NEXT-GENERATION BUILDING MECHANICAL SYSTEMS

HOW MANUFACTURERS CAN CAPTURE VALUE THROUGH INNOVATION IN MULTIFUNCTIONAL SYSTEMS

INSIGHT BRIEF

November 2018

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HIGHLIGHTS

- Rocky Mountain Institute's (RMI's) REALIZE initiative aims to catalyze zero carbon retrofits in the US affordable multifamily housing sector using an approach developed in the Netherlands by Energiesprong, a government-funded program that developed a standardized retrofit and funding approach for social housing.
- REALIZE calls for mechanical manufacturers to develop multifunctional, packaged, all-electric heating, ventilation, and air-conditioning (HVAC) and domestic hot water (DHW) equipment solutions to meet the growing demand in the multifamily housing sector for easy-to-install, retrofit-ready systems.
- REALIZE believes that consolidating the functions and operations of mechanical equipment will be essential as building control systems and grid-integrated design become more mainstream.
- The analysis found that there is potential to retrofit 16.1 million units of affordable and market rate multifamily housing in American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) climate zones 3, 4, and 5, with annual energy savings totaling as much as $4.3 billion.
- REALIZE determined the performance requirements, estimated energy savings, and value-based price points for these integrated HVAC and DHW systems. This analysis did not look at electric system upgrade costs or installation costs, in order to isolate the economics of the equipment only.

INTRODUCTION

On the path to decarbonizing the United States building stock, existing buildings present an enormous challenge: these buildings require energy upgrades that can be complicated, costly, and time-intensive due to their bespoke nature. These reasons often disincentivize building owners from doing anything above what is required to improve their buildings. Aside from reducing building owners' and tenants' operating expenses, addressing the amount of energy and type of fuel used in these buildings can dramatically reduce overall energy consumption in the United States and make significant progress toward reaching climate goals.

To address these issues in the multifamily buildings sector, Rocky Mountain Institute (RMI) is catalyzing the development of standardized, net-zero carbon retrofit packages through its REALIZE initiative. REALIZE's approach is based on a Dutch model known as Energiesprong that combines prefabricated exterior facade panels with an all-electric heating, ventilation, and air-conditioning (HVAC) module and rooftop photovoltaic (PV) panels to achieve net zero energy with minimal tenant and site disruption. In fact, many of these retrofits can be completed in less than a week without tenants having to leave their units.

A typical Energiesprong retrofit project (image courtesy of Energiesprong)

A row of Energiesprong retrofits (left) in the Netherlands (image courtesy of Energiesprong)

REALIZE aims to organize a similar retrofit model in the United States, starting with the affordable multifamily housing sector. REALIZE is targeting common multifamily building types in regions with a high density of multifamily housing to expedite the scaling of this approach. Although preliminary models will be for the affordable multifamily sector, REALIZE hopes to enable this retrofit methodology in the larger multifamily market, the single-family market, and potentially the small-to-medium commercial market segment.

Successful implementation of such a model requires the development of the right mechanical systems solution for these retrofits. The key to scaling across the greater US multifamily sector will be creating and commercializing HVAC and domestic hot water equipment solutions with the following characteristics:

- **Multifunctional:** The mechanical system solution should provide heating, cooling, ventilation, dehumidification, and domestic hot water. Additional functionalities, such as on-site PV consumption via an inverter and battery storage, are desired for the mechanical system as well.
- **Packaged:** The equipment used to meet the functional needs of the mechanical unit should be packaged together into one integrated system. This will allow for simpler installation and scalability.
- **All-electric:** As the grid becomes cleaner and policies begin to demand the use of clean energy in all sectors, deploying all-electric solutions will be the most impactful strategy for building retrofits. The Netherlands has already developed all-electric solutions as the country is phasing out natural gas use by 2050 in public housing. Similarly, large cities like Los Angeles, Vancouver, and New York City are currently considering creating electrification targets for buildings.

This insight brief (1) details the functional needs for such a system; (2) quantifies the multifamily market size for the proposed system in ASHRAE climate zones 3, 4, and 5; and (3) quantifies the potential energy and cost savings that such a system can provide across these climate zones. The analysis found that there is potential to retrofit 16.1 million units of affordable and market rate multifamily housing in ASHRAE climate zones 3, 4, and 5, with annual energy savings totaling as much as $4.3 billion. This market can be captured through manufacturer innovation, retrofit commitment from building owners, and policy support from cities and states.

