M3 Math Modeling Challenge 2025:

Hot Button Issue: *Staying Cool as the World Heats Up*

Team #18262

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Executive Summary

To the Memphis Office of Emergency Management,

Due to climate change in recent years, heat waves hitting the City of Memphis are becoming more frequent, more extreme, and longer[1]. Because of this, it is important to understand the effect that rising outdoor temperatures will have on the homes of Memphis residents, how it will affect energy usage, and how to react to extreme heat waves that could potentially cause power outages.

We developed a model of heat-flow between the environment and an idealized model of a house. We modeled the three main mechanisms of heat transfer - conduction, convection, and radiation - using physical laws. We provided a large number of parameters describing house layout and materials, allowing non-air-conditioning interventions to be tested for effectiveness at keeping a house cool.

We also looked at the energy usage of the Memphis power grid through history, and used this data to predict how it will change in the future. From our data, we can predict that the power grid should be prepared to handle an increase of 0.0169996 billion kilowatt hours of electricity per year over the summer.

To provide the local government with an actionable plan to equitably combat the growing risks of power outages caused by heat waves in each neighborhood, we developed a model that uses factors associated with each zip code to determine a Heat Vulnerability Score (HVS) for each zip code in the Memphis Metropolitan Area. The HVS is on a scale from 1 to 100, with the most at risk community being given a HVS of 100. The HVS generated by our model allows the city and its officials to combat the increasing threat of dangerous heat wave induced power outages across the city by allocating resources and personnel to zip codes more at risk in the case of an outage. We weighted different factors based on concrete data and research. Some of the most important factors that contribute to the HVS are average income, percentage of the population that are children or elderly, and average age of the houses in the community. After running our model against the factors associated with each zip code we determined that the neighborhoods of East Memphis and Colonial Yorkshire located in the zip code 38111 will be the least affected during a heat wave induced power outage. Meanwhile, Lakeland, Arlington, and Brunswick in 38002 will be the most high risk neighborhoods.

We encourage the Memphis Office of Emergency Management and the community to take our findings into consideration in order to best prepare for the yearly increase in dangerous heat waves. This will take everyone's united efforts to make sure we fulfill our responsibility of taking care of our neighbors.

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Q1: Hot to Go

1.1 Defining The Problem

The first problem asks us to model the indoor temperature of a non air-conditioned home throughout the day during a heat wave for a given city. We decided to use Memphis, Tennessee as our city. To figure out the indoor temperature, we combined data of typical houses in Memphis with laws of heat exchange.

1.2 Assumptions

1.2-1 **Perfect convection in the house**

Justification: Actual differences in convection between homes and areas of each home is impossible to calculate, and said differences will have little to no effect on indoor temperature.

1.2-2 **Heat from people and the use of appliances is negligible**

Justification: The amount of heat created from people and use of appliances in the house will be different for every home, and will have little to no effect on indoor temperature

1.2-3 **All houses are perfect squares, with every floor being the same size. Each story is 12 feet tall, every wall has a 35% WWR (Window to Wall Ratio), and every apartment unit has 2 exposed sides with no exposed ceiling. Every building has the minimum insulation standards, in compliance with the IECC.**

Justification: Keeping all houses similar, will make our model much simpler and require less input variables

1.2-4 **Heat Conductivity of the furniture in the house will increase with socioeconomic status**

Justification: More expensive/luxury furniture tends to be made of materials that absorb more heat such as counters, large fish tanks, wooden couches, etc.

1.2-5 **Outside temperature of objects, ground, and air is the same and all consistent with the data given by Mathworks**

Justification: The radiation of heat that is given off by nearby objects will be different for every home, and will have little to no effect on indoor temperature.

1.2-6 **The house can be treated as an object with uniform temperature and heat fluctuation.**

Justification:

1.3 Variables

Constants			Parameters	
Bricks/asphalt/dr	1200	kg/m^3	Floor height	2
Bricks/asphalt/dr	1000	J/(kg K)	Floor number	2
Air density	1.2	kg/m^3	Floor area	100
Air heat capacity	1005	J/(kg K)	Floor area sqrt	10
Stefan-Boltzman	0.0000000567		Roof thickness	0.1
			Wind speed	10
			Vertical convecti	43.7
			House absorbtiv	0.6
			House emmissiv	0.8
			Ground emmissi	0.9
			Atmosphere emı	0.8
			Roof sq meters	141.4213562
			Outer walls footp	10
			Inner walls footp	10
			Roof volume	14.14213562
			Outer walls volu	40
			Inner walls volun	40
			Total heat capac	31380.71187
			Latitude of Mem	0.6131478
			Solar declination	0.4088977778
			Wall r-value	20
			Attic r-value	38
			Window r-value	3.33
			Windows sq met	5

Fig: Independent variables (constants and parameters) of the model. The only dependent variable is change in the house's total heat over an hour, which feeds back into the model in the form of the temperature at the next timestamp.

