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ENGINEERING

LIFE CYCLE COST
OF SMALLER, HIGHER EFFICIENCY PACKAGED ROOFTOP UNITS

310 W. 20th St., Ste. 200, Kansas City, MO 64108 816-997-9601 DialecticEng.com

INTRODUCTION

Purchasing smaller packaged rooftop equipment to serve a space can be one of the bigger expenses on a project. Owners, property managers and other project partners are often unsure which type of equipment best suits their business and space.

Beyond the initial purchase cost, there are other considerations such as energy usage, efficiency, equipment availability, owner requirements and engineer recommendations that help decide what equipment to purchase. To say there are many factors to consider is an understatement.

When comparing the additional cost for a higher or premium energy efficiency the question is: What economic benefit is there to going with a higher efficiency rooftop unit?

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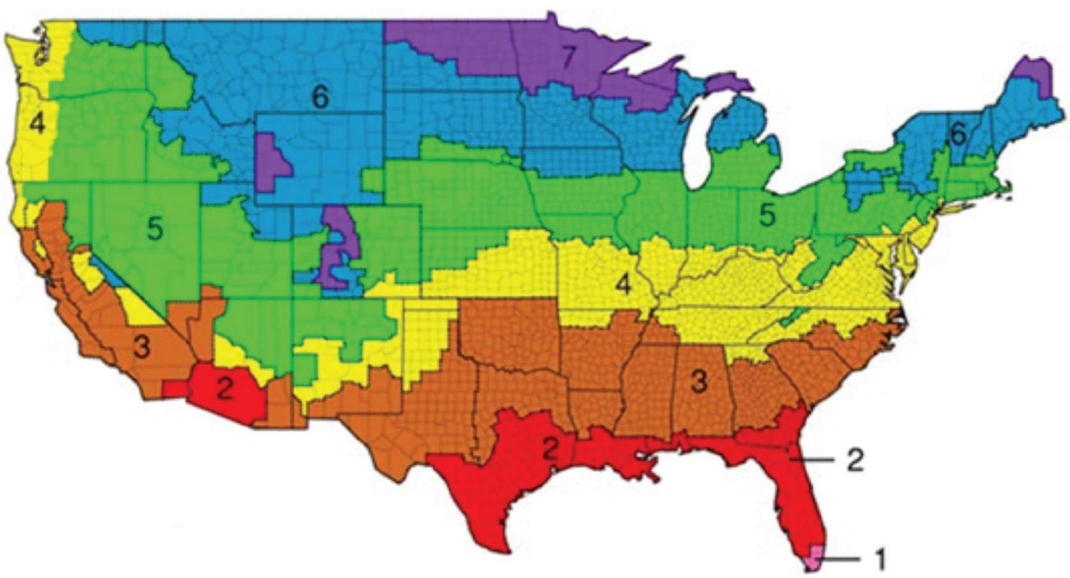
Cover Photo: Nikki R. Probert

For this paper we performed a life cycle cost analysis (LCCA) for smaller natural gas heat and electric heat rooftop units to determine relative economic benefits for stepping up to high and ultra-high efficiency rooftop units, using manufacturer standard efficiency units as a baseline.

Our LCCA used a 30-year life cycle cost for payback time to cover the additional cost premiums for rooftop units. For this comparison we used 6 ton, 12.5 ton, and 20 ton units. Included in this comparison is general information about HVAC equipment costs and options available for standard, high efficiency and ultra-high efficiency units. Results are based on fuel types, equipment efficiencies and purchase costs.

For our analysis we selected representative cities of general interest in seven climate zones. This analysis is for general information to begin a conversation regarding the relative merit of choosing higher efficiency equipment over today's standard efficiency equipment.

Our LCCA began with an energy model. We decided to use a square, single-story building having four exposures (north, south, east and west) that is compliant with the 2015 International Energy Conservation Code (IECC) climate zones 1-7.



All of Alaska in Zone 7
except for the following
Boroughs in Zone 8.

Bethel
Dellingham
Fairbanks N. Star
Nome
North Slope

Northwest Artic
Southeast Fairbanks
Wade Hampton
Yukon–Koyukuk

Zone 1 includes
Hawaii, Guam,
Puerto Rico,
and the Virgin Islands

US climate zones as referenced in IECC and ASHRAE 90.1

Energy Model Input Data

We used the following data points for our energy model:

Internal loads of 1.26 W/ft² (2015 IECC Building Area Method) for retail lighting, 0.25 W/ft² for equipment loads, and 67 ft²/person having a sensible load of 245 Btu/hr/person and latent load of 205 Btu/hr/person.

