High-Performance Packaged Terminal Heat Pump Market and Development Research Report

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High-Performance Packaged Terminal Heat Pump Market and Development Research Report

Final Report

Prepared for

New York State Energy Research and Development Authority

Albany, NY

Prepared by

Taitem Engineering, PC

New York

Simona Li
Project Manager

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Table of Contents

List of Figures

List of Tables

Executive Summary

ES.1 Market Conditions

Based on the market data analyzed, there are at least 100,000 PTACs/PTHPs that could be retrofit to a high-efficiency cold-weather PTHP in New York State without the need for fuel switching or exterior wall renovations. However, one challenge that still needs to be addressed for these retrofits is defrost condensate disposal.

- From LL87 data, there are an estimated 25,000 electrically heated PTACs in New York City that are excellent candidates for replacement with a high-efficiency cold-weather PTHP.
- From a survey of the total number of guest rooms in New York State hotels outside of NYC, there are an estimated 75,000 electrically heated PTACs that are excellent candidates for replacement with a high-efficiency cold-weather PTHP.

From LL87 data, there are an estimated 185,000 PTACs installed in large buildings (more than 50,000 SF) in New York City. Because this data is limited to larger buildings, this most likely means there are more than 250,000 PTACs in New York City. However, the LL87 data does differentiate between standard and nonstandard size units. Historically, nonstandard size units have been found in larger buildings where heating may have been through steam or hot water coils. As a result, a substantial fraction of the NYC PTACs may be nonstandard size, and therefore, not well suited for replacement with a standard high-efficiency cold-weather PTHP. The large number of local manufacturers serving the nonstandard size replacement market is also an indicator that the quantity of nonstandard size PTACs is not negligible.

Economic conditions are poor for retrofit in gas-heated buildings in New York City due to the low cost of natural gas and the high cost of electricity in New York City. Conditions are slightly better Upstate due to the lower cost of electricity. There are also some technical challenges for retrofits that, while not insurmountable, make the potential market for retrofits more difficult.

For new construction, the initial low cost and the potential for higher efficiency, as well as fewer technical challenges for issues such as condensate disposal, combine to offer a more promising market for a high-efficiency PTHP. Also, the better building envelope means smaller capacity PTHPs, which allows for higher-efficiency PTHPs within the fixed PTHP sleeve size.

It should be noted that there is an increase in construction currently happening in the hotel and multifamily sectors, which is significantly adding to the base of installed PTACs annually.

ES.2 Existing Technology

PTACs have a rich history in New York State, originally developed here and the market for PTAC/PTHP is growing; increased use in multifamily buildings. It is anticipated growth in high-end new multifamily might slow as they are displaced by split system heat pumps, which are quieter. However, growth is expected to continue in low-end new multifamily where cost of split systems is limiting, and make-up air is required to each apartment, often achieved through PTAC/PTHP.

Current efficiency of PTACs and PTHPs are low (relative to mini splits) and there is overuse of electric resistance heat in PTHPs for several reasons:

- No PTHPs operate in heat pump down to the midwinter design temperature
- Most PTHPs operate as heat pumps only down to the 30s
- When they shift to electric-heat-only (for example at 30°F), they stay electric-heat-only until the temperature rises a good bit above the cutout temperature (for example, above 40°F). So, during many cold spells, they will stay in electric heat mode until a warm spell occurs, even if the temperature has risen above the temperature at which the heat pump mode was locked out.
- Recovery from setback or units being off typically put the units into electric-heat-only.
- Indoor air temperature sensor location may cause units to be put into electric-heat-only mode.
- Malfunctions or heat pump issues (compressor failure, etc.) cause the units to revert to electric-heat-only.

Costs of PTHPs are low:

- PTHP costs are low, around $1,000 for materials (including sleeve, cord, and grille). Cost difference between PTHPs and PTACs of the same size is also small, typically under $100 (10%) more for the PTHP.
- PTHPs equipment averages about $300 less than mini split heat pumps for the most common PTHP sizes (nominal three-quarter to one ton) and with installed costs included, mini splits cost almost twice that of PTHPs.
- Higher efficiency PTHP's cost more than lower efficiency PTHP's: A 10% increase in efficiency costs approximately 30% more.
- No correlation was found between PTHP cost and the outdoor temperature below which the units operate as electric heat only.

The expected useful life of PTHP's is approximately 15 years. However, in hospitality buildings, replacement is sometimes more frequent—as often as every five to 10 years—because they are reportedly changed for aesthetic and/or noise reasons.

PTHPs currently manufactured in the U.S. use refrigerant R-410a, which has a high global warming potential (GWP). To reduce the environmental impact of refrigerant leaks, lower-GWP refrigerants must be adopted. Heat pump manufacturers overseas are starting to use refrigerant R-32, which has about one-third the global warming potential of R-410a. Currently, the EPA is evaluating the use of R-32 for equipment designed for use in a single room, including PTHPs, but approval for its use still needs to be adopted nationally.

- PTHP efficiency is regulated by U.S. Department of Energy (DOE) who sets minimum efficiency regulations for manufacturers.
    - There may be some confusion in the IECC and NYS Code, which call for efficiencies lower than DOE but may not be allowed to do so due to federal preemption rules.
    - A few off-record anecdotal reports from industry insiders that systems do not operate at rated efficiencies.
    - Replacement PTHPs have lower efficiency requirements than new PTHPs.
    - PTACs and PTHPs introduce unwanted infiltration into buildings, adding to energy inefficiency.
    - PTHPs are not available as Energy Star® products.
    - PTHPs have lower efficiency requirements than comparable-capacity mini split heat pumps.

ES.3 Possible Technology Improvements

A major need is in the area of disposing of defrost condensate. It is not clear that any of the current PTHPs have the capacity to dispose of significant defrost water over an extended period of time. This means that either a technical solution is needed to evaporate condensate internal to the heat pump or a new drain may need to be installed on the building interior to avoid freezing conditions.

Adequate low-temperature capacity and high heat pump efficiency in a standard-size PTAC sleeve seem potentially well within reach, contrary to prevailing concerns about the sleeve not being big enough. However, this will require substantial new product development work and testing/qualification. PTHP efficiencies could increase by more than 30% within the existing standard sleeve size, with current technologies, even for larger-capacity (15000 Btu/hr.) PTHPs. Even higher efficiencies would be possible if the total depth of PTHPs were increased.

Higher capacity and efficiency in smaller through-wall AC units and smaller nonstandard PTAC sizes may be a larger challenge. There is a need for alternative refrigerants to reduce global warming potential from the commonly used refrigerant R-410a; the possibility of using refrigerant R-32 and development of PTHPs using refrigerants with zero impact on global warming is strongly encouraged. Detailed recommendations in areas such as reducing infiltration, reducing thermal conduction losses, sound, and more are included in the report.

1 Technology Overview

The packaged terminal heat pump (PTHP) is the heat pump version of the packaged terminal air conditioner (informally called PTAC, pronounced p-tack).

In its Standard 310/380 Packaged Terminal Air Conditioners and Heat Pumps, the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) formally defines PTACs and PTHPs. Most importantly, note the inclusion of a sleeve, which is provided separate from an unencased refrigeration system that provides heating and cooling, as well as the intent to be mounted through-wall.

1.1 Packaged terminal air-conditioner:

A wall sleeve and separate unencased combination of heating and cooling assemblies specified by the manufacturer and intended for mounting through the wall. It includes refrigeration components, separable outdoor louvres, forced ventilation, and heating availability by purchaser's choice of hot water, steam, or electrical resistance heat.

Note: Models designated as "cooling only" units need not include heating elements if the physical characteristics and arrangement of the refrigeration system are identical to those of models with heating availability.

1.2 Packaged terminal heat pump:

A separate unencased refrigeration system installed in a cabinet having a function and configuration similar to that of a packaged terminal air-conditioner. It uses reverse cycle refrigeration as its prime heat source and should have other supplementary heat source(s) available to purchasers with the choice of hot water, steam, or electric resistance heat.

PTACs have been largely adopted due to a number of benefits, including ease of installation (does not require a refrigeration technician), ease of service (units can be easily slid out of a permanent sleeve for repair in a central location and replaced with spare units), low cost, and room-by-room temperature control. However, some disadvantages have prevented further market penetration, including compressor noise, low efficiency, and air leakage through the units and sleeves.

2 History

PTACs likely got their origins in through-wall air conditioners in the 1930s, just a few years after the development of air conditioning, as mentioned in a 1935 issue of Popular Mechanics:

> Compact and so low in height that it fits below the window sill of the average home or office, a self-contained air conditioning unit is ready for the market. Its capacity is sufficient for one large room...Almost at the 'touch of a button,' it is possible to have the air cooled, dehumidified, circulated, and filtered.[1]

The most popular PTAC size, 16" high and 42" wide, was developed in the late 1950s. It was released in 1958 by the Remington company, which was founded in Cortland, NY, by Herbert Livingston Laube. It was initially marketed as "incremental" air conditioning, a new type of decentralized system. Eventually all other major air conditioning manufacturers were forced to develop decentralized air conditioning products.

By the 1980s, the PTAC market was mature with many other manufacturers (GE, Carrier, Trane, Amana, and others). The initial market was predominantly hotels, which continues to be the case, specifically in lower-end hotels and motels. However, PTACs have also always seen some limited application in other commercial buildings, such as offices, nursing homes, and apartment buildings.

3 Historic Market Conditions

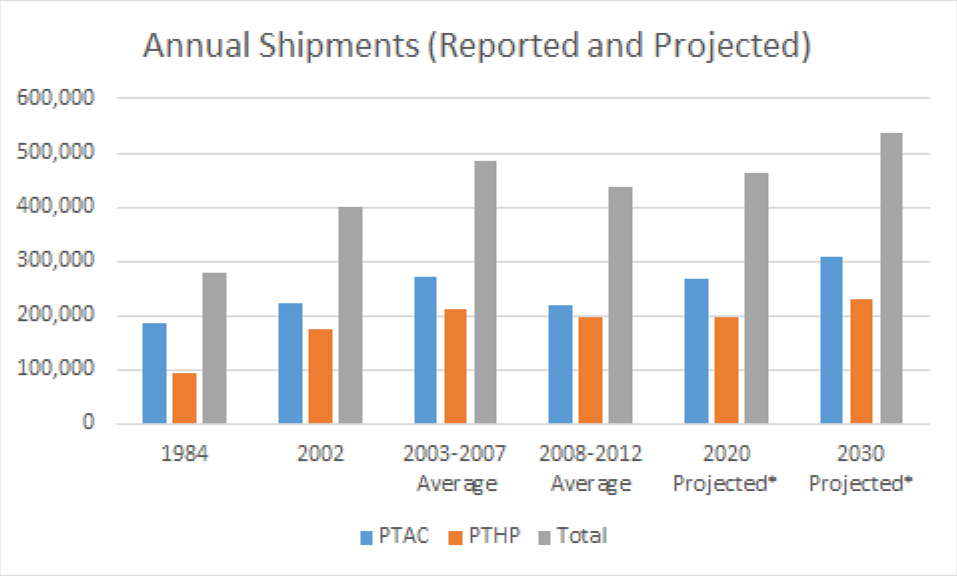
3.1 National

By 1984, annual shipments of PTACs were reported as approximately 185,000 units and PTHPs as approximately 94,000 units, for a total of 279,000 units.[2] Since then, total PTAC and PTHP shipments grew to approximately 400,000 units per year in 2002, comprised of 44% PTHPs, 6% cooling-only PTACs, and 50% PTACs with non-heat-pump forms of heat (electric resistance or steam/water coils).[3]

The DOE's 2008 minimum efficiency standards rulemaking report projected total PTAC/PTHP shipments of 450,000 in 2012 and 650,000 in 2042; of which, nonstandard sizes would be 30,000 units in 2012, decreasing to 15,000 units by 2042. However, the DOE's 2015 minimum efficiency standards rulemaking report found that average shipments dropped during the recession.[4]

Figure 1. Annual PTAC/PTHP shipments and projections

Reported and projected annual shipments of PTACs and PTHPs in the U.S. Projected numbers are for standard-size PTACs and PTHPs only.



A 2008 study by Pacific Northwest National Laboratories quotes an earlier study on lodging heating and cooling that found hotels/motels are the biggest end users of PTAC and PTHP, accounting for 70% of the PTAC and PTHP market. More detailed market data showed that among the four most common sizes of PTAC, (7,000 Btu/hr, 9,000 Btu/hr, 12,000 Btu/hr, and 15,000 Btu/hr), the PTAC and PTHP of 9,000 kBtu/h capacity accounted for approximately 50% of the U.S. PTAC and PTHP market in 2000.[5]

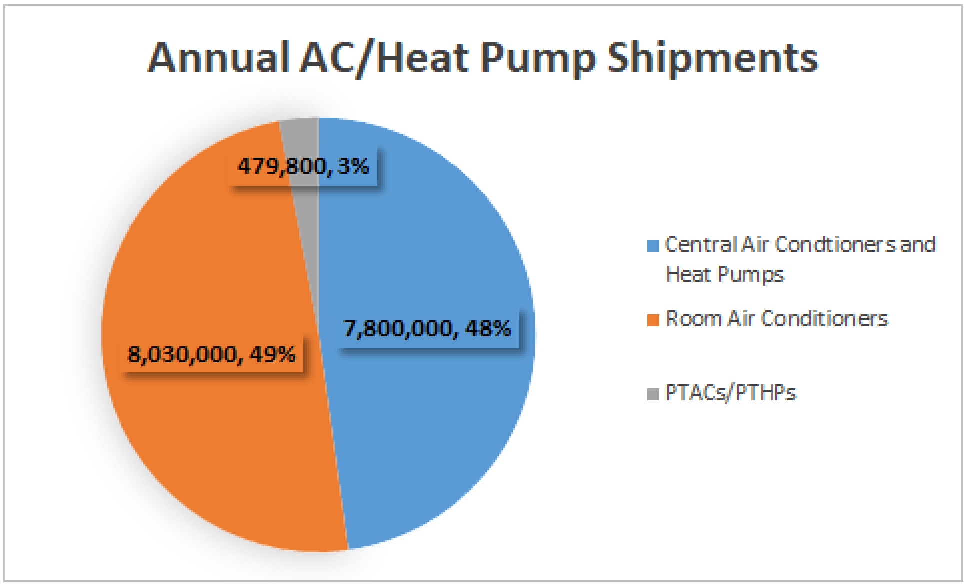
The increased use of PTACs in multifamily buildings is a more recent development, likely dating to the building booms of the mid-1990s and early 2000s. There have been many reported complaints about PTACs from residents in multifamily housing including noise, air leakage, failure, and inadequate temperature control.[6] With the advance of heat pumps, specifically mini split and VRF systems, PTAC installations in multifamily buildings is on the decline. It is a likely possibility that the 20- to 30-year phenomenon of PTACs in multifamily buildings will end. However, the use of PTACs in lower-end hotels is likely to continue due to their cost and ease of installation and maintenance. For noise reasons, higher-end hotels will likely continue to move to fan coils, water-source heat pumps, and VRF systems.

4 Current Market Conditions

4.1 National

To understand the potential market for PTHPs, it is important to review the current market conditions for PTACs and PTHPs since PTHPs could entirely replace the PTAC market. In recent years, PTAC shipment statistics have not been provided by AHRI or the U.S. government, reportedly because the number of manufacturers is too small to guarantee confidentiality. However, using the projected shipments from the 2008 DOE rulemaking, it is estimated that current annual shipments are 260,000 for PTACs and 195,000 for PTHPs. For reference, this makes up only about 3% of the total annual AC and heat pump shipments, as shown in Figure 2.[7]

Figure 2. Annual AC/Heat Pump Shipments in the U.S.



4.2 New York City Market

4.2.1 LL87 Data

New York City's Local Law 87 (LL87) data from 2013 to 2015 was analyzed to assess the PTAC market share in NYC. Some of the project data was incomplete, so it is possible that the results are underreported. It is also important to clarify that these results are for large buildings (>50,000 sf) only; therefore, the actual numbers of PTACs installed in NYC is greater.

In the LL87 data set analyzed, PTACs were the primary heating and/or cooling equipment used in 3.6% of the projects. When extrapolated to all LL87 buildings (13,858 tax lots or “projects” in total), it is estimated that a total of 493 projects utilize PTACs. Similarly, when the total quantity of PTACs found to be installed in the data set analyzed was extrapolated to all LL87 buildings, there are approximately 185,000 PTACs installed covering 92 million square feet of conditioned area.

For the three years of LL87 data analyzed, only 46 projects were identified to be electrically heated, representing only 1.3% of all projects. Of these projects, only 16 appear to have electrically heated PTACs, or 0.5% of all projects. Extrapolated out for all LL87 buildings, it is estimated there are 63 large buildings (>50,000 sf) with electrically heated PTACs for which a high-efficiency cold-weather PTHP could be installed without fuel switching issues. In total, it is estimated that 26,000 PTHPs would be needed to complete these retrofits.

Another important distinction about the NYC market place is that many of the existing PTACs are likely nonstandard size. Actual numbers of standard vs. nonstandard size are unknown, but it appears that a significant portion are nonstandard size as this retrofit market is able to support seven PTAC manufacturers local to New York State or near NYC (see PTHP Availability and Ratings section for further discussion of manufacturers). Due to the variability in nonstandard size PTACs, it is less likely that a manufacturer will develop a high-efficiency cold-weather PTHP that is nonstandard size.

