<u>Rainwater as a Source of Geothermal Energy: A Heat Storage Experiment</u>

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Thesis

In this experiment, I will demonstrate the ability of an insulated container to maintain the temperature of relatively warm rainwater for use during periods of cold outside weather as a source of stored geothermal energy. As a source of geothermal energy, rainwater has the potential to halve wintertime heat pump energy usage through simple means of capture and storage. Although the months of January and February are typically the coldest in Nova Scotia, with daily minimum temperatures that are frequently -10C or colder, it is also typical for these periods of cold weather to be punctuated by periods of warm weather where air and rainwater temperatures reach 10C or higher. This relatively warm rainwater, which accumulates rapidly over large surface areas like rooftops, parking lots, and roads, can be stored for use with water-source heat pumps as a source of geothermal energy. Using relatively warm rainwater, heat pumps can produce heat using much less energy than air sourced heat pumps and cold outside air. A rooftop with dimensions of 15Mx15M will accumulate 2250L of rainwater with 10mm of rainfall. Wintertime rain events often deliver much more rain than this and will produce as much as 10,000L. If this rainwater is captured, it can be used as a source of geothermal energy for water-source heat pumps and greatly reduce heat and hot water costs relative to outside air temperatures of -10C or lower. To be useful, however, this rainwater must be able to be stored for extended periods without significant heat loss in order to substantially reduce heating costs between rainfall events. Fortunately, the results of this experiment indicate that rainwater can be stored for extended periods without excessive heat loss that would reduce its usefulness as a source of *stored* geothermal energy.

Findings

The ability to store the heat energy contained within water for extended periods does not rely as heavily on the insulation of the storage container but rather its surface area to volume ratio. The larger the storage tank, the lower the surface area to volume ratio and the lower the heat loss. For a large, well insulated container, rainwater heat loss could be maintained at less than 0.5C per day.

A basic analysis reveals that rainwater can reduce heat pump energy usage by an average of 34.5%. However, the thermal energy within an average winter's month worth of rain falling on a single family household, equal to 16,875L, can be used up within 4.7days given the high rate of daily household energy usage for heating and hot water. In comparison to a standard heat pump, this might result in monthly energy savings of approximately 31kwh. When additional rainfall is capture from other hard surfaces attached to a property, this figure can be doubled. Better management of the rainwater, such as saving it for the coldest parts of the day, can further increase the energy savings. 31kwh-60kwh in electricity savings is not a small amount of power, even if it represents a small amount of revenue. A solar photovoltaic array only produces its peak output for a few hours on sunny days and even then will seldom reach its peak generating capacity in Nova Scotia during the wintertime. The cost of a storage tank, by comparison, might be much lower and so provide a more profitable source of energy.

Ultimately, the potential for rainwater as a source of geothermal energy depends on the volume of rainwater captured with the amount captured increasing rapidly with the size of the catchment area. Doubling of length of a square catchment surface results in a quadrupling of the catchment area.

Rainwater as geothermal energy may, therefore, be especially suited to large rooftops or other large, non porous, surfaces such as parking lots and roadways. There is over 1700km of municipal roadways in the Halifax Regional Municipality with millions of liters of rainwater accumulating on them each month. In the long-run, perhaps cities can be designed to take better advantage of this overlooked resource.

Rainwater storage also has further potential benefits. In the wintertime, a heat pump using stored rainwater will not suffer the disadvantage of icing and need to go through energy-consuming defrost cycles. Stored thermal energy within rainfall can also be augmented by passive and active solar energy. Decorative features like ponds and fountains can be used to 'recharge' rainwater heat storage systems during days where the outside temperature is above zero. Solar structures, like greenhouses, can be used to collect solar heat and store it within the rainwater for later use. In the summertime rainwater can be used as a heat-sink for air conditioning and refrigeration systems. Rainwater also be used for lawns and gardens as an alternative to using clean drinking water for these purposes.

Experimental Design

This simple experiment will be conducted using an insulated container, formed out of a clean garbage can, and miscellaneous insulating materials, and holding within it a 18L container of water. The water temperature of the container will be measured at regular intervals using a digital fish tank thermometer that does not require either the insulated container or container of water to be opened. To ensure an accurate measurement of the *average* temperature of the water within the water container, I will shake the insulated container for 30 seconds and allow the water to settle before taking a measurement.

