Island Energy Plan
6.0 HVAC/Buildings
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Introduction

The Martha's Vineyard Commission has set goals for reductions in both greenhouse gas (GHG) emissions and fossil fuel use. Buildings are a key target for reductions, as their fossil fuel use represents over 30% of the Island's GHG emissions.

Strategies to reduce GHG emissions in buildings include upgrades to building enclosures and building systems (mechanical and lighting), as well as fuel switching from fossil fuels to electricity. Many of these approaches also yield increased resilience to the impacts of climate change. Enclosure and systems upgrades reduce emissions by reducing loads. Fuel switching reduces emissions by substituting a system (usually a heat pump) that combines efficiency gains with a lower carbon content energy source (electricity) to deliver the same amount of usable energy to the end use. Electrically-driven systems can also be powered by onsite and locally-generated renewable energy, cutting emissions further. Increasingly, buildings are being designed and operated to be *net zero*, in which an onsite renewable energy system (usually solar electric) generates as much or more energy on an annual basis than the building and its inhabitants consume.

The strategies discussed here are all currently available. Superinsulation as a primary load reduction strategy has over forty years of practice in North America. Cold climate air source heat pumps are a more recent evolution of an old technology, first appearing about a dozen years ago. Heat pump water heaters and pool heaters have had a similar time in the marketplace. The reduction of non-thermal loads in buildings, such as cooking and lighting, have been similarly advanced in the last decade with induction cooktops and LED lighting.

Building energy is consumed by the following loads:

- Space heating and cooling
- Ventilation (more significant in densely occupied, non-residential buildings, like schools, and also in indoor pools, laboratories, and hospitals)
- Dehumidification
- Water heating
- Lighting
- Appliances and other plug loads
- Process loads (ice rinks, indoor and outdoor pools, cannabis facilities, industrial uses)

Fossil fuels are often burned for space heating, water heating, and pool heating, and electricity powers the rest. Martha's Vineyard has no natural gas, so propane and fuel oil are the only thermal fuels used in buildings, and each has a higher GHG intensity per BTU than natural gas (19% and 38%, respectively.)

Load Reduction – Enclosure

Martha's Vineyard is a heating-dominated climate for most buildings. Space heating is usually the largest energy use in small, enclosure-dominated buildings such as houses and non-residential (mostly) wood-frame buildings. Heat loss is due to conduction through the walls, foundation, and roof, which is mitigated by insulation in these assemblies, and through air leakage in and out of the building. In older buildings, air leakage can be the largest single component of heat loss.

In heating load reduction practice, it's worth distinguishing weatherization from Deep Energy Retrofit. Weatherization is usually performed by a specialty subcontractor, who pursues air leakage reduction and addition of insulation in accessible locations (typically attics, kneewalls, and basements/crawl spaces). With skilled personnel, savings of 10-20% are possible and often very cost-effective, especially when subsidies are available from Cape Light Compact. Weatherization may not make a sufficient reduction in the heat load to enable a cost-effective switch from a fossil-fueled heating plant to an air source heat pump. However, a heat pump may be added to reduce fossil fuel usage during the heating season and also provide summer cooling.

In a Deep Energy Retrofit (DER), the entire building enclosure is upgraded, either from the exterior or the interior. The drivers are typically major deficiencies that need to be addressed (comfort, mold, air quality, water issues, pests, decay) and/or exterior claddings (roof, sidewalls) or interior finishes that are due for replacement. Significant new amounts of insulation are added, and a draft-free air barrier is installed. Often, mechanical systems may also be at the end of their useful service lives as well. Many DERs have converted to all-electric systems (heat pumps) and some go further with onsite solar electricity to achieve net zero energy performance. DERs are usually managed by construction professionals rather than weatherization subcontractors, as multiple trades require coordination. As might be expected, a DER will cost substantially more than weatherization, but the building owner receives a high performance result that is comfortable, healthy and safe, durable, and with minimal or no energy costs.

Load Reduction – Systems

The most common heating and hot water systems on Martha's Vineyard are fossil-fueled boilers, furnaces, and water heaters. Strategies for reducing fuel consumption (without fuel switching) include:

- Replacing outdated, inefficient, and over-sized boilers with state-of-the-art products, usually with sealed combustion equipment.
- Sealing and insulating furnace/fan coil/cooling system ducts, especially when they are located outside the thermal boundary of the enclosure, especially in an attic or kneewall.
- Implementing better controls – changing control settings so that pumps and blowers don't run unless a thermostat is calling for heating or cooling; resetting the temperature of heating water circulated according to the outdoor temperature.

It's worth recognizing that fossil fuel systems use electricity to operate controls, burners, pumps, and blowers. This usage can be significant, and worthy of effort to reduce.

In buildings with large ventilation loads, adding energy recovery systems can save as much as 75-80% of the ventilation load and reduce the required heating and cooling system size appreciably. An added benefit is that moisture is also recovered, leading to higher relative humidity (RH) in winter and lower summertime RH. Not only is the cooling system able to be downsized, its dehumidification ability is enhanced as well.

