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Making Residential Heating and Cooling Climate-Friendly in New York State

Arjun Makhijani, Ph.D.

July 2017 (revised report)

Prepared for
Alliance for a Green Economy

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Preface

New York State has set a goal of reducing greenhouse gas emissions by 40 percent by the year 2030 and 80 percent by the year 2050. About three-fifths of the state's greenhouse gas emissions in 2011 came from the direct use of fossil fuels in transportation (39.3 percent) and in buildings for space and water heating (21.4 percent). To reach greenhouse gas reduction targets it will be necessary to make significant reductions in both these sectors. This study focuses on strategies for phasing out direct use of fossil fuels (natural gas, fuel oil, and propane) in buildings in New York.

This report examines cost and greenhouse gas emission implications of converting homes in the residential sector from fossil fuel space and water heating to efficient electric systems. Such conversions also make space and water heating "renewable grid ready" -- that is, as the proportion of renewable energy in New York's electricity grid increases, greenhouse gas emissions continue to decline.

Natural gas is the most common fuel used for space and water heating in buildings. In recent years there has been a realization of the vastly greater short-term damaging role of natural gas compared to carbon dioxide and of measurements indicating that leaks of methane are larger than previously thought. Further, production of natural gas using the technique of hydraulic fracturing appears to be responsible for increasing the overall leak rate. Addressing the issue of greatly reducing or eliminating fossil fuel use in buildings, has therefore become an increasingly important issue to meet greenhouse gas reduction goals.

Weatherization of homes is also critical for reducing energy use and emissions. Ideally, both should be implemented simultaneously (and this is often done), so that heat pump equipment can be sized accordingly. The better the weatherization the lower the size and cost of the heat pump. We have not considered weatherization in this report, even though it is a critical element to converting homes. This is because it is difficult to generalize at what point improvement in weatherization would result in reduced heat pump size and therefore in reduced heating, ventilation, and air-conditioning (HVAC) equipment cost. The problem is especially complex in New York because of the varying ages of the housing stock, its large variety, and the three climate zones. In general, our conclusions regarding the benefits of conversion will be valid; indeed, weatherization carried out after a good audit should improve the economics of conversion from fossil fuel to heat pump systems, especially in New York City and its environs (including Long Island), where electricity is more expensive relative to other parts of New York.

This report addresses policies to encourage and assist the transition to low emissions systems in residential space and water heating, notably in buildings with one to four housing units each, which constitute over two-thirds of New York's housing. It also addresses the benefits of assisting low-income households to make the transition to efficient electric space and water heating systems.

I would like to thank Bill Nowak and Jens Ponikau, of NY-GEO, and Hal Smith of Halco, who shared their expertise and experience in New York's HVAC sector with me. My interviews with them are in Attachments A and B. Hal Smith of Halco and Tim Judson of the Nuclear Information and Resource Service provided useful reviews, as did Jessica Azulay and Andra Leimanis of Alliance for a Green Economy (AGREE). Annie Makhijani, IEER Project Scientist, compiled New York State housing and

energy data. Lois Chalmers, IEER Librarian and Bibliographer, checked the report. As the author of the report, I alone am responsible for any errors that remain.

IEER prepared this study for AGREE; we appreciate being selected for this task and especially thank Jessica Azulay who commissioned the study on behalf of AGREE. I would, for my part, also like to thank the Park Foundation whose generosity allowed AGREE to commission IEER to do this study.

Arjun Makhijani
January 2017

Note for the revised report:

I revised this report because John Ciovacco of Aztec Geothermal pointed out that the values I had used for the coefficient of performance of cold climate heat pumps were too high for New York climate zones. I agreed with this observation and have changed the energy and economic estimates relating to those heat pumps using values estimated by the Department of Energy and provided to me by Mr. Ciovacco. I want to thank him for helping to improve the accuracy of this report.

In revising the report I decided to eliminate Attachment C, dealing with performance-based rebates, from the report. I found that having two different approaches to rebates (CO_2 emissions reduction and peak reduction as one approach, presented in the body of the report, and performance-based as a second approach presented in Attachment C) was confusing. Further, since cold climate heat pump performance is quite variable across New York climate zones, the approach of using CO_2 and peak reduction values that is in the body of the report is superior at least for New York State.

Finally, I have also taken the occasion of the revision to note that the New York State Energy Research and Development Authority (NYSERDA) has issued a roadmap for renewable heating. Its general direction is along the lines advocated in this report, though the two were independently developed.

Arjun Makhijani
June 2017

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June 2017 (revised)

Report Overview

Space and water heating and air conditioning in New York State's buildings are responsible for more CO_2 emissions – about 50 million metric tons in 2011 – than the entire electricity sector (including electricity imports) – about 42 million metric tons. The residential sector represents over 60 percent of the space conditioning and water heating emissions. Similarly, direct use of natural gas in buildings is greater than its use in the electricity sector, even as the latter use has grown substantially. Eliminating the use of fossil fuels, including natural gas, as completely as possible is essential for New York to achieve its 2050 goal for deep reductions of greenhouse gas emissions. The importance of phasing out direct use of natural gas is *enhanced* when we take into account the warming impact of methane leaks associated with natural gas use at various stages of production and transport.

The most straightforward way to address the elimination of fossil fuel use is by adopting efficient electric heating, ventilation, and air-conditioning (HVAC) and water heating systems. They are commercially available. There are several other advantages of adopting this approach in addition to reduction of CO_2 emissions due to combustion of fossil fuels:

- Electrification creates an HVAC sector that is renewable grid ready. In other words, as the grid is decarbonized using renewable resources, the emissions from all things driven by electricity, including heating and air-conditioning systems, decline. A fully renewable electricity sector will then automatically mean zero emissions from heating and cooling buildings, if direct use of fossil fuels is completely eliminated for those applications.
- Geothermal and cold climate (air-to-air) heat pumps provide air conditioning much more efficiently than conventional central air-conditioning systems.[1] As a direct result heat pumps reduce peak loads on the grid and decrease the need to invest in additional peaking generation. Peak load reduction also reduces transmission congestion and the costs associated with it.

[1] We recommend that New York State consider geothermal heat pumps or cold climate heat pumps. The latter are a special type of air-to-air heat pump. All air-to-air heat pumps use the same approach, extracting heat from the outside air in the winter and then pumping it up to the temperature needed for space heating. However, ordinary air-to-air heat pumps lose efficiency rapidly below the freezing point of water. This means that they become inefficient and use auxiliary heat when it is coldest. In contrast, cold climate heat pumps operate efficiently down to low temperatures – 5°F or lower. Hence, if air-to-air heat pump technology is used, it is critical that New York State encourage cold climate rather than ordinary heat pumps.

- Leaks of methane would be reduced. Methane is the main constituent of natural gas and a powerful greenhouse gas. Methane leak reductions would enhances the direct CO2 reductions by between about 20 percent and 150 percent in a fully renewable grid (in which no natural gas is used for electricity generation). The latter figure corresponds to a 5 percent leak rate and a 20-year global warming potential.
- Investment in efficient equipment substitutes an upfront cost for continued high energy costs. This can be very beneficial for low-income households, since high energy burdens are part of a complex of economic, health, and housing issues that contribute to serious and all-too-often devastating problems like ill-health and homelessness.
- The use of fuel oil and propane in home heating is common in New York. These are relatively expensive fuels; there is no reason to delay their conversion to efficient electric systems.
- Conversion of natural gas systems to efficient heat pumps is usually not economical on a straight dollar-cost basis. However, when the social cost of carbon emissions, reduction of peak load, and upstream methane emissions are taken into account, the economic case for retrofitting with efficient electric systems improves greatly. For the case studies of typical apartments in two-to-four unit structures, the retrofits are not economical. The costs in the case of multi-unit structures are quite variable; hence this conclusion should not be generalized; rather a case-by-case approach to multi-unit structures is needed whereby retrofits with both geothermal heat pumps (GHPs) and cold climate heat pumps are evaluated.
- Reduction of the first cost of efficient electric systems is one of the keys to making conversion from natural gas economically attractive more widely.

Principal Recommendation: New York State should adopt a policy of converting fossil fuel heating systems to efficient electric systems.[2] Cold climate heat pumps and geothermal heat pumps are widely available technologies that can serve this purpose. Other leading heat pump technologies could reduce cost and/or increase efficiency as could widespread adoption of both GHPs and cold climate heat pumps. Water heating conversions should be done at the same time, where possible. Incentives for efficient heat pump systems should be based on value to society and the grid, including reduction of CO_2 emissions and reduction of peak loads.

It would be most efficient to start in four areas:

- Conversion of fuel oil and propane systems to efficient heat pump systems.
- Conversion of all low-income households using fossil fuels, including natural gas, to efficient electric systems wherever it reduces energy costs and is economical after rebates. Lowering energy burdens will provide low-income families as well as other New Yorkers with significant non-energy benefits.
- An end to the promotion of natural gas by NYSERDA, which should not provide rebates for conversion of fuel oil and propane systems to natural gas.
- Exclusive use of efficient electric systems in new housing construction and in retrofits in areas where there is no natural gas infrastructure at present; the focus in such cases should be on the more efficient geothermal heat pumps.

[2] Since the completion of the report and prior to this revision, the New York State Research and Development Authority (NYSERDA) has published a *Renewable Heating and Cooling Policy Framework* (NYSERDA 2017). This puts the State of New York in the direction advocated in this report. IEER's comments on NYSERDA 2017 are in Makhijani 2017.

Summary

Carbon dioxide (CO_2) emissions in New York State due to space and water heating and air conditioning of buildings are second only to transportation and higher than all electricity use: about 50 million metric tons compared to 70 million metric tons for transportation and 42 million metric tons for the electricity sector[3] in 2011. Within the buildings sector, the residential sector accounts for about 63 percent of the total, which amounted to 31.4 million metric tons – 17.5 percent of New York's total CO_2 emissions in 2011. This report is concerned with strategies to reduce CO_2 emissions associated with space and water heating and air conditioning in the residential sector as well as the CO_2-equivalent of the methane emissions associated with the use of natural gas. We also discuss policies that would make the reduction of emissions in the space conditioning sector economically equitable.

We have analyzed residential space and water heating and air conditioning in New York by climate zone (New York State has three), by housing type, and by fuel type.

Natural gas and fuel oil are the most common fuel sources for space heating. Most of New York State does not have severe summers. Room air conditioners are more common than central air conditioners. Low electricity use for air conditioning and heating with fossil fuels during cold winters makes CO_2 emissions from the direct use of fossil fuels (natural gas, fuel oil, and propane) the largest single source of greenhouse gas (GHG) emissions in the residential sector: 26 million metric tons of CO_2. This amount represents about 15 percent of New York's energy sector CO_2 emissions. Figure S-1 summarizes CO_2 emissions in New York's energy sector for the year 2011.

[3] Commercial sector space and water heating emissions due to fossil fuel use estimated by IEER from commercial sector energy data from EIA's *State Energy Consumption Estimates* for New York (EIA SEDS Consumption 2016, New York, Table CT5). Fractions of natural gas and fuel estimated from the Department of Energy's *2011 Buildings Energy Data Book* (DOE EERE 2012 BEDB, Table 3.1.4 at http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.1.4); the fraction of electricity used for cooling and ventilation was also estimated from this source. Commercial sector electricity use as a fraction of the total from NY *State Electricity Profiles* (EIA States 2016 New York, Table 8) and electricity sector CO_2 emissions from EIA States 2016 New York, Table 7.

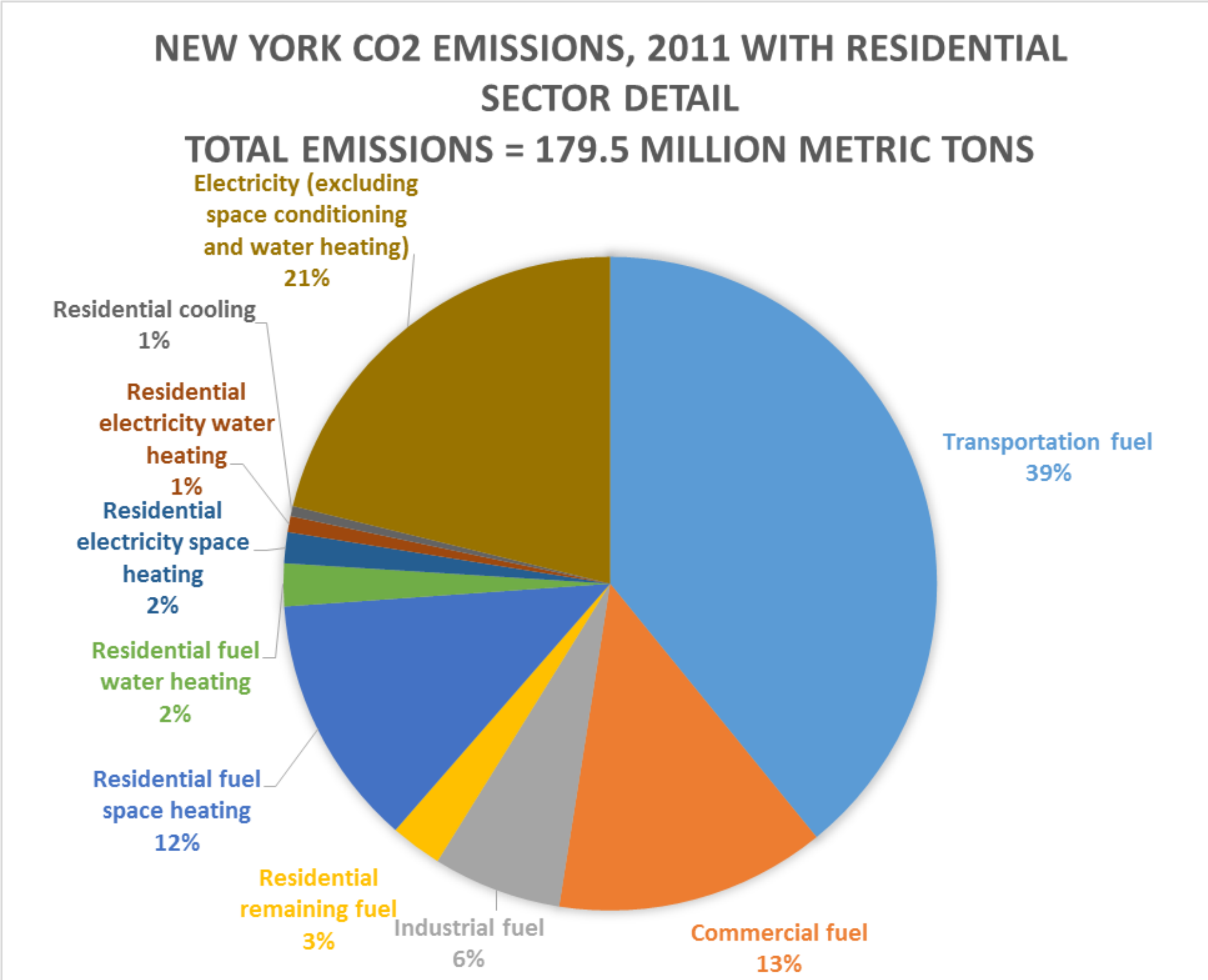

Figure S-1: New York State energy sector CO_2 emissions for 2011, with residential sector details
Source: NYS GHG Inventory 2015, Table S-1; residential sector detail: IEER calculations

We analyzed energy use and emissions in the concerned end uses from statewide data, by climate zone, and by prototypical residences in Climate Zone 4 and Climate Zone 5, and focused on structures with one to four housing units. While we did not analyze Climate Zone 6 separately, the findings are applicable to Climate Zone 6, which is colder in the winter but requires less air conditioning in the summer. We studied two types of residences:

- A **single unit structure**, heated by fuel oil or natural gas, with central air conditioning and natural gas water heating. We analyze the replacement of the existing space heating and air-conditioning system with either a geothermal heat pump or a cold climate air-to-air heat pump;
- An **apartment in a two-to-four unit** structure presently heated by natural gas and cooled using a room air conditioner. The combination would be replaced by a cold climate heat pump.[4]

[4] These structures can be retrofitted with geothermal heat pumps. It was not considered in this report since it is more difficult to estimate typical costs.

Principal findings

1. New York must greatly reduce or eliminate direct use of fossil fuels in the residential sector to achieve its 2050 greenhouse gas reduction goal of 80 percent. Space heating and water heating are the most important direct uses of fossil fuels in the residential sector. Replacement of fossil fuel systems by efficient heat pump technologies[5] is the single most important approach to accomplishing this purpose.[6] Emissions in the space and water heating sector will decrease further as the fraction of renewable energy is increased in New York's renewable electricity supply and fossil fuels are phased out.
2. Based on New York State greenhouse gas inventory data and Energy Information Administration data, we estimate that New York's residential sector space heating, water heating, and air conditioning accounted for about 31.4 million metric tons of CO_2 emissions, or about 17.5 percent of New York's total of 179.5 million metric tons from all sectors in the year 2011. The residential sector has high direct natural gas use. When methane emissions due to natural gas leaks are taken into account, the estimate of emissions increases by between 2.4 and 19 million metric tons of CO_2-equivalent per year. The former figure uses the EPA leak rate of about 1.6 percent and a 100-year warming potential relative to CO_2 of 34; the latter uses a 5 percent leak rate and a 20-year warming potential of 86.
3. In 2011, the direct use of natural gas in residential and commercial buildings was about 58 percent greater than New York's use of natural gas for in-state electricity generation. The use of natural gas in buildings has been increasing faster than that in the electricity sector: in 2014 building use was 72 percent greater than electricity sector use; however, the electricity sector amount is more variable since it is more sensitive to price. This shows that the replacement of natural gas space and water heating systems by efficient renewable-ready electric systems is an essential strategy for climate protection.
4. It is generally economical to retrofit fuel oil and propane heated buildings with either cold climate or geothermal heat pumps. The former have a lower first (or up-front) cost. The latter have a higher first cost but are more efficient and last longer. Heat pumps are lower in total cost over the lifetime of the systems, even before any credit for reduced CO_2 emissions is taken into account.
5. Retrofitting natural gas heating plus air-conditioning systems with geothermal heat pumps is not economical at present relative prices and first costs. But it is often economical to retrofit natural gas systems when the benefits of emission and peak load reductions are taken into account. The economics of conversion from natural gas to efficient electric systems deteriorate in areas with relatively high electricity prices (New York City and its environs). A reduction in the first cost of efficient electric systems would make retrofitting natural gas heating systems with efficient electric systems economical under a far wider variety of circumstances.[7]
6. Geothermal and cold climate heat pumps provide efficient air conditioning and therefore provide the benefit of reducing both peak load and CO_2 emissions. Accounting for these benefits is important when assessing the costs and benefits of converting natural gas to geothermal and cold climate heat pump systems. It is also important to account for reduced methane leaks.

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[5] The commonly used resistance baseboard electric heating is the least efficient electric heating technology. Heat pumps are more efficient, but vary a great deal in how much more efficient. By "efficient heat pumps" we mean heat pumps that are at least 2.5 times more efficient than resistance heating.

[6] Reducing heating requirements by weatherization is also important.

[7] A reduction in first cost is one of the goals of New York's renewable heating roadmap (NYSERDA 2017, Chapter 4).

7. The annual energy costs for homes currently heated with fuel oil or propane would be lower after conversion to efficient heat pump systems. This would reduce the cost of energy assistance to New York State ratepayers and taxpayers in the context of the New York Public Service Commission's decision to limit energy burdens of low-income households to 6 percent, presuming it will be applied in these cases.
8. Employing efficient electric heat pump systems for heating reduces price volatility for households, when compared to fuel oil, propane, and natural gas heating systems. It is important to consider the deleterious effects of fossil fuel price volatility, especially on low-income households. The effect of fuel price volatility can be approximately quantified and should be taken into account when calculating benefits.
9. Passive house construction is economical for new homes.
10. Two new cold climate heat pump technologies could improve efficiency, reduce cost, and make retrofitting natural gas systems with efficient heat pumps more economical with shorter payback times. They would also make phasing out natural gas more rapid, producing more immediate climate benefits due to methane leak reductions. One is a solar-thermal assisted heat pump, developed in British Columbia.[8] It is similar to a geothermal heat pump, except that a special solar thermal collector replaces the geothermal well. Another uses an advanced dual compressor system – a technology that has been tested but not commercialized.

Recommendations

1. New York should aim to retrofit fuel oil and propane heated homes with efficient electric systems, such as heat pumps, within 20 years in all cases where this is technically feasible.
2. Fossil fuel and electric water heaters using resistance technology should also be replaced, using de-superheaters[9] (when geothermal heat pumps are used for space heating) or heat pump water heaters (when cold climate heat pumps are used for space heating) whenever physically feasible.
3. New York should prioritize retrofits for low-income residences in cases where annual energy costs would be reduced. In such cases, conversion from fossil fuels to efficient electric heating systems should be considered as a strategy to implement the Public Service Commission's order to limit the energy burden of low-income households to 6 percent of household income.
4. The benefit of reducing cost of carbon emissions and peak loads should be used to set rebates. The present value of these two benefits should be used to reduce the first cost of efficient heat pump systems.
5. The carbon-equivalent impact of methane leak reductions (priced at the social cost of carbon) should also factor into setting rebates for efficient electric heat pumps.
6. Given the urgency of the climate crisis, the 20-year warming potential of methane and realistic leak rates should be factored in when computing the CO_2-equivalent value for reduced methane emissions. Net leak reductions – the reduction due to elimination of direct use of natural gas for heating and the increase because of natural gas in electricity generation – should be used.
7. Given that methane leaks considerably increase CO_2-equivalent emissions from natural gas systems, new natural gas infrastructure should be avoided and incentives should not be

[8] SunPump FAQ 2016

[9] In this context, "de-superheater" is a term for the heat exchanger that uses waste heat from the space heating part of the heat pump to heat water, thereby reducing the amount of electricity needed to produce a given amount of hot water.

provided for conversion from fuel oil or propane heating to natural gas. Rather, all incentives should be directed toward the conversion of fossil fuel heating to efficient electric systems.

