significant improvements in both engine reliability and efficiency. These advances in engine technology now provide engines that are not only more fuel efficient, but more reliable. Additionally, new emissions control technology has led to engines with cleaner emissions and lower criteria pollutants (contributors to smog). Today's internal combustion engines are not your grandfather's engine; they are packed with high tech components and are significantly improved in terms of reliability, fuel efficiency, and emissions.

Summary

Stable natural gas supply and increased focus on energy costs, energy efficiency, and responsible environmental management will increase the use of natural gas engine driven water heating.

References

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Metro Area	Commercial Gas Price[1] [$/MMBtu]	Max 14 hours/day (6 AM to 8 PM) Operating Hours	Max 14 hours/day (6 AM to 8 PM) Weighted COP	Max 14 hours/day (6 AM to 8 PM) Annual Gas Savings	24 hours/day Operating Hours	24 hours/day Weighted COP	24 hours/day Annual Gas Savings
Atlanta	$14.93	4,984	1.71	$21,400	8,457	1.67	$34,100
Baltimore	$10.87	4,760	1.65	$13,500	7,987	1.62	$21,400
Boston	$12.85	4,600	1.59	$13,800	7,768	1.56	$22,300
Chicago	$8.65	4,348	1.62	$9,340	7,244	1.59	$14,700
Cincinnati	$10.41	4,663	1.64	$12,500	7,800	1.60	$19,600
Cleveland	$10.41	4,325	1.62	$11,100	7,292	1.59	$17,800
Dallas Ft Worth	$8.16	5,042	1.76	$12,700	8,587	1.71	$20,200
Denver	$7.56	4,614	1.63	$8,846	7,503	1.59	$13,200
Detroit	$9.38	4,199	1.61	$9,564	7,029	1.57	$15,100
Honolulu	$35.09	5,110	1.86	$64,602	8,760	1.83	$106,247
Houston	$8.16	5,102	1.79	$13,500	8,726	1.74	$21,500
Los Angeles	$7.75	5,110	1.66	$10,700	8,760	1.63	$17,400
Miami	$11.09	5,110	1.86	$20,400	8,760	1.83	$33,500
Minneapolis St Paul	$7.96	3,871	1.62	$7,608	6,439	1.59	$12,000
Nassau[2]	$40.54	5,110	1.86	$74,636	8,760	1.83	$122,751
New York	$10.72	4,652	1.63	$12,500	7,897	1.60	$20,400
Philadelphia	$11.83	4,722	1.64	$14,400	7,920	1.61	$22,800
Philadelphia (Propane)[3]	$32.43	4,722	1.64	$39,642	7,920	1.61	$63,721
Phoenix	$12.15	5,110	1.84	$21,500	8,760	1.80	$35,000
Pittsburgh	$11.83	4,531	1.61	$13,000	7,644	1.57	$20,600
Portland	$11.86	5,097	1.58	$14,000	8,724	1.54	$22,400
Riverside	$7.75	5,108	1.73	$11,800	8,758	1.66	$18,100
San Diego	$7.75	5,110	1.68	$11,100	8,760	1.65	$18,000
San Francisco	$7.75	5,110	1.59	$9,518	8,760	1.56	$15,400
Seattle	$12.26	5,085	1.55	$13,700	8,691	1.51	$22,000
St Louis	$10.80	4,618	1.68	$13,500	7,785	1.64	$21,600
Tampa	$11.09	5,108	1.83	$19,300	8,757	1.78	$31,100
Washington DC	$12.99	4,761	1.65	$16,100	7,955	1.61	$25,000

[1] *Reflects 2009 pricing*
[2] *Natural gas not available. Analysis assumes commercial propane @ $3.75/gal*
[3] *Analysis assumes commercial propane @ $3.00/gal*

Table 1. Potential savings, gas engine-driven heat pump with 120° water.