THE TECHNOLOGY NEEDED

Given current policy trends, such as California's SB100, as well as the growing demand for net zero energy or passive house design, the decarbonization of heating systems through electrification will help pave the way for high-efficiency buildings. Heat pumps—one of the most efficient sources of electric heating—will become one commonly used solution, especially as the technology progresses and performs better in colder climates. We expect the integrated packages described in this report to be foundational not just for REALIZE, but for many other types of multifamily, single-family, and commercial buildings, for retrofits and new constructions alike. Developing the next generation of heating and cooling technologies that can be rapidly scaled will provide a market opportunity far beyond the affordable multifamily sector, enable manufacturers to stay ahead of policy trends, and help improve brand visibility for industry leaders.

To begin this transition, one technology that REALIZE would like to see deployed in retrofit solutions is a packaged, multifunctional, all-electric mechanical system that can be installed in each dwelling in a multifamily housing structure. Because of the all-electric project goal, high-efficiency heat pump technology will likely be leveraged in such systems. Details of the product specifications for the system type that REALIZE hopes to see utilized in retrofits across the multifamily sector are detailed in Table 1.

Table 1: Basis of design specifications for the desired mechanical system

SYSTEM COMPONENT	DESIGN CRITERIA
FUEL	All-electric
HEATING & COOLING SYSTEM	Air-to-air heat pump OR air-to-water heat pump with variable speed compressors and insulated pipes/ducts
REFRIGERANT	Low-global warming potential refrigerants
DEHUMIDIFICATION	Humidity control provided by an independent dehumidifier, or by humidity control integrated with the HVAC device (preferred)
VENTILATION & EXHAUST	Provided based on rates required in ASHRAE standard 62.2 or local code, whichever is more stringent
ENERGY RECOVERY	Energy recovery ventilator with at least 80% sensible heat recovery effectiveness
FILTRATION	Meets Minimum Efficiency Reporting Value (MERV) rating 13 minimum
DOMESTIC HOT WATER	Provided by heat pumps and integrated into space-conditioning heat pumps to capture waste compressor heat during cooling (preferred) OR stand-alone heat pump water heater
CONTROLS	Occupant controls allow tenants to control space temperature set points, fan speeds, and system modes

Combining all of these functions into one unit will allow for quicker installation times and reduce the information barrier that causes consumers to delay purchasing new mechanical equipment. Both of these results should help to increase market uptake and transform the retrofit market.

IIIIIIII STATE OF THE MARKET, UNITED STATES AND ABROAD

US MARKET

Several companies in the United States have already developed more efficient and compact heat pumps but have yet to package additional functions together to create an integrated mechanical solution. **As building controls and grid-integrated design become more mainstream, there will be a need to consolidate the functions and operations of mechanical equipment.** Without multifunctional, packaged, all-electric equipment products, meeting the needs of a clean-energy electricity grid will become increasingly difficult due to fragmented systems. There is currently no product available in the United States that incorporates heating, cooling, hot water,

dehumidification, ventilation, and heat recovery into a single system. There are, however, some integrated systems that include four out of five of the desired outputs. The three most common combinations of functions are:

- Energy recovery ventilator (ERV) with additional heating and/or cooling
- Air-to-air heat pump system providing heating, cooling, and ventilation
- Air-to-water heat pump system providing hydronic heating, cooling, and DHW

The following table summarizes the features offered by larger manufacturers in the United States:

Table 2: Combined mechanical systems available in United States

	HEATING	COOLING	VENTILATION	ERV	DEHUMIDIFICATION	DHW	SYSTEM TYPE
BUILD EQUINOX	✓	✓	✓	✓	✓		Conditioning ERV with heat pump core
TRANE	✓	✓	✓				Air-to-air heat pump
DAIKIN	✓	✓				✓	Air-to-water heat pump
MINOTAIR	✓	✓	✓	✓	✓		ERV with heat pump and dehumidifier
DANDELION ENERGY	✓	✓	✓			✓	Geothermal heat pump
AERMEC	✓	✓				✓	Air-to-water heat pump
GOODMAN	✓	✓	✓				Air-to-air heat pump
SPACEPAK	✓	✓	✓		✓		Air-to-water heat pump + air-handling unit
CHILLTRIX	✓	✓				✓	Small air-to-water ductless heat pump

