Utilizing the Thermoelectric Properties of Concrete: An Analysis of the Most Electric-and-Cost-Efficient Materials in to Generate a Voltage from Concrete Using the Seebeck Effect

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Abstract

The urban heat island (UHI) effect describes the tendency of urban areas to be significantly hotter than nearby rural areas. One of the leading causes of this effect is due to the thermal properties of concrete, which absorbs lots of thermal energy and slowly radiates it into the environment, but through utilizing the Seebeck effect- a phenomenon in which a temperature difference between semiconductors creates voltage- concrete can be modified into modules for harnessing thermoelectric energy. In this study, our team tested the effects on the electrical efficiency of different materials within concrete. To achieve this, our team curated 19 4.0 x 1.0 x 0.8 in. distinct samples of concrete, each with different combinations of materials including Iron (III) Oxide, Fly Ash, Carbon Fiber, and Graphite Powder. Our data collection consisted of 4 trials: One with copper end caps at 72° (C72), one without copper end caps at 72°(N72), one with copper end caps at 32°(C32), and one without copper end caps at 32°(N32), where the samples had their maximum produced voltages between different time intervals measured. After initial experimentation, our team found that hybrid samples or samples with less water yielded higher amounts of electricity and produced voltage at a faster rate after 5 minutes under the simulated environments. Our findings indicate that samples of thermoelectric concrete with lower concentrations of water and higher concentrations of iron oxide, carbon fiber, and fly ash were most effective in the generation of voltage.

Background

The urban heat island (UHI) effect describes the tendency of urban areas to be significantly hotter than nearby rural areas. One of the leading causes of this effect is due to the thermal properties of concrete. Concrete and asphalt, cornerstones of urban design, absorb lots of thermal energy, and slowly radiate it into the environment (Zafra, 2025). Not only does this make urban areas hotter and much worse to live in during warm seasons, but it is also highly wasteful energy-wise. Of course, building solar panels on sidewalks and roads would be impractical. Thus, by utilizing the Seebeck effect, a phenomenon in which a temperature difference between semiconductors creates voltage, concrete can be modified into modules for harnessing thermoelectric energy. Thermoelectric devices are suitable for this need, since they emit no carbon dioxide emissions and have no moving parts (Singh et al., 2021). Cement-based thermoelectric materials (CTEMs) are a rapidly expanding field of scientific research. Increases in energy demand and the introduction of carbon neutrality goals have made CTEMs a popular field of research in recent years (Li et al., 2025). This research will also allow remote areas to have off-grid clean energy generation with zero moving parts and low maintenance. Additionally, the conversion from thermal energy to electrical will aid in mitigating the UHI effect and reducing heat waste in urban areas. With less heat being radiated back into cities - especially ones in dangerously hot areas –they may not only generate clean and convenient energy, but to also cool down, thus reducing dangers that come with extremely high temperatures such as heat stroke, seizures, increased pollutants, and death (CDC, 2026). The application of CTEMs in civil infrastructure would thus lead to a healthier, cleaner, and lower-maintenance city design.

In our team's analysis of previous work in CTEMs, it seemed that the samples used in studies were on a very small scale, so in addition to creating new combinations of hybrid samples, our team strived to include a more accurate depiction of how the filler materials would affect the voltage produced on a larger scale. Because of this, our team opted for larger molds, measuring at 4.0" x1.0" x 0.8" or approximately 40ml, during the construction of our samples.

In addition, our team aimed to further the demonstrated applicability of thermoelectric concrete in civil infrastructure. None of the other research on CTEMs that we had seen included a comparison of the price of each sample compared to how they performed. Considering that a large concern for city planners and architects is factoring the cost of using a material versus its benefits, our team decided to include an economic efficiency evaluation. This would compare the total voltage that each of the samples generated over the trial and compared them to the price of the sample, thus providing insight into which sample is not only the most electrically efficient but also the most cost efficient.

Research Question

Our objective in this study was to determine the most electric and cost-efficient combination of fillers in concrete samples under a variety of environmental simulations; thus our research questions were how the incorporation of graphite powder, fly ash, carbon fiber, iron II oxide, and copper end caps in concrete samples affect the produced voltage from the samples when a temperature difference is applied to each side in simulated environments, and how does the cost per voltage change for each sample in the trials?

Null Hypothesis

Our null hypothesis is that the addition of fillers to concrete will have no impact on the voltage produced via the Seebeck Effect and that the ratio of the cost to the voltage produced by each sample will not show a more effective sample than the control.

Hypothesis

Our team hypothesized that hybrid blends of fillers would be the most optimal in producing a voltage and that their improved efficiency would offset the additional costs of their materials. More specifically, we hypothesized that the hybrid combination of Iron II Oxide and Graphite Powder with copper end caps would show the most optimal results for both voltage generation and cost efficiency throughout our trials.

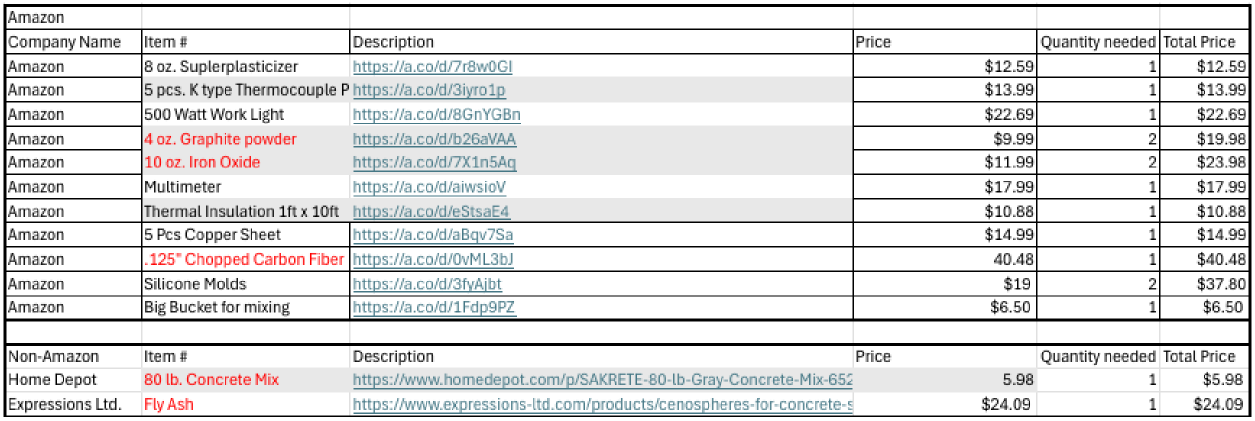
Materials and Methods

Sample Creation

Before beginning experimentation, our team first had to curate the needed samples. To achieve this, we first pulled viable fillers that we believed would be effective to our goal and listed them along with all other materials needed for our research. Once we had compiled our materials list, we created a comprehensive budget including vendors and prices. This was necessary not only to receive funding and order for our objects but also became useful for calculating the cost analysis for each sample. A listing of our budget is shown below.

Figure 1.

Depicted below is a table depicting our materials used as well as cost and quantity.