1.4 The Model

Our model attempts to predict a house's internal temperature over a 24 hour period by iteratively predicting one-hour changes. We do this by breaking down energy transfer between the house and the environment (surrounding air, radiative objects, and the sun) into three main categories - radiation, convection, and conduction. Each hour we find the net energy change in the house (modeled as a perfect thermodynamic system with a uniform temperature) and divide it by an estimate for the house's effective heat capacity to get hourly temperature changes. Adding these to the initial internal temperature, we get a new internal temperature and can repeat the process.

Radiation

To find the total heat exchange due to radiation in an hour, we explored the equations that described the total heat absorbed by the house from the sun, ΔH_s, heat absorbed from surroundings, ΔH_n, and heat lost from the house by emitting heat, ΔH_e.

The first order of business is to calculate H_s. All heat terms can be written as $Power \cdot hour$, since heat is power multiplied by time. This form is useful because there exist equations that describe how much power an object absorbs from the sun given solar radiation intensity S, the house's surface area A, and absorptivity constant a. H_s can be written as the following:

$$H_s = A \cdot S \cdot a$$

Solar radiation intensity is calculated by $S_0 \cdot \cos(\theta)$, where S_0 is a solar constant equal to 1,360 and θ is the solar zenith angle. $\cos(\theta)$ is calculated with the equation:

$$\cos(\theta) = \sin(\phi) \cdot sin(\delta) + \cos(\phi) \cdot \cos(\delta) \cdot \cos(h),$$

where ϕ is the latitude of the house in Memphis (roughly 35.15 degrees north), δ is the solar declination (which is about 23.44 degrees for June 21st), and h is the angle based on solar time.

The absorptivity constant is a number from 0 to 1 that tells how much radiation the house will absorb based on the color and materials of the house. For a house with typical colors and building materials, a is approximately 0.6.

In our model, each heat flux term contains the factor of surface area A, so the surface area can be factored out and multiplied back in the final calculations.

The next terms to find are the heat absorbed by the surroundings and emitting by the house, both of which can be modeled by Stefan-Boltzmann equation:

$$P = \varepsilon \sigma A T^4$$

where ϵ is the emissivity of object, σ is a constant, A is the surface area of the house, and T is the temperature of the house. Since the temperature of the house at any given moment is what we're solving for, that is an unknown, so we used the temperature of the previous hour as a close approximation. Then by researching the emissivity values for typical houses and environmental factors (including ground and atmosphere), we could get the total heat emitted by the house and absorbed by the environment.

Conduction

The second major way heat flows in and out of our house is conduction. Since we model our house as a solid block of uniform temperature, we just need to model conduction between this surface and the surrounding air (another uniform, ideal thermodynamic system). We find the hourly heat flux over each of the three major interfaces in between the house and outside air (insulated exterior wall, attic, and windows) by plugging their thermal resistances into the conduction equation $\frac{dH}{dt} = \frac{\Delta T}{r}$. We then multiply these numbers by the exposed surface areas of their respective materials to get the heat flow.

Convection

The final source of heat flow is convection - air either flowing through gaps in a house's surface or flowing over walls, cooling them. We determined that this first factor ("natural convection") was negligible (~3% of heat exchange with 1 square meter of total gaps and 1 meter/s of airflow). The second one, "forced convection," is more significant. We figured out the hourly energy flux due to forced convection using Newton's law of cooling[2] - $(\frac{d\Delta H}{dt} = -h(v)A\Delta T)$- where $h(v)$ is the convective heat transfer coefficient for a vertical wall, using the empirical approximation[3] $5.7 + 3.8V$, A is the surface area of the house, and ΔT is the temperature differential between the house and air.

Putting it all together

Having equations for all three forms of heat transfer, we can get our total energy transfer into (or out of) the house $\Delta H = \Delta H_{\text{rad}} + \Delta H_{\text{conv}} + \Delta H_{\text{cond}}$. Now all we need is the effective heat capacity of the house. We assume the walls are made entirely of gypsum drywall and the roof of asphalt - the two lowest heat-capacity components for a worst-case heating scenario. We estimate the total mass of walls and ceiling - assuming walls take up approximately 10% of the house's footprint and the roof is approximately 3 inches thick. Adding these components together we get a total C_eff and get $T_t = T_{t-1} + \Delta H/C_eff$

1.5 Results and Discussion

We find that our model of an un-air-conditioned house tracks closely with outdoor temperatures, typically with a one- to two-hour lag. This intuitively matches our expectations. On testing the model with the provided example temperature ranges and a variety of values for parameters, it proved robust - only when you push it to extremes like an outdoor temperature of 0K does the model break and decouple from outside conditions (the one-hour timestep, usually fine for small delta T's, causes a huge overupdate in that case.) Below is one example of a model result.