Many of these products offer nearly all the functionality needed to meet REALIZE specifications, but there is a notable market shortcoming in that none of the products include both energy recovery ventilation and domestic water heating. Some larger companies, such as Panasonic, Daikin, and Mitsubishi, offer all the required products, but they do not package them into the same system. Across the US market, a clear opportunity exists to combine and package equipment into one unit.

In addition, it is important to note that the majority of the heat pump heating and cooling systems do not come in a size smaller than two tons, which is far more than the anticipated system size needed for one multifamily dwelling. In developing packaged solutions, manufacturers should also consider right-sizing their offerings to the lower loads of multifamily dwellings. In REALIZE's analysis, air-to-air heat pump systems could be sized as small as one-half to one-third of a ton. For

combination systems that include capacity for ventilation loads, capacities as low as 11,000 Btu/hr are sufficient. Manufacturers should update their product sizing offerings to respond to the fact that passive buildings, and even new construction, have much more robust thermal envelopes and lower air infiltration rates, which result in significantly lower load.

MARKETS ABROAD

Since 2013, Energiesprong has worked in the European market to develop mechanical system solutions that meet their projects' goals and can be deployed at scale. Mechanical system suppliers for Energiesprong projects include Factory Zero, Nilan, and Drexel und Weiss. All three of these manufacturers produce a so-called magic box that offers multiple functions in one packaged unit. Although these systems are well suited for a European climate, few packaged systems include dehumidification capabilities, which would be needed in a US product.

The following table summarizes the range of products and functions available in Europe:

Table 3: Mechanical systems available in Europe

	HEATING	COOLING	VENTILATION	ERV	DEHUMIDIFICATION	DHW	SYSTEM TYPE
FACTORY ZERO	✓	✓	✓	✓		✓	Energy module
NILAN	✓	✓	✓	✓		✓	Energy module
VIESSMAN	✓	✓				✓	Air source heat pump (ASHP)
DREXEL UND WEISS	✓	✓	✓	✓		✓	Energy module
DAIKIN	✓	✓				✓	ASHP
MITSUBISHI	✓	✓				✓	ASHP
ZEHNDER	✓	✓	✓	✓			Ground source heat pump
PANASONIC	✓	✓				✓	ASHP
SANDEN	✓	✓				✓	ASHP, CO_2 refrigerant

It is worth noting that many of the large mechanical system manufacturers, such as Mitsubishi and Zehnder, offer more complete heat pump solutions in Europe than they do in the United States. The two main options for expanding the availability of multifunction products in the United States are:

1. **Transfer existing products from outside the United States into the US market:** For larger companies that might have products similar to those required by the REALIZE model, work with US branches to get them UL listed and available in US markets. This option is most suited to solutions that can plug into existing HVAC and hot water heating infrastructure. For example, an air-to-water heat pump solution could integrate into existing hydronic systems commonly seen in ASHRAE climate zones 4 and 5.

2. **Invest in research and development to produce new products:** If existing technologies do not meet all the criteria needed or if the manufacturer is small, investing in research and development might be the best path to market. This will require more up-front investment; however, it will likely yield the highest-quality product.