Natural Gas Engine-Driven Heat Pumps

Technological advances lead to higher efficiency and lower emissions

A natural gas engine driven heat pump water heater extracts energy from the atmosphere and pumps this heat to useful temperatures. Free waste heat from the engine is captured and re-purposed, adding to the unit's capacity and efficiency. A gas engine heat pump, with reclaimed engine waste heat, can result in a coefficient of performance (COP) twice that of a conventional boiler, resulting in significant fuel savings and a reduced carbon footprint. Commercial and industrial sites with substantial requirements for domestic hot water, process hot water, or space heating, are ideal applications. These include hotels, hospitals, nursing homes, recreation centers, student dormitories, swimming pools & water parks.

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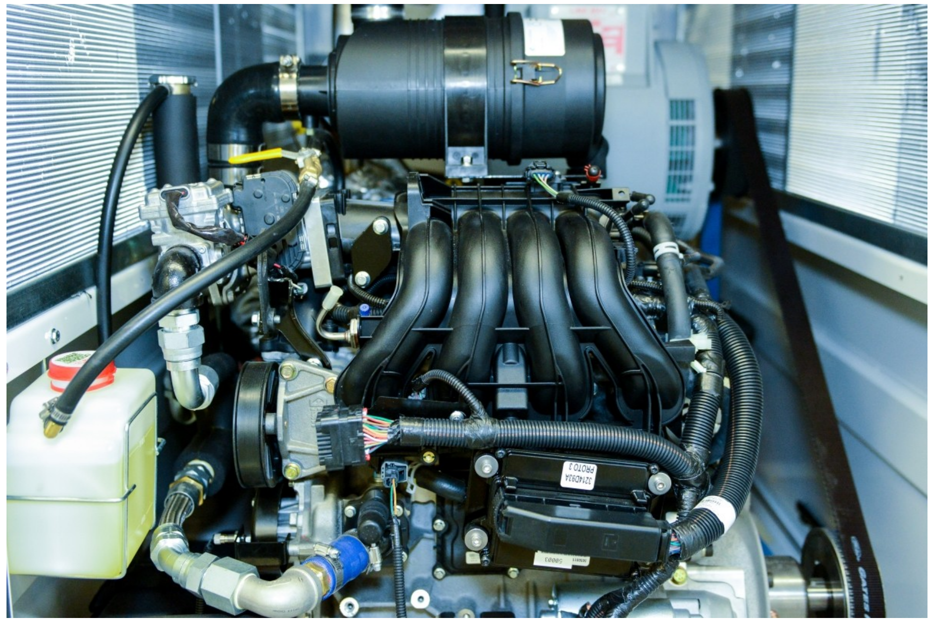
The confluence of economic, environmental, and national security concerns has led to a renewed interest in natural gas heating. Natural gas is an obvious choice for heating; it is readily available, cost effective, and has the lowest carbon content of any fossil fuel. Additionally, natural gas chillers can be utilized for cooling in summer months to reduce electric demand and grid congestion. While the use of gas heating and cooling has increased, the technology used for natural gas heating technology has failed to keep pace. The traditional approach of heating fluid with a flame has remained largely unchanged and results in appliances with 85%-95% efficiency.

Typical packaged air-source gas engine-driven heat pump.

Natural gas engine-driven heat pumps offer commercial and industrial energy consumers an economic alternative to gas water heaters. Heat pump technology is an advanced method of generating heat.

Traditional heating methods that involve the combustion of fossil fuels do not fully extract the chemical energy of the fuel because they are merely transferring thermal energy. By contrast, a heat pump cycle capitalizes on the availability of the combustion process by producing work via the engine to move heat from a cold reservoir to a warm reservoir through a standard Carnot cycle. The amount of heat that can be moved is many times the heat contained in the fuel powering the machine, thus providing a two to three-fold benefit.

