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REPORT

GTI PROJECT NUMBER 22271

Through-the-Wall High-Efficiency Packaged Condensing Furnace/Air Conditioner Field Characterization Study

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Background

Although the technology for non-weatherized indoor gas space heating equipment has been commercially available for decades, the introduction of condensing Through-the-Wall (cTTW) packaged furnace and AC units only began in late 2013. In the beginning of 2018, the five top manufacturers of TTW products listed in Table 1 offered high-efficiency TTW units. By the end of 2018, only four of the five offered high-efficiency TTW product lines with up to 95% annual fuel utilization efficiency (AFUE) or thermal efficiency (TE) ratings in residential and commercial applications, respectively. While these product lines are in a relatively early commercialization and market adoption phase, they have the potential to deliver significant gas savings to utilities and end users, compared to conventional non-condensing systems at a standard 80% AFUE/TE rating. cTTW packaged units offer a significant near-term program and market opportunity to displace traditional warm-air furnaces with higher efficiency units. The price premium for cTTW units range from $300 to $500 above standard efficiency TTW.

Table 1: Packaged Condensing Through-the-Wall Product Offerings from Manufacturers, as of December 2018

Company	cTTW HVAC Product Line	Condensing Product Line	Heating Capacity Range [MBH]	Cooling Capacity Range [EER, Tons]
Allied Air Enterprises (owned by Lennox)	Magic-Pak www.magic-pak.com http://www.magic-pak.com/products/v-series/	V-Series HWC Unit; Up to 95% TE	22-55	9.2-11 & 1-2.5
National Comfort Products	Comfort Pack www.nationalcomfortproducts.com http://www.nationalcomfortproducts.com/comfort-pack-1	(Entry into market, 2018) CPG-Series; Up to 95% AFUE	(New) 25-50	(New) 9.2 & 1-2.5
Marvair (owned by AirXcel, formerly Suburban Manufacturing)	DynaPack www.airxcel.com https://www.airxcel.com/suburban-ap/hvac/dynapack	H-Series DYPA Unit; Up to 92% AFUE	39-52	10-10.6 & 1-3
Aerosys Inc.	AeroPak www.aerosysinc.com	(Exit from market, 2018) APG-Series Unit; Up to 95% AFUE	(Former) 40-60	(Former) 9 & 1-2
Napoleon Heating & Cooling	CondoPak www.condopak.com http://condopack.com/specifications	PSC-Series Unit; Up to 93% AFUE	15-50	9-10.8 & 1-2

As the housing market recovers from recent economic downturns, the multifamily housing market continues to rebound faster than the single-family housing market. Freddie Mac forecasts the multifamily housing demand to remain strong, primarily due to post-recession trends in demographics and homeownership. Specifically, many past and present perspective homebuyers now find themselves unable to secure mortgages for single-family homes, given the more conservative lending practices today. Recent reports[1] estimates that more than 19,000 multifamily units have been built in Chicago since 2010, and more than 25,000 units are planned for delivery by 2020. The report attributes this trend to a demographic shift, availability of employment, and preferences for dwelling types.

Notable proposals to study the cTTW product category have been favored by mainstream energy research institutions, energy efficiency incentive program administrators, and leading

1 KIG's Chicago Multifamily Market Report 2016 and Institutional Property Advisors's Chicago Multifamily Market Report – 2019 Outlook

manufacturers since 2015. With increased understanding of the performance and current market penetration of this technology, best practices may be derived to capture the natural gas savings potential for the utility and its customers.

Study Methodology

Conducted in Illinois, this study, on behalf of The Peoples Gas and North Shore Gas Energy Efficiency Programs, focuses on the greater Chicago and Cook County areas. These two areas provide the basis for an overview of the product market, including a review of regulatory codes concerning this category of condensing technologies and a field pilot evaluation of real-world residential cTTW operations.

Product Market Overview

Manufacturers, developers, and field contractors were interviewed to supplement the published technical literature. Real-world market conditions and first-hand practices and challenges have a significant impact on the longevity of high-efficiency technologies and products in their early commercialization phase. For instance, a known challenge of condensing technologies is the issue of how to handle acidic condensate wastes from a combustion process. Poor initial handling can result not only in property damage and resident discomfort but can leave a lasting tarnished reputation for the product category in the marketplace. It is also important to be aware of prescriptive regulatory codes, as they evolve with and shape future technology markets.

Questions addressed by this overview include:

- What are opportunities for contractor practices and/or standardization in the market?
- What is the current market acceptance?
- Has the industry resolved physical concerns for exhaust venting and freezing?
- What are the code requirements for condensate management and their implications for new construction or retrofit replacement units?

Field and Practice Overview

Early manufacturer forays into this category of high-efficiency condensing packaged Through-the-Wall units began in 2011, with a majority of participating manufacturers citing foreseeable increases in market demand and aggressive U.S. Department of Energy (DOE) pursuit of higher Annual Fuel Utilization Efficiency (AFUE) requirements. Interest in the components of the technology (condensate drainage, exhaust venting, and retrofit applications) has increased since 2012. No previous energy savings study has been performed on this technology. Due to this lack of independent operational data, field monitoring must be used to validate the performance of existing cTTW units installed in colder-climate multifamily residential applications. The comfort aspect of this consumer product (e.g., temperature of air delivery, no damage/freezing on the building exterior) must be characterized under real-world conditions to understand the economic impacts of this product category.

Questions addressed by this overview include:

- How do measured gas use savings compare to baseline minimum efficiency equipment (80% AFUE)?
- How cost-effective are the expected gas savings, or deemed savings value, with respect to the incremental cost of high-efficiency equipment?
- What are opportunities for contractor practices and/or standardization in the market?

- Does this technology adequately maintain indoor temperatures for occupant comfort that are comparable to minimum-efficiency equipment?
- Has the industry resolved physical concerns for exhaust venting and freezing?