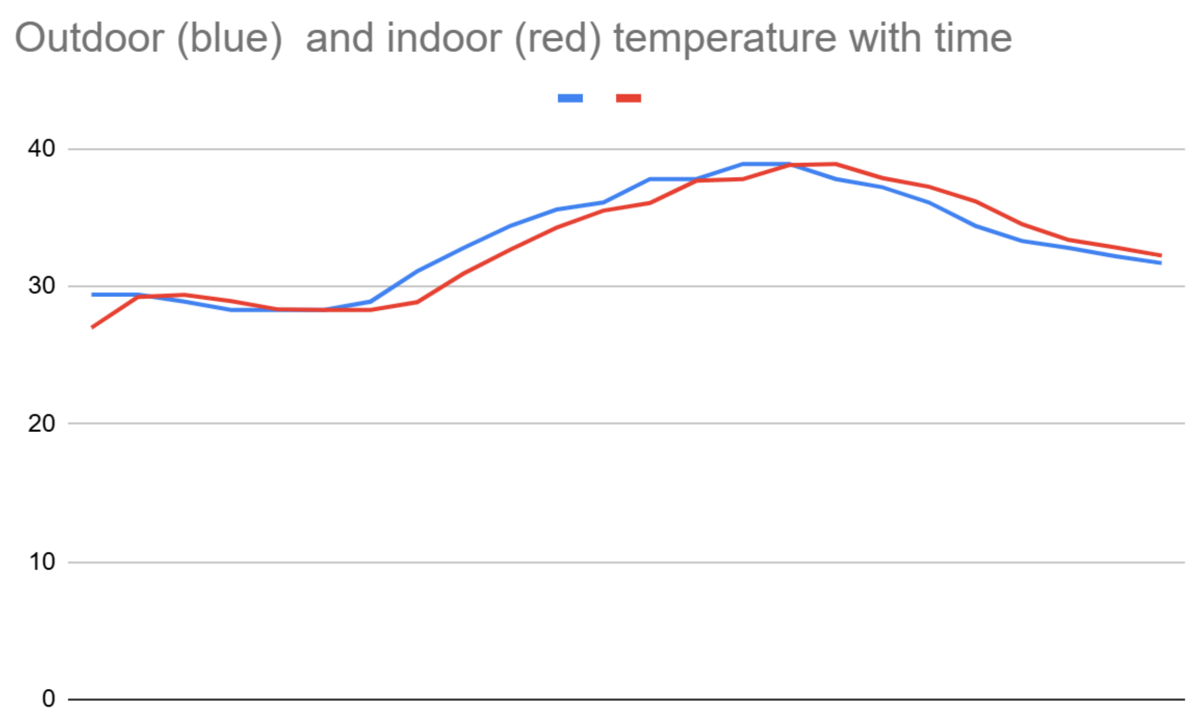

Fig: Relationship between indoor and outdoor temperature predicted by our temperature model over one of the sample 24-hour periods

Reductions in the rate of heat flow (and thus maximum temperature of the house) were observed on increasing the r-value of materials exposed to the outdoors, thickening the walls, increasing the volume-to-surface-area ratio, and, interestingly but intuitively, increasing the effective heat capacity of the house. This last result is especially interesting in that it hints at an alternative form of insulation - highly heat-absorbing materials *inside* of a house's rooms, as heat capacity of a house is dominated by solid materials. Adding anything from large slabs of exposed concrete to large fish tanks could be used to reduce the heating of houses, in addition to traditional measures like using higher quality insulation.

1.8 Strengths and Weaknesses

Strengths

1. Having a model based on heat change allows for predicting the temperature of a whole day just based on an initial temperature and variable rates of change.
2. Our model allows us to test the effectiveness of different materials by plugging in different parameters in our heat flux equations.

Weaknesses

1. Our model assumes that a house is a single uniform unit that has consistent instantaneous heat flow. This is an overgeneralization as temperature changes on the outer walls aren't immediately

reflected on the inside. There can be large temperature gradients across the walls, which would be more faithfully modeled by heat flow differential equations. Given more time we would have at least treated our house as TWO separate thermal systems - the outside walls and the interior.