Electric heat pumps share this Carnot efficiency benefit, but by substituting a gas engine for the electric motor, additional waste heat can be recovered and added to the overall heat output, boosting the efficiency by more than 30%. In addition, by adding this high grade hot water to the process, the delivered heating temperature with a gas heat pump can exceed those of electric unit. An engine driven heat pump, coupled with recovered heat from the engine jacket and exhaust, can achieve coefficients of performance



The advanced automobile engine in the Ilios high efficiency water heater.

(COP) up to 1.4 – 2.0, more than doubling the efficiency of conventional water heaters (0.85). Moreover, since the gas heat pump burns half the fuel, the carbon emissions are proportionately reduced.

Rationale for Development

A natural gas engine driven heat pump traditionally consists of a vapor-compression refrigeration cycle which includes a condenser, evaporator, throttling valve, and compressor; whereby the compressor shaft work is provided by a reciprocating engine. The current practice of generating electricity at a central plant is inherently inefficient as 50-60% of the input energy is rejected in the form of low-grade waste heat to the environment. There is also an additional 3-5% loss associated with transmission through the grid and finally a 3-5% loss in electric motor efficiency. By locating the fuel-conversion process on site via a natural gas engine, the majority of the waste heat from the engine can be recovered and purposefully used. Although a typical internal combustion engine has a thermal efficiency of 30-35%, it is common practice in mechanical CHP to recover up to 85% of the remaining energy that would normally be lost as waste heat. Due to this waste heat available from the engine, it is advantageous to operate in a heating only mode where the utmost efficiency can be realized.

Technical Advantages

The gas engine heat pump has several technological advantages over traditional means of water heating. An engine driven compressor allows for efficient capacity control by reducing engine speed to load follow. Traditional misconceptions about cold weather operation can easily be put to rest. Cold weather operation is possible and very efficient when compared to a boiler due to the engine waste heat recovery. Even when in defrost mode, most gas engine driven heat pumps can still deliver heat to the building via engine waste heat.

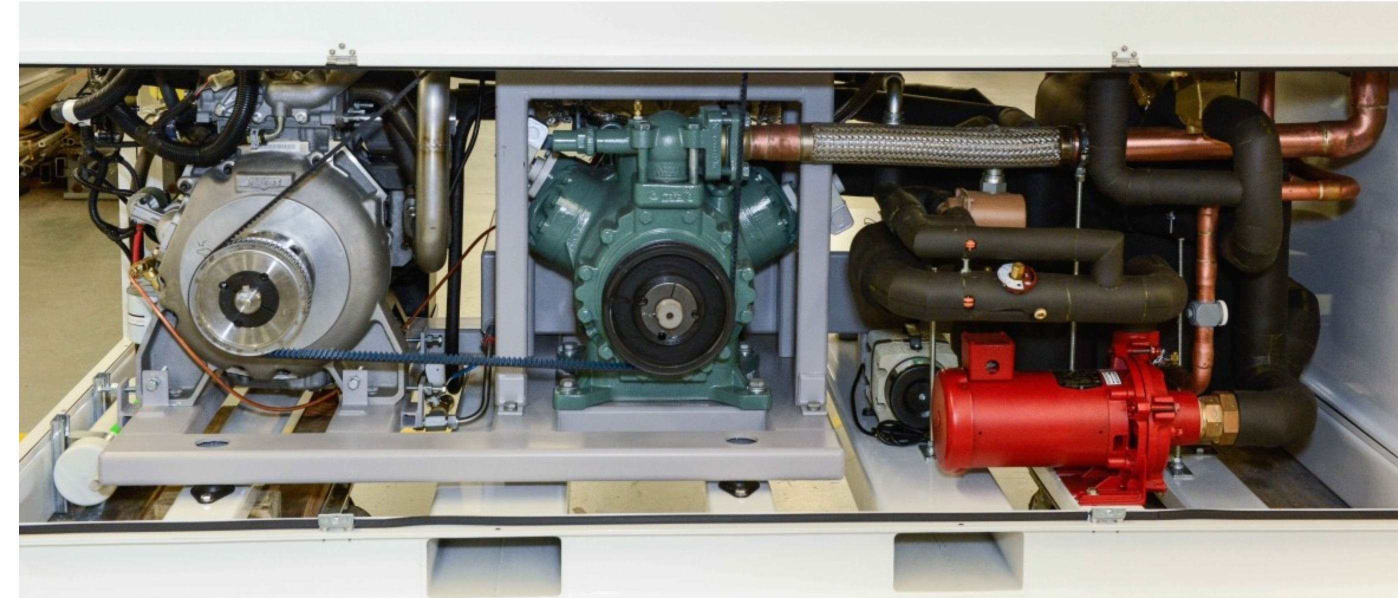
Engines themselves have come a long way from their troublesome, maintenance intensive predecessors. Today's engine driven heat pumps leverage the advantages and progression of the automotive industry; specifically increased reliability, efficiency, and durability. With electronic ignition, coil on plug technology, and cylinder heads which provide a cleaner more efficient burn, the days of changing plugs and wires with every oil change are history. All of the improvements in engine efficiency that have been implemented in cars, such as variable valve timing (VVT), and advanced engine cycles (i.e. the Atkinson cycle which is used in many hybrid cars), can now benefit gas engine driven heat pumps. Constant valve adjustments are no longer necessary as engines now have "set-for-life" valve trains. New improved synthetic oils coupled with large dry-sump oiling systems provide thousands of hours between simple oil and filter changes.

