Cold Climate Heat Pumps – reviewing total energy use and GHG emissions in Vermont
October 9, 2017

Even when making conservative assumptions across the board and assuming that heat pumps are powered by electricity generated by fossil fuels rather than renewables, modern cold climate heat pumps reduce total energy use and reduce greenhouse gas emissions compared to even the best fossil fuel alternatives. That is true today, and will only be more true over time given increasing requirements for renewable energy in Vermont.

To compare fossil fuel heating (or biomass or biofuel – any on-site combustion really) to cold climate heat pumps in terms of energy use and GHG emissions, you need to take into account all of the energy losses both types of heating deal with. For combustion, that's basically the efficiency of the heating unit. For heat pumps, you've got a lot more going on – the COP (coefficient of performance – the equivalent to the efficiency of a fossil fuel heater), the losses of electricity as it moves through the transmission and distribution system, and the efficiency of the power plants that are providing the electricity the heat pump ends up using. For the purposes of this exercise, we'll assume the homes are identical from a building efficiency standpoint.

Typical fossil fuel heating units have been around 80% efficient for a while (so every 5 units of energy in the oil burned produces 4 units of useable heat), though newer units can be as efficient as 95%. [1]

Cold climate heat pumps (CCHPs) use COP rather than "efficiency" because they move heat around (from outside to inside a building) rather than creating it through combustion. Because of this, they're able to functionally have efficiencies *above* 100% (which would be a COP of 1.0). Put another way, if you use one unit of electricity in a CCHP to move heat into your house, you actually wind up with more than one additional unit of heat in your home. Estimates of the real-world COP for modern CCHPs range from around 2.5 to over 3.0. The Vermont Department of Public Service uses a conservative estimate of 2.4 (meaning you get 2.4 units of heat energy into your home for every one unit of electric energy you power your heat pump with). [2]

Since heat pumps are powered by electricity, we have to also take into account other inefficiencies in the electric system. One way electricity is lost is as it's moved around through the transmission and distribution grid (the "poles and wires"). Nationally, about 4.7% of all electricity generated is lost in this way.[3] Vermont's electric system is somewhat more efficient than that, with losses of approximately 2.2%.[4]

More energy is lost in the electricity generation process. Combustion-based power plants (coal, oil, gas, biomass, etc.) typically lose more than half the energy that is put into them, mostly as waste heat.

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[1] http://publicservice.vermont.gov/sites/dps/files/documents/Pubs_Plans_Reports/Fuel_Price_Report/2016/November%202016%20Fuel%20Price%20Report.pdf

[2] Id

[3] https://www.eia.gov/tools/faqs/faq.php?id=105&t=3

[4] https://www.eia.gov/electricity/state/vermont/state_tables.cfm Table 10, using the methodology described in https://www.eia.gov/tools/faqs/faq.php?id=105&t=3

Looking at the regional New England electric grid (ISO-NE) and the generators likely to provide power for a CCHP, there are a range of reasonable estimates one could use for how much energy is lost in the generation of the electricity that is required by a newly installed heat pump.

ISO-NE states plant efficiency using a term called "heat rate," which is measured in is MMBTU/MWh. Since there are 3.412 MMBtu of energy in a MWh, a theoretical plant with a heat rate of 3.412 would be 100% efficient, one with a heat rate of 6.824 would be 50% efficient, etc. EIA has a longer description here: https://www.eia.gov/tools/faqs/faq.php?id=107&t=3.

In ISO-NE in 2015 (the most recent year data is available), the average heat rate for "marginal units" is 8.1.[5] Roughly speaking, these are the power plants that are the last to kick on at a given time, so if you're increasing electric usage by, say, installing heat pumps, it is reasonable to use those (mostly fossil fuel) plants' performance as you calculate the total energy use that additional electric demand results in.