Amazon					
Company Name	Item #	Description	Price	Quantity needed	Total Price
Amazon	8 oz. Suplerplasticizer	https://a.co/d/7r8w0GI	$12.59	1	$12.59
Amazon	5 pcs. K type Thermocouple P	https://a.co/d/3iyro1p	$13.99	1	$13.99
Amazon	500 Watt Work Light	https://a.co/d/8GnYGBn	$22.69	1	$22.69
Amazon	4 oz. Graphite powder	https://a.co/d/b26aVAA	$9.99	2	$19.98
Amazon	10 oz. Iron Oxide	https://a.co/d/7X1n5Aq	$11.99	2	$23.98
Amazon	Multimeter	https://a.co/d/aiwsioV	$17.99	1	$17.99
Amazon	Thermal Insulation 1ft x 10ft	https://a.co/d/eStsaE4	$10.88	1	$10.88
Amazon	5 Pcs Copper Sheet	https://a.co/d/aBqv7Sa	$14.99	1	$14.99
Amazon	.125" Chopped Carbon Fiber	https://a.co/d/0vML3bJ	40.48	1	$40.48
Amazon	Silicone Molds	https://a.co/d/3fyAjbt	$19	2	$37.80
Amazon	Big Bucket for mixing	https://a.co/d/1Fdp9PZ	$6.50	1	$6.50
Non-Amazon	Item #	Description	Price	Quantity needed	Total Price
Home Depot	80 lb. Concrete Mix	https://www.homedepot.com/p/SAKRETE-80-lb-Gray-Concrete-Mix-652	5.98	1	$5.98
Expressions Ltd.	Fly Ash	https://www.expressions-ltd.com/products/cenospheres-for-concrete-s	$24.09	1	$24.09

Note: The identified fillers and concrete mix we utilize are shown in red text.

Our team identified Graphite Powder (GP), Iron II Oxide (Fe_2O_3), Chopped Carbon Fiber (CF), and Fly Ash (FA) as viable fillers for this study due to their previous success individually and affordability as compared to other potential materials.

While awaiting the arrival of our selected materials, our team focused on how to properly create our samples. Following various video tutorials on how to create and cure concrete, along with Portland cement manufacturers' manual, our team developed our first four samples, two controls, one Fe_2O_3, and one GP sample. When checking these initial samples, however, we observed cracking and found the samples were very brittle: falling apart easily and weak to the touch. Upon further research, we learnt to strengthen concrete; you must wet cure it: keeping the cement continuously moist and hydrated to maximize strength and durability. This is because water evaporates which leaves air pockets within the concrete: thus, leaves it fragile and brittle. This is an especially prevalent issue in smaller scaled samples, where the ratio of the exposed surface area of the concrete to its total volume is much higher than what is typically curated. To mitigate this problem, as the cement was left to cure, our team blanketed it in damp paper towels as a barrier to prevent water from evaporating and keeping the water within the system.

Figure 2.

Initial Concrete Samples

Note: Initial samples of concrete left to dry in open air and show structural instability. The photo depicts two control samples and one Iron II Oxide sample.

Figure 3.

Revised methodology of wet curing being used on latest concrete samples.

Note: Damp paper towels placed on top of samples to allow concrete to absorb water while curing.

Our revised method of wet curing the samples led to great improvements in our next samples, where we noted that the concrete seemed much more stable and didn't show large air pockets or cracks like before. The initial samples were disposed of, as their structural instability would cause increased difficulty in physical experimentation along with possibly skewing results; however, this realization of how impactful the amount of water added to the mixture could affect the structure of samples, our team was curious as to whether the amount of water in samples would also affect the thermoelectric properties of the concrete, thus our team also created a control sample and a sample with all of our fillers with 75% as much water to observe any effects. In addition, another change in methodology was spacing each sample in every other slot. This was to prevent cross contamination between samples as materials were added to their slots. Samples were labeled using paper while curing and were marked with a sharpie once cured to maintain clear organization of the concrete.

After completing our sample curation, our team ended with the following 19 samples: the Control, Control with 0.75x Water, Iron II Oxide, Carbon Fiber, Graphite Powder, Fly Ash, Iron II Oxide + Carbon Fiber, Iron II Oxide + Graphite Powder, Iron II Oxide + Fly Ash, Carbon Fiber + Graphite Powder, Carbon Fiber + Fly Ash, Graphite Powder + Fly Ash, Iron II Oxide + Carbon Fiber + Graphite Powder, Iron II Oxide + Carbon Fiber + Fly Ash, Iron II Oxide + Graphite Powder+ Fly Ash, Carbon Fiber + Graphite Powder + Fly Ash, Iron II Oxide*2 + Carbon Fiber*2 + Fly Ash*2, All Materials (everything), and All Materials with 0.75x Water.

Data Collection

Our team's data collection consisted of 4 types of trials. One with copper end caps at 72° (C72), one without copper end caps at 72°(N72), one with copper end caps at 32°(C32), and one without copper end caps at 32°(N32).

In our second trial, we began measuring the copper covered concrete with one end being placed in a properly made ice bath according to an article from ThermoWorks that allowed the cool side to measure at approximately 32°F (Thermoworks). The other side of the concrete was then hit with the heat lamp for 5 minutes, with the highest voltage produced between different time intervals being recorded in an Excel table.

Because the Manassas Park Library has temperature-controlled rooms, our team was able to maintain a reliable outside temperature over the course of our trials. In our trials on April 16th and 17th in their Study Rooms. These rooms were set to an internal temperature of approximately 72°F. In our trials with coolant, we utilized ice water that measured at approximately 32°F.

Our team ensured that our apparatus was fully set up and tested to ensure proper functionality as before beginning any experimentation. An image of the K-Type Temperature probe attached to our temperature-measuring multimeter is pictured below in figure 3. This was used initially to ensure proper starting temperatures prior to each trial.

Figure 3.

Thermocouple setup

Note: The setup of the thermocouple to ensure accurate starting temperatures at the beginning of each trial. Photo taken by author on April 16th, 2026.

For safety, our team determined that sunglasses in the lab are not optional, which in addition to making us look cool, provided us with protection from the brightness of the heat lamp as pictured below.

Figure 4:

Personal Protective Equipment in the lab.

Note: Photo taken by author on April 17th, 2026.

Prior to experimentation, the concrete samples were covered in copper foil end caps. In preparation for the C32 and C72 trials. Images of these samples are shown below.

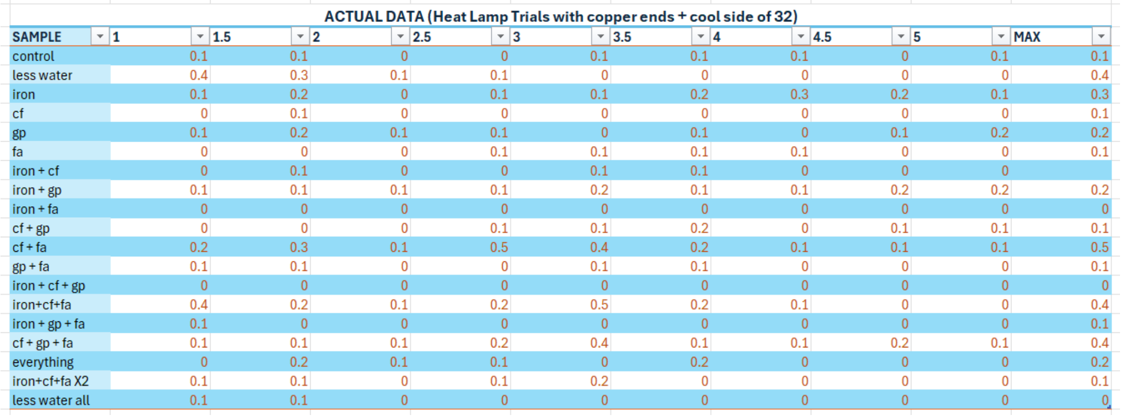
Figure 5, 6.