From an emissions standpoint, engine driven heat pumps have also taken advantage of controls developed by the automotive industry. Improved air-fuel ratio (AFR) control has allowed the use of multiple stage catalytic converter systems to reduce levels of criteria pollutants such as NO_X and CO well below the levels of current boiler technology.

System Design & Implementation

Commercial gas engine driven heat pump water heaters can be produced in many configurations which utilize a multitude of sources for evaporator heat extraction. The most common configuration using an air-cooled evaporator will be discussed.

In this configuration, heat is extracted from the outdoor air through an air-cooled evaporator coil. As with any air-source heat pump, the overall COP (coefficient of performance) of the heat pump is a function of the outdoor temperature or "source" temperature. Most designers and engineers are quick to understand this concept as it follows the 2^{nd} Law of Thermodynamics or in simple terms Carnot efficiency. The efficiency



A look inside the Ilios high efficiency water heater.

service as it ensures expert service and attention.

Economic Benefits

For locations with significant hot water requirements such as water parks, swimming pools, hotels, hospitals, apartment buildings & recreation centers, a natural gas engine driven heat pump can cut fuel consumption and carbon emissions by half. However, several factors contribute to the economic performance and savings that can be realized through the installation of a natural gas engine driven heat pump.

Ambient Temperature

An air source heat pump extracts air from the ambient environment. System efficiency and corresponding savings therefore differ based on ambient weather conditions. Warmer climates with higher ambient temperatures have will have higher efficiency and more fuel savings than cooler climates. As shown in Figure 4 above the Energy Code Climate Zone Map, not all geographic areas are equal from an ambient temperature perspective.

Run Hours

The installed cost of an air source heat pump is the same whether it runs 24 /7 or not at all. For each hour it runs, it saves fuel in comparison to less efficient existing equipment. Realized savings are based on the difference in percent efficiency over existing water heating equipment multiplied by the number of hours this increased % efficiency can be achieved. Longer run hours will allow increased savings over a given time period and therefore decrease the payback period. For this reason, it essential to utilize a natural gas engine driven heat pump in an environment with a significant thermal load where it can be "first on and last-off" so that run hours are maximized.

Relative Fuel Price

As with all efficiency programs, increased savings are realized in absolute terms when fuel costs are increasing or relatively high. The percent savings is a function of system efficiency, but absolute savings are a function of fuel cost, system efficiency, and run hours. Table 1 below shows potential, savings that can be realized at various locations throughout the country based on, ambient temperature, run hours and local fuel price.