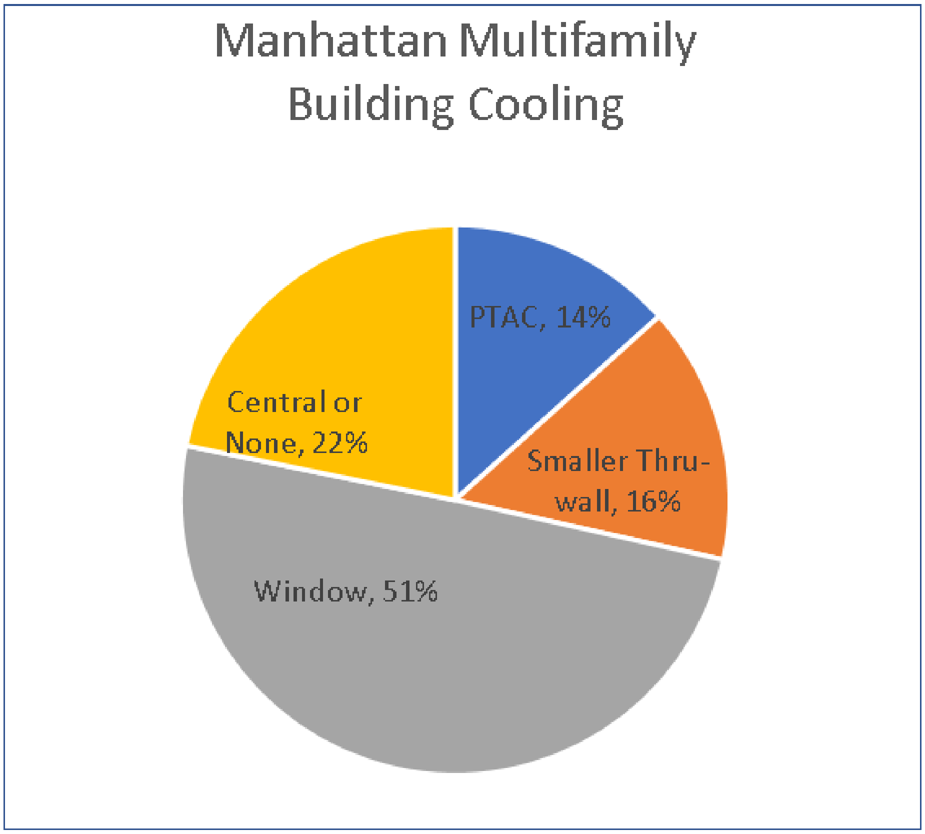
4.2.2 Manhattan - Small Sample Study

Recently, members of the study team (May 10, 2018) traveled around Manhattan and took photos of multifamily buildings in different areas of the city. The sample is reasonably good and represents more than 160 buildings from the southern tip of Manhattan to the northern end, from the Financial District through the Lower East Side, midtown Manhattan, and the Upper East Side. Affordable and market-rate buildings are both well-represented. It is important to note that it is not an entirely random sample because it was limited to Manhattan and represented the specific neighborhoods inspected.

From the photos, buildings were divided into four groups by the type of visible-from-exterior room air conditioning: PTAC, through-wall room AC (smaller than PTAC), window AC, and “none.” The number of stories was also recorded and the rough age of the building (pre-1950, 1950–2000, and 2000–present). Results of this limited study are as follows:

- Window units are the most common room AC in pre-1950 buildings.
- Through-wall AC units (which are smaller than PTACs but utilize a through-the-wall sleeve), are the most common room AC in buildings from 1950–2000.
- PTACs/PTHPs are the most common room AC in newer buildings (2000–present).
- PTACs serve 14% of buildings sampled. This is higher than two other estimates, LL87 data analysis, and a survey of NYSERDA multifamily existing building projects.
- Through-wall units serve 16% of buildings.
- The highest fraction (51% of buildings) have window units, although this also is primarily smaller buildings, so whereas this represents over 50% of buildings, it represents a smaller percent of total room AC units.
- Buildings that have either central AC or no AC represent 19% of the buildings.
- Buildings with PTAC or through-wall units have more units per apartment (or "per window"), because window units have mostly been used as a problem-solver, whereas PTACs and through-wall were designed into the buildings. PTACs and thru-wall units are below about 65% of windows in the buildings they serve, whereas window units are only in about 40% of windows in buildings they serve.
- PTACs (which are installed in 17-floor buildings on average) and through-wall units (13-floor buildings on average) are installed in taller buildings than window units (nine-story buildings on average). Buildings with no room AC are 14 floors on average.

Figure 3. Multifamily building cooling systems found in small sample study of Manhattan



As a check, a sample (265 buildings) of NYSERDA multifamily energy projects in existing buildings were examined, from a time when the program served both affordable and market-rate buildings (completed projects in the fall of 2013). This sample had fewer PTACs (1.1% of buildings statewide and 2.2% in New York City) than the small sample of multifamily buildings in Manhattan (14% of buildings). This could possibly be explained because PTACs are used in more modern buildings and are less likely to have been candidates for NYSERDA energy work.

4.3 Multifamily New Construction

As discussed previously, in the past 20-30 years there has been a trend toward the installation of PTACs in new multifamily buildings. An analysis of projects that participated in NYSERDA's Multifamily Performance Program New Construction confirm this trend. Of the 473 projects where data was available, 184 projects, or 39% in total, utilized PTACs.

In addition to low cost and ease of installation, PTACs may be favored in multifamily new construction because of the requirement to provide make-up air. PTACs often have integral outdoor air louvers within the equipment, which have been acceptable to both NYSERDA and building code enforcement as a means to provide make-up air. As a result, PTACs become a cheap option to provide heating, cooling, and make-up air, but unfortunately, they are not the most energy-efficient option for any of those needs.

4.4 Hotels

In 2015, New York City had approximately 107,000 hotel rooms in 696 hotels.[8] In addition, there are plans to add an additional 26,500 to this total by end of 2019 for a total of 133,500 rooms. From the LL87 data analyzed, 39% of hotels are cooled with PTACs, 45% with fan coils, and 16% with other systems. Using this market-share rate, it is estimated that a total of 52,000 PTACs/PTHPs will be installed in NYC by 2019.

Assuming the same market rate of PTACs in NYC of 39%, it can be estimated that 82,000 PTACs are installed in hotels across New York State. Anecdotal evidence has shown that Upstate hotels are more likely to have PTACs, and the PTACs that are installed are more likely standard size.

To estimate the prevalence of PTACs/PTHPs in non-NYC hotels, the heating systems installed in hotels in Tompkins, Cortland, and Onondaga counties were analyzed. In total, 97 hotels were sampled with a total of 69, or 71%, having PTAC/PTHPs installed. All of the PTACs/PTHPs in this sample set appear to be standard size. With a total of 210,000 hotel rooms in New York State[9] and 107,000 in NYC, there are a total of 103,000 non-NYC hotel rooms. Extrapolating these results to the rest of the non-NYC hotel market in the State, there is an estimated total of 73,130 PTACs/PTHPs installed, of which the majority are standard size units.

Based on the two completed analyses (Local Law 87 and non-NYC hotel sampling), there are an estimated 125,000 PTACs/PTHPs installed in New York State hotels.

4.5 Opportunities

Based on the market data analyzed, there are approximately 100,000 PTACs/PTHPs that could be retrofit to a high-efficiency cold-weather PTHP in New York State without the need for fuel switching or exterior wall renovations. The resulting annual energy savings from this retrofit would be approximately 274 MWh/yr. for a total annual cost savings of $32,600,000 and a total annual carbon emission reduction of 326,000 lbs. CO2. Further analysis of the energy savings opportunities can be found in the Energy Savings section.

The trend toward the installation of PTACs in multifamily buildings provides strong support for the need for a high-efficiency PTHP that can fully meet the heating loads in New York State climates. By eliminating the need for a hot water coil, steam coil, or natural gas piping, construction costs are significantly reduced, which can be used to cover any premium costs for the higher-efficiency PTHPs (see further discussion in PTHP for New Construction section).

4.6 Challenges

Due to the current low cost of natural gas and high cost of electricity in NYC, it is not financially effective to replace a non-electric PTAC with a PTHP in NYC, even if a high-efficiency cold-weather PTHP was developed. See the Energy Savings section for further discussion.

Nonstandard size PTACs make up much of the NYC marketplace, and due to the size variability in these nonstandard PTACs, it may be unlikely that a manufacturer will develop a high-efficiency cold-weather PTHP that is nonstandard size. Installation of a standard size PTHP in a nonstandard size sleeve would require extensive exterior wall renovations and is unlikely to occur.

Another major challenge for the high-efficiency cold-weather PTHP retrofit is how to deal with defrost condensate removal. A further discussion on this challenge can be found in the Defrost Requirements section.

5 PTHP Availability and Ratings

According to the DOE Compliance Certification Database, there are at least 33 manufacturers selling standard size PTHP equipment in the U.S. that comply with federal conservation standards.[10]

5.1 Physical Size

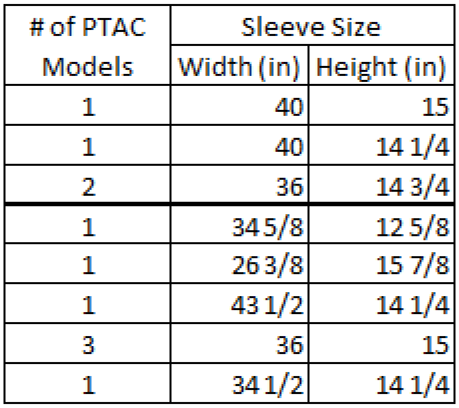
Recently, the industry has mostly standardized on 42" x 16" PTAC and PTHP sizes. There are some manufacturers that still produce nonstandard size units, but these are mostly focused in the retrofit market. Of these manufactures, there are two that sell nonstandard size units.

Photo 1. Standard size PTHP

Photo 2. Nonstandard size PTAC with hot water coil

Historically, manufactures had not agreed on a standard size. As a result, many of the PTACs installed in NYC have different size sleeves and different locations of existing steam and hot water coils. As regional manufactures developed solutions to replace these older PTACs, they had to design them to fit into the existing sleeves and work with existing hot water/steam coil locations. As a result, these manufactures offer around 10 different options for replacement PTACs. For example, one NYC regional manufacture currently offers PTACs to fit into eight different size sleeves.

Table 1. NYC regional manufacturer PTAC sleeve size offerings



# of PTAC Models	Sleeve Size	
	Width (in)	Height (in)
1	40	15
1	40	14 1/4
2	36	14 3/4
1	34 5/8	12 5/8
1	26 3/8	15 7/8
1	43 1/2	14 1/4
3	36	15
1	34 1/2	14 1/4

It is surprising to see that this manufacturer does not currently offer a standard size PTAC; the PTAC they market for new construction is nonstandard size.

5.2 Capacity and Efficiency

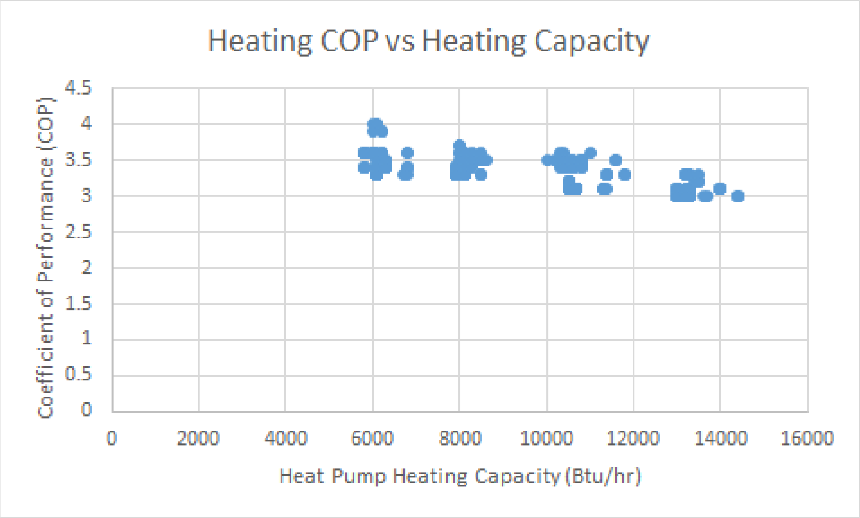
There are four common capacities for PTACs and PTPHs: 7,000 Btu/hr., 9,000 Btu/hr., 12,000 Btu/yr., and 15,000 Btu/yr. It is typical for the heat pump heating capacity to be slightly lower than the cooling capacity by approximately 11%. Table 2 shows a sample of the four common capacities for four different brands and the difference between the heating and cooling capacities.

Table 2. Comparison of cooling and heating capacities of the four common PTHP sizes

Size (Btu/hr)	Avg Cooling Capacity (Btu/hr)	Avg Heating Capacity (Btu/hr)	% Difference
7,000	7,200	6,225	-14%
9,000	9,275	8,050	-13%
12,000	11,850	10,650	-10%
15,000	14,525	13,325	-8%
		Average	-11%

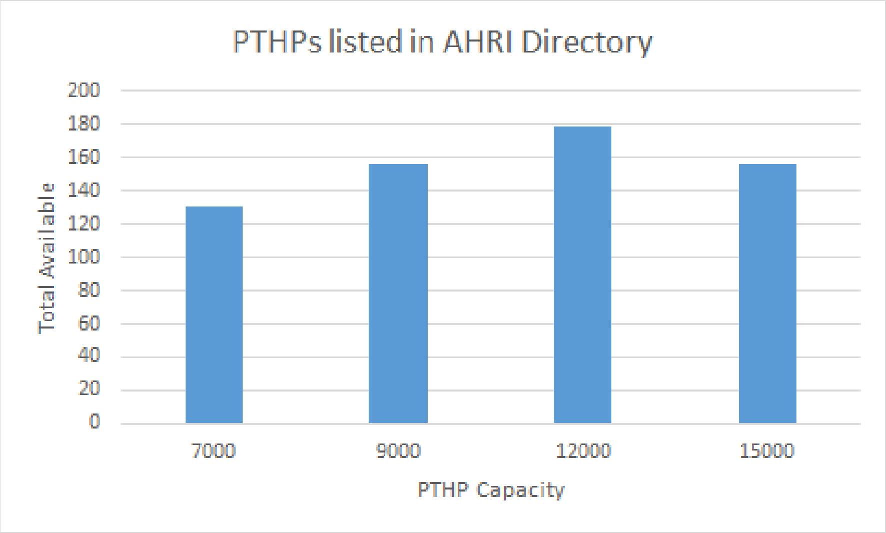
The highest COP currently available for a PTHP is 4.0 and the lowest is 3.0, with smaller units typically having higher efficiencies. Efficiencies are calculated according to AHRI's 310 test standard (see Regulatory Considerations for more information on testing). Figure 4 compares heat pump heating capacity vs. COP for all PTHPs listed in the AHRI directory.[11]

Figure 4. PTHP heating COP compared to heating capacity



The analysis presented in Figure 5 shows that total availability of PTHPs across the four common sizes is fairly uniform. However, availability does not directly correlate to the actual quantity of each size that are installed.

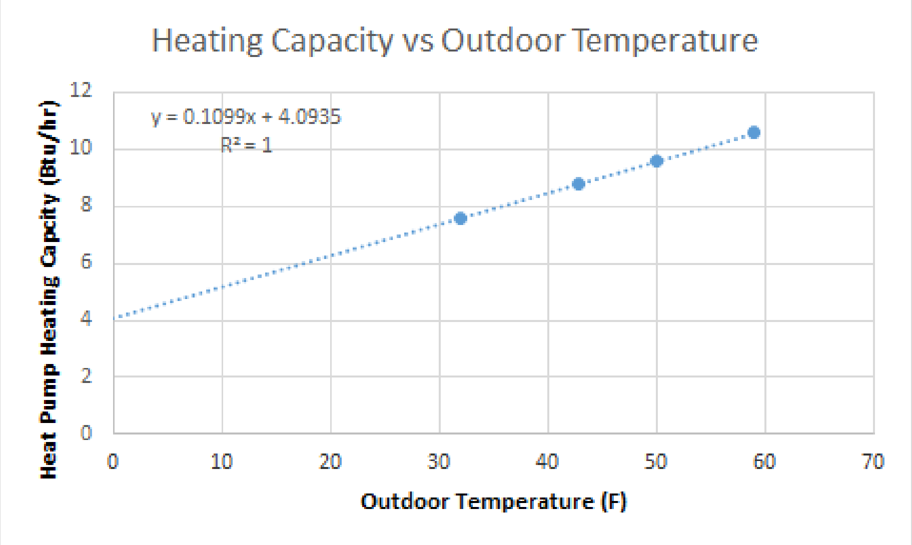
Figure 5. Total available PTHPs in each size as per the AHRI Directory



The smallest heat pump heating capacity PTHP listed in the AHRI is 5,800 Btu/hr. With the construction of more energy-efficient buildings and the reduction of heating loads in existing buildings through energy retrofits, there may be a market for either a lower heating capacity PTHP and/or PTHPs that have variable speed compressors. For addition discussions on heat pump sizing and capacity needs, see the Capacity Needs section.

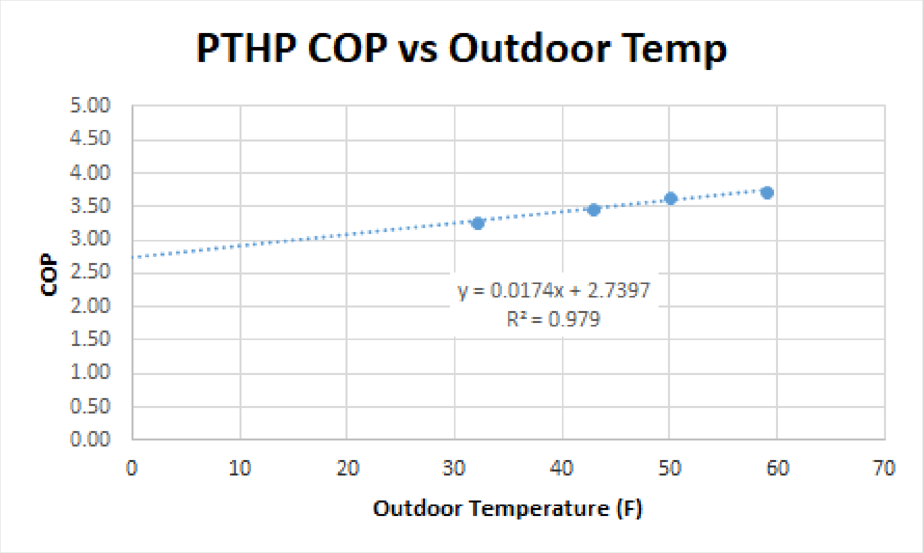
Because the AHRI 310 test standard only requires efficiency and capacity ratings be taken at one test condition, most PTHP manufacturers do not report lower temperatures ratings. Figure 6 shows the data from one manufacturer who reported lower temperature heat pump heating capacities. Based on the assumed linear relationship between heat pump capacity and outdoor temperature, at 0°F outdoor temperature, the heat pump capacity appears to be 55% less than what it is at the 47°F test standard temperature.

