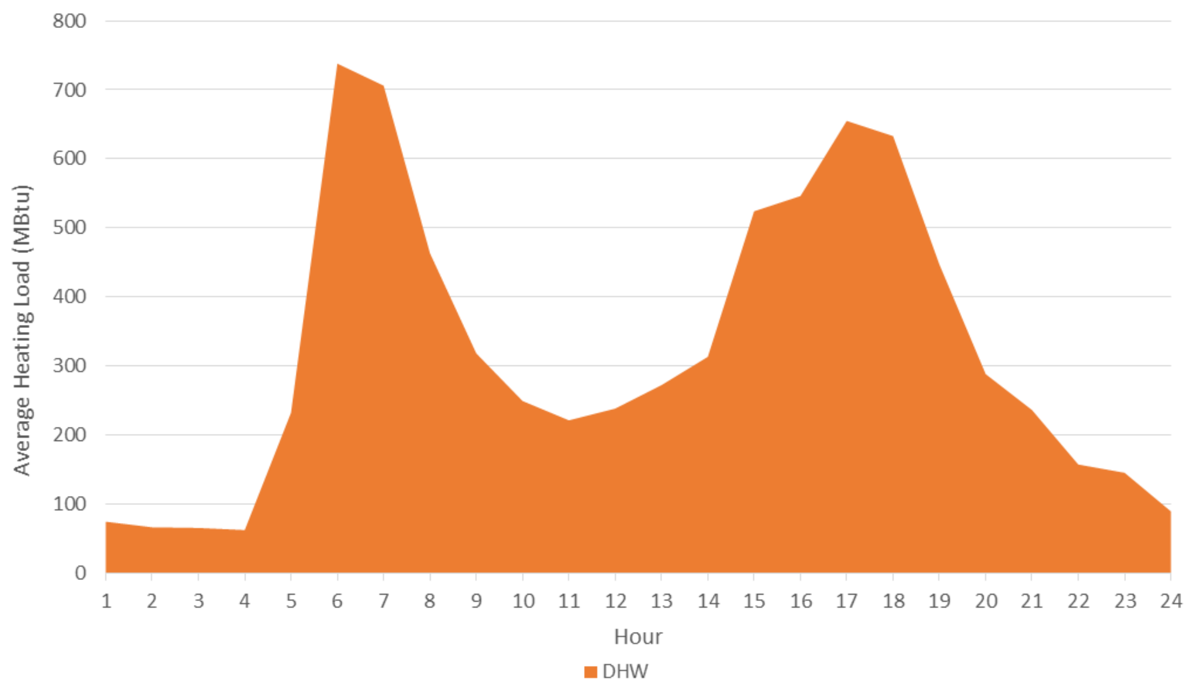

Figure 13. Summer Average Hourly Heating Loads for 20-Floor Multifamily Building in Baltimore, MD

On a typical day, both electric and heating loads see a sizable bump in the morning as tenants take showers, cook breakfast, and get ready for work. There is another bump in late afternoon and evening hours as tenants come back home, prepare dinner, and use their appliances. Heating loads tend to peak in the morning, and electricity loads tend to peak in the evening.

Load profiles were analyzed for each of the five climate zones, and the general load shape patterns remained consistent with those shown in Figures 10-13. Space heating and cooling loads are the primary difference, with buildings in colder climates requiring higher quantities of space heating for longer periods, and those in hotter climates needing higher quantities of air conditioning for more hours of the year. In all cases, space heating was not required during summer months, and cooling was not required during winter months, so the only consistent thermal requirements on an annual basis came from DHW loads. While DHW loads vary significantly throughout a given day, hot water storage tanks can be used to consistently utilize the available thermal energy from CHP. The amount of hot water storage would be relatively minimal, and primarily used to store thermal energy produced from the CHP system during nighttime operation when hot water requirements are minimal (12:00 to 4:00 AM in the charts above). The stored hot water can then be applied to the high morning loads between 6:00 and 8:00 AM.

Typical CHP performance characteristics for electric and thermal output were compared to the load profiles, and some general conclusions were drawn from the analysis:

- ***Sizing to average DHW loads enables efficient utilization of electricity and thermal energy*.**
  - This strategy results in a relatively small CHP system, but can be applied to both master-metered and direct-metered buildings with central water heating.
- Common area electric loads are more consistent than tenant electric loads, and ***sizing to common area loads is a viable strategy***, especially for direct-metered buildings
  - Sizing to the average common area electric load (including exterior lighting and building operations) would result in relatively efficient CHP system operation, with thermal energy utilized for DHW and some space heating loads.
- ***Sizing to full building electric loads increases the CHP size***, which can result in improved performance and lower per-kW costs, but ***variable loads may lead to low operational efficiency***.
  - To avoid oversizing for winter months, avoid cooling loads when sizing the CHP system.

With loads for domestic hot water and non-cooling electricity remaining relatively consistent across climate zones, general rules of thumb for CHP sizing can be developed.

3.4 CHP Sizing Strategies

There are several CHP sizing strategies that can be implemented at multifamily buildings. To maximize operational efficiency, CHP units can be sized to average DHW loads. During periods of low DHW demand, thermal energy from the CHP system can be stored in a hot water storage tank, to be used during higher demand periods. In colder climates, DHW loads are higher in winter months, so sizing to average summer DHW loads will result in full utilization of available thermal energy year-round. The drawback to this strategy is the small size of the CHP system, which can result in a higher installation cost per kW and limit the total potential energy savings. Another common strategy is to size the system to provide baseload electricity for the building while using available thermal energy for DHW and space heating loads. The primary drawback to this configuration is low thermal utilization during periods when space heating is not required.

Another strategy would be to improve thermal efficiency by adding an absorption chiller to the system allowing thermal energy from the CHP system to be utilized for cooling loads. However, absorption chillers are a significant capital expense, and it may be difficult to recover the investment with seasonal operation.

When determining the maximum size for baseload CHP systems compared to building electric loads, seasonal cooling loads may be ignored to avoid oversizing. With the use of an absorption chiller, thermal energy from CHP systems – rather than electricity – can be applied to the seasonal cooling loads. A CHP system sized for baseload electricity will be sized no larger than the building’s average non-cooling electric load.

In this analysis, three different sizing strategies for multifamily buildings were considered:

1. Sizing to fully utilize CHP heat for DHW loads, with thermal energy only used for water heating,
2. Sizing to average non-cooling electric loads, and utilizing thermal energy for space heating and/or cooling (in addition to water heating), and
3. Sizing to average electric loads for common areas only (for direct-metered buildings), utilizing thermal energy for DHW and space heating.

Multifamily building loads vary depending on building size, configuration, and climate.[48] In an effort to understand how these CHP sizing strategies can be applied, energy loads were modeled and analyzed for differently-sized multifamily buildings in each of the five identified climate zones. Building loads were normalized on a square foot basis to directly compare the results of the load analysis and develop rules of thumb for CHP sizing.

Normalized Average Energy Loads for Different Building Sizes and Climate Zones

Using the eQUEST tool, 8,760-hour[49] load profiles were developed for multifamily buildings for different building sizes (5, 10, 20 and 30 floors) in each of the five climate zones to evaluate relationships between building size, climate, and energy loads, and determine if rules of thumb could be developed for multifamily CHP sizing. All buildings were modeled with typical energy efficiency measures (lighting, windows, and roof insulation) in place.

When average building loads are normalized by square footage, similar results were obtained for non-cooling total building loads, common area loads, and DHW loads across all building sizes and climate zones, meaning that general rules of thumb can be derived for sizing CHP systems to multifamily buildings regardless of variations in size and climate. The results of the analysis are shown in Table 5.

Average non-cooling loads are relatively consistent across modeled building sizes and climate zones, at close to 0.7 kW per thousand square feet for the whole building, or 0.3 kW per thousand square feet for common areas. The average summer DHW loads[50] tended to fall close to 0.65 MBtu/hr per thousand square feet, which translates to about 0.15 kW per thousand square feet when factoring in typical CHP efficiencies.

[48] Building loads also vary based on socio-economic characteristics, but data was not available to accurately represent these attributes at the national level in the analysis.
[49] There are 8,760 hours in a year.
[50] Average Summer DHW loads were used due to the seasonal variation in hot water loads in colder climates.

Table 5. Normalized Building Loads by Climate Zone and Building Size, with Energy Efficiency Measures

Climate Zone (1=cold, 5=hot)	Building Size (floors)	Full Building (with cooling) average annual load (kW/1000 sq ft)	Full Building Non-Cooling average annual load (kW/1000 sq ft)	Common Area Non-Cooling average annual load (kW/1000 sq ft)	Average Summer DHW Load (MBtu/hr, per 1000 sq ft)
1	**5**	0.80	0.72	0.30	0.70
1	**10**	0.73	0.66	0.28	0.66
1	**20**	0.73	0.65	0.27	0.66
1	**30**	0.72	0.65	0.27	0.66
2	**5**	0.85	0.71	0.29	0.61
2	**10**	0.75	0.65	0.28	0.58
2	**20**	0.75	0.65	0.27	0.58
2	**30**	0.75	0.65	0.27	0.58
3	**5**	0.80	0.69	0.27	0.61
3	**10**	0.75	0.65	0.27	0.66
3	**20**	0.75	0.65	0.27	0.66
3	**30**	0.75	0.65	0.27	0.66
4	**5**	0.77	0.69	0.28	0.67
4	**10**	0.75	0.66	0.28	0.67
4	**20**	0.75	0.66	0.27	0.67
4	**30**	0.75	0.66	0.27	0.67
5	**5**	0.88	0.68	0.27	0.50
5	**10**	0.81	0.66	0.28	0.56
5	**20**	0.81	0.66	0.28	0.56
5	**30**	0.81	0.66	0.28	0.56

Source: ICF Analysis of Modeled Multifamily Building Loads

3.5 Rules of Thumb for Multifamily CHP Sizing

There are several site-specific factors that can impact decisions on CHP size. The primary differences are based on how the building is metered for electricity and how CHP thermal energy will be applied. For example, a building that is master-metered for electricity can apply significantly more CHP electricity to building loads than one with direct-metered electricity. Therefore master-metered buildings can support larger CHP systems, although the utilization of thermal energy from CHP may be limited.

The previous load analysis shows that, while space heating and cooling requirements for multifamily buildings vary depending on location, other electricity and water heating loads remain relatively consistent across the climate zones. These loads are also consistent across different sizes of multifamily buildings with 50 or more housing units when normalized on a square foot basis. In analyzing the technical and economic potential for multifamily CHP, three sizing options are considered, using the average values presented in Table 6.

Table 6. Normalized CHP Sizing for Multifamily Buildings: Rules of Thumb

CHP Sizing Strategy	Advantages	CHP Size (kW/1000 sq ft)
1. Average Summer DHW load	Efficiently utilizes all available electricity and thermal energy	0.15
2. Average non-cooling electric load	Maximizes CHP size and bill savings (master-metered buildings)	0.7
3. Average common area* electric load	Maximizes CHP size and bill savings (direct-metered buildings)	0.3

*Common area loads include entryways, lobbies, hallways, elevators, external lighting, and building operations

These values for multifamily building loads can be applied to a given multifamily building's total square footage to estimate the appropriate CHP size. While building energy consumption requirements will vary depending on size, design and construction factors, the figures in Table 6 can be considered general rules of thumb for CHP sizing.

These rules of thumb were used to develop estimates for CHP applicability in multifamily buildings based on the total number of housing units. For each unit-based size range, an average square footage was derived from data included in the EIA's Residential Energy Consumption Survey, ranging from 10,000 to 800,000 square feet for the total building size. Then, the multipliers in Table 6 (kW/1000 sq ft) were applied to these building sizes to estimate a typical CHP size for each of the three different sizing strategies. The CHP sizes for each case are depicted in Table 7.

From the table, building owners can see how CHP could be sized for their respective buildings, based on the number of units or total square footage, using one of the three sizing strategies. For example, a 200,000 square foot building using sizing strategy 1 (0.15/kW) results in an estimated CHP capacity of 30 kW. Microturbines are available in sizes starting at 30 kW, and reciprocating engines are available for all potential CHP sizes. However, economics tends to be challenging for CHP systems sized smaller than 30 kW. For the analysis of technical and economic potential, only building size ranges that could support CHP systems 30 kW or larger are considered (represented with bold font in the table).