Federal Investment Tax Credits (ITC) and Accelerated Depreciation are currently available for qualified Combined Heat and Power (CHP) products including natural gas engine driven heat pumps. A qualified tax professional can determine specific benefits available to you and your clients. Additionally there may be additional incentives available through your local gas utility or state and local agencies.

These incentives can substantially reduce the payback time for an engine driven gas heat pump. The payback for a typical engine driven gas heat pump will be between 2-4 years dependent upon ambient temperature, thermal load, fuel cost, and available incentives.

Natural gas engine driven heat pumps represent an outstanding opportunity to reduce hot water heating costs and lower greenhouse gas emissions.

While the concept of a natural gas engine driven heat pump is not new, advances in internal combustion engine technology by the automobile industry have led to

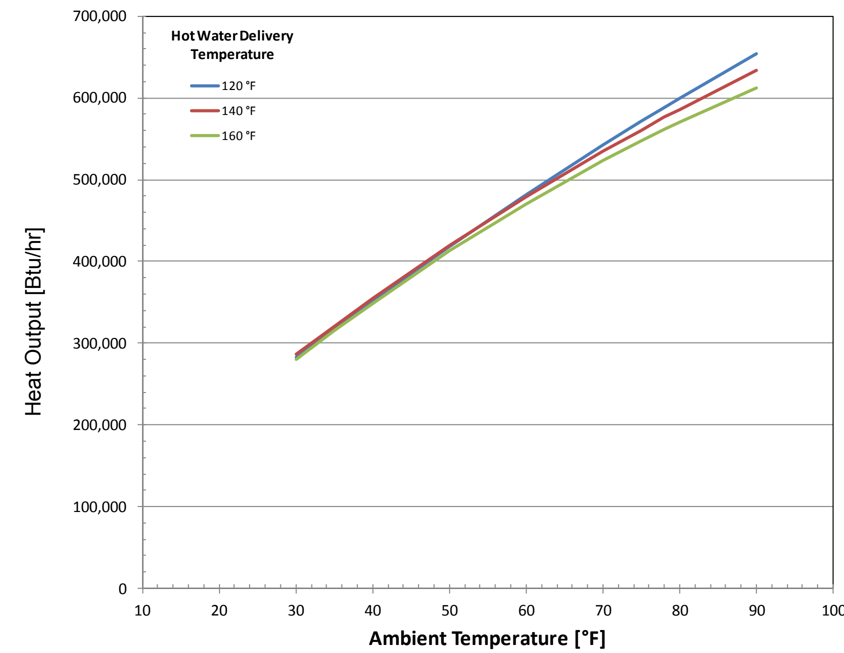


FIGURE 1. Heat output vs. ambient temperature.