2. We ignore appliances and people, two additional sources of heat, as there’s a wide range of possible appliances and energy efficiencies.

Q2: Power Hungry

2.1 Defining The Problem

The second question asks us to create a model that can predict the maximum demand that the power grid in Memphis should be prepared to handle during the Summer months, and to predict any major shifts that will happen 20 years from now.

2.2 Assumptions

2.2-1 **The percentage of energy that Memphis uses in comparison to the amount of energy used in the entire East South Central region is the same for every year.**

Justification: The MathWorks Math Modeling Challenge provided limited data, therefore assumptions had to be made on the energy usage in Memphis being consistently proportional to the energy usage in the East South Central region.

2.2-2 **The percentage of energy used during the summer months (June, July, and August) in comparison to all 12 months stays the same for every year.** [4]

Justification - The MathWorks Math Modeling Challenge provided limited data, therefore assumptions had to be made on the energy usage during the summer months in the East South Central region being consistently proportional to the energy usage during the whole year in that same region.

2.3 Variables

Symbol	Definition	Units
y	Year we are predicting	**Years**
P_{ESC}	0.0331 = Constant that represents the yearly energy usage of memphis as a percentage of the year usage of the East South Central area of the United States (taken from 2018)	**Percent**
P_Y	0.2874 = Constant that represents the summer months as a percentage of the yearly usage in memphis (taken from 2024)	**Percent**
U_E,U_M	Energy Usage per Year of the East South Central and Memphis, Respectively	**Billions of Kilowatt Hours**
U_{summer}	The result of our model, expected total electricity sales in billions of kilowatt hours during the summer months.	**Billions of Kilowatt Hours**

2.4 The Model

$$U_E(\mathbf{y}) = 1.787\mathbf{y} - 3286$$

$$U_M(U_E) = U_E * \mathbf{P_{ESC}}$$

$$U_{summer}(U_M) = U_M * \mathbf{P_Y}$$

$$U_{summer}(\mathbf{y}) = ((1.787\mathbf{y} - 3286) * \mathbf{P_{ESC}}) * \mathbf{P_Y}$$

The model uses a linear regression model trained on the Total Electricity Sales in the East South Central Region of the United States (in billions of kilowatt hours). From that data we get memphis' yearly usage for any given year by multiplying by the percentage $\mathbf{P_{ESC}}$. Finally we multiply yearly usage of Memphis by the percentage $\mathbf{P_{Y.}}$ to get the expected total of electricity sales in billions of kilowatt hours during the summer months of any given year.

2.5 Results

Year	Expected Energy Sales During the Summer in Billions of Kilowatt Hours (kWh)
2025	3.164717314
2026	3.181716938
2027	3.198716562
2028	3.215716186
2029	3.23271581
2030	3.249715433
2031	3.266715057
2032	3.283714681
2033	3.300714305
2034	3.317713929
2035	3.334713552
2036	3.351713176
2037	3.3687128
2038	3.385712424
2039	3.402712047
2040	3.419711671
2041	3.436711295
2042	3.453710919

2043	3.470710543
2044	3.487710166
2045	3.50470979

2.6 Discussion

In the year 2045, 20 years from now, the energy consumption needed by the Memphis power grid for the summer months will be 3.50470979 Billion kWh. Although this figure is accurate to historic trends, it does not take into account any unpredictable future occurrences, such as expansion of the xAI data center[5], expansion of energy-efficient technologies, or the rise of electric vehicles that is not consistent with past trends.

2.7 Strengths and Weaknesses

The model we created was made from a linear regression that creates an accurate model of the trends in the general East South Central region (Kentucky, Alabama, Tennessee, and Mississippi) over the past 25 years; and after scaling this model down to the proportions of Memphis during the summer months, we can accurately predict the peak demand that the power grid will need to handle over the next 20 years.

However, this model fails to predict any unforeseen future occurrences, and uses a regression model that while showing the general trends well, has some areas where the line of best fit doesn't match too well with the actual. It also uses large assumptions that do not account for any change in percentages from year to year on how the summer months make up the whole energy consumption, and also the percentage of energy that Memphis uses in comparison to the whole East South Central region.

Q3: Beat the Heat

3.1 Defining The Problem

The third question asks us to assign a score to a list of neighborhoods in Memphis, TN that accurately represents how vulnerable that neighborhood is to heat waves and heat wave induced power outages. The question then asks us to create a plan that utilizes this scoring system to equitably minimize the devastation caused by extreme heat waves and heat wave induced power outages.

3.2 Assumptions

3.2-1 **Income - Income has an inverse relationship with the risk value**.