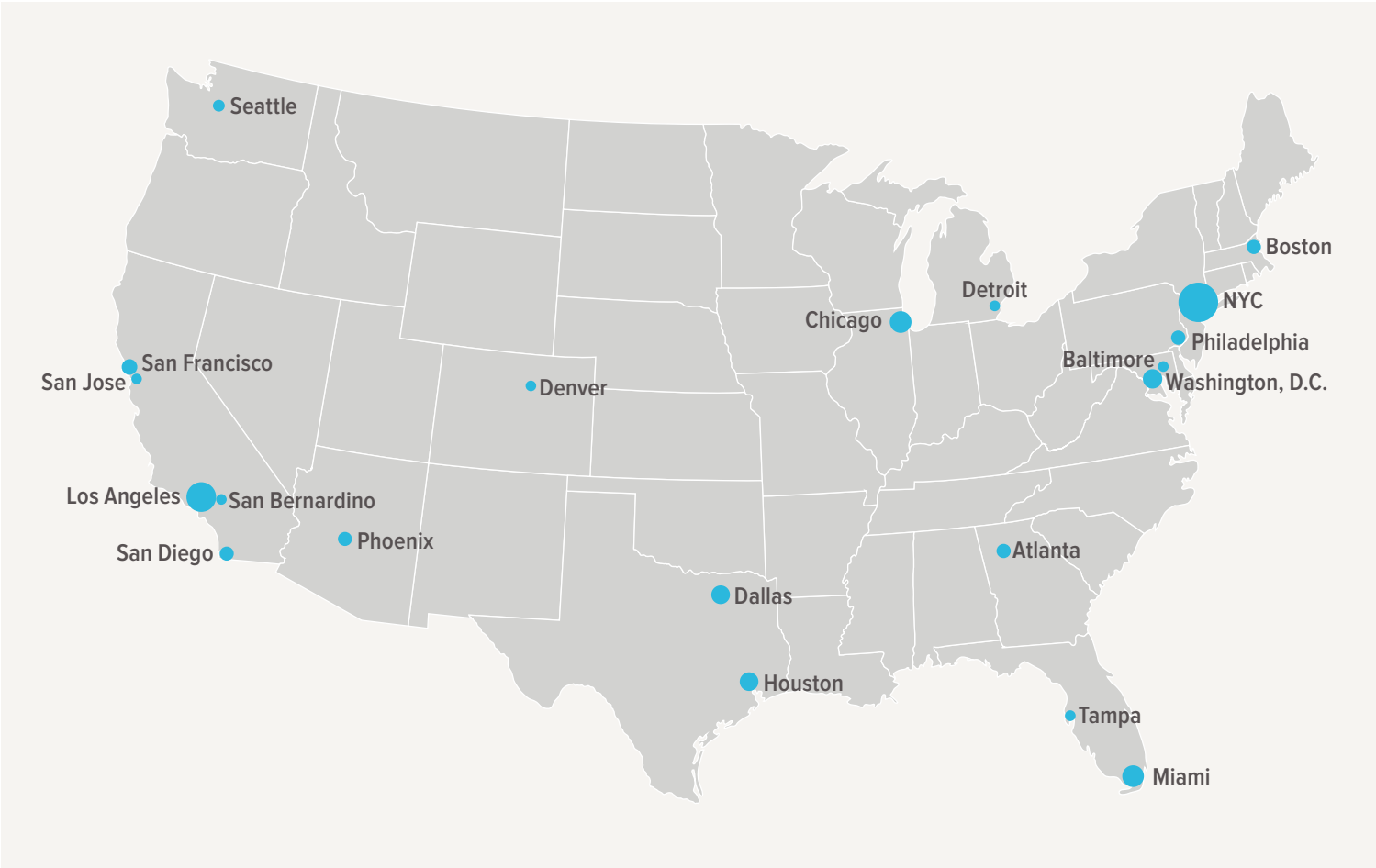
How manufacturers decide to pursue a path toward selling packaged, multifunction mechanical system products will depend on available resources, geographic presence, and the market demand for the technology.

US MARKET POTENTIAL

REALIZE quantified the potential market size for the mechanical systems described in the previous section and conducted an energy cost analysis to determine the economic value created by using these systems in regions with the highest populations in multifamily housing. Economic value, based on energy savings, is one way to consider pricing—it helps address the question, "How can the market support the cost of these combined systems?"[1]

To determine key regions to target, REALIZE used US census data to find cities with the largest populations living in multifamily buildings (see Figure 1).