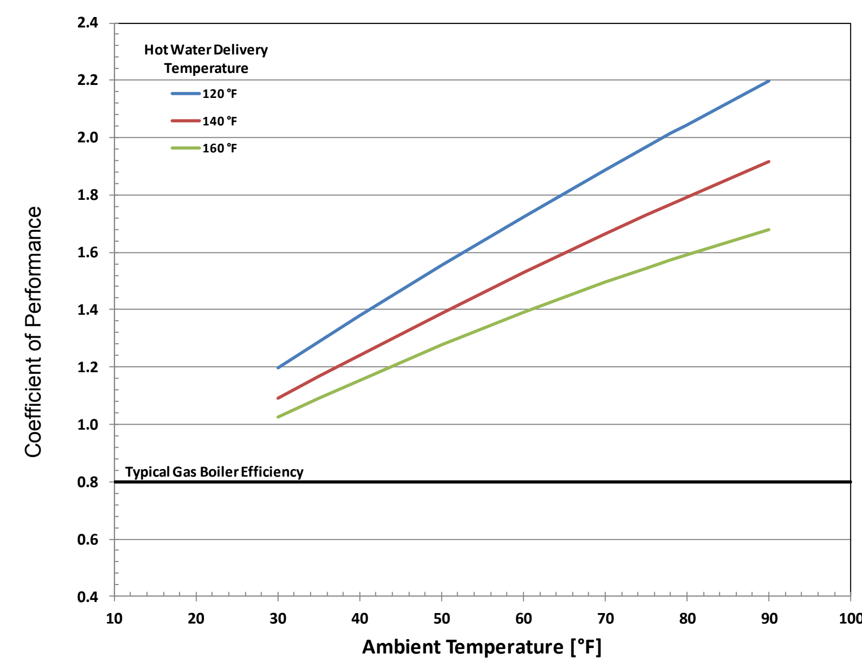


FIGURE 2. Performance vs. ambient temperature.

will increase as the source (air) and sink (hot water) temperatures approach one another.

However in addition to the performance varying with source temperature, the heating capacity also varies accordingly. An air-source heat pump hot water heater will provide the most heat from the condenser when the outdoor temperature is at its highest. As the outdoor temperature decreases so does the capacity of the heat pump. This is due to the decrease in compressor suction temperature as the outdoor temperature decreases, thereby reducing the refrigerant density and subsequent mass-flow rate through the compressor. As a result the net refrigerating effect will decrease.

The advantage of heat pumps in general is that it is possible to have a coefficient of performance many times greater than unity. Coefficient of performance (COP) is defined by the following equation:

$$COP = \frac{Energy\ Out}{Energy\ In}$$

With traditional boilers, the COP is constant and can never be greater than unity as the best possible scenario is that all of the chemical energy in the fuel is utilized to heat water with nothing wasted. The graph in Figure 1 above shows typical COP curves as outdoor temperature changes. The graph below in Figure 2 shows the relationship between output and outdoor temperature.

As a designer or engineer, it is this caveat that becomes the most critical to system design. It is important that an air-source heat pump hot water heater is installed in such a way that it can meet the entire load in the summer months when its output is the greatest. This is essential to increase run hours, and as a result overall savings. In the warm months, the heat pump will act as the primary water heater for the facility and as ambient temperatures cool down in the winter months, it can act as a supplement to a traditional boiler. This concept works very well for retrofits as in many cases it can prevent large oversized boilers from running inefficiently in the summer to serve domestic hot water loads or pool heat in the absence of their space heating duties. It also has the advantage in new construction of replacing one or more boilers or simply using a smaller boiler and sharing the load. Consistent with Carnot efficiency, gas engine driven heat pump hot water heaters are the most efficient when the output water temperature is at it's lowest. Such applications include low-temperature heating such as domestic hot water, pool heating, radiant floors

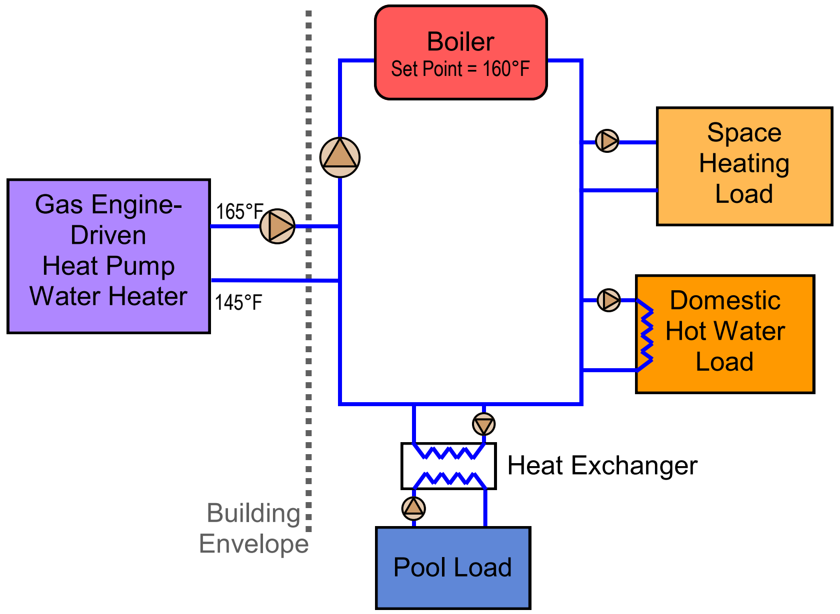


Figure 3. Simplified Installation serving multiple loads.