Concrete samples with copper end caps.

Results

Figure 7.

C32 trials and mV produced

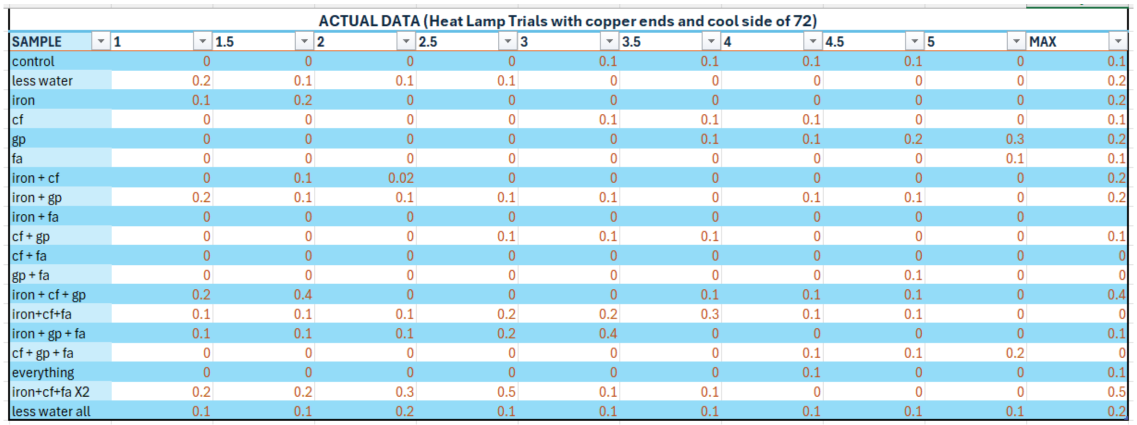


ACTUAL DATA (Heat Lamp Trials with copper ends + cool side of 32)

SAMPLE	1	1.5	2	2.5	3	3.5	4	4.5	5	MAX
control	0.1	0.1	0	0	0.1	0.1	0.1	0	0.1	0.1
less water	0.4	0.3	0.1	0.1	0	0	0	0	0	0.4
iron	0.1	0.2	0	0.1	0.1	0.2	0.3	0.2	0.1	0.3
cf	0	0.1	0	0	0	0	0	0	0	0.1
gp	0.1	0.2	0.1	0.1	0	0.1	0	0.1	0.2	0.2
fa	0	0	0	0.1	0.1	0.1	0.1	0	0	0.1
iron + cf	0	0.1	0	0	0.1	0.1	0	0	0	
iron + gp	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.2
iron + fa	0	0	0	0	0	0	0	0	0	0
cf + gp	0	0	0	0.1	0.1	0.2	0	0.1	0.1	0.1
cf + fa	0.2	0.3	0.1	0.5	0.4	0.2	0.1	0.1	0.1	0.5
gp + fa	0.1	0.1	0	0	0.1	0.1	0	0	0	0.1
iron + cf + gp	0	0	0	0	0	0	0	0	0	0
iron+cf+fa	0.4	0.2	0.1	0.2	0.5	0.2	0.1	0	0	0.4
iron + gp + fa	0.1	0	0	0	0	0	0	0	0	0.1
cf + gp + fa	0.1	0.1	0.1	0.2	0.4	0.1	0.1	0.2	0.1	0.4
everything	0	0.2	0.1	0.1	0	0.2	0	0	0	0.2
iron+cf+fa X2	0.1	0.1	0	0.1	0.2	0	0	0	0	0.1
less water all	0.1	0.1	0	0	0	0	0	0	0	0

Figure 8:

C72 trials and mV produced

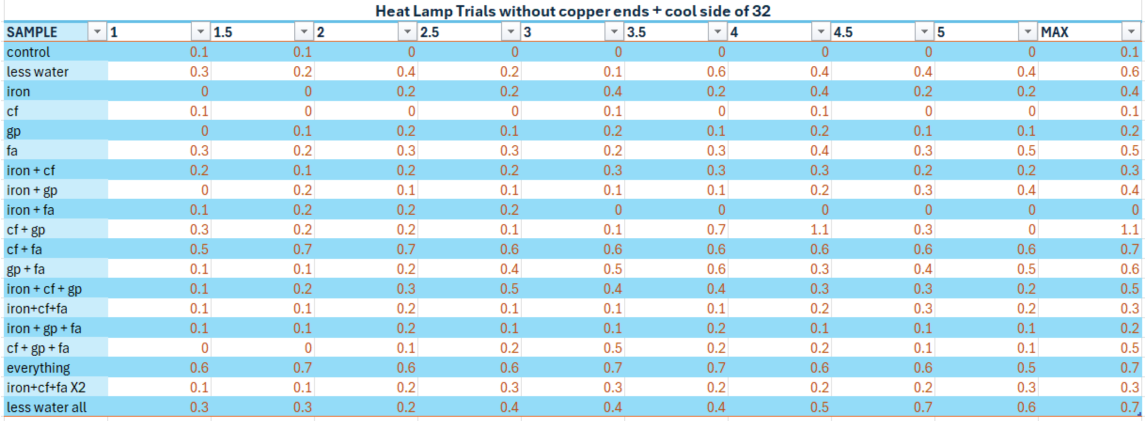


ACTUAL DATA (Heat Lamp Trials with copper ends and cool side of 72)

SAMPLE	1	1.5	2	2.5	3	3.5	4	4.5	5	MAX
control	0	0	0	0	0.1	0.1	0.1	0.1	0	0.1
less water	0.2	0.1	0.1	0.1	0	0	0	0	0	0.2
iron	0.1	0.2	0	0	0	0	0	0	0	0.2
cf	0	0	0	0	0.1	0.1	0.1	0	0	0.1
gp	0	0	0	0	0	0.1	0.1	0.2	0.3	0.2
fa	0	0	0	0	0	0	0	0	0.1	0.1
iron + cf	0	0.1	0.02	0	0	0	0	0	0	0.2
iron + gp	0.2	0.1	0.1	0.1	0.1	0	0.1	0.1	0	0.2
iron + fa	0	0	0	0	0	0	0	0	0	
cf + gp	0	0	0	0.1	0.1	0.1	0	0	0	0.1
cf + fa	0	0	0	0	0	0	0	0	0	0
gp + fa	0	0	0	0	0	0	0	0.1	0	0
iron + cf + gp	0.2	0.4	0	0	0	0.1	0.1	0.1	0	0.4
iron+cf+fa	0.1	0.1	0.1	0.2	0.2	0.3	0.1	0.1	0	0
iron + gp + fa	0.1	0.1	0.1	0.2	0.4	0	0	0	0	0.1
cf + gp + fa	0	0	0	0	0	0	0.1	0.1	0.2	0
everything	0	0	0	0	0	0	0.1	0	0	0.1
iron+cf+fa X2	0.2	0.2	0.3	0.5	0.1	0.1	0	0	0	0.5
less water all	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2

Figure 9:

N32 trials and mV produced

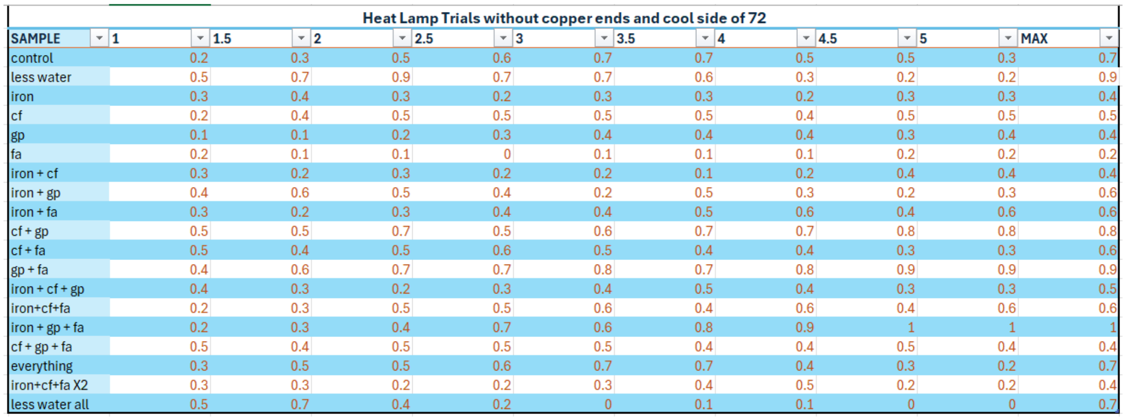


Heat Lamp Trials without copper ends + cool side of 32

SAMPLE	1	1.5	2	2.5	3	3.5	4	4.5	5	MAX
control	0.1	0.1	0	0	0	0	0	0	0	0.1
less water	0.3	0.2	0.4	0.2	0.1	0.6	0.4	0.4	0.4	0.6
iron	0	0	0.2	0.2	0.4	0.2	0.4	0.2	0.2	0.4
cf	0.1	0	0	0	0.1	0	0.1	0	0	0.1
gp	0	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.1	0.2
fa	0.3	0.2	0.3	0.3	0.2	0.3	0.4	0.3	0.5	0.5
iron + cf	0.2	0.1	0.2	0.2	0.3	0.3	0.3	0.2	0.2	0.3
iron + gp	0	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.4	0.4
iron + fa	0.1	0.2	0.2	0.2	0	0	0	0	0	0
cf + gp	0.3	0.2	0.2	0.1	0.1	0.7	1.1	0.3	0	1.1
cf + fa	0.5	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.7
gp + fa	0.1	0.1	0.2	0.4	0.5	0.6	0.3	0.4	0.5	0.6
iron + cf + gp	0.1	0.2	0.3	0.5	0.4	0.4	0.3	0.3	0.2	0.5
iron+cf+fa	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.3	0.2	0.3
iron + gp + fa	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.2
cf + gp + fa	0	0	0.1	0.2	0.5	0.2	0.2	0.1	0.1	0.5
everything	0.6	0.7	0.6	0.6	0.7	0.7	0.6	0.6	0.5	0.7
iron+cf+fa X2	0.1	0.1	0.2	0.3	0.3	0.2	0.2	0.2	0.3	0.3
less water all	0.3	0.3	0.2	0.4	0.4	0.4	0.5	0.7	0.6	0.7

Figure 10:

N72 trials and mV produced



Heat Lamp Trials without copper ends and cool side of 72

SAMPLE	1	1.5	2	2.5	3	3.5	4	4.5	5	MAX
control	0.2	0.3	0.5	0.6	0.7	0.7	0.5	0.5	0.3	0.7
less water	0.5	0.7	0.9	0.7	0.7	0.6	0.3	0.2	0.2	0.9
iron	0.3	0.4	0.3	0.2	0.3	0.3	0.2	0.3	0.3	0.4
cf	0.2	0.4	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.5
gp	0.1	0.1	0.2	0.3	0.4	0.4	0.4	0.3	0.4	0.4
fa	0.2	0.1	0.1	0	0.1	0.1	0.1	0.2	0.2	0.2
iron + cf	0.3	0.2	0.3	0.2	0.2	0.1	0.2	0.4	0.4	0.4
iron + gp	0.4	0.6	0.5	0.4	0.2	0.5	0.3	0.2	0.3	0.6
iron + fa	0.3	0.2	0.3	0.4	0.4	0.5	0.6	0.4	0.6	0.6
cf + gp	0.5	0.5	0.7	0.5	0.6	0.7	0.7	0.8	0.8	0.8
cf + fa	0.5	0.4	0.5	0.6	0.5	0.4	0.4	0.3	0.3	0.6
gp + fa	0.4	0.6	0.7	0.7	0.8	0.7	0.8	0.9	0.9	0.9
iron + cf + gp	0.4	0.3	0.2	0.3	0.4	0.5	0.4	0.3	0.3	0.5
iron+cf+fa	0.2	0.3	0.5	0.5	0.6	0.4	0.6	0.4	0.6	0.6
iron + gp + fa	0.2	0.3	0.4	0.7	0.6	0.8	0.9	1	1	1
cf + gp + fa	0.5	0.4	0.5	0.5	0.5	0.4	0.4	0.5	0.4	0.4
everything	0.3	0.5	0.5	0.6	0.7	0.7	0.4	0.3	0.2	0.7
iron+cf+fa X2	0.3	0.3	0.2	0.2	0.3	0.4	0.5	0.2	0.2	0.4
less water all	0.5	0.7	0.4	0.2	0	0.1	0.1	0	0	0.7

Data Analysis

Of the copper-capped samples at 72°F, we found that the Iron Oxide, Carbon Fiber, and Fly Ash combination produced the highest total voltage produce. This can be seen below in the following figures 11 & 12.

Figure 11.

Bar graph of produced mV of copper-capped samples at 72°F at different time points from one to five minutes.