The **building envelope** construction complies with climate zone-specific energy standard ASHRAE 90.1 2013 (similar to 2015 IECC) requirements for:

- Steel-framed exterior walls and fixed metal-framed windows
- Exterior wall heights are 16 feet
- 15% window area on each exposure, resulting in 27% glazing of the wall exposure below a 9-foot ceiling
- Roofs insulated entirely above deck

Proper size of the unit in relation to the space is very important in helping support unit efficiency. **Cooling efficiencies** of rooftop units were obtained from equipment manufacturers and used in the energy model simulations. They are listed in the tables below.

Cooling Efficiencies (EER) – NATURAL GAS Heat Rooftop Units						
	Manufacturer A			Manufacturer B		
	Standard efficiency	High efficiency	Ultra-High efficiency	Standard efficiency	High efficiency	Ultra-High efficiency
6 ton	11.2	12.2	13.1	11.2	13.1	12.8
12.5 ton	10.8	12.1	12.4	11	12.1	12.4
20 ton	11.7	13.2	14.0	12.4	14.0	–

Manufacturer B did not produce 20 ton ultra-high efficiency units.

Cooling Efficiencies (EER) – ELECTRIC Heat Rooftop Units						
	Manufacturer A			Manufacturer B		
	Standard efficiency	High efficiency	Ultra-High efficiency	Standard efficiency	High efficiency	Ultra-High efficiency
6 ton	11.0	12.0	13.0	11.2	13.1	13.0
12.5 ton	10.8	12.1	12.4	11.0	12.1	12.4
20 ton	9.8	12.0	12.0	10.0	11.0	–

Manufacturer B did not produce 20 ton ultra-high efficiency units.

Rooftop unit economizers promote HVAC energy savings where they are applicable. An economizer promotes saving money by taking cooler outdoor air when it isn't too hot or humid, and blowing it into the space to do cooling with little to no refrigerant compressors operating to cool the air. This is called free cooling, though it isn't entirely free as the unit fan must still operate to blow air into the space to cool it.

We compiled the following economizer options used in the load analysis and they are based on 2015 IECC, Table C403.3.3.3.

Climate Zone	Location	Economizer
1a	Honolulu, Hawaii	Dry bulb economizer, off when outside air > 65° F
2a	Tallahassee, Florida	Dry bulb economizer, off when outside air > 65° F
3a	Oklahoma City, Oklahoma	Dry bulb economizer, off when outside air > 65° F
4a	Kansas City, Missouri	Dry bulb economizer, off when outside air > 65° F
5a	Omaha, Nebraska	Dry bulb economizer, off when outside air > 70° F
6b	Helena, Montana	Dry bulb economizer, off when outside air > 75° F
7	Anchorage, Alaska	Dry bulb economizer, off when outside air > 75° F

Life Cycle Cost Methodology

There are different life cycle methodologies and each have their merit. For our LCCA we used a net present value (NPV) method to perform the first cost, annual electric and natural gas cost calculations using fuel prices at reasonable inflation escalation rates.

The NPV method takes the sum of all future cash flows and converts their values into present-day dollars. The present dollars are used to contrast considered energy comparisons between the different equipment efficiencies and costs. For example, $100 today might be "worth" $98 next year if inflation over that period was 2%. Future cash flows are calculated as annual energy cost savings with inflation. Miscellaneous costs are assumed to be the same regardless of efficiency of the equipment. This cash flow is then discounted back into present-day dollars based on the designated discount rate. The break-even point, or payback time, is the time in the future when the additional cost for the chosen premium efficiency unit matches future energy cash flow savings when discounted to present day dollar values. We used a discount rate of 3.5%.

Our NPV methodology assumes a 15-year life for the rooftop units as listed in 2015 ASHRAE Applications, Table 4. At 15 years new equipment was added to continue the calculation to the 30-year mark. It is not likely systems extending beyond the 15-year standard life expectancy would be pursued for most projects, but in some rare cases, a 20-year life cycle may be considered.