Table 7. Estimated Building Sizes and CHP Capacity by Building Size Range and CHP Sizing Strategy

Building Size Range (units)	Building Average sq ft	Strategy 1: Average Summer DHW Load (CHP capacity, kW)	Strategy 2: Non-Cooling Electric Load (CHP capacity, kW)	Strategy 3: Common Area Electric Load (CHP capacity, kW)
5-19	10,000	2	7	3
20-49	30,000	5	21	9
50-99	60,000	9	**42**	18
100-199	125,000	18	**84**	**36**
200-299	200,000	**30**	**140**	**60**
300-499	300,000	**45**	**210**	**90**
500-799	500,000	**75**	**350**	**150**
>800	800,000	**120**	**560**	**240**

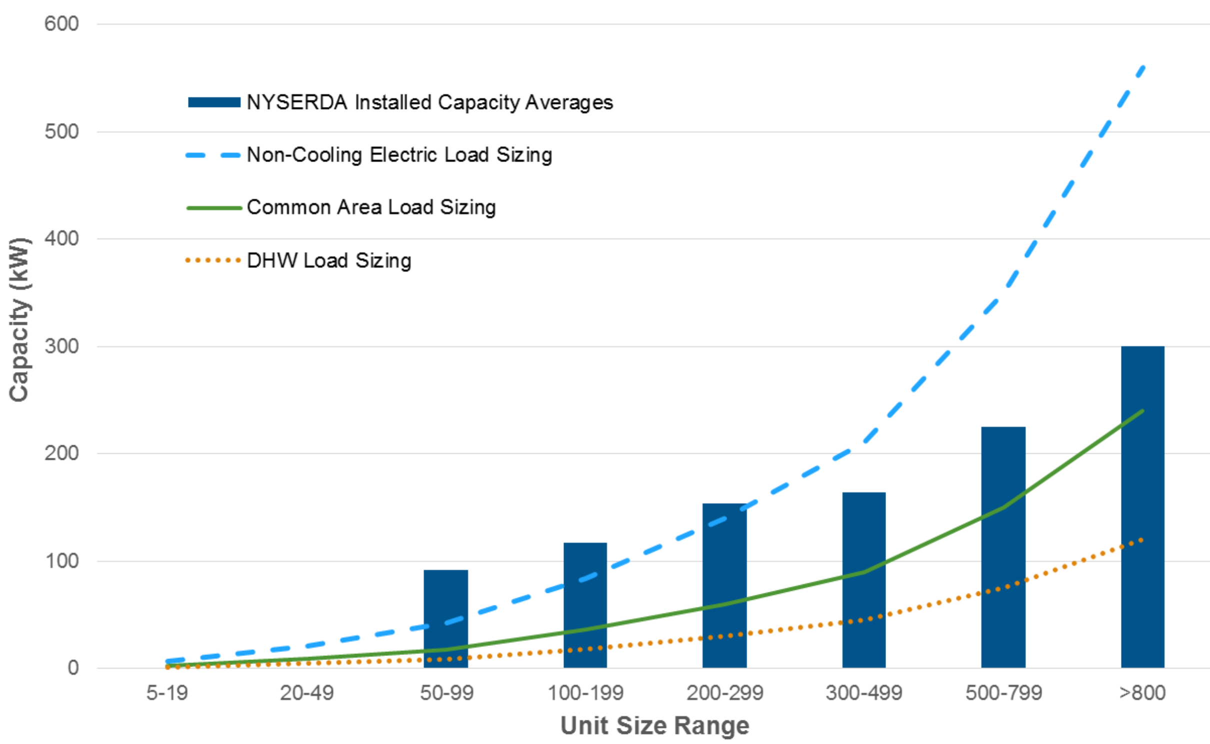

Figure 14. Modeled CHP Size Estimates Compared to Average NYSERDA Multifamily CHP Sizes

In practice, CHP at New York multifamily buildings tends to be sized to provide baseload electricity, hot water, and space heating to building tenants. Despite potential losses in efficiency, economics for larger CHP installations may supersede smaller DHW sizing options, especially in areas with high electricity pricing like New York City. For example, as shown in Figure 14, CHP systems in New York tend to be sized larger than NYSERDA's conservative sizing guidelines for master-metered multifamily buildings in the 100 – 199 unit and 200 – 299 unit size ranges (0.25 – 0.35 per apartment, or 50-70 kW for a 200-unit building).[51]

While larger CHP systems may have favorable economics, operational efficiencies and thermal utilization may not be as high as smaller systems sized to efficiently displace DHW loads. Electric capacity factors and thermal utilization percentages for CHP operation will depend on which sizing strategy is selected, the location of the system, and whether the thermal energy will be used for space heating and/or cooling. These factors are taken into consideration for the economic analysis presented in the next section.

[51] New York State Energy Research and Development Authority (NYSERDA). Combined Heat and Power Program, PON 2568 Summary, CHP Sizing Guidelines. http://nyserda.ny.gov/PON2568

4.0 Quantifying the Opportunities for Multifamily CHP

With the CHP sizing strategies and rules of thumb developed in Section 3, the total technical and economic potential for CHP in multifamily buildings was estimated. Four data sources were used to develop a data set representing the number of buildings that are suitable for new CHP installations.

1. **The U.S. Census Bureau** tracks the number of housing units located in multifamily buildings, by state, for buildings with 5-19 units, 20-49 units, and 50 or more units.
2. **The U.S. Energy Information Administration** (EIA) collects detailed statistics for energy and building characteristics of multifamily housing as part of their *Residential Energy Consumption Survey* (RECS).
3. **The U.S. Department of Housing and Urban Development** (HUD) maintains several housing data sources, including comprehensive property-level data for a sample of close to 30,000 multifamily buildings.
4. **The U.S. Department of Energy's CHP Installation Database** quantifies existing CHP installations at multifamily buildings – these buildings are not considered for new CHP installations.

Data from all these sources was used to yield several multifamily buildings in each state that could potentially support CHP installations. The technical potential, economic potential, and carbon savings potential for CHP in multifamily buildings was evaluated in four steps, described below and outlined in Figure 15.

1. **Maximum Technical Potential**, which assumes that all multifamily buildings not currently utilizing CHP can install a CHP system, with electricity supplied to both common areas and tenants (CHP sized to average non-cooling electric load).
2. **Achievable Technical Potential**, which applies percentages for central water heating and master-metered electricity, where CHP size for direct-metered buildings is limited to average common area electric load.
3. **Economic Potential**, which, using state average energy prices and CHP cost and performance parameters, evaluates economics for CHP systems with different sizing strategies, where buildings with payback periods under 10 years are said to have economic potential for CHP.
4. **Carbon Savings Potential,** which evaluates the potential for carbon dioxide equivalent savings compared to separate heat and utility-purchased power for multifamily buildings with demonstrable economic potential for CHP.

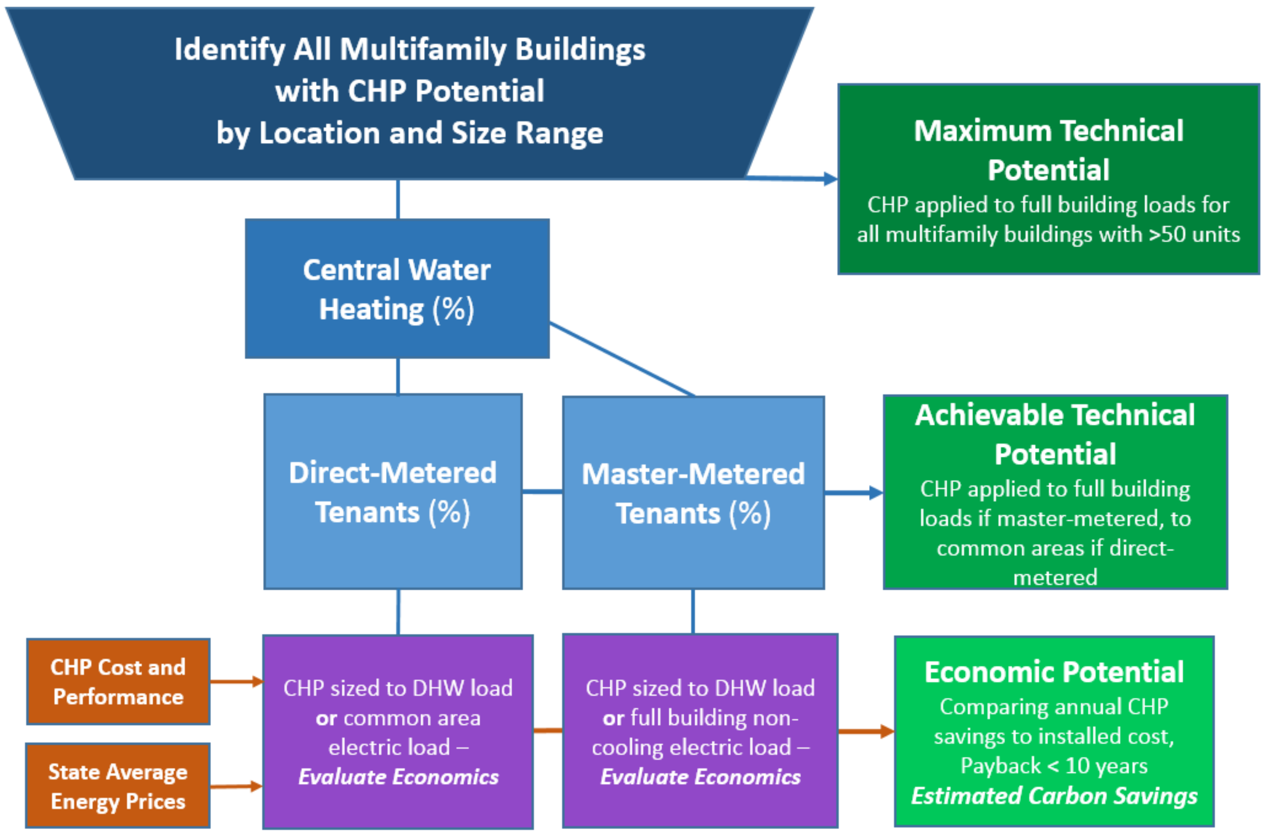

Figure 15. Approach for Estimating the Technical and Economic Potential for Multifamily CHP

4.1 Dataset for Multifamily Buildings by Location and Size

A dataset was compiled to estimate the total number of multifamily buildings by size range (number of units) and location (Census Division and state). Each data source provided critical information for quantifying the total multifamily housing market by location and size range. The dataset was compiled by taking the following steps:

1. Residential Energy Consumption Survey (RECS) data[52] yielded the total number of representative multifamily buildings by Census Division and size range:
    a. 50-99 units (smallest calculated size for CHP in master-metered buildings)
    b. 100-199 units (smallest calculated size for CHP in direct-metered buildings)
    c. 200 or more units (smallest calculated size for CHP when sized to DHW loads)

[52] Energy Information Administration (EIA). *Residential Energy Consumption Survey (RECS)*. 2009.
Note: the 2009 RECS survey included data for the total size of the multifamily building for each representative dwelling, but this information was not included in the 2015 RECS survey data.

2. Housing and Urban Development (HUD) data[53] included more granular information on properties located in large multifamily buildings. This data was assumed to be a representative sample of building sizes for large multifamily properties and was used to approximate the distribution of buildings with 200 or more units by Census Division.[54] HUD percentages by building size ranges (200-299, 300-499, 500-799, and 800 or more units) were applied to the RECS-derived data for the total number of buildings with 200 or more units in each Census Division.
3. The number of housing units represented by the building totals developed in Steps 1 and 2 were estimated for each size range and Census Division.
4. U.S. Census data[55] (number of housing units in buildings with 50 or more units, by state) was used to refine the estimates developed in Steps 1 and 2 by comparing the total number of housing units from the Census data to the total number of units estimated with RECS and HUD data in Step 3. The ratios were used to develop final estimates by state and size range.
5. Existing multifamily CHP stock[56] was deducted from the totals to determine the net potential for new CHP installations in each state. Building size ranges for existing CHP installations were unknown but estimated based on the size of the CHP system.

Table 8. Total Multifamily Buildings without CHP, by Size Range and Census Division[57]

Census Division	50-99 Units	100-199 Units	200-299 Units	300-499 Units	500-799 Units	>800 Units	Total Number of Buildings
East North Central	6,139	856	665	244	59	10	7,973
East South Central	1,213	1,305	84	23	1	0	2,625
Mid-Atlantic	8,946	4,612	799	418	94	40	14,908
Mountain	4,326	494	76	23	0	0	4,920
New England	1,925	912	108	29	1	3	2,979
Pacific	11,601	2,346	495	166	32	4	14,643
South Atlantic	10,439	2,753	820	300	29	6	14,348
West North Central	3,205	653	62	15	2	2	3,939
West South Central	3,414	823	908	177	17	6	5,343
Total U.S.	51,208	14,754	4,016	1,395	235	69	71,678

[53] U.S. Department of Housing and Urban Development (HUD). Active Multifamily Portfolio-Property Level Data. 2016. http://portal.hud.gov/hudportal/HUD?src=/program_offices/housing/mfh/presrv/mfhpreservation
[54] RECS survey data can be extrapolated to estimate the total number of multifamily housing units and buildings by size range, but the sample sizes for large (≥200 unit) buildings is limited. HUD data provided the best indicator of how large multifamily buildings with 200 or more units are distributed by size and Census Division.
[55] United States Department of Commerce, Census Bureau. Advanced Search through American Fact Finder. https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml
[56] US Department of Energy. CHP Installation Database. Maintained by ICF. Data current through Dec. 31, 2017. https://doe.icfwebservices.com/chpdb/
[57] Columns show the number of buildings in each size range, based on the number of units in the building (i.e. 50-99, 100-199, 200-299, 300-499, 500-799, and 800 or more units).

These steps resulted in state-level estimates for CHP opportunities at multifamily buildings by size range, as summarized in Table 8, by Census Division and building size range. Figure 16 shows the breakdown of Census Divisions. Based on the analysis, there are approximately 72,000 buildings with 50 or more units that could potentially support commercially available CHP options. While there are potential buildings for multifamily CHP installations across the country, the Mid-Atlantic, Pacific, and South Atlantic Census Divisions have the highest number of CHP candidates.