Field Pilot Overview and Data Analysis

To fully characterize the representative operation of cTTW units in a multifamily residential setting, GTI sought pilot sites through local area developers and contractors. The criteria for multifamily setting selection stipulated that a property possess:

- Apartments at different elevations (more than ground floor units)
- Windows/exterior walls in multiple combinations of cardinal directions (N, S, E, W)
- One Packaged Through-the-Wall Furnace/AC unit per apartment
- One thermostat set-point per apartment
- Ability to provide access for data acquisition system integrity checks throughout the pilot

Pilot Site Information

St. Elizabeth Residences complex, built in 2016 by a local property developer and management company, eagerly participated in the field evaluation with GTI. There were four multifamily buildings in this income-eligible complex in Channahon, IL. The buildings, which were ready for occupants in the summer of 2017, were three-story and contained a total of 12 apartments per building with outdoor balconies, resulting in four apartments per floor. A single packaged cTTW conditions an entire apartment year-round. Figure 1 shows the packaged cTTWs, which are in unconditioned utility closets on the balconies of individual apartments. There are two different sizes of packaged cTTWs per building. They are:

1. 22MBH Heating and 1 Ton Cooling cTTW units for first-floor one-bedroom apartments
2. 33MBH Heating and 1.5 Ton Cooling cTTW units for the second-floor two-bedroom apartments and for the larger, third-floor one-bedroom apartments

Figure 1: Monitored Three-Story Multifamily Building at St. Elizabeth Residences, Channahon, IL

A total of seven (7) apartments were selected from the single complex for study. Figure 2 and Figure 3 show the installed configurations of the cTTW units, with supply air, return air, and condensate piping visible. Notice in **Error! Reference source not found.** that condensate and cooling coil drain pipes drain in the underfloor drain pipes. The underfloor drain pipes re-enter the building. Not shown in the figures is the exterior grille, which houses the exhaust air pipe and the outdoor air intake pipe for the unit.

Figure 2: cTTW Furnace/AC Unit in a utility closet

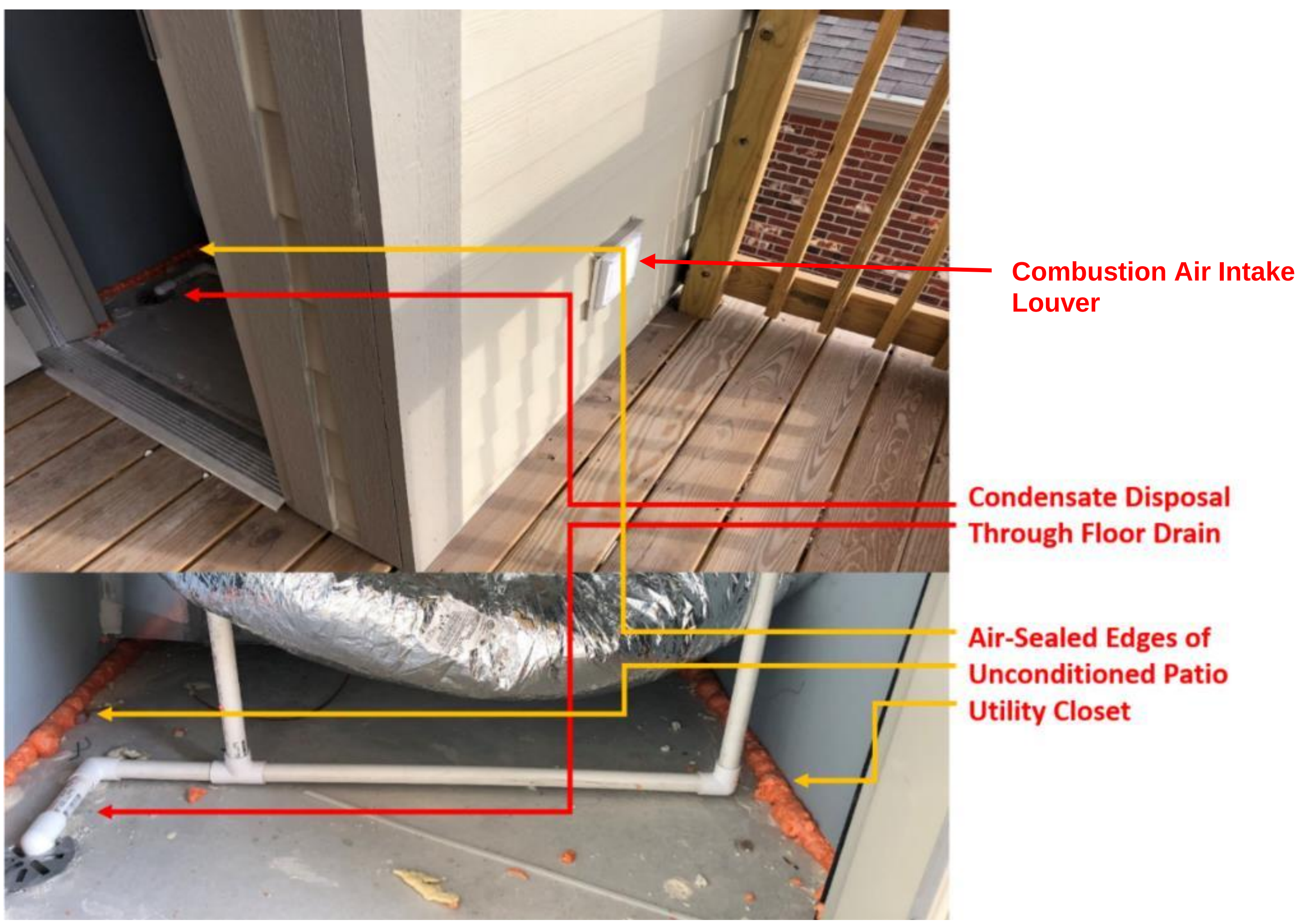


Figure 3: Close-up of cTTW Condensate Drain Placement and Utility Closet Air-Sealing

Data Collection System

The design of the data monitoring system around these existing installations used both stand-alone HOBO data loggers and WIFI-enabled wireless equipment. Figure 4 through Figure 11 in Table 2 show the instruments used to collect critical data. Locations for these non-intrusive sensors on the equipment and in the apartments are shown in equipment schematic (Figure 12) and floor plans (Figure 13). The physical barriers (sheet metal, walls, etc.) between the data collection points made a remote data logging system (e.g., a LogicBeach logger) impractical. A trade-off for the convenience of site access was the increased risk that a failed small sensor would not be detected immediately.

