Extreme Heat on Residential Electricity Demand: A Case Study in a Hot-Humid Climate

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Background

Extreme Heat: Increasingly frequent and intense heat events across the U.S., are raising concerns around heat-related illness and stress, particularly for vulnerable groups, and are contributing to increased electricity demand for cooling that can result in higher energy burdens for low-income households.

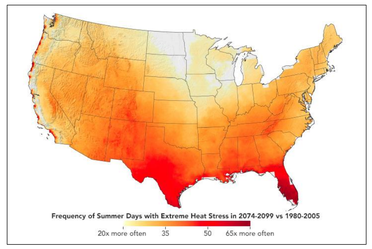

Figure 1. Projected changes in the frequency of extreme summer heat exposure in the U.S. Source: NASA Earth Observatory.

Driving Research Questions:

- Within Tallahassee, FL (Leon County) how does daily residential electricity use **respond to rising Heat Index**?
- Does there appear to be a **difference in energy consumption response** between households at differing income levels?

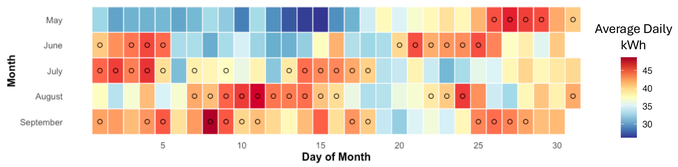

Figure 2. Heatmap of average daily electricity consumption for all homes across May – September 2019. Black circles denote days when Heat Index exceed 103°F (NWS Danger Zone Threshold).

Panel Data and Model Structure

Dataset Overview: Examine daily electricity consumption for over 80,000 households in Tallahassee for the 2019 summer period (May – September), merged with daily weather conditions, and socioeconomic demographic data.

Merged Household Weather Data

- Leon County Daily Electricity (kWh) Usage per Household from 2011-2021; entails >120,000 households
- NOAA (NWS, NCEI) & gridMET Weather Records (Temperature, Wind Speed, Precipitation, Specific Humidity, Dew Point, Heat Index)
- 5-Year ACS Demographic Information (Income, Race / Ethnicity, Educational Level, etc.)

Piecewise Two-Way Fixed Effects Model: Includes household fixed effects, with controls for weather variables The breakpoint (bp) captures the shifts in electricity use.

$$\ln(\text{Consumption}_{it}) = \alpha_i + \gamma_t + \begin{cases} \beta_1 \cdot HI_{it} + M_{it} + \varepsilon_{it}, & HI_{it} \le bp \\ \beta_1 \cdot bp + \beta_2 \cdot (HI_{it} - bp) + M_{it} + \varepsilon_{it}, & HI_{it} > bp \end{cases}$$

Results

Evaluation of a Breakpoint in the Rate of Energy Consumption Across Heat Index

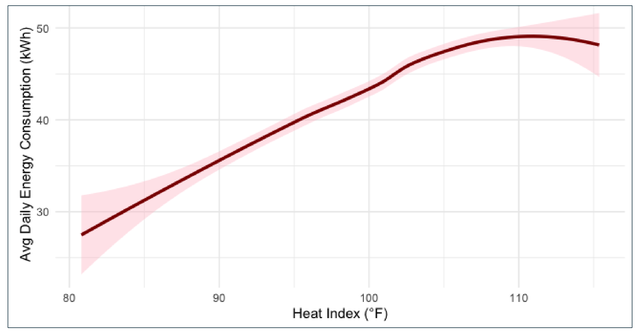

Figure 3: Locally Estimated Scatterplot Smoothing (LOESS) relationship between Heat Index and average daily electricity use for ~80,000 Tallahassee households during May – September 2019. The shaded band indicates the 95% confidence interval.

Modeling the Electricity Consuming Behavior Across Heat Index for Residents

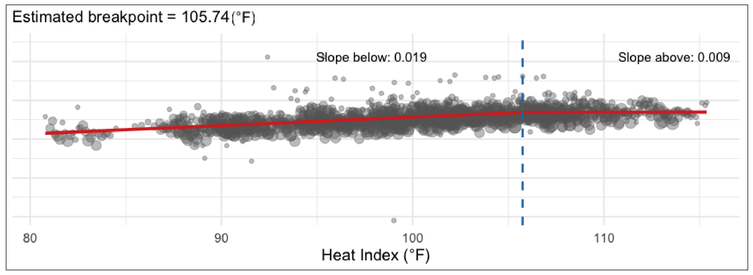

Figure 4. Segmented regression of Heat Index on the average log of daily electricity consumption (N = 79,584 premises). The estimated breakpoint is 105.74°F. The fitted slopes indicate a stronger marginal increase in usage below the breakpoint (1.9%) and a reduced response above it (0.9%).