Observations

The observations gathered in this experiment were collected at '2' hour intervals with a break of 10 to 12 hours between sometime after mid night and noon the next day in data collection for necessary sleep breaks. In Experiment 1, the container of water experienced 4.5C of cooling over the 24 hour period which spanned the entire experiment. In Experiment 2, which covered 2.5 24 hour periods, the container of water experienced a total cooling of 8.5C for an average cooling per day of 3.4C. The rates of cooling in the two experiments differ somewhat for two reasons. The first experiment was conducted on a relatively colder day, as shown by the average daily temperature of Experiment 1 versus Experiment 2. For Experiment 2, I also improved upon the insulation of the container slightly.

Time (Feb 26 & 27)	Water Temperature (C)	Outside Temperature (C)
6:15pm	11.0	-8
8:15pm	10.4	-8
10:15pm	10.0	-9
12:15am	9.6	-10
2:15am	9.0	-10
12:15pm*	6.9	0
2:15pm	6.8	1
4:15pm	6.5	0

6:15pm	6.3	0

Table 1

Time (March 2,3,&4)	Water Temperature (C)	Outside Temperature (C)	Wind Chill (C)
12:45pm (Mar 2)	11.6	-14	-27
2:45pm	10.8	-14	-26
4:45pm	10.1	-13	-24
6:45pm	9.6	-11	-22
8:45pm	9.0	-10	-20
10:45pm	8.6	-10	-20
12:45am (Mar 3)	8.1	-10	-20
10:45am	6.0	-5	-15
12:45pm	5.8	-3	-15
2:45pm	5.6	-1	-9
4:45pm	5.3	-1	-9
6:45pm	5.1	-1	-8
8:45pm	5.0	-2	-8
10:45pm	4.9	-3	-9
12:45am (Mar 4)	4.8	-3	-9
12:45pm	3.8	2	2
2:45pm	3.7	3	3
4:45pm	3.5	3	3
6:45pm	3.5	-1	-1
8:45pm	3.4	-1	-7
10:45pm	3.3	-3	-11
12:45am (Mar 5)	3.1	-5	-13

Table 2

Analysis

Stored Rainwater Temperature Analysis

The high rates of cooling of 4.5C and 3.4C for Experiments 1 and 2 are due to the relatively large surface area to volume ratio of the 20L container used in the experiment. As can be seen Table 3 below, a larger container will have a much lower surface area to volume ratio and so will lose heat at a proportionately lower rate. 1000L is equal to 1 cubic meter. Although still quite small in terms of its exterior dimensions, a 1000L container will lose heat at a rate only 27.2% that of the 20L container. For a 4000L container the rate of heat loss will be 17.3% of the 20L container and for 8000L it will be 13.6%.

For a 8000L container, this equates to a rate of cooling of 0.46C per day, and it would take 21.7 days for the tank to cool to 0C--assuming insulation as good or better than was used in my garbage can (a high likelihood). During the coldest winter months, it is typical to have at least two or more 'warm' rainfall events per month. Therefore, accumulated rainwater can be stored for a long enough period, without excessive heat loss, to be available every day of a given month as a geothermal energy source.

Volume	Length	Surface Area to Volume Ratio	Relative Surface Area of a 20L container
20	27.1	.22	1
100	46.4	.129	1.7
500	79.4	.076	2.89
1000	100	.06	3.67
2000	126.0	.048	4.58
4000	158.7	.038	5.79
8000	200.0	.030	7.33
16,000	251.9	.024	9.17

Table 3

Rainwater Accumulation

As can be seen in Table 4, a significant amount of rainwater will accumulate even on relatively small surface areas. A typical residential roof might produce 2250L of rainwater in a single 10mm rainfall event. As wintertime rainfall events of even 50mm are common, up to 12,000L could be expected. A small to medium sized parking lot could produce anywhere from 9000L to 125,000L, depending on the amount of rainfall. However, this pales in comparison to the millions of liters of rainwater that falls on city streets, sidewalks, and parking lots throughout even a small city such as Halifax. The potential for rainwater as a source of geothermal energy, stored either in surface tanks or underground wells, is enormous and could be especially useful for large residential and commercial centres.