Table 2: Placement and Specification of Monitoring Devices

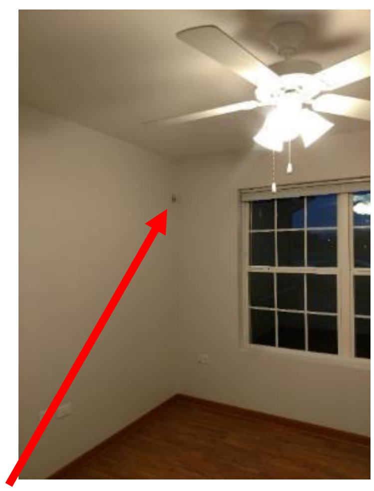
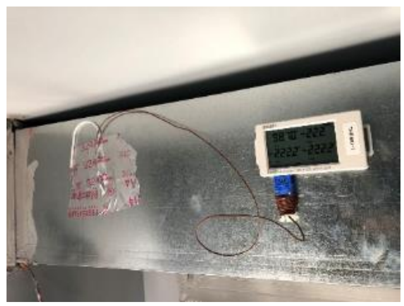
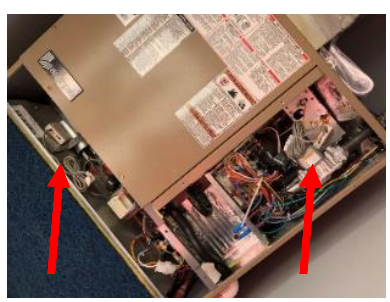
Equipment Name	Manufacturer / Model	Placement	Pictures	Purpose	Accuracy & Error
HOBO Temperature / Relative Humidity 3.5% Data Logger	Onset UX100-003	1 per: • Thermostat • Far Corner • 2nd Room	 *Figure 4: Thermostat Temperature Sensor under the Thermostat Control Panel in Apartment 101*  *Figure 5: Temperature Sensor Placement*	Measure Room Air Temperatures	-4°F to 158°F ± 0.38°F

			 *Figure 6: Placement of Second Room Temperature Sensor in Apartment 202*		
HOBO Thermocouple Data Logger with Omega T-Type 30 AWG Subminiature Connector Thermocouples	Onset UX120-014M & Omega 5SRTC-GG-T-30-72	1 per: • Supply Air Duct • Exhaust Air Grille	 *Figure 7: Supply Air Thermocouple Secured to Duct to Apartment 101*  *Figure 8: Exhaust Thermocouple Secured to Grille of Apartment 101*	Measure Supply Air and Exhaust Air Temperatures	-454°F to 700°F ±1.8°F
Hawkeye Fixed Trip Point Split-Core Current Switches	Veris Industries H300	1 per: • Fan Motor Power Wire • Gas Valve Power Wire		Measure On/Off State of Fan Motor and Gas Valve Operation	0.15 Amp Trip
HOBO Pulse Data Logger	Onset UX120-017	1 per Hawkeye	*Figure 9: Fan Motor State Logger (left) and Gas Valve State Logger (right) Installed in Apartment 101*	Record On/Off Operation State	N/A

Nest Outdoor Camera	Nest Outdoor	1 per site	 *Figure 10: Nest Camera Placement to View cTTW Exterior Grilles of Apartment 102 and Apartment 202*	Record Any Freezing on Exterior Exhaust Grilles	N/A
Velocity WIFI Jetpack	AT&T	1 per site		Transmit Video Recording in Real-Time	25 feet range
HOBO U30 USB Weather Station 10 Channel Smart Sensor Data Logger Kit	Onset U30-NRC-SYS-C & M-TPB-KIT & SOLAR-6W	1 per site	 *Figure 11: HOBO Weather Station, South of the Monitored Apartment Building*	Measure & Record Outdoor Air Temperature and Wind/Gust Speed	-40°F to 167°F ± 0.38°F 0 to 170 mph ±2.4mph or 4%

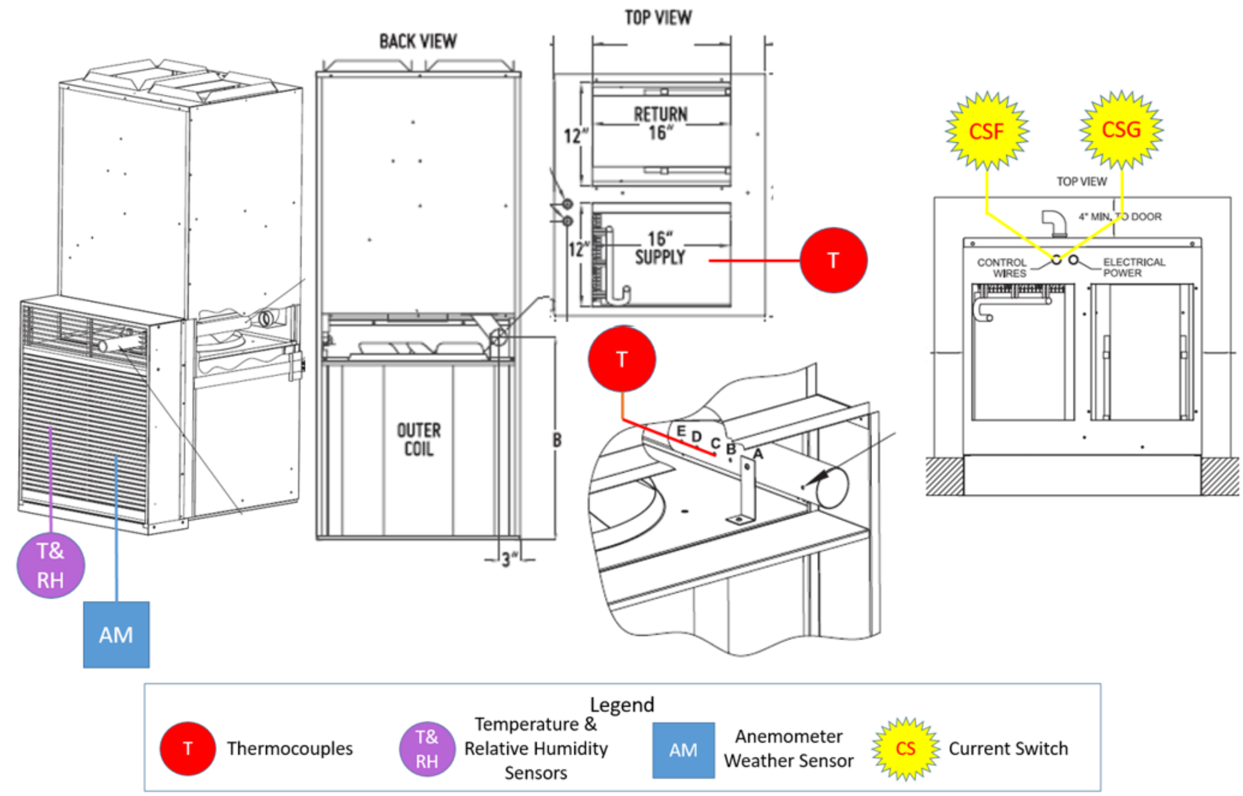


Figure 12: Equipment Monitoring Points

Figure 13: Floorplans of 1-Bedroom and 2-Bedroom Apartments with Sensor Placement