Table 4 Comparison of Service Life Estimates

	Median Service Life, Years			Median Service Life, Years			Median Service Life, Years	
Equipment Item	Abramson et al. (2005)	Akalin (1978)	Equipment Item	Abramson et al. (2005)	Akalin (1978)	Equipment Item	Abramson et al. (2005)	Akalin (1978)
Air Conditioners			**Air Terminals**			**Condensers**		
Window unit	N/A*	10	Diffusers, grilles, and registers	N/A*	27	Air-cooled	N/A	20
Residential single or split package	N/A*	15	Induction and fan-coil units	N/A*	20	Evaporative	N/A*	20
Commercial through-the-wall	N/A*	15	VAV and double-duct boxes	N/A*	20	**Insulation**		
Water-cooled package	>24	15	**Air washers**	N/A*	17	Molded	N/A*	20
Heat pumps			**Ductwork**	N/A*	30	Blanket	N/A*	24
Residential air-to-air	N/A*	15[b]	**Dampers**	N/A*	20	**Pumps**		
Commercial air-to-air	N/A*	15	**Fans**	N/A*		Base-mounted	N/A*	20
Commercial water-to-air	>24	19	Centrifugal	N/A*	25	Pipe-mounted	N/A*	10
Roof-top air conditioners			Axial	N/A*	20	Sump and well	N/A*	10
Single-zone	N/A*	15	Propeller	N/A*	15	Condensate	N/A*	15
Multizone	N/A*	15	Ventilating roof-mounted	N/A*	20	**Reciprocating engines**	N/A*	20
Boilers, Hot-Water (Steam)			**Coils**			**Steam turbines**	N/A*	30
Steel water-tube	>22	24 (30)	DX, water, or steam	N/A*	20	**Electric motors**	N/A*	18
Steel fire-tube		25 (25)	Electric	N/A*	15	**Motor starters**	N/A*	17
Cast iron	N/A*	35 (30)	**Heat Exchangers**			**Electric transformers**	N/A*	30
Electric	N/A*	15	Shell-and-tube	N/A*	24	**Controls**		
Burners	N/A*	21	**Reciprocating compressors**	N/A*	20	Pneumatic	N/A*	20
Furnaces			**Packaged Chillers**			Electric	N/A*	16
Gas- or oil-fired	N/A*	18	Reciprocating	N/A*	20	Electronic	N/A*	15
Unit heaters			Centrifugal	>25	23	**Valve actuators**		
Gas or electric	N/A*	13	Absorption	N/A*	23	Hydraulic	N/A*	15
Hot-water or steam	N/A*	20	**Cooling Towers**			Pneumatic	N/A*	20
Radiant heaters			Galvanized metal	>22	20	Self-contained		10
Electric	N/A*	10	Wood	N/A*	20			
Hot-water or steam	N/A*	25	Ceramic	N/A*	34			

*N/A: Not enough data yet in Abramson et al. (2005). Note that data from Akalin (1978) for these categories may be outdated and not statistically relevant. Use these data with caution until enough updated data are accumulated in Abramson et al.

First cost comparisons for rooftop unit equipment is the premise of this evaluation. It is the cost difference between the standard efficiency unit and the high efficiency unit, and between the standard efficiency unit and the ultra-high efficiency unit, that must be overcome over the life of the unit with energy efficiency money saved to determine whether there is a rate of return or payback for the additional cost. Otherwise there is no hypothetical monetary incentive to purchase a higher efficiency option.

Manufacturers' cost of HVAC equipment is always changing. To be able to provide a 30-year analysis we used **cost-percentage increases** for each manufacturer over the baseline standard efficiency units as shown below.

Cost Comparison – NATURAL GAS Heat Rooftop Units				
	Manufacturer A		Manufacturer B	
	High efficiency cost increase	Ultra-High efficiency cost increase	High efficiency cost increase	Ultra-High efficiency cost increase
6 ton	16.7%	31.6%	35.4%	74.3%
12.5 ton	12.8%	21.7%	17.7%	24.2%
20 ton	5.1%	18.6%	12.4%	–

Manufacturer B did not produce 20 ton ultra-high efficiency units.

Cost Comparison – ELECTRIC Heat Rooftop Units				
	Manufacturer A		Manufacturer B	
	High efficiency cost increase	Ultra-High efficiency cost increase	High efficiency cost increase	Ultra-High efficiency cost increase
6 ton	30.2%	44.5%	35.6%	64.7%
12.5 ton	22.1%	66.3%	35.6%	66.8%
20 ton	10.1%	11.3%	29.9%	–

Manufacturer B did not produce 20 ton ultra-high efficiency units.

Annual natural gas and electric costs were calculated based on energy usage obtained directly from the energy model program, which uses approximate state utility rates.

Fuel prices are always a concern and fluctuate due to environmental factors and other things beyond anyone's control. To determine the **annual fuel escalation rates** for our LCCA, we started with initial utility rates obtained from the Energy Information Administration (EIA) 2015 average commercial sector prices listed below.