Figure 6. LG model LP093HDUC1 heating capacity vs. outdoor temperature



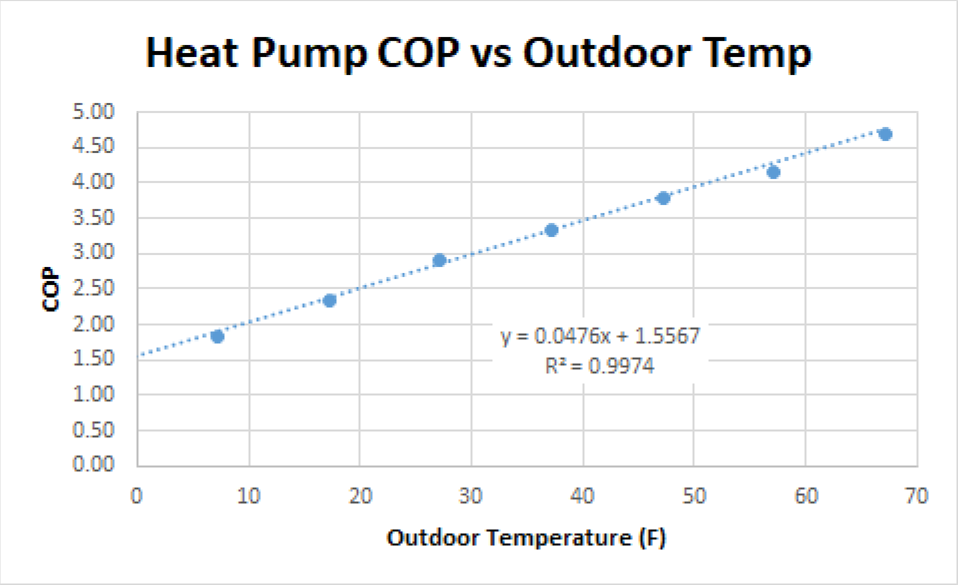
This same manufacturer also reported the rated COP of their heat pump at different outdoor temperatures, shown in Figure 7. Based on the linear relationship found for other single-speed compressor heat pumps (Figure 8), it is assumed this PTHP also has a linear relationship of COP with outdoor temperature. Using the data provided, an analysis was performed to determine the approximate curve of the PTHPs COP vs. outdoor temperature. The estimated performance (~2.75 COP) of this PTHP at 0°F outdoor temperature based on this linear relationship does seem mistakenly high given other heat pump efficiencies at this outdoor temperature (1.5 - 2.0 COP), which calls the published efficiencies into question.

Figure 7. LG PTHP model LP093HDUC1 rated COP vs outdoor temperature



Given the performance of existing single-speed compressor heat pumps, shown in Figure 8, it is assumed that a similar COP would be feasible at lower temperature for PTHPs if defrost issues are addressed so they can operate at lower temperatures.

Figure 8. Carrier heat pump model 25HCC518A30 rated COP vs. outdoor temperature



Of the PTHPs currently on the market, all manufacturers appear to use a single-speed compressor except for three: Applied Comfort, Arama, and Friedrich. While these manufacturers utilize a variable speed compressor, none of them do active defrost; therefore, they switch over to electric resistance heat at approximately 40°F. This basically negates the advantage of having a variable-speed compressor for heat pump mode. The Arama model claims to have an HSPF of 7.6, but how they determined this rating is unclear.

Interviews with manufacturers confirmed the need for a seasonal efficiency rating for PTHPs. Manufacturers who currently use variable-speed compressors expressed that because of the AHRI rating at a single test condition. the efficiencies their unit achieves are not properly reflected. Other manufacturers currently using single-speed compressors expressed that having a test standard for seasonal efficiencies would incentivize them to utilize variable-speed compressor technology.

5.3 Regional Manufacturers

There appears to be five New York State manufacturers of PTACs, as listed, three of which currently manufacture PTHPs.

- Islandaire (PTHPs available)
- Simon Aire
- Ice-Air (PTHPs available)
- EMI - RetroAire (PTHPs available)
- Cold Point Corp - Adirondack-Aire (Vertical and A/C Sleeve HPs available)

In addition to the five New York State PTAC manufacturers, there are two other manufacturers near to NYC, but neither show PTHPs available on their website.

- Evergreen Products LLC (New Jersey)
- Comitale National, Inc. (Pennsylvania)

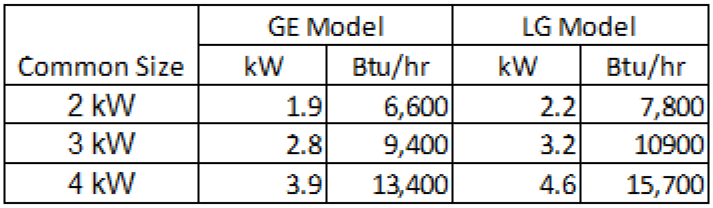
There may be other regional manufacturers not noted here. Some manufacturers have offices or headquarters in New York, even though their manufacturing operations are out of State. Daikin U.S., for example, is headquartered in Manhattan, but manufacturers its PTACs and PTHPs in Houston, TX. Fujitsu General America, headquartered in Fairfield, NJ, has a large showroom on Broadway.

Based on a review of their current offerings and interviews with manufacturers and building professionals, it appears that the regional PTAC manufacturers are the main supporters of the NYC nonstandard size PTAC replacement market. Two of these manufactures, Islandaire and Ice-Air, seem to have a larger presence in the PTAC new construction market producing units for hot water, steam, and gas-fired heating in addition to their PTHP offerings.

6 Electric Resistance Heat

All PTHPs currently on the market have an electric resistance heater installed to provide electric resistance heating in different circumstances. There are three common sizes for these electric resistance heaters, shown in Table 3.[12,13]

Table 3. Common electric resistance heater sizes for two manufacturers (kW is at 208V)



Common Size	GE Model		LG Model	
	kW	Btu/hr	kW	Btu/hr
2 kW	1.9	6,600	2.2	7,800
3 kW	2.8	9,400	3.2	10900
4 kW	3.9	13,400	4.6	15,700

The electric resistance heaters within the PTHPs are typically initiated for three reasons:

- Frosting on the outdoor coil
- Space temperature setpoint greater than current space temperature
- Electric heat boost designed to bring space to setpoint quickly

A simple test was performed on a PHTP installed in a hotel room to evaluate the initiation of electric heat. During this test, the equipment was found to operate in the electric resistance heat only mode despite the outdoor temperature being mild (56°F) and the unit having been allowed to go through at least one full heating cycle. The findings from this test can be found in Appendix A. These results confirm concerns about electric heat being initiated unnecessarily impacting the efficiency of existing PTHPs.

6.1 Electric Resistance Heat Switch Over Temp

Due to issues surrounding defrost (see the Defrost Requirement section), most PTHP manufacturers shut off the heat pump and switch to electric resistance heat only when frost conditions are present. Of the 25 manufacturers with AHRI certified PTHPs, only two manufacturers appear to do active defrost. As a result, the most common outdoor temperature that PTHPs switch to electric resistance heat is 40°F. Active defrost allows two manufacturers to operate in heat pump mode to lower outdoor temperatures (25°F and 33°F). However, even though these units do active defrost, they often initiate an electric resistance boost heat option even before these colder outdoor temperatures are reached, which reduces overall efficiency even at mild temperatures.

6.2 Electric Resistance Boost

All manufacturers appear to have an electric boost option that initiates the electric resistance heater even when outdoor temperature would allow heat pump mode operation. The first reason for initiating electric boost heat is to bring the space up to temperature quickly. For example, some manufacturers have an automatic option called instant heat mode or quick heat recovery, which runs the electric heater to bring room up to temperature quickly “when first energized.” By “first energized” it appears the manufacturers are referring to the unit’s first heating cycle when switched from either “off” or “cooling” modes.

Electric boost heat is also initiated when the space temperature setpoint is greater than the current space temperature. Depending on the manufacturer, the difference between the setpoint and space temperature needed to initiate electric heat differs. Some manufacturers initiate the electric heat if the setpoint is >2°F of the current space, while others are more conservative with their use of the electric heat, only initiating it when setpoint is >4°F or >8°F than the current space temperature.

Unfortunately, electric boost heat is often activated because of user error in operating PTHPs. It is reported users often turn up the thermostat to try to get heat faster. As a result, the equipment controls think the unit can’t keep up with the space temperature load and it switches over to electric resistance heat. Since the air coming off the indoor coil during electric heat is typically warmer than when in heat pump mode, this reinforces the behavior of turning up the setpoint to heat the room.

Another common issue is the location of the indoor temperature sensor and its impact on electric boost heat. Since the sensor is typically located directly next to the indoor coil, the residual heat from this coil, even when the unit is off, results in the equipment thinking that the indoor space temperature is greater than it is. As the room temperature slowly drops, the indoor temperature sensor may be reporting a buffered temperature. When the temperature sensor does call for heat, the unit kicks on and pulls cooler indoor air across the indoor coil. The equipment controls get an actual reading on indoor air temperature, which can be far enough outside of the setpoint range to initiate the electric boost heat option.

Based on interviews with industry professionals, it appears that disabling the electric boost heat option cannot be easily achieved with the current controls used. These two issues, along with switching to all electric heat when defrost is necessary, drastically reduces the effective COP of PTHPs.

7 Defrost Requirements

The capability to effectively defrost is a primary requirement for PTHP's to be able to save more energy by operating in heat pump mode with low outdoor air temperatures. Both major PTHP manufacturers that do have a defrost cycle tout the defrost as a way to save additional energy by extending the operation of the PTHP in heat pump mode.

Defrost itself presents a variety of challenges. Three issues may present specific challenges to manufacturers and installers in the development of cold-climate PTHPs for use as replacement for PTACs and inefficient PTHPs:

- **Water removed from outdoor coils by defrost needs to be drained.** Existing PTACs and PTHPs typically do not have drains because most remove cooling condensate by use of a "slinger ring" on the outdoor fan, which slings condensate onto the outdoor coil. This is not an acceptable approach for defrost water, as water slung onto the outdoor coil will not evaporate and may refreeze. If existing PTACs do have drains, these drains may be to the outdoors and present a risk of freezing. Retrofitting new interior drains would be difficult and costly.
- The steel cases of the PTHP may present a risk of freezing for water that has been removed by the defrost cycle. This is due to their conductivity before the water is fully able to drain.
- The cost and effort to develop and test reliable defrost approaches may be significant. This is especially true for smaller PTAC/PTHP manufacturers.

7.1 Conditions During Which Frost Occurs

Frost occurs primarily in the range of temperatures between 20°F and 40°F outdoor air temperature. There is frequently a misconception that frost only occurs below freezing outdoors (32°F). However, frost occurs due to the refrigerant temperature being below freezing, and not the air temperature being below freezing. The refrigerant temperature is colder than the outdoor air temperature, typically 10-20°F colder. So it is possible for frost to occur when the outdoor air temperature is as warm as 40°F. Below 20°F, the outdoor air cannot hold as much moisture, so frost formation is less likely but it does not meant that defrost does not occur. One study estimated that approximately 90% of defrost energy is used between 20 and 40°F, in traditional split system heat pumps.[14]

7.2 How Current PTHP’s Defrost

Most PTHPs operate only as heat pumps during warmer outdoor temperatures, avoiding the need to defrost. Instead of addressing the need to defrost, they switch to electric resistance heat around 40°F outdoor temperature.

A common defrost strategy (“time-temperature” defrost) automatically puts the system through a defrost periodically when the temperature is cold, even if defrost might not be required. The more energy-efficient “demand defrost” strategy is used in more sophisticated systems and reduces defrost energy use by not enforcing periodic defrost cycles, but rather only defrosting if frost is detected.

Two PTHP’s were identified that do active defrost, those made by GE and by LG. These manufacturers both use reverse cycle defrost, in other words, they reverse the refrigerant cycle to move the heat from the indoor coil to the outdoor coil (by operating in cooling).

Excerpts from GE and LG product literature give some insight into each of their defrost cycles:

GE Zoneline:

- During the defrost cycle, both indoor and outdoor fans stop, and the compressor will operate in the cooling mode to remove frost from the outdoor coil. After defrost, the unit will restart in electric heat to quickly warm the room to the desired comfort level. [15]
- Zoneline heat pumps utilize a reverse-cycle, demand defrost system to extend heat pump operation and increase savings from extended operation. The microprocessor determines the need for defrosting from criteria based on continuous compressor running time, outdoor air temperature and outdoor coil temperature. When defrosting is required, the unit reverses the flow of refrigerant to direct the hot gas into the outdoor coil to melt the frost buildup. Before and after the reverse-cycle defrost, the unit shuts off the compressor to allow the refrigerant pressures to equalize throughout the system. During these periods of pressure equalization, the full resistance heat capacity of the unit is activated to help ensure room comfort conditions during the defrost cycle. The unit remains in the defrost cycle for a minimum of three minutes and up to a maximum of nine minutes. The defrost cycle terminates when the outdoor coil reaches a temperature of 68°F or the maximum time has been reached.[16]
- The AZ65 series heat pump features reverse-cycle defrost and simultaneous supplemental resistance heat, when needed, to maintain room comfort.[17]
- Note mention of “simultaneous.”
- Enables heat pump to operate at lower temperatures when other systems switch to more expensive electric resistance heat.[18]

Note how the defrost is marketed as enabling greater use of the more efficient heat pump cycle, at lower temperatures.

LG PTHP:

- When the unit starts operating in the heating mode outdoor unit start freezing, to protect from freezing, Defrost Control is used. Defrost operation take place when pipe temperature reaches -1C (30°F), T(OD air temp – OD pipe temp)≥12 C (54°F). Defrost condition operates minimum 3 minutes and maximum 9 minutes for complete one cycle.[19]

  Note – this has a mistake. When expressed as a difference in temperature, 12°C is not 54°F, but is rather 22°F.

- Reverse Cycle Defrosting – PTHP Only. This feature enables the unit to activate the reverse cycle defrost to prevent the formation of ice on the outdoor unit, which is exposed to cold environment. Formation of ice reduces the airflow through the coil and hence the efficiency of the air conditioning unit. The LG PTHP employs an active reverse cycle defrost function to melt the ice off the outdoor coil for ensuring room comfort conditions and savings from extended operation.[20]

Similar to GE, LG promotes defrost as enabling savings by extending operation of the heat pump to lower outdoor temperatures.

7.3 Defrost Condensate Disposal

Slinging condensate, which has drained off the indoor coil into the drain pan, onto the outdoor coil is normal in cooling mode, when the outdoor coil is hot and so can evaporate the condensate. This slinging action typically happens automatically with a "slinger ring" on the outdoor propeller fan, which lifts and throws the condensate on the outdoor coil; however, this is undesirable for heat pump defrost. Some of the ice that forms on the outdoor coil in heating mode is removed during defrost by evaporation (the widely recognized "puff of steam" during defrost), but much of it melts and drains into the drain pan as water. It does not make sense to sling cold water that has just melted back onto the outdoor coil that still has ice on it. Following the defrost, as the system goes back into heat pump mode, it is undesirable to sling water onto the outdoor coil because it is cold and will not evaporate the water and may refreeze it.

The two manufacturers that currently do active defrost utilize an automatic drain valve to dispose of the defrost condensate in the drain pan so that it doesn't freeze and cause damage to the outdoor propeller fan. This automatic drain valve is located in the base pan of the PTAC housing and is a temperature activated valve that opens when the temperature approaches freezing (around 45°F). One manufacturer describes this valve:

> Condensate Drain Valve. The most widely used method of disposing of heat pump condensate is with a temperature-activated drain valve. This is a device mounted in the base pan of a heat pump unit with a bellows that expands on temperature rise and contracts with temperature drop. A shaft with a rubber plug on the end is connected to the bellows. When the outdoor temperature remains above a certain temperature, the bellows is expanded and the plug fits tightly into a hole in the bottom, or base pan, of the unit. When the plug is blocking the hole, as it should be during cooling operation, the condensate water is contained in the base pan. At temperatures when heating is required, the bellows contracts, the rubber plug is retracted from the hole and the heat pump condensate water is allowed to drain into the wall case. The valve is fully open at approximately 45°F.[21]

When open, the valve allows condensate and defrost condensate to drain directly into the PTAC sleeve. Once in the PTAC sleeve, which acts a secondary drain pan, the condensate can drain out via three routes.

1. Condensate is drained out of holes located on the exterior edge of the PTAC sleeve, which allows the condensate to drip from the sleeve down the side of the building and/or directly to the ground.
2. Condensate can drain to the exterior edge of the PTAC sleeve where an external pipe directs the condensate to a specific location outside the building.
3. An internal drain is connected directly to the bottom of the PTAC sleeve, which would route all condensate through piping in the interior of the building.

In a cold climate where condensate will refreeze, utilizing option one or two is often unrealistic because of the potential for ice buildup on the building or another undesirable location, such as a sidewalk. As a result, the solution is to install a permanent drain connection in the PTAC sleeve to the interior building. For new construction, installing interior drains may be feasible, but for retrofit situations with an existing unit that did not do active defrost without an internal drain, replacing with a cold-weather high-efficiency PTHP would require installing an interior condensate drain, which would be difficult and expensive.

GE also uses another method for removing defrost condensate in its PTHPs called Internal Condensate Removal (ICR). This process involves pumping defrost condensate from the outdoor base pan to a collector tray above the indoor coil, which then slowly drains onto the indoor coil. The water draining onto the indoor coil hits the warm coil and evaporates. This minimizes the total amount of condensate that needs to be disposed; however, GE does not guarantee that all defrost condensate can be disposed of this way and said that if absolutely no defrost condensate can drain to the exterior, then an interior drain is the only option. GE application engineers did mention that ICR process has been successful in disposing of defrost condensate in some mid- and high-rise buildings in the mid-Atlantic region that has cooler winter temperatures. Unfortunately, the IRC method of defrost condensate removal also comes with some drawbacks; for example, it cannot be used within two miles of a coastline as the salt in the air could be brought into the room with the condensate and damage the indoor coil. This would prevent use in NYC. In addition, there are concerns around introducing outdoor contaminants such as smells and mold from the outdoor drain pan into the indoor environment and increasing the humidity of the indoor environment.