Justification: This is due to higher income areas generally having more resources readily available, like generators, access to ac, private pools, and the ability to leave the affected area among others.

3.2-2 **Age of Home (Built Before 1990) - The age of the home has a direct relation with the risk value.**

Justification: This is due to older homes having worse insulation, therefore the older a home is, the higher the risk value due to more heat entering the home through conduction and radiation.

3.2-3 **Age of Home (Built After 1989) - The age of the home has an inverse relation with the risk value.**

Justification: This is due to newer homes having better insulation; for example, since 1990, most new homes built use spray foam to insulate the walls, which is not only more effective at insulating, but easier and safer to install. New forms of insulation are also being developed like drill and fill and soundproofing insulation.

3.2-4 **Percentage of Old and Young People - The percentage of old and young people has a direct relation to the risk value.**

Justification: This is because older and younger people are less likely to be able to take care of themselves and provide a way to escape any high temperature scenarios, especially during a power outage.

3.2-5 **Reliance on Public Transportation - Reliance on public transportation has a direct relation with the risk value.**

Justification: This is due to people that rely on public transportation being subject to higher levels of heat while waiting outside, and not being able to easily access places where they can cool down.

3.2-6 **Developed Space - The developed space in a neighborhood has an inverse relation to the risk value**.

Justification: This is due to the developed space like parks, greenspaces, and other shaded and cooled spaces, allowing people to have a space that is cooler than the surrounding area or their homes.

3.3 Variables

Symbol	Definition	Units	Weight
I	Average Income	**United States Dollar**	1.0
OY	Percentage of Old and Young People	**Percent of People**	0.5
A_1	Homes built 2010-Present	**Number of Homes**	0.7
A_2	Homes built 1990-2009	**Number of Homes**	0.4
A_3	Homes built 1970-1989	**Number of Homes**	0.3
A_4	Homes built 1950-1969	**Number of Homes**	0.4
A_5	Homes built before 1950	**Number of Homes**	0.7
OL	Developed Space:Open Land Ratio	**Number of Homes**	0.2
PT	Reliance on Public Transportation	**Number of People**	0.6

3.4 The Model

Our model takes in the variables listed in 3.3 for each zip code and normalizes them in comparison to the other zip codes and then multiples each normalized variable by a weighting. If a variable is weighted higher, then it is more impactful to the vulnerability score. Each variable is also characterized by either having a direct or inverse relationship to the vulnerability score (for example: median income has an inverse relationship with risk. If the median income is higher in a zip code, the vulnerability score will be lower).

This model calculates risk by summing weighted variable contributions based on their relationship to risk. If a factor has a *direct* relationship, its value is multiplied by its weight and added to the total risk. If the relationship is *inverse*, the model assumes that lower values contribute to higher risk. The final risk score represents an aggregated measure of multiple weighted risk factors.

Finally we normalize the output on a scale of 1-100, giving us a vulnerability score between 1-100 with 100 being the highest risk. The code used to store the data and solve this model was written in python and can be found in the Code Appendix.

3.5 Results

Neighborhood	ZIP-code	Score (1-100)
East Memphis, Colonial Yorkshire	38111	**1.00%**
East Midtown, Central-Gardens, Cooper Young	38104	**6.82%**
South Memphis	38106	**10.78%**
Coro Lake, White Haven	38109	**11.10%**
Frayser	38127	**15.00%**
Midtown, Evergreen, Overton Square	38112	**22.31%**
Hollywood, Hyde Park, Nutbush	38108	**25.21%**
North Memphis, Snowden, New Chicago	38107	**25.60%**
Egypt, Raleigh	38128	**28.75%**
Uptown, Pinch District	38105	**31.57%**
South Forum, Washington Heights	38126	**33.62%**
Bartlett, Zipcode-2	38134	**40.77%**
East Memphis	38117	**46.96%**
South, Riverdale	38141	**47.88%**
Rossville	38066	**58.38%**
Germantown, Zipcode-1	38138	**60.63%**
Oakland	38060	**62.99%**

Bartlett,-Zipcode-3	38135	**64.63%**
Downtown, South Main Arts District, South Bluffs	38103	**65.43%**
Bartlett, Zipcode-1	38133	**65.84%**
Hickory, Withe	38028	**72.45%**
Cordova, Zipcode-2	38018	**73.74%**
Windyke, Southwind	38125	**79.59%**
Germantown, Zipcode-2	38139	**80.73%**
Cordova, Zipcode-1	38016	**81.31%**
Lakeland, Arlington, Brunswick	38002	**85.80%**
Collierville, Piperton	38017	**100.00%**

3.6 Discussion

The main focus during the development of this model was ensuring the variable weights aligned with the importance of the variables relationship to the risk a community faces during a power outage due to a heat wave. In order to assign a fair weight value to each variable, we first ranked each variable based on how detrimental extreme heat and/or loss of power would be as each variable increased or decreased. We then used these rankings to assign a value, 0-1, that represents how impactful it is, and whether it was directly or inversely related to the issue.