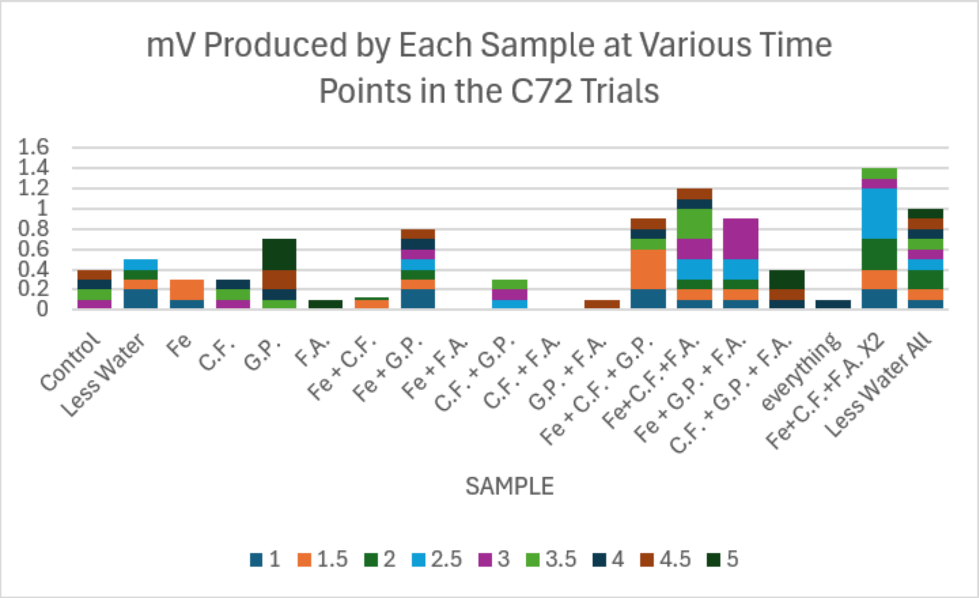
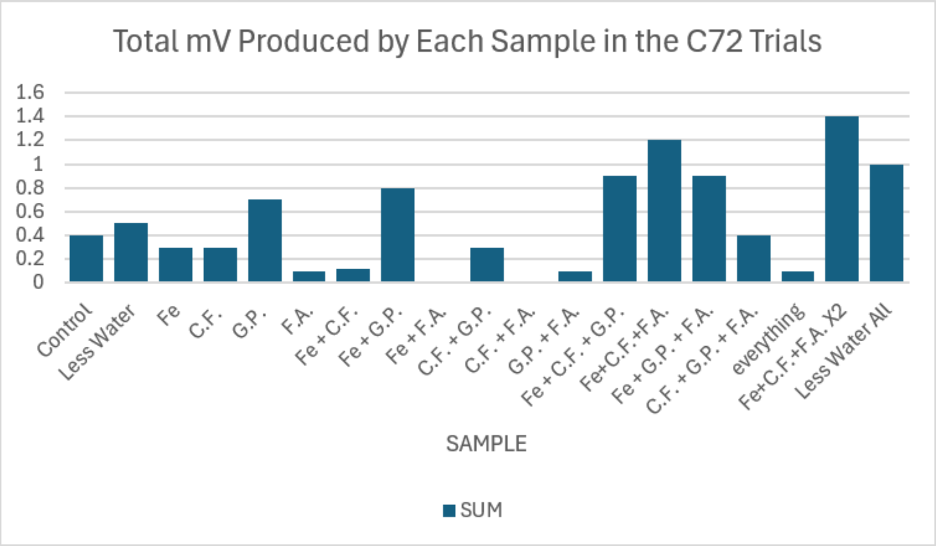


Figure 12.

Bar graph of total mV of copper-capped samples at 72°F



In the copper-capped samples at 32°F, we found that the Carbon Fiber and Fly Ash combination produced the highest total voltage produce. This can be seen below in figures 13 and 14.

Figure 13.

Bar graph of produced mV of copper-capped samples at 32°F at different time points from one to five minutes.

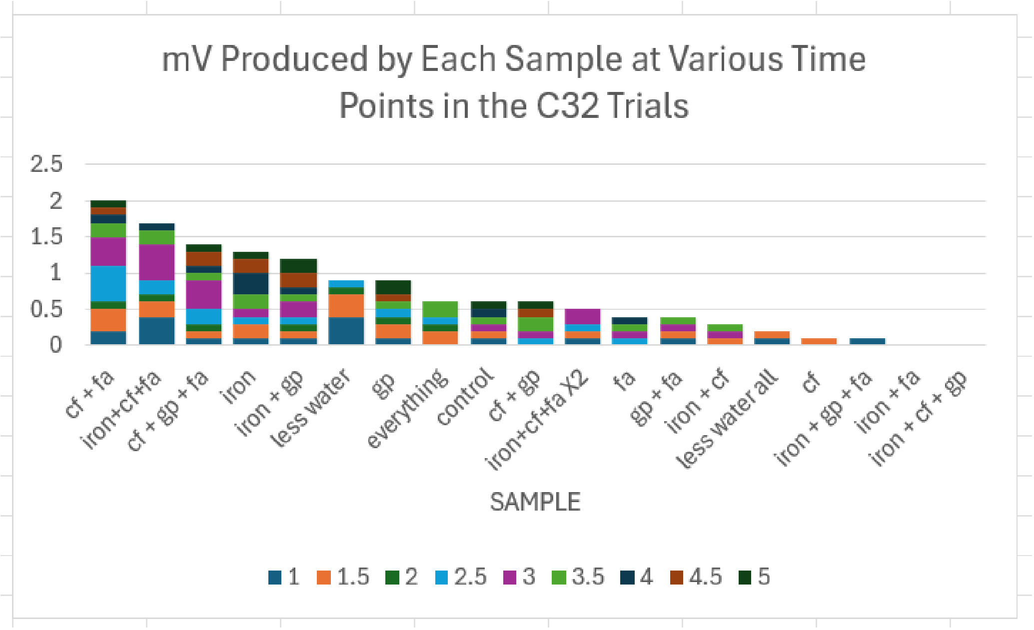
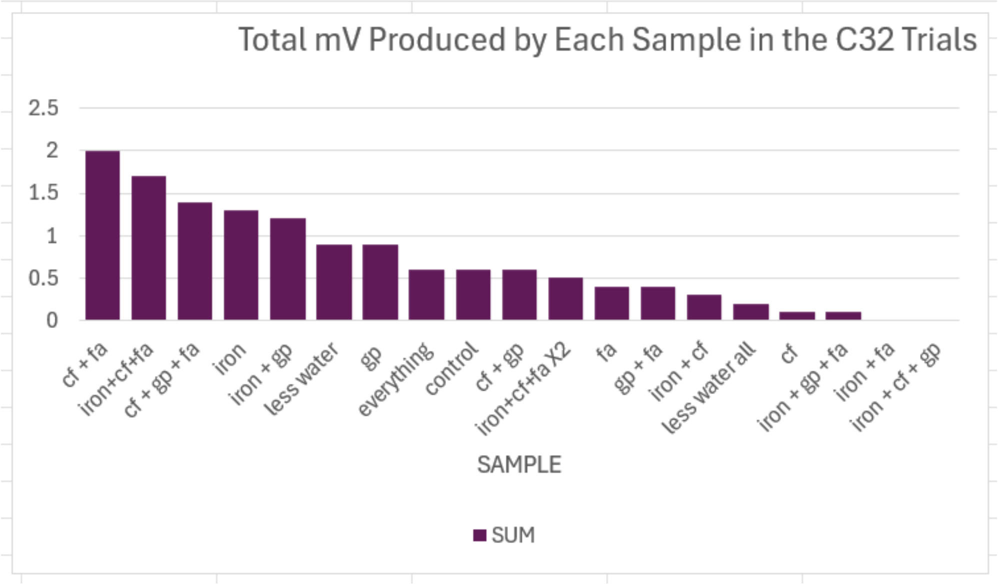


Figure 14.

Bar graph of total produced mV of copper-capped samples at 32°F



In the samples without copper at 72°F, we found that the Graphite Powder and Fly Ash combination had the highest total voltage produce. This can be seen below in figures 15-16.

Figure 15.

Bar graph of produced mV of samples without copper-caps at 72°F at different time points from one to five minutes.