Figure 16. Map of Census Divisions

4.2 Technical Potential for Multifamily CHP Installations

The technical potential for multifamily CHP is an estimation of the total market size that can support CHP to serve electric and thermal loads at multifamily buildings, constrained only by technological limits.[58] The first step in estimating the technical potential is to determine the appropriate CHP sizes for each multifamily building size category. This was calculated by applying the estimated CHP sizes from Table 7 in the previous section to the appropriate number of buildings from Table 8 above. Two types of technical potential were estimated:

1. The **Maximum Technical Potential**, which assumes that all electric and thermal loads at multifamily buildings could be served by CHP
2. The **Achievable Technical Potential**, which narrows down the Maximum Technical Potential based on the estimated number of buildings with central water heating and direct-metered electricity. Buildings without central water heating are removed, while a size constraint is applied to buildings with direct-metered electricity.

[58] A 2016 U.S. Department of Energy CHP technical potential report (U.S. DOE, U.S. Technical Potential in the U.S., 2016) identified the same maximum technical potential in the multifamily sector. This study considers more sector-specific factors to provide an achievable technical potential and the economic potential for CHP at multifamily buildings in each state.

Maximum Technical Potential for Multifamily CHP

The maximum technical potential for multifamily CHP was calculated by assuming that all multifamily buildings have the potential to size a CHP system to the full building, including tenant loads. The sizing strategy employed was to size the CHP unit to the average non-cooling electric load, using available thermal energy for domestic hot water, space heating, and/or space cooling (with an absorption chiller). Some multifamily buildings do not have central water heating, and many are not master-metered for electricity, and these factors can affect CHP applicability and sizing. Central water heating and electricity metering are taken into consideration when narrowing the *maximum technical potential* down to the estimated *achievable technical potential*.

For the technical and economic potential estimates in this report, only CHP systems 30 kW or larger are feasible, as this represents the current commercially available product offerings for the U.S. market. This translates to buildings with a minimum of about 50 units when sizing to full building loads. The maximum technical potential for multifamily buildings for all Census Divisions and size ranges is shown in Table 9.

Table 9. Maximum Technical Potential (MW) for Multifamily CHP (All Buildings, Maximum Size)

Census Division	50-99 Units	100-199 Units	200-299 Units	300-499 Units	500-799 Units	>800 Units	Total Capacity (MW)
East North Central	258	72	93	51	21	5	500
East South Central	51	110	12	5	0	0	178
Mid-Atlantic	376	387	112	88	33	22	1,018
Mountain	182	42	11	5	0	0	239
New England	81	77	15	6	0	2	181
Pacific	487	197	69	35	11	2	802
South Atlantic	438	231	115	63	10	3	861
West North Central	135	55	9	3	1	1	203
West South Central	143	69	127	37	6	3	386
Total U.S.	2,151	1,239	562	293	82	39	4,367

Overall, the maximum technical potential for multifamily CHP is estimated to be 4.4 GW. This is directly comparable to the 4.3 GW of technical potential for multifamily buildings estimated in the 2016 DOE report.[59] However, much of the potential for multifamily buildings could be difficult to realize depending on the design of the building regarding water heating and electricity metering. The ***achievable technical potential***, defined as the amount of potential that can be reasonably achieved with current multifamily building design limitations, is estimated in the next sub-section.

[59] Ibid.

Achievable Technical Potential for Multifamily CHP

To efficiently utilize CHP, multifamily buildings would typically have a central boiler or water heater that supplies hot water to all the building's tenants. The potential for CHP in a multifamily building is also limited by the way electricity is metered to the tenants. If tenants are direct-metered directly to the utility (i.e. they pay their own electric utility bills) then applying CHP electricity to individual housing units can be a major challenge. In such building configurations, the CHP system size would be limited to average common area loads. The achievable technical potential for multifamily buildings takes these design elements into consideration. Each of these elements is further discussed below, before they are used to derive the achievable technical potential.

Achievable Technical Potential Assumptions

Central Water Heating

Residential water heating plays an important role in determining the feasibility of a multifamily CHP project. If small water heaters are located within individual housing units, then heat from a CHP system cannot be recovered and delivered to the tenants as domestic hot water (DHW). Although thermal output from CHP units can be applied to space heating and cooling loads, domestic water heating loads are more consistent throughout the year, providing a base load of thermal energy for efficient CHP utilization.

Large multifamily buildings are more likely to have central water heating than small buildings with relatively few units. RECS data confirmed this correlation based on the number of households that obtain domestic hot water from boilers or heaters that serve multiple units. While about 40-50 percent of buildings with five-to-fifty units have central water heating, 80-90 percent of buildings with over 100 units receive domestic hot water from central boilers.[60] RECS data also showed that buildings with master-metered electricity are more likely to use central water heating.

Electricity Metering

Only a certain percentage of multifamily buildings are master-metered for utility electricity. With master-metered buildings, electricity from the CHP system can be delivered to individual tenants. According to RECS data, less than 20 percent of multifamily households pay for electricity through rent or condo fees, indicating that their buildings are master-metered. However, this value is skewed by the large number of small multifamily buildings with less than 50 units. When paired with the associated building size, there is a clear trend towards larger apartment buildings having master-metered electricity.[61] The correlations between building size, master-metered electricity, and central water heating are shown in Figure 17.

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[60] Energy Information Administration (EIA). *Residential Energy Consumption Survey (RECS)*. 2009.
[61] Ibid.

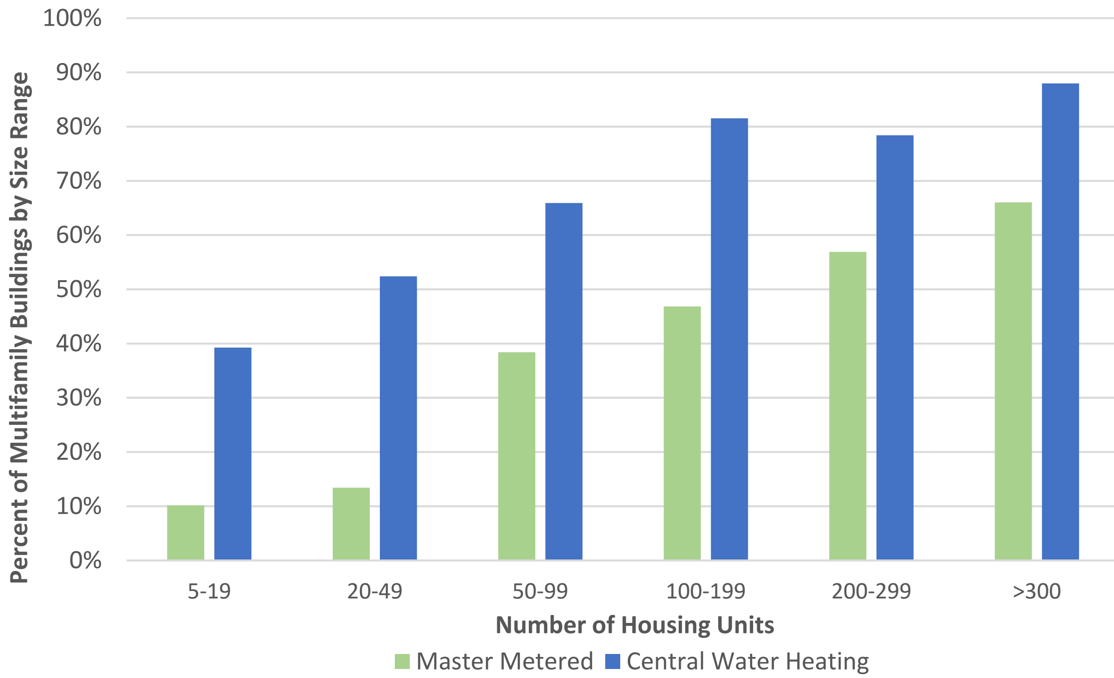

Figure 17. Multifamily Buildings with Master-Metered Electricity and Central Water Heating, by Size Range

Achievable Technical Potential Results

Percentages for central water heating and master-metered electricity were applied to the total building counts, and CHP systems were sized based on whether the building is master-metered or a direct-metered for electricity. In master-metered buildings, the CHP systems were sized to the average non-cooling building load. For direct-metered buildings, the CHP systems were sized to the average common area electric load, resulting in smaller CHP systems and increasing the minimum building size to 100 housing units. Given the sizing limitations for buildings that are direct-metered, the total number of buildings evaluated for achievable technical potential was reduced from 71,678 to 32,192.

While some buildings, both master-metered and direct-metered, may opt for smaller CHP installations, and sizing systems to cover DHW loads, this analysis evaluates the technical potential for larger systems that can use additional thermal energy for space heating and/or cooling.

The achievable technical potential for master-metered buildings, with CHP sized to average non-cooling electric loads with typical energy efficiency measures, is broken down by Census Division and size range in Table 10.

Table 10. Achievable Technical Potential (MW) for Master-Metered Multifamily Buildings with Central Water Heating

Census Division	50-99 Units	100-199 Units	200-299 Units	300-499 Units	500-799 Units	>800 Units	Total Capacity (MW)
East North Central	77	31	50	32	14	4	208
East South Central	15	47	6	3	0	0	72
Mid-Atlantic	113	165	60	54	22	17	431
Mountain	55	18	6	3	0	0	81
New England	24	33	8	4	0	1	70
Pacific	146	84	37	22	8	2	298
South Atlantic	132	98	62	39	7	2	340
West North Central	40	23	5	2	0	1	71
West South Central	43	29	69	23	4	2	170
Total U.S.	645	527	303	181	57	29	1,742

The achievable technical potential for new CHP installations at master-metered multifamily buildings is estimated at 1.7 GW. With this sizing strategy, an absorption chiller may be required to efficiently utilize the CHP system's thermal energy year-round, especially in warmer climates. However, absorption chiller installations may not be economical, and the energy load analysis showed that most of the available thermal energy from CHP can be utilized for DHW and space heating loads in this configuration.

For multifamily buildings whose tenants are direct-metered directly to the utility, the CHP size would likely be limited to the electric loads for common areas (including exterior lighting and building operations). Only buildings with 100 or more housing units are considered large enough to support commercial CHP installations when tenants are direct-metered for electricity. The estimated achievable technical potential for direct-metered buildings, shown in Table 11, can be added to the 1,742 MW of achievable technical potential from master-metered buildings to get the total achievable technical potential.

Overall, the achievable technical potential for CHP at multifamily buildings is estimated at 2.1 GW from over 32,000 buildings. This is almost half of the 4.4 GW of maximum technical potential if all multifamily buildings with 50 or more units could support CHP systems sized to the full building load. U.S. Census data[62] (number of housing units in buildings with 50 or more units, by state) was used to distribute the Census Division estimates into state-level estimates for achievable technical potential, with the results shown in Figure 18. The top five states – New York, California, Florida, Texas, and Illinois – account for

[62] United States Department of Commerce, Census Bureau. Advanced Search through American Fact Finder. https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml. Accessed December 2017.

1.1 GW of potential, more than half of the U.S. total. This shows that multifamily CHP potential follows more populous states with large urban areas.

Table 11. Achievable Technical Potential (MW) for Direct-Metered Multifamily Buildings with Central Water Heating (Electric Sizing for Common Areas Only)

Census Division	100-199 Units	200-299 Units	300-499 Units	500-799 Units	>800 Units	Total Capacity (MW)
East North Central	12	13	7	2	1	34
East South Central	18	2	1	0	0	20
Mid-Atlantic	62	15	11	4	2	95
Mountain	7	1	1	0	0	9
New England	12	2	1	0	0	15
Pacific	32	9	4	1	0	47
South Atlantic	37	16	8	1	0	62
West North Central	9	1	0	0	0	11
West South Central	11	17	5	1	0	34
Total U.S.	199	77	37	10	4	327

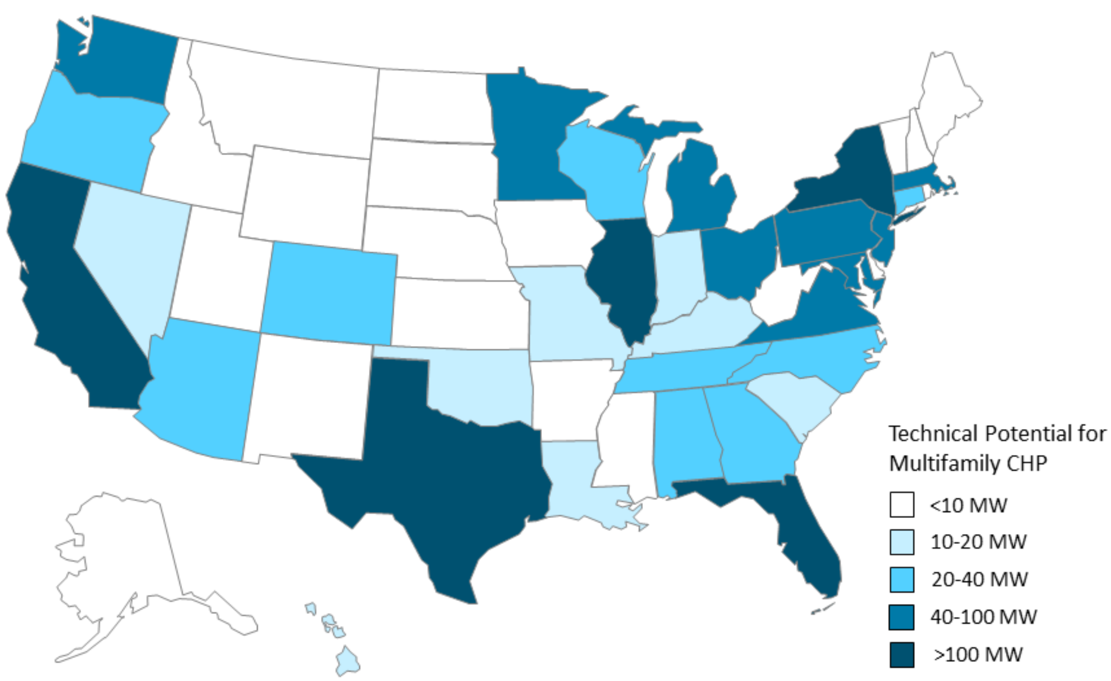

Figure 18. Achievable Technical Potential for Multifamily CHP by State

The achievable technical potential for multifamily CHP is highly concentrated in the Mid-Atlantic, South Atlantic, and Pacific regions of the U.S. It is also primarily concentrated in smaller buildings, and within unit size ranges of 50 – 199 units (see Figure 19).

