Interim Report - Thermal Energy Storage

by Nicholas Allan

Problem Definition

Existing residential energy infrastructure is dependent on fossil fuels. 15% of total U.S. natural gas consumption in 2022 was used for residential purposes. Based on 2020 US energy usage data, over 90% of natural gas used in homes is for space heating and water heating. The total energy consumption for space and water heating from natural gas, propane, and fuel oil in homes is approximately the same as the total electrical energy usage. This indicates that the electrical grid would need to output twice what it currently does annually to replace fossil fuel heating with electric heaters. Heat pumps could significantly mitigate this issue, as they can be around 3-5 times more energy efficient in space heating than electric resistance heating and 2-3 times more efficient at heating water than electric. Unfortunately, heat pumps are not as consistent in their performance and application as other heating methods. Air-source heat pumps are less effective the colder the outside air it is drawing energy from is; ground-source heat pumps require significant drilling/digging of the ground, which can be hindered by local geology. Because of these limitations, it may make sense to store heat with thermal energy storage (TES) to use when the heat pump is insufficiently efficient or non-functional due to ambient temperature or insufficient electricity availability.

Methodology

The first thing I need to do is determine the energy demand of a house. Using this, I can determine what size a potential storage solution would be needed to meet the energy demand. TES solutions could be further weighted based on the safety of the required materials, initial capital cost, and disruption caused by installation and maintenance. Depending on the complexity and available information for certain solutions, modeling the heat transfer in more detail may be required.

Progress

So far, I have determined the energy demand of a 2000 ft^2 house. I found a 2020 dataset for heating degree day (HDD) values, which measures the difference between a baseline temperature (65 °F) and the average temperature for the day. Using this data, I determined the peak HDD value of 2020 for the country, which was in North Dakota. I then found recommended R-values for walls, doors & windows, and the ceiling for the region. Using the temperature difference calculated by using the peak HDD, the R-values, and the area of the walls, doors/windows, and ceiling of the house (40x50x8.5 ft, 15/85 window to wall area ratio) I determined the hourly heat demand for a house insulated to recommended levels on the coldest day of the year in North Dakota. To check the size this would take in a basic example, I calculated the volume of a water tank would need to be around 400 cubic feet to store enough heat to handle a consecutive week of the coldest day of the year. This could be done with a cylinder 8 ft in diameter and height, which could easily fit above or below ground.

Expected Results

I expect that by continuing this project I will find a TES solution that will help mitigate the efficiency and reliability concerns of heat pumps, allowing for more effective deployment of the technologies and ultimately reducing carbon emissions in the residential energy sector.

Citations

1. https://www.eia.gov/energyexplained/natural-gas/use-of-natural-gas.php
2. https://www.eia.gov/consumption/residential/data/2020/c&e/pdf/ce4.1.pdf
3. https://www.energy.gov/energysaver/heat-pump-systems
4. https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/degree_days/ddayexp.shtml
5. https://ftp.cpc.ncep.noaa.gov/htdocs/degree_days/weighted/daily_data/2020/StatesCONUS.Heating.txt
6. https://www.energystar.gov/saveathome/seal_insulate/identify_problems_you_want_fix/diy_checks_inspections/insulation_r_values
7. https://www.e-education.psu.edu/egee102/node/2057