Figure 1: Top 20 multifamily housing core-based statistical areas in the United States[3]



Overall, the top 20 cities by multifamily population represent approximately 12.8 million units out of a total of 21.1 million multifamily units across the United States (60% of units), with the largest densities of units located in New York City, Los Angeles, Chicago, and Dallas. The team took these cities as representative cases for ASHRAE climate zones 3, 4, and 5 and ran an analysis of potential energy savings that were likely to be observed from a REALIZE retrofit across those regions. **Expanding the analysis to these regions, and not just to the cities, resulted in a total of 16.1 million units that could potentially be candidates for REALIZE retrofits using integrated heat pump technology.**

REALIZE used the analysis to determine a range of economic value for the proposed mechanical system based on the estimated energy cost savings across the 16.1 million units in those regions. REALIZE modeled a typical multifamily building in each of the top four representative cities before and after a REALIZE retrofit to determine cost savings. Details of the modeling parameters applied to a typical three-story, 15-unit multifamily building are illustrated in Tables 4 and 5.

Table 4: Envelope upgrades in cool and mixed climates (representative cities: Chicago, New York City)

	EXISTING CONDITIONS		AFTER RETROFIT	
	COOL	MIXED	COOL	MIXED
WALLS	R-4.3		R-32.3	R-24.3
ROOF	R-14		R-42.1	R-38.1
FLOOR TO UNHEATED BASEMENT	R-4.1		R-23.2	R-13.9
WINDOWS (U-VALUE)	0.76		0.26	0.26
WINDOWS (SOLAR HEAT GAIN COEFFICIENT [SHGC])	0.76		0.41	0.35

Table 5: Envelope upgrades in warm and hot climates (representative cities: Los Angeles, Dallas)

	EXISTING CONDITIONS		AFTER RETROFIT	
	WARM	HOT	WARM	HOT
WALLS	R-3.1	R-3.2	R-10.8	R-10.8
ROOF	R-20.9		R-20.9	R-14
FLOOR TO UNHEATED BASEMENT	R-3.3		R-13.8	R-13.8
WINDOWS (U-VALUE)	1.22		0.25	0.25
WINDOWS (SHGC)	0.86		0.27	0.27

The mechanical upgrades were consistent for all climates. Although four different existing heating systems were considered, all other equipment upgrades were constant, as described in Table 6. The existing air-conditioning (A/C) system was not varied across the regions as efficiencies and replacement costs are fairly consistent across most in-unit system types.

Table 6: Mechanical upgrades all climates

	EXISTING		RETROFIT	
SYSTEMS	TYPE	EFFICIENCY	TYPE	EFFICIENCY
DOMESTIC HOT WATER HEATER	Natural gas, in unit	75%	Heat pump, in unit	2.25 Coefficient of performance (COP)
COOLING	Central unit A/C	Energy Efficiency Ratio (EER): 11 (COP equivalent of 3.22)	Air-source heat pump	2.5 COP heating 4 COP cooling
HEATING	Boiler, natural gas	75%		
	Boiler, fuel oil	65%		
	Electric resistance	100%		
	Furnace, natural gas	80%		

The analysis enabled the determination of the present value of overall energy cost savings, which in turn represents REALIZE's retrofit project cost target. The cost target is arrived at by assuming that energy cost savings are leveraged into a financing package. It was assumed that 30% of the total retrofit project costs would be spent on mechanical systems and would therefore be the hypothetical price limit that manufacturers would need to reach for the integrated heat pump system to be cost-effective.

Thus, the value-based price point (e.g., the upper bound for pricing of these systems based on economic value) for the integrated heat pump heating system came to between **$8,000 and $9,500 per unit.** This is between **$2,300 and $3,800 per unit** greater than a business-as-usual mechanical system retrofit cost of approximately $5,700. These costs are detailed in Table 7.

Table 7: Business-as-usual mechanical system equipment costs*

ITEM DESCRIPTION	COST PER UNIT
ASHP, Seasonal energy efficiency ratio (SEER) 18, 9.3 Heating seasonal performance factor	$2,900
Heat pump water heater, 50 gal.	$1,100
ERV	$700
Dehumidifier	$1,000
Total business-as-usual cost	$5,700
Incremental potential cost of proposed unit based on economic value	$2,300–$3,800
Cost threshold for proposed unit based on economic value	$8,000–$9,500

*Equipment costs only. Installation and potential electrical upgrade costs not included. REALIZE acknowledges that the excluded costs can, in some cases, be significant. However, they have been excluded because this analysis aims to isolate the actual equipment value-based price points for mechanical manufacturers.