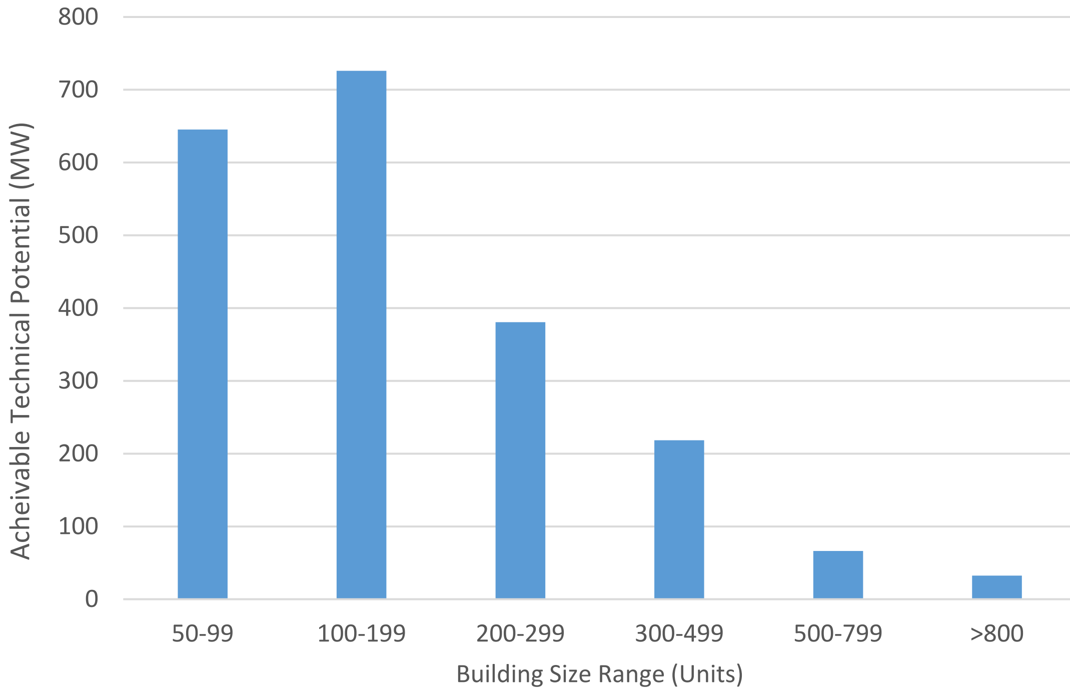

Figure 19. Achievable Technical Potential for Multifamily CHP by Sizing Strategy and Building Size Range

Sites with achievable technical potential were evaluated for economic viability by applying CHP cost and performance and state average energy prices.

4.3 Economic Potential for Multifamily CHP Installations

Economic potential for CHP in multifamily buildings is estimated using two sizing strategies, typical CHP cost and performance characteristics, and state average energy prices. Most CHP installations for multifamily buildings would be retrofits to existing buildings, so the analysis focuses on existing multifamily buildings with *achievable technical potential* (as defined in the previous section). However, there are benefits to incorporating CHP into new building construction and this approach requires close coordination between building developers and CHP developers.[63]

The first sizing strategy is for systems sized to building electric loads, using available thermal energy for both DHW and space heating. For master-metered buildings, systems are sized to the average non-

[63] A recent example is the Hudson Yards development in New York City, where real estate developers coordinated with CHP developers to install a 13.2 MW CHP system as part of district energy microgrid to serve mixed-use buildings, including 2 residential towers. More information is available at: https://www.enr.com/articles/43831-hudson-yards-emerges-on-west-manhattan-skyline

cooling electric load. For direct-metered buildings, systems are sized to the average electric load for common areas only. The second sizing strategy is sizing the CHP system to cover DHW loads, ensuring full thermal utilization and high operational efficiency, but severely limiting the CHP system size. Due to the higher efficiency, economics may be more favorable for the smaller DHW-sized option.

Absorption chillers, which can convert thermal energy into chilled water for space cooling, have been implemented in some multifamily installations, typically in areas with high peak summer electricity pricing. They are best evaluated on a case-by-case basis. For a high-level economic analysis based on state average prices, traditional CHP systems without cooling were found to be more economical than absorption chiller options, due to the additional equipment and installation costs associated with chillers.

While natural gas access can vary across the country, most multifamily buildings are in urbanized areas with widespread access to natural gas. For that reason, natural gas access is often considered a prerequisite for economic CHP installations. The majority of commercially available CHP equipment is designed for natural gas, and over 99 percent of current multifamily CHP installations use natural gas as a fuel. Based on this statistic, the economic analysis assumed all CHP units use natural gas as a fuel, and that all multifamily buildings that can support CHP will have access to natural gas.

Economic Potential Assumptions

To estimate economic potential for multifamily building CHP installations, the achievable technical potential was combined with CHP cost and performance characteristics, and CHP operating and thermal utilization assumptions. Two CHP technology options were the basis for these assumptions: 1) reciprocating engines, and 2) microturbines. These are the two most common CHP technology options for the size ranges appropriate for multifamily buildings.

Microturbines offer quiet operation, lower emissions, and lower maintenance costs compared to reciprocating engines. Reciprocating engines, however, offer a higher electric efficiency and a lower installed cost. The higher efficiency and lower installed cost led to engines being the more economical option for this analysis. Additionally, engines have a higher electric-to-thermal ratio for CHP efficiency, which is a better fit for typical multifamily building loads. Both microturbines and reciprocating engines are offered as packaged CHP systems, which simplify and facilitate installation, and can be an ideal fit for multifamily buildings.

Equipment Cost and Performance

Data collected for the EPA's 2017 *Packaged CHP Systems* addition to the *Catalog of CHP Technologies* was used for equipment cost and performance in the economic analysis.[64] The CHP size breakdowns, associated equipment, and key cost and performance characteristics are shown in Table 12.

[64] U.S. Environmental Protection Agency, Combined Heat and Power Partnership. *Catalog of CHP Technologies*. September 2017. https://www.epa.gov/chp/catalog-chp-technologies

Table 12. CHP Equipment Characteristics Used in Economic Analysis

CHP Size	Associated CHP Equipment	Installed Cost ($/kW)	Electric Efficiency (HHV)	Total CHP Efficiency (HHV)	Maintenance ($/kWh)
<70 kW	35 kW packaged CHP engine	$4,400	29.0%	78.5%	$0.021
70-99 kW	75 kW packaged CHP engine	$3,300	27.0%	82.2%	$0.021
100-279 kW	100 kW packaged CHP engine	$2,900	29.6%	82.5%	$0.024
280-499 kW	285 kW packaged CHP engine	$2,700	34.1%	81.6%	$0.019
≥ 500 kW	550 kW packaged CHP engine	$2,200	34.3%	81.8%	$0.017

CHP Operation and Thermal Utilization

As shown in the load profile analysis presented in Chapter 4, when CHP systems are sized to average non-cooling electric loads, many of the mid-day and nighttime building loads will fall below the size of the CHP system. During these hours, the CHP system will not be utilized to its full capability. In addition, space heating loads are likely to be minimal for several months of the year, resulting in limited thermal utilization.

Multifamily building load profiles were compared with CHP electric and thermal outputs to estimate the equivalent full-load operating hours (based on electric load following) and thermal utilization percentages (based on DHW and space heating loads) for different CHP sizing options. Smaller systems sized for DHW loads can operate efficiently near full-load for most of the year, while larger systems sized for electric loads do not operate as efficiently. Table 13 shows the electric and thermal utilization characteristics applied to different CHP sizing strategies in the economic analysis.

Table 13. Electric and Thermal Utilization Assumptions for CHP Economic Analysis

CHP Sizing Strategy	Equivalent full-load operating hours	Thermal Utilization Percentage
Master-Metered Buildings: Average Non-Cooling Electric Load Sizing	6,000	60%
Direct-Metered Buildings: Average Electric Load Sizing for Common Areas	7,000	80%
All Buildings: Sizing to Average Summer DHW Loads, with hot water storage	8,000	100%

Although full load operating hours and thermal utilization can vary depending on building characteristics, CHP equipment, and climate, these general assumptions were derived from modeled energy loads and CHP performance, and applied to all multifamily buildings for this high-level economic analysis.

Energy Costs

Energy costs were based on 2016 annual state averages from the Energy Information Administration (EIA).[65] For electricity costs, the average commercial rate for electricity was used, with the assumption that 90 percent of the retail rate can be avoided with CHP electricity. This avoided electricity rate percentage is meant to account for fixed charges, time-of-use rates, demand charges and other rate components that may not be avoided with on-site power generation. Using average state commercial electricity prices will provide a conservative estimate for CHP project economics, because electricity prices in high-density urban areas – where multifamily buildings are found – tend to be higher than those in rural areas and therefore tend to be higher than statewide average.

For natural gas, average commercial prices tend to represent typical rates for customers with seasonal gas loads. The state average commercial gas price, as reported by EIA, was used to represent the typical natural gas price for multifamily building customers Installing a CHP system results in a consistently high volume of gas purchases, and gas utilities may offer lower rates, either through tariff rate structures or negotiation with the customer. In this analysis, the cost of gas for a CHP customer is reduced 10 percent compared to the cost of gas prior to the CHP installation.

Economic Potential Results

Simple payback periods were calculated using the assumptions described in the previous sub-section for each of the multifamily buildings identified to have achievable technical potential for CHP (section 4.2). Facilities that could obtain payback periods of less than 10 years were considered to have *economic potential* for CHP. For certain locations and building sizes, the strategy of sizing to electric loads and using available thermal energy for both DHW and space heating produced favorable economics. However, this strategy results in less efficient operation compared to sizing CHP systems to DHW loads. Many multifamily buildings showed stronger economics for a smaller CHP system sized to efficiently cover DHW loads. In this analysis, for a given building, if both sizing strategies resulted in a favorable payback period, the larger sized CHP system was selected to estimate the total economic potential.

The map in Figure 20 shows which states can support multifamily CHP projects with payback periods less than 5 years, 7 years, 10 years, and 15 years. This represents the lowest estimated payback period for multifamily CHP in each state, which may only be achievable for specific building sizes and/or CHP sizing strategies.

[65] U.S. Department of Energy, Energy Information Administration. Data accessed January 2018.

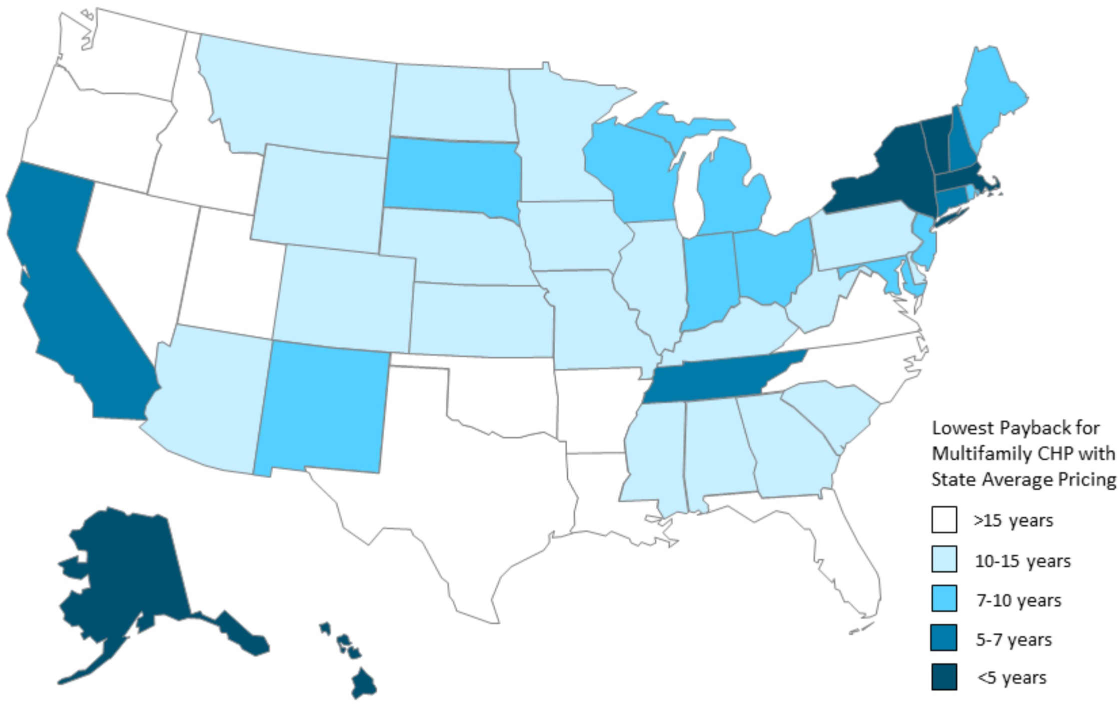

Figure 20. Lowest Estimated Payback Period by State for Multifamily CHP

The total economic potential for multifamily buildings is broken down by electricity metering (master-metered vs. direct-metered) and sizing strategy (electric vs. DHW loads) in Table 14. It is notable that economic potential was found with favorable payback periods for multifamily CHP using both sizing strategies, in both master-metered and direct-metered buildings. Although this report defines economic potential as a simple payback period of less than 10 years, the table also shows the amount of potential for multifamily homes with a 10- to 15-year payback period. Additional incentives or higher local electricity pricing could potentially improve payback periods for these buildings.