8. A pilot project testing solar-assisted heat pump technology should be implemented in each of New York State's climate zones. Another heat pump technology, developed jointly by Oak Ridge National Laboratory and Emerson Climate Technologies, has an advanced compressor and has been tested in Ohio in an actual home.[10] NYSERDA should deploy this advanced compressor heat pump on a pilot basis side by side with the solar-assisted heat pump. These two technologies may reduce the cost of eliminating fossil fuels from the space and water heating sector and permit wider deployment of highly efficient heat pumps.
9. Passive house construction and efficient electric heating systems should be required for new residential construction starting in the year 2020. Strong consideration should be given to using GHPs exclusively in new construction whenever technically feasible.

[10] Abdelaziz and Pham 2016

I. Introduction

The purposes of this study are to:

- Examine the role of direct fossil fuel use for residential space and water heating in New York State's energy system.
- Examine the greenhouse gas emissions associated with residential space and water heating in New York.
- Examine the technical aspects of converting from fossil fuels to electricity.
- Examine the economic and greenhouse gas emissions aspects of the conversion.[11]
- Address issues that may especially affect low-income households.
- Suggest priorities for conversion and policies that would accelerate the necessary conversion to a renewable-ready space and water heating sector.

Direct use of fossil fuels for space and water heating in New York's residential sector accounted for about 26 million metric tons of CO_2 emissions in 2011,[12] of a total of energy-related emissions in that year of 179.5 million metric tons. When air conditioning and electric space and water heating are added, the total emissions represented by the sector studied in this report amount to about 31.4 million metric tons per year.

While we have not analyzed the commercial sector in detail here, we estimate that commercial sector emissions would be somewhat smaller.[13] The direct use of fuels in the commercial sector was responsible for about 24 million metric tons of CO_2 emissions in 2011. National data indicate that about 65 percent of the direct use of natural gas and 48 percent of the direct use of fuel oil in the commercial sector is for space and water heating.[14] Applying these ratios to New York indicates that about 12 million metric tons of CO_2 were emitted by direct use of fossil fuels for space and water heating in the commercial sector. Nearly 7 million metric tons of CO_2 were emitted due to air-conditioning and ventilation requirements of commercial buildings. Thus nearly 20 million metric tons of CO_2 emissions were attributable to New York's commercial sector space, heating, water heating, air-conditioning and ventilation requirements.

Putting these estimates together indicates that space and water heating and air conditioning together account for approximately 50 million metric tons, or about 28 percent of New York's energy-related CO_2 emissions of 179.5 million metric tons in 2011. Overall deep reductions in CO_2 emissions in the coming decades will therefore require a deep reduction in the direct use of fossil fuels in the buildings sector, including the residential sector. The importance of the buildings sector can be gauged by a single

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[11] We will mainly address CO_2 emissions and make some comments on the collateral benefits of reducing methane emissions by reducing natural gas use in New York's residential sector.

[12] Calculated by IEER from New York EIA Fact Sheet (EIA RECS 2009 New York) and DOE Buildings Energy Data Book (DOE EERE 2012 BEDB, Table 2.1.5).

[13] The total CO_2 emissions resulting from direct fuel use in the residential sector in New York in 2011 were about 30.9 million metric tons compared to about 24.1 million metric tons for the commercial sector. (NYS GHG Inventory 2015, Table S-1.)

[14] Calculated by IEER from DOE EERE 2012 BEDB, Table 3.1.4.

comparison point: the entire electricity sector of New York had CO_2 emissions of 42 million metric tons in 2011.[15]

It is important to note the role of natural gas in the combined residential and commercial buildings sector. When all uses are taken into account, total natural gas use in buildings exceeded the amount used for electricity generation in 2011 by 59 percent and in 2014 by 72 percent.[16]

When burned, natural gas generally has lower CO_2 emissions per unit of energy output than other fossil fuels; however, this is a very partial story in terms of its impact on climate. That is because methane (CH_4), the main constituent of natural gas, is a very powerful greenhouse gas. Its global warming potential is about 34 times greater than CO_2 on a 100-year time frame; and 86 times greater on a 20-year time frame.[17] The large difference between the two is due to the fact that methane has a short lifetime in the atmosphere compared to CO_2. The rapid <u>deterioration</u> of the climate picture <u>and</u> the <u>need</u> for near total elimination of energy-sector greenhouse gas emissions in the coming decades means that is it essential to factor in the impact of methane, and therefore of natural gas, on a 20-year time frame.

Further, leaks of natural gas at the point of production, in long-distance pipelines, and in distribution systems appear to be higher than estimated by the U.S. Environmental Protection Agency.[18] When the higher global warming potential and the higher end of leak estimates are taken into account, the impact of methane leaks in warming (CO_2-equivalent) terms may well be higher than that due to direct CO_2 emissions from burning natural gas (Chapter V, Section 4.i).

This report covers about 63 percent of the building-sector CO_2 emissions associated with space and water heating and air conditioning represented by residential structures with one to four housing units per structure.[19] Natural gas is the primary space and water heating fuel in New York State. We therefore also discuss the implications of reducing methane leaks for CO_2-equivalent GHG reductions.

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[15] NYS GHG Inventory 2015, Table S-1. Electricity sector emissions include those associated with electric air-conditioning and with electric space or water heating.

[16] Calculated from the residential, commercial, and electric power sector tables for New York State (EIA SEDS Consumption 2016, New York, Tables CT4, CT5, and CT8) in the *State Energy Consumption Estimates* of the Energy Information Administration.

[17] IPCC5 Physical Science 2013, Table 8.7 (p. 714)

[18] For a discussion of various estimates of methane emissions, see Howarth 2014.

[19] See Sections IV and V for details.

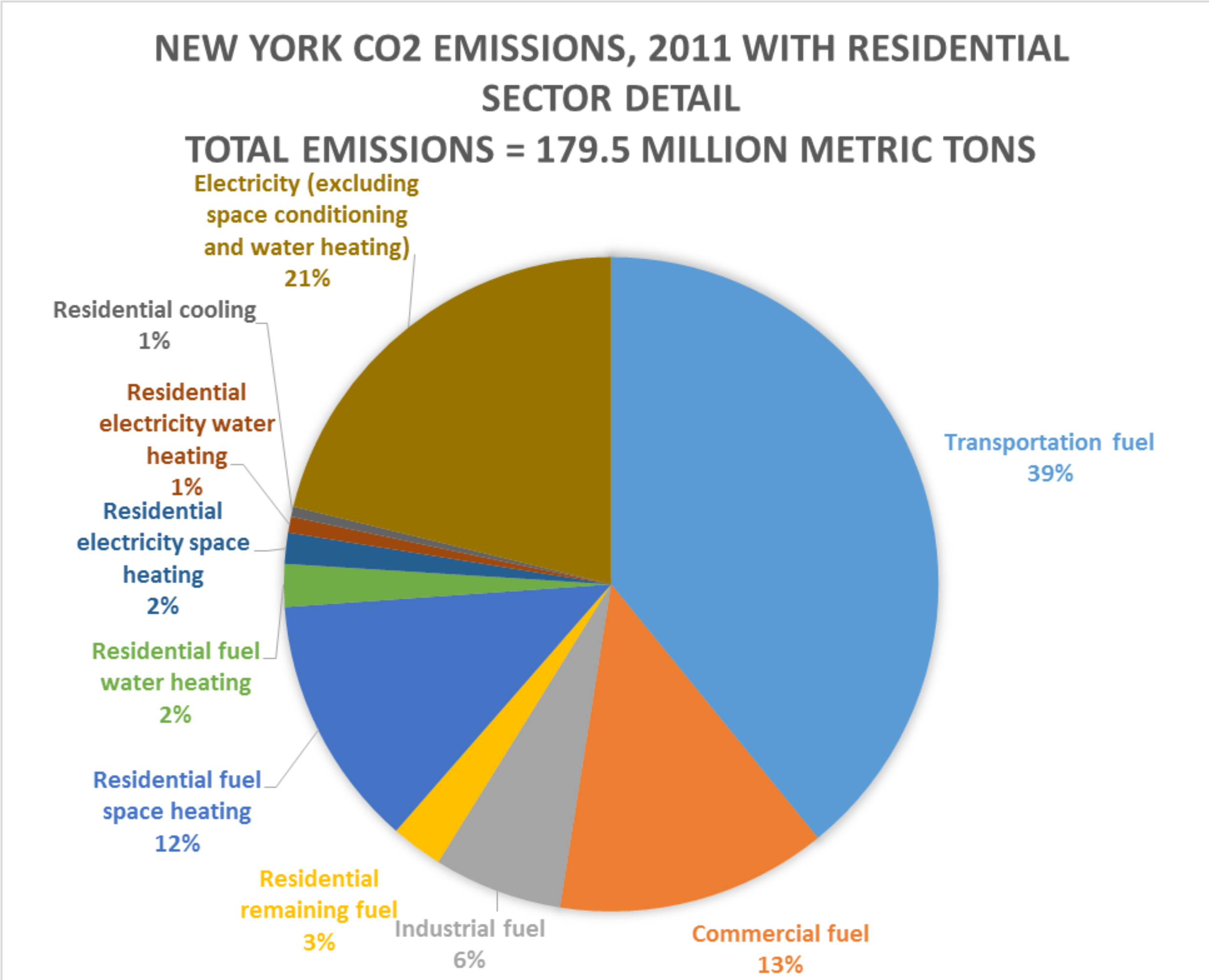

Figure I-1: New York State energy sector CO_2 emissions for 2011, with residential sector details. Source: NYS GHG Inventory 2015, Table S-1; residential sector detail: IEER calculations

There are several approaches for reducing direct fuel use for space and water heating. The most direct way, using commercial technology that is widely available, is to convert fossil fuel space and water heating systems to efficient electric ones. This reduces energy requirements at the point of use. It can also reduce primary energy use, which includes losses incurred during electricity generation, depending on the efficiency of the heat pump water heater and the pattern of hot water use. Thermal electricity generating plants, notably coal and nuclear, discharge about two-thirds of the energy in fuel as waste heat.

The conversion to efficient electric systems also prepares the ground for a continual reduction of CO_2 emissions from the space and water heating sector as the electricity system is made more renewable compared to the present one. New York's emissions per megawatt-hour of electricity generation were just under a quarter of a metric ton per MWh in 2014.[20] This level of emissions per unit of electricity is relatively low when compared with other states; it will further decline as New York implements its plans

[20] Calculated from EIA States 2016 New York, Table 7, EIA's state electricity profile for New York.

to increase renewable energy to 50 percent by 2030.[21] As the grid is made more renewable using solar and wind energy, thermal losses in electricity generation are gradually eliminated, making the system more efficient. The grid can be made fully renewable in 25 to 35 years, at which point the CO_2 emissions from electric space and water heating systems will go to zero.[22]

II. Space heating and cooling in New York

Space heating is the largest single residential energy use in New York State, representing 57 percent of residential energy at the point of use. Water heating accounts for another 17 percent. In contrast, cooling represents only about 1 percent of the energy at the point of use.[23] However, New York State has varied climate zones, where the balance of heating and cooling is quite different. Upstate New York has far greater heating requirements than New York City and its environs, which in turn has higher cooling requirements relative to the upstate regions.

The New York State Energy Research and Development Authority (NYSERDA) has divided the state into three climate zones, shown in Figure II-1. We will use these zones in our analytical framework in this report.

[21] DSIRE NYS RPS 2016
[22] For a detailed roadmap of a fully renewable and reliable grid, see Makhijani 2016.
[23] EIA RECS 2009 New York. Electricity at the point of use is converted at the rate of 3,412 Btu per kilowatt-hour; this conversion does not take into account losses in converting fuel into electricity at the power station or transmission and distribution systems.

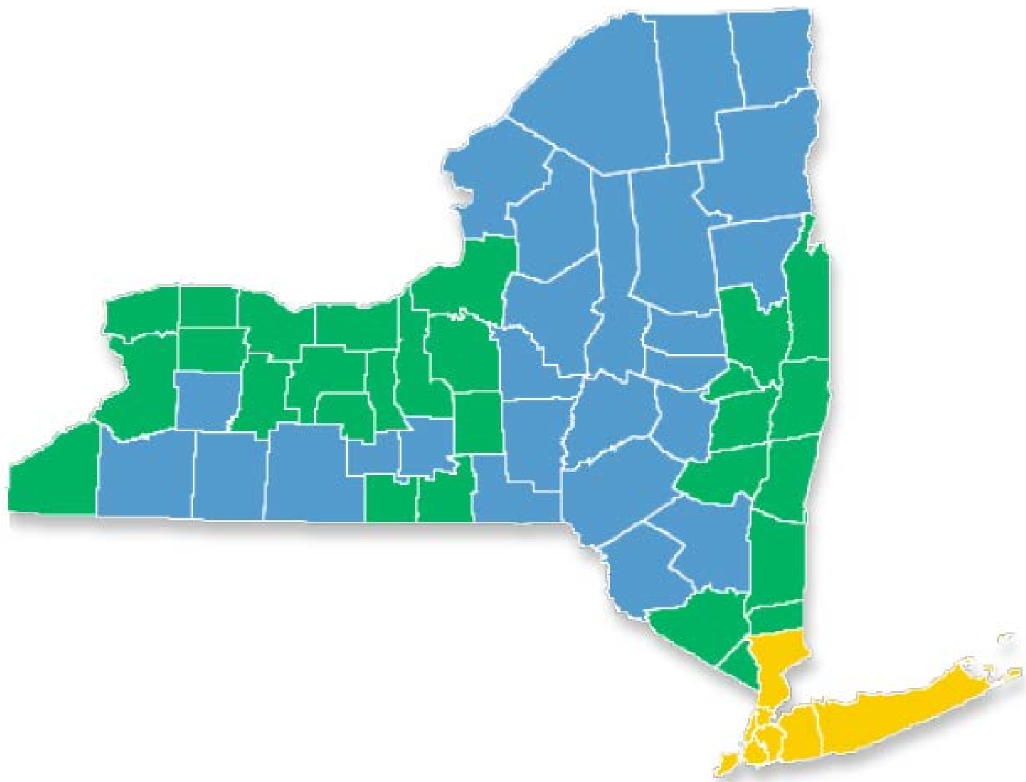

Figure II-1: Map of Climate Zones in New York State. Yellow = Climate Zone 4; Green = Climate Zone 5; Blue = Climate Zone 6. Source: NYSERDA 2015, v. 1, p. 3

The heating system methods of households in the three zones are shown in Tables II-1 (all housing units), II-2 (structures with one to four units), and II-3 (structures with five or more units).[24]

Overall, about ninety percent of housing units use heating systems that burn fossil fuels directly for heating. Most of these units use natural gas (56 percent); fuel oil is the second most prominent heating fuel (27 percent). Only a small fraction of homes use electricity (seven percent) for heating and an even smaller number use wood or wood pellets. Some large buildings also have steam heating; fossil fuels are usually used to produce the steam.

The cooling system characteristics of households in the various zones are shown in Tables II-4 through II-6. Table II-4 shows cooling system data for all housing units; Table II-5 shows the data for structures with one to four units; Table II-6 shows the data for structures with five or more units.[25] Unlike many states with warm and humid climates where central air conditioning dominates, room air conditioners are the most common type of cooling technology, followed by central air conditioners. Since summers are not very harsh in much of New York State compared to the more southerly states along the Atlantic coast, almost a million New York households have no cooling system at all. Households without cooling systems are mainly in structures with one to four units, rather than apartment buildings with five or more units. The cooling requirements in Climate Zone 4 (New York City and environs) are markedly

[24] Data compiled by IEER from Volumes 1 and 2 of NYSERDA 2015.

[25] Data compiled by IEER from Volumes 1 and 2 of NYSERDA 2015.

greater than in Climate Zones 5 and 6. There are about 550 cooling degree days on average in the latter two zones; the total annual cooling degree-days in Climate Zone 4 are about double that.[26]

Figures II-2 and II-3 show the heating and cooling system characteristics (respectively) of households in New York State by climate zone.

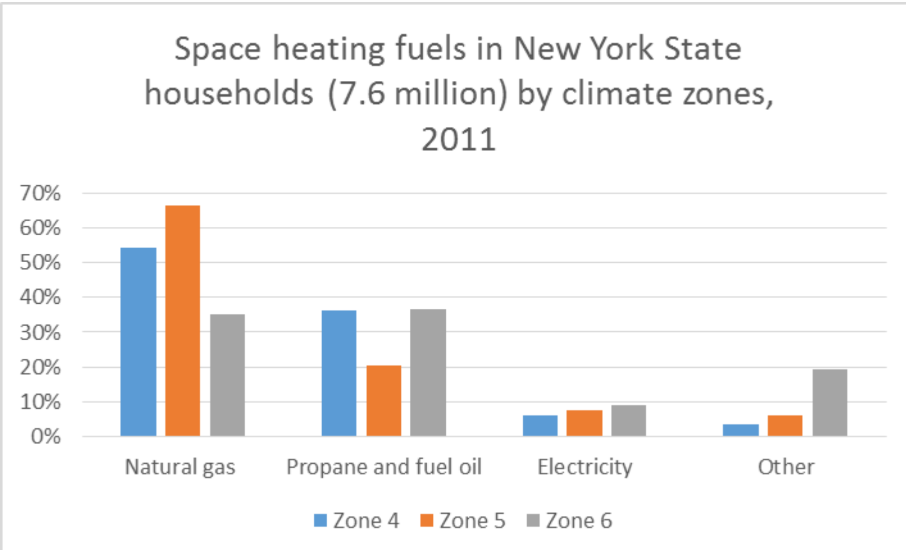

Figure II-2: Space heating fuels, percentage of households, by climate zone, 2011
Source: Compiled by IEER from NYSERDA 2015, Vols. 1 and 2

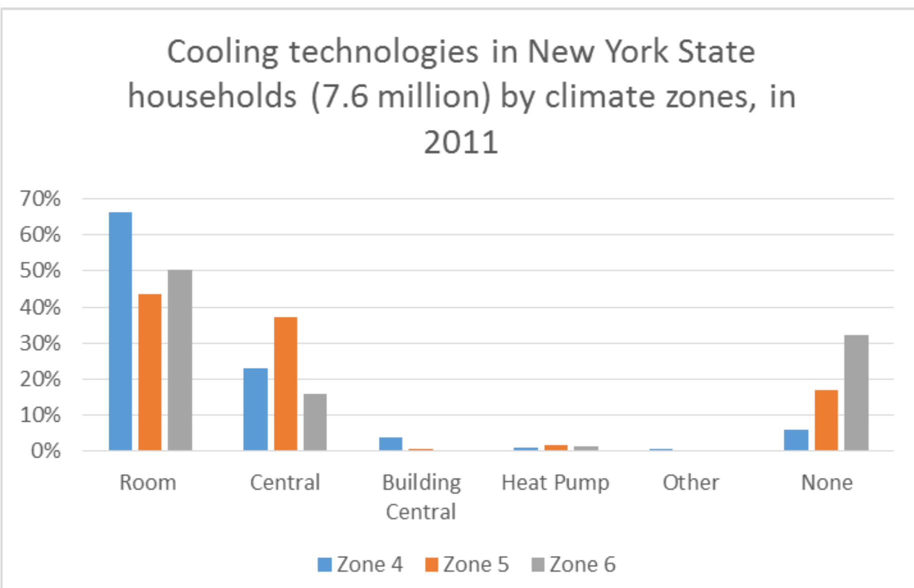

Figure II-3: Space cooling technologies, percentage of households, by climate zone, 2011
Source: Compiled by IEER from NYSERDA 2015, Vols. 1 and 2

[26] Heating and cooling degree days are from NYSERDA Degree Days 2016. Cooling degree days provide a temperature-related measure of air-conditioning requirements in a particular area.

There are generally significant differences in the energy use patterns of single unit housing structures and structures with 2 or more units. There are also energy use differences between structures with 2 to 4 housing units and those with 5 or more units. Most of the housing units in the latter type of structure are in large buildings. In this report we will not analyze housing units located in structures with 5 or more units, just under one-third of the total. Of the 5+unit structures, almost 90 percent are in New York City and its environs – that is, in Climate Zone 4.

This analytical framework is well-suited to consider the question at hand: the energy, CO_2 emissions, and cost implications of converting fossil fuel used for space and water heating to electric systems.

The data in the *NYSERDA Residential Statewide Baseline Study* (NYSERDA 2015) do not distinguish between structures that have only one unit and those that have 2 to 4 units. These data are available for New York City, where about 56 percent of all housing units in the state were located in 2011. We used the split between one unit and 2 to 4 unit housing structures in the New York City area as being typical of other areas of the state to create a statewide picture. We tested the aggregated energy picture that emerged for space heating and cooling against published statewide data and found reasonable agreement; this provided the basis for selecting the "typical" heating and cooling examples that we analyze in this report.