Governing Calculations

From these collected data, the field pilot was able to quantitatively assess the cTTW furnace operation. Since the furnace warms indoor air by burning natural gas and transferring that heat in from outdoors, it's necessary to calculate the total heat generated using the outdoor air temperature measured at the following: 1) the weather station; 2) the room (or "return") air temperature at the hall thermostat; and 3) the temperature of air delivered to the room through the supply duct. A description of the process and the calculations used are shown below:

- A rise in temperature, or an Air Temperature Rise, between the cold air that will burn in the furnace and the exhaust air that exits the furnace can be calculated when the furnace is operating. For instance, an Exhaust Temperature Rise of 15°F may be representative of a furnace burner operating in a fully "on," steady heating mode.

  Equation 1

$$Exhaust\ Temperature\ Rise\ or\ DelT_{Exh}\ [°F] = Exhaust\ Air\ Temperature\ [°F] - Outdoor\ Air\ Temperature\ [°F]$$

  Similarly, the Air Temperature Rise, or the rise in temperature between the room air temperature measured by the room thermostat (said to "return" to the furnace) and the temperature of air that a furnace delivers through the apartment supply air duct, also shows when the furnace is heating the apartment. When present in real equipment operation data, a positive observed Air Temperature Rise indicates that the unit is providing heat to the dwelling (e.g., rather than simply providing air circulation or ventilation).

  Equation 2

$$Air\ Temperature\ Rise\ or\ DelT_{Air}\ [°\mathrm{F}] = Supply\ Air\ Temperature\ [°\mathrm{F}] - Room\ Thermostat\ Temperature\ [°\mathrm{F}]$$

  The heat content delivered by the supply air duct to the apartment may then be calculated. The length of time that the furnace fan operates to push warm air through the duct is summed and entered into the air heat transfer equation with the duct air flowrate (based on manufacturer specifications).

  Equation 3

$$Heat\ Delivered\ [BTU] = \frac{Fan\ Motor\ Runtime[seconds] * 1.08\ \left[\frac{Btu}{CFM * °F}\ per\ Hour\right] * Airflow\ Rate\ [CFM] * DelT_{Air}[°F]}{3600\ seconds\ per\ Hour}$$

The furnace gas valve current switch data record the on-off signals when the furnace burns fuel, to measure total fuel consumption by Equation 4:

  Total Fuel Consumed by the furnace can be calculated from the operation of the gas valve. Every second that the gas valve is open, the equipment receives its rated capacity of BTUs per Hour of natural gas to burn. The length of time that the furnace burns fuel is summed as Gas Valve Runtime over the monitored period and multiplied by the furnace's rated input capacity to find total fuel consumption.

  Equation 4

$$Total\ Fuel\ Consumed\ [BTU] = Gas\ Valve\ Runtime\ [seconds] * \frac{Furnace\ Input\ Capacity\ [BTU\ per\ Hour]}{3600\ seconds\ per\ Hour}$$

If so inclined, the overall thermal efficiency may be calculated from the known fuel consumed (Equation 4) and heat delivered (Equation 5):

Equation 5

$$Thermal\ Efficiency\ [\%] = \frac{Total\ Heat\ Delivered\ [BTU]}{Total\ Gas\ Consumed\ [BTU]} * 100\%$$

Lastly, it should be noted that the apartments were monitored from late-December 2017 through mid-March 2018, through some of the coldest days of the heating season, to observe a full range of cTTW behavior. Logger integrity and interim data checks occurred during site visits in mid-January and mid-February, prior to final data collection in mid-March. Because the study covers a unique period, any results or conclusions calculated from these data must be normalized to an accepted industry standard, such as heating degree days (HDDs). Thus, the outdoor weather data were used to calculate HDDs via Equation 6 and Equation 7:

- Heating Degree Days (HDDs) are a measure of “how cold” a particular day was compared to a 65°F desired temperature. The varying occupancy rates and events in each apartment affected the amount of comparable data between apartments. Normalizing one apartment’s fuel consumption over a defined period against that period’s cumulative HDDs allows for fuel consumption to be compared across different times and apartments. HDDs are calculated daily and summed over the whole monitoring period to find this normalizing factor. For reference, the Chicago area generally sees over 6,000 HDDs over the course of one year.

Equation 6

$$HDD\ [\text{on a given day}] = 65°\text{F} - \text{Average Outdoor Temperature}\ [°\text{F}\ ]$$

Equation 7

$$Cumulative\ HDDs\ [in\ a\ given\ time\ period] = \sum_{First\ Day\ of\ Monitoring}^{Last\ Day\ of\ Monitoring} Daily\ HDDs$$

Additionally, throughout the course of monitoring, some pitfalls in the data collection procedure became apparent. Standardizing protocols used to clean the experimental data across apartments for comparative purposes, and the notes associated with each, are described in Appendix D: Field Data Processing Notes. The two primary setbacks were from bleeding current and from installation-related condensate pipe freezing issues, as follows:

Bleeding Current Issues: The electrical power to the fan motors of some units would not cease completely. Thus, the current switches were constantly in the “on” state as long as the cTTW unit had a power supply. Unfortunately, troubleshooting did reduce the current trickle to below the 0.15 amp sensible threshold of the current switches, as shown in Figure 14 due to a naturally higher current draw when equipment is “on.” Of the original seven monitored apartments, five possessed a bleeding current characteristic, which prevented a robust calculation of thermal efficiencies across all apartments using true fan data.