Table 14. Economic Potential (kW) for Multifamily CHP, by Sizing Strategy and Payback Period

CHP Sizing Strategy	Potential Capacity (kW), <5 Years	Potential Capacity (kW), 5-7 Years	Potential Capacity (kW), 7-10 Years	Potential Capacity (kW), 10-15 Years
Master-Metered - Electric	12,306	24,809	333,723	248,156
Master-Metered - DHW	112	3	3,407	15,000
Direct-Metered - Electric	6	26,073	116,190	27,041
Direct-Metered - DHW	44	0	843	2,170
Total (All Buildings)	12,469	50,885	454,164	292,366

Opportunities for payback periods under 5 years appear to be limited based on state average pricing. Economics for areas with high electricity prices like New York City may not be captured using state average electricity pricing, although this bias may be reduced by the fact that multifamily buildings in dense urban areas also experience higher construction costs (e.g. wages of trade laborers, liability insurance, etc.) compared to statewide averages. Most of the economic potential (454 MW) is for buildings with estimated payback periods in the 7- to 10-year range. Overall, there is 518 MW of economic potential estimated for multifamily CHP with payback periods under 10 years, from 6,493 total buildings. Additionally, there is 292 MW of multifamily CHP potential with payback periods in the 10- to 15-year range that could become economical with local energy prices or CHP incentives.

While several states have the potential to support multifamily building projects with favorable payback periods, not all states have a high number of large multifamily buildings that can support CHP. Most economic potential for multifamily CHP comes from areas with high electricity prices and large multifamily buildings, most notably New York and California. Table 15 shows how the economic potential (payback period <10 years) breaks down by state and building size.

Table 15. Economic Potential (<10-year payback) by State and Building Size Range

State	50-99	100-199	200-299	300-499	500-799	>800	Total
New York	0	171,960	55,346	47,772	19,119	14,038	308,235
California	0	88,628	39,558	22,890	6,704	1,422	159,203
Massachusetts	0	8,270	6,868	3,197	207	805	19,347
Connecticut	0	11,333	2,488	1,117	85	331	15,354
New Jersey	0	0	0	0	2,016	3,361	5,377
Hawaii	0	0	1,338	774	129	27	2,268
Ohio	0	0	0	0	901	892	1,793
Michigan	0	0	0	0	714	707	1,421
Alaska	547	448	175	97	34	7	1,308
Vermont	0	720	158	71	5	21	975
Wisconsin	0	0	0	0	458	454	912
Rhode Island	0	0	415	193	40	127	775
New Hampshire	0	0	105	46	8	60	219
District of Columbia	0	0	0	0	126	36	162
Indiana	0	0	0	0	0	80	80
Maryland	0	0	0	0	0	66	66
Other States	0	0	0	0	6	15	21
Total	547	281,359	106,451	76,158	30,554	22,449	517,517

4.4 Estimate of Emission Savings Potential

The EPA's *Energy and Emissions Savings Calculator*[66] was used to model the emissions that could be avoided with CHP at multifamily buildings. The latest available data from eGRID (2016 data, using 2014 emissions values) were applied based on the eGRID subregions in which the states are located, as well as

[66] United States Environmental Protection Agency, Combined Heat and Power (CHP) Partnership. *CHP Energy and Emissions Savings Calculator*. 2017. https://www.epa.gov/chp/chp-energy-and-emissions-savings-calculator.

the average transmission and distribution losses. Emissions were calculated for each state that showed economic potential. The results, using CO_2 equivalent values, are summarized in Table 16.

Table 16. Estimated Carbon Dioxide Equivalent Emissions Reductions from Multifamily Buildings with Economic CHP Potential

State	eGRID Subregion	CO_2 equivalent (Tons/year)
New York	NYCW	345,280
Massachusetts	NEWE	17,684
New Jersey	RFCE	14,376
California	CAMX	12,847
Connecticut	NEWE	9,389
Ohio	RFCW	7,718
Michigan	RFCM	7,448
Hawaii	HIMS	7,208
Wisconsin	MROE	4,896
Rhode Island	NEWE	1,220
Alaska	AKGD	893
District of Columbia	RFCE	719
Vermont	NEWE	596
New Hampshire	NEWE	435
Indiana	RFCW	336
Maryland	RFCE	255
Other States	N/A	64
Total U.S.	N/A	431,362

While California was the clear runner-up to New York for the total amount of economic potential for multifamily CHP, it ranks fourth according to estimated emissions impact due to the regional grid having low utility emissions. Massachusetts was second in estimated emissions impact, with the next highest amount of economic potential after New York and California.

New Jersey had the third highest potential emissions reductions despite being ranked fifth in terms of economic potential. This is largely because New Jersey showed a significant amount of economic potential for smaller systems sized to efficiently cover DHW loads with 8,000 hours of full-load operation and 100% thermal utilization. Meanwhile, Connecticut – despite showing significantly more economic potential – ranked lower in terms of emissions savings because most of the potential was for larger, less-efficient CHP systems in master-metered buildings (modeled with 6,000 hours of full-load operation and 60% thermal utilization).

Based on this analysis, multifamily CHP installations have the potential to significantly reduce carbon dioxide-equivalent emissions compared to installations with separate heat and utility power, with over 400 thousand tons per year estimated to be able to be avoided in buildings that have economic potential for CHP.

On-site CHP systems are more efficient than separate heat and utility power due to the elimination of transmission and distribution line losses from utility electricity and the utilization of captured thermal energy. Baseload CHP systems fueled by natural gas tend to displace energy that would be produced by a mix of fossil fuels at central utility plants, and the higher efficiency of CHP can lead to significant reductions in carbon dioxide equivalent emissions.

When CHP systems are sized according to the electric load in multifamily buildings, the thermal energy from CHP may not be fully utilized. In the analysis, 60-80 percent thermal utilization was estimated, depending on whether the systems were sized for full building loads or common areas only for direct-metered buildings. This can reduce the positive emissions impact compared to applications with higher thermal utilization. Additionally, utility fossil fuel grid emission levels can vary considerably depending on region and fuel mix. These factors were considered when estimating the potential carbon dioxide equivalent emissions impact for multifamily buildings with economic potential for CHP.

5.0 Opportunities and Challenges in Multifamily CHP Project Development

To gain an understanding of the opportunities and challenges for CHP installations specific to the multifamily sector, a review of existing relevant literature was conducted and supplemented with insights gained through phone interviews with several industry stakeholders. Relevant literature consists of publicly available research reports, project case studies, and news articles related to the development of CHP in multifamily buildings. Interviewees included owners of multifamily buildings, developers of CHP projects with experience in multifamily buildings, project financiers, technical assistance providers, and policy advocates for CHP in the multifamily sector.

There are opportunities and challenges that apply to CHP installations across the commercial and institutional sectors.[67] CHP has the potential to cost-effectively improve energy efficiency, reduce emissions, and provide resilience to host facilities. However, there are many site-specific factors that can influence the effectiveness of CHP including system sizing, operational efficiency, utility grid emissions, and local energy prices. These factors were considered and evaluated earlier in this report with an analysis of CHP sizing relative to multifamily building energy loads (Chapter 3) and an evaluation of economics and potential emission savings for CHP in multifamily buildings (Chapter 4). In this chapter, the perception of CHP opportunities and challenges in the multifamily sector are explored from several different perspectives.

Existing literature on CHP in multifamily buildings is not extensive, but some information is available. The US Department of Housing and Urban Development (HUD) and US Department of Energy's (DOE) Oak Ridge National Laboratory collaborated to create three CHP guides to identify important considerations and help building owners navigate the process of installing CHP.[68] In addition, HUD included considerations related to CHP in a toolkit to help integrate renewable energy in affordable housing.[69] Most recently, the DOE's CHP for Resiliency Accelerator produced several resources to support consideration of CHP solutions at critical infrastructure, including a CHP for Resilience Site

[67] EPA and DOE. "Combined Heat and Power: A Clean Energy Solution". August 2012. https://www.energy.gov/sites/prod/files/2013/11/f4/chp_clean_energy_solution.pdf.

[68] HUD and DOE. "CHP Guide #1 Q&A for Multifamily Housing". September 2005. https://www.hud.gov/sites/documents/CHPGUIDE1.PDF; "HUD CHP Guide #2: Feasibility Screening for CHP in Multifamily Housing". May 2009. https://www.energy.gov/sites/prod/files/2013/11/f4/chpguide2.pdf; "HUD CHP Guide #3: Introduction to the Level 2 Analysis tool for Multifamily Buildings". September 2010. https://www.energy.gov/sites/prod/files/2013/11/f4/chpguide3.pdf.

[69] HUD Community Planning and Development (CPD). "Renewable Energy Toolkit for Affordable Housing". https://www.hudexchange.info/resources/documents/Renewable-Energy-Toolkit.pdf

Screening Tool.[70] The tool provides an individual site screening assessment for CHP based on a variety of user inputs, including metrics specific to multifamily buildings.[71]

More than 20 detailed case studies of CHP in multifamily buildings were collected and reviewed to gain insight on the project development process and system performance for current CHP installations.[72] The majority of available data comes from installations in New York, primarily New York City, due to the success of NYSERDA's CHP Program and targeted outreach campaign. NYSERDA's CHP Program provided tools to help building owners overcome challenges and measure CHP system performance.[73]

Additional information was gained through phone interviews conducted with industry experts that have knowledge of CHP and the multifamily sector. Stakeholders were identified for interviews based on a review of existing multifamily CHP installations as well as knowledge of CHP policies and incentives in this sector.

In total, seven interviews were conducted in March 2018, each providing a unique point of reference for how multifamily CHP opportunities and challenges are perceived. Results and insights from these interviews and case studies are incorporated into this chapter to highlight the opportunities and challenges for multifamily CHP as viewed from these four different perspectives. Overall, four different stakeholder perspectives were considered:

- Owners of multifamily buildings
- CHP project developers and financiers
- Policy advocates for CHP in multifamily buildings
- The low-income and affordable housing sector

5.1 Owner Perspective

Literature reviewed and interviews conducted for this report suggest a close alignment between the potential benefits of combined heat and power in multifamily buildings and the goals of many multifamily building owners: cost savings, improved environmental outcomes, improved resilience in the face of storms and natural disasters, and the social benefits deriving from these. Yet despite this alignment, multifamily building owners are *not* driving demand for CHP in multifamily buildings.

For owners, the barriers to CHP implementation are diverse and multi-layered, ranging from simple lack of knowledge, to economics and decision-making, to financing barriers. In a present-day snapshot of the

[70] US DOE. CHP for Resiliency Accelerator. https://betterbuildingsinitiative.energy.gov/accelerators/combined-heat-and-power-resiliency
[71] US DOE. *CHP for Resilience Site Screening Tool*. https://resilienceguide.dg.industrialenergytools.com/CHPscreener
[72] NYSERDA. "Case Studies and Feature Articles, Technology, Combined Heat and Power." https://www.nyserda.ny.gov/About/Publications/Case-Studies-and-Features
[73] New York State Energy Research and Development Authority (NYSERDA). Distributed Energy Resources Integrated Data System. https://der.nyserda.ny.gov/

owner perspective on CHP, the challenges appear to outweigh the benefits. But a few NYSERDA case studies[74] suggest that this balance, given the right factors, could tip towards greater owner demand for CHP, especially considering that resilience is a primary emerging benefit for multifamily building owners.

Owner Challenges and Opportunities

For owners, the following factors represent both a challenge and an opportunity:

- Knowledge of CHP and the decision-making process in considering CHP
- The economics and financing of CHP
- Resilience to extreme weather conditions

Knowledge and the Decision-making Process

As discussed in Chapter 2 of this report, there are various types of multifamily building owners. A basic division, for purposes of the present discussion, can be drawn between owner-occupants and owner-managers with renter-occupants.[75] For all owner types, common influences for considering CHP are (1) a favorable spark spread and positive economic return; (2) the need for upgrades to an existing central system; (3) the availability of public-sector financial incentives for CHP; (4) the availability of CHP vendor and contractor expertise, and; (5) owner familiarity with or recognition of the benefits of CHP.

In the realm of owner-occupants, partnering with an engaged and knowledgeable board or management company is one of the top critical factors of success for a CHP multifamily project. Condominium or cooperative boards are comprised of unit owners who may or may not have engineering knowledge or prior experience of technical issues related to building systems and efficiency measures. Owner motivation understandably may begin with the wish for reductions in operating costs and increases in human comfort and environmental stability. But the learning curve towards CHP implementation, according to interviewees for this report, is comparatively steep. Where implemented, as in the example of The Brevoort apartment building in New York City, owner board members included engineers and members who, in filmed testimony, described their awareness of the polluting effects of conventional heating fuels such as fuel oil number 6 even before New York City policy mandated the switch to alternative fuel sources.[76] Another potential challenge can be political complications of governing boards of owner-occupants. Stakeholders may ask themselves, "Do we have a champion on board? Can a small community of people oppose or stop the project from going forward?"