Complete Dataset Model of Electricity Consumption Across Income Quintiles

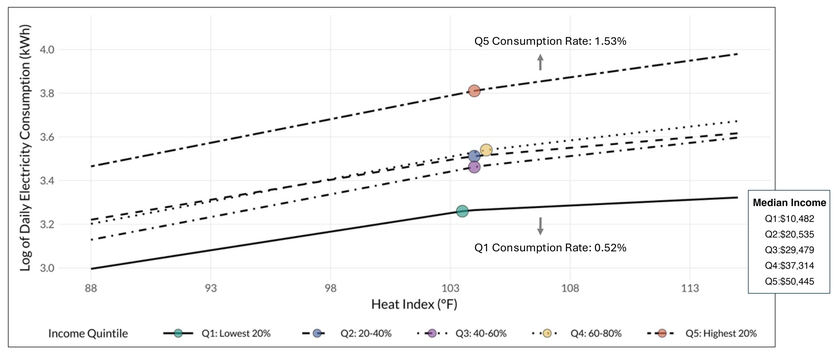

Figure 5. Modeled log of electricity use by income quintile against Heat Index. Each quintile exhibits increase in consumption with divergence above their respective breakpoint.

Rebate Subset Model of Electricity Consumption Across Income Quintiles

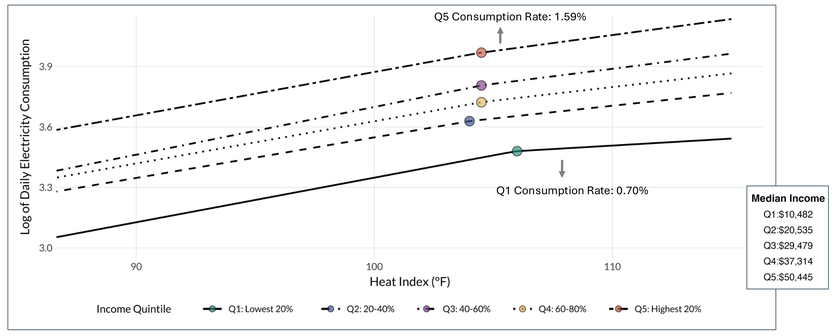

Figure 6. Modeled log of electricity use by income quintile against Heat Index for rebate subset (N = 5,838). Quintiles similarly increase until divergence above breakpoints.

Discussion and Conclusion

- In Leon County, **electricity use rises steadily with heat index** 105.74°F, but plateaus at high levels, reflecting **behavioral and technical limits on cooling**.
- At extreme Heat Index the relationship between Heat Index and income **diverges with lower-income groups restricting cooling demand,** increasing heat-related risks.

Policy Implications: For utilities and policymakers these findings underscore the importance of targeted support to reduced energy burden under extreme heat. Programs that provide energy-efficiency upgrades (WAP) and utility bill assistance (LIHEAP) can provide pathways to offsetting energy affordability concerns.

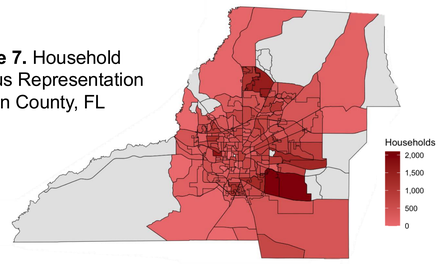

Figure 7. Household Census Representation in Leon County, FL

References and Acknowledgements

[1] D. Habeeb, J. Vargo, and B. Stone, "Rising heat wave trends in large US cities," *Nat Hazards*, Apr. 2015
[2] D. Maia-Silva, R. Kumar, and R. Nateghi, "The critical role of humidity in modeling summer electricity demand across the United States," *Nat Commun*, Apr. 2020
[3] L. Huang, D. Nock, S. Cong, and Y. (Lucy) Qiu, "Inequalities across cooling and heating in households: Energy equity gaps," *Energy Policy*, Nov. 2023

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