Surface Area (M^2)	Rainfall Amount (mm)	Accumulated Rainfall (L)
225 (15M^2)	10	2250
900 (30M^2)	10	9000
2500 (50$M^{2)}$	10	25,000
10,000 (100M^2)	10	100,000

Table 4

The Amount of Energy Contained Within Rainwater

Using the results of a previous study and local weather data, it is possible to get a sense of the amount of energy available in rainwater for single family homes or larger developments including district heat.[1]

In the previous study, I estimated the wintertime cold performance of a heat pump using temperature differences between a heat pump's warm interior operating temperature and its cold exterior operating temperature. Based on these findings, inside temperatures of 20C and outside temperatures of -10C

[1] Frederick Thomas, Wintertime Solar Heat Production and Storage.

correspond to a heat pump COP of 2.2C. An outside temperature of 0C corresponds to a heat pump COP of 3.0, and an outside temperature of 10C corresponds to a heat pump COP of 3.8.

Therefore, with an outside air temperature of -10C, a heat pump might be expected to consume 0.455kwh of electricity to produce 1kwh of heat. At an outside temperature of 0C, the heat pump will produce the same amount of heat using 0.333kwh of electricity, 0.122kwh or 27% less than at an -10C. At an outside temperature of 10C, the heat pump will use approximately 0.263kwh of electricity to produce 1kwh of heat, 0.192kwh or 42% less than the heat pump would use at -10C.

56.2mm, 65.2m, 95.5mm, and 81mm of rain fell in Halifax, NS, during the months of December, January, February, and March (ending 2021), respectively. For ease of analysis, I will use the 'average' rainfall amount per month during this period which is equal to approximately 75mm. For a typical single family residential roof, with dimensions of 15M x 15M, this is equal to roughly 16,875L of rainwater per month. According to an online energy calculator, it would take 197kwh to heat this volume of water from 0C to 10C. That means that 197kwh of equivalent heat can also be extracted from the same volume of rainwater before it freezes. Based on the same earlier study, a typical 100 year old small family home that is well insulated, in Halifax, NS, and is heated by resistance-based electric heat might consume 42kwh of electricity a day during the coldest part of the winter for heating. 197kwh would provide 4.70 days of reduced heating costs between 27% and 42%. At a COP of 2.2, 197kwh of electric resistance-based heat would require 90kwh when produced by a heat pump. At a further average heat pump energy savings of 34.5%, this would result in a 31kwh reduction in monthly power consumption.

It also typical that the hard surface areas accompanying a typical single family home, such as driveways, patios, and roof surfaces belonging to outbuildings, to be at least equal to the surface area of a household's rooftop. In this case, double the rainwater would be available for use. By way of comparison, a nearby double tennis court has a perimeter of approximately 30M by 30M. With an average monthly rainfall of 75mm, it will accumulate 67,500L of rainwater per month. At 10C, 788kwh of heat could be extracted from it before it cools to 0C to provide 18.8 heating days at 34.5% reduced heat pump energy costs. Roadways and parking lots would also provide another large source of rainwater for geothermal energy system. According to the municipal website, the Halifax Regional Municipality current maintains 1772km of asphalt paving. There is no estimation for the total surface area of parking lots within the municipality. Ultimately, municipal rainwater collection systems could be designed to aggregate rainwater at collection points where it could be used in conjunction with large scale residential and commercial developments or paired with district heating systems to distribute the heat energy produced from it. For smaller surface areas, such as household rooftops, the costs may not outweigh the benefits, but for larger volumes of rainwater, and where economies of scale can be generated in system costs, rainwater might prove cost effective as a source of geothermal energy.