The decision-making process of owner-managers with renter-occupants is less hampered by internal politics. Here, owners can directly engage with CHP contractors without the need for board consensus or a lengthy approval process. Indeed, in the case of all ownership types the availability and involvement

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[74] New York State Energy Research and Development Authority (NYSERDA). "Case Studies and Feature Articles." https://www.nyserda.ny.gov/About/Publications/Case-Studies-and-Features

[75] This report does not analyze how more various and minutely-differentiated ownership "types" affect owner willingness to adopt energy efficiency measures – for example, in the case of owners of large, property-managed portfolios.

[76] Tecogen. "The Brevoort Condo Co-op in NYC (Technical) Powered by Tecogen Cogeneration". April 10, 2013. https://youtu.be/OzJJVL-aMhE

of expert CHP vendors and subcontractors is key to the success of CHP implementation in the case. These experts tend to cluster in political jurisdictions where policy and public sector financial incentives for CHP exist, such as New York State and the Commonwealth of Massachusetts. Yet even with favorable policy conditions, stakeholders interviewed reported that the decision-making and education process takes longer with multifamily clients than with other clients, such as those in the industrial sector, who are steeped in technical knowledge of energy systems and environmental regulation and thus understand the benefits of CHP after the first or second meeting. In the multifamily sector, the decision-making process can take several months or years.

CHP Economics and Financing

From an owner's perspective, the underlying project economics are the strongest predictor of CHP implementation, and a strong financial case is often linked to the presence of high utility rates and the availability of public sector incentives and/or financing. Low prices for natural gas have made CHP attractive to many owners on a purely economic basis. Owners' awareness of the need for increased urban resilience -- the ability to reduce risk and provide a haven during storms – may lead to more widespread implementation of CHP retrofits in multifamily buildings with shared energy systems.

According to one stakeholder with experience in New York State, there are places outside of New York City with many multifamily buildings (Syracuse, Rochester, Buffalo, and Albany) that could be candidates for CHP, but these areas still do not see signs of strong activity, primarily because of economics. While the economic comparison is still positive in upstate New York, the strongest case for CHP in multifamily buildings is in New York City due to higher electricity prices and a larger spark spread, greater awareness of incentive availability, the amount of the incentive ($1,500+/kW), and NYSERDA's reassurance that the vendor has been vetted.

As much as incentives may open the door to CHP for owners, debt or lack of reserve funds may close it. Mortgage consent can be a significant barrier to CHP implementation. According to a project financier interviewed for this report, lenders typically will be required to identify collateral for loans they make. In their words, "most coops or multifamily rentals have a mortgage on the building and financiers typically need to get consent for undertaking the project or using collateral from the mortgage lender . . . for example, building owners may have an agreement with their mortgage lender that, if they're going to take on a project more than $3 million, consent is needed to ensure the building won't be in jeopardy of [defaulting on] mortgage payments." In general, according to the interviewee, most multifamily buildings do not have proper reserve funds set aside and do not have money or resources to finance necessary upgrades.

Finally, consideration of other potential energy efficiency upgrades that can be made in the building is another important factor enabling optimal sizing of CHP systems, so that owners make the right size investment upfront and experience the greatest cost savings after the system is installed.

Resilience to extreme weather conditions

For owners, economic returns of CHP may be a prime driver, with environmental benefits second. In geographies vulnerable to storms or climate change, CHP's social benefits are beginning to emerge. According to one interviewee, resilience is of great interest to people in areas where they feel resilience is needed, especially when they consider that back-up generators can fail after six hours. While most buildings currently rely on diesel generators when the electric grid goes down, many facilities including multifamily buildings have installed CHP to solve some of the challenges with traditional approaches to back-up generation. CHP systems can be equipped to ensure uninterrupted power to critical loads during unexpected outage events, which provides safety and security to tenants.[77]

"I know that if ConEdison fails, that this building will not. I know that I don't have to worry about people who are 80 or older climbing multiple stairs to get to their apartments. I don't have to worry about anybody not having water. So for me personally, the cogen system is really a safeguard and it gives me, as the president of this board, a tremendous piece of mind."

- Diane Nardone, Board President, The Brevoort

Source: Tecogen, Inc. "The Brevoort Condo Co-op in NYC Powered by Tecogen Cogeneration." April 10, 2013. https://www.youtube.com/watch?v=-SIbcNG_cQY. Photo Credit: Real Estate Weekly.

New York City's *The Brevoort* is a case study in the triple bottom line (economic, environmental, and social) benefits of installing CHP. Partly motivated by New York State and City policies away from the use of fuel oil and towards clean energy, the cooperative board of The Brevoort apartment building on Fifth Avenue in lower Manhattan converted their heating system, which had been using 185,000 gallons of no. 6 oil per year, to a CHP system running on natural gas. The cost to implement was $3.2 million;[78] with $300,000 per year realized in cost savings.[79]

When in 2012 Superstorm Sandy knocked out the utility grid in lower Manhattan, the retrofit revealed the protective, social benefits of CHP. The Brevoort's CHP system could supply its residents with heat, water, and electricity (essential also for elevator conveyance, a near-necessity in high-rise buildings) making it one of the few buildings in

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[77] For more information on five multifamily buildings that remained operational with CHP during Hurricane Sandy, see U.S. Department of Energy (DOE), the U.S Department of Housing and Urban Development (HUD), and the U.S. Environmental Protection Agency (EPA), "Guide to Using Combined Heat and Power for Enhancing Reliability and Resiliency in Buildings". September 2013. https://www.epa.gov/sites/production/files/2015-07/documents/guide_to_using_combined_heat_and_power_for_enhancing_reliability_and_resiliency_in_buildings.pdf

[78] Zimmer, Amy. "5 Ways to Green Your Building and Get Money to Do It". *DNA Info.* July 16, 2014. https://www.dnainfo.com/new-york/20140716/midtown/5-ways-green-your-building-get-money-do-it/

[79] Real Estate Weekly. "Greenwich Village co-op The Brevoort embraces clean energy." July 6, 2016. https://rew-online.com/greenwich-village-co-op-the-brevoort-embraces-clean-energy/

continuous operation during this widespread disruption. Normal building occupancy is 720 people; during Sandy, occupancy increased to 1,500 as residents opened their homes to family and friends without power or water. Studies have documented the advantage of CHP, when designed for reliability, over backup generators in cases of grid outage: natural gas lines tend to be stable infrastructure for fuel supply; CHP provides for both thermal (heating and/or cooling) and electricity needs; CHP, as it operates continuously, does not experience lag times in start-up; and CHP has markedly lower emissions than diesel generators.[80]

The potential deployment of hybrid CHP systems using rooftop-mounted photovoltaic (PV) panels and energy storage as the basis of an even cleaner and more resilient energy system than natural gas-powered CHP alone -- is a further, yet-unrealized, and potentially powerful future for energy generation in the multifamily sector. The addition of PV and energy storage technologies may provide an improved value proposition compared to stand-alone CHP systems, considering additional emissions reductions and the potential to participate in utility markets. Similarly, the addition of CHP to solar and storage systems can significantly increase resiliency benefits. More information about the use of distributed generation technologies for resilience and to screen individual multifamily building sites for resilience and CHP can be found in the Individual Site Assessment Tools (DOE Distributed Generation for Resilience Planning Guide).[81]

5.2 Developer Perspective

Several entities besides building owners are usually involved in the development of CHP projects. In some cases, the building owner will hire an engineering consulting firm to help with planning and managing the project. Another approach is to contract with a turn-key CHP developer, who will design, develop, and build the project themselves and hand ownership over to the building owner after the CHP system is operational. Or, the building owner may choose to partner with a third-party investor or other firm that forms a team to finance and develop the project under a variety of potential ownership arrangements.[82] In either case, the developer could face challenges including the need to educate building decision makers on CHP technologies and the potential benefits of a CHP installation. In this section, the opportunities and challenges for multifamily CHP are considered more broadly from the perspective of a project developer.

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[80] US HUD, US DOE and US EPA. *Guide to Using Combined Heat and Power for Enhancing Reliability and Resiliency in Buildings*. September 2013. https://www.epa.gov/chp/guide-using-combined-heat-and-power-enhancing-reliability-and-resiliency-buildings

[81] US DOE. *Distributed Generation (DG) for Resilience Planning Guide*. 2019. https://betterbuildingsinitiative.energy.gov/sites/default/files/attachments/DG%20for%20Resilience%20Planning%20Guide%20-%20report%20format.pdf.

[82] For more information, see EPA, "CHP Project Development Steps". https://www.epa.gov/chp/chp-project-development-steps.

Multifamily CHP Opportunities for Developers

The interests of third-party developers are primarily centered on the technical and economic viability of a project. From this perspective, the economic viability of any potential CHP system is the primary driver of a successful project, and the system's economic viability is fundamentally linked to its technical design. When designing a CHP system, historical data on electric and thermal energy use helps identify the optimal equipment for expected power needs and availability of data is critical. In multifamily buildings, information on electricity consumption tends to be readily available, but data on thermal consumption is less monitored and measured.

The most efficient CHP systems, and typically the best financial return, are produced when CHP systems are sized to meet the building's thermal loads. This requires accurate temporal data for hot water and space heating loads, which can be difficult to obtain. For new construction, more conservative estimates may be used for sizing since developers work from forecasted loads instead of measured data.

Developer Challenges for Multifamily CHP

The biggest challenge for developers of CHP in multifamily building space is identifying building candidates with a strong technical fit and a good economic case. One strategy for increasing the viability of CHP is to take advantage of economies of scale and serve heating loads of multiple buildings. For example, a 300 kW CHP system serves the nine-building multifamily complex at Roosevelt Landings, achieving an economy of scale that lowers energy costs, reduces CO2 emissions by approximately 1,600 tons per year, and provides resilience through "black start" capabilities.[83]

Including multifamily buildings in a larger CHP project with a mix of commercial buildings can create a new set of challenges in coordinating between multiple stakeholders and building owners, but it can also provide benefits related to CHP sizing, operational efficiency, and economies of scale. A recently announced 13.2 MW CHP project at Hudson Yards, the largest private real estate project in the US, will serve two multifamily residential towers with a mix of commercial building space including offices and a hotel. Mixed-use buildings can provide higher, more consistent loads throughout the day during times when residential units are mostly unoccupied, which leads to greater system efficiencies and more favorable project economics. These types of developments can also lead to additional drivers for CHP uptake. For example, one of the reasons the developers of Hudson Yards pursued CHP was for its environmental benefits and the installation assisted with achieving LEED certification for buildings within the complex.[84]

After a promising candidate has been identified based on building loads and local energy prices, most of the potential barriers to developing CHP in a multifamily building are not profoundly different from barriers experienced in other sectors. The kinds of regulatory issues than can arise, such as

[83] New York State Energy Research and Development Authority (NYSERDA). "Case Studies and Feature Articles, Technology, Combined Heat and Power". https://www.nyserda.ny.gov/About/Publications/Case-Studies-and-Features
[84] Hudson Yards New York. "Ten Hudson Yards Designated LEED Platinum." January 2, 2018. https://www.hudsonyardsnewyork.com/press-releases/ten-hudson-yards-designated-leed-platinum/

interconnection delays, confusing utility standby rate charges, and time-consuming permitting approvals are relatively common across any commercial or institutional CHP project. Similarly, the need to have a good team in place that can leverage engineering expertise, bring relationships with established vendors, and provide quality service and maintenance over the life of the system are all typical aspects of CHP development.

Educating the Building Owner

CHP developers in the multifamily sector may uniquely experience certain issues, especially around the need to educate the building owner. It is often up to the developer to demonstrate the CHP value proposition. Educating the multifamily client about a large, capital, construction project can take more time than it does in other sectors, which may have more internal engineering capabilities or experience with large-scale energy projects. This education process can result in longer timeframes for decision making that can take several months or even years, particularly when working with rental buildings owned by large rental companies or co-ops where the co-op board membership might change annually. According to one project developer, “It just takes time. It isn’t the kind of thing where someone just goes and buys a cogeneration plant. It’s a construction project and it takes time to educate people.”

Some of the most successful CHP installations at multifamily buildings have been led by invested and engaged cooperative boards with members that are savvy in the financing and engineering requirements for large construction projects. Additionally, most building owners and board members can easily relate to the resilience benefits of CHP, and this can be one of CHP’s greatest selling points from the perspective of a project developer during the education process.

To overcome educational barriers with multifamily stakeholders in New York, NYSERDA prioritized education and outreach and developed innovative opportunities to engage with potential CHP hosts. This included inviting building owners to attend breakfasts, participate in site tours, and talk with other building managers about their experiences with CHP. Potential CHP hosts could hear their peers explain what the process is like and ask questions about their main concerns. Participants are interested in learning things like, “How much of a resource drain was it?” “Was there discomfort during the process for tenants?” These actions by developers can help building owners be a part of community, learn from peers, and gain confidence in CHP project options.

5.3 Policy Advocate Perspective

A policy environment that supports CHP deployment is consistently present in areas where CHP is used in multifamily buildings. Many multifamily CHP projects have had access to some type of incentive, financing assistance, or technical support through state or utility-administered programs aimed at encouraging CHP. These policies or programs are not typically targeted specifically to the multifamily sector, but more often prioritize the use of CHP in applications that effectively achieve broader public policy goals such as encouraging energy efficiency and economic development, increasing the resilience of critical facilities, and improving the environment and reducing GHG emissions.