It is not uncommon for the bottom the outdoor unit of split heat pumps becoming blocks of solid ice, ostensibly due to melted water refreezing on cold base pans before being able to drain away. As a result, split-system heat pumps in cold climates use electric heaters in their base pans. It can be assumed that PTHPs operating at colder temperatures are at risk of such freezing, related to frost on the coil and the defrost cycle used to remove such frost. Colder outdoor temperatures will mean colder PTHP cases, with a higher risk of defrost condensate freezing. Counter measures will likely be required during product development to prevent such problems, including possible use of a base pan heater, possible use of low-conductivity base materials (e.g., plastic rather than metal) or other approaches, and testing of frost formation and efficacy of disposal strategies at different temperatures and outdoor humidity conditions.

8 Ventilation/Integrated Make-up Air

A summary of notes regarding PTAC/PTHPs and the integration of ventilation and make-up air is provided as follows:

- The New York State Mechanical Code and NYSERDA multifamily new construction program both allow makeup air via PTACs/PTHPs.
- Most PTHPs manufacturers provide an outdoor air damper to integrate make-up air into their heat pump operation.
- The control of this outdoor air damper is dependent on the manufacturer, but for the most part the outdoor air louver is either fixed open or closed (see Photo 3).
- Typically, the amount of outdoor air that is actually drawn into the room is dependent on the speed of the indoor fan. The range in most cases is reported to be anywhere from 30 CFM on low speed to 80 CFM on high speed. When the indoor fan is not operating, the outdoor air damper remains open and natural building pressures determine the outdoor air rate or in some cases exhaust rate if the room is positively pressured (see Photo 3).
- A few manufacturers have a dedicated outdoor air system within their PTHPs that has a separate fan to provide a constant amount of make-up air. These systems also have an integral dehumidifier for outdoor air when above 55% RH. Because of the impact of ventilation and infiltration on the indoor temperature sensor, it is recommended to install a separate wall thermostat when using an outdoor air kit to avoid a unit-mounted temperature sensor from reporting incorrect indoor temperature due to the introduction of outdoor air.
- Integrated make-up air impacts the load on the PTHP, which could cause PTHPs to be oversized for mild temperatures (both heating and cooling).
- It is unlikely that energy recovery can be provided on make-up air through a PTHP.
  As a result, PTHPs are not a good way to provide make-up air. It is recommended that high-efficiency cold-weather PTHPs do not have integrated make-up air.
- There is a need to provide energy recovery on ventilation, which is not currently feasible with PTACs or PTHPs.

Photo 3. Passive make-up air vent in PTAC

Out of interest, the added heat load of make-up air ventilation integrated in PTACs/PTHPs is estimated as follows. Assuming 15 CFM per PTHP (ASHRAE requires 15 CFM per person, which for a one-bedroom would be two people, and with two PTHPs in a one-bedroom apartment, the total make-up air would be 30 CFM per apartment). For a design day in Syracuse with a design outdoor temperature of -3°F, the added load of 30 CFM represents 1,183 btu/hr. For a design day in New York City with a design outdoor temperature of 13°F, the added load of 30 CFM represents 923 btu/hr. These additional loads would need to be accounted for when sizing the PTHP.

9 Thermostat and Controls

All PTHPs have thermostats and controls integral to the unit. While some manufacturers offer auxiliary wall mounted thermostats as an add-on, they are not standard. Until recently, these wall mounted thermostats needed to be hard wired to the unit. As a result of the additional cost and complexity, this was not typically done.

As discussed in the Electric Resistance Boost section, there are issues with the space temperature sensor being located directly next to the indoor coil rather than on an interior wall as is standard with most heating equipment controlled by a thermostat. In addition to the electric boost issues, the indoor temperature sensor located next to the coil may also contributes to greater swings in room temperature.

With the development of wireless controls, it seems likely that PTHPs could be cost effectively controlled by a wireless thermostat properly located on an interior wall. In addition, wireless thermostats and controls can also be integrated into building management systems for additional monitoring and configuration.

9.1 Occupancy Based Controls

In the hospitality sector, guest rooms are often unoccupied for long periods of time. Through the implementation of occupancy-based controls significant energy savings can be achieved. A study from 2012, prepared by the Pacific Northwest National Laboratory, showed that projects within the study had an average energy savings of 18.4% per hotel room.[22]

New high-efficiency cold-weather PTHPs should be sure to include simple interconnection with occupancy-based controls. If inverter driven compressors are adopted, occupancy controls may be less advantageous as shutting the compressor off and then running it at full capacity to bring a room to setpoint may, at times, be less efficient than letting the compressor stay running at a low speed.

10 Electrical Requirements

One possible concern for PTAC to PTHP retrofits is the availability of adequate power. For retrofit situations where an existing electric resistance PTAC was installed, the existing power should be sufficient to power the new PTHP. For existing hot water/steam/gas-fired PTACs, the feasibility for the PTHP will be dependent on whether the existing power is 110 V and/or if the new high-efficiency cold-weather PTHP will have electric resistance heat.

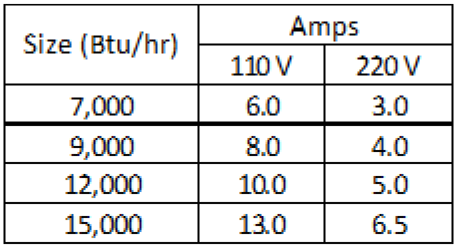
If the non-electric heat PTAC is currently powered by 220 V power, existing power will be more than adequate for a PTHP with no electric resistance heat and most likely adequate for a PTHP with a small amount of electric resistance heat. A 15,000 Btu/hr. PTHP with 2 kW of electric heat would still be able to operate on a 220 V 15-amp circuit. If a larger electric heater in the new PTHP is desired (3 kW to 5 kW), although not recommended, then either a 20 Amp or 30 Amp 220 V circuit will be required.

Some existing non-electric heat PTACs may be operated by 110 V power. For these situations, it is still feasible to install a PTHP of 15,000 Btu/hr or less; however, it is unlikely that there will be adequate power for this PTHP to have electric resistance heat. It appears that all currently available PTHPs are operated on 220 V power, likely because they all have electric resistance heat.

To effectively compete with mini split heat pumps that are typically not installed with such backup heaters and avoid the risk of overuse of electric heaters as is currently the case, it is not recommend that the high-efficiency cold-weather PTHP have a backup electric resistance heater. As such, this cold weather PTHP should also be available in both 110 V and 220 V options, which would allow these PTHPs to be retrofit into an existing building without additional power requirements.

Based on a review of PTAC and PTHP literature, the approximate current requirements to operate the compressor at 110 V and 220 V are listed in Table 4.

Table 4. Compressor operating amps for 110 V and 220 V PTHPs



Size (Btu/hr)	Amps	
	110 V	220 V
7,000	6.0	3.0
9,000	8.0	4.0
12,000	10.0	5.0
15,000	13.0	6.5

If a high-efficiency cold-weather PTHP is developed with an electric resistance heater, either as for backup or supplementary heat, then 220 V power would be required, which may limit its feasibility to be retrofit in the existing building market.

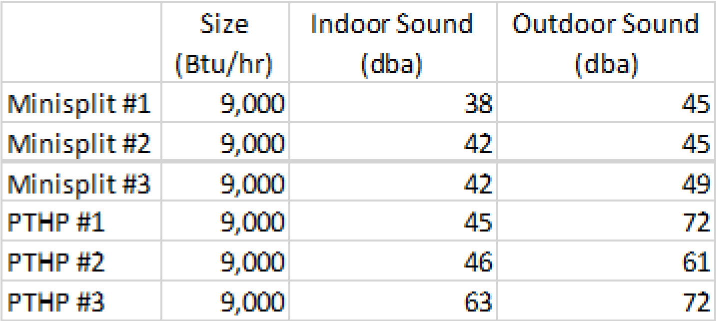
11 Quality and Comfort Issues

PTACs and PTHPs tend to be low-cost commodity products within the HVAC space/ecosystem for a variety of reasons: they are used as low-end, highly affordable products and do not require trained HVAC technicians for installation; their sales volumes are generally in the low hundreds of thousands of units per year; and many PTACs/PTHPs manufacturers are small businesses. With relatively small market sizes and likely low profit margins, it's speculated that manufacturers cannot justify investments in product development or quality. Therefore, product quality is viewed as low, as indicated by air leakage, simple controls, low energy efficiency, limited ventilation capabilities, and limited range of heat pump operation. There truly is a need for higher-quality and higher-efficiency PTHPs.

11.1 Sound

- Historically PTACs are reported as noisy. Compressors are located within the same unit and only separated by sheet of metal and small amount of insulation.
- Two sound ratings should be reviewed:
    - STC (Sound Transmission Class) which rates how much sound can pass through the equipment
    - Indoor sound in dba and outdoor sound in dba of the unit in operations
- Indoor sound ratings are still all over the map (40 dba - 60+ dba indoor).
- Outdoor sound ratings are significantly higher than mini split heat pumps systems (see Table 5), which can lead to noise complaints as discussed further in Site Visit Findings section.
- Sound ratings are not always provided.
- Reducing noise of PTHPs will be necessary for proper adoption of the technology.

Table 5. Minisplit heat pump vs. PTHP sound ratings



	Size (Btu/hr)	Indoor Sound (dba)	Outdoor Sound (dba)
Minisplit #1	9,000	38	45
Minisplit #2	9,000	42	45
Minisplit #3	9,000	42	49
PTHP #1	9,000	45	72
PTHP #2	9,000	46	61
PTHP #3	9,000	63	72

11.2 Temperature of Air Blowing Off Indoor Coil

- With existing PTHP technology, the temperature of the air coming off the indoor coil is already low.
- As outdoor temperatures drop, the temperature of the indoor coil drops slightly as well, reducing the air temperature leaving the indoor coil.
- At some point, lower-temperature supply air, while still much warmer than the space temperature, begins to feel uncomfortable to the occupants, especially as it drops significantly below their skin temperature.
- Occupants are used to heat feeling “hot.” As a result, they may think or feel like the equipment is not working correctly when operating in heat pump mode.
- A leaving air temperature of 90°F could meet the load requirements for a room; however, this feels cool to the touch (skin temp of 98°F > air temp of 90°F).
- As previously discussed, the low supply air temperature can result in the room occupants turning up the thermostat, trying to get more heat, causing the unit to go into electric heat mode.

11.3 Climate Control

- Temperature swings: Currently most PTHPs do not have variable speed technology, and as a result, do not easily maintain proper temperature within the space they serve.
- Dehumidification: In addition, because they are not variable speed, they often cool the space quickly without providing proper dehumidification.

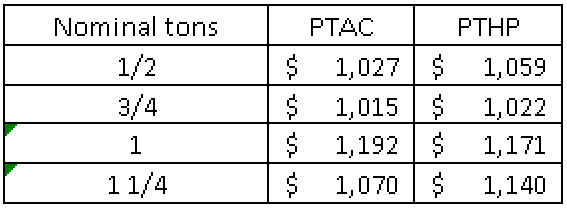
12 Product Costs

Product costs are widely available on the internet from a variety of distributors (AJ Madison, Home Depot, Grainger, etc.).

A sample of product costs were obtained and tabulated. See Appendix B. Average costs are included in Table 6.

Table 6. PTAC vs. PTHP equipment costs

Average costs including sleeve, outdoor grille, and power cord.



Nominal tons	PTAC	PTHP
1/2	$ 1,027	$ 1,059
3/4	$ 1,015	$ 1,022
1	$ 1,192	$ 1,171
1 1/4	$ 1,070	$ 1,140

PTAC costs include electric resistance heat. All costs include sleeve, outdoor grille, and power cord. Costs generally do not include a drain kit, which typically costs $20. The average PTHP costs $22 more than the average PTAC in the same size range. Costs are somewhat unpredictable. Note that the average one-ton PTHP unexpectedly costs less than the average PTAC cost.

When a smaller sample of paired PTAC and PTHP from the same manufacturer, in the same size range, are examined, the average cost differential is $94 (PTHP cost relative to PTAC). Sample sizes were small, two and five of each nominal capacity size for PTACs and for PTHPs.

However, the cost differential between PTHP's and same-sized PTACs (with electric heat) is small, typically less than 10%. To assess the cost differential between PTHP's and mini splits, pairs of units between the same manufacturer were examined, in the same nominal size range. The costs shown in Table 7 are for the equipment only and do not include accessories such as electrical wiring, refrigerant piping (for mini splits), external thermostats, and/or installation costs.

Table 7. PTHP vs. Minisplit equipment

Costs only for same size and same manufacturer

Mfr	Nominal cooling capacity (tons)	PTHP	Minisplit	Difference $	Difference %
LG	3/4	$ 901	$ 1,505	$ 604	67%
LG	1	$ 936	$ 939	$ 3	0%
Mr. Cool	1	$ 1,052	$ 1,328	$ 276	26%
Friedrich	3/4	$ 879	$ 1,262	$ 383	44%
Friedrich	1	$ 879	$ 1,843	$ 964	110%

With one exception, the equipment cost of mini splits are significantly more expensive than PTHPs. The data listed in Table 7 is the equipment costs only and if you were to add in costs for additional materials (electrical, refrigerant lines, thermostats) and labor, mini splits would be even more expensive almost costing twice as much in total. See Table 8 for a comparison that includes these added costs.

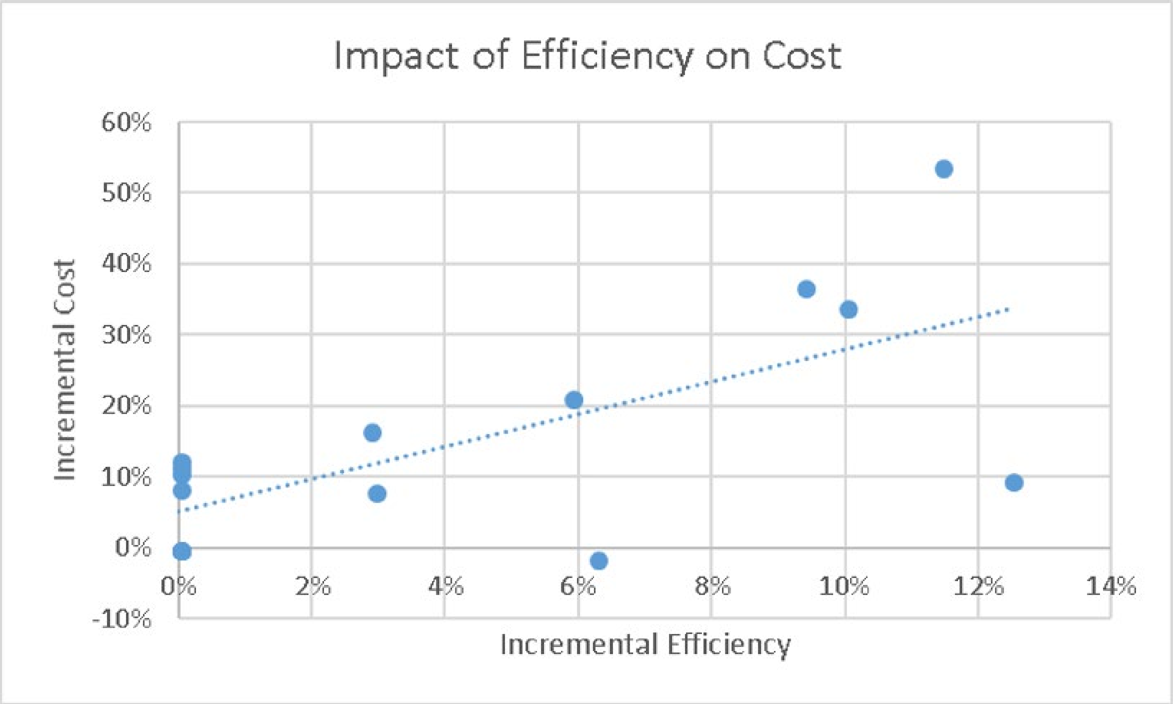
Table 8. PTHP vs. Minisplit

Estimated installed costs for same size and same manufacturer

Mfr	Nominal cooling capacity (tons)	PTHP	Minisplit	Difference $	Difference %
LG	3/4	$ 1,119	$ 2,155	$ 1,036	93%
LG	1	$ 1,153	$ 1,589	$ 436	38%
Mr. Cool	1	$ 1,052	$ 1,978	$ 926	88%
Friedrich	3/4	$ 1,038	$ 1,912	$ 874	84%
Friedrich	1	$ 1,038	$ 2,493	$ 1,455	140%
	Average	$ 1,080	$ 2,026	$ 945	88%

Incremental cost (how much higher in cost a PTHP is relative to the lowest-cost unit in its nominal size range) were plotted against incremental efficiency (how much higher the COP of a PTHP is relative to the lowest-cost unit in its nominal size range) to evaluate how much more a high-efficiency PTHP cost than a low-efficiency PTHP. Results are shown in Figure 9.

Figure 9. Incremental cost vs. incremental efficiency of PTHPs



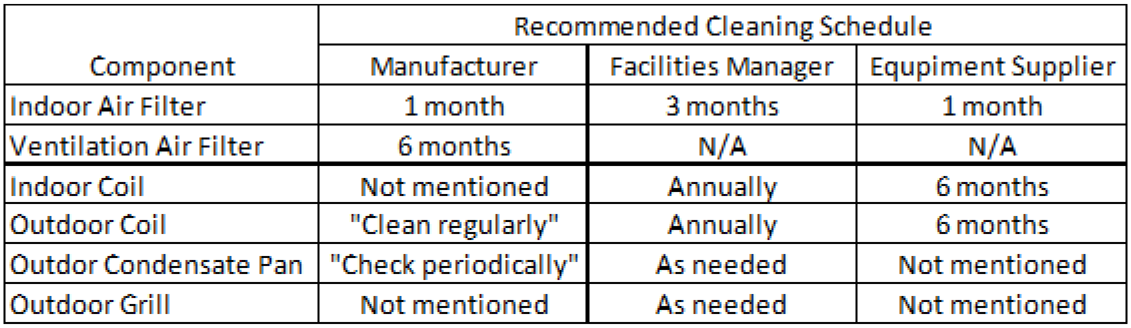
The data shown in Figure 9 is somewhat scattered, but there is clearly a trend toward higher cost for higher efficiency. It is estimated that a unit 5% more efficient costs about 17% more than its low-efficiency counterpart, and a unit 10% more efficient costs about 28% more than a low-efficiency counterpart. Whereas higher efficiency does increase product cost, the increase in cost still allows high-efficiency PTHPs to be more affordable than mini split heat pumps; for example, approximately $300 for a 10% increase in efficiency relative to a $1,000 nominal PTHP cost.