Although for this analysis I assumed temperature differences based on a -10C outside air temperature, actual temperatures can vary greatly between the coldest parts of the day and the warmest. Very cold days can also be followed by warmer days in close succession. Therefore, it would be better to 'save' the energy within stored rainwater for the colder parts of a day or the coldest days. If used only for 12 hours a day, 16,875L of rainwater would provide 9.4 half days of reduced heating costs. By doing so, the average energy savings could be increased through increasing the average temperature difference between the outside air temperature and the temperature of the stored rainwater. There were 10 days in February when the minimum temperature was below -10C with the coldest being -13.8C. These minimum temperatures were paired with maximum temperatures that, for all but one, were at least 5C warmer with the smallest difference equal to 2.6C and the largest difference being equal to 16.7C.[2]

During this time, there were also 10 days when the outside temperature was above 0C with 9 of the days reaching at least 3C. These above zero days can also be used to 'recharge' the rainwater with thermal energy. The rainwater could be recirculated over rooftops, using an electric pump, to absorb the heat from the air and the sun (which can cause the temperature of the surfaces it strikes to rise far above the daytime air temperature). Decorative features like fountains, ponds, and waterfalls can also be used to transfer heat energy from the surrounding environment back into the rainwater.

Rainwater storage can also provide useful benefits other times of the year. It can be used as a heat-sink for air conditioning and refrigeration. It can also be used on lawns and gardens to promote greener and more abundant natural surroundings as a substitute for the use of clean drinking water for this purpose.

Conclusion

The amount of geothermal heat energy that can be extracted from rainwater depends on the amount of rainwater available. At the rate at which a family home uses energy, the amount of heat energy contained in one month's rainfall amount will provide 4.7 days of reduced heat costs of about 34.5% and roughly equal to 31kwh. The average reduction in heating costs equal to 34.5% can be increased if the rainwater is used during the coldest parts of the month rather than continuously during both warmer and colder periods. If all hard surfaces belonging to a property are used for rainwater capture, such as driveways, patios, and the roofs of outbuildings attached to the property, this figure can be doubled.

Although 31kwh does not represent a significant amount of revenue, it is a significant amount of energy. There is the potential, if captured in large volumes using roadways and parking lots, for rainwater to provide a large source of geothermal energy. Large retaining ponds and holding tanks can be incorporated into large scale developments to take advantage of economies of scale in design and construction costs versus single residential units. Conversely, heat and be produced from rainwater in central catchment areas and then distribute the heat energy collected via district heating systems.

Ultimately, the viability of any energy system depends on its profitability—its returns relative to cost. As long as construction costs can be kept low, smaller scale rainwater energy systems can be profitable. Because the heat energy can be used up so rapidly in the winter by residential heating demands, it may not be necessary to heavily insulate rainwater storage tanks. As long as they are kept out of the wind, the low surface area to volume ratio of a large tank might be sufficient to reduce heat loss to an acceptable level during the period in which the heat energy within it can be used up.

[2] See Appendix A.

A household rainwater storage system producing between 30kwh-60kwh of electricity per month would be roughly equivalent to a 1kw solar photovoltaic system. Likely the costs of such a system would be greater than a rainwater capture and storage system. Therefore, rainwater can potentially be used as more cost effective source of alternative energy than other popular alternatives already in common use. During the summertime it can also act as a heat sink for air conditioning and refrigeration systems and provide irrigation for lawns and gardens instead of using clean drinking water for these purposes.

Appendix

Day	Max Temp (°C)	Min Temp (°C)	Total Rain (mm)	Total Precipitation (mm)
1	-0.6	-4.6	0	0
2			38.6	53.2
3			9	9
4			1.4	1.4
5			3.2	4.8
6	7.7	-1.7	14.6	14.6
7	-1.8	-4.4	0	25.6
8	-1.6	-10	0	21.3
9	-4.5	-11.2	0	0
10	-6.4	-13.8	0	0
11	-7.2	-13.2	0	0.6
12	-4	-13.7	0	2.4
13	-4.2	-9.5	0	0
14	-1.9	-10.5	0	0
15	-0.5	-7	0	0.2
16	6.9	-4.3	2.6	3.4
17	5.8	-8	0	0
18	-5.4	-9.9	0	0
19	-2.7	-8.8	0	0
20	-4.8	-7.8	0	9.8
21	-3.4	-8.9	0	0
22	0	-7.5	0	2
23	4.1	-1.4	9.8	13.2
24	3.6	-1.2	0	0
25	6.1	-7.8	6	6
26	-6.2	-10.5	0	0
27	5.6	-11.1	10.3	11.4
28	5	-3.8	0	0

February2021 Climate Data