Climate Zone	Location	2015 EIA Rates	
		Natural Gas ($/MCF)	Electricity ($/kWh)
1a	Honolulu, Hawaii	31.17	0.2693
2a	Tallahassee, Florida	10.92	0.095
3a	Oklahoma City, Oklahoma	8.12	0.0768
4a	Kansas City, Missouri	8.87	0.101
5a	Omaha, Nebraska	6.4	0.0867
6b	Helena, Montana	8.13	0.1023
7	Anchorage, Alaska	8.01	0.1744

Then, we designed a formula to incorporate the yearly fuel price escalation rates from the U.S. Department of Commerce, Energy Price Indices and Discount Factors. The results were generated based on energy model results, energy rates and included first cost and replacement costs. Our LCCA uses a conservative price escalation rate of 4%.

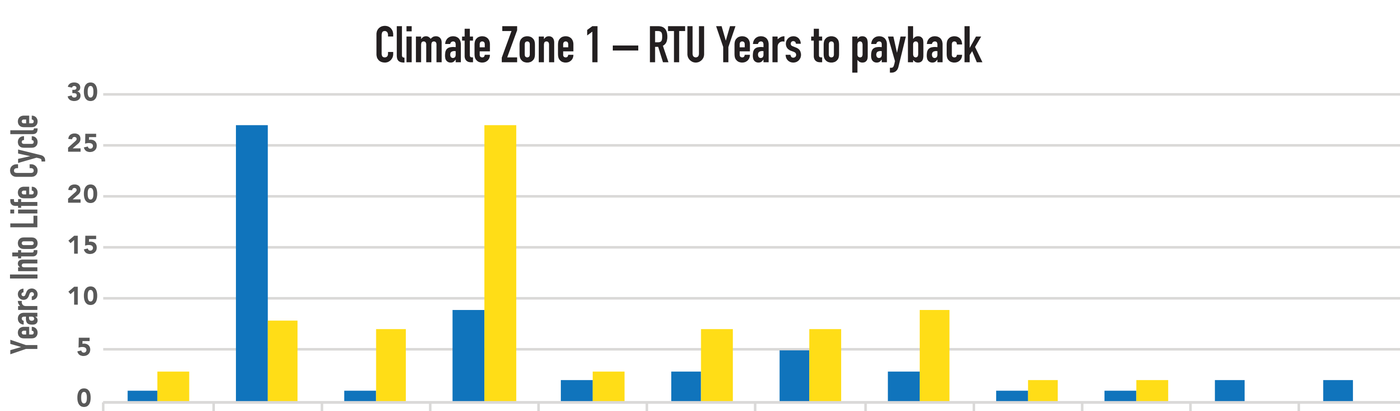
Analysis Results

The following charts show life cycle cost returns for gas and electric heat rooftop units for the 6 ton, 12.5 ton, and 20 ton units, where applicable.

Paybacks of 30 years in the charts below indicate a return greater than 30 years, which is the extent of the LCCA. To help find a payback, the range of the data was extended to 30 years to allow for a longer period for more time to result in savings. Unfortunately, for some equipment the payback never occurs due to the initial cost being so high that the energy saved cannot produce a payback without including replacement units in the calculation at some point or at least at the 15-year mark. At the juncture where replacement need to be added, newer technologies will likely be available resulting in better savings and a new analysis would be performed.

Additional factors beyond results to consider

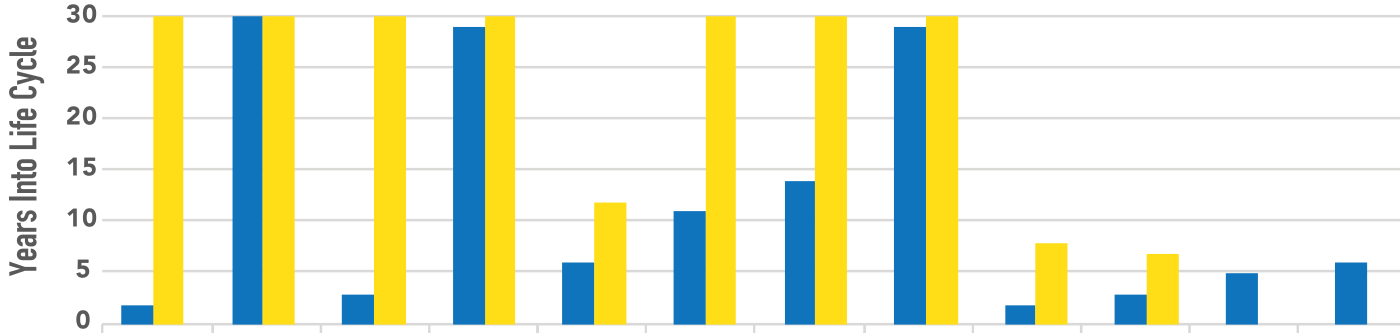
- Installation and maintenance costs were not factored into our analysis as these costs were assumed to be similar between manufacturers.
- Salvage costs were assumed to be $0 for equipment at the end of its life cycle.