13 Operation and Maintenance

For PTACs and PTHPs to operate correctly over their useful life, it is important that they are properly maintained. During site visits, a varying degree of maintenance practices were observed from no maintenance at all to maintenance monthly. Maintenance consists mainly of cleaning the components listed in Table 9. Failure to properly clean and maintain these components may result in reduced air flow, poor heat exchange and reduction in efficiencies and capacities, and poor indoor air quality.

Table 9. Recommended cleaning schedule

Per one manufacturer, a facilities manager, and an equipment supplier.



Component	Recommended Cleaning Schedule		
	Manufacturer	Facilities Manager	Equipment Supplier
Indoor Air Filter	1 month	3 months	1 month
Ventilation Air Filter	6 months	N/A	N/A
Indoor Coil	Not mentioned	Annually	6 months
Outdoor Coil	"Clean regularly"	Annually	6 months
Outdor Condensate Pan	"Check periodically"	As needed	Not mentioned
Outdoor Grill	Not mentioned	As needed	Not mentioned

It is important to note that cleaning the outdoor coil, which should happen at a minimum once annually, requires that the PTHP be removed from the sleeve. Given that occupants in multifamily buildings reside permanently in their apartments, PTACs/PTHPs installed in these building are less likely to be properly maintained.

14 Capacity Needs

For PTHPs to replace PTACs in New York State, it is important that they be able to meet the design day heating requirements. When speaking with manufacturers, they expressed concern about diminishing capacities at lower temperatures. However, this is likely an issue that can be overcome, especially with variable speed compressors. In addition, some buildings, such as those built to current codes or better, may have much lower heat loads than manufacturers realize.

Manufacturers are also very concerned with lower air temperatures off the indoor coil with lower outdoor temperatures, which could have an impact on comfort. Going from 95°F air temperature leaving the indoor coil to even 90°F can result in occupants feeling “cold air blowing.” See discussion in the Quality and Comfort Issues section regarding temperature of air coming off the indoor coil.

To determine appropriate capacity requirement for cold weather PTHPs, apartment heat loads were evaluated for a theoretical multifamily building located in Syracuse and NYC for different building construction types. Existing eQuest energy models for actual buildings were used to determine heat loads for the 35% better than code and ASHRAE 2004 buildings. The existing building heat loads were determined based on professional experience and buildings that have gone through NYSERDA’s Multifamily Performance Program. Passivehouse heat loads are set by the Passive House Institute U.S. standard. The results from this analysis are listed in Table 10.

Table 10. Apartment design day heat loads

For a theoretical multifamily building at different building construction types.

		Design Day Conditions		
Climate Zone	Building Construction Type	Apartment Heat Load (Btu/hr)	PHTP Capacity (Btu/hr, assumes 3 units)	Outdoor Temp (F)
Syracuse	Passivehouse	4,677	1,559	-3
Syracuse	35% better than code	12,696	4,232	-3
Syracuse	ASHRAE 2004	17,044	5,681	-3
Syracuse	Existing Good	24,875	8,292	-3
Syracuse	Existing Poor	34,825	11,608	-3
NYC	Passivehouse	3,881	1,294	13
NYC	35% better than code	9,363	3,121	13
NYC	ASHRAE 2004	12,816	4,272	13
NYC	Existing Good	24,875	8,292	13
NYC	Existing Poor	34,825	11,608	13

Assumptions for the analysis presented in Table 10 are as follows:

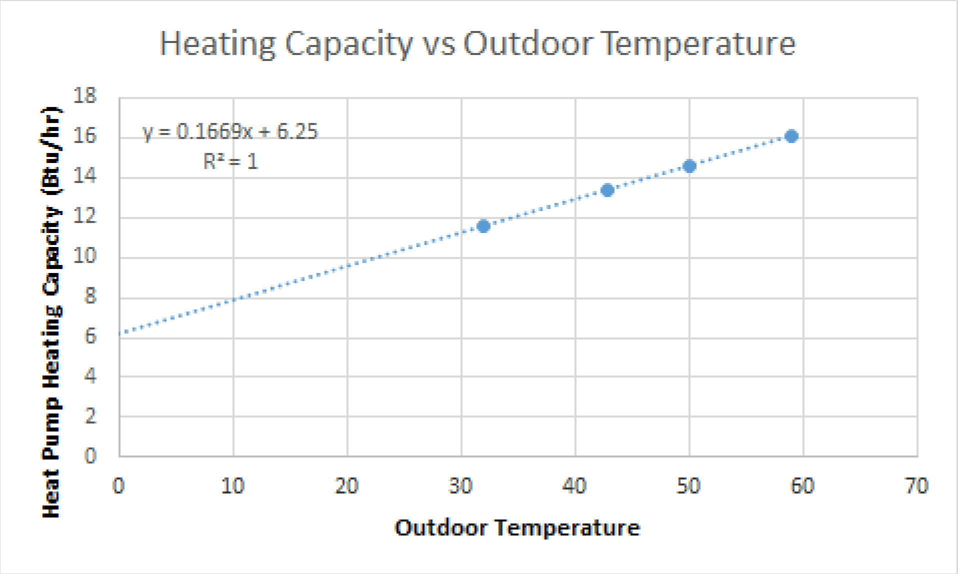
- Apartment heat loads are assuming two bedrooms, 995 square feet, and average for each building type and climate zone.
- The design day heat load on an apartment built to ASHRAE 2004 and an apartment built to 2015 NYS ECCC can be considered very similar.
- The 35% better than code is based on a whole building energy model and does not necessarily meant that the building heat load is 35% lower than 2015 NYS ECCC.
- Existing building heat loads are estimates based on professional experience and buildings that have gone through the NYSERDA Multifamily Performance Program.
- Existing buildings in NYC are typically mid- to high-rise masonry construction with poor insulation and significant air leakage, which is why the design day heat load is the same as buildings in Syracuse despite the design day temperature being warmer.

While the analysis for Table 10 was based on multifamily buildings, one can expect similar heat load requirements for the hospitality sector where typical hotel rooms are between 300 and 350 square feet and typically served by one PTHP.

With current single speed PTHP technology, the capacity of a 15,000 Btu/hr. unit at Syracuse (-3°F) and New York City (13°F) design day temperatures is approximately 6,000 Btu/hr. and 8,000 Btu/hr., respectively. This does not account for any impacts on capacity resulting from the need to do defrost.

Figure 10. Heat pump heating capacity vs. outdoor temperature

For 15,000 btu/hr PTHP (LG model LP153HDUC).



With single-speed compressor technology currently available, PTHPs should be able to meet the design day heating load for buildings built to ASHRAE 2004 and better in both NYC and Syracuse (see Figure 10). The development of a high-efficiency cold-weather PTHP with a variable speed compressor, may be able to meet the design day heat loads for some existing buildings. In the mini split air source heat pump marketplace there are many manufacturers who provide equipment which achieves rated capacity at 5°F. If this same technology could be transferred to PTHP equipment, then it's likely that electric heat would be unnecessary to meet the design heat load of buildings.

In addition to manufacturer's concerns around air temperature and comfort, they've also expressed concerns with the ability of PTHPs to quickly bring a space up to temperature without the use of electric heat. Again, variable speed compressors should help solve this problem.

Back-up heat, if properly controlled, could help. However, this may not be the ideal solution. The risk of back-up heat becoming the primary source of heat is just too great. PTHPs are best positioned to deliver energy efficiency if they mimic the prevailing strategy of split heat pumps in energy-efficient applications by simply not including backup electric resistance heat.

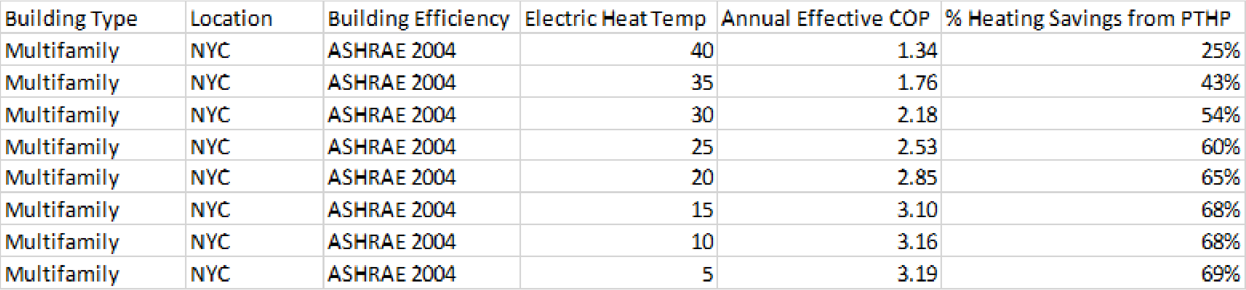
15 Energy Savings

15.1 PTHP Retrofit vs. Electric Resistance

An analysis was conducted to assess energy savings from reducing the temperature at which electric resistance heat is used (e.g., below which heat pump mode is deactivated). Since cold-weather performance of PTHPs is not reported by manufacturers, for this analysis it's assumed the cold-weather COP is similar to other single-speed heat pumps. No penalties are assumed for defrost, base pan heater (if needed), and electric resistance boost (which would reduce actual COP). In other words, these are best-case energy savings. While this analysis may overstate the savings, it shows the potential from developing a high-efficiency cold-weather PTHP. This analysis also highlights how little energy is currently being saved by most PTHPs, many of which have switchover temperatures of 40°F or higher, relative to straight electric resistance heat. The results from this analysis for NYC and Syracuse are show in Tables 11 and 12 respectively.

Table 11. Electric resistance heat switch-over temp and annual effective PTHP COP

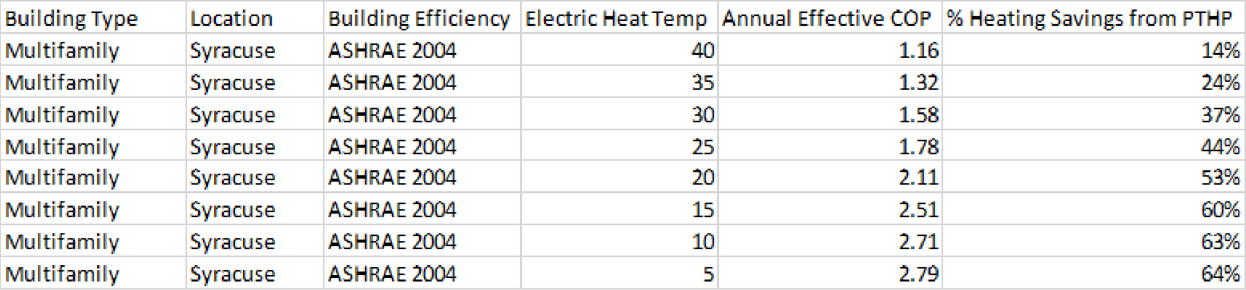
New York City



Building Type	Location	Building Efficiency	Electric Heat Temp	Annual Effective COP	% Heating Savings from PTHP
Multifamily	NYC	ASHRAE 2004	40	1.34	25%
Multifamily	NYC	ASHRAE 2004	35	1.76	43%
Multifamily	NYC	ASHRAE 2004	30	2.18	54%
Multifamily	NYC	ASHRAE 2004	25	2.53	60%
Multifamily	NYC	ASHRAE 2004	20	2.85	65%
Multifamily	NYC	ASHRAE 2004	15	3.10	68%
Multifamily	NYC	ASHRAE 2004	10	3.16	68%
Multifamily	NYC	ASHRAE 2004	5	3.19	69%

Table 12. Electric resistance heat switch-over temp and annual effective PTHP COP

Syracuse



Building Type	Location	Building Efficiency	Electric Heat Temp	Annual Effective COP	% Heating Savings from PTHP
Multifamily	Syracuse	ASHRAE 2004	40	1.16	14%
Multifamily	Syracuse	ASHRAE 2004	35	1.32	24%
Multifamily	Syracuse	ASHRAE 2004	30	1.58	37%
Multifamily	Syracuse	ASHRAE 2004	25	1.78	44%
Multifamily	Syracuse	ASHRAE 2004	20	2.11	53%
Multifamily	Syracuse	ASHRAE 2004	15	2.51	60%
Multifamily	Syracuse	ASHRAE 2004	10	2.71	63%
Multifamily	Syracuse	ASHRAE 2004	5	2.79	64%

The percentage savings listed in Tables 11 and 12 are the assumed savings from the PTHP as compared to electric resistance heat only. A field study completed an air source heat pump installed in Connecticut determined the average COP across the heating season was 2.9.[23] It seems reasonable that the annual effective COPs can be achieved.

The results from the analysis were used to estimate the payback from switching from an existing PTHP (with a. electric resistance switch over temp of 40°F) to a high-efficiency cold-weather PTHP (with no electric resistance heat). Assuming an installed cost of $1,500 per high-efficiency cold-weather PTHP, the projected payback would be less than three years in both NYC and Syracuse as detailed in Table 13.

Table 13. Payback from installing high efficiency cold weather PTHP

To replace existing PTHP with 40°F electric resistance switch-over temp.

Location	Building Construction Type	Installed Cost ($/unit)	$/yr savings per unit installed	Payback (years)
NYC	ASHRAE 2004	$1,500	$623	2.4
Syracuse	ASHRAE 2004	$1,500	$706	2.1

Even if the cost to install a high-efficiency cold-weather PTHP was much greater ($5,000/unit) due to technological improvements in the unit or the need to run interior drains to deal with defrost condensate, the payback would still be approximately eight years, as detailed in Table 14.

Table 14. Payback from installing high efficiency cold weather PTHP

To replace existing PTHP with 40°F electric resistance switch-over temp, assuming high installed cost ($5,000).

Location	Building Construction Type	Installed Cost ($/unit)	$/yr savings per unit installed	Payback (years)
NYC	ASHRAE 2004	$5,000	$623	8.0
Syracuse	ASHRAE 2004	$5,000	$706	7.1

15.2 PTHP Retrofit vs. Gas Heat

A simple calculation was done to assess energy cost savings by converting a gas-heated building in NYC to PTHPs. Assuming that electricity costs $0.19/kWh and the PTHP has an effective COP of 2.0, and gas costs $1.0/therm with the system's heating efficiency of 50%, it is still cheaper to heat with gas ($20.00/MMBtu) than electric ($26.38/MMBtu); therefore, there would not be cost savings associated with this retrofit.

For Syracuse and other non-NYC areas where electricity is cheaper (estimated $0.10/kWh), the cost to heat with electricity (assuming a COP of 2.0) becomes cheaper ($14.65/MMBtu) than an inefficient natural gas system (50% efficiency); therefore, there may be cost savings associated with a PTHP retrofit of gas heated building. However, even with the very low assumed natural gas heating efficiency, the payback from a PTHP retrofit is still in the range of 20 to 30 years. Even with PTHPs having a useful life of 15 years, this is still not a cost-effective investment.

There is the potential added benefit for building owners to transfer heating cost to the tenant by installing PTHPs to replace non-electric PTACs or non-electric heating systems in general. However, anecdotal evidence from interviews with professionals in the field suggests that in NYC, due to the high price of electricity and the fact that tenants are not used to paying for heat, switching heating to the tenants has caused major backlash on several projects. Even if it can be done, the owner will likely have to reduce rents to offset the increased costs to the tenants.

15.3 Electric PTAC retrofit with Minisplit

A demonstration project in NYC reported 48% weather-normalized energy savings (whole apartment usage, not heating and/or cooling) in one one-bedroom apartment, from replacing two electric PTACs with a mini split heat pump system (one outdoor unit, two indoor units).

The sleeve needed to be resized to fit the mini split outdoor unit with some facade work required. Work inside the apartment was necessary to route the refrigerant line set. Estimated building-wide costs were approximately $15,000/apartment (for both one- and two-bedroom apartments; there was not much price difference between the two).

The savings were reported by another industry professional, but without raw data. As a result, the total heat load savings and estimated payback are unknown. While the realized savings were substantial, due to the extensive facade and interior work required, the residents of the building decided not to move forward with a building-wide retrofit.

16 Expected Useful Life

One source estimates the useful life of PTACs to be 15 years.[24] This is similar to what multifamily industry professionals have also reported to be expected life. In the DOE’s technical support document for its minimum efficiency rulemaking, they originally specified 10 years as the useful life but that was later reduced to eight years based on stakeholder input.[25] The focus of DOE’s work appears to be PTAC/PTHPs in hospitality, the dominant application for this type of equipment across the U.S., where aesthetic considerations likely call for more frequent replacement. Expected useful life in multifamily buildings is more likely the reported 15 years. In comparison, air source heat pumps are expected to have a useful life of approximately 20 years.[26]

17 Regulatory Considerations

17.1 Energy Efficiency

The first minimum energy efficiency requirement for packaged terminal heat pumps dates back to ASHRAE's very first version of its Standard 90, which appeared in 1975, a direct result of the energy crisis of 1973. PTHPs are specifically mentioned as being covered, and the minimum efficiency was set at a COP of 2.2 at 47°F outdoors, and a COP of 1.2 at 17°F outdoors, which were to go into effect January 1, 1977. The standard further required higher efficiencies which were to go into effect January 1, 1980, with a COP of 2.5 at 47°F outdoors, and a COP of 1.5 at 17°F outdoors. The rating conditions of 47°F and 17°F are still in use today. ASHRAE Standard 90-1975 already references ARI's 310, specifically "Standard 310-70 Standard for Packaged Terminal Air Conditioners." ARI (The Air Conditioning and Refrigeration Institute) was a predecessor to AHRI (The Air Conditioning, Heating, and Refrigeration Institute), which still maintains an updated version of this original Standard 310.

The DOE issued preemptive standards for minimum efficiency for heating and cooling equipment in 1987, commonly referred to as "NAECA," the National Appliance Energy Conservation Act, likely an extension of the earlier 1975 Energy Policy and Conservation Act (EPCA). Preemptive means that states and other local government cannot require higher equipment efficiencies. These minimum efficiency requirements are periodically updated, every few years, although sometimes can stay stagnant at a particular level. The minimum efficiencies are set by the DOE through a rule-making process. The DOE typically uses consultants to evaluate tradeoffs of efficiencies, considering energy costs and other factors. The DOE's overall mandate appears to promote energy efficiency while also safeguarding consumer interests and taking manufacturers' input for setting efficiency standards.