Income[6] was rated most important at 1.0 because people with higher incomes have more options to avoid the heat, such as running generators or taking trips out of town during power outages [7,8,9]. The next most important variable was very old and very new homes at 0.7[6], which were rated that way because older homes were not built with new insulation technologies like Polyurethane spray foam.[6] We used a similar system for homes that were relatively new and relatively old, both having equal and opposite ratings of 0.4. For the middle set of homes[6], we picked a low value of 0.3 because these homes likely have modest systems for cooling and ventilation. The next variable was reliance on public transportation[6], which we ranked above average at 0.6 because during heat wave induced power outages, if available, public transportation will become dangerous as current systems across the United States are not designed for these high temperatures.[5] We decided that the next most impactful variable was the percentage of old or young people in an area at a rating of 0.5[6], because these groups are especially vulnerable to health issues related to extreme heat as young people tend to give off more body heat, and old people don't sweat as much or have the heart strength to pump the necessary blood to cool the body.[13,14] The least important variable that we selected was the ratio of developed land to open area[6], such as communal parks, lakes, nature reserves, etc. We chose a low weight of 0.2 for this because these areas lower neighborhood temperatures[15], but will have less of a direct impact on the neighborhood's risk.

Utilizing this Heat Vulnerability Score (HVS), the Memphis city government can accurately predict which neighborhoods will need the most assistance during a heat wave. The single plan that can be implemented in Memphis (and cities across the world) can be broken up into three main parts: before, during, and after a heat wave. Before a heat wave starts, city governments can promote heat risk education for residents in high-risk areas, informing citizens about the dangers of heat induced illness and what steps to take to prevent them[16]. Cities can also invest in modern forecasting equipment to give more awareness and time to prepare directly before a heat wave. Utilizing this lead time, cities can prepare for phase two, which takes place during the heat wave. During a heat wave, cities can create temporary cooling stations in public facilities, such as schools or libraries, that help the community cope with the heat. These cooling stations could be similar to the Hub Warming and Cooling Center[9], which provides an air conditioned building, water, Wi-Fi, and power to those who are in need. As well as cooling stations, the city could increase the availability of public transportation by increasing the number of routes and the frequency that a bus drives them. This temporary change will help to alleviate the stress put on the public transportation system and people who must walk or bike due to the extreme heat. The final part of this plan will take effect after the heatwave is over. In the event that there is a heat wave induced power outage, power companies should prioritize neighborhoods with the highest HVS score to get power back first. This is because these areas will have the worst consequences of long-term power outages. In order to reduce the devastation that future heat waves will cause, the Memphis government should rebuild any infrastructure that was damaged by heat waves, such as roads, with newer, more resistant materials. The final step of the plan connects to the first-collecting data, understanding what parts of the plan were executed well and what wasn't, and updating the education and forecasting policies accordingly. Using this cyclical plan[11], the city of Memphis, Tennessee can prepare for, respond to, and recover from extreme heat waves equitably.

3.7 Sensitivity Analysis

Through our model, we are able to better understand what some of the needs of certain communities around Memphis may be during a heat wave. For example, we are able to tell that the Collierville and Piperton community will likely need more government assistance than the East Memphis and Colonial Yorkshire community because of the economic and developmental factors used in our scoring model. The results of our model are completely dependent on our parameters, however, changing the parameters would likely not change the order of scores very much because we picked broad factors that combine multiple variables. Therefore, even a major change to what factors are considered would likely not result in major changes to our result.

3.8 Strengths and Weaknesses

Our Weighted Sum Model (WSM) is accurate due to our ability to take into account many factors and assign a level of importance to each. Our Model takes different socioeconomic, historic, and developmental factors into consideration to develop a risk value that can accurately predict how vulnerable a neighborhood will be during a heat wave. This allows us to provide the local authorities with a Heat Vulnerability Score which will allow them to easily and equitably allocate resources to the affected communities.

However, using the Weighted Sum Model requires us to assign arbitrary values to how important we believe each factor is. Despite using recent research to defend our weighted assignments, it is impossible to truly weigh each variable perfectly. It is also impossible to account for every factor that might impact the effect a heat wave induced power outage has on a community.