	6 ton High Eff. (Gas Heat)	6 ton High Eff. (Elec. Heat)	6 ton Ultra-High Eff. (Gas Heat)	6 ton Ultra-High Eff. (Elec. Heat)	12.5 ton High Eff. (Gas Heat)	12.5 ton High Eff. (Elec. Heat)	12.5 ton Ultra-High Eff. (Gas Heat)	12.5 ton Ultra-High Eff. (Elec. Heat)	20 ton High Eff. (Gas Heat)	20 ton High Eff. (Elec. Heat)	20 ton Ultra-High Eff. (Gas Heat)	20 ton Ultra-High Eff. (Elec. Heat)
Manufacturer A	1	27	1	9	2	3	5	3	1	1	2	2
Manufacturer B	3	8	7	27	3	7	7	9	2	2	–	–

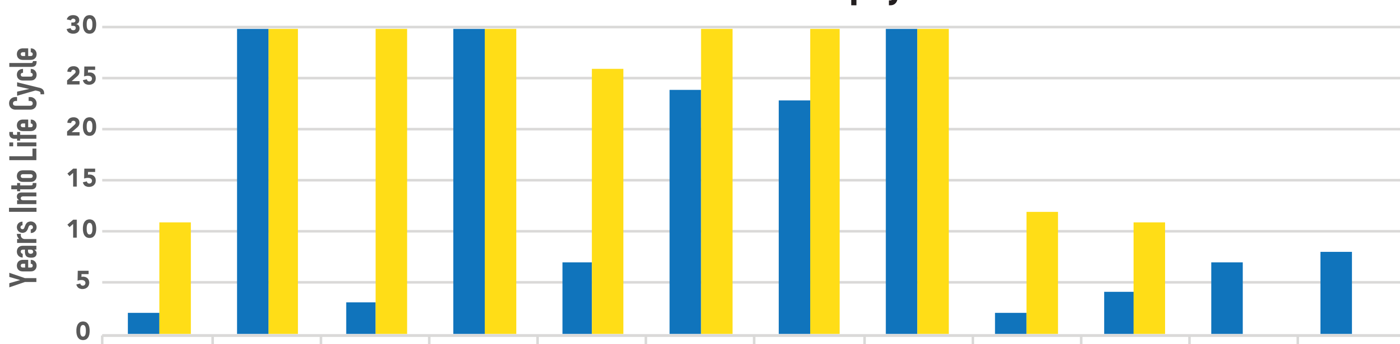
Analysis Results continued

Climate Zone 2 – RTU Years to payback



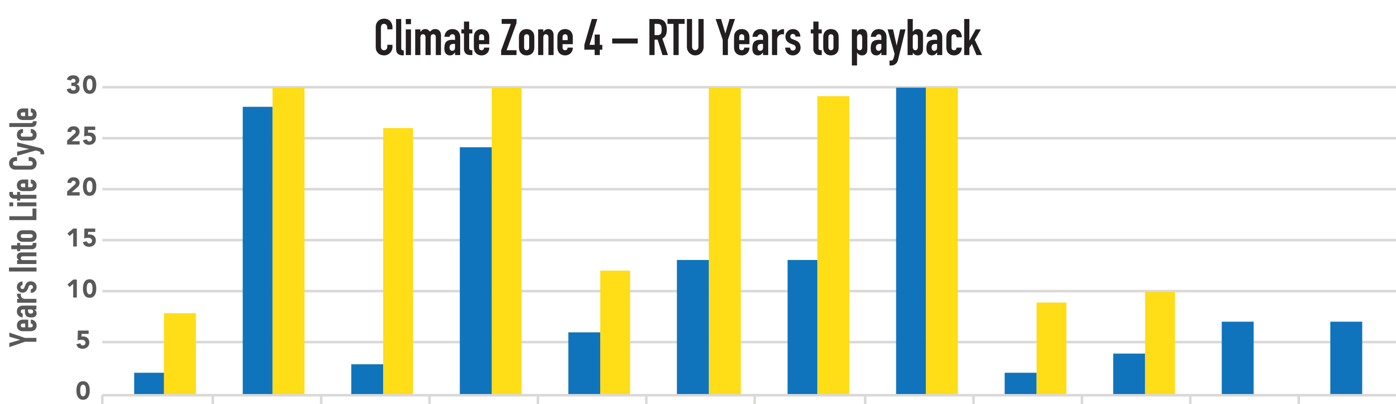
	6 ton High Eff. (Gas Heat)	6 ton High Eff. (Elec. Heat)	6 ton Ultra-High Eff. (Gas Heat)	6 ton Ultra-High Eff. (Elec. Heat)	12.5 ton High Eff. (Gas Heat)	12.5 ton High Eff. (Elec. Heat)	12.5 ton Ultra-High Eff. (Gas Heat)	12.5 ton Ultra-High Eff. (Elec. Heat)	20 ton High Eff. (Gas Heat)	20 ton High Eff. (Elec. Heat)	20 ton Ultra-High Eff. (Gas Heat)	20 ton Ultra-High Eff. (Elec. Heat)
Manufacturer A	2	30	3	29	6	11	14	29	2	3	5	6
Manufacturer B	30	30	30	30	12	30	30	30	8	7	–	–