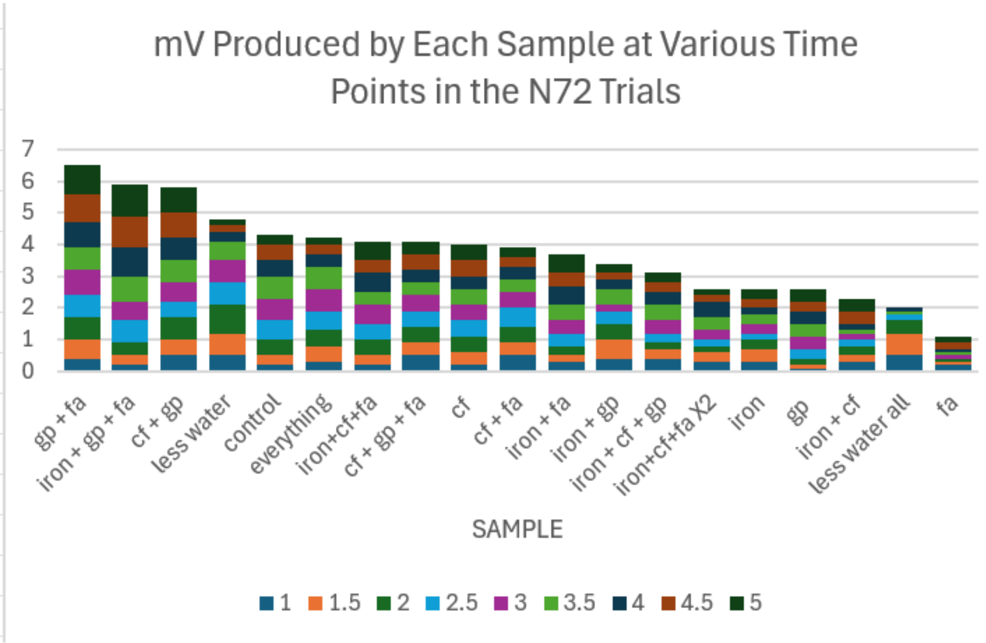
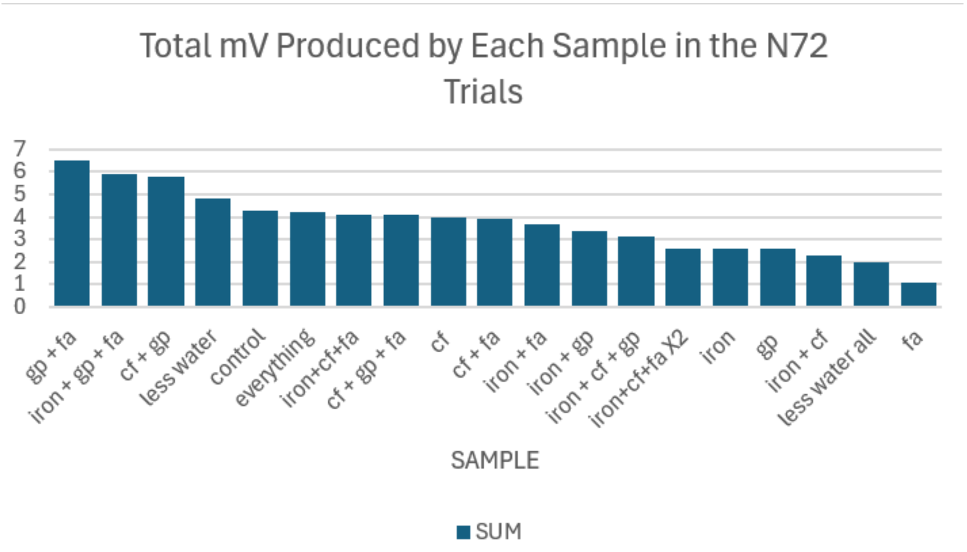


Figure 16.

Bar graph of total produced mV of samples without copper-caps at 72°F



In the samples without copper at 32°F, we found that the sample with all the fillers (carbon fiber, fly ash, graphite powder, iron oxide) produced the highest total voltage produced. This can be seen below in figures 17-18.

Figure 17.

Bar graph of produced mV of samples without copper-caps at 32°F at different time points from one to five minutes.

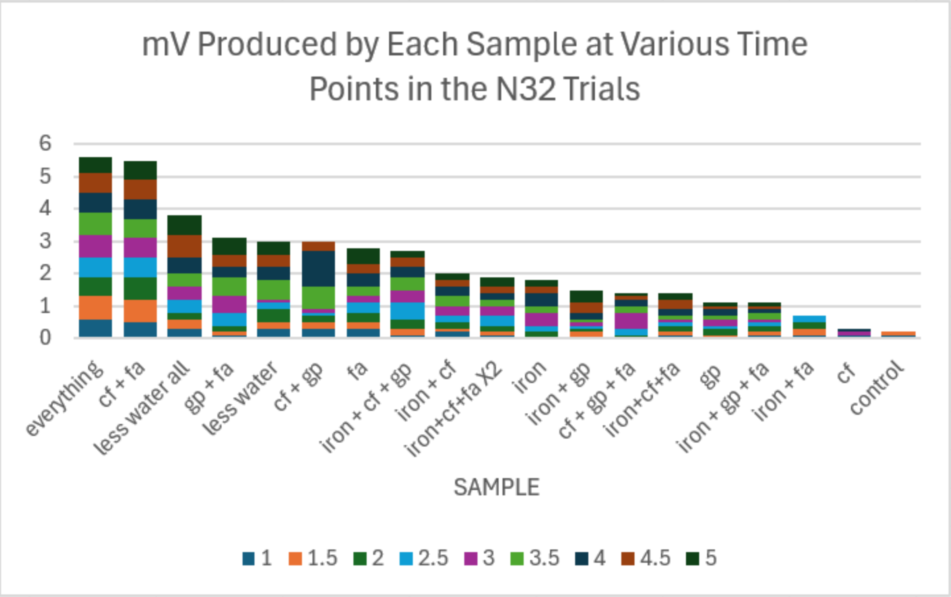
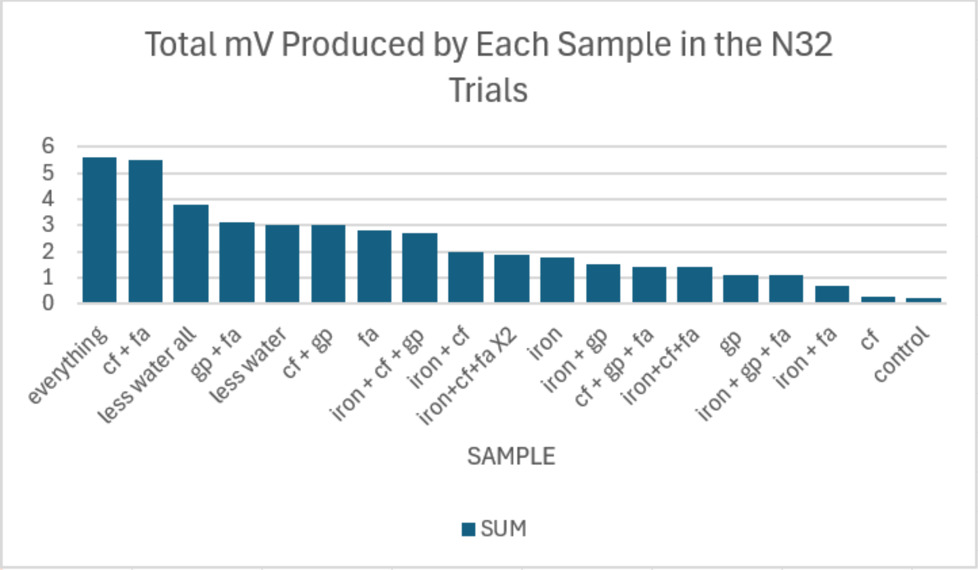


Figure 18.