REALIZE assumes that until manufacturers are able to scale up production, this price point might not be achievable. Energiesprong has observed cost reductions for mechanical systems of around 70% over the past five years. These cost reductions, as observed by Energiesprong, can be achieved in several ways:

- **Standardized factory manufacturing:** Ideally, all of the component parts will come from one supplier and will be designed to enable an assembly line-style manufacturing process. Custom designed parts that fit together for quick assembly will reduce production costs for the manufacturer.
- **Reduced installation costs:** As contractors and designers become more familiar with this type of technology, installation and electrical system upgrade costs will likely come down. Additionally, system variations can be pre-integrated and designed to dovetail with common types of existing infrastructure, which can further reduce installation costs. Ideally, smaller system sizes could allow for existing electrical capacity to be adequate for these technologies, thereby eliminating the need for electrical panel upgrades.
- **Mass procurement through demand aggregation:** Once products have been developed, manufacturers should work with large portfolio owners to ensure that high demand for their products is secured. Partnering with REALIZE could provide one such avenue for demand aggregation. REALIZE will be working to aggregate demand in the market and hopes to see mechanical costs drop by 70%, as they did in the Netherlands over the first five years of the Energiesprong program.

POTENTIAL IMPACT OF TECHNOLOGY DEPLOYMENT

Overall, the potential impact of these packaged, multifunctional, all-electric systems at the manufacturer, building-occupant, and regional levels is significant. REALIZE estimates the total annual energy cost savings potential for the 16.1 million affordable and market rate units in climate zones 3, 4, and 5 that the initiative is targeting to be around $4.3 billion annually. These cost savings can be translated into revenue opportunities for manufacturers when energy cost savings are used to finance these systems. This market opportunity does not even account for potential deployment in single-family or commercial applications, which could have even more significant energy and energy cost savings.

In addition to the financial benefits, retrofitting buildings with multifunctional systems, starting with the affordable housing sector, will deliver marked improvements to occupant comfort, health, and general quality of life. When installed in buildings that have received deep envelope improvements, these systems will provide the resiliency benefit of longer performance during power outages. Pairing these low-energy mechanical systems with PV and a smart inverter can even allow the systems to function during outages. Without the combustion of natural gas in units so equipped, occupants will be less likely to be exposed to potentially dangerous levels of pollutants. All-electric buildings, when paired with PV, a smart inverter to enable self-consumption, and controls, can also provide grid interactivity that can reduce peak demand on the electric grid and curtailment of power from variable renewable energy sources.

CALL TO ACTION

Building owners, policymakers, and manufacturers should take a number of actions to promote the development of packaged, multifunctional mechanical systems:

1. **Building owners** must boldly commit to implementing all-electric, deep energy retrofits for their properties to ensure equipment manufacturers will have demand for their products.
   - A large amount of committed demand will give manufacturers the opportunity to make packaged systems at lower costs and introduce existing systems from other geographies.
2. **Policymakers** must support the process of introducing new technologies in the United States.
   - Promote building electrification and facilitate research and development activities so that equipment manufacturers can develop advanced, electric heating systems.
   - Provide energy-efficiency incentives for packaged, multifunctional all-electric mechanical systems that can serve as gap financing until manufacturing processes are fully mature and can deliver at cost.
3. **Manufacturers** must develop new technologies or introduce existing products into the US market.
   - Many manufacturers already offer the types of products required for these retrofits in foreign markets. Once these products are made available in the United States, these retrofits will be much simpler and more cost-effective.
   - An opportunity also exists for manufacturers to enter this market with newly developed technology if they invest in research and development now.

REALIZE hopes to help guide this concerted effort in the market to ensure that all parties collaborate with one another. The time to act on building energy retrofits is now, and through the development of packaged, easily deployable systems, mechanical manufacturers can help facilitate these retrofits.

RMI would like to thank the following key contributors:
Shannon Allison (Integral Group)
Sean Armstrong (Redwood Energy)
Jordan Dentz (The Levy Partnership)
Stefan Gracik (Integral Group)
Evan Hollas (Taitem Engineering)
Jasper van den Munckhoff (Energiesprong)

ENDNOTE

[1] Installation or existing condition modification costs were considered out of scope for this analysis.