Climate Zone 3 – RTU Years to payback

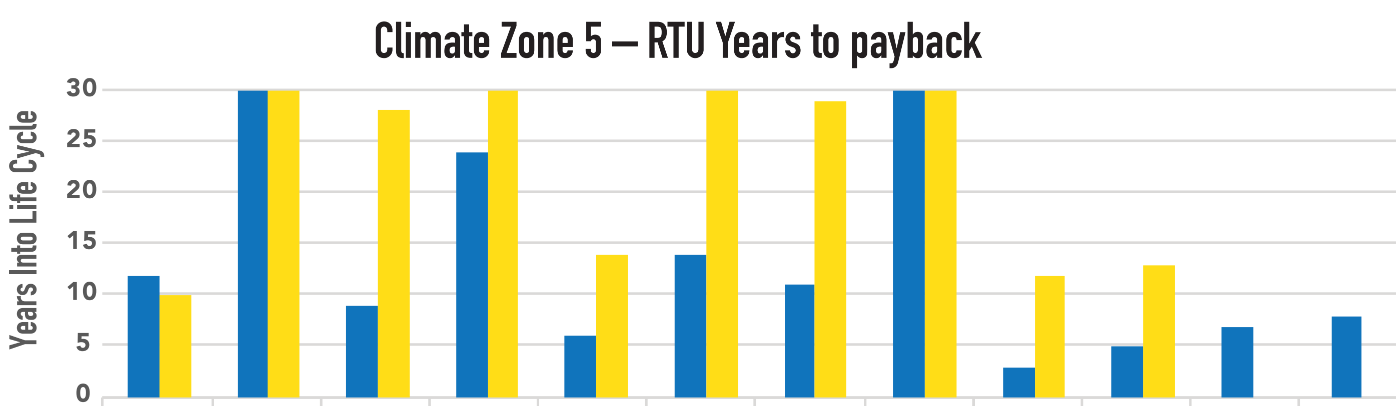


	6 ton High Eff. (Gas Heat)	6 ton High Eff. (Elec. Heat)	6 ton Ultra-High Eff. (Gas Heat)	6 ton Ultra-High Eff. (Elec. Heat)	12.5 ton High Eff. (Gas Heat)	12.5 ton High Eff. (Elec. Heat)	12.5 ton Ultra-High Eff. (Gas Heat)	12.5 ton Ultra-High Eff. (Elec. Heat)	20 ton High Eff. (Gas Heat)	20 ton High Eff. (Elec. Heat)	20 ton Ultra-High Eff. (Gas Heat)	20 ton Ultra-High Eff. (Elec. Heat)
Manufacturer A	2	30	3	30	7	24	23	30	2	4	7	8
Manufacturer B	11	30	30	30	26	30	30	30	12	11	–	–