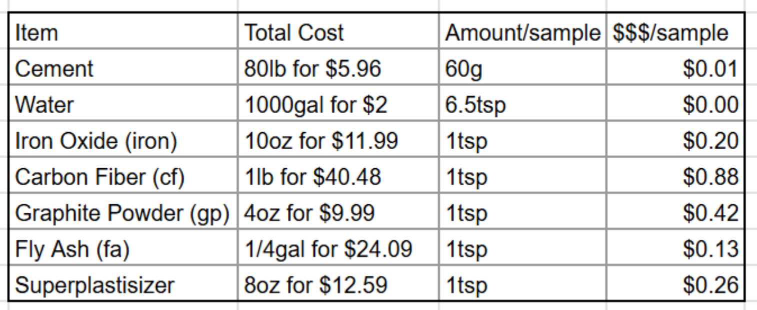
Bar graph of total produced mV of samples without copper-caps at 32°F



Our goal of this research was to determine which concrete mix would be the most cost effective compared to voltage output. To determine this, we got the unit cost of each item per sample. Using those values, we then established the total cost for each of the 19 samples by adding the amounts. The unit cost can be found in figure 19 and the cost of each sample was found in figure 20.

Figure 19.

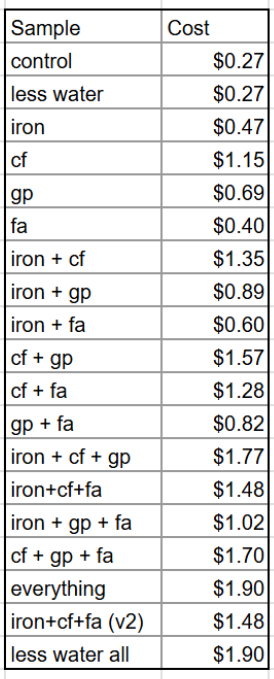
Cost and amount of each item in each sample.



Item	Total Cost	Amount/sample	$$$/sample
Cement	80lb for $5.96	60g	$0.01
Water	1000gal for $2	6.5tsp	$0.00
Iron Oxide (iron)	10oz for $11.99	1tsp	$0.20
Carbon Fiber (cf)	1lb for $40.48	1tsp	$0.88
Graphite Powder (gp)	4oz for $9.99	1tsp	$0.42
Fly Ash (fa)	1/4gal for $24.09	1tsp	$0.13
Superplastisizer	8oz for $12.59	1tsp	$0.26

Figure 20.

Cost of each of the 19 samples.



Sample	Cost
control	$0.27
less water	$0.27
iron	$0.47
cf	$1.15
gp	$0.69
fa	$0.40
iron + cf	$1.35
iron + gp	$0.89
iron + fa	$0.60
cf + gp	$1.57
cf + fa	$1.28
gp + fa	$0.82
iron + cf + gp	$1.77
iron+cf+fa	$1.48
iron + gp + fa	$1.02
cf + gp + fa	$1.70
everything	$1.90
iron+cf+fa (v2)	$1.48
less water all	$1.90

After determining the cost of each sample, we then compared it to the total amount of mV produced. This can be seen in figures 21-24.

Figure 21.

Voltage Generated compared to mixtures and its cost for C72 Trials.

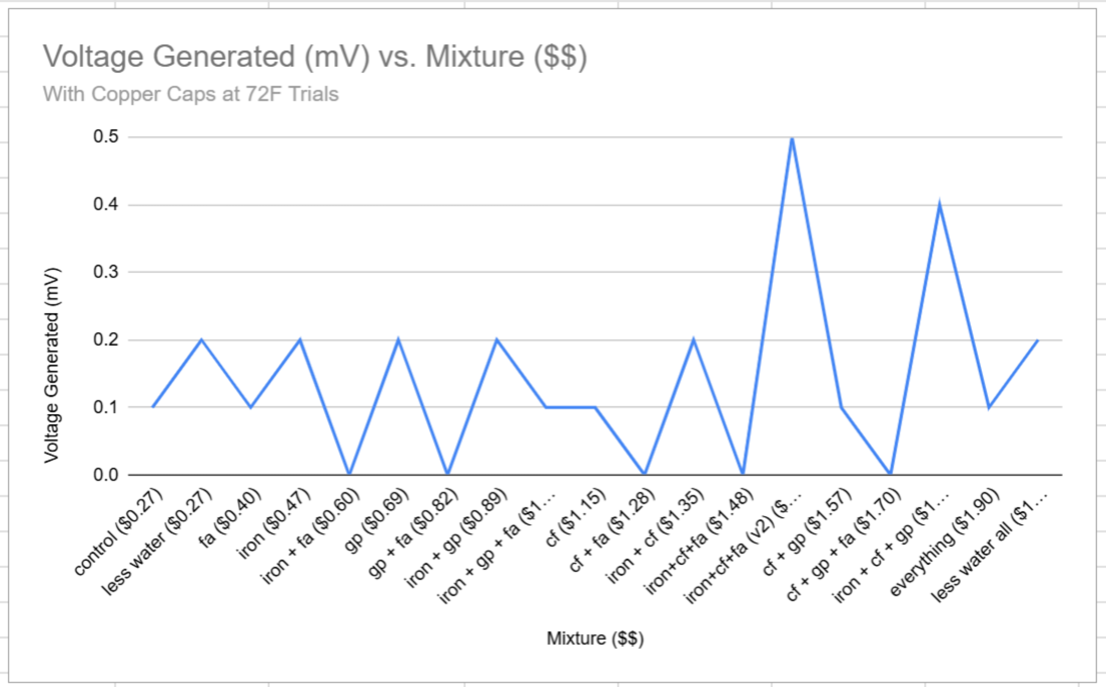


Figure 22.

Voltage Generated compared to mixtures and its cost for C32 Trials.

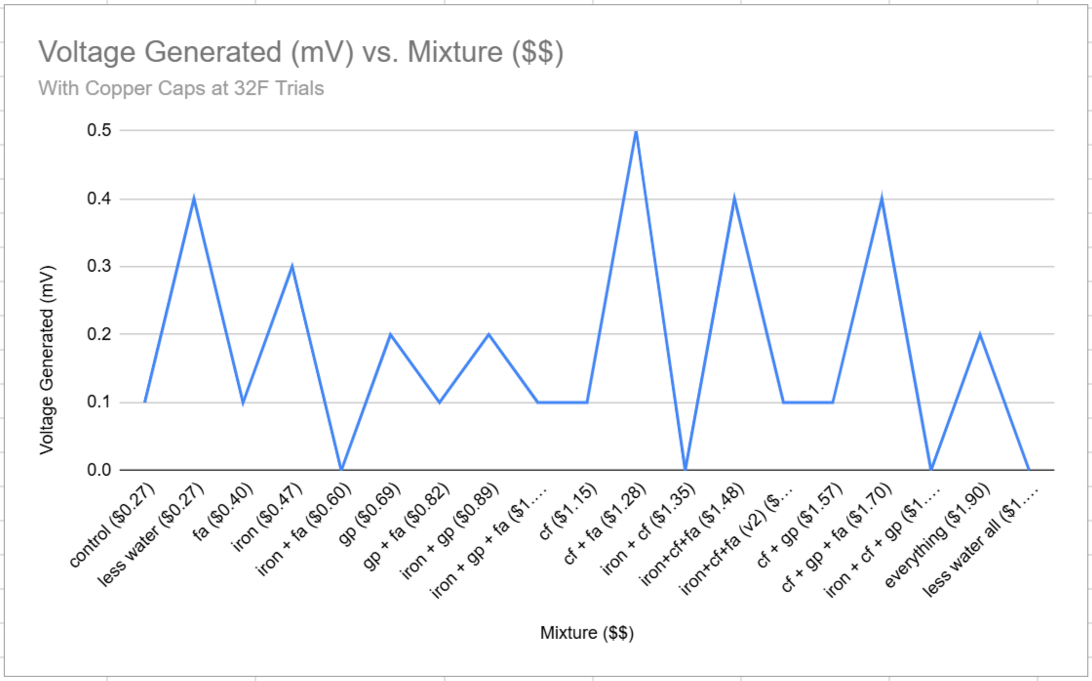


Figure 23.