Lighting system load reductions may also have high potential. Replacing halogen lighting common in high-end residences with LEDs can result in 80% load reduction, as well as decreasing cooling loads. In non-residential buildings, both lighting efficiency upgrades and controls that keep lights off when spaces are unoccupied or daylight is adequate to light a space can drop lighting energy significantly.

Appliances and office/entertainment/IT equipment have all undergone major efficiency improvements. The lowest cost reduction is assiduous use of the OFF switch when the equipment is not required!

Monitoring/Datalogging

Any effort at serious load reduction begins with energy consumption records, preferably three years of monthly records. To zero in on where conservation work will have the highest benefit, it often makes sense to implement targeted monitoring of specific energy use. An example might be at a school, where it might be important to separate electricity used for a walk-in cooler from energy used for lighting, or for operating boiler pumps. Datalogging equipment is relatively low cost and can be deployed on a short term basis to better inform the most effective energy reduction strategies.

Fuel Switching

Switching from burning fossil fuels in a building to providing thermal energy with electricity is a decarbonization strategy in grid regions where the GHG loading is low (the grid is fairly clean) and continuing to drop. Carbon-free electricity is increasingly generated locally with solar and wind. As of 2017, the utility grid serving New England had a CO_2-equivalent (CO2e) emissions loading of 682 lbs/MWh (200 lbs per million BTU). Using grid electricity in a heat pump at a Coefficient of Performance of 2.5 (COP – units of energy delivered per unit of energy input) results in an emissions rate of 80 lbs of CO2e per million BTU (MMBTU) delivered. Propane burned at 85% efficiency has an emissions rate double that – 163 lbs/MMBTU – and fuel oil at 80% efficiency is 2-1/2 times as high, at 202 lbs/MMBTU. This is conservative for two reasons. First, it ignores all the electricity consumed by the fossil fuel systems to run the burners, pumps, and blowers. Second, water heating with fossil fuels is significantly less efficient than home heating, especially in the warm season when a boiler is being fired only to make hot water. This is especially true on the Vineyard with its much higher summer population and consequent hot water demand.

Heating and Cooling

Heat pumps use electricity to move heat from a colder location to a warmer one, as a refrigerator does. Unlike refrigerators, heat pumps are reversible, providing heating in the winter and cooling in the summer. Heat pumps can use either the outdoor air (Air Source Heat Pumps, ASHP) or the ground (Ground Source Heat Pumps, GSHP) as the source of heat. With the introduction of affordable variable-speed inverter-driven ASHPs from Japan in the mid-2000s, the heat pump market exploded. Traditionally, ASHPs were not used in cold climates, as their output dropped as the outdoor temperature dropped, while the heating demand of the building was increasing, and the difference was made up with costly electric resistance strip heaters.

Today ASHP products are heating buildings efficiently in northern New England without back-up electric heat. The indoor configurations range from ductless wall, floor, or ceiling cassettes to mini-duct systems to centrally ducted systems similar to fossil-fuel furnaces. These systems are used effectively in commercial and institutional buildings as well as homes. As of 2019, ASHP products that heat water instead of air are beginning to reach the market, and will offer the potential of replacing a fossil-fuel boiler with a heat pump. What is not readily available now is a heat pump that will generate the 160°F – 180°F water temperature provided by a boiler. To use the existing fintube baseboard in a building thus requires either adding additional heat emitters or reducing the heating load of the building so that a lower water temperature will be sufficient to meet the heating load. There are Japanese ASHPs using carbon dioxide as the refrigerant to make hot water, and these are capable of boiler-level water temperatures, so this technology is on its way.

The best time to consider switching from a fossil-fuel driven system is when the existing system is at the end of its service life and needs replacement. Another driver is the desire to add air conditioning to a building that has a system that only provides heating. For a marginal cost, the added system can provide heating as well as cooling.

A lower cost option is to add a single zone ASHP, usually with a wall or floor cassette, in the main level zone of a house with a fossil-fuel heating system. Used wisely, the ASHP can displace up to 80% of the fossil fuel used for heating. Large scale studies pioneered in the Pacific Northwest and in Maine show an average energy savings of 40%. For buildings with electric resistance or propane heat, cost savings of 30-50% are typical.

Overall, heat pumps are the best choice for new construction or a gut renovation. They cost less and use less energy to operate than their fossil fuel competition, saving money and energy over the life of the building. Installation cost is comparable, and less than a system that includes fossil fuel heating and a separate air conditioning system.

In existing homes, analysis should be done at the time of system replacement to assess the viability of replacing a fossil fuel system with a heat pump system. Often this will depend on the load of the house (lower is easier) and the condition of the balance of the distribution system. Replacing just the boiler with no other repair/replacement will be less costly than a total heat pump replacement, but it's important to include all costs of a system upgrade. For example, a masonry chimney may need substantial repairs to assure continued safety, and that money can be better spent on the fuel switch to electric heat pumps.