Table II-1: Heating characteristics of New York households. Overall (single and multiple family), 2011, by climate zone

	Electricity	Natural gas from underground pipes	Propane (bottled gas)	District steam	Fuel oil	Kerosene	Wood/wood pellets	Solar	Geothermal	Other, specify (coal)	Total
Zone 4	277,022	2,533,721	19,947	61,472	1,667,311	0	12,467	0	12,467	66,459	4,650,866
Zone 5	158,534	1,430,935	182,585	1,922	252,912	11,532	84,565	1,922	11,532	15,376	2,151,814
Zone 6	74,685	295,513	126,225	0	179,832	42,854	98,954	779	6,233	11,687	836,763
Subtotal	510,242	4,260,170	328,756	63,394	2,100,055	54,386	195,986	2,701	30,232	93,522	7,639,444

Table II-2: Heating characteristics of New York households: structures with one to four units, 2011, by climate zone

	Electricity	Natural gas from underground pipes	Propane (bottled gas)	District steam	Fuel oil	Kerosene	Wood/wood pellets	Solar	Geothermal	Other, specify (coal)	Total
Zone 4	149,600	1,326,452	19,947	7,480	952,452	~0	12,467	~0	12,467	12,467	2,493,331
Zone 5	130,692	1,235,809	182,585	1,922	246,009	11,532	84,565	1,922	11,532	15,376	1,921,942
Zone 6	56,100	260,241	126,225	0	176,091	42,854	98,954	779	6,233	11,687	779,166
Subtotal	336,392	2,822,502	328,756	9,402	1,374,552	54,386	195,986	2,701	30,232	39,530	5,194,439

Table II-3: Heating characteristics of New York households: structures with five or more units, 2011, by climate zone

	Electricity	Natural gas from underground pipes	Propane (bottled gas)	District steam	Fuel oil	Kerosene	Wood/wood pellets	Solar	Geothermal	Other, specify (coal)	Total
Zone 4	127,422	1,207,270	0	53,992	714,859	0	0	0	0	53,992	2,157,535
Zone 5	27,842	195,126	0	0	6,903	0	0	0	0	0	229,872
Zone 6	18,585	35,272	0	0	3,740	0	0	0	0	0	57,598
Subtotal	173,850	1,437,668	0	53,992	725,502	0	0	0	0	53,992	2,445,005

Table II-4: Cooling systems in New York households: overall, by climate zone, 2011

	Room	Central	Building central	None	Heat pump	Other	Total
Zone 4	3,084,426	1,062,930	174,935	268,401	39,893	22,440	4,653,026
Zone 5	936,628	803,971	9,664	363,965	33,973	5,766	2,153,966
Zone 6	421,580	132,235	1,266	268,671	10,616	1,558	835,927
Subtotal	4,442,633	1,999,137	185,865	901,038	84,482	29,764	7,642,919

Table II-5: Cooling systems in New York households: structures with one to four units, by climate zone, 2011

	Room	Central	Building central	None	Heat pump	Other	Total
Zone 4	1,294,039	954,946	0	182,013	39,893	22,440	2,493,331
Zone 5	814,904	730,338	0	342,106	30,751	5,766	1,923,864
Zone 6	391,141	125,446	0	250,891	9,350	1,558	778,387
Subtotal	2,500,083	1,810,729	0	775,010	79,994	29,764	5,195,582

Table II-6: Cooling systems in New York households: structures with five or more units, by climate zone, 2011

	Room	Central	Building central	None	Heat pump	Other	Total
Zone 4	1,790,387	107,985	174,935	86,388	0	0	2,159,695
Zone 5	121,724	73,633	9,664	21,860	3,221	0	230,102
Zone 6	30,439	6,790	1,266	17,780	1,266	0	57,540
Subtotal	1,942,550	188,407	185,865	126,027	4,487	0	2,447,337

Table II-7: Households in one unit and two-to-four unit structures in the three New York Climate Zones

	1 to 4 units	1 unit	2 to 4 units
Zone 4	2,493,331	1,749,219	744,112
Zone 5	1,921,942	1,455,997	465,945
Zone 6	779,166	590,269	188,897
Subtotal	5,194,439	3,795,486	1,398,953

Source: NYSERDA 2015 and for New York City: US Census NYC 2013 AHS, Table C-01-AO-M, New York City

Of the housing units left out of the study (those in buildings of 5 or more apartments), almost 90 percent are in Climate Zone 4 (New York City and environs, including Long Island). These data are shown in Table II-8.

Table II-8: Households in buildings with five or more units, by climate zone

	5 or more units
Zone 4	2,159,695
Zone 5	230,102
Zone 6	57,540
Subtotal	2,447,337

Source: NYSERDA 2015

In effect, our omission of buildings with five or more units in this study is very largely coincident with the omission of large apartment buildings in New York City and its environs. Even so, more than half of the housing units in Climate Zone 4 are included in this assessment.

We have omitted the large apartment buildings, mainly in the New York City area, due to the complexity of modeling them by the methods used in this study. Specifically, it would be very difficult to represent the variety of buildings so as to reasonably estimate the cost impact (and hence the economic feasibility) of eliminating or greatly reducing the use of fossil fuel use for space and water heating in large apartment buildings. The energy use and emissions per unit would be expected to be lower than in the single unit and two-to-four unit buildings due to lower losses via exterior surfaces and smaller floor area. Large apartment buildings represent about a third of the total housing units in the state; their space and water heating may be on the order of one quarter of the total for the residential sector. Given their importance, this is an area that deserves further study.

III. Technologies for reducing HVAC-related CO_2 emissions

Fossil fuel use for space heating can be reduced in a variety of ways. For new buildings, it is important is to adopt the passive house approach, which relies on the design and orientation of the structure and its features to eliminate most of the demand for heat. This can easily be accomplished in new buildings.

A passive house approach for new buildings is especially applicable in Climate Zones 5 and 6, where cooling requirements, as indicated by cooling degree days, are relatively low. Passive house standards are most stringent for the building envelope. They eliminate three-fourths or more of the energy used for heating and cooling[27] and yet cost only five to ten percent more compared to standard construction.[28] Single family, detached home construction data indicate an additional cost of between $12,000 and $24,000 to build to these standards.[29] This does not take into account the near-certain result that enactment of passive house standards would lower that additional cost, because such construction currently tends to be custom-designed. Total annual energy costs in Climate Zone 5 in a typical detached single family structure would typically be about $2,700, including all energy uses. Of this the space conditioning and water heating costs are about $1,700. (See Section IV.2, Table Zone 5-B.) If the total energy savings in heating and cooling bills due to passive construction amount to about three-fourths of the total shown in Table Zone 5-B, the present value of the savings over 22 years would be about $21,000. Typically passive houses also have very efficient appliances, which would reduce electricity use and bills for other uses of electricity that space heating, cooling, and water heating. At $300 per year in savings, and a typical appliance life of 10 years, the present value of the savings would be about $2,600.[30] Hence the total energy bill savings indicated would offset the upper end of the added cost of passive construction, justifying the promulgation of such standards. The benefits are magnified when low-income housing is built to these standards, due to increased non-energy benefits such as improved health. One would also expect fewer evictions and foreclosures due to greatly decreased conflicts between paying energy bills and making rent or mortgage payments.[31]

However, new housing only slowly replaces existing structures. The main issue that needs to be addressed in regard to phasing out space heating and cooling related CO_2 emissions, is retrofitting existing buildings. The most common approach for converting fossil fuel space heating to an efficient electric system is to use some kind of “heat pump.” This is a machine that draws energy in the form of heat from the environment (the air or the ground or a water body); this energy is then “pumped up” to the temperature required to provide comfortable space heating by a machine that is essentially an air conditioner operating in reverse. It takes the outside heat and puts it into the house, while an air conditioner does the reverse.

Almost all heat pumps can be run in reverse to provide air conditioning (cooling) in the summer. The conversion from fossil fuels to efficient cold climate heat pumps thus presents the added opportunity of making air conditioning more efficient through the suitable choice of equipment, since such heat pumps also typically cool more efficiently.[32] This would reduce energy use and air-conditioning-related CO_2

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[27] Gregor 2015

[28] Passive House Institute 2016. The added cost per square foot is smaller for larger buildings.

[29] Data on construction cost are from National Association of Home Builders (Taylor 2015, Table 2). We used the construction cost as 60 percent of $400,000, which approximates the typical values provided for 2011, 2013, and 2015.

[30] We use a 22-year calculation for present value for heating as the average between a 30-year mortgage and a 15-year life of HVAC equipment. We assume that about a third of the electricity used in appliances and lights would be saved in a passive house compared to a standard new house.

[31] See Makhijani, Mills, and Makhijani 2015 for a detailed discussion of non-energy benefits of lowering the energy bills of low-income households to affordable levels.

[32] The efficiency of a heat pump for a given outdoor winter (or summer) temperature depends on a number of factors including the efficiency of the compressor and the motor that drives it as well as the refrigerant that is used as the operating fluid to transfer heat (or cold) from one side of exterior walls of the house to the other. The use of high efficiency compressors, variable speed motor drives, and refrigerants that boil at low temperatures (such as 50°F below zero) makes cold climate heat pumps more efficient than typical equipment. Geothermal heat pumps are even more efficient since they extract (or dump) heat from (or into) the ground, where the year-round temperature is more even.

emissions. Making air conditioning more efficient has the added advantage of reducing summer peak loads and hence overall costs of the system of electricity supply. This is because overall electrical system capacity is geared to meeting peak load. Peaking capacity, notably from gas turbines, sits idle for well over 90 percent of the year and often over 95 percent of the year. The capital costs of capacity must be paid whether the system is producing or not. The idle time is the main factor that makes supplying peak load expensive.

Two different types of heat pumps – air-to-air and geothermal are commonly used.

1. Air-to-air heat pumps draw heat from outside air in the winter and pump it up to a higher temperature to provide heating in the structure. The reverse process takes place in the summer, when heat is taken from inside the house and dumped into the outside air in a manner similar to the operation of a refrigerator. As noted, we recommend the more efficient cold-climate heat pumps from among the air-to-air heat pumps for use in New York State.
2. Geothermal heat pumps take heat from the ground (or a water body) and pump it up to heat the home in the winter, with the reverse process occurring in the summer for cooling.

Each system has variants but the broad principle of heat pumps is that they take "free" energy from the environment in the winter, thus providing greater heating than would be available using electricity as a heat source alone. Both types of heat pumps use electricity to run the pumps – the electricity is for a motor to drive the compressor and another motor to drive a fan. Figure III-1 shows a schematic of a heat pump operating in the winter as a heating system – drawing heat from the outside air, pumping it up to the requisite temperature and providing heat for the house.

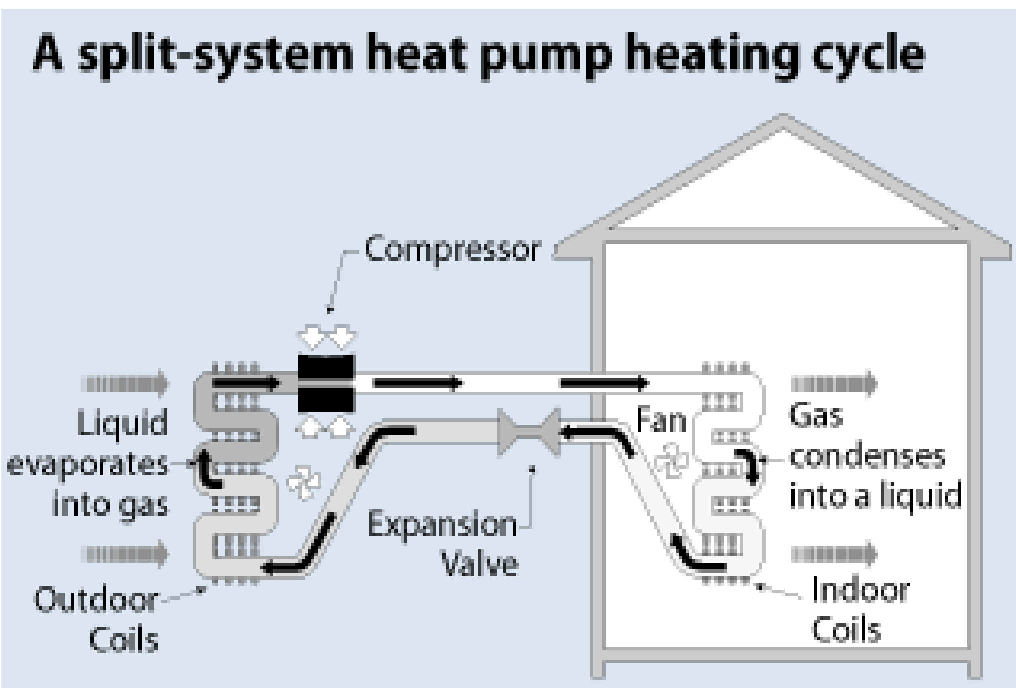

Figure III-1: A heat pump operating in heating mode. Evaporation is the means by which heat in the outside air is absorbed by a liquid refrigerant that boils at low temperature (as low as -50°F).
Source: DOE EERE 2013, http://energy.gov/eere/energybasics/articles/air-source-heat-pump-basics

Figure III-2 shows a schematic of a closed-loop geothermal heat pump, operating in air-conditioning mode. It also has a de-superheater; this is a device that extracts some of the heat that would otherwise be wasted and uses it for hot water. Thus, a geothermal heat pump not only reduces space heating requirements and makes air conditioning more efficient; it also reduces energy requirements for hot water – more so in the summer than in the winter.

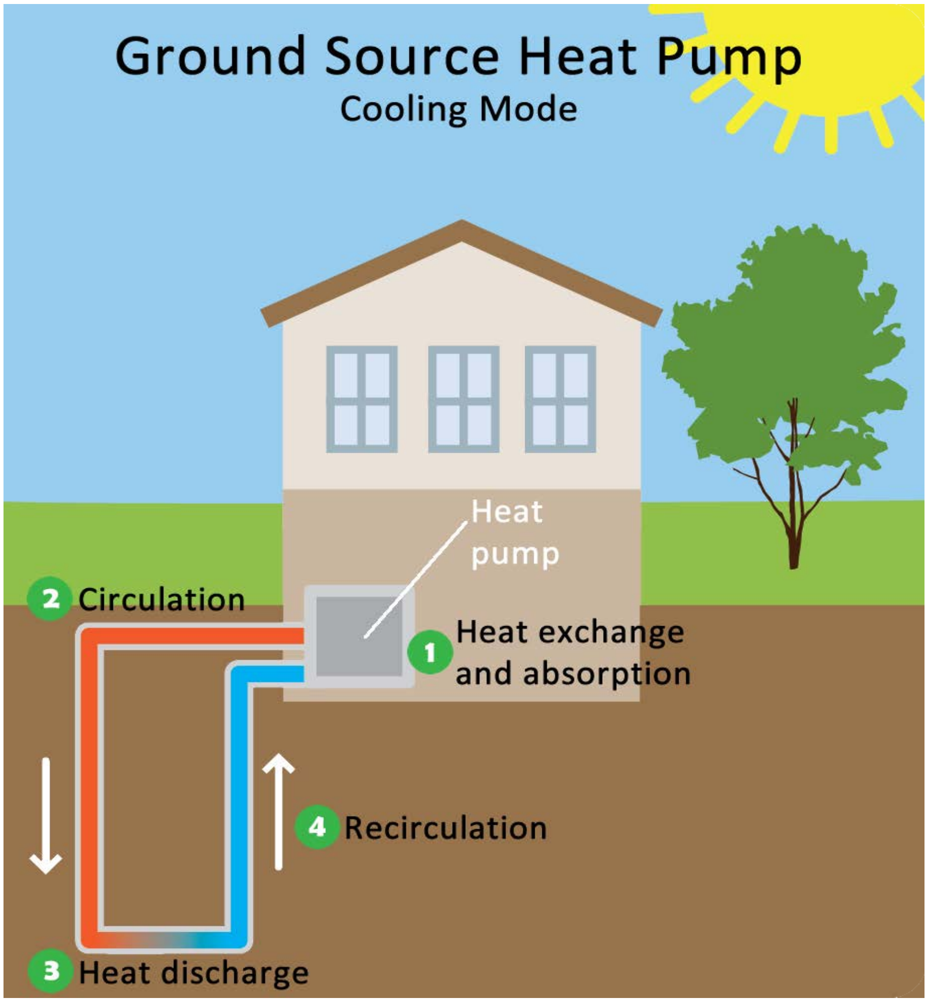

Figure III-2: A geothermal heat pump shown a cooling mode. The indoor equipment is as in Figure III-1, but the circulation of the refrigerant is reversed. Source: EPA Geothermal 2016

The big advantage of geothermal heat pumps is that, at depths of more than a few feet, the ground remains well above freezing temperatures, making it a reliable and predictable source of heat available to the heat pump system. The air-to-air heat pump, in contrast, must extract heat from a wide range of air temperatures.

Air-to-air heat pumps have their compressor coils outdoors; they can therefore become covered with snow or frost, reducing efficiency and requiring energy for defrosting. In contrast, geothermal heat pumps have all their equipment indoors – and the well is underground. This not only assures better performance overall, but also results in longer equipment life. The biggest disadvantage of geothermal heat pumps is the up-front cost. Specifically, the closed loop system required for a vertical well or horizontal coils adds a considerable amount to the overall cost, with the former generally being more expensive than the latter.[33] Cold climate heat pumps are air-to-air heat pumps that operate efficiently down to low temperatures, well below freezing. However, a geothermal heat pump is even more efficient than a cold climate heat pump. Moreover, the only outside equipment, the geothermal ground-loop, is underground. Unlike an air-to-air heat pump, the compressor and condensing coil are inside the house. A geothermal heat pump therefore typically lasts much longer than an air-to-air heat pump; the ground loop can be expected to last as long as the house. The higher efficiency and durability offset much of the added cost of the geothermal heat pump.

Efficient extraction of heat requires, among other things, a refrigerant that boils at low-temperatures. Many ordinary air-to-air heat pumps are relatively inefficient below the freezing point of water and require supplemental strip heat (i.e., a resistance heating element) as a backup at low temperatures.[34] This means that the heat pump aspect of the device is lost, since little or no heat is being derived from the atmosphere.

Air-to-air heat pump efficiency can be increased by using low boiling point refrigerants. These are called cold climate heat pumps. Modern "cold-climate" heat pumps use R-410A as a refrigerant, which boils at about -55^{o}F;[35] they are therefore able to extract heat from the air at far lower temperatures than those generally encountered in New York State. The same refrigerant is used in geothermal heat pumps. Evidently, the refrigerant will boil more vigorously and the vapor will achieve a higher temperature, the higher the ambient temperature. For this reason, geothermal heat pumps are more efficient (all other things being equal) than air-to-air heat pumps.

Figure III-3 shows the performance of three different types of air-to-air equipment at various temperatures.

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[33] There are also open loop geothermal systems that use groundwater or surface water as a heat source.

[34] Even highly efficient heat pumps generally have a resistance heating element in case of extreme weather.

[35] Wikipedia R-410A 2016, https://en.wikipedia.org/wiki/R-410A. R-410A is the typical way in which the refrigerant is designated in the HVAC industry. It is a hydrofluorocarbon and, therefore, is also known as HFC-410A. It is a greenhouse gas that is more than 2,000 times more powerful than CO_2 (100-year averaging time). (Rajendran 2011) Replacement of R-410A by a refrigerant that is less potent or not a greenhouse gas is desirable. Actually CO_2 is a good refrigerant. It's boiling point at -109^{o}F is even lower than R-410A. A global treaty to reduce the use of HFCs was arrived at in October 2016. (UNEP 2016)

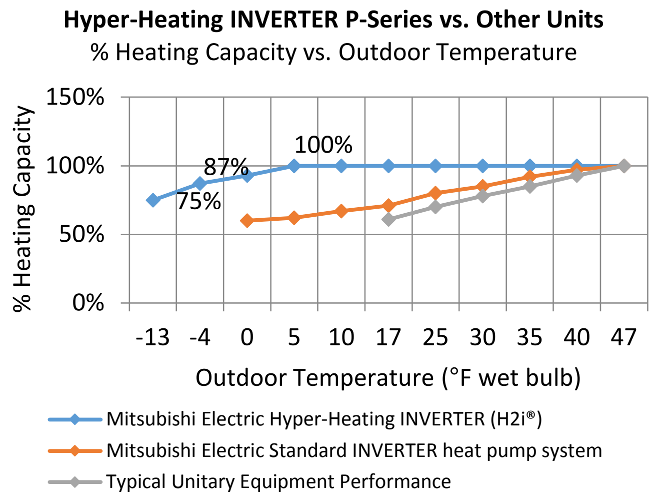

Figure III-3. Heating capacity of heat pumps at various outdoor temperatures (before correction for defrost). Source: Recreated by IEER from Mitsubishi 2010, p. 7.

It is evident from Figure III-3 that "cold climate" heat pumps can provide efficient heating down to about 5°F.

Even cold climate heat pumps lose heating capacity at temperatures around 5°F and below. However, temperatures in New York State, especially in Climate Zones 5 and 6, are frequently below that level. Geothermal heat pumps do not have the problem of falling performance at low temperatures, but they are far more expensive than cold climate heat pumps, essentially due to the added cost of the ground loop that collects the heat from the ground. We therefore examine two emerging heat pump technologies that could improve performance over cold climate heat pumps and with lower cost than geothermal heat pumps.

1. Solar assisted heat pumps

The efficiency of air-to-air heat pumps at low temperatures can be improved by combining them with solar thermal technology. Normally, solar thermal technology is used for hot water supply. The working fluid heated in the solar panel is either water or anti-freeze; it stays liquid throughout the process. Solar thermal technology is not suitable for the rigorous demands of space heating in cold climates, not least because solar energy availability is lowest in the winter when the need is greatest. However, if a refrigerant that boils at a very low temperature (such as R-410A at -55°F) is circulated in solar thermal panels, much more heat can be extracted.

This new approach to extracting heat from the winter sun using a low-boiling point refrigerant has been joined to air-to-air heat pump technology. Further, unlike a normal air-to-air heat pump, no outside compressor is needed if the application is only for heating. The operation is similar to an air-to-air heat pump from there on. The enhancement of heat extraction by solar panels allows the heat pump to operate at higher efficiency at any given temperature. This technology is being commercialized by a Canadian company, SunPump Solar, based near Vancouver, British Columbia. Basically, the solar thermal panels replace the ground loop of the geothermal heat pump.[36] The system can also deliver hot water. As with essentially all heat pumps, it has an electric resistance element for extreme circumstances. One evaluation put the coefficient of performance (COP) at 7 in the daytime (presumably on a sunny day) and 2.7 at night.[37] Coefficient of performance indicates how much heat is provided for each unit of electricity consumed. Thus a COP of 7 means that 7 units of heat will be delivered into the house for each unit of electrical energy consumed. Since it is basically an air-to-air heat pump, it works even when the solar panels are covered with snow, as long as the refrigerant can boil.

SunPump Solar has sold about 100 heat pumps to date.[38] While most installations are in the Vancouver, British Columbia, area, there are also installations in climates more nearly comparable to the northeastern United States, like the home shown in Figure III-4, in Prince Edward Island.

Figure III-4. Two views of solar thermal panels associated with a SunPump heat pump on Prince Edward Island, Canada. Source: SunPump Gaudin 2016 (Solar Source Ltd, PEI, Canada. www.sunpump.solar)

The climate on Prince Edward Island is slightly colder than that of Albany, New York (in Climate Zone 5). It would appear therefore that this technology could be used in a wide variety of situations in New York State, probably across all its climate zones.