Figure 14: Verification of Fan Motor Current during “On” Call in Apartments 102, 203, and 301

Unconditioned Utility Closet and Condensate Pipe Freezing Issue: The property managers learned of condensate pipe freezing in the non-conditioned utility closets, which caused some units to shut off temporarily. A local mechanical contractor resolved the freezing issue by drilling a hole of approximately 1.5" in the air supply duct to heat the mechanical closet, as shown in Figure 15. The location of the hole upstream of the air supply duct thermocouple measurement affected the captured Air Temperature Rise metric from all apartments, which may subsequently cause a slight underestimation of delivered energy efficiency of the cTTW units.

Figure 15: Utility Closet Air Supply Duct Hole, Observed in Apartments 102, 203, and 301 on January 12, 2018

Results and Discussion

Field and Practice Findings

The objectives of this study were to quantify gas savings compared to minimum-efficiency (80% AFUE) equipment, as well as measured thermal efficiency to condensing AFUE ratings, and to verify occupant comfort. Condensate management has been a pressing issue in condensing natural gas equipment. The market understanding has evolved over time and recognized the need to handle the condensate safely and effectively. The applications of condensate technologies bring unique challenges and needs to be evaluated for effective market penetration. The data provided by field pilot help to answer the following questions:

- What are the efficiency and deemed gas savings of high-efficiency equipment compared to baseline minimum-efficiency equipment (80% AFUE)?
- How cost-effective are the expected gas savings with respect to the reported incremental cost difference?
- Does this technology adequately maintain indoor temperatures for occupant comfort that are comparable to minimum efficiency equipment?
- What are the opportunities and challenges for the technology from observed contractor practices and/or standardization in the market?
- Has the industry resolved physical concerns related to exhaust venting and freezing?

Operating Efficiencies:

The overall performance of the cTTW units is summarized in Table 3. This performance was normalized using heating degree days. A calculated average Fuel Consumed per HDD ratio was 3,007 BTUs per HDD in steady-state, "automatic setting" operation (e.g., no occupant interference with the thermostat setting), as shown in Appendix B: Steady-State Gas Consumption Rate Calculations TableAppendix B: Steady-State Gas Consumption Rate Calculations Table. Only timeframes when the unit operated in heating mode were included in this energy analysis.

Because of the apartments with bleeding current, thermal efficiencies could only be estimated from true fan data from Apartment 102 and partial fan data from Apartment 101. A range of possible Heat Content (or thermal efficiencies, TE) delivered to the apartments was calculated by iterating over the range of manufacturer settings. The calculated thermal efficiencies of cTTWs ranged from 74% to 95% in first-floor apartments. The rated AFUE efficiencies of monitored cTTWs were 95%. The AFUE rated cTTWs efficiencies are at a single point and operating at full-load capacities. The furnaces are usually oversized for a designed condition. Thus, they tend to operate in part-load condition for majority of the heating season, far away from the AFUE tested condensing conditions. This results in operating efficiencies that are lower than the AFUE rated efficiencies. The field test confirmed the operating efficiencies of cTTWs to be lower than AFUE rated efficiencies.

However, the AFUE rated efficiencies are widely accepted in energy efficiency communities as well as for marketing products to consumers per DOE directives. Therefore, the economic and energy analysis performed in this section are based on the AFUE rated efficiencies of 95%.

Table 3: Energy Analysis and Temperature Results for Seven Apartments with Through-the-Wall Units

Apartment [#]	Facing Direction	Rated Capacity [Input Btu/Hr]	Total Fuel Consumed [Btu]	Total Measured Gas Valve Runtime [Hrs]	Total HDDs Observed	Explanation of Monitoring Period Discontinuities	Average Apartment Temperature [°F]	Average "Far" Temperature [°F]	Average 2nd Bedroom Temperature [°F]	Average Supply Temperature when running [°F]	Maximum Supply Temperature Observed [°F]
101	Southeast	22000	1,287,742	62.8	371.6	Unoccupied. Fan motor data logger failure to record after 2018-01-02.	71.5	70.0	N/A	98.4	108.0
			10,008,783	488.2	2874.4	Unoccupied. Exhaust temperature data logger disconnection after 2018-02-27.	70.8	69.0	N/A	92.9	118.5
102	Southwest	22000	9,391,050	458.1	3128.4	Unoccupied.	68.6	67.2	N/A	96.9	117.9
104	Northwest	22000	10,331,317	504.0	2814.0	Unoccupied. Fan logger shows manual shut-off 2018-03-12.	70.0	71.3	N/A	100.1	144.5
			417,175	20.4	167.8	Occupied as of move-in, 2018-03-15. Thermostat preference reduced from 70°F to 60°F.	67.1	67.6	N/A	95.3	108.7
201	Southeast	33000	6,710,467	216.5	3012.1	Unoccupied.	69.8	67.1	66.1	85.3	118.4
202	Southwest	33000	9,786,700	315.7	3082.8	Unoccupied.	72.8	70.8	69.2	90.3	128.2
203	Northeast	33000	7,888,467	254.5	2614.4	Unoccupied.	69.1	68.2	64.2	84.7	150.3
			500,650	16.2	112.4	Occupied as of move-in, 2018-03-15.	72.8	71.7	65.6	93.5	124.8
301	Southeast	33000	4,101,300	132.3	1891.6	Unoccupied. Gas logger shows manual shut-off 2018-02-26.	70.3	68.1	N/A	88.3	132.8
			444,850	14.4	300.7	Occupied as of move-in, 2018-03-01.	70.9	70.3	N/A	115.8	137.0
						Average Temperatures	70.4	69.0	66.5	92.1	
						Standard Deviation	1.34	1.58	2.50	5.93	

Economic Analysis:

A detailed economic analysis is presented in Appendix C: Savings Calculations Table. The accepted calculation for deemed savings (at 95% AFUE) gives the furnace a savings potential of 35 therms annually above minimal efficiency equipment (at 80% AFUE), or $16 annually, per unit. The price premium of $300 per cTTW unit from self-reporting manufacturers suggests that simple payback based on heating gas savings alone may approach 18+ years, about the same duration as the manufacturers' warranties on the units' heat exchanger.

Comfort Analysis:

The cTTW units maintained the temperature very well across all the monitored apartments. All monitored apartments had setpoint temperatures of 70°F. As shown Table 3, the average temperature near the thermostats in all apartments was 70.4°F. Similarly, the average temperature in the farthest point from thermostats was 69°F. The average supply air temperature was 92.1°F. The average supply temperature is a bit lower than the desired comfort temperature. However, the maximum supply air temperature is in the range of 108°F to 145°F, which is typical in forced air applications. The calculated average temperature accounts for supply air temperature during the purging cycle before and after the combustion.