Analysis Results continued

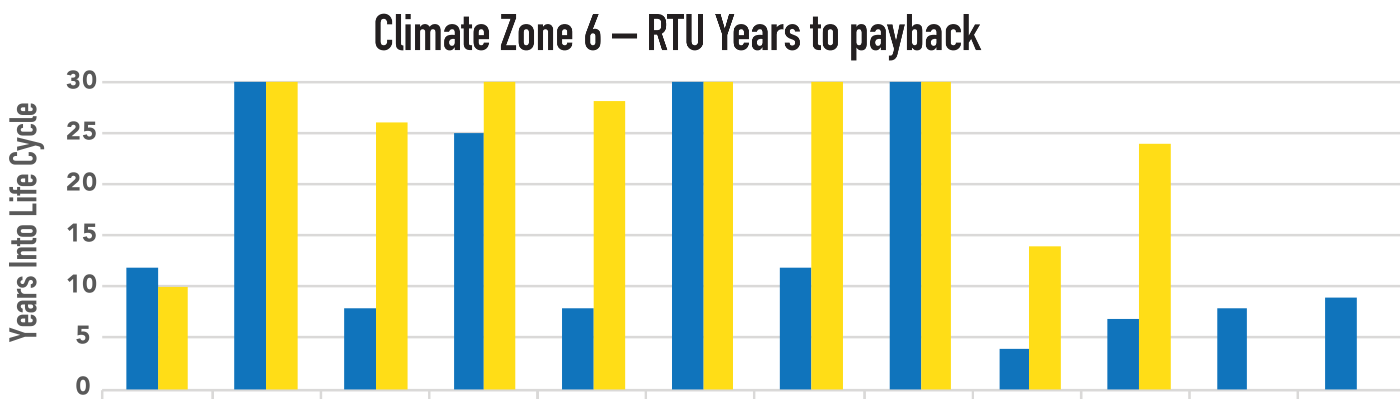


	6 ton High Eff. (Gas Heat)	6 ton High Eff. (Elec. Heat)	6 ton Ultra-High Eff. (Gas Heat)	6 ton Ultra-High Eff. (Elec. Heat)	12.5 ton High Eff. (Gas Heat)	12.5 ton High Eff. (Elec. Heat)	12.5 ton Ultra-High Eff. (Gas Heat)	12.5 ton Ultra-High Eff. (Elec. Heat)	20 ton High Eff. (Gas Heat)	20 ton High Eff. (Elec. Heat)	20 ton Ultra-High Eff. (Gas Heat)	20 ton Ultra-High Eff. (Elec. Heat)
Manufacturer A	2	28	3	24	6	13	13	30	2	4	7	7
Manufacturer B	8	30	26	30	12	30	29	30	9	10	–	–

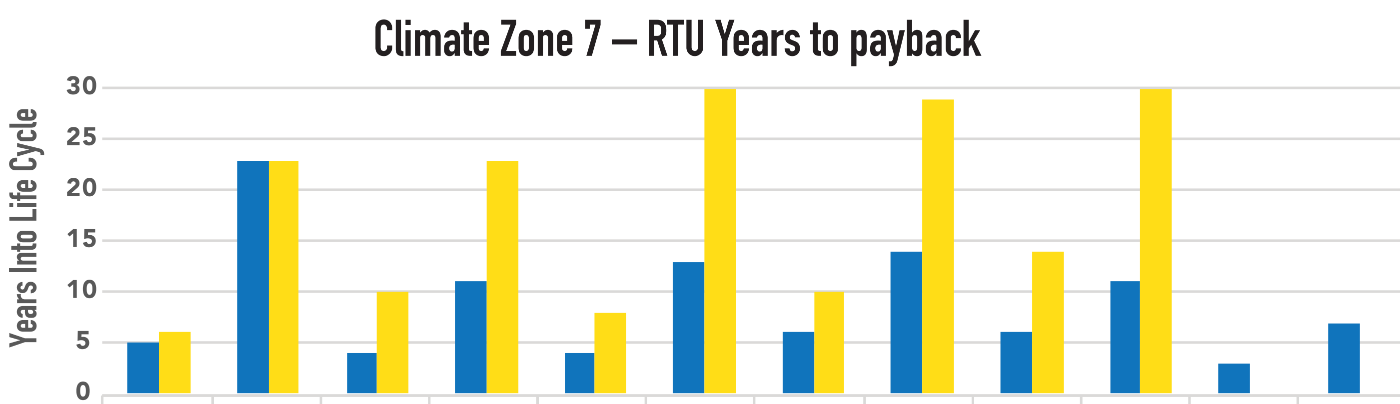


	6 ton High Eff. (Gas Heat)	6 ton High Eff. (Elec. Heat)	6 ton Ultra-High Eff. (Gas Heat)	6 ton Ultra-High Eff. (Elec. Heat)	12.5 ton High Eff. (Gas Heat)	12.5 ton High Eff. (Elec. Heat)	12.5 ton Ultra-High Eff. (Gas Heat)	12.5 ton Ultra-High Eff. (Elec. Heat)	20 ton High Eff. (Gas Heat)	20 ton High Eff. (Elec. Heat)	20 ton Ultra-High Eff. (Gas Heat)	20 ton Ultra-High Eff. (Elec. Heat)
Manufacturer A	12	30	9	24	6	14	11	30	3	5	7	8
Manufacturer B	10	30	28	30	14	30	29	30	12	13	–	–