Conclusions

We examined the issue of heat waves in Memphis, Tennessee, specifically the impact of outdoor heat on the temperature inside of homes. In order to find the relationship, we used an iterative algebraic model which predicted the temperature inside using 1 hour iterations. This model predicts that the indoor temperature lags about an hour or two behind the outdoor temperature, but will still have the same overall temperature throughout the day.

In order to find the peak demand on Memphis' power grid, we used a linear regression to model the past 20 years of electricity consumption in the East South Central region of the U.S.. We then found the relation between Memphis' yearly electricity consumption compared to the East South Central region which was 0.0331, as well as the relation between the electricity consumption of the summer months compared to the East South Central Region which was 0.2874. The model predicted that over the next 20 years peak energy demand would increase to 3.505 billion kWh in the year 2045.

Question three asked us to generate a score for the neighborhoods of Memphis, Tennessee based on the vulnerability of that community to a heat wave induced power outage. We chose to rate each zip code based on eight factors that contributed either directly or inversely to the risk of the community. Each factor was weighted differently based on its significance, this significance was determined based on current research and assumptions detailed in 3.6. Our model gave us a Heat Vulnerability Score (HVS) between 1 and 100 with zip codes rated at 100 HVS being the most vulnerable to the dangerous conditions of a heat wave induced power outage.

In conclusion, as heat waves become a more common threat to the people of Memphis' lives we encourage the local businesses and government to take a more active role in preventative actions to protect our communities. From ensuring building codes continue to enforce realistic insulation rating benchmarks for residences, to building more open spaces like parks in communities with higher HVS ratings to lower temperatures, the community must unite to combat this growing danger and protect our neighbors.

References

1. https://www.chathamhouse.org/2024/08/heat waves-extreme-heat-and-climate-change
2. https://www.sfu.ca/~mbahrami/ENSC%20388/Notes/Forced%20Convection.pdf
3. https://bigladdersoftware.com/epx/docs/8-3/engineering-reference/outside-surface-heat-balance.ht
4. https://www.mlgw.com/images/content/files/pdf/Fact%20%26%20Figures.pdf
5. 5https://www.commercialappeal.com/story/money/business/development/2025/01/08/xai-supml
6. https://m3challenge.siam.org/897bjhb54cgfc/.
7. https://www.thisoldhouse.com/heating-cooling/reviews/air-conditioner-costs
8. https://www.localmemphis.com/article/money/consumer/saving-you-money/electricity-is-going-to-cost-more-this-summer-than-in-years-past-how-you-can-save/522-5667576c-94f7-441a-82ce-c18767b83
9. https://choateshvac.com/whole-home-generators/#:~:text=Initial%20costs%3A%20Prices%20typically%20range,installation%20adding%20%242%2C000%20to%20%2410%2C000.
10. https://www.addictinsulation.com/insulation-through-the-decades.php
11. https://www.hospitalityhub.org/warming-cooling/
12. https://link.springer.com/article/10.1007/s00484-021-02074-4
13. https://www.cdc.gov/heat-health/risk-factors/heat-and-older-adults-aged-65.html#:~:text=What%20increases%20risk-,People%20aged%2065%20years%20or%20older%20are%20more%20prone%20to,normal%20body%20responses%20to%20heat.
14. https://www.npr.org/2024/12/06/nx-s1-5215837/young-people-heat-risk-climate-change
15. 2c4
16. https://www.cdc.gov/heat-health/about/index.html?CDC_AA_refVal=https%3A%2F%2Fwww.cdc.gov%2Fextreme-heat%2Fabout%2Findex.html
17. https://www.apha.org/-/media/files/pdf/factsheets/climate/extreme_heat.pdf
18. ercomputer-in-memphis-tennessee/77441157007/
19. https://chatgpt.com
20. https://www.eia.gov/outlooks/steo/data/browser/#/?v=20&f=M&s=0&start=202401&end=202412&id=&ctype=linechart&maptype=0&map=&linechart=~ELTCP_ESC
21. https://www.ceh.ac.uk/news-and-media/news/green-spaces-and-wetlands-keep-cities-cool-during-heat waves#:~:text=Green%20spaces%20and%20water%20can,cools%20the%20air%20by%20evaporation.