Exhaust Grill Freezing Concerns:

Anecdotally, there were concerns with flue gas freezing on the exterior grill. The freezing of grill would invite unintended consequences to the safe and normal operations of cTTWs. As a part of the pilot study, GTI installed an exterior camera to record the exterior grill of a cTTW. Figure 16 shows a snapshot of an extreme low-temperature day. The snapshot confirms that there is no accumulation of ice on the exterior grill.

Figure 16: Still-frame from Nest Camera on January 1, 2018 at 14:23:45
Apartment 102 Exhaust visible for comparison with Process Plant Steam in Background

Condensate Management:

The best condensate management practices were not followed at the monitored host site. The cTTWs are housed in non-weatherized balcony closets. The building experienced many instances of cTTWs not operating due to condensate lines freezing when outdoor temperatures were extremely low. The specifying engineer and installing contractor resorted to a value engineering solution. The solution was to weatherize the closet by opening a small hole in the supply duct. This is an energy wasteful solution since in favorable outdoor conditions, the opening dumps the conditioned air uncontrollably. Figure 17 illustrates the value engineered condensate management approach.

Figure 17: Supply Duct – Left Picture: no hole to weatherize the closet; Right Picture: a small hole to weatherize the closet and mitigate the condensate freezing issues

Condensate Management Code Findings:

Resolving the condensate management issues associated with this technology is an opportunity for broader adoption. A portion of the Product Market component of this study is devoted to answering concerns about condensate management, such as:

- What are the code requirements for condensate management and their implications for new construction or retrofit replacement units?

Previous studies of codes and regulations have reviewed two nationally and internationally recognized model codes and standards bodies—the International Code Council (ICC) and the International Association of Plumbing and Mechanical Officials (IAPMO). These two standards often serve as the basis of state, county, and local codes. Per prior studies, general mechanical and plumbing codes regulate the disposal of condensate from fuel-burning appliances by neutralization or dilution, as well as placing restrictions on the drainage system materials. Provisions for condensate management may be in either a dedicated section of the code, with explicit mention of origin from fuel-burning appliances, or in sections that regulate the disposal of corrosive or indirect wastes. Notably, some (but not all) model codes differentiate between condensate from fuel-burning appliances and condensate from air-conditioning units. In the Chicago and Cook County, IL areas, Cook County generally references the State of Illinois and ICC models for plumbing, mechanical, and building codes, while the City of Chicago keeps a number of additional, supplemental code chapters for use within city limits.

Chicago's mechanical code also leaves room for interpretation, stopping just outside the boundary of equipment and deferring absolute remedies to a manufacturer's instructions for some equipment, primarily residential equipment. When codes defer to manufacturers' instructions for condensate management, variability is introduced. As seen in the monitored host site, the original installation did not address the condensate management per best practices. The approach taken by the host site to address the condensate management is not a prudent and energy efficient approach. Of the cTTW manufacturers' instructions analyzed in Table 4, most mention condensate management, but only one explicitly highlighted the treatment of condensate.

As manufacturers bring more condensing technologies to market, the energy efficiency program can help address condensate management best practices. One way to do this is by adopting codes to stipulate the effective means of safe and proper disposal of condensate management.

Table 4: Characterization of Installation Instructions Provided by cTTW Manufacturers, as of December 2018

Feature	Manufacturer				
	A	B	C	D	E
Explicit Distinction Between Flue and Coil Condensate Treatment or Installations					X
Explicit Distinction in Start-Up for Condensate			X		X
Implicit Distinction Between Flue and Coil Condensate in Treatment, Installation Instructions, or Diagrams		X	X	X	X
No Explicit Distinctions between Flue and Coil Condensate	X	X		X	
Explicit Condensate Maintenance Recommendations			X		
Add-Ons Available for Flue Condensate Management					X
Materials Available for Unspecified Condensate Management	X			X	X
Contains Conditioned Space/Freezing Warnings			X		X
Notes Additional General Condensate Safety Features		X			
Condensate or Vapor Hazards Mentioned in Flue Venting		X	X		
No Condensate or Vapor Hazards Mentioned in Venting	X			X	X
Offers Electric Heat Alternative	X	X	X	X	

State of cTTW Technology and Market Findings

The market for high-efficiency technology products is constantly in flux. The information obtained from interviews with multiple manufacturers, contractors, and developers for this study provided answers to the following questions:

- What are opportunities for contractor practices and/or standardization in the market?
- What is the current market penetration of these units?

Multiple manufacturers interviewed during this study referenced the highly competitive nature of the multifamily market, which is defined as a building type with 3 or more individual apartment units. Multifamily and condominium designs are often based on smaller spaces than homes, with lower load requirements that are adequately served by smaller, vertical packaged units. Within the past 5 years, Canadian markets have driven the leading edge of high-efficiency unit development because of the prospect of stricter codes and 90% minimum efficiency standards. As manufacturers anticipate and adapt to these impending regulatory shifts, they are capturing the early market shares and seeking additional markets that are a good fit for this more efficient technology.

The recent North American resurgence in demand for low operating cost, high-efficiency units has come mainly through the income-eligible and retirement-aged communities. The higher demand for cTTWs in these two sectors is due to available tax incentives for energy efficient buildings and the local need for dual-fuel buildings. The two (self-proclaimed) leading manufacturers also cite the densely-populated Ontario demographic changes, and the western Canadian petroleum industry booms as drivers for demand.

The new construction sector for low- and mid-rise developments has seen initial introductions in many U.S. cold climate regions, with some manufacturers reporting as much as 40% increase in 2018 from 2017 year's sales. Manufacturers also report steady upticks in willingness to retrofit with higher-efficiency models (to 80% AFUE from mid-70% AFUE), comprising 60% or more of sales volumes after 5 years of double-digit growth, particularly in the nascent hospitality chain markets. As U.S. DOE regulations are set to increase the minimum cooling-side efficiencies of packaged units to 11 EER in late 2019, cTTW manufacturers are increasingly targeting residential and light commercial retrofit and replacement opportunities for their available and evolving high-efficiency condensing technology product offerings. From a manufacturer's perspective, addressing challenges for this condensing technology category will involve solving both a push and a pull demand aspect of the market.