NYSERDA's CHP Program

In New York, CHP plays a clear role in supporting several the state's policy objectives, including the governor's strategy to build a cleaner, more resilient and affordable energy system known as *Reforming the Energy Vision*. NYSERDA's CHP Program (PON 2568) incentivized the installation of CHP and was one of the most successful programs in the country at encouraging CHP in the multifamily sector. During a four-year term (2014-2017) of its first-come, first-serve CHP Program for all sectors, NYSERDA issued purchase orders in support of 129 CHP projects, of which 102 were located at multifamily buildings (or mixed-use buildings presumed to be typical of NYC marketplace consisting of ground-level commercial with upper-level multifamily residential) for an aggregated capacity of more than 25 MW.[85] In order to receive an incentive, in almost all cases systems were required to be capable of independent operation during grid outages ("black-start capable"), and installed to provide priority power during grid outages.[86]

One of the main reasons for NYSERDA's programmatic success in multifamily buildings is its catalog approach for packaged CHP systems, which allowed customers to easily select from a set of pre-engineered CHP modules supplied by approved CHP vendors. NYSERDA's catalog included components to educate the consumer about CHP and provided a rule of thumb for CHP sizing (100 kW for a 300-unit building) to place CHP's use in an easy-to-understand concept. The approved vendors act as a single point of responsibility for the entire project and provide a five-year maintenance and warranty agreement on the CHP system.[87] This approach improves buyer's confidence, ensures vendors are experienced at delivering projects, and simplifies the process for multifamily stakeholders that may be less familiar with large capital projects than buyers in other sectors.

Environmental Policies

Environmental policies at the local level can also be a contributing factor to the growth of CHP in multifamily buildings, which was the case in New York City. In 2011, a rule known as "Local Law 43," required buildings in New York City to replace No. 6 heating oil with cleaner grades of heating oil and eventually phase out their use for natural gas.[88] The law prompted some multifamily building owners to consider replacing existing boilers with CHP to comply with the regulation. For example, Stevenson Commons, an affordable housing community located in The Bronx, NY began exploring CHP as an option for compliance with the law and in 2012, installed a 525 kW CHP system in partnership with a third-party developer. The developer owns and operates the system, allowing Stevenson Commons to keep

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[85] Levy, Dana. New York State Energy Research and Development Authority (NYSERDA). Personal communication. April 24, 2018.
[86] US DOE, Better Buildings Initiative. "CHP for Resiliency Accelerator Partner Profile: NYSERDA". https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/NYSERDA.pdf
[87] New York State Energy Research and Development Authority (NYSERDA). Combined Heat and Power Program, PON 2568 Summary, CHP Sizing Guidelines. http://nyserda.ny.gov/PON2568
[88] The City of New York. Local Laws of the City of New York for the Year 2010. No. 43. http://www.nyc.gov/html/gbee/downloads/pdf/ll43-2010.pdf

energy costs down for tenants and comply with the rule without a large upfront capital outlay or ongoing maintenance expenses.[89]

Policy initiatives in other parts of the country have also successfully encouraged CHP in multifamily buildings. A combination of CHP programs in Massachusetts, which are aimed at increasing energy efficiency and reducing the need for conventional power generation in the Commonwealth, supported installations in at least four multifamily buildings in 2016.[90] The Alternative Energy Portfolio Standard, administered by the Department of Energy Resources (DOER), provides $/kWh production incentives for CHP and has streamlined administrative procedures so that smaller, multifamily-sized projects can take advantage without burdensome reporting requirements. CHP projects at multifamily buildings can also qualify for a $/kW capital incentive through a utility-administered program, which allows the utility to track energy savings from CHP projects and count them toward their energy efficiency targets.

Utility Policies and Incentives

Policy makers in Maryland have taken a similar approach and encourage the use of CHP as an important part of utilities' strategy for reaching the reductions in energy consumption required by the EmPOWER Maryland initiative. CHP installations at two multifamily buildings are benefitting residents while also helping utility company PEPCO (Potomac Electric Power Company) achieve its savings target. Multifamily customers may also qualify for grant funding through the Maryland Energy Administration's CHP Grant Program, which complements the utility-provided incentives and encourages CHP for resilience at critical infrastructure facilities. In general, states that have seen greater CHP deployment, especially in harder-to-reach sectors such as multifamily buildings, tend to include utilities as dedicated partners that can also benefit from CHP installations.

Utility Incentives for CHP in Multifamily Buildings in Maryland

To achieve statewide energy efficiency goals, Pepco, a public utility serving customers in Maryland and Washington, DC has partnered with multifamily building owners and provided incentives for CHP systems at two sites in Chevy Chase, MD.

A 75-kW system provides electricity and hot water at the Wisconsin Place Apartments (above) and a 150 kW system powers the 4701 Willard Apartments (below).

Photo credit: Equity Apartments

In the future, as more utilities gain experience collaborating with customers on CHP, programs may evolve to achieve specific goals for the electric distribution grid. For example, through the Brooklyn

[89] Aegis. "Stevenson Commons." https://aegischp.com/casestudy/stevenson-commons/

[90] Commonwealth of Massachusetts. "Program Summaries: Summaries of all the Renewable and Alternative Energy Portfolio Standard Programs." https://www.mass.gov/service-details/program-summaries

Queens Demand Management (BQDM) program, New York's largest electric utility, ConEdison, offers incentives to projects that include CHP and reduce demand in a targeted area in order to avoid a $1.2 billion substation upgrade. Facilitated in partnership with NYSERDA, the utility and state agency have supported several customer-sited CHP systems at multifamily buildings with an emphasis on the system's ability to relieve load in a targeted location during a specified period (summer peaking hours). As more utilities invest in low-cost alternatives to traditional grid infrastructure, CHP systems at multifamily buildings may be well-positioned to provide value at times and locations where the electrical grid needs it most.

5.4 Low Income Multifamily Perspective

Since 2000 and the establishment of its CHP Demonstration Program, the NYSERDA has offered CHP-related support and incentives, with by far the greatest proportion of implemented projects in the multifamily and hospitality sector.[91] Of a collection of fifteen representative NYSERDA case studies of CHP in multifamily buildings,[92] six, or 40%, have focused on CHP-powered affordable multifamily buildings in New York City. NYSERDA's case studies on affordable multifamily buildings could suggest that, where the availability of financial incentives and technical support intersect, the affordable subsector of the multifamily building market may be ready and willing to adopt CHP. These installations also provide greater resilience for populations that might be adversely affected by power outages.[93]

Low-income and affordable housing has several key characteristics that appear favorable for CHP installation. This sector encompasses predominantly rental housing; thus, owners, whether public sector, non-for-profit or private-sector, are the decision makers, a contrast to the slower, consensus-driven process of tenant-run condominium or cooperative boards. If affordable multifamily residential buildings are master-metered (a desirable precondition for CHP), the owner is likely to pay the utility costs, recouping these in the tenant's net rent or, in the case of buildings with subsidized rents, from a utility allowance. Thus, especially in geographies where energy is expensive, owners of affordable master-metered buildings have a compelling reason to reduce costs to keep their expenditures low and their rent affordable.

At least two common master-metered affordable housing ownership types could potentially benefit from CHP implementation. The first type, the most prevalent, is what one expert interviewed for this report terms "naturally occurring" affordable housing, which is non-subsidized older housing stock. Owners of these buildings, as for all market-rate properties, are looking for opportunities to reduce

[91] Kear, Edward and Mark Gundrum. "NYSERDA's CHP Program: A Little History". New York State Energy Research and Development Authority (NYSERDA). June 20, 2012.
[92] Correspondence between Dana Levy, NYSERDA and Neeharika Naik-Dhungel, U.S. EPA's CHP Partnership Program Manager. April 2018.
[93] Preliminary analysis in New York City has shown that multifamily buildings at public housing campuses have more attractive characteristics (large electric and thermal requirements, etc.) that made them better candidates for CHP than other multifamily building stock. Further exploration of this premise and whether it extends to other parts of the country is an area for additional research.

expenses and increase net operating income. CHP implementation, especially in locations where incentives are present and climate resiliency is a priority, may be appealing. The second type is housing operated by public housing authorities (PHAs) in which *PHAs rather than tenants pay for utilities.* PHAs follow U.S. Department of Housing and Urban Development (HUD) requirements in setting utility allowances (UAs) for tenants, which become part of the tenant's net rent. According to Evan White's *Utilities in Federally Subsidized Housing,* "when the owner pays for utilities, tenants have virtually no financial incentive to conserve because utility costs, whether great or small, do not affect their monthly payments."[94] In such cases, PHAs operating master-metered buildings under the fixed rent subsidy paid them by HUD may have incentive to implement energy saving systems like CHP.[95] HUD caps tenant rent at 30% of income, regardless of utility costs; in locations where utility costs are high relative to the revenue from rent, owners have an incentive to reduce their own costs through energy saving investments.

While CHP can provide cost-effective energy savings, the economics of CHP installations can be challenging compared to other energy efficiency measures. First costs for CHP are higher, and without incentives may be prohibitively expensive. Operating and capital budgets for taxpayer-funded affordable housing[96] tend to be low, so maintenance may be deferred and building infrastructure poor or failing, so that priorities other than the installation of CHP may be more pressing. According to an expert in energy efficiency and multifamily buildings interviewed for this report:

"Affordable multifamily housing providers are strapped, both in terms of funding and financing and staff time and capacity they can devote to thinking about making their buildings more efficient. The ones that do pay attention to upgrades tend to be on the larger side, with more resources, or they've been approached by an incentive program to help them incorporate CHP. This is one reason why people are more familiar with CHP in New York . . . state incentive programs like NYSERDA's can have a big impact."[97]

State and federal entities have the power to decide whether and how to support energy efficiency in the affordable multifamily sector. In new construction, states typically have a scoring system to rank

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[94] White, Evan. *Utilities in Federally Subsidized Housing: A Report on Efficiency, Utility Savings, and Consistency.* Goldman School of Public Policy, UC Berkeley Law at Boalt Hall. June 2012. https://aceee.org/files/pdf/resource/white_utilities_in_federally_subsidized_housing_2012.pdf

[95] Other affordable housing types operating under different subsidy programs with different rules may face disincentives to implementing energy saving improvements. For example, master-metered affordable housing properties subsidized using the low-income housing tax credit (LIHTC) are not subject to HUD rules; LIHTC properties use actual or modeled energy costs to set utility allowances and determine subsidies, and these increases or decrease as utility costs increase or decrease. This circumstance represents a disincentive to making energy saving improvements that might be otherwise funded from an increase in net operating income. For a summary of utility allowances in subsidized affordable rental housing, see California Housing Partnership Corporation, "An Affordable Housing Owner's Guide to Utility Allowances," April 2016, https://chpc.net/wp-content/uploads/2016/04/UA-Guide_April-2016Web.pdf

[96] Note that private capital also plays a role in funding affordable housing.

[97] Stefan Samarripas, American Council for an Energy-Efficient Economy. March 29, 2018 telephone interview.

projects that apply for the low-income housing tax credits (LIHTCs), with some criteria based on LEED (Leadership in Energy and Environmental Design), ENERGY STAR, or other green building certifications. The LEED and Enterprise Green Communities green building rating systems heavily weight energy and carbon savings in terms of their overall scoring. The Enterprise Green Communities Criteria, specifically developed for low-income communities, also rewards the incorporation of disaster-resilient energy systems,[98] a primary benefit of CHP.

Judging from the case studies of NYSERDA-sponsored affordable housing (see Table 17), the triple bottom line value of implementing CHP has resulted in significant financial, environmental, and social benefits both to residents and the greater New York City community, as CHP enhances electrical grid stability.

Table 17. Selected NYSERDA-sponsored CHP Installations in New York City Affordable Housing

Affordable Housing Unit, NYSERDA-sponsored New York City CHP	Year CHP implemented	Generation capacity	Estimated annual energy or carbon savings
Sea Park West	2010	150 kW	$69,000
Concord Court Apartments	2012	100 kW	50% energy savings
Roosevelt Landings	2014	300 kW	1600 tons CO2
Times Square Apartments	2017	200 kW	$116,000 projected
Grace Towers	2017	70 kW	Data unavailable
Remeeder Houses Apartments	2017	35 kW	Data unavailable

To promote the further adoption of CHP in the affordable multifamily sector, state and federal governments can choose to implement policy incentivizing clean energy sources in public and affordable housing, or they can choose to offer financial incentives to implement CHP, such as in New York State. Federal agencies such as HUD may also play a role in facilitating connections between public housing authorities with experience installing CHP and housing authorities without CHP expertise to enable knowledge sharing and promote best practices.

Additional drivers for CHP in affordable multifamily buildings can include the following:

- **Utility programs that promote clean energy specifically in affordable and public housing.** One interviewee observed that "if utilities cast the widest net possible with their programs, they probably won't reach multifamily or affordable multifamily. They're not likely to go for the hard to reach, unless they design a program specifically for that sector." Utilities in Massachusetts offer support and rebates for public housing CHP projects. The Boa Vista apartments in New

[98] Enterprise. *2015 Enterprise Green Communities Criteria Checklist.* https://www.enterprisecommunity.org/sites/default/files/media-library/solutions-and-innovation/green/ecp-2015-criteria-checklist-11-15.pdf

Bedford, MA implemented CHP in 2009 for an installed system cost of $197,000 after an $18,000 utility rebate; with annual savings of $58,000, simple payback was less than four years.[99]

- **Public sector-sponsored lending institutions for green retrofits**, such as the Connecticut Green Bank.
- **Building operator training,** a need that applies to all multifamily buildings, not just affordable developments. According to one interviewee, “building staff in general are not very familiar with advanced technologies and energy savings systems, especially large ones, so you need to train the staff to be able to operate and maintain the equipment to keep capturing savings. Opportunities for training building operators could be helpful.”