Code Appendix

Code is written in Python using the standard libraries

```
def get_info():
    zipcodes = []
    firstline = True
    with open("normdata.csv","r") as file:
        lines = file.readlines()
        for line in lines: #for each line in the file
            if firstline:
                firstline = False
            else:
                line = line.rstrip() #strip \n
                line = line.split(",") #split based on ,
                for i in range(len(line)):
                    if i != 0:
                        line[i] = float(line[i])
                zipcodes.append(Zipcode(*line))
    return zipcodes
```

Figure 1. Method to import data for a .csv file and store it in a list of Zipcode() classes

```
def get_risk(self):
    risk = 0
    for key, factor in self.factors.items():
        if factor["relationship"] == "direct":
            risk += factor["value"] * factor["weight"]
        elif factor["relationship"] == "inverse":
            risk += (1 - factor["value"]) * factor["weight"]
    return risk
```

Figure 2. The get_risk() method in the Zipcode() class used to generate a risk value based on the factors value, relationship, and weighting

```python
#defines lists used
zipcodes = get_info()
risks = []
scaled_risks = []
#iterates through the Zipcodes and gets the risk for each zip code
for zip in zipcodes:
    risks.append(zip.risk)
#finds min and max risk to use in normalization
min_risk = max(risks)
max_risk = min(risks)
#converts risks to normalized/scaled risks (0-100)
for risk in risks:
    scaled_risks.append(1 + ((risk - min_risk) / (max_risk - min_risk)) * 99)
#print normalized/scaled risks (1-100)
for srisk in scaled_risks:
    print(str(srisk))
```

Figure 3. Code ran to import data, generate risk for each zip code, normalize/scale the risk values on a scale of 1-100 and finally print the risk in the same order as the data imputed through the .csv

```python
'''

Zipcode class to hold all data related to a specific zip code

Methods:

    __init__(): takes in all data associated to a specific zip code given
in the data

        self.neighborhood: String

        self.ZIP_code: String

        self.factors: dict{dict{value,relationship,weight}}

            all factors taken into consideration when calculating risk,
each factor will have a normalized value,

            relationship (direct/inverse), weight (significance to risk)

        self.risk: float

            risk value for this zip code calculated using self.get_risk()

    get_risk(): computes factors and returns a risk value, higher value
means a zip code is at more risk
```

```
        iterates through self.factors and adds them to a risk value after
multiplying by value weighting

'''

class Zipcode():


    def __init__(self, Neighborhood, ZIP_code, Number_of_households,
Population,

                 Households_with_one_or_more_people_65_years_and_over,
Households_with_one_or_more_people_under_18_years,

                 Population_with_Bachelor_degree_or_higher,
Median_household_income, Households_with_no_vehicles,

                 Households_with_1_plus_vehicles,
Proportion_of_developed_open_space,

                 Primary_mode_of_transportation_walking_or_public_transit,
Homes_built_2010_or_later,

                 Homes_built_1990_to_2009, Homes_built_1970_to_1989,
Homes_built_1950_to_1969, Homes_built_1950_or_earlier,

                 Detached_whole_house, Townhouse, Apartments,
Mobile_Homes_Other,

                 Percentage_of_Old_and_Young_people,
Percentage_of_Educated_Population):


        self.neighborhood = Neighborhood

        self.ZIP_code = ZIP_code


        # Create a dictionary to store values, relationships, and
weightings

        self.factors = {
```

```
            "median_household_income": {"value": Median_household_income,
"relationship": "inverse", "weight": 1},

            "developed_open_space": {"value":
Proportion_of_developed_open_space, "relationship": "inverse", "weight":
0.2},

            "public_transit_usage": {"value":
Primary_mode_of_transportation_walking_or_public_transit, "relationship":
"direct", "weight": 0.6},

            "homes_built_2010_or_later": {"value":
Homes_built_2010_or_later, "relationship": "inverse", "weight": 0.7},

            "homes_built_1990_to_2009": {"value":
Homes_built_1990_to_2009, "relationship": "inverse", "weight": 0.4},

            "homes_built_1970_to_1989": {"value":
Homes_built_1970_to_1989, "relationship": "direct", "weight": 0.3},

            "homes_built_1950_to_1969": {"value":
Homes_built_1950_to_1969, "relationship": "direct", "weight": 0.4},

            "homes_built_1950_or_earlier": {"value":
Homes_built_1950_or_earlier, "relationship": "direct", "weight": 0.7},

            "percentage_old_and_young": {"value":
Percentage_of_Old_and_Young_people, "relationship": "direct", "weight":
0.5},


        }


        self.risk = self.get_risk()


    def get_risk(self):

        risk = 0

        for key, factor in self.factors.items():
```

```
            if factor["relationship"] == "direct":
                risk += factor["value"] * factor["weight"]
            elif factor["relationship"] == "inverse":
                risk += (1 - factor["value"]) * factor["weight"]
        return risk


    def __str__(self):
        return str(self.zip_code)
```

Zipcode() class used to store and compute factors. the get_risk() method was also shown in figure 2.