The average heat rate for marginal units ("LMUs" for short – "locational marginal units" is the full term) in ISO-NE in 2015 was 6.7. That equates to a 51% efficiency. Heat pumps run the most during the winter, however, so it's worth looking at monthly heat rates as well. From December to March, monthly heat rates are 6.5, 6.8, 8.0, and 6.5, respectively.[6] Since January and February are the months that demand the most heat, and have a higher heat rate (due to more less-efficient oil and coal plants running), let's assume all CCHP electricity comes at their average heat rate, 7.4 (or 46% efficiency).

To determine the total energy use from when fuel goes into a power plant until heat comes out of the unit on your wall, we need to combine the effect of the COP, line losses, and plant efficiency. Let's assume a home needs 100 MMBtu of heat over the course of the year (a bit higher than most estimates for a typical VT home, but useful as a round number in the right ballpark). Taking the Department's conservative COP of 2.4, you need to use roughly 42 MMBtu of electricity (100/2.4). Translating that into electric terms, you need about 12,300 kWh (42,000,000 BTU / 3412 BTU/kWh). Then, taking into account line losses, power plants need to generate about 12,600 kWh to deliver that electricity (12,300 kWh / 97.8% transmission & distribution efficiency). Finally, to generate 12,600 kWh mostly in winter months from marginal units, you would need an estimated 27,400 kWh worth of energy inputs (12,600 kWh / 46% plant efficiency), or 93.5 MMBtus of energy (27,400 kWh * 3412 BTUs/kWh).

So, using conservative estimates across the board, you would need to use 93.5 MMBtus of energy to produce 100 MMBtus of usable heat in a Vermont home. To generate that same 100 MMBtus of heat by burning oil or another fossil fuel in your furnace or boiler, you would need 105 to 125 MMBtus of fossil fuel inputs (100 MMBtus / 95% and 80% efficiency, respectively). Put another way, a CCHP installed today is at least 11% to 25% more efficient than a fossil fuel heating unit.

Second, greenhouse gasses. These calculations are a little simpler. Returning to the fact that CCHPs are used the most in the middle of winter, the average CO2 emissions from LMUs in January and February in

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[5] https://www.iso-ne.com/static-assets/documents/2017/01/2015_emissions_report.pdf

[6] Id

ISO-NE is 900 lbs per MWh generated.[7] Taking into account line losses, that functionally goes up to 920 lbs. We know we need 12,300 kWh, or 12.3 MWs, and that will create 11,300 lbs of CO2, or 5.11 metric tons, assuming all of the generation is coming from LMUs, which again are primarily fossil fuel plants. GHG emissions from the burner tip of a fossil fuel heating unit range from a low of 117 lbs of CO2 per MMBtu of natural gas to a high of 161 lbs/MMBtu for oil.[8] Factoring in the energy lost in burning the fuel for heat (again, from 5 to 20%), the lowest GHG emissions would be for a high-efficiency gas unit (roughly 5.6 metric tons: 105 MMBtus * 117 lbs/MMBtu / 2200 lbs/tonne). That's roughly 10% more than the CCHP. An 80% efficient oil unit would result in 9.1 metric tons, or 80% more than the CCHP.

All of the above calculations are assuming the "worst hypothetical case" scenario. This reflects the most conservative realistic numbers for every aspect of the calculation, and ignores Vermont's actual renewable policies and electric mix. The reality on the ground is much more favorable for heat pumps than this. For one, Vermont has a requirement that all Vermont utilities provide at least 55% renewable electricity to their customers (ramping up to 75% by 2032). We also have roughly 10,000 solar systems in Vermont, many of which are installed on homes that will be (or are) early adopters of CCHPs as well. Hundreds of MW more in-state renewables are required in the next 15 years, which will continue to increase the efficiency and emissions benefits of heat pumps. And that all is to say nothing of the ISO-NE mix as a whole getting more efficient and new heat pumps getting more efficient and cost effective over time. Building a market now will ensure that those newer, even more beneficial CCHPs are adopted more quickly down the road.

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[7] Id

[8] https://www.eia.gov/tools/faqs/faq.php?id=73&t=11