Analysis Results continued



	6 ton High Eff. (Gas Heat)	6 ton High Eff. (Elec. Heat)	6 ton Ultra-High Eff. (Gas Heat)	6 ton Ultra-High Eff. (Elec. Heat)	12.5 ton High Eff. (Gas Heat)	12.5 ton High Eff. (Elec. Heat)	12.5 ton Ultra-High Eff. (Gas Heat)	12.5 ton Ultra-High Eff. (Elec. Heat)	20 ton High Eff. (Gas Heat)	20 ton High Eff. (Elec. Heat)	20 ton Ultra-High Eff. (Gas Heat)	20 ton Ultra-High Eff. (Elec. Heat)
Manufacturer A	12	30	8	25	8	30	12	30	4	7	8	9
Manufacturer B	10	30	26	30	28	30	30	30	14	24	–	–



	6 ton High Eff. (Gas Heat)	6 ton High Eff. (Elec. Heat)	6 ton Ultra-High Eff. (Gas Heat)	6 ton Ultra-High Eff. (Elec. Heat)	12.5 ton High Eff. (Gas Heat)	12.5 ton High Eff. (Elec. Heat)	12.5 ton Ultra-High Eff. (Gas Heat)	12.5 ton Ultra-High Eff. (Elec. Heat)	20 ton High Eff. (Gas Heat)	20 ton High Eff. (Elec. Heat)	20 ton Ultra-High Eff. (Gas Heat)	20 ton Ultra-High Eff. (Elec. Heat)
Manufacturer A	5	23	4	11	4	13	6	14	6	11	3	7
Manufacturer B	6	23	10	23	8	30	10	29	14	30	–	–

Conclusions

Choosing smaller packaged rooftop units can be an involved process with many options from different manufacturers. Not only are there an array of equipment sizes from each, but they also have comparatively different efficiency ratings.

General observations:

- Electric heat units do not appear to be good investments due to the excessive payback periods.
- Paybacks are attractive for gas fired heating in most categories with the exception of ultra-high equipment.
- Initial equipment purchase pricing makes Manufacturer B less attractive in many categories. This would tend to imply that bidding manufacturers is probably better than flat specs.
- Standard units are much more efficient than in the past due to code energy efficiency ratio (EER) escalation making efficiency upgrades harder to justify. In the future, energy codes may defeat LCCA as energy consumption will be deemed more important than equipment first costs. To help illustrate this point, this is already true for roofing insulation thickness as energy codes require R values in most climate zones that will not show an economic justification. Unless monetary incentives are provided, above standard efficiency equipment may cease to be relevant someday.
- Not all rooftop unit efficiency improvements are the same. For the most part, energy efficiency in today's rooftop units are unique to the manufacturer.

Even without a payback, rooftop units have a large influence on energy production and usage requirements from the power grid. For this reason, energy efficiency, as in EER, will continue to be pressed higher to mitigate the need for additional power plant production capacity. At some point new power plant capacity will be added and increased energy rates will follow. This will provide a reason for new analysis and the potential that a payback could be achieved as energy rates rise, where at this juncture some options do not payback.

Each project has unique HVAC needs with different requirements to consider. The conclusions we reached with our LCCA may not hold true for the payback analysis of your particular situation. That's why you need an experienced MEP partner to help analyze the rate of return of a higher efficiency rooftop unit.

Dialectic engineers have nationwide experience with different HVAC systems in all climate zones in the U.S. We help our clients and project partners sort out what is available compared to your individual business needs, and help you make the best, most cost-efficient decision.

Our team of design engineers are always happy to answer your questions. Contact us today.

310 W. 20th St., Ste. 200, Kansas City, MO 64108 816-997-9601 DialecticEng.com

References

ASHRAE. NSI/ASHRAE/IES Standard 90.1-2013 – Energy Standard for Buildings Except Low-Rise Residential Buildings

IECC. 2015 International Energy Conservation Code (IECC), U.S. Climate Zone Map and Table C403.3.3.3 - International Code Council, Inc.

ASHRAE. 2015 HVAC Applications - Owning and Operation Costs, Table 4

U.S. Energy Information Administration

U.S. Department of Commerce – National Institute of Standards and Technology – Energy Price Indices and Discount Factors

Carrier's load simulation program, Hourly Analysis Program (HAP), version 5.1 was used to perform HVAC energy output for multiple climate zones