The DOE's preemptive standards have an exemption for small manufacturers (less than $8 million/year in sales) and allow states to petition for exemptions. The small manufacturer exemption may hold some importance because replacement PTACs and PTHPs are sometimes made by smaller manufacturers.

Efficiencies for certain classes of equipment may not always be consistent with other classes of equipment. For example, the efficiency requirements for PTAC/PTHPs are generally lower than the requirements for split systems, recognizing the challenges of higher efficiencies in PTAC/PTHPs due to space constraints. During the most recent rule-making, Goodman, a PTAC/PTHP manufacturer, stated that the newest efficiency requirements can be accommodated within the standard PTAC/PTHP sleeve size, but that increased efficiencies over time would “manufacturers likely would need to increase the physical size of the equipment, which would significantly impact consumer utility and/or the cost of installation.”[27] However, analysis indicates that PTAC/PTHPs there still is opportunity to increase the maximum efficiency possible within their current standard sleeve size (see Impact of Physical Size on Efficiency section).

Having different efficiency requirements for different types of equipment (for example, PTAC/PTHPs vs. split systems) inadvertently biases equipment marketability, likely making PTAC/PTHPs popular for many new buildings because they are cheaper.

Packaged terminal heat pumps were covered in New York’s first energy code, the New York State Energy Conservation Construction Code of January 1, 1991, with a minimum required COP of 2.6, at the 47°F outdoor air temperature rating condition. This increased to a COP of 2.7 on January 1, 1992. However, by 1992, the energy code was already referencing the preemptive federal standards. There is no mention of a required efficiency at 17°F, likely reflecting the reality that no PTHP’s operate down to 17°F.

In the early 2000s, New York State changed to basing its energy code on the International Energy Conservation Code (IECC). In 2000, IECC’s requirement for PTHP COP’s were: 2.9 - (0.026 x Cap/1000), where Cap is the rated capacity in Btu/hr. Capacities below 7,000 Btu/hr. were pegged at an efficiency corresponding to a capacity of 7,000 Btu/hr, which was approximately 2.7. Capacities above 15,000 Btu/hr. were pegged at an efficiency corresponding to a capacity of 15,000 Btu/hr., which was approximately 2.5. These COP’s all refer to the standard rating condition of 47°F outdoor temperature.

The most recent version of the IECC (2015) requires the COP of PTHP’s in new construction to be 3.2 - (0.026 x Cap/1000), which means approximately a COP of 3.0 at 7,000 Btu/hr. and 2.8 at 15,000 Btu/hr. PTHP’s used as replacements can still be rated at 2.9 - (0.026 x Cap/1000), in other words no change from the year 2000, which represents COP’s in the range of 2.5–2.7. These COPs all refer to the standard rating condition of 47°F outdoor temperature. This is the version of IECC currently in force in New York State.

ASHRAE Standard 90.1 is another important standard that, while not having the force of law, is frequently used as a reference standard (and an optional compliance path for the IECC), for buildings which are four stories and higher (including multifamily). The DOE also is required to consider efficiencies in ASHRAE Standard 90.1 when considering its own rules.

While there has been some "leapfrogging" in required PTHP efficiencies between ASHRAE, the IECC, and DOE rules, in general the IECC and the DOE rules tend to follow ASHRAE, with a delay of a few years.

In 1999, ASHRAE set its PTHP COP at 3.2 - (0.026 x Cap/1000), with fixed values of 3.0 below 7,000 Btu/hr. and 2.8 above 15,000 Btu/hr., for standard sizes of PTHPs, and 2.9 - (0.026 x Cap/1000) for nonstandard PTHP sizes, with fixed values of 2.7 below 7000 Btu/hr and 2.5 above 15,000 Btu/hr. Note that these efficiencies were approximately higher than the IECC at the time and how ASHRAE divided efficiencies into standard and nonstandard sizes, which IECC and DOE had not done. The 2004 and 2010 versions of ASHRAE Standard 90 left these requirements unchanged.

ASHRAE's most recent version of Standard 90.1 is dated 2016, and requires PTHP COPs to be a minimum of 3.7 - (0.052 x Cap/1000), which means approximately a COP of 3.3 at 7,000 Btu/hr. and 2.9 at 15,000 Btu/hr. Its prior version (2013) had the same efficiency requirements. The confusing genesis of efficiency standards may best be followed by considering the requirements for 7,000 Btu/hr. and 15,000 Btu/hr. PTHPs, over time as detailed in Table 14.

Table 14. COP Requirements for PTHPS overtime

	COP requirement	
PTHP Size:	**7,000 Btu/hr**	**15,000 Btu/hr**
ASHRAE 90, 1975	2.2	2.2
ASHRAE 90, 1980	2.5	2.5
NYS Energy Code, 1991	2.6	2.6
NYS Energy Code, 1992; also DOE federal requirements	2.7	2.7
ASHRAE 90-1999 through 2010 (until 10/8/2012) (2)	3.0	2.8
IECC 2000; also NYS Code	2.7	2.5
IECC 2003 through present, also current NYS Code a	3.0	2.8
ASHRAE 90-2010 (after 10/8/2012), 2013, 2016[b], and DOE's 2008 Rules (also effective in 2012)	3.3	2.9

Notes:

[a] Lower efficiency is allowed for replacement PTHPs, approximately 10% lower. Replacement PTHPs are defined as applying only to units with existing sleeves smaller than 42" x 16", and so applies only to existing nonstandard sleeve sizes.

[b] Lower efficiencies are allowed for nonstandard PTHP sizes, approximately 10% lower until 10/8/2012, approximately 20% lower after 10/8/2012. This is partially the same as the definition of "replacement" in note (1), but is not restricted to replacing existing units, so could ostensibly be applied to nonstandard size PTHPs in new construction.

Interestingly, the prescriptive requirements in IECC and the New York State Energy Code are lower than those required by the DOE rules. However, the DOE rules presumably preempt the State code requirement.

PTHPs play another interesting role in ASHRAE Standard 90, serving as the "baseline" heating and cooling system for residential buildings four stories and higher, for purposes of whole building energy modeling, but only for southern climates, so this requirement does not impact New York State. The baseline heating and cooling system for New York State is PTACs with a 75% hydronic fossil fuel boiler system. In either case (northern or southern climates), since PTACs with 75% hydronic boilers and PTHPs are both systems that are relatively inefficient, this requirement allows proposed heating and cooling system types to “look good” relatively easily, for purposes of building modeling. This makes “better-than-code” buildings (LEED, NYSERDA's multifamily new construction program, buildings that seek to comply with the federal 179D tax deduction, or even buildings seeking to comply with the energy code using the whole-building path) appear better than they really may be, due to the poor baseline. If a building uses a high-efficiency PTAC with a high-efficiency boiler, it is able to show better-than-code performance, while having introduced PTAC envelope losses into the building. Therefore, the low efficiency ratings of PTAC/PTHPs may have an unintended consequence on the design and performance of many new buildings.

ASHRAE Standard 189.1 is its Standard for the Design of High-Performance Green Buildings, and so is supposed to serve as a better-than-code requirement. The latest edition of Standard 189.1 is dated 2014. Puzzlingly, it requires a flat COP of 2.8 for PTHPs, regardless of the PTHP capacity. In other words, its PTHP efficiency requirement is lower than the ASHRAE Standard 90.1 This is presumed a mistake, as the standard has other mistakes; for example, calling for an outdoor temperature of 95°F for the heating rating condition.

EPA considered developing requirements for PTAC/PTHPs in 2011 but decided against it.[28] ASHRAE also has standards for test methods, which set requirements for airflow measurements and other test parameters, which are referenced by AHRI’s Standard 310.

17.2 Test Conditions

In the AHRI Standard 310/380 Packaged Terminal Air Conditioners and Heat Pump the primary test condition for PTHP’s in heating is 70°F indoor air temperature, 47°F outdoor air temperature. Tests are conducted with “zero external static pressure,” to simulate the absence of ductwork.

A secondary test condition called the part-load test is 70°F indoor air temperature, 62°F outdoor air temperature, but this test is only required for systems that are capable of capacity reduction.

The AHRI test standard makes no mention of test requirements/options for units with variable speed compressors other than to state in section 5.4 (Part-load rating) that “systems that are capable of capacity reduction shall be rated at each step of capacity reduction provided by the refrigeration system(s) as published by the manufacturer.” These tests would presumably all be run at the defined part-load test rating condition.

The PTAC/PTHP AHRI test standard 310 makes no mention of a test at 17°F outdoor temperature, which is used for unitary and packaged heat pumps. The AHRI test standard makes no mention of energy used for defrost. In other words, no penalty is applied for the energy required for defrost. This contrasts with AHRI Standard 210-240, that covers unitary air source heat pumps (such as split systems), that does penalize a heat pump’s energy use because it includes a defrost test and account for defrost energy in its ratings.

The AHRI test standard makes no mention of auxiliary heaters, such as base pan heaters used to melt frozen water from defrost. This is also in contrast with AHRI Standard 210-240, that covers unitary air source heat pumps (such as split systems), which as of the 2017 version now refers to including power from such heaters in testing.

17.3 Energy Efficiency Requirements Compared to Split Systems

For reference, the efficiency requirements for PTHPs can be compared to those for split system heat pumps. For larger air source heat pumps (over 65,000 Btu/hr), the required efficiency is a COP of 3.3, 10% higher than the required COP of 3.0 for standard size PTHP’s and 20% and higher than the COP’s of 2.5-2.7 required for nonstandard size PTHPs. The comparison to larger heat pumps is given only because the efficiency requirement for larger heat pumps is also a simple COP at 47°F outdoors, so it’s easier to compare apples to apples. Smaller air source heat pumps (< 65,000 Btu/hr.) are rated with a Heating Season Performance Factor (HSPF), that accounts not only for steady operation, operation over a variety of outdoor temperatures, and transient operation (cycling on and off). The required HSPF for these heat pumps is 8.2, since January 1, 2016, in the IECC. The units for HSPF are not dimensionless, as they are for COP, but are in units of Btu/hr. per watt. It can be converted to the dimensionless units of COP by dividing by 3.412. So, an HSPF of 8.2 represents a COP of 2.4. However, this is not an apples-to-apples comparison, because the test conditions for the HSPF is different than the 47°F test condition for the PTHP COP. A better comparison is to compare the steady-state COP at 47°F for a heat pump that is rated with an HSPF of 8.2. One example, the Daikin model FHQ42MVJU/RZQ42PVJU9, with an 8.2 HSPF rating, has a COP of 3.4 at 47°F outdoor temperature, more than 10% higher than the required COP of 3.0 for PTHPs in new buildings, and more than 20% higher than the required COP's of 2.5-2.7 for replacement PTHPs. The issue here is that PTHPs are not required to be as efficient as split system heat pumps. This allows PTHPs to be cheaper than split system heat pumps, for reasons above and beyond their simple construction.

17.4 Other Tests

While AHRI Standard 310 does not formally cover safety or other aspects of PTACs/PTHPs, it does address conformance to a variety of requirements other than energy efficiency, including: Maximum High-Temperature Operation Tests, Voltage Tolerance Test, Insulation Effectiveness Test (Cooling), Condensate Disposal Test (Cooling), and Air Infiltration Test.

- The Maximum High-Temperature Operation Test is to verify that the equipment will operate continuously even at warm temperatures (80°F indoors and 75°F outdoors, in heating; 80°F indoors and 115°F outdoors in cooling).
- The Voltage Tolerance Test is to verify that the equipment will operate continuously even when subject to nonstandard voltages.
- The Insulation Effectiveness Test ensures that condensation ("sweat") does not form in the unit, in cooling.
- The Condensate Disposal Test ensures that condensate is adequately disposed of, and so does not fill the condensate pan and overflow.

17.5 Air Infiltration

Of particular interest relating to energy use is the Air Infiltration Test, conducted at 25 Pa (outdoor air pressure higher than indoor air pressure), and for which the requirement appears to be leakage less than 2 CFM per linear foot of wall sleeve. The requirement is somewhat unclear in the standard:

- During the entire test, the measured air flow rate, L/s (ft3/min), leaking into the indoor portion shall be considered to be the infiltration rate through the equipment and shall not exceed 3.1 L/(s•m) [2 ft3/(min•ft)] at the perimeter of the wall sleeve where it normally projects through the wall.

It is unclear whether the 2 CFM/ft requirement refers to total infiltration through the unit, divided by the length of the sleeve perimeter, or whether the 2 CFM/ft requirement refers to air leakage specifically at the perimeter of the wall sleeve. Total infiltration is divided by sleeve perimeter length because the standard requires the ventilation damper to be closed and it would be difficult to specifically measure leakage only at the sleeve perimeter. Since a standard PTAC is 16" high by 42" wide, the standard PTAC sleeve perimeter is 116", or 9.67 feet, the infiltration requirement of 2 CFM per foot of sleeve perimeter length translates into 19.3 CFM (this would be informally referred to as 19.3 CFM25). To visualize this level of leakage as a hole in a wall, the "equivalent leakage area" is estimated to be about three square inches.

In field testing of air leakage through PTACs, it was found that the actual equivalent leakage area was 6.7 square inches per PTAC.[29] For these field tests the leakage measured was through the PTAC unit, between the PTAC unit and sleeve, and between the sleeve and wall. This is slightly different than the test required by AHRI, which does not require the leakage between the sleeve and the wall to be reported. However, despite this difference in the test, it's concluded that either PTACs either do not typically meet the AHRI air infiltration requirement, or that PTAC installation introduces infiltration over and above infiltration in the PTAC units themselves.

17.6 Sound

PTACs and PTHPs are regulated for sound through AHRI Standard 300, formally ANSI/AHRI Standard 300: 2015 Standard for Sound Rating and Sound Transmission Loss of Packaged Terminal Equipment. While testing is required, there are no minimum requirements for PTACs and PTHPs and reporting the results from these tests to the marketplace is also not required.

18 Impact of Physical Size on Efficiency

The standard PTHP size is 16" high by 42" wide. Depths vary by manufacturer, are commonly around 21", but can be shallower, such as Amana's 16" depth.

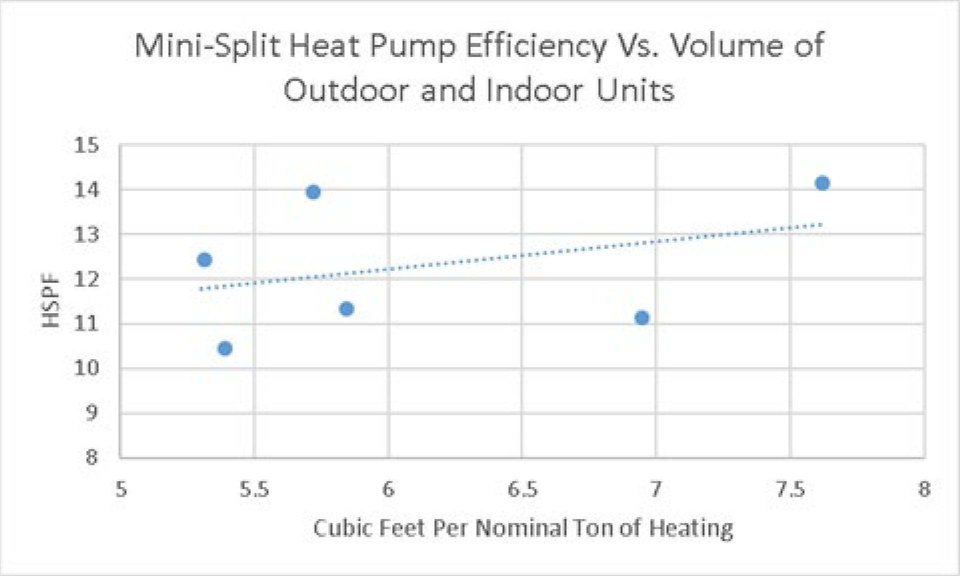
A common presumption is that the PTHP's standard size limits their efficiency.

The efficiency of heat pumps (and any vapor compression mechanical refrigeration system) is predicated by the size of the heat exchangers. Larger heat exchangers allow systems to deliver higher efficiency.

Assuming the heat exchanger size is restricted by the geometric volume of the overall heat pump equipment, the existing PTHP's and mini splits can be examined to see what the impact and potential of size is on efficiency. An analysis of mini split heat pump efficiency for six different mini splits in the one- to two-ton nominal heating range, from five different manufacturers, is provided in Figure 11.

Figure 11. Minisplit heat pump efficiency vs. volume

Outdoor and indoor units in cubic feet.



Although the data has some scatter, mini split heat pumps, with their relatively higher efficiencies (than PTHPs), are configured within relatively smaller equipment packages, with total equipment volumes in a somewhat narrow band of 5-8 cubic feet per nominal ton of heating.

By comparison, the typical PTHP has a relatively large volume of about 8.2 cubic feet and serves PTHPs with heating capacities in the 6,000-15,000 Btu/hr nominal heating capacity range, representing 6.6-16.4 cubic feet per nominal ton of heating. This runs counter to the perception that PTHPs are constrained by their equipment size and for efficiency. Assuming the equipment (fans, compressor, heat exchangers) can be configured as efficiently in the PTHP "box", larger PTHPs (15,000 Btu/hr nominal capacity) in a standard PTHP sleeve size could be developed to provide efficiencies over 12.5 HSPF. Smaller-capacity PTHPs, in the 6,000-9,000 Btu/hr nominal heating capacity range, should be able to meet or exceed the highest HSPF's available for mini splits, within the standard sleeve size.

Smaller PTHP sleeves, such as Amana's 16" deep unit, have a volume per ton that is lower, going as low as 5.5 cubic feet per ton. This would limit the HSPF, but a reasonably good HSPF of 12 should still be possible.

It's presumed that the required components can be fit in the PTHP configuration, but this would need to be confirmed. However, at first glance, PTHPs may be able to reach significantly higher efficiencies than they currently do. Using relationships between COP (efficiency at 47°F) and HSPF from example mini split heat pumps, estimates of possible PTHP efficiencies, within a standard 42" x 16" x 21" sleeve, are listed in Table 15.