Consumer reactions to adoption of cTTW technology vary, and manufacturers thus far have pursued solutions on multiple levels. The traditional sales model in the industry relies on manufacturer sales to wholesalers, or representatives, who market the product to the builders, design engineers, and architects. To encourage more of a "pull" for the technology from end-users and tenants, some manufacturers wish to debunk decades-old concerns of condensate management, by designing fail-safe condensate trap heaters and additional condensate neutralizing device add-ons, or electric heat taps, based on customer feedback. Other strategies include efforts to simplify a high-efficiency product's design, components, and installation processes for the contractors, to improve the field troubleshooting and serviceability experience. Of the manufacturers interviewed, many hold to the principle of local decision-making by technically experienced wholesalers and are eager to hear "down the chain" of consumer feedback to improve their technical training and support offerings to ensure the technology category meets end-user needs.

Additionally, corporate outlook on the future of condensing technology, and building trends, drives multiple "pushes" in favor of high-efficiency TTW technology uptake. The most common frustration among manufacturers is the lukewarm reception or lack of reception by design engineers and architects to the piping needs of cTTW during the design phase of building planning. In support of technology development, the large internal research teams of the manufacturers attempt to stay ahead of diverse building code requirements and regional preferences (e.g., electric usage overtakes natural gas usage in non-midwestern states). Though the scope of this study did not include the cooling side of TTW technology, some manufacturers cited ongoing advancements in refrigeration design, and intend to improve refrigerant specifications in future iterations of cTTW products. The trend among manufacturers is to pursue higher efficiency in order to meet or exceed the top-down requirements of the future (e.g., nation-wide efficiency requirements).

Summary

The pilot study demonstrated that the operating efficiencies can be lower than the AFUE rated efficiencies. This is primarily due to part load and short cycling. The AFUE rating follows a single point test rather than the variable operation found in a real-world heating load situation.

A common manufacturer concern was how to overcome the confusion associated with the multitude of solutions to adequately address condensate freezing, installation, and drainage challenges. Condensate freezing became an issue in this pilot only because no condensate management practices were implemented. It is recommended that the specifying and installing contractor follow the manufacturers' recommended approaches for condensate management. The technology category would benefit from further observation and standardization of contractor practices to preempt ad hoc, patchwork solutions.

Further research on practical methods of retrofitting older units with high-efficiency replacement units is desired by manufacturers. Ongoing engagement with manufacturers in this technology category has suggested increased competition and cost premiums for the higher-efficiency product lines. The degree of product support varies across manufacturers, with some providing best-practices training specific to their products and others relinquishing that control to local contractors. While all manufacturers in this space offer various auxiliary structural components (e.g., louvers, wall sleeves) tailored to new construction applications, none have released plug-and-play, retrofit-ready solutions for existing buildings. Appendix E contains links to manufacturers' provided manuals, technical guides, and/or product specifications.

A recommended next-step is to obtain Energy Star qualification for this product category in multifamily applications to reach a critical mass of support. Energy Star labeling applies to condensing furnaces but such labeling is not applied at present to cTTWs, even though cTTWs have similar AFUE rated efficiencies as single residential furnaces in range of 90%+ AFUE ratings. Energy Star is widely known and associated with energy efficient products, and the inclusion of cTTWs to Energy Star would help further their adoption.

In Illinois, the TRM measure 4.4.40 Gas High Efficiency Single Package Vertical Air Conditioner addresses the cTTW product category. The official product name of cTTW per DOE guidelines is Single Package Vertical Air Conditioner. The measure stipulates savings per AFUE rated efficiencies, rather than operating efficiencies, to be consistent with other condensing product category class.

Nomenclature

Nomenclature	Term
AFUE	Annual Fuel Utilization Efficiency, a measure of equipment thermal efficiency
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
BTU or Btu	British Thermal Units
BPH	BTU per Hour
CFM	Cubic Foot per Minute
cTTW	Condensing Through-The-Wall Unit
DOE	Department of Energy
EER	Energy Efficiency Ratio
HDD	Heating Degree Day
IFGC	International Fuel Gas Code
IMC	International Mechanical Code
IPC	International Plumbing Code
IFC	International Fire Code
ICC	International Code Council
NFPA	National Fire Protection Association
IAPMO	International Association of Plumbing and Mechanical Officials
MBH	1,000 BTUs per Hour
OAT	Outdoor Air Temperature
TE	Thermal Efficiency
Therms	A common unit of measure for natural gas. 100,000 BTUs
TTW	Through-The-Wall Furnace/AC Pack
RH	Relative Humidity

Appendix A: References

1. Historical Heating Degree Days data. https://www.degreedays.net/. Last accessed 8/27/2018.
2. Heating Degree Days Calculated in the United States. https://en.wikipedia.org/wiki/Degree_day#United_States. Last accessed 8/27/2018.
3. Sensible Heat in Air-to-Air Heat Transfer. https://www.engineeringtoolbox.com/cooling-heating-equations-d_747.html. Last accessed 8/27/2018.
4. Natural Gas Energy Content (Btu to Therms). https://www.eia.gov/dnav/ng/ng_cons_heat_a_EPG0_VGTH_btucf_a.htm. Last accessed 8/27/2018.
5. People's Gas Natural Gas Cost Rates per therm. https://www.icc.illinois.gov/ags/pgarates.aspx. Last accessed 8/27/2018.
6. Bingham, L. (2015). Condensate Management (GTI Project No. 21809.2.1). Prepared for Utilization Technology Development Company.