So far the system has been installed in heating mode only. An outside compressor and coil would need to be added for central air conditioning. However, it would not be needed in most circumstances in New York's Climate Zones 5 and 6, where room air conditioners are the more common form of air conditioning. Thus it would appear that this new solar-assisted heat pump technology may be ideal for New York, notably in situations where room air conditioning is used or there is no air-conditioning at all.

2. *Oak Ridge/Emerson advanced cold climate heat pump*

[36] See the company's FAQ at https://www.sunpump.solar/solar-heating-f-q. (SunPump FAQ 2016)

[37] Alter 2015. The company is also combining the solar thermal panel with solar PV so that the system generates heat for the heat pump and electricity for other uses (including operating the heat pump compressor).

[38] Personal email communication, Lois Chalmers with SunPump Solar CEO, Bruce Gray, November 5, 2016 (Gray 2016)

Another approach to improving upon cold climate heat pumps is an advanced cold climate air-to-air heat pump developed by Oak Ridge National Laboratory and Emerson Climate Technologies, with innovative compressor arrangements, which can operate efficiently down to -13°F. This is considerably better than currently sold cold climate heat pumps, which go down to about 5°F – the efficiency declines at lower temperatures (see Figure III-4 above). Other than the advanced compressor design optimized for very low temperature operation, this system is basically the same as a normal air-to-air heat pump. The system has been tested in a real home in Sydney, Ohio; performance was slightly better than expected;[39] however, the technology has not yet been commercialized. There appear to be no technical obstacles to its commercialization, as far as IEER can determine. The main obstacle appears to be that there is not an uptake of the technology for manufacturing, possibly reflecting a complex legal-economic situation. If commercialized, the Oak Ridge/Emerson scroll compressor heat pump may be the most economical cold climate heat pump suited for all climate zones in New York State.

3. Heat pump water heaters

Residential water heating is responsible for about 3 percent of New York State's energy sector CO_2 emissions; about two-thirds of that is due to direct use of fuels (mainly natural gas) and the rest is resistance electric water heating. As with space heating, water heating can be made much more efficient either through the use of heat pump water heaters to replace natural gas and resistance heaters or through waste heat recovery in conjunction with geothermal heat pumps. We have already discussed the latter in a previous section.

Heat pump water heaters work on the same principle as space heating heat pumps. However, the practical implications are somewhat different in that the heat pump will generally draw its "free" energy from the ambient air inside a utility room, closet, or garage where it is located rather than from outside the structure, as is the case with space heating heat pumps.

Heat pump water heaters cool down the air around them when they withdraw energy from it to heat the water. If the heat pump water heater is in a conditioned space, it means that air-conditioning energy requirements are reduced in the summer, while heating requirements are made higher in the winter. As a first approximation, there is no net effect in the spring and fall. A second consideration is that there must be a sufficient volume of air[40] around the heat pump water heater from which it can draw energy. This can restrict the use of heat pump water heaters. For instance, it may not be feasible to install them in apartments where resistance or natural gas water heaters are installed in closets or other tight spaces. In such cases, a SunPump device or on-demand electric water heaters may be an appropriate way to reduce direct fossil fuel use for water heating.

i. Retrofitting electric water heaters

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[39] Abdelaziz and Pham 2016. The heat pump uses two scroll compressors operating in parallel.
[40] The volume of air needed is a structure-specific design parameter that will be vary from one installation to the next.

About one-fifth of New York State households in one-to-four unit structures use electric water heaters[41] -- about one million households in all. A heat pump water heater costs $900 more than a regular electric water heater; it is about 3 times as efficient. Figure III-5 shows the investments and payback in a scenario that replaces 10,000 electric resistance water heaters per year over a period of 10 years for a total of 100,000 replacements.

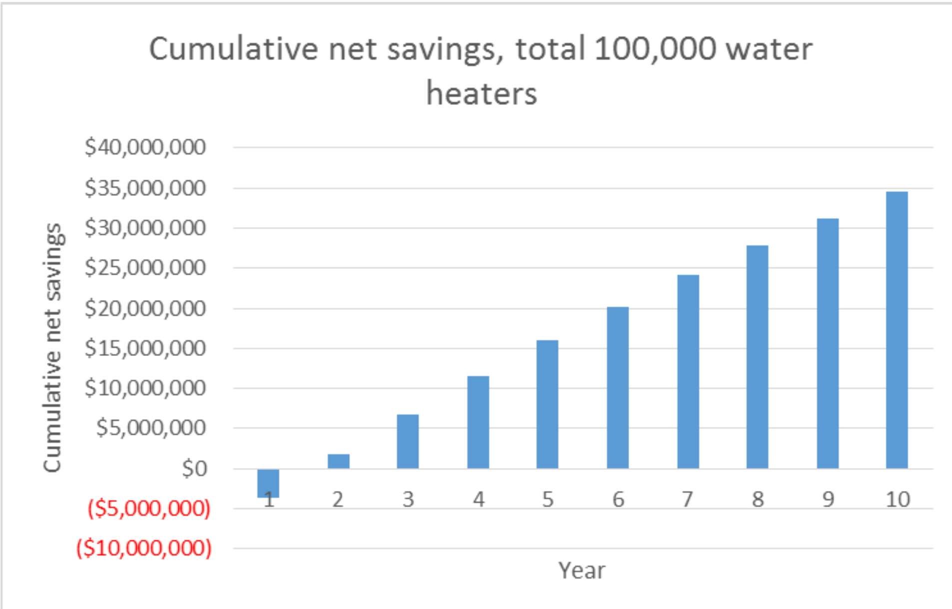

Figure III-5: Net cumulative savings, over ten years, obtained by replacing 10,000 electric resistance water heaters each year with electric heat pump water heaters in low-income households currently receiving assistance. Source: IEER.

It is clear that such a retrofit program could have significant value, especially for low-income households. Given New York's program to limit household energy bills of low-income households to 6 percent of income, the reduced electricity bills would also reduce assistance costs.

IV. Case studies of conversion from fossil fuels to electricity

Figure I-1 above shows that conversion of direct fossil fuel use for space and water heating in New York State to electric systems that can be powered by renewable energy is essential for achieving deep reductions in CO_2 emissions by the middle of the century. We developed case studies of typical situations in Climate Zones 4 and 5 that would allow evaluation of heating technology retrofits to households, while also being, when put together, approximately representative of New York State as a whole, except for large apartment buildings.[42]

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[41] NYSERDA 2015, v. 1, Table 38. The proportion is 37 percent in structures with five or more units. (NYSERDA 2015, v. 2, Table 27) We have not analyzed the latter in this report. The same reasoning for electric water heater conversion would apply in the case of large apartment buildings. The technical potential for retrofitting heat pump water heaters would be limited in such cases by the lack of suitable locations for their installation.

[42] As previously noted, we exclude buildings with five or more units from the quantitative parts of our analysis even though the technologies discussed here may have applicability to many of them. As a result about two-thirds

1. Approach to selecting case studies

We consider buildings with one housing unit (detached or attached) and buildings with 2 to 4 units, in Climate Zones 4 and 5. We exclude buildings with five or more housing units from this analysis. Almost 90 percent of the 5+ housing unit buildings are in Climate Zone 4 – that is New York City and its environs (including Long Island). This separation of building types is important for a variety of reasons, including the prevalence of room air conditioning as the single most common type of cooling in New York State. We assume that central air conditioning is much more likely to be used in single family structures (attached or detached), while room air conditioning is more likely to be used in structures with more than one housing unit. In turn, the partition of central and room air conditioning is important in evaluating the cost of HVAC system retrofits and payback time.

New York State's baseline survey does not include a breakdown of housing units into 1 unit buildings and 2 to 4 unit buildings. Rather, it provides data only for 1 to 4 unit buildings and buildings with 5 or more units. We used New York City data, where a more refined breakdown is available, to infer approximate numbers of buildings in each climate zone. New York City represents about 56 percent of the total households in the State; hence the method should provide values that are adequate for the purposes of the analysis in this report. The results of our analysis are shown in Table IV-1.

Table IV-1: New York State housing by climate zone and number of units per structure (rounded)

	1 unit	2 to 4 units	5 or more units	Total
Zone 4 (actual)	1,749,000	744,000	2,160,000	4,653,000
Zone 5 (approximate)	1,456,000	466,000	230,000	2,152,000
Zone 6 (approximate)	590,000	189,000	58,000	837,000
Total	3,795,000	1,399,000	2,447,000	7,641,000

Source: IEER analysis based on *NYSERDA Residential Statewide Baseline Study* (NYSERDA 2015, v. 1 and v.2) (see Tables II-7 and II-8 above), and New York City data (US Census NYC 2013 AHS, Table C-01-AO-M, New York City).

We analyzed a single family detached structure and an apartment in a two to four unit building in both Climate Zone 4 and Climate Zone 5. For the single family structure, we considered pre-retrofit fuel oil heating and natural gas heating. For the apartment, we considered only pre-retrofit natural gas heating. Electric heating is not common in New York State (only nine percent of the total). We used prices of electricity, natural gas, and fuel oil typical of each zone for the year 2013.

To examine whether the structures we chose were typical, we checked our household case studies against the total heating and cooling energy statewide totals, making approximate adjustments for house types not represented in the case studies. This provides a check on the representativeness of the case studies for policy making purposes.

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of New York's residence are included in this part of the study. While we have not explicitly analyzed Zone 6, the analysis for Zone 5 generally applies, with the caveat that heating requirements are somewhat higher and cooling requirements somewhat lower in Zone 6 compared to Zone 5.

2. *Case studies*

i. Single unit structure

Table Zone 4-A compares site energy use, CO_2 emissions, and peak power demand for a single unit structure in New York's Climate Zone 4 using oil or natural gas as a fuel with a retrofit using a geothermal heat pump or retrofit using a cold climate heat pump. In all these comparisons, we assume that the fossil fuel heated home uses natural gas water heating. For the geothermal retrofit, we assume that a de-superheater is installed. In the case of a cold climate heat pump, we assume that a heat pump water heater is installed.

Table Zone 4-A: Site energy use, cumulative CO_2 emissions over 15 years, and peak power demand – Detached Climate Zone 4 housing unit

ZONE 4 DETACHED STRUCTURE - ONE HOUSING UNIT				
	Oil	Natural gas	GHP	Cold Climate HP
Space heating, MMBtu/y	60	60	12	18
Water heating, MMBtu/y	12	12	4	2
Electricity, fan/pump+A/C, MMBtu/y	8	8	4	4
Total site energy, MMBtu/y	80	80	20	25
Peak Load (A/C), kW	2.2	2.2	0.8	1.2
Cumulative CO_2, mt, 15 years	81.4	63.1	14.2	17.5
CO_2 reduction vs oil, mt, 15 years	N/A	N/A	67.1	63.9
CO_2 reduction vs natural gas, mt, 15 years	N/A	N/A	48.8	45.6
Peak load reduction, kW	N/A	N/A	1.4	1.0

Source: IEER calculations.

Notes: 1. Oil and natural gas heating based on a 1,500 to 2,000 square foot single housing unit structure. Heating estimate is derived from the Energy Star template, using an 80 percent efficiency for oil and natural gas furnaces, and rounded to one significant figure.

2. Geothermal system heating coefficient of performance (COP) assumed = 4[43] and cold climate heat pump COP assumed = 2.6.[44] Annual average heat pump water heater COP assumed = 3.[45] Geothermal heat pump de-superheater would supply 54.7 percent of the hot water,[46] with the rest being supplied by resistance electric heat. The overall COP of hot water supply would be about 1.7.

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[43] For COPs of Energy Star geothermal heat pumps see Energy Star GHP 2016. We have used 4, which is about 20 percent lower than the best performing closed loop system in this list. The range of COPs is 3.6 to 4.8.

[44] For cold climate heat pump performance see Winterize Maine 2014, p. 15. This document provides HSPF (heating system performance factor values) in the 10 to 12.5 range for ductless systems. These COPs assume that the homes have been insulated and leak-proofed well enough to prevent frequent operation of strip heat. The Energy Information Administration has published a spreadsheet with climate-adjusted HSPF values. (EIA Calculator 2014) The adjusted HSPF value for New York City for a high-end cold climate heat pump with a rated 12.5 HSPF is 8.8, which corresponds to a COP of about 2.6.

[45] A GE GeoSpring 50 gallon water heater has a nameplate COP of 3.25. (Lowe's GeoSpring 2016). We use a slightly lower value here to take account of the lower net efficiency in the winter and higher net efficiency in the summer, with the former being more important.

[46] NY-Geo 2016, p. 23

3. MMBtu means million Btu. Site energy for electricity is obtained by using 1 kWh-electrical = 3,412 Btu.

4. New York CO_2 emissions for 2017 per MWh of electricity = 0.242 metric tons, based on the value for 2014. (EIA States 2016 New York, Table 7). We use 2017 as the first year of program implementation for the purpose of calculation of CO_2 emission reductions. We estimated an emission rate of about 0.1 metric tons per MWh in 2030, given New York's renewable energy target of 50 percent by that date. Cumulative emissions for 15 years were calculated using an average of these two values (i.e., 0.171 metric tons per MWh).

Table Zone 4-B shows the annual cost comparison; Table Zone 4-C shows the overall analysis of present value over 15 years. Since the geothermal heat pump is expected to last for 25 years and the closed loop well for 50 years, we assume a residual value for the geothermal heat pump in the overall cost comparison. All other equipment is assumed to last for 15 years. [47] In all cases, we assume that the retrofit takes place at the time when the fuel oil or natural gas furnace needs replacement. Thus, only the net cost increase of a heat pump system over a fossil fuel system is taken into account.

Table Zone 4-B: Annual energy costs and savings – Detached Climate Zone 4 housing unit

COST AND SAVINGS ZONE 4 DETACHED HOUSING UNIT				
	Oil	Natural gas	GHP	Cold Climate HP
Energy cost (space+water heating +A/C)	$2,665	$1,970	$1,586	$1,949
Annual energy cost savings, relative to oil	N/A	N/A	$1,078	$715
Annual energy cost savings, relative to natural gas	N/A	N/A	$384	$20
Total energy cost, including non-heating and cooling uses, $/y	$3,904	$3,209	$2,825	$3,189
Energy burden @poverty level (3-person household), based on total energy cost	20%	16%	14%	16%
Assistance to keep energy burden @6% of income, $/y	$2,732	$2,037	$1,654	$2,017

Source: IEER calculations

Notes: 1. Fossil fuel and electricity prices were assumed to be constant in real dollars. 2. Natural gas cost in Zone 4 = $18.32 per million Btu[48]; fuel oil = $29.86 per million Btu[49]; electricity = $0.27 per kilowatt-hour (rounded). [50] These are values for 2013. Natural gas and fuel oil prices are lower in 2016, but they have been much higher than those assumed in this report. See Section V.5, below.

We note that households at the poverty level with oil-heated homes in New York Climate Zone 4 have a very high energy burden – 20 percent of income, assuming a household with three people with income at the federally defined poverty level ($19,530 for the year 2013). Installation of an efficient heat pump system (including an efficient electric water heating system) significantly reduces the energy burden. Another way of looking at it, is that there is a direct benefit to ratepayers and/or taxpayers for retrofitting low-income homes heated with oil, propane, or kerosene. This is because the New York Public Service Commission (PSC) has ordered that energy burdens of low-income households be limited

[47] For air to air heat pump system life, see CEE 2016. For geothermal heat pump system life, see DOE EERE 2016.

[48] Consolidated Edison rate in NYSERDA Trends 2015, Appendix F-4

[49] New York City fuel oil price, NYSERDA Oil Price 2016. Conversion parameter: #2 fuel oil = 138,000 Btu/gallon, Energy Star Conversions 2015, Figure 3.

[50] Consolidated Edison rate in NYSERDA Trends 2015, Appendix F-1

to 6 percent of household income.[51] This means that some combination of ratepayer and taxpayer funds will be required to provide the funds whenever energy burdens are more than 6 percent of gross income. Such programs are often called Percentage of Income Payment Plans. In the case of homes heated with natural gas, the annual energy bill would typically be lowered in case of retrofitting with a GHP but not materially with a cold climate heat pump.

We note that the New York PSC's affordability order clearly applies only to New Yorkers who heat their homes with electricity or natural gas, [52] which are both within the purview of the PSC. Low-income households which heat with fuel oil, propane, or kerosene – used by about 2.4 million households[53] -- will continue to be eligible for federal heating assistance. But they also need to be included within the New York State program to limit energy bills to 6 percent of income, not least because these households tend to have the highest energy burdens.

The New York PSC appears to have recognized the problem; the PSC Affordability Order opens the door for the inclusion of low-income households that use fuel oil and propane for heating in the percentage of income affordability program:

> At present, enrollment in most utility low income affordability programs generally is provided automatically to customers on whose behalf the utility received a HEAP [Home Energy Assistance Program] payment; however, recent events may clear a path for extending eligibility to all HEAP recipients, regardless of fuel type. Due to federal requirements, OTDA [Office of Temporary and Disability Assistance] has instituted new performance measures that are intended to ensure that HEAP benefits are targeted to those households with the greatest need. OTDA, with the assistance of the utilities, will now be required to gather and report certain data for all HEAP recipients, regardless of fuel type. To comply with the federal requirements, beginning with the 2015-2016 HEAP program year, OTDA intends to begin providing lists of all HEAP recipients in their respective service territories to the utilities, so that they can provide the required data.[54]

Reducing the energy bills of low-income households, for instance by subsidizing more efficient heating systems and by making building envelopes less leaky, has the direct effect of reducing bills. Since everything above 6 percent of income would be covered by assistance, reducing the bills under a percentage of income payment plan reduces the amount of assistance needed – dollar for dollar until the energy bills reach 6 percent of the low-income household's income. This benefit is in addition to the non-energy benefits of lowering energy burdens, such as reduced homelessness and greater capacity to meet food and medical needs.[55]

Table Zone 4-C shows cumulative direct costs, as well as the CO_2 and peak load reduction benefits. We have calculated payback time in two ways:

- On the basis of direct costs alone;

[51] NYS PSC Affordability Order 2016, pp. 3, 14-15
[52] NYS PSC Affordability Order 2016, fn. 8 on p.8
[53] NYS Energy Plan 2015, v. 2 (End-Use), Table 7 (p. 17)
[54] NYS PSC Affordability Order 2016, pp. 14-15
[55] Makhijani, Mills, and Makhijani 2015

- On the basis of direct costs plus benefits from reducing CO_2 emissions and reducing peak loads.

Table Zone 4-C: Cumulative cost comparison over 15 years, with and without CO_2 and peak load benefits – Detached Climate Zone 4 housing unit

15 YEAR COST COMPARISON, PRESENT VALUE, ZONE 4 DETACHED HOUSING UNIT				
	Oil	Natural gas	GHP	Cold Climate HP
Initial system cost	$4,000	$4,000	$24,000	$8,300
System residual value @15 years	$0	$0	$7,510	$0
Added cost of heat pump system	$0	$0	$12,490	$4,300
Annual energy cost	$2,665	$1,970	$1,586	$1,949
Annual savings in energy cost compared to oil			$1,078	$715
Simple payback time for oil retrofit, years	N/A	N/A	11.6	6.0
Annual savings in energy cost compared to natural gas	N/A	N/A	$384	$20
Simple payback time, for NG retrofit, years	N/A	N/A	32.6	211.1
Present value of energy costs, over 15 years	$31,809	$23,514	$18,934	$23,271
Cumulative total costs	$35,809	$27,514	$31,424	$27,571
Cumulative savings, present value, compared to oil	N/A	N/A	$4,385	$8,238
Cumulative savings, present value, compared to natural gas	N/A	N/A	($3,910)	($57)
CO_2 reduction benefit, cumulative, relative to oil	N/A	N/A	$2,612	$2,485
Peak load reduction benefit, present value			$1,382	$982
Total net cost, oil retrofit	$35,809	N/A	$27,431	$24,104
Cumulative savings relative to oil, with CO_2 and peak load reduction benefits	N/A	N/A	$8,378	$11,705
CO_2 reduction benefit, cumulative, relative to natural gas	N/A		$1,900	$1,773
Peak load reduction benefit, present value			$1,382	$982
Net cost, natural gas retrofit	N/A	$27,514	$28,143	$24,816
Cumulative savings relative to natural gas, with CO_2 and peak load reduction benefits	N/A	N/A	($629)	$2,698

Source: IEER calculations

1. Social discount rate of 3 percent in constant dollars was used to compute present value. We have assumed no inflation in fuel or electricity costs.

2. We used a social cost of carbon of $42.87 per short ton (about $39 per metric ton), which is the value adopted for 2017-2019 by the New York Public Service Commission in its evaluation of subsidies for upstate nuclear power plants (NYS PSC CES Order 2016, Appendix E, Table 2 (p. 12)). We have not taken into account any increase in the social cost of carbon.
3. We estimated cumulative present value peak load reduction value as $1,000 per kilowatt of peak load reduced by combining a value for generation capacity avoided ($600/kW from AEE 2015, Tables 2.1 and 3.1, and a value for avoided transmission and distribution investments from NYS DPS REV 2015, Table 2).

A note on the social cost of carbon is in order. We used the same value as that used for 2017-2019 by the New York State PSC for its calculation of subsidies for upstate nuclear power plants. Given that the climate disruption appears to be more rapid and severe than thought in the past decade, the near-term social cost of carbon is likely to underestimate carbon reduction benefits of efficient heat pumps. It should also be noted that the social cost of carbon is highly dependent on the discount rate used. A 2015 NY PSC paper states that the 2030 social cost of carbon is projected to be $17 per metric ton at an average discount rate of 5 percent, $55 per metric ton at a discount rate of 3 percent, and $80 per ton at a discount rate of 2.5 percent – all in 2011 dollars.[56] A lower discount rate – and therefore a higher social cost of carbon -- is more appropriate given the scale of socio-economic damage estimated to be caused by climate disruption. By this measure, the value of carbon reduction shown in Table Zone 4-C should be increased, possibly by as much as a factor of two.

We also note that we have not included the social (health) benefits from the reduction of air pollutants such as sulfur dioxide and nitrogen oxides.

Tables Zone 4-B and 4-C show that it is economical to replace fuel oil space heating by either geothermal heat pump (with a hot water de-superheater) or a cold climate heat pump plus a heat pump water heater; the simple payback times are about 12 and 6 years (rounded) respectively. The lower first cost of the latter produces higher net benefits – the cumulative net savings over 15 years were estimated (by IEER) at about $4,000 for when an oil furnace is retrofitted with a geothermal heat pump and about $8,000 in the case of a cold climate heat pump.