Table 15. PTHP size, current COP requirements, and estimated possible COP

PTHP Size:	7,000 Btu/hr	15,000 Btu/hr
Current IECC/NYS requirements, COP	3.0 COP	2.8 COP
Current DOE/ASHRAE requirements, COP	3.3 COP	2.9 COP
Taitem Estimate of Possible COP	> 4.5 COP[a]	3.8 COP

Notes:

The curve fit shows an HSPF as high as 17. But since there were no other mini split efficiencies as high as 17 HSPF, the estimate is limited to a more conservative "> 14 HSPF," which corresponds to a mini split COP of "> 4.5."

These estimates are based on current technologies, but future advances in compressor, fan, and motor efficiencies may allow even higher efficiencies. In its 2015 rulemaking report, the DOE projected that 7,000 Btu/hr. PTHPs could readily reach a COP of 3.8, and 15,000 Btu/hr. PTHPs could readily reach a COP of 3.2. For the 15,000 Btu/hr. 3.2 COP PTHP, a projected incremental manufacturing cost of $35 was projected, over a baseline (current efficiency) manufacturing cost of $464, a 7.5% increase.

In this discussion, the question arises whether a deeper PTHP size dimension would be possible. If so, this would allow added space for more heat exchanger surface, in order to further raise PTHP efficiencies. PTHP's are almost always flush with the outside wall with typical wall thickness are approximately 12". For a standard PTHP depth of 21", this means that the PTHP projects 9" into the room. For reference, mini split wall-mounted units typically range from 8-12" but can be as much as 14" deep. Conservatively taking 12", the high end of the typical 8-12" range, as being acceptable for projection, and assume a typical wall thickness of 12", then the depth of PTHPs could readily be increased to 24", while keeping the standard 16" x 42" face dimensions. This 3" increase in depth would increase the volume of the system by almost 15%, allowing for a significant increase in heat exchanger sizes, and so allowing further increases in PTHP efficiency.

19 PTHP for New Construction Market

In considering the total market for PTHPs, it is important to also evaluate the new construction market. As the NYSERDA multifamily new construction program shows, with almost 40% of projects using PTACs, this market may be substantial.

If technology improvements can be achieved (increased efficiency, low-temperature operation, defrost, defrost condensate removal, air-leakage reduction, reduced thermal conductivity, sound reduction, etc...), PTHPs could be a cost-effective option for new high-performance buildings.

A simplified analysis was performed to compare PTHPs to VRF heat pumps. Assuming one PTHP per 330 sqft. (1000 sf, two bedroom apartment) at a cost of $2,000 installed each or $6/sqft, PTHPs compare very favorably to VRF systems $25/SF. For example, for a 100,000 sf building, it would cost $2,500,000 for a VRF system, but only $600,000 for PTHPs. This provides $1,900,000 savings, which could be invested in building efficiency and renewables.

Benefits over split system heat pumps:

- Lower installed cost
- Repairs
  - Easy to swap out if there is an issue, reducing downtime
  - Cheaper to repair, can be done out of apartment
- No future issues with refrigerant lines being inaccessible within walls of the building
- Indoor and outdoor coil electric use paid by tenant
- No need to find location for outdoor units

Limitations as compared to split system heat pumps:

- Lower efficiency, unless efficiency issues are fully addressed
- Sound – outdoor unit is directly adjacent to living space; split system heat pump outdoor units can be located elsewhere
- Outdoor coil maintenance more difficult (need to access apartments and remove unit)
- Potential for air infiltration
- Thermal bridge in the building envelope

Shortcomings that must be addressed to allow PTHPs to compete with split system heat pumps:

- Variable speed compressor
- Improved efficiency
- Defrost capabilities
- Sound
- Air infiltration
- Thermal conductivity

Other things that should be considered:

- Wall mounted thermostat
- Maintenance plan
- Filter cleaning
- Indoor coil cleaning
- Outdoor coil cleaning
- Base pan cleaning
- Condensate drain

20 Other Equipment

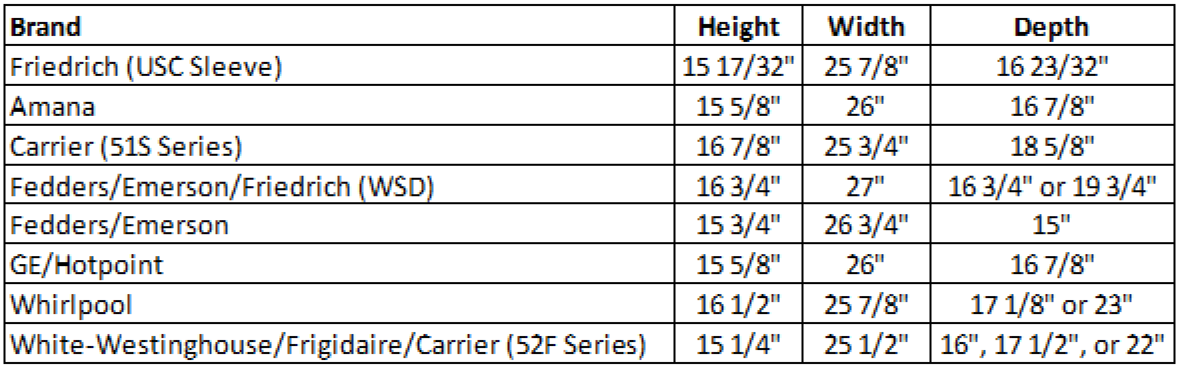
In addition to PTACs/PTHPs there are other various types of equipment that are available that provide both heating and cooling through a packaged system on the exterior wall of a building. A discussion is included below on some of the equipment that is available. It may be worth looking into some of these other types of equipment to see how they address some of the current shortcomings of PTACs/PTHPs and/or to evaluate whether there is an opportunity for development of a high-efficiency cold-weather version of each to further support the electrification of heat in buildings.

When considering these other options, it is important to consider that outdoor coils should be cleaned at least once annually. Therefore, it is important that they can be easily accessed for cleaning.

20.1 AC Sleeves

Because a large percentage of buildings have through-the-wall AC sleeves, it is also important to evaluate options for these penetrations. These penetrations are smaller than PTAC sleeves, typically around 27" x 15", but there is not a standard size, and there remains variability among manufacturers. See Table 16 for various manufacturers and their AC sleeve sizes.

Table 16. Through-the-wall AC sleeve size for different manufacturers



Brand	Height	Width	Depth
Friedrich (USC Sleeve)	15 17/32"	25 7/8"	16 23/32"
Amana	15 5/8"	26"	16 7/8"
Carrier (51S Series)	16 7/8"	25 3/4"	18 5/8"
Fedders/Emerson/Friedrich (WSD)	16 3/4"	27"	16 3/4" or 19 3/4"
Fedders/Emerson	15 3/4"	26 3/4"	15"
GE/Hotpoint	15 5/8"	26"	16 7/8"
Whirlpool	16 1/2"	25 7/8"	17 1/8" or 23"
White-Westinghouse/Frigidaire/Carrier (52F Series)	15 1/4"	25 1/2"	16", 17 1/2", or 22"

Currently, some manufacturers offer an off-the-shelf heat pump option for AC sleeves. For example, the Friedrich Wall Master has a heat pump that fits in an AC sleeve and provides 11,300 btu/hr. in cooling and 8,900 btu/hr. in heating. Due to the limited size of the sleeve, and therefore, limited size of the indoor and outdoor coils, the efficiencies are much lower than PTHPs. For the Friedrich heat pump, the COP is 2.3. The same issues are present with AC sleeve heat pumps that are present with PTHPs including electric heat boost, heat pump defrost capabilities, heat pump defrost condensate removal (defrost drain kits are available), and electric resistance heat switch over temp (35°F - 40°F).

Additional analysis should be completed on the existing options and feasibility to develop a heat pump option that can fit into AC sleeves and still meet desired cold weather and efficiency requirements similar to that of the proposed high efficiency cold weather PTHP.

20.2 VTACs and VTHPs

Similar to PTACs/PTHPs are Vertical Stack Air Conditions (VTACs) and Vertical Stack Heat Pumps (VTHPs). Like a PTAC/PTHP, this equipment contains both the indoor and outdoor coils within one assembly with a louver connecting the outdoor unit to the outdoors. VTACs/VTHPs are typically installed in a small mechanical closet in the corner of the room they serve and are often found in larger capacities than PTACs/PTHPs. The rely on a condensate drain to deal with condensate removal for both air conditioning and defrost. Not to be confused with vertical stack water source heat pumps or vertical stack fan coils.

Manufacturers of VTACs/VTHPs have begun to market variable speed and cold weather heat pump options. For example, Friedrich VRP equipment is listed as having a variable speed compressor and operating in heat pump mode down to 0°F. Unfortunately, at the time of this report Friedrich has not yet published data on the low temperature performance of their VRP. They are expected to release this data by the end of 2018.

20.3 Wall Mount Mini Packaged System

Another alternative to PTACs/PTHPs is what some manufacturers call a “Wall Mount Mini Packaged” system. For example, the manufacturer YMGI markets this equipment under the model name “Harmony Elite.” These units utilize a 10” deep design which is mounted on the wall. The ducting for the “outdoor coil” is through two six-inch holes cut in the outside wall and ducted to the outside. The company also lists these units as operating down to 14°F, but this cold weather operation could not be confirmed, and no information was provided on efficiency and capacity at these lower temps nor how defrost is dealt with. Visit http://ymgigroup.com/ymgi-products/harmony-elite/ for more information.

20.4 Eco-Snap AC

The Eco-Snap AC is a product currently being developed by the National Renewable Energy Laboratories that is designed as a split system without the need for refrigerant line set. The concept is that the outdoor unit is mounted on the exterior wall directly opposite the indoor unit and all refrigerant, electrical, and communication is run through a single penetration in the exterior wall. Since this product is currently in development no technical specifications were available nor is it available for testing or purchase. Visit https://www.energy.gov/eere/ampedup/articles/new-easy-install-air-conditioning-unit-frees-window-space-snap for more information.

21 Refrigerants

Until the early 1990s, PTACs and PTHPs almost all used refrigerant 22, which has been phased out due to its ozone depletion potential. As of the present, all PTAC/PTHPs surveyed use refrigerant R-410a. R-410a has a global warming potential (GWP) when released into the atmosphere. Its GWP score is 1923.

A likely near-term replacement for R-410a is R-32, which is already reportedly used in heat pumps and air conditioners overseas, which has a GWP score of 677, almost one-third that of R-410a. However, R-32 is mildly flammable, so its use in the U.S. has so far been restricted by the EPA. There were reports in 2015 that Daikin was planning to introduce an Amana PTAC with R-32, but after speaking with Amana representatives they clarified this release has been put on hold.

22 Conduction and Air Leakage

22.1 Conduction

There are at least two manufacturers (Ice Air and GE) that are already selling thermally broken PTAC sleeves, which greatly reduce the conduction losses through the sleeve as compared to metal sleeves. Any manufacturer that develops a high efficiency cold weather PTHP should also provide a thermally broken sleeve available for purchase.

For additional information on the potential conductive loses though room ACs in general, please see the Tech Tip on Room Air Conditioner Conductive Loses developed by Taitem Engineering for the New York State Homes and Community Renewal Weatherization Assistance Program.[30]

Of the PTACs inspected for this report, they all contained approximately 1" of fibrous insulation (~R-4) between the indoor coil and outdoor coil. Increasing the total R-value of this insulation to R-8 would result in savings of approximately 9 kWh/yr/unit or $1.31/yr/unit (assuming 4000 HDD/ year, a COP of 2.5 for the heating system, and $0.20/kWh for energy costs). Assuming a PTHP lifetime of 15 years, total cost savings from increasing the insulation between the indoor and outdoor coil would be approximately $20. Not a significant amount, but potentially enough to cover the cost for installation of the increased insulation.

22.2 Air Leakage

PTACs have a history of being installed in a manner that results in significant air leakage at the exterior walls. There are two points of connection that if not properly sealed result in air leakage. The first is between the PTAC sleeve and wall assembly and the second is between the PTAC equipment and sleeve. Since PTACs have a total perimeter of 9.7 ft, even a small crack at either of those locations would result in a significant leakage area. As discussed previously, a study to conducted by Steven Winter Associates for the Urban Green Council measured an average total leakage area of PTACs to be 6.7 sq. inches resulting in an energy penalty of between $32 and $45 per year.[31]

Since outdoor coils require cleaning at least once annually, maintaining an airtight seal between the unit and the sleeve can be difficult, especially overtime. It is very important that manufactures developing solutions to reduce air infiltration must take this durability issue into consideration.

23 Product Development Criteria

Based on findings to date, the following product development criteria are recommended.

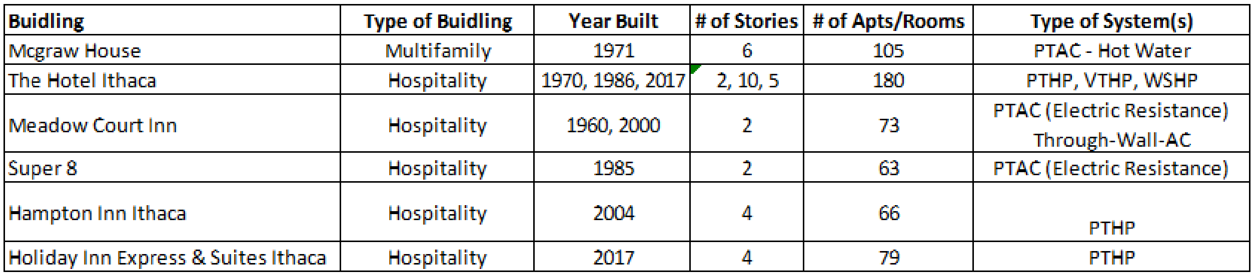
- Capacity range: 3,000-15,000 Btu/hr nominal heating capacity. Of particular note is a need for PTHPs in smaller capacity sizes (3,000-6,000 Btu/hr) than the common current 6,000-15,000 Btu/hr offerings, to meet the need of smaller loads in new buildings that meet the current energy code, expected more efficient energy codes, and high-performance buildings (Passive House, net zero ready, etc.).
- Efficiency:
    - PTHPs with variable speed compressors. This is considered a threshold requirement (mandatory) in order to deliver high efficiency at part-load, full capacity at low outdoor temperatures, lower noise, and performance that matches the performance of typical split system heat pumps.
    - Encourage AHRI to develop a PTHP efficiency rating that recognizes the benefits of variable speed compressors, as is done with split system heat pumps, and that also recognizes the benefits of low-temperature operation. The current heat pump efficiency rating condition (steady state operation at 47°F outdoor temperature) does not recognize the important benefits of operation in heat pump mode down to the winter design temperature (approximately 15°F Downstate and 0°F Upstate).
    - Develop PHTPs that operate in ranges of efficiency similar to or exceeding split system heat pumps, in order to compete with split system heat pumps, deliver comparable energy savings, and do so in a more cost-effective manner. Not only should efficiencies meet federal minimum efficiencies equal to split systems, but efficiencies should readily be able to meet best-of-class efficiencies, even in current PTHP capacities (up to 15000 Btu/hr) and standard sleeve sizes (16x42).
    - Consider developing a standard parallel to NEEP's "cold climate heat pump" that promotes the development and adoption of efficient PTHPs. The standard should comprise both a strong set of requirements for efficient operation, meeting most or all of these product development criteria, but should also have a branding and listing component, such as NYSERDA Deep Energy PTHP, even if the program is self-certifying.
- Physical Size:
    - Standard 16x42 sleeve. Manufacturers are encouraged to consider units that have larger depths than the common current 21" depth (and frequently smaller). Depths of 24" and even larger will not protrude into the room more than common typical split system indoor units and will allow extra space for larger heat exchangers and less-constrained airflow, which in turn will allow higher efficiencies.
    - Nonstandard sleeves (smaller than 16x42). Creative approaches are encouraged, such as:
        - Packaged indoor heat pumps that can have their outdoor airflow ducted through existing sleeve wall penetrations, such as the YMGI "wall mounted mini packaged system."
        - Split systems where the outdoor unit fits into existing sleeves.
- Strategies to defrost in cold weather, including prevention of ice formation in the base pan.

- Strategies to minimize or eliminate use of electric resistance heat:
    - A variety of common strategies that rely on electric resistance heat (startup, recovery from setback, defrost mode, etc.) should be minimized or eliminated.
    - To effectively compete with split heat pumps and deliver comparable savings, PTHPs should seek to adopt the "no electric heat" approach that has seen success with split heat pumps.
    - Operation in heat pump mode should meet or exceed the low-temperature operation of split heat pumps, currently commonly -13°F or lower. Owners must be assured that adequate heat will be provided even at the coldest midwinter conditions, both from the perspective of real need and to overcome perceptions that heat pumps do not provide adequate heat in cold weather.
    - Defrost using reverse cycle operation should be promoted, rather than the use of electric resistance heaters.
- Implementation Considerations:
    - Building envelope integration to minimize heat loss. This should be achieved through both improved materials and installation techniques. It's also important to take into consideration that units must be removed frequently for proper maintenance and any air leakage or conductivity improvements need to be durable.
- Minimize air leakage: Reduce air leakage from two CFM/LF (AHRI Standard 310/380) to one CFM/LF.
- Minimize conductive losses. Maximum conductive losses through the entire assembly (PTHP and sleeve) to be 0.3 Btu/hr/SF/F. Encourage AHRI to develop a test standard to support this requirement, to be added to AHRI Standard 310/380. (See http://www.taitem.com/wp-content/uploads/Taitem-AC-Conduction-Loss-Tech-Tip-2012.3.26.pdf)
- Building decision-maker considerations:
    - Cost: Price premium to a building owner is less than 25% of a standard model with same capacity.
    - Ease of installation: Similar to existing PTACs. The key challenge is to provide condensate disposal without need for a new drain to an interior location, such as by evaporation on the indoor coil.
    - Noise levels: Indoor sound level is less than 50 decibels (dBA) when on high speed.
- Other considerations:
    - Use of alternative refrigerants such as R-32
- Installation, operation, maintenance, and reliability requirements:
    - Generally similar to existing PTACs.
    - Estimated useful life of 20 years. (Current estimates range from five to 20 years.)
    - Installation and servicing do not require refrigeration certifications or licenses.
    - Unit should be able to be removed from sleeve so that it can be serviced, outdoor coil can be cleaned, and exterior wall grille can be cleaned. (Similar to existing PTACs.)