Voltage Generated compared to mixtures and its cost for N72 Trials.

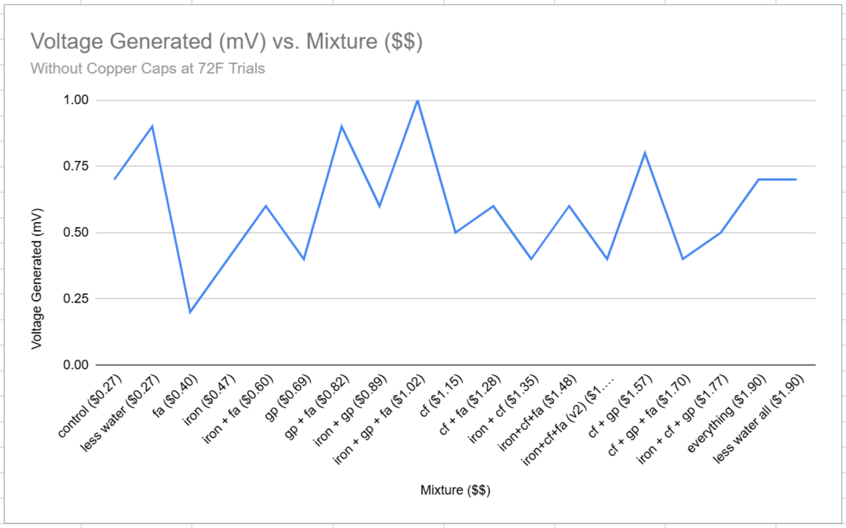
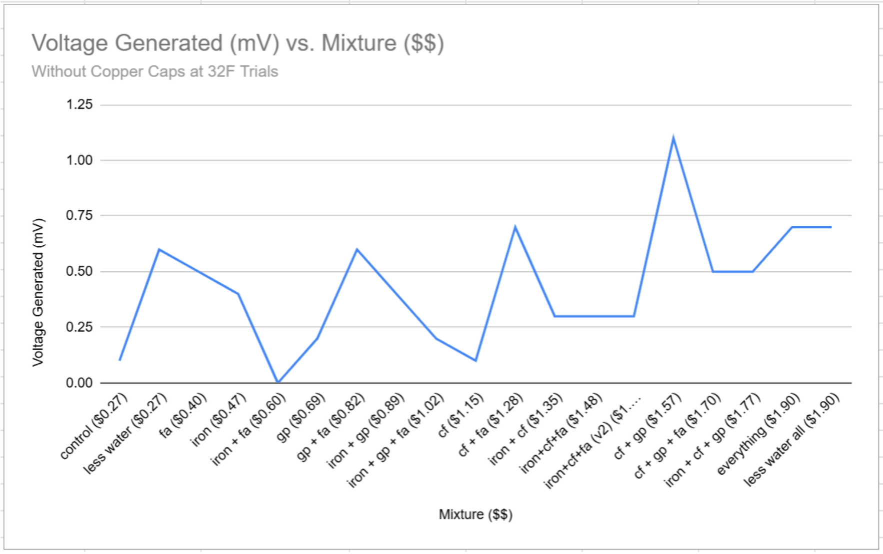


Figure 24.

Voltage Generated compared to mixtures and its cost for N32 Trials.



Discussion

The voltage produced by the C72 trial (Figure 8) was much lower than previously hypothesized; however, we theorize that the copper may reflect and block large amounts of the applied heat rather than aiding in the absorption heat and conduction of the electricity as previously theorized.

Our team noted that the samples with less water or more of the added materials on average absorbed heat and created electricity earlier than the samples found with more water but then quickly dissipated that energy. We theorize that this may be due to the samples holding a lower heat capacity or

In our second trial, we began measuring the copper covered concrete with one end being placed in a properly made ice bath, according to an article from ThermoWorks, that allowed the cool side to measure at approximately 32°F (ThermoWorks).

In the C32 trials, the concrete samples remained in their copper end caps, but a higher temperature difference was applied to the ends of the concrete, with the end that was 72degreesF in the last trial now being set to 32degreesF. In this trial, our team noticed that the Iron II Oxide + Carbon Fiber + Fly Ash x2 sample preformed best and that, similar to the previous trial, samples with a lower concentration of water and a higher concentration of the fillers yielded higher voltages throughout this trial.

Once the copper end cap trials concluded, our team began the trials with bare samples. These samples would likely be more realistic and accurate to civil applications of concrete. Our team also believed that these would yield higher voltages than the copper end cap trials after feeling that much of the heat was being reflected.

Due to the extent that our team believes that the copper in the C32 and C72 trials blocked the heat from reaching the concrete and creating a strong heat gradient, this trial should not be treated as a realistic interpretation as to how samples would act under higher temperatures differences like what is seen in the N32 and N72 trials. These trials may however provide some insight into how the samples act under lower temperature gradients. In these trials, the control sample preforms much closer to the average sample, while the control continuously preformed much worse in the N trials, compared to other samples tested. This insinuates that some of the materials and combinations created in this study become less effective at generating a voltage than regular concrete when put at lower temperature differences. In particular, Iron II Oxide + Fly Ash and Iron II Oxide + Carbon Fiber + Graphite Powder seemed to not produce any voltage in the C32 trials. The Iron II Oxide + Fly Ash and Graphite Powder + Fly Ash samples seemed to also not yield any voltage during the C72 trials.

Regarding the cost analysis, our data showed that the Less Water sample was the most cost efficient in all trials. The data from this sample indicates that concrete with less water may hold a lower heat capacity, thus generating a more prominent temperature gradient over 5 minutes. This low heat capacity, coupled with the sample's lack of added materials made it the most economically viable option; however, our team notes that this lack of water in the Less Water sample may hold similar structural instabilities to the dry cured samples initially produced and thus may not be considered a suitable material for building until reliable strength is shown in the material.

Conclusion

Through further research and development in the field of CTEMs and exploring the applications of the Seebeck Effect in civil infrastructure, more efficient and lower-maintenance methods of collecting clean energy may be discovered. In further works, exploring how the addition of thermoelectric amplifying filaments to concrete affects its structural integrity over time would be highly practical to understanding its potential as a tool in civil engineering, especially infrastructure such as in buildings, roads, and sidewalks that are oftentimes exposed to heat on one side for prolonged periods of time. In addition, the development of a device such as a reliable streetlamp utilizing this effect in thermoelectric concrete would be incredibly useful to showing its realistic applicability as a keystone in civil and city engineering. In coming years, thermoelectric devices using the Seebeck effect in civil builds may prove to be the lowest maintenance option for generating clean energy in cities, suburbs, and roads as the designs and materials used for them are proven to be durable and efficient.

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