[99] New England US DOE CHP Technical Assistance Partnership. “Boa Vista Apartments.” June 2015. http://www.chptap.org/Data/projects/boavistachp.pdf

6.0 Conclusions

Multifamily buildings have several qualities that make them ideal candidates for CHP, and they are the fastest growing building type in terms of new CHP installations from 2015 through 2017.[100] However, the multifamily building sector is complex, and there are many site-specific factors that need to be considered when evaluating CHP options. To efficiently utilize the thermal energy from CHP, a multifamily building typically needs central water heating. To apply CHP electricity to full building loads, a multifamily building needs to be master-metered for electricity. Ownership structure, building size, location, and energy prices also have an impact on the viability of potential multifamily CHP installations.

This report took these considerations into account to quantify the opportunities for multifamily CHP across the U.S. Overall, there is estimated to be over 4.4 GW of technical potential for CHP at multifamily buildings, if CHP electricity can be applied to full building loads (the *maximum technical potential*). When considering building limitations due to central water heating and direct-metered electricity, the *achievable technical potential* is estimated at 1.7 GW. Applying economic calculations for potential CHP installations, the economic potential for multifamily buildings is estimated to be 518 MW. The results of the CHP market analysis, with the number of buildings and total associated CHP potential for these three estimates, are summarized in Table 18 (a reiteration of Table 1).

Table 18. Technical and Economic Potential for Multifamily CHP

Estimate	Number of Buildings	Total Potential (MW)
Maximum Technical Potential	71,678	4,367
Achievable Technical Potential	32,192	1,742
Economic Potential	6,493	518

Incentives for CHP can play a large role in helping projects become economical, and in translating economic potential into CHP adoption. This is most evident in New York State where many recent multifamily CHP installations have taken place with NYSERDA incentives. Favorable policies, along with outreach efforts and education can help multifamily building owners understand the benefits of CHP.

If all multifamily buildings with economic potential install CHP systems, the results suggest a significant potential for reduced emission savings. According to the analysis conducted with EPA's Energy and Emissions Savings Calculator, taking regional emission factors and estimates for transmission and distribution losses into account, over 430,000 tons of carbon dioxide equivalent emissions could be

[100] US Department of Energy. CHP Installation Database. Maintained by ICF. Data current through Dec. 31, 2017. https://doe.icfwebservices.com/chpdb/

reduced on an annual basis.[101] As the results show, there are a number of opportunities throughout the U.S. for CHP to provide energy savings and resiliency for multifamily building tenants and owners while reducing emissions.

During this analysis, two trends were observed as factors likely to influence market growth for CHP in multifamily buildings. These are (1) the role of CHP in strengthening the resilience of buildings and providing capability to island from the grid, and (2) the emergence of hybrid CHP systems that integrate renewable technologies. CHP is a demonstrated, cost-competitive solution that has enabled residents to shelter-in-place when faced with extreme weather events in recent years. For that reason, several states have developed resilience policies and plans that encourage CHP at critical facilities. Looking to the future, hybrid CHP systems that integrate solar and storage are an emerging strategy for balancing the resilience needs of the multifamily sector with broader emission reduction goals. Concepts and themes associated with resilience and hybrid CHP systems are briefly addressed in this report. However, with the increase in state and local renewable policies and decreasing costs associated with renewable technologies, this is a topic for further discussion, more detailed analysis, and future research.

[101] Results from economic analysis applied to EPA Energy and Emissions Savings Calculator (https://www.epa.gov/chp/chp-energy-and-emissions-savings-calculator) with modeled CHP performance characteristics and 2014 eGRID values by sub region (released 2016) for fossil fuel utility emissions.

Appendix A: Existing Resources for CHP in Multifamily Buildings

CHP and Multifamily Building Resources

Groberg, R., MacDonald, J.M., & Garland, P. 2008. ***Promoting Combined Heat and Power for Multifamily Properties***. 2008 ACEEE Summer Study on Energy Efficiency in Buildings. http://aceee.org/files/proceedings/2008/data/papers/2_402.pdf.

This whitepaper provides a comprehensive summary of the subject of CHP in multifamily buildings. It summarizes how to use public tools available for building developers interested in evaluating CHP for their buildings and reviews several federal support mechanisms created to help facilitate CHP technology in multifamily buildings.

NYCEEC. ***Clean Energy Pays Off in the Multifamily Market.*** A case study from NYCEEC. https://nyceec.com/wp-content/uploads/Roosevelt-Landings-case-study-NYCEEC-web.pdf.

This case study describes NYCEEC's experience providing financing for a series of clean energy retrofits at Roosevelt Landings, a 1,003-unit mixed income apartment complex in New York City. The retrofit, which included the installation of a 300 kW CHP system, resulted in several lessons learned that may be relevant for other large and aging multifamily rental buildings.

U.S. Department of Energy (DOE). 2019. ***Efficiency-Resilience Nexus***. https://betterbuildingsinitiative.energy.gov/resilience

The resources found on this page are intended to help organizations across different sectors take steps to build resilience and increase their ability to bounce back from natural disasters and other stressors. These resources can be used to minimize vulnerabilities to climate-related impacts through resilience planning, implementing new energy technologies, and decreasing energy demand in facilities. They include a guide that provides information and resources on how DG, with a focus on CHP, can help communities meet resilience goals and ensure critical infrastructure remains operational regardless of external events. If used in combination with a survey of critical infrastructure at a regional level, this guide also provides tools and analysis capabilities to help decision makers, policy makers, utilities, and organizations determine if DG is a good fit to support resilience goals for critical infrastructure in their specific jurisdiction, territory, or organization.

U.S. DOE, U.S. Department of Housing and Urban Development (HUD) & U.S. EPA. 2013. ***Guide to Using Combined Heat and Power for Enhancing Reliability and Resiliency in Buildings***. https://www.epa.gov/sites/production/files/2015-07/documents/guide_to_using_combined_heat_and_power_for_enhancing_reliability_and_resiliency_in_buildings.pdf.

In response to Hurricane Sandy, the U.S. Department of Energy (DOE), U.S. EPA, and Department of Housing and Urban Development (HUD) developed a guide for using CHP to enhance resiliency in buildings. The guide highlights sites that were powered by CHP and continued operations when the electric grid went down during the storm. Five of the sites were multifamily buildings, which illustrate the benefits of CHP systems in multifamily buildings during unexpected grid outages.

U.S. DOE. Oak Ridge National Laboratory (ORNL) prepared for HUD. September 2010. ***HUD CHP Guide #3: Introduction to Level 2 Analysis Tool for Multifamily Buildings**.* Available at https://portal.hud.gov/hudportal/documents/huddoc?id=chpguide3.pdf

The third guidance document from HUD and DOE that explains how a Level 2 Analysis Tool was created and for whom it is best suited. It is the first analysis tool specifically geared toward multifamily building owners, managers and developers and is designed to help them determine if CHP is right for their multifamily building. In addition to determining system cost, payback, and sizing, the Level 2 Analysis Tool can show users other energy conservation measures for their building, like new windows or chiller/boiler replacement. This feature is helpful for users wanting to combine a CHP system installation with additional building upgrades.

U.S. DOE. ORNL prepared for HUD. May 2009. ***HUD CHP Guide #2: Feasibility Screening for Combined Heat and Power in Multifamily Housing**.* https://portal.hud.gov/hudportal/documents/huddoc?id=chpguide2.pdf

The second guidance document created by HUD and introduces the HUD/ORNL Level 2 CHP analysis tool, as well as other feasibility guidelines for CHP in multifamily buildings. The document provides screenshots of the tool and examples of some data inputs.

U.S. DOE. ORNL prepared for HUD. 2005. ***CHP Guide #1: Q&A on Combined Heat and Power for Multifamily Housing**.* https://portal.hud.gov/hudportal/documents/huddoc?id=chpguide1.pdf

The first guidance document HUD developed with DOE targeted at CHP in Multifamily buildings. The first answers key questions about CHP to help educate multifamily building owners and managers. It reviews the general building specifications that are favorable for CHP and the benefits associated with converting from conventional power and heat technologies to CHP.

U.S. HUD, Community Planning and Development, ***Renewable Energy Toolkit for Affordable Housing***, 2018.

The U.S. Department of Housing and Urban Development (HUD) developed a toolkit for renewable energy in affordable housing, which included suggestions for the installation of CHP. The toolkit recommends multifamily buildings with 100 or more housing units as a screening mechanism for CHP viability.

Witty, Sam and Gita Subramony. 2016. ***Roadmap to Distributed Generation: Innovative Tools for CHP Adoption**.* https://aceee.org/files/proceedings/2016/data/papers/11_771.pdf.

This paper describes the methodology behind a market assessment tool used by NYSERDA to identify New York City buildings that would make ideal candidates for CHP. The tool identifies potential CHP program participants, including multifamily buildings, and assist participants with navigating the

CHP installation process. The tool also provides information on key decision makers at the buildings identified to facilitate program outreach and includes a preliminary screening analysis of CHP installations on building loads and operating costs.

General CHP Resources

New York State Energy Research and Development Authority (NYSERDA). ***DG Integrated Data System***. Available from https://der.nyserda.ny.gov/.

NYSERDA maintains an online tracking system that monitors the performance of CHP installations that have taken advantage of available incentives through their CHP program. The data provides details on how recent multifamily CHP systems have been sized and how they are performing.

US DOE. 2019. ***U.S. DOE Combined Heat and Power Installation Database****,* maintained by ICF. Available at https://doe.icfwebservices.com/chpdb/.

The DOE CHP Installation Database is a data collection effort sponsored by DOE and maintained by ICF. The database contains a comprehensive listing of CHP installations of all sizes and applications installed in the United States. Users can sort state-by-state data on all CHP installations located at multifamily buildings as specified in the "application" field.

US DOE. 2016. ***Combined Heat and Power Technical Potential in the United States****.* https://www.energy.gov/sites/prod/files/2016/04/f30/CHP%20Technical%20Potential%20Study%203-31-2016%20Final.pdf.

This report provides national data on the technical potential for CHP by system size range, facility type, and location. The study includes an estimate of the market size for CHP in multifamily buildings constrained only by technological limits, which measures the ability of CHP technologies to fit customer energy needs without regard for economic or market factors.

US DOE*.* ***CHP Technical Assistance Partnerships (CHP TAPS)****.* http://energy.gov/eere/amo/chp-technical-assistance-partnerships-chp-taps.

DOE's CHP Technical Assistance Partnerships (CHP TAPs) provide market opportunity analyses, education and outreach, and technical assistance. The CHP TAPs provide targeted outreach and education about CHP benefits to a variety of stakeholders including policy makers, regulators, energy end-users, and trade associations through the DOE's CHP Deployment Program.

US EPA. 2015. Combined Heat and Power Partnership, ***Catalog of CHP Technologies***. https://www.epa.gov/chp/catalog-chp-technologies.

This report provides an overview of how CHP systems work and the key concepts of efficiency and power-to-heat ratios. It also provides information and performance characteristics of five commercially available CHP prime movers. Data collected for the 2017 *Packaged CHP Systems* chapter of the *Catalog of CHP Technologies* can be used to estimate equipment cost and performance of systems typical of multifamily buildings.

US EPA. Combined Heat and Power Partnership, ***Is My Facility a Good Candidate for CHP?*** https://www.epa.gov/chp/my-facility-good-candidate-c.

On its website, EPA's CHP Partnership lists a series of initial questions to help users evaluate whether a facility is a good candidate for CHP. It includes access to additional resources, including an excel-based tool to estimate the economic feasibility of a CHP project and an online guide of the steps involved in CHP project development, from initial qualification to CHP system operation and maintenance.

Energy Efficiency in Multifamily Building Resources

Brown, Matthew and Mark Wolfe. 2007. ***Energy Efficiency in Multi-Family Housing, A Profile and Analysis****.* Washington, DC: Energy Programs Consortium. Available at https://aceee.org/files/pdf/resource/brown_and_wolfe_energy_efficiency_in_multifamily_housing_2007.pdf.

This paper describes the number and types of multifamily housing units in the country as a percentage of the total U.S. housing stock, the income level of those who inhabit multifamily buildings and whether they rent or own their units. It also describes energy use, evaluates the potential for energy efficiency in multifamily buildings, and provides a summary of policy issues impacting the sector.

Hynek, D., M. Levy, and B. Smith. 2012. ***Follow the Money: Overcoming the Split Incentive for Effective Energy Efficiency Program Design in Multi-family Buildings***. Wisconsin Division of Energy Services. In Proceedings of 2012 ACEEE Summer Study on Energy Efficiency in Buildings. Available at https://aceee.org/files/proceedings/2012/data/papers/0193-000192.pdf.

This paper offers a taxonomy of multifamily buildings and their financial environments. It is intended to help program designers and evaluators think through program designs and parameters to overcome the split incentive barrier and design the most effective multifamily building program possible.

Samarripas, S., D. York, and L. Ross. 2017. ***More Savings for More Residents: Progress in Multifamily Housing Energy Efficiency***. Washington, DC: American Council for an Energy Efficient Economy. Available at http://aceee.org/research-report/u1702.

This report is an assessment of multifamily energy efficiency programs in US metropolitan areas with the most multifamily households. The report documents how energy efficiency programs have changed in the context of dynamic housing markets and statewide policy environments. It includes an analysis of the number, spending, offerings, and targeted participants of current programs and their potential for further expansion.