Over 120,000 homes in Climate Zone 4 with one to four housing units per structure are heated with propane. Since prices of propane per unit of energy are broadly comparable with fuel oil, the economics of replacing propane systems with efficient electric ones should be broadly comparable.

The relatively high electricity prices in New York's Climate Zone 4 reduce the savings compared to other climate zones, where fuel oil prices are comparable but electricity prices are lower.

If the same house as modeled above had a natural gas furnace, the economics of retrofitting are more complex. Annual energy costs are reduced if the furnace is retrofitted with a geothermal heat pump; the energy costs are about equal in the case of retrofitting with a cold climate heat pump. Total direct costs, including the much greater first cost of a geothermal heat pump and low natural gas costs (relative to fuel oil), make a geothermal heat pump retrofit uneconomical unless collateral benefits such as CO_2 emission and peak load reductions are taken into account. In that case, the 15-year cost of a geothermal heat pump retrofit is about the same as continuing to use natural gas, compared to cumulative savings of about $2,700 in the case of a retrofit with a cold climate heat pump.

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[56] NYS DPS REV 2015, Table C-1 (p. C-7)

We have also performed the same calculations for a 1 unit residential structure in Climate Zone 5. The results are displayed in Tables Zone 5-A through Zone 5-C. Note that air-conditioning requirements in Zone 5 are considerably lower than in Zone 4.

Table Zone 5-A: Site energy use, cumulative CO_2 emissions over 15 years, and peak power demand – Detached Climate Zone 5 housing unit

	ZONE 5 DETACHED STRUCTURE - ONE HOUSING UNIT			
	Oil	Natural gas	GHP	Cold Climate HP
Space heating, MMBtu/y	90	90	18	33
Water heating, MMBtu/y	12	12	4	2
Electricity, fan/pump+A/C, MMBtu/y	4	4	2	1
Total site energy, MMBtu/y	106	106	25	37
Peak load (A/C), kW	2.2	2.2	0.8	1.2
Cumulative CO_2, mt, 15 years	112.1	82.2	17.4	26.0
CO_2 reduction vs oil, mt, 15 years	N/A	N/A	94.7	86.1
CO_2 reduction vs natural gas, mt, 15 years	N/A	N/A	64.8	56.2
Peak load reduction, kW	N/A	N/A	1.4	1.0

Source: IEER calculations. For notes see Table Zone 4-A above, except that we have used a COP of 2.2 for the cold climate heat pump for Climate Zone 5.

Table Zone 5-B: Annual energy costs and savings – Detached Climate Zone 5 housing unit

COST AND SAVINGS, ZONE 5 DETACHED HOUSING UNIT				
	Oil	Natural gas	GHP	Cold Climate HP
Space + water heating +A/C energy cost	$2,896	$1,797	$1,211	$1,809
Annual energy cost savings, relative to oil	N/A	N/A	$1,685	$1,087
Annual energy cost savings, relative to natural gas	N/A	N/A	$586	($11)
Total energy cost, including all electricity uses	$3,875	$2,777	$2,191	$2,789
Energy burden @poverty level (3-person household)	20%	14%	11%	14%
Assistance to keep energy burden @6% of income, $/y	$2,704	$1,605	$1,019	$1,617

Source: IEER calculations. For notes see Table Zone 4-B above, except that energy prices for Zone 5 were as follows: Fuel oil = $27.86 per million Btu; natural gas = $15.66 per million Btu; electricity = $0.17 per kWh.[57]

[57] Capital district region fuel oil price, NYSERDA Oil Price 2016; Central Hudson natural gas price (NYSERDA Trends 2015, Appendix F-4); Central Hudson electricity prices (NYSERDA Trends 2015, Appendix F-1).

Table Zone 5-C: Cumulative cost comparison over 15 years (present value), with and without CO_2 and peak load benefits – Detached Climate Zone 5 housing unit

15 YEAR COST COMPARISON, PRESENT VALUE, ZONE 5 DETACHED HOUSING UNIT				
	Oil	Natural gas	GHP	Cold Climate HP
Initial system cost	$4,000	$4,000	$24,000	$8,300
System residual value @15 years	$0	$0	$7,510	$0
Added cost of heat pump system	N/A	N/A	$12,490	$4,300
Annual energy cost	$2,896	$1,797	$1,211	$1,809
Annual savings in energy cost compared to oil	N/A	N/A	$1,685	$1,087
Simple payback time for oil retrofit, years	N/A	N/A	7.4	4.0
Annual savings in energy cost compared to natural gas	N/A	N/A	$586	($11)
Simple payback time for NG retrofit, years	N/A	N/A	21.3	N/A (Note 1)
Present value of energy costs, over 15 years	$34,570	$21,458	$14,457	$21,595
Cumulative total costs	$38,570	$25,458	$26,947	$25,895
Cumulative savings, present value, compared to oil			$11,622	$12,674
Cumulative savings, present value, compared to natural gas			($1,489)	($437)
CO_2 reduction benefit, cumulative, relative to oil			$3,682	$3,348
Peak load reduction benefit, present value			$1,382	$982
Total net cost, oil retrofit	$38,570	N/A	$21,883	$21,565
Cumulative savings relative to oil			$16,687	$17,004
CO_2 reduction benefit, cumulative, relative to natural gas			$2,522	$2,188
Peak load reduction benefit, present value			$1,382	$982
Total net cost, natural gas retrofit	N/A	$25,458	$23,043	$22,725
Cumulative savings relative to natural gas			$2,415	$2,733

Source: IEER calculations. For Table Zone 5-C notes, see Table Zone 4-C above.
Note 1: Energy cost is slightly higher for a cold climate heat pump than with a natural gas system. So energy cost alone cannot result in a positive payback time.

Energy costs for GHP systems are much lower than for oil heating systems and also somewhat lower for cold climate heat pump systems. When the reduction in CO_2 emissions and peak load reduction are taken into account, retrofitting of oil systems saves over $15,000 over 15 years in both retrofit cases. In the case of retrofitting natural gas systems, the overall savings are much smaller – on the order of $2,000 to $3,000 over 15 years, but the retrofits are still economically justified.

Over 180,000 homes in Climate Zone 5 with one to four housing units per structure are heated with propane. Since prices of propane per unit of energy are broadly comparable with fuel oil, the economics of replacing propane systems with efficient electric ones should be broadly comparable.

ii. An apartment in a small multi-unit structure

Finally, we also examined the energy, CO_2, peak load, and cost implications of retrofitting an apartment now using natural gas space and water heating with a cold climate heat pump. We evaluated only a cold climate heat pump retrofit in this case. Tables Zone 4-D and Zone 4-E show the results for Climate Zone 4. Retrofits with geothermal heat pumps are also possible in many situations, but the design and cost considerations are complex; hence we do not consider that option in this report.

Table Zone 4-D: Energy and cost data for retrofitting an apartment with a cold climate heat pump (Climate Zone 4)

CLIMATE ZONE 4 APARTMENT		
	Natural gas	Cold Climate HP
Space heating, MMBtu/y	28	9
Water heating, MMBtu/y	8	2
Electricity, fan/pump+A/C, MMBtu/y	2	1
Total site energy, MMBtu/y	38	11
Peak load (A/C), kW	1.5	0.6
Cumulative CO_2, mt, 15 years	30.0	7.6
CO_2 reduction vs natural gas, mt, 15 years	N/A	22.4
Peak load reduction, kW	N/A	0.9
Total energy cost $/y	$820	$849
Annual energy cost savings, relative to natural gas $/y	N/A	($29)
Energy burden @poverty level (2-person household)	11%	11%
Assistance to keep energy burden @6% of income, $/y	$807	$837

Source: IEER calculations. See notes to Tables Zone 4-A and 4-B. A room air conditioner with an SEER of 8 is assumed for the pre-retrofit situation.

Table Zone 4-E: Cumulative cost estimates over 15 years for retrofitting an apartment with a cold climate heat pump (Climate Zone 4)

APARTMENT IN CLIMATE ZONE 4		
	CUMULATIVE COSTS AND SAVINGS	
	Natural gas	Cold Climate HP
Initial system cost	$2,000	$5,100
System residual value @15 years	$0	$0
Added cost of heat pump system	N/A	$3,100
Annual energy cost	$820	$849
Annual savings in energy cost (Note 1)	N/A	($29)
Simple payback time, years		N/A
Present value of energy costs, over 15 years	$9,785	$10,137
Cumulative total costs	$11,785	$15,237
Cumulative savings, present value, compared to natural gas	N/A	($3,452)
CO_2 reduction benefit, cumulative, relative to natural gas	$0	$870
Peak load reduction benefit, present value	$0	$900
Total net cost	$11,785	$13,467
Cumulative savings relative to natural gas	N/A	($1,682)

Source: IEER calculations. See notes to Table Zone 4-C and Zone 4-D

Note 1: Energy cost is slightly higher for a cold climate heat pump than with a natural gas system. So energy cost alone cannot result in a positive payback time.

The relatively high electricity price in Climate Zone 4 makes a retrofit with a cold climate heat pump uneconomical, even when the benefits of peak load and CO_2 and methane leak emission reductions are taken into account. It should also be noted that the cost of retrofits in multi-unit apartment buildings may be highly variable; therefore this conclusion should be treated with caution. There are likely to be many situations in which the retrofit cost per apartment is lower than assumed here. In any case, the calculations here indicate that a reduction in first cost of cold climate heat pumps (or a higher heating COP at the same cost) would enable retrofits to be economical in a wider range of situations where apartments are concerned.

Tables Zone 5-D and 5-E show the same calculations for an apartment in Climate Zone 5.

Table Zone 5-D: Energy and cost data for retrofitting an apartment with a cold climate heat pump (Climate Zone 5)

CLIMATE ZONE 5 APARTMENT		
	Natural gas	Cold Climate HP
Space heating, MMBtu/y	28	10
Water heating, MMBtu/y	8	2
Electricity, fan/pump+A/C, MMBtu/y	2	1
Total site energy, MMBtu/y	38	12
Peak load (A/C), kW	1.3	0.6
Cumulative CO_2, mt, 15 years	29.4	8.8
CO_2 reduction vs natural gas, mt, 15 years	N/A	20.6
Peak load reduction, kW	N/A	0.7
Total energy cost	$1,236	$1,184
Annual energy cost savings, relative to natural gas	N/A	$53
Energy burden @poverty level (2-person household)	8%	8%
Assistance to keep energy burden @6% of income, $/y	$306	$253

Source: IEER calculations. See notes to Table Zone 4-D and Table Zone 5-B.

Table Zone 5-E: Cumulative cost estimates over 15 years for retrofitting an apartment with a cold climate heat pump (Climate Zone 5)

CLIMATE ZONE 5 APARTMENT		
	CUMULATIVE COSTS AND SAVINGS	
	Natural gas	Cold Climate HP
Initial System Cost, $	$2,000	$5,100
System residual value @15 years	$0	$0
Added cost of heat pump system	N/A	$3,100
Annual energy cost	$663	$611
Annual Savings in energy cost	N/A	$53
Simple payback time, years		59.0
Present value of energy costs, 15 years	$7,918	$7,291
Cumulative total costs	$9,918	$12,391
Cumulative savings, present value, compared to natural gas	N/A	($2,473)
CO2 reduction benefit, cumulative	N/A	$802
Peak load reduction benefit, present value	N/A	$733
Total net cost	$9,918	$10,856
Net savings	N/A	($938)

Source: IEER calculations. See notes to Table Zone 5-C and Zone 5-D.

Some general observations in regard to apartments are in order:

- We expect a wide variation in retrofit costs and a wide variation in retrofit benefits.
- If the size of the system can be reduced by increasing the energy efficiency of the building envelope, a cold climate heat pump retrofit of natural gas heated buildings may become economical, especially if the existing structure has significant opportunities for low-cost envelope energy efficiency retrofits.
- There are almost 1.4 million oil-heated households in structures with one to four units. Among these, there are likely to be a significant number of buildings with two to four units each that are oil heated. A retrofit is likely to be economical in such cases. However, we have not been able to determine the number of oil-heated households in two-to-four unit buildings to evaluate the impact in detail.
- A reduction in the cost of cold climate heat pumps is critical for making retrofits of natural gas heated apartments economical in a wide variety of situations, presuming emission and peak load reduction benefits are taken into account.
- Geothermal heat pump retrofits should also be evaluated for multi-unit buildings with due attention to site-specific design issues.

3. Observations and recommendations based on the case studies

1. The case studies indicate that, when physically reasonable, geothermal heat pump or cold climate heat pump retrofits for structures of one to four housing units that are heated with fuel oil or propane will generally be economical. In the case of low-income households that use either fuel, there will also be significant benefits to the public at large in New York State due to the reduced need for energy assistance. ***Recommendations: New York should prioritize policies, such as rebates and Green Bank financing, that would facilitate the rapid retrofitting of fuel oil and propane heated homes to efficient electric systems. In areas where there is no natural gas infrastructure, New York should go directly to efficient electric systems****.*
   .
2. The case studies indicate that, when physically reasonable, efficient heat pump retrofits are economical for one unit structures that are heated with natural gas if credit is taken for CO_2 emission reductions and peak load reductions. Cost reductions and/or efficiency improvements are needed for cold-climate heat pump retrofits in two-to-four unit structures are to be economical. ***Recommendation: New York should prioritize retrofitting of one unit low-income households that now heat with natural gas with geothermal or cold climate heat pumps notably when the annual energy cost is lower****. New York should also prioritize cost reduction of efficient heat pump systems which would increase the variety of situations in which cold climate and geothermal heat pump retrofits will be economical.*[58]

3. We have used a single price for fuel oil, natural gas, and electricity in each climate zone in assessing the economics of replacing fossil fuel systems by efficient electrically driven systems.

[58] NYSERDA envisions cost reductions as a major part of its renewable heating strategy. See NYSERDA 2017, Chapter 4.

Over the long-term, increases in oil and natural gas prices are expected in a business-as-usual scenario, where large-scale use of fossil fuels is assumed to continue. Given that renewable energy costs are declining, it is possible that a differential price rise in fossil fuel costs may make retrofitting natural gas systems more economical.

In this context it is important to consider that both natural gas and fuel oil prices are quite volatile. They can and do skyrocket from time to time and then fall again, sometimes precipitously. However, the social and economic effects of price increases and decreases are not symmetrical, especially for low- and middle-income households. When prices fall, there are generally many other needs ranging from rent/mortgage payments, food, and medicine that are often only partially fulfilled. When prices increase, those who already have high energy burdens experience even greater financial stress. The effects can range from damaging to devastating (including eviction)[59] in the absence of emergency assistance. For instance, New York State received an emergency allocation of $33 million for low-income heating assistance during the severe winter of 2014-2015.[60] ***Recommendation: New York should factor in oil and gas fuel price volatility in setting rebates and other incentives for replacing fossil fuel heating systems with efficient electric ones, especially when it comes to assistance to low-income households in making the switch***.

4. The case-study tables above show only the benefit of direct CO_2 emission reductions. They do not include reduction of methane emissions associated with natural gas.[61] Methane emissions estimates vary a great deal; however, the evidence is that, with hydrofracturing ("fracking") production of natural gas on the rise, emissions have also increased.[62] There is also evidence that leaks in natural gas distribution systems are considerable.[63] The methane leakage estimates of the U.S. Environmental Protection Agency (EPA) appear to be on the low side. In addition, the EPA (along with many others) uses a 100-year global warming potential for methane. The EPA's low estimate of leaks (about 1.6 percent) with a 100-year warming potential increases the CO_2-equivalent emission rate by about 20 percent. A higher, but reasonably well-founded, estimate of leaks at 5 percent with a 20-year warming potential would result in about a 150 percent increase in CO_2-equivalent emissions. When natural gas is used for electricity generation, the net methane leak reduction is lower. ***Recommendation: New York should take due account of the net avoided CO_2-eq methane leaks using a 20-year global warming potential for methane (see Chapter V, Section 4).***

5. Lowering the cost of electricity for low-income households by providing them with universal solar access could also make retrofitting from natural gas to efficient heat pumps more attractive especially in the Climate Zone 4 area, which has high electricity costs. The high electricity cost reduces the benefit of going from fossil fuel heating to electricity; this is a particularly material consideration for structures heated with natural gas. The low cost of utility-scale solar energy could alleviate this problem if it is procured specifically for low-income

[59] See Makhijani, Mills, and Makhijani 2015, for details, and Desmond 2016, p. 15-16.
[60] Schumer and Gillibrand 2015
[61] Methane is the main constituent of natural gas. See Howarth 2014 and Makhijani and Ramana 2014 for discussions of the impact of leak rates and global warming potentials on estimates of greenhouse gas emissions in terms of CO_2-equivalent mass units.
[62] Howarth 2014
[63] Bernstein 2014

households. Universal solar access can be provided to low-income households most efficiently and economically if the state government uses purchase power agreements to acquire solar electricity on behalf of households receiving assistance. Further, solar electricity, having no fuel, is immune to risk arising from fuel price volatility. Detailed analysis of the situation in Maryland, where electricity costs are lower, indicates that no ratepayer funds need be involved.[64] ***Recommendation: New York should commission a study about options for providing low-cost universal solar access to low-income households (along with energy efficiency improvements). This will structurally reduce energy bills as well as CO_2 emissions.***

6. We have used widely available commercial technology as the basis for our cost calculations. This may understate the benefits and overstate costs. As we have discussed, there are at least two heat pump technologies – one involving solar thermal panels and the other high efficiency dual compressors – that could increase efficiency, reduce cost, or do both. Widespread adoption of these (or related technologies) would make retrofitting essentially all natural gas heated homes much more economically straightforward than it appears at present. ***Recommendation: New York should explore emerging technologies for heat pumps that could significantly lower the cost of retrofitting fossil fuel heating systems.***

7. Current high efficiency heat pumps use R-410a as a refrigerant; this is a greenhouse gas with a warming potential relative to CO_2 of 2088 on a 100-year comparison basis and more than double that on a 20-year basis. The relatively short lifetime of R-410a (about 17 years) [65] compared to CO_2 makes it a candidate for early replacement by another refrigerant with much less impact. As it turns out CO_2 can be used as a refrigerant. It has a much lower warming impact than R-410a; in addition, it has the potential to increase the efficiency of heat pumps. It is used in in North America in commercial sector installations. It is not yet used in the residential sector, since it requires higher pressures, among other complications.[66] We mention it here because conversion to efficient electric technologies will take place over time and it is important to encourage the development of the most efficient technologies with the lowest warming impact. The direct and indirect economic benefits will also increase. ***Recommendation: New York should explore the use of CO_2 as a refrigerant in residential heat pumps.***

V. Conclusions

1. Overall perspective

As noted in Section I, about 31.4 million metric tons of New York's yearly energy related CO_2 emissions of 179.5 metric tons are attributable to residential space heating, water heating, and air conditioning. When the commercial sector is included, these three end uses of energy in buildings account for about 50 million metric tons of CO_2 emissions, or 28 percent of the energy sector CO_2 emissions total. Of this, about 40 million metric tons are represented by the direct use of fossil fuels in buildings for space and water heating. Some perspective on the magnitude of emissions due to direct fossil fuel use for space

[64] Makhijani, Mills, and Makhijani 2015
[65] Wikipedia Refrigerants 2016
[66] Building Green blog 2013

and water heating in New York's buildings can be gained by comparison to a single number: New York's entire electricity sector (including electricity imports) was responsible for about 42 million metric tons (23.4 percent) of CO_2 emissions in 2011.

In addition, the space and water heating sector is natural gas intensive. When seen from a 20-year global warming potential perspective of climate protection, the importance of reducing natural gas for space and water heating in New York State increases considerably. The natural gas related CO_2-equivalent emissions increase by between about 20 percent and 150 percent, depending on the leak rate assumed, compared to the current practice of accounting for the CO_2 created by combustion of natural gas alone.

2. *Case studies in context*

The vast majority of residential space and water heating involves the direct use of fossil fuels. In this report, we have considered prototypical examples of fossil fuel use that cover about two-thirds of New York's housing units. The omitted units are in large structures that have 5 or more apartments each; almost 90 percent of these are in New York City and its environs (Climate Zone 4). The heating requirements for these units would be considerably lower than for units studied because (i) climate Zone 4 has a milder winter than the rest of the state, (ii) apartment units in large buildings are likely to be smaller than detached units, which constitute the majority of units studied, (iii) apartments are much more likely to have room rather than central air conditioning, and (iv) the heating and cooling requirements in large, multi-story structures per unit area are generally lower than for detached structures. These considerations indicate that the prototypical cases studies in Section IV represent 75 to 80 percent of New York State's space heating, water heating, and air-conditioning requirements – or roughly 25 million metric tons per year.

New York cannot attain its 2050 target of reducing greenhouse gas emissions by 80 percent relative to 1990[67] without substantially reducing and, probably, nearly completely eliminating CO_2 emissions from the direct use of fossil fuels in the residential sector. There are three principal, complementary ways to do this for existing structures:[68]

- Improving building envelopes to reduce heat loss in the winter and coolness loss in the summer.
- Retrofitting HVAC and water heating systems to convert them from fossil fuels to efficient electric systems, notably efficient heat pump space and water heating systems.
- Reducing emissions per unit of electricity generation, which in turn reduces the emissions from all electricity using devices including heat pump systems. In effect, converting direct fossil fuel use to efficient electric systems makes them "renewable-grid-ready"; this automatically further reduces emissions when the fraction of renewable energy is increased as a proportion of total electricity requirements.

[67] NYS PSC CES Order 2016, fn. 1 on p. 2
[68] The same set also applies to commercial sector buildings.

3. Retrofitting fuel oil and propane systems

It is generally economical to replace oil-fueled space heating with cold climate heat pumps, presuming that the retrofit is technically feasible, in all climate zones in New York State. This applies even when fuel oil prices are below $2 per gallon.

It is generally economical to replace oil-fueled space heating with geothermal heat pumps in Climate Zones 5 and 6 even down to very low fuel oil prices well below $2 per gallon. This is because the price of electricity is low enough and the efficiency of geothermal is high enough to permit an economical conversion.