Appendix B: Steady-State Gas Consumption Rate Calculations Table

Calculation	Value	Description
Sum of Gas Consumption across all apartments, in BTUs		
	1,287,742 BTU	Gas Consumption in Apartment 101, Period 1
+	10,008,783 BTU	Gas Consumption in Apartment 101, Period 2
+	9,391,050 BTU	Gas Consumption in Apartment 102, Whole Period
+	10,331,317 BTU	Gas Consumption in Apartment 104, Period 1
+	6,710,467 BTU	Gas Consumption in Apartment 201, Whole Period
+	9,786,700 BTU	Gas Consumption in Apartment 202, Whole Period
+	7,888,467 BTU	Gas Consumption in Apartment 203, Period 1
+	4,101,300 BTU	Gas Consumption in Apartment 301, Period 1
=	59,505,826 BTU	Total Gas Consumption in Steady-State Operation, in BTU
Sum of Heating Degree Days across all apartments, in HDDs		
	371.6 HDDs	HDDs in Apartment 101, Period 1
+	2874.4 HDDs	HDDs in Apartment 101, Period 2
+	3128.4 HDDs	HDDs in Apartment 102, Whole Period
+	2814.0 HDDs	HDDs in Apartment 104, Period 1
+	3012.1 HDDs	HDDs in Apartment 201, Whole Period
+	3082.8 HDDs	HDDs in Apartment 202, Whole Period
+	2614.4 HDDs	HDDs in Apartment 203, Period 1
+	1891.6 HDDs	HDDs in Apartment 301, Period 1
=	19,789.3 HDDs	Total HDDs, in Steady-State Operation
Normalized Fuel Consumption		
	59,505,826 BTU	Total Gas Consumption, Btus in Steady-State Operation
÷	19,789.3 HDDs	Total HDDs, in Steady-State Operation
=	3,007.0 BTU/HDD	Average Steady-State Gas Consumption per HDD

Appendix C: Savings Calculations Table

Calculation	Value	Description
Projected Annual Gas Consumption, in Btus		
	3007.0 BTu/HDD	Average Gas Consumption in 95% AFUE “condo pack”
x	6273 HDD	Annual HDDs observed at Chicago O’Hare International Airport Weather Station, 8/2017-7/2018
=	18,862,911 BTU	Annual Gas Consumption, in BTUs
Convert Btus to therms		
	18,862,911 BTU	Annual Gas Consumption
÷	99,976 BTU/therm	Natural Gas BTU-to-therm conversion rate
=	188.67 therms	Annual Gas Consumption, projected, in therms
Back-Calculate Heat Delivered at 95% AFUE		
	188.67 therms	Annual Gas Consumption, in therms
x	0.95	Rated High-Efficiency AFUE
=	179.24 therms	Annual therms necessary to maintain apartment temperature at 100% efficiency
Back-Calculate therms At 80% AFUE		
	179.24 therms	Annual therms necessary to maintain apartment temperature at 100% efficiency
÷	0.80	Efficiency of baseline furnace
=	224.05 therms	Annual therms consumption to maintain apartment temperature at 80% efficiency
Annual Therm Savings Potential Between 95% and 80% AFUE		
	224.05 therms	Annual therms consumption to maintain apartment temperature at 80% efficiency
-	189.87 therms	Annual Gas Consumption, projected, in therms
=	35.38 therms	Annual Therm Savings Potential

Calculation	Value	Description
Annual Monetary Savings Potential Between 95% and 80% AFUE		
	35.38	Annual Therm Savings Potential
x	$0.4549/therm	People’s Gas Prices, as of December 2018 *not including taxes
=	$16.09	Annual Savings Potential, per average apartment unit

Appendix D: Field Data Processing Notes

	Data Process	Applicable Where:	Description
1	Exclude Cooling Cycles	Calculated Air Temperature Rise was negative (i.e., air was cooler after passing through the cTTW unit)	If the air supplied by the Through-the-Wall furnace pack was cooler than the air returning to the furnace pack, then the unit was not circulating air for heating purposes during the monitored heating season. These timeframes were isolated via filtering the calculated DelTAir value for non-negative values only, which resulted in minimal data loss (~a few thousand seconds per apartment). These timeframes were excluded from energy analysis. These timeframes were included in temperature analysis.
2	Exclude Known Heating Interruptions	Equipment was shut down by external conditions	During the course of this study, the condensate lines of some units froze due to the choice of installation location. These timeframes were isolated via reporting by the property management office and duct supply air temperatures below 40°F. Majority of instances occurred in mid-January 2018. These timeframes were excluded from energy analysis. These timeframes were excluded from temperature analysis.
3	Separate Known Heating Setting Change or Disruptions	Human intervention or interference changed the unit's heating control settings	During the course of the study, management and tenants adjusted the equipment control settings. Patterns included: Residents lowering the temperature setpoint Residents manually making forced heating calls Management reducing fan operation to Auto in second-floor units on 1/17/2018 (First- and third-floor units were already in Auto.) These timeframes were isolated via reporting by the property management office and known resident move-in dates. These timeframes were partitioned and analyzed separately as shown in the results tables. These timeframes were included in energy analysis. These timeframes were included in temperature analysis.
4	Exclude Data Logger Collection Errors	Thermocouple data logger equipment showed signs of failure (e.g., unreasonably high/low measurements of exhaust air temperature)	Toward the conclusion of the data collection period, some sensors began to show wildly variable and unrealistic values, indicating monitoring equipment was approaching the end of its useful life. These timeframes were isolated via visual review and pinpointing on all thermocouple data streams. These timeframes were excluded from energy analysis. These timeframes were included in temperature analysis (which did not rely on the failed thermocouples).

Appendix E: Manufacturers Application Guide & Technical Specifications

1. **Magic-Pak**
   - Landing Page: http://www.magic-pak.com/products/v-series/hwc.asp
   - Application Guide: http://www.magic-pak.com/specification/application-guides.asp
   - Installation Guide: http://www.magic-pak.com/literature/installation-instructions/V-Series_HWC9_Install.pdf
2. **National Comfort Products:**
   - Information for Designers & Specifiers: http://www.nationalcomfortproducts.com/specifiersdesigners
   - Information for Contractors: http://www.nationalcomfortproducts.com/contractors
3. **Suburban Applied Products:**
   - Dynapack H Series – 95% TE: https://www.airxcel.com/docs/default-source/suburban/dynapack/suburban_dynapack_h_series_owners_manual_205096_10-29-18_rev-7.pdf?sfvrsn=68ba186b_4
   - Features: https://www.airxcel.com/docs/default-source/suburban/dynapack/dynapack_features_9-10.pdf?sfvrsn=8c5e0e6b_10
   - Architect's and Engineer's Manual: https://www.airxcel.com/docs/default-source/suburban/dynapack/suburban_dynapack_dypa_a-e_manual_rev_2.pdf?sfvrsn=7dd8026b_12
4. **Napoleon, Condo Pack:**
   - Installation Manual: http://condopack.com/docs/high/manuals/CondoPack-HighEff-Manual-June2018.pdf
   - Specification Document: http://condopack.com/docs/high/specifications/CondoPack-HighEff-TechSpec-June2018.pdf

END OF REPORT