Hot Water

Heat pump water heaters (HPWH) are the alternative to heating water with propane or oil or electric resistance. The principal configuration is a 50 – 80 gallon tank with a small air-to-water heat pump built-in on the top. Heat is removed from the air around the unit (usually in a basement) and delivered to the water in the tank. HPWHs also have back-up electric resistance elements to speed up recovery of hot water production in high usage periods. HPWHs operate at a COP of 3 or more, so they represent both a significant cost and emissions saving over oil or gas-fired systems. An additional benefit in our coastal climate is that as the air is cooled to extract heat, moisture is also removed and the HPWH has a mild dehumidification effect on its surroundings. Also, Martha's Vineyard peak hot water loads are in the summer months, when HPWH efficiency is at its best.

Swimming Pools

Pools are traditionally heated with propane, at efficiencies below the best heating equipment for buildings. Heat pump pool heaters (HPPH) operate in the warmer weather and at COPs of 4-5, so they provide a significant reduction in both operating cost and emissions load. The output of a HPPH is lower than most propane-fired pool heaters, so the initial heat up of the pool when it is filled at the beginning of the season takes longer.

Other Appliance Opportunities for Fuel Switching

There are other opportunities inside the building to use more efficient, electrically-driven appliances to replace fossil fuel appliances and reduce costs and emissions. Heat pump clothes dryers are substantially more efficient than traditional electric and propane dryers, and have the additional advantage that they don't need to be vented to the outdoors. They do take longer to dry a load of laundry. Gas cooktops and ovens can be replaced by electric induction cooktops, increasing efficiency by over 2:1, while providing a faster warmup, better control, and no negative indoor air quality impacts.

Risks and Benefits

The largest risk of wide-scale adoption of heat pump technologies is that current refrigerants are potent GHGs in themselves (R410a has a CO_2e of 2,088) and that refrigerant leaks are extremely detrimental to the climate. Many installers are not following manufacturers' instructions for proper installation of flared connections, and not properly pressure testing and evaluating an installation for leaks before it is charged with refrigerant. The long term solution to this will be sealed factory-charged systems with no onsite handling of refrigerant, similar to refrigerators. Distribution of energy will most likely be hydronic, with a water/antifreeze mix.

An additional risk of heat pumps is that in a grid-scale power failure they won't produce heat, and if they are to be driven by a site-based generator it will need to be substantially larger than one that can power the burner/pumps/blowers of a fossil fuel system. Over time, the penetration into the market of distributed solar electric generation and battery storage will diminish this issue, particularly as EVs proliferate and vehicle-to-building (V2B) systems evolve to make the EV the back-up for the building, charged daily by onsite solar electricity.

There are a number of benefits to removing fossil fuels from buildings. Liquid fuels (fuel oil and kerosene) are stored inside buildings and subject to spills which can contaminate the indoor environment permanently. Propane always carries an explosion risk, and both liquid and gaseous fuels are flammable.

Eliminating combustion inside a building eliminates the potential for carbon monoxide poisoning and death. Switching from propane to electric cooking reduces indoor air respiratory irritants such as oxides of nitrogen and fine particulates (although some particulates remain from the cooking process itself, particularly from frying.)

Final Thoughts and Recommendations

The two most important challenges of heat pumps replacing fossil fuel equipment are refrigerant leakage control and the availability of heat pumps that directly replace boilers. Neither requires new technology, but rather enough of a perceived demand in the US market to make products available here.

To accelerate the shift towards all-electric, renewably powered buildings, there is a set of key strategies to apply – some are in place already. The biggest gap is in education – for consumers, for installer and specifiers, for creating the tradespeople prepared to implement this transition. Some strategies are below.

- Make guidance documents readily available, both print and web-based, for both consumers and installer/specifiers on air source heat pumps. These are available from the Northeast Energy Efficiency Partnership and the MA Clean Energy Center. Documents that show economic and other benefits will be particularly useful.
- Raise awareness of the alternate energy credits incentive for heat pumps (MA DOER)
- Publicize rebates for installing heat pumps and HPWHs (Cape Light Compact and Mass Save)
- Promote free/low cost energy efficiency audits for residential and commercial/institutional buildings (Cape Light Compact)
- Steer installers/specifiers to training on how to properly size, select, and apply heat pumps
- Sponsor and facilitate trades education to increase the number of trained refrigeration technicians, and re-train fossil fuel technicians
- Support trades education on assessing building energy usage and implementing prioritized energy efficiency measures
- Distribute guidance documents for both consumers and builders about low-cost, energy-efficiency upgrades available during re-siding, re-roofing, and window replacement projects
- Secure a ban on fossil fuel used for heating, hot water, and pool heating in new construction and major additions/renovation to homes and commercial buildings
- Require energy use metering and submission of monthly energy use by fuel for all DRI projects, to build a database of actual performance
- Promote community procurement programs for heat pumps and heat pump water heaters