In Climate Zone 4, electricity is much more expensive ($0.27 per kWh), so fuel oil needs to be about $3 per gallon or more for conversion to be economical. These observations relate to direct costs only and do not take the value of peak load or carbon emissions reductions into account. When the benefits of CO_2 emissions and peak load reductions are taken into account fuel oil costs can drop to the $2.25 to $2.50 range for economical conversion.

Propane prices, in terms of energy content, are generally comparable to or higher than fuel oil, so the economics of conversion from propane to efficient electric systems are comparable. However, propane heating systems are often used in mobile home situations for which geothermal heat pumps may not be suitable as a retrofit technology.

These observations do not take into account the benefit of reducing and eventually eliminating volatility in energy prices. Electricity prices fluctuate much less than fuel oil or even natural gas prices. Thus, low fuel oil or natural gas prices should not be the point of reference for evaluating the economics of retrofitting existing fossil fuel systems with efficient electric ones. Rather the cost of fuel price volatility should be evaluated and factored in (see Section V.5 below in this chapter).

4. Retrofitting natural gas systems

The analysis in this report shows that the economics of retrofitting natural gas systems with cold climate heat pumps in single unit structures are marginal in both Climate Zones 4 and 5 on the basis of direct costs alone. When CO_2 emissions and peak load reductions are taken into account, the economics improve considerably. Our conclusions for Climate Zone 5 broadly apply to Climate Zone 6, which is colder than Climate Zone 5 ; prevailing fuel prices are broadly similar in the two zones. The picture for apartments depends on the specifics of the structure and the size of the retrofit needed.

Retrofitting natural gas systems with geothermal heat pumps is not economical on a straight cost basis in many circumstances, but can become so when CO_2 emissions and peak load reductions are taken into account, especially in Climate Zone 5 and by extension, Climate Zone 6.

In addition, natural gas consists mainly of methane. When methane leaks are factored in, the benefit of CO_2-equivalent reductions is substantially increased, especially if the 20-year warming potential of methane is used. This benefit is reduced by the fact that natural gas is also used for electricity generation in New York (see natural gas discussion below).

A reduction of the cost of GHPs and cold climate heat pumps will make retrofits more generally economical. Reducing cost therefore an important goal.[69]

New heat pump technologies, discussed in Sections III.1 and III.2, may also help reduce costs; we recommend pilot projects to test them in New York conditions.

i. Perspective on natural gas use

It is important to consider the replacement of natural gas space and water heating systems by efficient electric systems in the context of the overall transition away from fossil fuels, including natural gas. There has been considerable discussion of, and controversy about, the role of natural gas in electricity generation on the way to a fully renewable electricity system. But there has been less discussion about the relative uses of natural gas for electricity generation compared to its direct use in buildings.

New York used 466 trillion Btu of natural gas for electricity generation in 2014.[70] The residential sector use of natural gas in 2014 was about 473 trillion Btu,[71] the vast majority of which is for space and water heating.[72] Commercial sector direct use of natural gas in 2014 was about 330 trillion Btu, about 65 percent of which was for space and water heating.[73]

In all, the direct use of natural gas for space and water heating in buildings is roughly 40 percent greater than New York's use of natural gas for in-state electricity generation. This shows that the replacement of natural gas systems by efficient electric ones that will be powered by renewable energy as the grid becomes more renewable is an essential goal for climate protection.

Natural gas use is also a principal cause of methane emissions. There is a wide range of estimates for methane leaks, from 1.6 percent to 5 percent or more. Table V-1 shows the natural gas use, methane leaks, CO_2 emissions due to burning the gas, and the CO_2-equivalent emissions due to methane leaks at two leak rates, using a 100-year and a 20-year global warming potential (GWP) for methane. The values shown are for a one unit building in Climate Zone 5.

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[69] Cost reduction is one of the goals of the renewable heat program initiated by New York in 2017. See NYSERDA 2017.
[70] EIA SEDS Consumption 2016, New York, Table CT8 (electric power sector)
[71] EIA SEDS Consumption 2016, New York, Table CT4 (residential)
[72] DOE EERE 2012 BEDB, Table 2.1.5. The BEDB data are national.
[73] EIA SEDS Consumption 2016, New York, Table CT5 (commercial) and DOE EERE 2012 BEDB, Tables 3.1.4. The BEDB data are national.

Table V-1: Natural gas use, CO_2 emissions, and CO_2-equivalent emissions due to methane leaks, using a Climate Zone 5, one unit building example

	leak rate 1.6%	leak rate 5%
Natural gas use per household, million Btu/y	102	102
Methane leaked, metric tons/y	0.030	0.095
CO_2-eq emissions due to methane leaks, 100-year GWP, metric tons/y	1.03	3.24
CO_2-eq emissions due to methane leaks, 20-year GWP, metric tons/y	2.61	8.20
CO_2 emissions due to burning natural gas, metric tons/y	5.40	5.40
Increase in CO_2-eq, using 100-y GWP	19%	60%
Increase in CO_2-eq, using 20-y GWP	48%	152%

Source: IEER
Note: The methane content of natural gas ranges from 87 to 97 percent (Union Gas 2016). We used 95 percent in our calculations. For a discussion of methane leaks, see Howarth 2014 and Makhijani and Ramana 2014.

The percentage increases in CO_2-equivalent emissions are independent of the amount of natural gas use; rather they depend only on the leak rate and the global warming potential. Of course the absolute amount of CO_2-equivalent emissions depends on the amount of natural gas use. In the case of the example in Table V-1 above, the CO_2 emissions from combustion of natural gas alone are 5.4 metric tons per year. But a 20-year GWP for natural gas with a 5 percent leak rate increases that by 152 percent to a total of 13.6 metric tons of CO_2-eq per year.

It is important to note that the net effect of replacing the direct use of natural gas for heating by electricity is reduced when natural gas is also used for electricity generation. For instance, in the above example, a 5 percent leak rate and a 20-year warming potential results in an 8.2 metric ton CO_2-eq emission reduction when a cold climate heat pump is used instead. But the electricity generation for the cold climate heat pump would have been associated with methane leaks of about 2.2 metric tons (using the same leak rate) in the above example for the 2015 New York electricity generation mix. The net reduction in CO_2-eq emissions would therefore be about 6 metric tons by the switch from natural gas to cold climate heat pump. A switch to a geothermal heat pump would result in a net CO_2-eq reduction of 7 metric tons; this is because a GHP is more efficient and uses less electricity than a cold climate heat pump.

As the grid becomes more renewable and natural gas use for electricity generation is reduced, the benefit of switching to electric heating increases. For a fully renewable grid, the full value of CO_2-eq reductions would be realized.

5. *Value of eliminating fuel price volatility*[74]

Going from fossil fuel space and water heating systems to efficient electric ones has an important similarity with going from fossil fuel electric generation, notably natural gas-fueled electric generation, to solar and wind electricity. The latter transition eliminates fuel price risk entirely. There are modest operations and maintenance (O&M) costs, but these are, on the whole, fixed by the size, type, and

[74] The paragraphs below on the price volatility of natural gas are largely based on Makhijani 2016.

location of the renewable electricity system. In other words, there are essentially no variable O&M costs. This means that electricity prices become predictable – an important consideration for businesses and for households since it allows reliable budgeting.

Retrofitting fossil fuel heating systems with efficient electric systems eliminates almost all volatility, but in two steps:

- First, electricity costs are much less volatile than natural gas, petroleum, or propane costs. Thus converting from natural gas, propane, or fuel oil to efficient electric heating systems reduces the volatility in household energy costs. This is an important general consideration, particularly for low-income households. When fuel prices rise sharply, household energy bills can skyrocket, especially in the winter. This sharpens and greatly increases the food-fuel-medicine-rent/mortgage conflicts felt by low-income households. The consequences range from damaging to dire, all the way to illness and homelessness.
- Second, New York is on a path to greatly increasing the renewable energy component in its electricity system. At present, New York's electricity system has large components of natural gas and nuclear energy. Natural gas generated electricity is significantly vulnerable to fuel price volatility. Nuclear O&M and fuel costs have in the past (before about 2005) been relatively stable; however, that has changed in recent years. As New York's electricity supply moves to much greater shares of solar and wind energy complemented by its existing hydropower resources, electricity costs are likely to be less variable and much more predicable than at present.

Figure V-1 shows historical fuel oil prices in the New York City area and in the New York State Capital District (Albany). The ratio of maximum to minimum fuel oil prices (in current dollars) in both regions has been more than three over the period from 2000-2001 to 2015-2016.

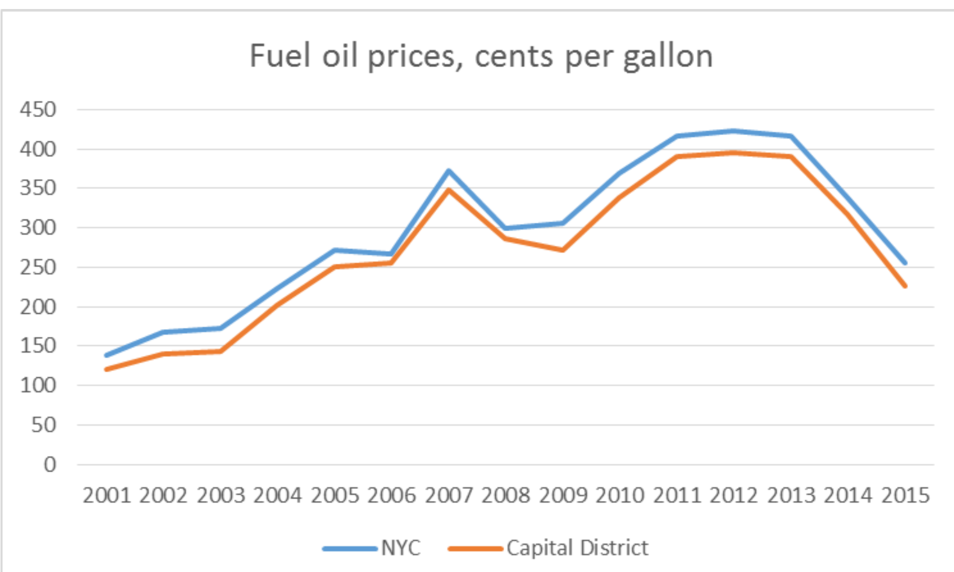

Figure V-1: Fuel oil prices in the New York City and Capital District regions of New York State.
Source: Compiled by IEER from NYSERDA Home Heating Oil database at https://www.nyserda.ny.gov/Cleantech-and-Innovation/Energy-Prices/Home-Heating-Oil (NYSERDA Heating Oil 2016)

Note: The prices shown are simple unweighted averages over the period for which data were available for any given year.

Figure V-2 shows the wellhead prices of natural gas. This is the kind of volatility that caused the former CEO of Duke Energy to bring a famous aphorism coined by Ben Franklin into the fossil fuel era:

> Ben Franklin said there are two certainties in life: death and taxes. To that, I would add the price volatility of natural gas.[75]

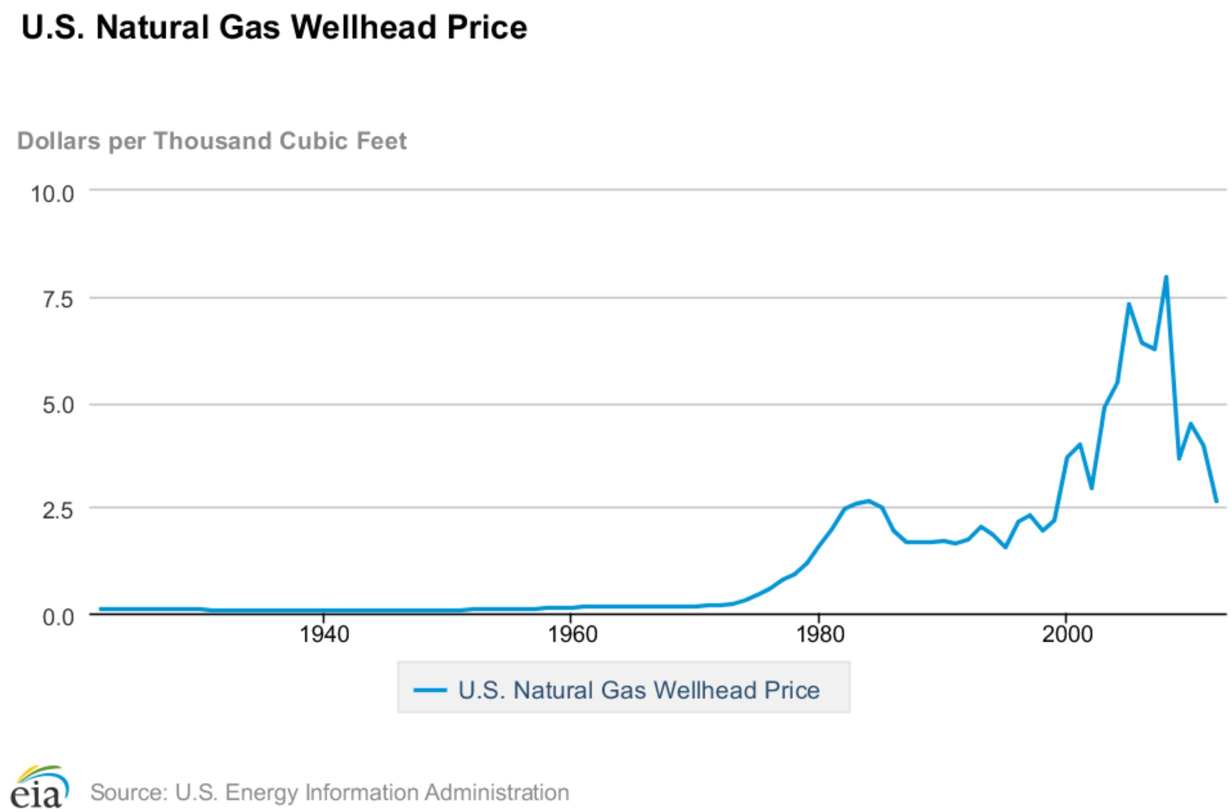

Figure V-2: Natural gas wellhead price, for about 90 years
Source: EIA Natural Gas Wellhead 2016

Residential prices paid by consumers are not as variable, since the relatively stable costs of transporting and delivering the gas are added to wellhead prices and since the distribution component of residential natural gas price is regulated. The ratio of annual average maximum to minimum prices (in current dollars) is almost two between 1999 and 2016. Electricity prices in the same period have varied by about 50 percent; the variation in annual average electricity prices since 2006 has been about 20 percent (statewide average).[76] As we have noted, there are significant regional differences in electricity prices in New York and this affects the economics of retrofitting HVAC systems.

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[75] Jim Rogers, as quoted in Huber 2012, p. 5

[76] Electricity prices from 2006 to 2016 from NYSERDA Electricity Prices 2016; Natural gas prices between 2006 and 2016 from NYSERDA Natural Gas Prices 2016; and annual average data prior to 2006 from NYSERDA Trends 2015, Table 4-1.

A detailed consideration of the value of reducing fuel price volatility in the residential space and water heating sector is beyond the scope of this report. But we can indicate an order of magnitude of this value by examining how it has been evaluated in comparing natural gas generation to wind and solar generation.

Since wind and solar generation have zero fuel cost, they provide a valuable fuel price hedge in the context of an electricity system with a significant component of natural gas generation. The Rocky Mountain Institute, in a 2012 study, evaluated this aspect by comparing a wind farm with a new combined cycle natural gas plant in the case of the Public Service Company of Colorado. The net present hedge value of wind energy was estimated at about $22 per megawatt-hour, at a discount rate of 8 percent and at about $36 per megawatt-hour at a discount rate of 6 percent compared to a single stage gas turbine over a 23-year period.[77]

The fuel use in the gas turbine was assumed equal to 7 million Btu per megawatt-hour.[78] This means that the fuel price hedge value of wind energy would be between about $3 and $5 per million Btu over the 23 year period.[79]

In our case, the period of comparison is 15 years. Using the same values over a shorter period of time would give a fuel price hedge value of $2 to $4 per million Btu over a 15-year period. It would be higher if a lower discount rate were used. Not all of this benefit would accrue in the case of an HVAC retrofit since much of New York's electricity is generated using natural gas fuel (about 40 percent in 2014[80]). We will use $3 as the value of reducing fuel price risk in the case of natural gas.

For instance, in Climate Zone 5, the annual value of reducing natural gas price risk per year would be roughly $300 per year (rounded) for a one unit structure; the present value of 15 years of risk reduction would be $3,600 (using a social discount rate of 3 percent). The value in the case of fuel oil is much higher both since fuel oil price volatility is greater and since far less oil than natural gas is used for electricity generation.[81]

The value of the hedging risk should especially be considered in light of the high energy burdens of low-income households. The effect of price spikes in heating fuel can be devastating for low-income households because such spikes exacerbate already serious food/energy/medicine/housing cost conflicts. New York's decision to limit energy burdens to six percent can be expected to greatly alleviate these conflicts and to insulate low-income households from natural gas and fuel oil price volatility. On the other hand, such spikes would cause the amount of assistance needed to increase, increasing costs for ratepayers and/or taxpayers (depending on how energy assistance is funded). The value of the hedge would accrue entirely to ratepayers and/or taxpayers. Since price spikes would be avoided, spikes in assistance requirements would be eliminated as well.

Finally, it is important to note that when New York transitions to a fully renewable electricity system, fuel price volatility as it affects space heating would be entirely eliminated by a transition to efficient electric heating.

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[77] Huber 2012, Figure 10b (p. 18)
[78] Huber 2012, p. 22.
[79] The present value of the hedge in $/MWh divided by the heat rate in million Btu per MWh.
[80] EIA States 2016 New York, Table 5
[81] Oil fueled about 1.6 percent of New York's electricity generation in 2014. (EIA States 2016 New York, Table 5)

6. Equity considerations

Reducing the risk of heating bills skyrocketing in years that are far colder than normal has significant benefits for low-income households. It will also have significant benefits for New York ratepayers and/or taxpayers once the New York Public Service Commission's decision to limit the energy bills of low-income households to 6 percent of gross income is fully implemented.

First, homelessness and medical expenses that are associated with homelessness are very high – much higher than the typical cost of energy assistance. We have not investigated this issue in detail for New York, but our research in Maryland indicates that the added shelter and medical costs could be more than 80 times the typical electricity bill assistance[82] in addition to the economic distress such as loss of a job or educational opportunity that the family may suffer. An all-sided consideration of such costs may be between $70,000 and $300,000 for a family of two becoming homeless.[83]

It is important to remember in this context that New York's program to limit household energy bills to 6 percent of gross income means that the most or all of the direct economic benefits of reduced energy costs of heating and cooling will go to ratepayers and/or taxpayers in the form of reduced need for assistance. The benefits of reduced volatility and reduced homelessness and associated incremental health costs would be in addition to these direct benefits, since those costs are also borne largely by taxpayers in one way or another.

In sum, the argument for transitioning from fossil fuel space and water heating systems, when CO_2 emission reductions, methane emission reductions, and peak load reductions are taken into account, is greatly strengthened by the added non-energy benefits that accrue to both ratepayers and low-income households in the case of people receiving energy assistance. It is difficult to put a total value on this added benefit but it could be of the same order of magnitude as the other benefits combined, especially when the reduction of volatility in winter heating bills is factored in.

New York has made an excellent decision to limit the energy burdens of its low-income households to six percent of income. The efficient electrification of space conditioning and water heating systems can reduce the long-term expense of the assistance implicit in that decision; in addition to providing significant social, economic, health, and environmental benefits.