and other low-temperature distribution systems which are gaining popularity. Industrial process hot water for manufacturing and food production are also perfect applications for gas engine driven heat pump water heaters. In addition to these low temperature applications, it is also possible to reach much higher output temperatures with the addition of the engine waste heat.

It is not uncommon for current technology to have a maximum delivered water temperature of 170° F which can work well with existing distribution systems found in older buildings for space heating as well as laundry and commercial dishwashing. The implementation into an existing building can be relatively straightforward as long as the engineer realizes that it is not an instantaneous water heater nor is it an intermittent heater. It needs to be sized to base load the building to ensure there is not unnecessary cycling or part-load operation. The simplest way to integrate a gas engine driven heat pump water heater is to use a primary/secondary piping configuration to enter the heating loop before the water returns to the boiler. This applies to building heating loops, pool heating, and indirect domestic hot water heating. The controls can be configured such that the boiler set point is slightly lower than the heat pump outlet temperature, which will prevent the boiler from running whenever the more efficient gas engine driven heat pump can meet the load on its own. This is traditionally referred to as a "first on, last off" configuration. Figure 3 above shows a simplified connection to a heating loop which serves multiple smaller loads. If any of the single loads are large enough it would make sense to use the heat pump to serve those loads directly.

Depending upon the configuration of the unit, whether it is an indoor or outdoor unit, and whether or not the water is potable; an isolation heat exchanger may be necessary. In this case there will be an additional heat exchanger and pump which needs to be sized appropriately and considered in the economic analysis.

Maintenance

Due to the aforementioned advances in engine technology and reliability, maintenance is now much more manageable. Depending on the site, run hours, load, and oiling system, the intervals will vary. Most current technology will at the very least allow for bi-monthly oil changes. Engine life can be upwards of 20,000 hours with proper adherence to recommended oil change intervals. Most manufacturers will provide a factory-service contract as an option when purchasing the equipment. It normally covers any type of maintenance or issues, normal or abnormal. Many facilities directors and building owners opt for factory

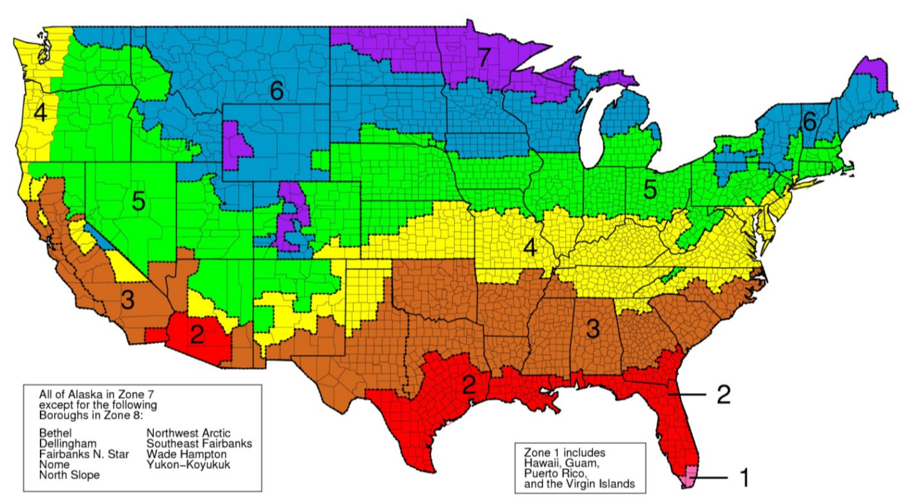


Figure 4. Energy-code climate-zone map.