24 Building Site Visits

Several site visits were completed to buildings that currently utilize PTACs and/or PTHPs for heating and/or cooling. These site visits helped inform the research and analysis and findings in this report. A list of the buildings visited for this study is included in Table 17.

Table 17. Site visits completed to analyze PTACs/PTHPs and installed conditions



Buidling	Type of Buidling	Year Built	# of Stories	# of Apts/Rooms	Type of System(s)
Mcgraw House	Multifamily	1971	6	105	PTAC - Hot Water
The Hotel Ithaca	Hospitality	1970, 1986, 2017	2, 10, 5	180	PTHP, VTHP, WSHP
Meadow Court Inn	Hospitality	1960, 2000	2	73	PTAC (Electric Resistance) Through-Wall-AC
Super 8	Hospitality	1985	2	63	PTAC (Electric Resistance)
Hampton Inn Ithaca	Hospitality	2004	4	66	PTHP
Holiday Inn Express & Suites Ithaca	Hospitality	2017	4	79	PTHP

General findings from site visits in addition to information that informed this report:

- Varying degrees of maintenance practiced from no maintenance to monthly maintenance.
- Sound was a big issue for many of the buildings, with some building managers/owners being pleased with the sound levels of the PTACs/PTHPs installed and others having major issues due to sound both with the occupants of the building and neighbors.
- When asked about the possibility of retrofitting their building with a high-efficiency cold-weather heat pump, most building owners/managers expressed interest. However, when asked if they would be willing to retrofit an internal condensate drain there was immediate hesitation.

25 Interviews

Interviews were conducted with several experts in the PTHP field and other industry professionals:

1. J Decker Ringo, Associate Director, Energy, Navigant. Phone interview conducted 5/3/2018. Mr. Ringo has served as Navigant's lead consultant on US DOE's latest energy efficiency rule for PTAC/PTHPs, in 2015. He performed teardowns of multiple units, then wrote up an engineering narrative of the rule, including evaluation of the costs for low-, mid- and high-efficiency units. He periodically examines the at market, has done compliance testing, and has also interpreted test rules for manufacturers.
2. Sean Brennan, Associate Director, Research, Urban Green Council. Phone interview conducted on 5/7/2018. Mr. Brennan was one of the leaders behind Urban Green's recent report for NYSERDA titled "Next Frontier for Energy Efficient Products," and specifically worked on PTAC aspects.
3. Marc Zuluaga, PE. Managing Director, Multifamily Energy Services, Steven Winter Associates. Phone interview conducted on 5/12/2018. Mr. Zuluaga worked on Steven Winter Associates well-received report "There Are Holes in Our Walls," prepared for Urban Green, on infiltration losses in through-wall air conditioners. He has also done research and given presentations on heat pumps.
4. Mike Brusic, Technical Director, Bright Power. Phone interview conducted on 5/11/2018.
5. Shuchita Prakash, Project Manager, ConEd. Phone interview conducted on 5/29/2018.

Interviews were conducted with several manufacturers:

1. Steve Santo, Application Engineer, GE Appliances
2. Nate Hyman, Northeast Regional Sales Manager - Amana PTAC,Goodman Company, L.P, a member of Daikin Group
3. Mark Soja, Hot Spot Energy. Sales for Arama PTACs/PTHPs.
4. Bill Liu, Ice Air
5. Friedrich
6. Island Aire
7. Applied Comfort
8. Frigidaire

26 Notable References

AHRI Certification Directory: Packaged Terminal Air Conditioners and Heat Pumps. https://www.ahridirectory.org/Search/QuickSearch?category=9&searchTypeId=3&producttype=5&SubmenuId=1733&ProgramId=5

AHRI Standard 310/380-2017 Packaged Terminal Air Conditioners and Heat Pumps.

ANSI/AHRI Standard 300: 2015 Standard for Sound Rating and Sound Transmission Loss of Packaged Terminal Equipment.

ENERGY STAR® Market & Industry Scoping Report Packaged Terminal Air Conditioners and Heat Pumps December 2011.

The Next Frontier for Energy Efficient Products. Urban Green Council prepared for NYSERDA, April 2018.

Technical Support Document, Energy Efficiency Program for Commercial and Industrial Equipment: Packaged Terminal Air Conditioners and Heat Pumps. U.S. Department of Energy, Assistant Secretary, Office of Energy Efficiency and Renewable Energy, Building Technologies Program, Appliances and Commercial Equipment Standards, June 2015.

Tech Tip: Room Air Conditioner Conductive Losses. Taitem Engineering prepared for New York State Homes and Community Renewal Weatherization Assistance Program, March 2012.

There Are Holes in Our Walls. Steven Winter Associates prepared for Urban Green Council, April 2011.

U.S. Department of Energy - Compliance Certification Management System: Air Conditioners and Heat Pumps - Packaged Terminal. https://www.regulations.doe.gov/certification-data/CCMS-4-Air_Conditioners_and_Heat_Pumps_-_Package_Terminal.html#q=Product_Group_s%3A%22Air%20Conditioners%20and%20Heat%20Pumps%20-%20Package%20Terminal%22

Appendix A: Test

GE Zoneline Packaged Terminal Heat Pump

Informal Test

Hotel Room

Cambridge, Ontario

5/19/18

Ian Shapiro

The following test was done in order to see if setting the setpoint of a heat pump much higher than the actual room temperature would trigger use of electric resistance heat. What we found was that the unit only ran in electric resistance heat mode, even though the outdoor temperature is a mild 56°F and the unit should be running in heat pump mode. We were not able to get the unit to run in heat pump mode at all. We conclude that some packaged terminal heat pumps have control problems, which we have heard of anecdotally, and that electric resistance heat is likely used much more than expected.

Wall-mounted thermostat

GE Model AZ38H09DABM2

Mfr date: 04/07

Cooling: 9000 Btu/hr

Heating: 8400 Btu/hr

COP: 3.6

This tells us it is a heat pump. A google search of the model number confirms it is a heat pump.

Electric resistance heat: Could be any one of three kits, which range from 2190 watts to 5130 watts.

Test start: 11:20 a.m.

Outdoor temperature: 56°F

Indoor temperature: 75°F

Unit status: Off

Thermostat status: Off

Timestamp: 0:00

Turned thermostat on. Thermostat default is 70°F. Unit goes right into cooling. Turned thermostat up to 76°F. Tried to get heat to come on. Unit immediately cycled off, to turn off the cooling. Stayed off for a few minutes, possibly going through a cycle-prevention timer mode.

Timestamp: 4:00 minutes

Unit is still off. Checked the thermostat. Setpoint is still 76°F. Actual is still 75°F.

Timestamp: 17:00 minutes

Unit is still off. Checked the thermostat. Setpoint is still 76°F. Actual is still 75°F. This is much longer than any cycle protection time.

Note that this unit is in "Auto" mode, and does not allow separate Heat and Cool modes, only Auto or Off.

Let's think through if this might be hysteresis. In a usual call for heating, let's say IF it had a heat-only mode, we might imagine the unit being off, the user setting it in heat-only mode, and let's say the room is at 68°F and the setpoint is 70°F. The unit turns on, heats the room up to 70°F, the thermostat is satisfied and turns the unit off, there might be overshoot to 70.5 (either because of fan off-delay or just because of a warm coil), temperature drops, the unit likely does not come on at 70°F but rather at some hysteresis lower than 70, let's say 69.2 (0.8°F hysteresis). Now, what might be happening in the room? Let's say that the actual 75 represents 75.4 (since it rounds to a single digit). And the setpoint is 76, which is NOT 0.8°F warmer than the actual (75.4°F). So, the unit THINKS it's in the hysteresis band, and is not calling for heat. Just speculation. (I don't know in fact that the hysteresis is 0.8°F.

Timestamp: 17:05 minutes (17 minutes, 5 seconds)

Turned setpoint up to 77°F. Unit came on immediately, with heat, but no compressor sound, and clearly the "burnt dust" smell of electric resistance heat.

This confirms that it is a hysteresis issue. The unit only calls for heat if the setpoint is 2°F higher than the actual temperature.

Timestamp: 19:00

Electric heat is still on. Setpoint is still 77°F, actual is still 75°F, room feels like it's warming up.

Timestamp: 20:00

Electric heat is still on. Setpoint is still 77°F, actual is still 75°F, room feels like it's warming up.

Timestamp: 21:00

Electric heat is still on. Setpoint is still 77°F, actual is still 75°F, room feels like it's warming up.

Timestamp: 22:00

Electric heat is still on. Setpoint is still 77°F, actual is still 75°F, room feels like it's warming up.

Timestamp: 23:00

Electric heat is still on. Setpoint is still 77°F, actual is still 75°F, room feels like it's warming up.

Timestamp: 23:15

Electric heat is still on. Setpoint is still 77°F, actual is 76°F, room feels like it's warming up.

Timestamp: 24:00

Electric heat is still on. Setpoint is still 77°F, actual is 76°F, room feels like it's warming up.

Timestamp: 25:00

Electric heat is still on. Setpoint is still 77°F, actual is still 76°F, room feels like it's warming up.

Timestamp: 26:00

Electric heat is still on. Setpoint is still 77°F, actual is still 76°F, room feels like it's warming up.

Timestamp: 27:00

Electric heat is still on. Setpoint is still 77°F, actual is still 76°F, room feels like it’s warming up.

Timestamp: 28:00

Electric heat is still on. Setpoint is still 77°F, actual is still 76°F, room feels like it’s warming up.

Timestamp: 29:00

Electric heat is still on. Setpoint is still 77°F, actual is still 76°F, room feels like it’s warming up.

Fan is on low, as indicated by the thermostat. I switched it to high, but just for a second and then switched it back to low. By sound, it seems to have been on low since the beginning.

Timestamp: 30:00

Mistakenly lowered setpoint to 76 (I hit the “down” button rather than the “display” button, which is what I was hitting to periodically see the actual temperature). Unit turned off. Immediately turned the setpoint back up to 77. Actual now has reached 77, so it must have satisfied right at the same time. Unit did not turn back on.

Timestamp 32:00

Unit is still off.

Timestamp: 33:00

Unit is still off. Setpoint and actual are both still 77.

Timestamp: 34:00

Unit is still off. Setpoint and actual are both still 77.

Timestamp: 35:00

Unit is still off. Setpoint and actual are both still 77.

Timestamp: 36:00

Unit is still off. Setpoint and actual are both still 77.

Timestamp: 37:00

Unit is still off. Setpoint and actual are both still 77. I thought I briefly saw “actual” jump to 76, but then back to 77.

Timestamp: 37:20

Unit is still off. Setpoint is 77 and actual changed to 76.

Timestamp: 38:00

Unit is still off. Setpoint is 77 and actual is now 76.

Timestamp: 38:00

Unit is still off. Setpoint is 77 and actual is back up to 77.

Timestamp: 38:45

Unit is still off. Setpoint is 77 and actual is back to 76.

Timestamp: 39:00

Unit is still off. Setpoint is 77 and actual is back to 77.

Timestamp: 40:00

Unit is still off. Setpoint is 77 and actual is back to 77. Refrigerator is on, so may be adding the little bit of heat to the room needed to push actual temperature back up.

Timestamp: 41:00

Unit is still off. Setpoint is 77 and actual is still at 77. Refrigerator is on, so may be adding the little bit of heat to the room needed to push actual temperature back up.

We are waiting for the thermostat ITSELF call for heat (rather than me calling for heat at the thermostat), to see if it comes on in heat pump mode.

Timestamp: 42:00

Unit is still off. Setpoint is 77 and actual is back down to 76.

Timestamp: 43:00

Unit is still off. Setpoint is 77 and actual is back to 77.

Timestamp: 44:00

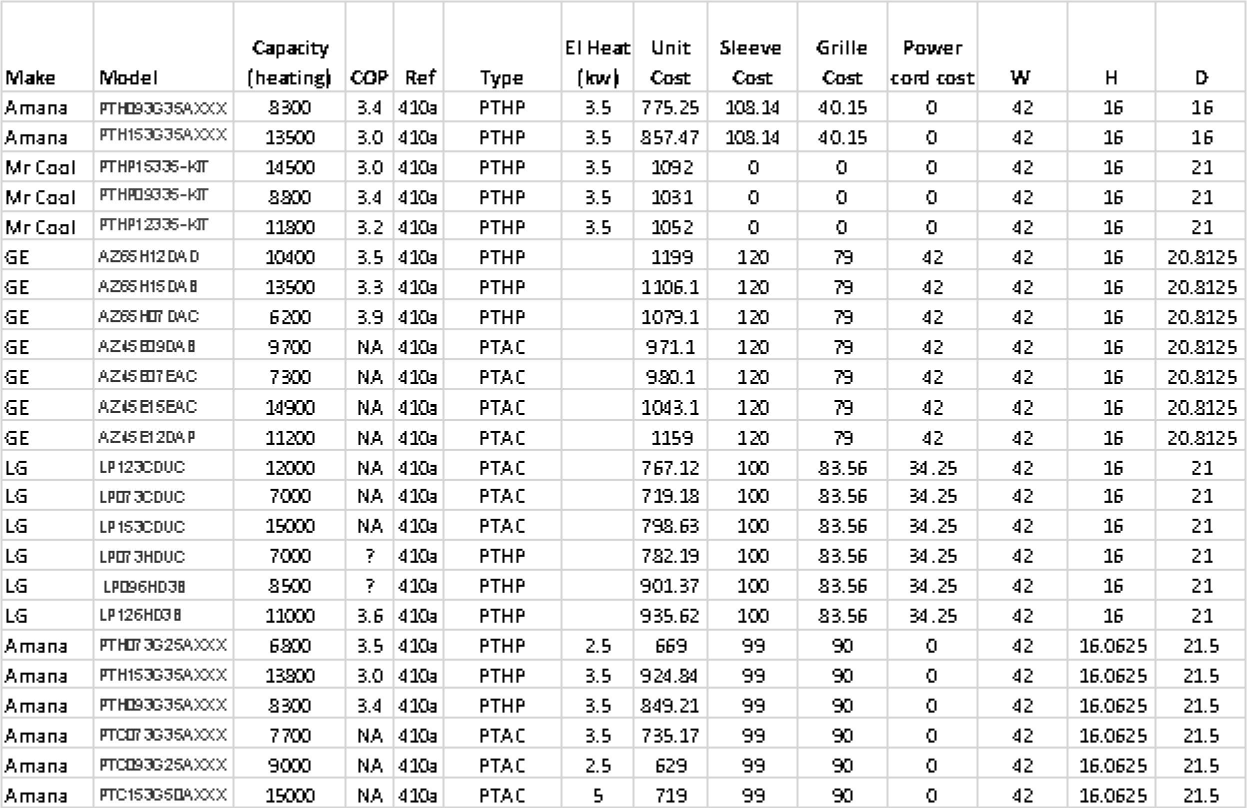
Unit is still off. Setpoint is 77 and actual is back to 76. Opened a window to try cool the room.

Timestamp: 45:00

Unit is still off. Setpoint is 77 and actual is down to 75. Heat came on. Electric only, no compressor!

Conclusions: The unit really should be running in heat pump mode, at this outdoor temperature. This particular control seems to be having problems doing anything other than electric heat mode, either if the user calls for heat, or if the thermostat calls for heat automatically after a natural off-cycle.

Appendix B: Example Product Costs



Make	Model	Capacity (heating)	COP	Ref	Type	El Heat (kw)	Unit Cost	Sleeve Cost	Grille Cost	Power cord cost	W	H	D
Amana	PTH093G35AXXX	8300	3.4	410a	PTHP	3.5	775.25	108.14	40.15	0	42	16	16
Amana	PTH153G35AXXX	13500	3.0	410a	PTHP	3.5	857.47	108.14	40.15	0	42	16	16
Mr Cool	PTHP15335-KIT	14500	3.0	410a	PTHP	3.5	1092	0	0	0	42	16	21
Mr Cool	PTHP09335-KIT	8800	3.4	410a	PTHP	3.5	1031	0	0	0	42	16	21
Mr Cool	PTHP12335-KIT	11800	3.2	410a	PTHP	3.5	1052	0	0	0	42	16	21
GE	AZ65H12DAD	10400	3.5	410a	PTHP		1199	120	79	42	42	16	20.8125
GE	AZ65H15DAB	13500	3.3	410a	PTHP		1106.1	120	79	42	42	16	20.8125
GE	AZ65H07DAC	6200	3.9	410a	PTHP		1079.1	120	79	42	42	16	20.8125
GE	AZ45E09DAB	9700	NA	410a	PTAC		971.1	120	79	42	42	16	20.8125
GE	AZ45E07EAC	7300	NA	410a	PTAC		980.1	120	79	42	42	16	20.8125
GE	AZ45E15EAC	14900	NA	410a	PTAC		1043.1	120	79	42	42	16	20.8125
GE	AZ45E12DAP	11200	NA	410a	PTAC		1159	120	79	42	42	16	20.8125
LG	LP123CDUC	12000	NA	410a	PTAC		767.12	100	83.56	34.25	42	16	21
LG	LP073CDUC	7000	NA	410a	PTAC		719.18	100	83.56	34.25	42	16	21
LG	LP153CDUC	15000	NA	410a	PTAC		798.63	100	83.56	34.25	42	16	21
LG	LP073HDUC	7000	?	410a	PTHP		782.19	100	83.56	34.25	42	16	21
LG	LP096HD3B	8500	?	410a	PTHP		901.37	100	83.56	34.25	42	16	21
LG	LP126HD3B	11000	3.6	410a	PTHP		935.62	100	83.56	34.25	42	16	21
Amana	PTH073G25AXXX	6800	3.5	410a	PTHP	2.5	669	99	90	0	42	16.0625	21.5
Amana	PTH153G35AXXX	13800	3.0	410a	PTHP	3.5	924.84	99	90	0	42	16.0625	21.5
Amana	PTH093G35AXXX	8300	3.4	410a	PTHP	3.5	849.21	99	90	0	42	16.0625	21.5
Amana	PTC073G35AXXX	7700	NA	410a	PTAC	3.5	735.17	99	90	0	42	16.0625	21.5
Amana	PTC093G25AXXX	9000	NA	410a	PTAC	2.5	629	99	90	0	42	16.0625	21.5
Amana	PTC153G50AXXX	15000	NA	410a	PTAC	5	719	99	90	0	42	16.0625	21.5

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New York State
Energy Research and
Development Authority

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov

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