[82] Makhijani, Mills, and Makhijani 2015, p. 11, for average assistance ($325 in 2013) and p. 91, for added medical and shelter costs per family that becomes homeless ($28,000).
[83] Makhijani, Mills, and Makhijani 2015, pp. 90-91 and Mangano 2013, slide 18

References

Abdelaziz and Pham 2016	Omar Abdelaziz and Hung Pham. *EERE Success Story—Energy-Efficient Heat Pump for Colder Regions Keeps Residents Cozy with Lower Utility Bills*. Washington, D.C.: U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, May 4, 2016. On the Web at http://energy.gov/eere/success-stories/articles/eere-success-story-energy-efficient-heat-pump-colder-regions-keeps.
AEE 2015	Navigant Consulting. *Peak Demand Reduction Strategy*. Washington, DC: Advanced Energy Economy, October 2015. On the Web at http://info.aee.net/peak-demand-reduction-report. Contributions from Brett Feldman, Matthew Tanner, and Cliff Rose.
Alter 2015	Lloyd Alter**. "**SunPump pumps new life into solar thermal heating," *Treehugger*, October 5, 2015. http://www.treehugger.com/clean-technology/sunpump-solar-powered-heat-pump-sort.html.
Bernstein 2014	Lenny Bernstein. "Researchers find nearly 6,000 natural gas leaks in District's aging pipe system," *Washington Post*, January 16, 2014. On the Web at https://www.washingtonpost.com/national/health-science/researchers-find-nearly-6000-natural-gas-leaks-in-districts-aging-pipe-system/2014/01/15/f6ee2204-7dff-11e3-9556-4a4bf7bcbd84_story.html.
Building Green blog 2013	Alex Wilson. *A Heat Pump Using Carbon Dioxide as the Refrigerant: A new generation of CO_2-based heat pumps could avoid the high global warming potential of standard refrigerants and generate much higher temperatures*. Brattleboro, VT: BuildingGreen, Inc., [2013?]. On the Web at https://www.buildinggreen.com/blog/heat-pump-using-carbon-dioxide-refrigerant. Author's last name from About Us. Date based on dates of comments for this and adjacent blog postings.
CEE 2016	Consortium for Energy Efficiency Inc. *Air-Conditioning and Heat Pump Efficiency 101*. Boston: CEE, accessed September 20, 2016. On the Web at http://www.ceedirectory.org/site/302/Air-Conditioning-and-Heat-Pump-Efficiency-101.
Desmond 2016	Matthew Desmond. *Evicted: Poverty and Profit in the American City*. New York: Crown, 2016. Information on the Web at http://www.penguinrandomhouse.com/books/247816/evicted-by-matthew-desmond/9780553447439/.
DOE EERE 2012 BEDB	D&R International, Ltd. *2011 Buildings Energy Data Book.* [Washington, DC]: Buildings Technologies Program, Energy Efficiency and Renewable Energy, U.S. Department of Energy, March 2012. Links on the Web at http://buildingsdatabook.eren.doe.gov/DataBooks.aspx, with pdf at http://buildingsdatabook.eren.doe.gov/docs%5CDataBooks%5C2011_BEDB.pdf and all tables at http://buildingsdatabook.eren.doe.gov/docs/DataBooks/2011_BEDB.xlsx.
DOE EERE 2013	U.S. Department of Energy. Office of Energy Efficiency & Renewable Energy. *Air-Source Heat Pump Basics*. Washington, DC, DOE EERE, August 19, 2013. On the Web at http://energy.gov/eere/energybasics/articles/air-source-heat-pump-basics.
DOE EERE 2016	U.S. Department of Energy. Office of Energy Efficiency & Renewable Energy. *Geothermal Heat Pumps*. (Energy Saver) Washington, DC: EERE, accessed September 21, 2016. On the Web at http://energy.gov/energysaver/geothermal-heat-pumps.
Donalds 2015	Samantha Donalds. *Renewable Thermal in State Renewable Portfolio Standards*. Montpelier, Vermont: Clean Energy States Alliance, April 2015. On the Web at http://www.cesa.org/assets/Uploads/Renewable-Thermal-in-State-RPS-April-2015.pdf

DSIRE NYS RPS 2016	Database of State Incentives for Renewables and Efficiency (DSIRE). *Renewable Portfolio Standard: Program Overview: New York.* Raleigh: N.C. Clean Energy Technology Center at North Carolina State University, last updated August 3, 2016. On the Web at http://programs.dsireusa.org/system/program/detail/93.
EIA Calculator 2014	Paul Hesse (Capstone Corporation). *Heating Fuel Comparison Calculator*. Version: HEAT-CALC-Vsn-D_1-09.xls. Washington, DC: U.S. Department of Energy, Energy Information Administration, National Energy Information Center, 2009, revised and updated as of June 6, 2014, apparently by Purdue University, Department of Agricultural and Biological Engineering, Renewable Energy Extension. On the Web at https://ag.purdue.edu/extension/renewable-energy/Documents/ON-Farm/heatcalc.xls. Some information from file "properties".
EIA Natural Gas Wellhead 2016	United States. Energy Information Administration. *U.S. Natural Gas Wellhead Price*. Washington, DC: EIA, Department of Energy, April 29, 2016. On the Web at https://www.eia.gov/dnav/ng/hist/n9190us3a.htm.
EIA RECS 2009 New York	U.S. Department of Energy. Energy Information Administration. *Household Energy Use in New York: A closer look at residential energy consumption*. Washington, DC: EIA, June 26, 2013. On the Web at https://www.eia.gov/consumption/residential/reports/2009/state_briefs/pdf/ny.pdf. Date from Properties. "All data from EIA's 2009 Residential Energy Consumption Survey."
EIA SEDS Consumption 2016	United States. Department of Energy. Energy Information Administration. *State Energy Consumption Estimates: 1960 Through 2014*. (DOE/EIA-0214(2014)) Washington, DC: EIA, June 2016. On the Web at http://www.eia.gov/state/seds/sep_use/notes/use_print.pdf and http://www.eia.gov/state/seds/seds-data-complete.cfm?sid=US. New York is at http://www.eia.gov/state/seds/seds-data-complete.cfm?sid=NY. -- Table CT4. Residential Sector Energy Consumption Estimates, 1960-2014, New York, at http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_use/res/use_res_NY.html&sid=NY. -- Table CT5. Commercial Sector Energy Consumption Estimates, 1960-2014, New York, at http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_use/com/use_com_NY.html&sid=NY. -- Table CT8. Electric Power Sector Consumption Estimates, 1960-2014, New York, http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_use/eu/use_eu_NY.html&sid=NY.
EIA States 2016 New York	United States. Department of Energy. Energy Information Administration. *State Electricity Profiles: New York Electricity Profile 2014.* Washington, DC: EIA, March 24, 2016. Links to each table on the Web at http://www.eia.gov/electricity/state/newyork. Updated annually. -- Table 5. Electric power industry generation by primary energy source, 1990-2014, at http://www.eia.gov/electricity/state/newyork/xls/sept05ny.xls. -- Table 7. Electric power industry emissions estimates, 1990-2014, at. http://www.eia.gov/electricity/state/newyork/xls/sept07ny.xls -- Table 8. Retail sales, revenue, and average retail price by sector, 1990 through 2014, at www.eia.gov/electricity/state/newyork/xls/sept08ny.xls.
Energy Star Conversions 2015	Energy Star. *Portfolio Manager Technical Reference: Thermal Energy Conversions*. Washington, DC: U.S. Environmental Protection Agency, Energy Star, June 10, 2015. On the Web at https://portfoliomanager.energystar.gov/pdf/reference/Thermal%20Conversions.pdf. Date from properties.

Energy Star GHP 2016	Energy Star. *ENERGY STAR Most Efficient 2016 — Geothermal Heat Pumps*. [Washington, DC]: U.S. Environmental Protection Agency and Department of Energy, Energy Star, accessed September 20, 2016. On the Web at https://www.energystar.gov/index.cfm?c=most_efficient.me_geothermal_heat_pumps.
EPA Geothermal 2016	U.S. Environmental Protection Agency. Geothermal Heating and Cooling Technologies. (Renewable Heating And Cooling) Washington, DC: EPA, updated March 18, 2016. On the Web at https://www.epa.gov/rhc/geothermal-heating-and-cooling-technologies.
Gray 2016	Bruce Gray (SunPump Solar). Personal email communication with Lois Chalmers, November 5, 2016.
Gregor 2015	Alison Gregor. "The Passive House in New York," New York Times, March 27, 2015. On the Web at http://www.nytimes.com/2015/03/29/realestate/the-passive-house-in-new-york-city.html.
Howarth 2014	Robert W. Howarth. "A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas," *Energy Science & Engineering*, April 22, 2014 (accepted). On the Web at http://www.eeb.cornell.edu/howarth/publications/Howarth_2014_ESE_methane_emissions.pdf.
Huber 2012	Lisa Huber. *Utility-Scale Wind and Natural Gas Volatility: Uncovering the Hedge Value of Wind For Utilities and Their Customers*. Snowmass, CO: Rocky Mountain Institute, July 2012. On the Web at http://www.rmi.org/cms/Download.aspx?id=6485&file=2012-07_WindNaturalGasVolatility.pdf.
IPCC5 Physical Science 2013	Intergovernmental Panel on Climate Change. *Climate Change 2013: The Physical Science Basis*. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley. Cambridge; New York: Cambridge University Press, October 2013. On the Web at www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf (366 MB), from link at http://www.ipcc.ch/report/ar5/wg1/. Errata at www.climatechange2013.org/images/report/WG1AR5_Errata_11122015.pdf. -- Chapter 8, at http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf.
Lowe's GeoSpring 2016	Lowe's. *GE GeoSpring 50-Gallon 240-Volt 10-Year Limited Residential Regular Electric Water Heater with Hybrid Heat Pump*. Mooresville, NC: Lowe's Companies, accessed on September 20, 2016. On the Web at http://www.lowes.com/pd/GE-GeoSpring-50-Gallon-240-Volt-10-Year-Limited-Residential-Regular-Electric-Water-Heater-with-Hybrid-Heat-Pump/50335967.
Makhijani 2016	Arjun Makhijani. *Prosperous, Renewable Maryland: Roadmap for a Healthy, Economical, and Equitable Energy Future*. Takoma Park, MD: Institute for Energy and Environmental Research, November 2016. On the Web at http://ieer.org/resource/energy-issues/prosperous-renewable-maryland-2016/.
Makhijani 2017	Arjun Makhijani. *Comments of the Institute for Energy and Environmental Research on the NYSERDA report "Renewable Heating and Cooling Policy Framework: Options to Advance Industry Growth and Markets in New York" (February 7, 2017)*. Takoma Park, MD: Institute for Energy and Environmental Research, March 8, 2017. On the Web at http://ieer.org/wp/wp-content/uploads/2017/03/IEER-Comments-NYSERDA-RHC-Framework-2017.pdf, from link at https://ieer.org/resource/carbon-emissions/nyserdas-renewable-heating-cooling/.

Makhijani and Mills 2015	Arjun Makhijani and Christina Mills. *Energy Efficient and Pollution-Free Space Heating and Cooling in Maryland: A report from the Renewable Maryland Project of the Institute for Energy and Environmental Research (IEER)*. Takoma Park, MD: Institute for Energy and Environmental Research, February 24, 2015. On the Web at http://ieer.org/wp/wp-content/uploads/2015/02/RenMD-Space-Conditioning-Feb2015.pdf, from a link at http://ieer.org/resource/energy-issues/energy-efficient-pollution-free/.
Makhijani and Ramana 2014	Arjun Makhijani and M.V. Ramana. *Comments by the Institute for Energy and Environmental Research on the 2014 Proposed Clean Power Plan of the U.S. Environmental Protection Agency*. Takoma Park, MD: IEER, December 1, 2014; resubmitted, with corrections December 8, 2014. On the Web at http://ieer.org/resource/energy-issues/ieer-comments-epa-proposed-clean. Docket EPA-HQ-OAR-2013-0602.
Makhijani, Mills, and Makhijani 2015	Arjun Makhijani, Christina Mills, and Annie Makhijani. *Energy Justice in Maryland's Residential and Renewable Energy Sectors*: *A report of the Renewable Maryland Project.* Takoma Park, MD: Institute for Energy and Environmental Research, October 2015. On the Web at http://ieer.org/wp/wp-content/uploads/2015/10/RenMD-EnergyJustice-Report-Oct2015.pdf, from a link at http://ieer.org/resource/energy-issues/energy-justice-marylands-residential/.
Mangano 2013	Philip F. Mangano. *Building the Business Case for Ending Homelessness*. [Presentation to the] California Workforce Association, Meeting of the Minds, Monterey, California, September 4, 2013. Boston: American Round Table to Abolish Homelessness, 2013. On the Web at http://www.calworkforce.org/images/plenary_phillip_mangano.pdf.
Mitsubishi 2010	Mitsubishi Electric HVAC Advanced Products Division. *Hyper-Heating Inverter for Residential and Commercial Applications: New technology for pumped-up heating performance!* (Form No. H2iBROM-4-10-10M SP) Suwanee, GA: Mitsubishi, updated April 2010. On the Web at http://www.mitsubishipro.com/media/226460/h2i_bro.pdf.
NY-GEO 2016	New York Geothermal Energy Organization. Re: Case 15-E-0302, In the Matter of the Implementation of a Large Scale Renewable Program, Order Expanding Scope of Proceeding and Seeking Comments, issued January 21, 2016. Staff White Paper on Clean Energy Standard, issued January 25, 2016 – Comments of NY-GEO, the New York Geothermal Energy Organization. Buffalo: NY-GEO, April 14, 2016. On the Web at http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={FCD0B215-13DE-4840-B7BD-B4465A40BA20}, from link at http://documents.dps.ny.gov/public/MatterManagement/CaseMaster.aspx?MatterCaseNo=15-e-0302. Sr.No. 192. Filing no. 117. Submitted to NYS Public Service Commission by Bill Nowak.
NYS DPS REV 2015	New York State. Department of Public Service. *Staff White Paper on Benefit-Cost Analysis in the Reforming Energy Vision Proceeding, [Case] 14-M-0101*. Albany, NY: DPS, July 1, 2015. On the Web at https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/c12c0a18f55877e785257e6f005d533e/$FILE/Staff_BCA_Whitepaper_Final.pdf.
NYS Energy Plan 2015	New York State Energy Planning Board. *The Energy to Lead: 2015 New York State Energy Plan*. Albany: The Board, 2015. On the Web at https://energyplan.ny.gov/Plans/2015. Volume I: -- *The Energy to Lead* Volume II: Technical Appendix -- End-Use Energy -- Impacts and Considerations -- Sources

NYS GHG Inventory 2015	New York State Research and Development Authority. *New York State Greenhouse Gas Inventory and Forecast: Inventory 1990 – 2011 and Forecast 2012 – 2030: Final Report.* Albany, NY: NYSERDA, April 2014; Revised June 2015. On the Web at https://www.nyserda.ny.gov/-/media/Files/EDPPP/Energy-Prices/Energy-Statistics/greenhouse-gas-inventory.pdf, from link at https://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Energy-Statistics.
NYS PSC Affordability Order 2016	New York Public Service Commission. *Order Adopting Low Income Program Modifications and Directing Utility Findings*, at a session of the Public Service Commission held in the City of Albany on May 19, 2016, Case 14-M-0565 - Proceeding on Motion of the Commission to Examine Programs to Address Energy Affordability for Low Income Utility Customers. Albany, PSC, Issued and Effective May 20, 2016. On the Web at http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={BC2F31C9-B563-4DD6-B1EA-81A830B77276}, from link at http://documents.dps.ny.gov/public/MatterManagement/CaseMaster.aspx?MatterCaseNo=14-m-0565&submit=Search+by+Case+Number. Filing number 75. Matter Number: 14-02621.
NYS PSC CES Order 2016	New York State. Public Service Commission. *Order Adopting a Clean Energy Standard*. Case 15-E-0302 - Proceeding on Motion of the Commission to Implement a Large-Scale Renewable Program and a Clean Energy Standard. Case 16-E-0270 - Petition of Constellation Energy Nuclear Group LLC; R.E. Ginna Nuclear Power Plant, LLC; and Nine Mile Point Nuclear Station, LLC to Initiate a Proceeding to Establish the Facility Costs for the R.E. Ginna and Nine Mile Point Nuclear Power Plants. Albany: PSC, August 1, 2016. On the Web at http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={44C5D5B8-14C3-4F32-8399-F5487D6D8FE8}. -- Appendices A through G, at http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={B3777382-228F-4268-A674-6B5B93B8614B}. Both from links at http://documents.dps.ny.gov/public/MatterManagement/CaseMaster.aspx?MatterCaseNo=15-e-0302. Filing number 352.
NYSERDA 2015	New York State. Energy Research and Development Authority. *NYSERDA Residential Statewide Baseline Study: Final Report*. (Report number 15-07) Albany: NYSERDA, July 2015. On the Web at http://www.nyserda.ny.gov/About/Publications/Building-Stock-and-Potential-Studies/Residential-Statewide-Baseline-Study-of-New-York-State. Summary Volume 1: Single-Family Report Volume 2: Multifamily Report Volume 3: HVAC Market Assessment Volume 4: Residential Short Term Potential Study Results Volume 5: Methodology and Data Tables Residential Statewide Baseline Study datasets
NYSERDA 2017	New York State. Energy Research and Development Authority. *Renewable Heating and Cooling Policy Framework: Options to Advance Industry Growth and Markets in New York.* Albany: NYSERDA, February 7, 2017. On the Web at https://www.nyserda.ny.gov/-/media/Files/Publications/PPSER/NYSERDA/RHC-Framework.pdf, from link at https://www.nyserda.ny.gov/Researchers-and-Policymakers/Renewable-Heating-and-Cooling.

NYSERDA Degree Days 2016	New York State. Energy Research and Development Authority. Monthly Cooling and Heating Degree Day Data. [Albany]: NYSERDA, last updated August 24, 2016. On the Web at http://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Weather-Data/Monthly-Cooling-and-Heating-Degree-Day-Data.
NYSERDA Electricity Prices 2016	New York State Energy Research and Development Authority. *Monthly Average Retail Price of Electricity – Residential*. Albany: NYSERDA, Prices last updated 09/09/2016. On the Web at https://www.nyserda.ny.gov/Cleantech-and-Innovation/Energy-Prices/Electricity/Monthly-Avg-Electricity-Residential.
NYSERDA Heating Oil 2016	New York State Energy Research and Development Authority. *Home Heating Oil Prices*. Albany: NYSERDA, accessed September 14, 2016. On the Web at https://www.nyserda.ny.gov/Cleantech-and-Innovation/Energy-Prices/Home-Heating-Oil, with historical data base at https://www.nyserda.ny.gov/-/media/Files/EDPPP/Energy-Prices/Home-Heating-Oil/heating-oil-propane-kerosene-price.XLS.
NYSERDA Natural Gas Prices 2016	New York State Energy Research and Development Authority. *Monthly Average Price of Natural Gas - Residential [2006-2016]*. Albany: NYSERDA, Prices last updated 09/09/2016. On the Web at https://www.nyserda.ny.gov/Cleantech-and-Innovation/Energy-Prices/Natural-Gas/Monthly-Average-Price-of-Natural-Gas-Residential, from link at https://www.nyserda.ny.gov/Cleantech-and-Innovation/Energy-Prices/Natural-Gas.
NYSERDA Oil Price 2016	New York State Energy Research and Development Authority. *Monthly Average Home Heating Oil Prices.* Albany: NYSERDA, Prices last updated October 14, 2016. On the Web at https://www.nyserda.ny.gov/Researchers-and-Policymakers/Energy-Prices/Home-Heating-Oil/Monthly-Average-Home-Heating-Oil-Prices.
NYSERDA Trends 2015	New York State Energy Research and Development Authority. *Patterns and Trends New York State Energy Profiles: 1999–2013*. Albany: NYSERDA, October 2015. On the Web at https://www.nyserda.ny.gov/-/media/Files/Publications/Energy-Analysis/1999-2013-Patterns-Trends.pdf, from link at https://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Patterns-and-Trends. -- Table 4-1. New York State Residential Energy Prices in Nominal Dollars, 1999–2013, at https://www.nyserda.ny.gov/-/media/Files/EDPPP/Energy-Prices/Annual-Prices/Annual-Prices-1999-2013-Residential.pdf.
Passive House Institute 2016	Passive House Institute. [*Home page*]. Chicago: PHIUS, accessed February 2, 2016. On the Web at http://www.phius.org/home-page.
Rajendran 2011	Rajan Rajendran. *Refrigerants Update*. Sydney, OH: Emerson Climate Technologies, Inc., September 19, 2011. On the Web at https://www.epa.gov/sites/production/files/documents/RefrigerantUpdates.pdf.
Schumer and Gillibrand 2015	Charles E. Schumer and Kirsten Gillibrand. *Schumer, Gillibrand Announce New York Will Receive Additional $33 Million From Federal Low Income Home Energy Assistance Program To Help Seniors And Low Income Families Offset The Cost Of Heating Their Homes – Second Installment of LIHEAP Funding Will Help New Yorkers In Midst Of Cold Winter*. (Press Release). [New York?]: Office of Schumer, January 23, 2015. On the Web at https://www.schumer.senate.gov/newsroom/press-releases/schumer-gillibrand-announce-new-york-will-receive-additional-33-million-from-federal-low-income-home-energy-assistance-program-to-help-seniors-and-low-income-families-offset-the-cost-of-heating-their-homes_second-installment-of-liheap-funding-will-help-new-yorkers-in-midst-of-cold-winter.
SunPump FAQ 2016	SunPump Solar Inc. *Solar Heating – Frequently Asked Questions*. Abbotsford, BC: SunPump, accessed September 15, 2016. On the Web at https://www.sunpump.solar/solar-heating-f-q.

SunPump Gaudin 2016	SunPump Solar Inc. *Gaudin Home – Prince Edward Island*. Abbotsford, BC: SunPump, accessed September 9, 2016. On the Web at https://www.sunpump.solar/portfolio-items/gaudin-home-pei. Image at https://www.sunpump.solar/wp-content/uploads/Todd-PEI-SunPump-roof-500.jpg.
Taylor 2015	Heather Taylor. *Cost of Constructing a Home*. (HousingEconomics.com Special Studies) Washington, DC: National Association of Home Builders, November 2, 2015. On the Web at http://www.nahbclassic.org/generic.aspx?sectionID=734&genericContentID=248306&channelID=3118&_ga=1.176914085.1438988363.1458836821. Links to a pdf.
UNEP 2016	United Nations. Environment Programme. *Countries agree to curb powerful greenhouse gases in largest climate breakthrough since Paris*. [Nairobi]: UNEP News Centre, October 15, 2016.
Union Gas 2016	Union Gas. *Chemical Composition of Natural Gas*. Chatham, Ontario: Union Gas Ltd., accessed November 11, 2016. On the Web at https://www.uniongas.com/about-us/about-natural-gas/Chemical-Composition-of-Natural-Gas.
US Census NYC 2013 AHS	U. S. Census Bureau. *2013 American Housing Survey for the New York City Metropolitan Area - Complete Set of Tables and Standard Errors*. Washington, DC: Bureau, [October 2014 and later]. From link at http://www.census.gov/programs-surveys/ahs/data/2013/ahs-2013-summary-tables/metropolitan-summary-tables---ahs-2013.html, see https://www2.census.gov/programs-surveys/ahs/2013/New_York_City.xls. In the Contents tab, click on hyperlink to Table C-01-AO in the row for General Housing Data, then tab: C-01-AO-M.
Wikipedia R-410A 2016	"R-410A," *Wikipedia*, modified on 27 August 2016. On the Web at https://en.wikipedia.org/wiki/R-410A.
Wikipedia Refrigerants 2016	"List of Refrigerants," *Wikipedia*, modified on 18 October 2016. On the Web at https://en.wikipedia.org/wiki/List_of_refrigerants.
Winterize Maine 2014	Chris Williams. *Cold Climate Heat Pump Buyers Guide*. Version 3 - Updated. Monroe, ME: Winterize Maine, October 20, 2014. On the Web at http://www.winterizemaine.com/uploads/1/3/1/2/13129746/winterizemaine_coldclimateheatpumpbuyersguide.pdf.

Attachment A: Notes of call with Bill Nowak and Jens Ponikau, NY-GEO

Final notes of conference call on 2016-03-31/reviewed by Bill Nowak and Jens Ponikau; comments incorporated. Approved for citation, quotation, and publication

Present: Bill Nowak: Executive Director, NY-GEO; Jens Ponikau: Certified Geoexchange Designer (CGD), Vice President, New York Geothermal Energy Organization (NY-GEO); Jessica Azulay (AGREE), Arjun Makhijani (IEER)

Arjun prefatory note: Notes are not verbatim. I intend to use them as part of my study on HVAC policy in New York in the context of the State's GHG reduction goals. I may cite these notes, quote them, and/or publish them in their entirety.

Arjun: We are studying Buffalo, Albany, and NYC (except high rise apartments) for HVAC energy consumption, conversion of direct fossil fuel use for space heating to efficient heat pumps, investment cost of conversion, and operating costs of the various systems. We are using the Energy Star heating and cooling calculation template for these cities and would like actual data to make sure that we are in the right ball park as to use and costs, and that the examples are representative. A part of the idea of going to efficient electric systems is to make space heating renewable-grid-ready.

Jens: This is exactly our thinking. We do only geothermal heat pumps. NYSERDA's study was biased relative to geothermal. Agencies were basing lack of support for geothermal heat pumps on the assumption that they are inefficient and cost too much. This is based on old data going as far back as the 1970s and on old refrigerants. GHPs perform much better now.

Cold climate heat pumps were celebrated in Europe. But there are practical issues of installing them. Their efficiency is hyped. They tend to dip into strip heat and this increases the energy use. The rating system is for a Southern California climate. This reduces efficiency as well. Cold climate heat pumps are only efficient when there is a single distribution point, for instance, if you have a studio apartment. In that case they are cheap to install. It is more complex and much less efficient if there are multiple heads. The cost advantage goes away when there are multiple delivery points. Cold climate heat pumps can operate at a low temperature, but you have the problem of the coils icing up. You then need resistance heat to defrost them, and during that time you also need resistance heat for the space. I have seen them freezing up too many times. I have a Mitsubishi cold climate heat pump in my office, just to see how it runs.

Also you have to remember that geothermal heat pumps last longer. The geo-exchange loop lasts the life of the house; the heat pump would last 25 years or 30 years. With an air-to-air heat pump the expected life is about 15 years.

We have worked with PSC staff to revise the NY State technical manual for Ground source heat pumps and the revisions were officially adopted by the Technical Manual Management Committee, whose voting members are utility representatives, in February of 2016. These revisions were based on annual monitoring data. [Arjun requested the manual. Bill Nowak sent it. Thank you Bill.]

In terms of size, we rarely go below three tons. Even if the house is smaller, the heat load does not decline proportionally. The cost does not go down much when you go from a 3-ton to a 2-ton system. Houses typically have a manual J heat loss of 35,000 Btu per hour. So it's not worth it to reduce the size;

if you use a 3-ton system then the strip heat won't come on much, if at all. In effect, we design for the worst case with a three-ton heat pump in such cases. We are talking about new construction here.

Arjun: What about typical installed costs of residential geothermal heat pump systems?

Jens: Costs are more market-specific than climate-specific. For a standard 2500 square-foot new detached house, built to the New York State code we would use a 3-ton system. This runs about $24,000 installed, with a horizontal loop and de-superheater hot water heater, with two tanks. We use variable speed compressors and blowers – a two-stage heat pump. A vertical-loop system costs $2,000 or $1,500 per ton more.

Markets like Albany and New York City have higher labor costs. People are reporting prices Albany $3,000 higher for a system like that; in NYC and Long Island it could be $8,000 more. A part of the problem is geology. Here in the Buffalo area, we hit bedrock at a 20-foot depth, so we need only 20 feet of casing. In Long Island, you have to go far deeper to hit bedrock and so you need much more casing. This raises costs.

Arjun: How about the typical retrofit installation? Can you retrofit insulation, etc., to reduce the heat pump size?

Jens: If we do retrofits, the typical installation could be 4 tons, compared to 3 tons for new construction. In the Buffalo area we can have dramatic differences with microclimates. Within 45 miles north or south of Buffalo there can be temperature differences of 30 F. It could be 8 F one place and -26 F on the same day 50 miles away. We have quite old houses, even going back to 1870. We advise people to invest in insulation and give recommendations for contractors to do insulation. But sometimes there are retrofit restrictions when houses are historic.

Arjun: Are most of your installations vertical wells?

Jens: No. About 10 percent of the cases are vertical; 90 percent are horizontal. This is not feasible in a lot of existing houses. But we can get creative and manage to do most existing single family houses. The economics work out when converting from fuel oil or propane to geothermal. But with natural gas, which is typical of city houses, it can be cost prohibitive at current natural gas prices and without proper incentives in place.

Arjun: Do you have pictures?

Jens: We monitor 20 of our systems live. You can see the performance at http://www.buffalogeothermalheating.com/sample_diagram.html.

Arjun: What fraction of existing houses can you do GHP?

Jens: We can do almost all single family [detached] houses in the Buffalo area; we can even do attached houses. If you are looking at apartment complexes we can do that [horizontal GHP], if there is adequate parking – and there usually is.

Arjun: Can you send me examples of the costs per apartment?

Jens: I can send you the Lockport Housing Authority paper. [Sent and received. Thanks.] There is an old storage building that was converted to 24 apartments. We did the whole building; it now has geothermal heat pumps. The footprint of the horizontal loop is one-third of the building. It depends on how creative you can get and how deep you can go.

Arjun: How do you balance heat pump size and weatherization investment?

Jens: Investment in weatherization can be quite high. If it is like a nice house in the Buffalo area, it can cost $50,000 just to replace the windows. But most of the time the standard data are valid.

Arjun: Have you worked with rental situations and landlords?

Jens: Landlords must see a benefit towards better marketing of their apartments. Landlords usually will not go for it. We have done 2 projects now with the Lockport Housing Authority, which obviously is looking at their bottom line; but they have [federal] HUD money for renovation. They have electric resistance heat. In the old days they had a special electric heat rate – a low cost hydropower rate. So they used electric resistance heat. Their energy consumption is very high. We have converted 72 units that were on resistance heat to geothermal heat pumps. There were three blocks, with 24 apartments in each. They are 2-story buildings. We have estimates of savings but not actual before and after retrofit data.

We have another retrofit – a development in a large building on Buffalo's West Side known as Horsefeathers. The building was not occupied, so we do not have before and after data. It is an old storage building that was converted to condos (see http://welserver.com/WEL0714/).

Arjun: So how did the balance between weatherization and heat pump size work out?

Jens: You want to make sure about what it costs to implement weatherization. Solar energy can also be a supplement, to some extent in place of weatherization because the cost of solar has come down. There is a point at which weatherization may be more expensive than the capital investment in free energy of a larger geosystem powered by a larger solar system.

Arjun: How about wind speed? I have found that high wind speeds can be a problem for strip heat coming on often.

Jens: Wind speed is a major issue. In that case you can use a larger heat pump system.

Arjun: Do you think that design should be based on wind chill temperature.

Jens: This is a huge issue. Air infiltration is the number one way in which old houses lose heat. You can catch a lot of low hanging fruit with the first $2,000 of investment in insulation, etc. There is an exponential curve [in terms of increasing cost]. Agree that air infiltration is the low hanging fruit. Fixating on the R value is not so relevant. NYSERDA has programs for energy audits and blower door tests at 50 Pa [pascals]. But keep in mind that with the reduction in cost of solar and improvement in efficiency, the balance is changing as outlined above. It might be a better investment to increase the geo system and the solar system which is powering it than to catch every high hanging fruit for insulation.

The other thing that might be helpful – a converted administration building. They wanted to gain experience and confidence in geothermal and were on gas and when we converted a building to geothermal. There was baseboard radiant and forced air heat as well. It was all replaced with variable-speed heat pumps. The savings were huge. They had R19 fiber glass; we replaced it with R38 foam. We modeled the savings due to the upgraded insulation, and adjusted the saving for the heating degree days. The rest of the savings were due to the geosystem.

The interesting portion for heat pump size is the entering water temperature. The indoor temperature is the same: 68 to 72 F and does not change. At the start of the heating season, in September, the ground temperature is 65 F or so. It goes down to about 32 at the end of the heating season. At that time the average water temperature is 41 F. Normally people calculate the Coefficient of Performance (COP) at 32 F but this is only at the end of the season; the vast majority of the season is at water temperatures that are much higher than 32 F. We monitor the water temperature and much of the rest of the system. The average COP in New York will probably be equal to just the first stage only, if the heat pump is sized for that. However, there is a pumping penalty. This is only to pump water through the heat exchanger. I would say the overall COP is in the 4.2 to 4.4 range, including pumping penalty for a dual stage system. Again, annual efficiency can be reliably calculated off the first stage (low stage) at 41 F for annual average COP, multiplied by the pumping penalty as outlined above. The same is the case for cooling EER, since the average annual entering water temp does not exceed 65 F due to cold ground in NYS.

Arjun: I have been adding 500 kWh per year for a 3-ton system as the pumping electricity requirement. Is that reasonable?

Jens: 500 kWh is reasonable. But you should note that we use the same pump for a 3-ton and a 5-ton system; so proportionately a 3-ton has a higher pumping penalty than a 5-ton. We use about 45 watts/ton. But it gets complex.

A 5-ton unit has a higher capacity, so if we put in a larger unit, it will have lesser runtime, since it satisfies the load quicker. Thus we have lesser pumping costs per ton with larger units. On the other hand, variable speed units run much longer, but reduce the pumping energy use by revving down the circulation pumps. Keep also in mind that part of the pumping power is already accounted for in the ARI ratings for geo heat pumps. Based on monitoring and modeling, we applied a multiplier to the ARI ratings.

NYS technical manual:
"EER and COP ratings provided in manufacturers' catalogs were developed under conditions specified in ISO 13256, which do not include fan and pump power external to the unit." An adjustment factor is applied to the manufacturers' catalog data to account for fan and pump power:

Unit Type	Stage	Pump power (W/ton)	Unit Type	$F_{cooling}$	$F_{heating}$
Variable	Low	45	Variable flow	0.85	0.93
Two-stage	Low	45	Variable flow	0.84	0.91
Variable	Low	45	Constant flow	0.75	0.86
Two-Stage	Low	45	Constant flow	0.80	0.88

Another way we applied it was 45 watts/ton x 2500 run hours = 112.5 KWh/ton annually.

The new variable speed heat pumps combined with variable speed circulation pumps have changed the game. They run more of the time, but at lower speed. The pumps rev down with compressor stage. They have remote control capability; we have that on 40 of our systems. We can reduce the 500 kWh – 2500 hours of run time at constant speed to 360 kWh per year. I would say if you assume about 120 kWh per ton per year for pumping with a variable speed pump, it would be a relatively realistic number, at least in our design book. We go out of our way to reduce pumping power because it is a parasitic loss. This is the best practice.

Arjun: Can you convert an existing hot-water and cold-water four-pipe system in a commercial building to geothermal heat pumps?

Jens: For a water to water heat pump that depends on how hot you have to make the water. If I have a new house with a radiant system, then water at 85 F is very efficient. But if you need 130 F water, then we lose 15% for every 10 F.

Arjun: How common is baseboard heating in your area?

Jens: We have it. Sometimes there are cast iron radiators. We exchange those for baseboard heaters with double fins. So it comes down to how much money should be spent on building improvement versus a larger geothermal system with less efficient baseboard. We converted an existing system where the annual cost of fuel oil was $20,000 to a geothermal system with electricity cost of $6,000. System was $165,000. So there was a ten or twelve year payback even with no investment tax credit.

Bill – NY has ~50 coops and municipal electric systems in smaller cities and towns that have historically received very inexpensive hydro power from NYPA. Electric resistance heat can be common in those areas, and NY is facing choices as demand for the hydropower increases and communities consider switching to natural gas, requiring a major investment in gas infrastructure. We contend they should instead move to heat pumps. Ontario is looking at the same issue and the Ontario Geothermal Association has presented a strong proposal there to emphasize geothermal instead.

Jens: There are physical limitations. If you look at last 5 to 8 years, dual stage systems have not become more efficient. In my opinion, they won't get much more efficient. New variable speed (capacity) systems are more efficient than a two-stage system. Units are oversized for 90 percent of their runtime, which now improves their efficiency, due to oversized heat exchangers. The claim is a COP of 4.9 annual efficiency, including pumping energy. There is nothing on the horizon to improve refrigerants. We are using 410a. In my opinion it is not the refrigerant but the heat exchanger size and materials that are the key to improving COP; we are getting to the point where efficiency is maxed out. It is important to note that manufacturer COP values do not include pumping power. So, you have to adjust the manufacturer COP by factoring in the specific pumping energy for that type of heat pump.

So far as cooling is concerned, peak reduction is a very important part of the benefit of geothermal heat pump systems. Supplying power at peak times is what is costing us [ratepayers] a lot of money. So geothermal heat pumps could offset new [peaking] power plants. Example: Average EER is between 25 and 40 at a water temperature of 67 F; it is EER 18-25 at a water temperature of 78 F. In New York State, we are never at 78 F. For a correctly sized system, cooling load is 70%-30% heating versus cooling in NYC, and 85%-15% in the rest of the state. As a result, ground loops are very oversized for cooling. I would estimate that there is a 1.8 kW reduction in summer peak load per 3-ton system. The air conditioners are probably running just in first (low) stage, consuming 1 kW, compared to 3 kW for a normal, central air-conditioning system. This is due to the sizing for heating, thus they are oversized for cooling and never engage second stage (high) stage, where their EER is less favorable. Again, the pumping penalty must be applied.

Arjun: Well Jens, thanks so much. I really appreciate the expertise you have shared with me. [Bill Nowak left the call about three-fourths of the way through the interview.]

Post-script added by Jens on review, quoting Fairey et al. 2004:

There are also several other aspects that artificially benefit the HSPF rated performance of air source heat pumps compared with that which will be encountered in the field. These are summarized briefly below:

- Whereas the defrost operation is typically based on the compressor runtime in real systems, the ARI procedure assumes there is no defrost operation below 17ºF where defrost operation will, in fact, be most often triggered due to extended compressor operation (see Section 4.2.1.3, ARI 210/240).
- Although the vast majority of air-source heat pumps operate auxiliary strip heat during the defrost cycle to prevent "cold blow," the ARI procedure specifically requires that strip resistance heaters be prevented from operating during the frost accumulation test. (Section 4.2.1.3). This is

important since such operation of strip heat during the 3-10 minute defrost cycles satisfies part of the house heating load at a lower efficiency that is not reflected in the ARI procedure.

- To achieve better performance in the most severe climate, the ARI procedure computes a smaller building load for the colder Climate Zone V than it does in the more moderate climate zones (I - IV and VI; see equation for BL (Ti) in Section A5.2.1). This results in much lower use of strip heat than would otherwise be encountered in the coldest locations. Conversely, the ARI procedure intrinsically assumes that homes in the mildest locations (Zone I) are just as well insulated as those in Zone IV.
- Finally, beyond standard test conditions, while lower than nominal indoor unit coil air flow will actually increase latent heat removal in cooling mode, there is no such compensation in heating mode. All reductions to system heating capacity due to low coil airflow are a loss to system operating efficiency, generally resulting in increased strip resistance backup.

Reference Publication: Fairey, P., D.S. Parker, B. Wilcox and M. Lombardi, "Climate Impacts on Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER) for Air Source Heat Pumps." *ASHRAE Transactions*, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA, June 2004.
http://www.fsec.ucf.edu/en/publications/html/fsec-pf-413-04/

NYS technical manual now penalizes air source heat pump performance for NYS climate per above study and reference.

Attachment B: Notes of interview with Hal Smith of Halco

Final notes of conference call on 2016-04-01 with Hal Smith (Halco); Jessica Azulay (AGREE); Arjun Makhijani; reviewed and returned with edits on July 28, 2016.

Notes are not verbatim.

Arjun: We are studying Buffalo, Albany, and NYC (except high rise apartments) for HVAC energy consumption, conversion of direct fossil fuel use for space heating to efficient heat pumps, investment cost of conversion, and operating costs of the various systems. We are using the Energy Star heating and cooling calculation template for these cities and would like actual data to make sure that we are in the right ball park as to use and costs, and that the examples are representative. A part of the idea of going to efficient electric systems is to make space heating renewable-grid-ready.

Hal: We participated in the *Heat Smart* program. We were one of three contractors. Heat Smart has a good model of pricing, including detailed pricing of geothermal. Heat Smart was part of Solarize Tompkins; it also included energy efficiency, geothermal heat pumps, air source heat pumps (ASHP), and weatherization. Solarize Tompkins is a community organization in Ithaca. Melissa Kemp led Solarize Tompkins. **(Matt Johnston headed up HeatSmart Tompkins)**

Most people on the Board of Solarize Tompkins are from Cornell; they were excited about air to air, and thought that it was the end-all of heating systems. They also thought geothermal had too much added cost.

There is a place for both geothermal and ASHP. ASHP will have a much shorter life expectancy; the likelihood of matching up the indoor and outdoor pieces is remotely 15-20 years down the line. AHSP expected life is 15-20 years. The expected life of a GHP is 25-30 years for the HP component; the ground loop is forever. I will send you heat smart pricing (I have attached this separately for you). It is all on the Solarize Tompkins web site on a per ton basis.

Typically for a 2,500 sq. ft. house that is weatherized, you are looking at a 4-ton system. The same for a new home: also 4 ton.

Arjun: What is the fraction of homes that can use a GHP?

Hal: We do 95 percent retrofit work. We have a small maneuverable drill rig; that way we can use a vertical rig and can drill on a small foot print. We put copper tube in the ground at the rate of 100 vertical feet of well per ton. The footprint is just a three-foot circle. We drill four diagonal 100 foot holes for a four-ton GHP. For water based geothermal, the well depths are deeper: 300 to 600 feet – 100 feet per ton. A lot of the time it is more efficient to drill deeper, but we have a small drilling rig.

So far as fraction of homes, I think we could install GHP in almost all detached homes. I just discussed this morning a job involving 162 new town homes. There would be a 2 ton or 2.5 ton unit and one well under each townhome, right under the utility room. Each townhome would have its own GHP unit. The estimate for each is down to $13,000 and $14,000, including duct work. That is because it is new work and the GHP and construction is part of the overall construction plan. The average home area will be 1,400 sq. ft.

Arjun: Are you comfortable with a requirement that new homes should be carbon neutral?

Hal: We are proud that we even net zero homes as retrofits. I showcase a New York Geo farm house from early 1800s. They had a horse barn. We weatherized with spray foam and installed solar panels. They have surplus electricity enough to charge two Chevy Volts. I will send you the case study. (attached separately)

Arjun: Is your climate zone close to Albany?

Hal: Our climate is closer to Buffalo. We have plenty of jobs where we use high-tech ASHP – Mitsubishi, Carrier, LG, and Fujitsu. They operate well down to -5 F; below that efficiency drops off significantly. The only thing with air source is that they will not last 20 or 25 years. Geothermal will go almost 30 years. The operating conditions for GHPs are same year round [because the well is underground and the heat pump is indoors]; in contrast ASHP have outdoor components.

Arjun: In your business, what fraction of installations are GHP and what fraction ASHP?

Hal: It is a first cost thing. GHP can be used most cases. Until recently, only air source heat pumps allowed ductless applications. But now LG has a GHP that can be combined with a ductless system. Basically, it is an inverter compressor with up to 9 circuits. It can do heating or cooling at any time; it cannot cool some units and heat others at the same time. It has the same line up as an ASHP. Instead of using an outdoor compressor, they use the indoor loop. They have also been used for high rises in the commercial sector.

There are emerging solutions to the first cost problem. For example, in the future, I see investors putting in the ground loop and you them a monthly fee for using it. It would be much like the solar leasing. It is already starting in Canada.

Arjun: How do you balance investment in weatherization, solar, and the size of the GHP?

Hal: We always do a comprehensive energy audit. We will not install a GHP until we have tightened up home to the very best we can. It always makes sense to do that for both cost and comfort. I don't agree with using a larger system instead of tightening up the home. And our systems do not use strip heat. There is a strip for emergency heat only, not backup.

We can spend $10,000 on weatherization pretty quickly. There are a lot of very leaky homes. Weatherization pricing follows with the EmPOWER program for income-eligible customers [i.e., low-income]. Heat Smart prices for weatherization were right in line with authorized EmPOWER payments for weatherizing low-income households.

Arjun: What about GHP costs?

Hal: Horizontal GHP typically runs $6500 per ton; vertical: $7,500/ton. For ASHP, the cost is $3900/ton installed.

Arjun: How much can the cost be reduced if orders are aggregated?

Hal: Aggregation reduces costs by 20 to 30 percent compared to a one-off system. Heat Smart cost estimates were based on 100 systems being ordered. The added cost for one-off installations is basically the customer acquisition cost. The Heat Smart program took the customer acquisition cost out of it.

Arjun: Is there any particular element of Heat Smart that is particular Tompkins County?

Hal: No. This would be typical. Sometimes Tompkins County may be more difficult in terms of regulations, but overall there is not a significant difference in cost between areas. We work as far east as Utica; to the west we work out to Batavia; to the south we work as far as the Pennsylvania border; to the north we go as far as Lake Ontario. I should say that Heat Smart only allowed water based heat pump systems; they were closed-loop vertical or horizontal GHP. They did not allow **direct exchange geothermal**. Heat Smart worked well for retrofits.

Arjun: Have you done many aggregated contracts?

Hal: Not many.

Arjun: How about pre-retrofit and post-retrofit energy data?

Hal: In the contracting business, there is not much pre and post data. We are getting to home automation that allows remote monitoring. So far monitoring GHPs with actual measured data has been non-existent. So it is not measured. As a result, it is complex to calculate true COP.

The rated COP does not include pumping energy. 500 kWh per year is a fair estimate for the pumping energy. It depends on what part of the country you are in. An old A/C system might be 6 or 8 SEER if it is 15 or 20 years old. The A/C hours in our area are few, so they last a long time. As a result there are a lot of old A/C systems. As a result, when you install GHPs, you are saving a couple of kilowatts in peak load for every old system you replace. We have been very successful with fuel oil and propane replacements. In the case of natural gas heating systems, it is a tough sell.

In the email dated July 12, 2016, you asked:

1. Do you have a compilation of Heat Smart Case Studies including costs and energy data, estimated or, preferably post-installation? **I do not, but you can contact Matt Johnston. His email is matt@solartompkins.org and phone number is 617-680-2646**
2. How much added electricity use is there annually when a water heater with a de-superheater is installed along with the GHP, in order to replace a gas or oil water heater? **Around $150-$200**