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Climate change impacts on future residential electricity consumption and energy burden: A case study in Phoenix, Arizona

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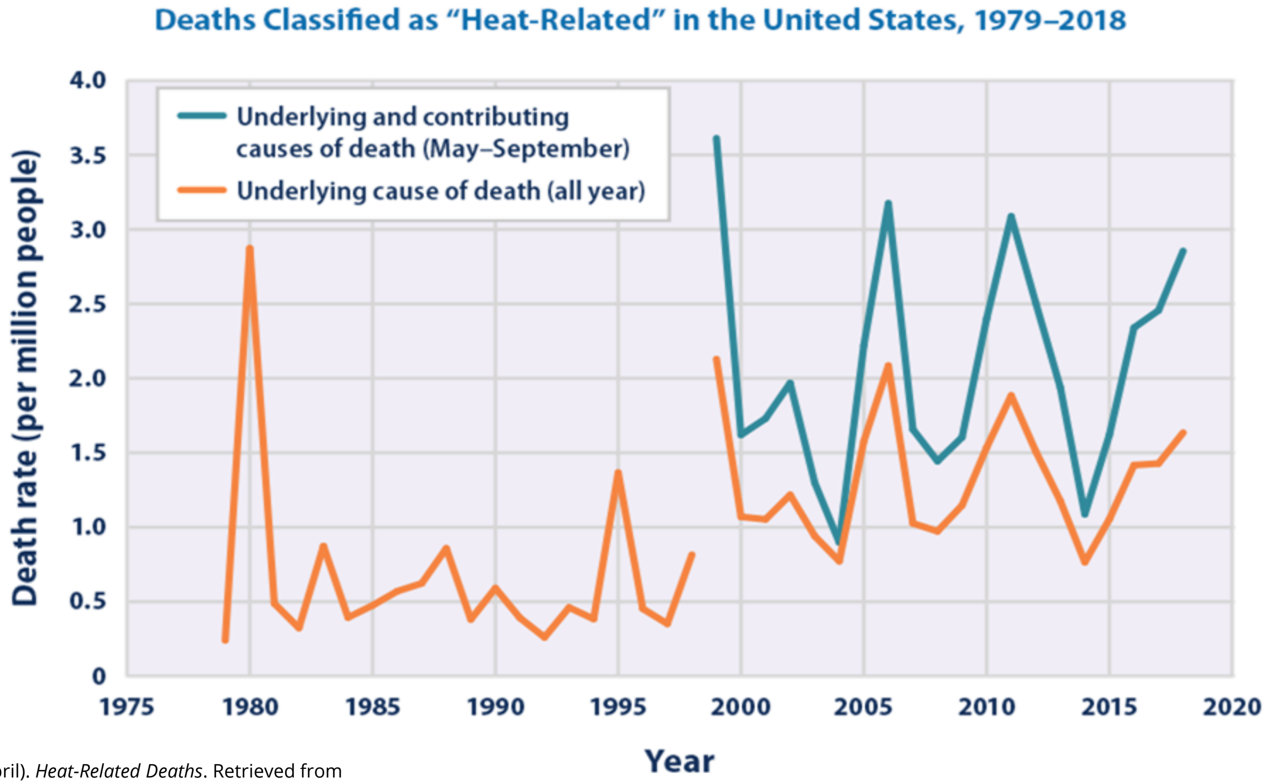
More than 11,000 Americans have died from heat-related causes since 1979



Source: U.S. EPA. (2021, April). *Heat-Related Deaths*. Retrieved from Climate Change Indicators: https://www.epa.gov/climate-indicators/climate-change-indicators-heat-related-deaths#tab-4

Reference QR code

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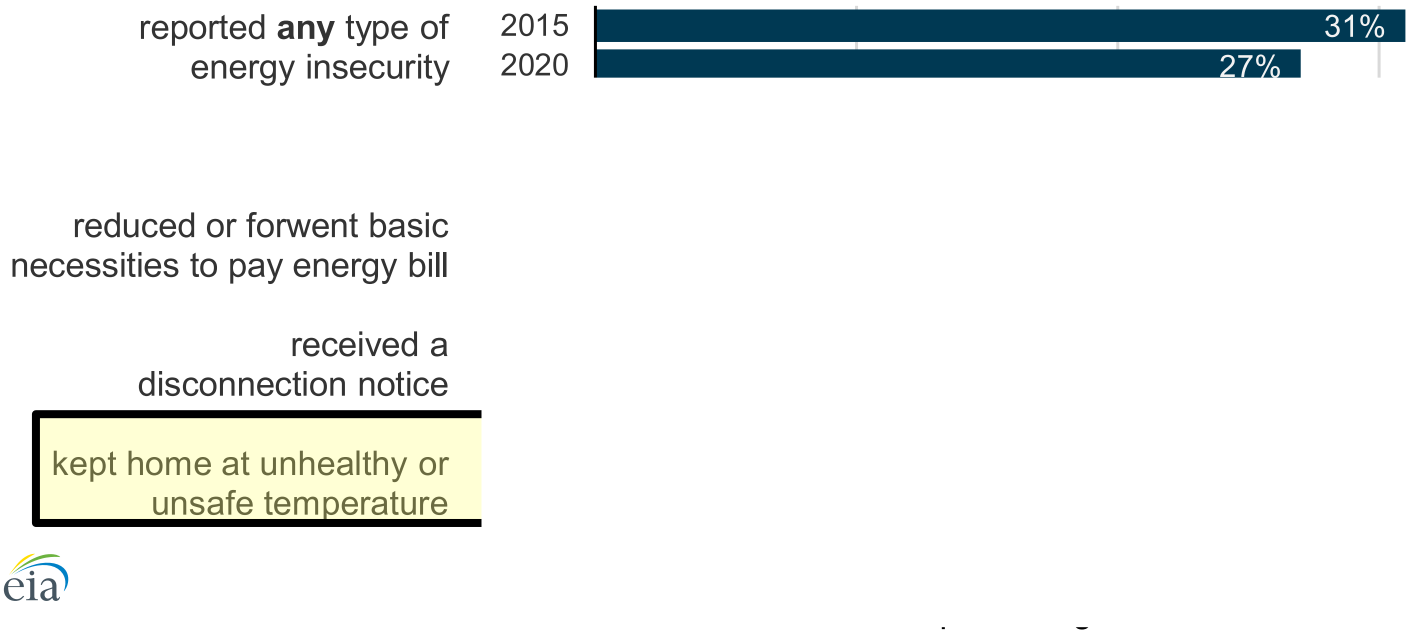
27% of Americans experience some form of energy insecurity

U.S. household energy insecurity measures (2015 and 2020)



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Source: U.S. EIA. (2022, April 11). *In 2020, 27% of U.S. households had difficulty meeting their energy needs*. Retrieved from Today in Energy: https://www.eia.gov/todayinenergy/detail.php?id=51979

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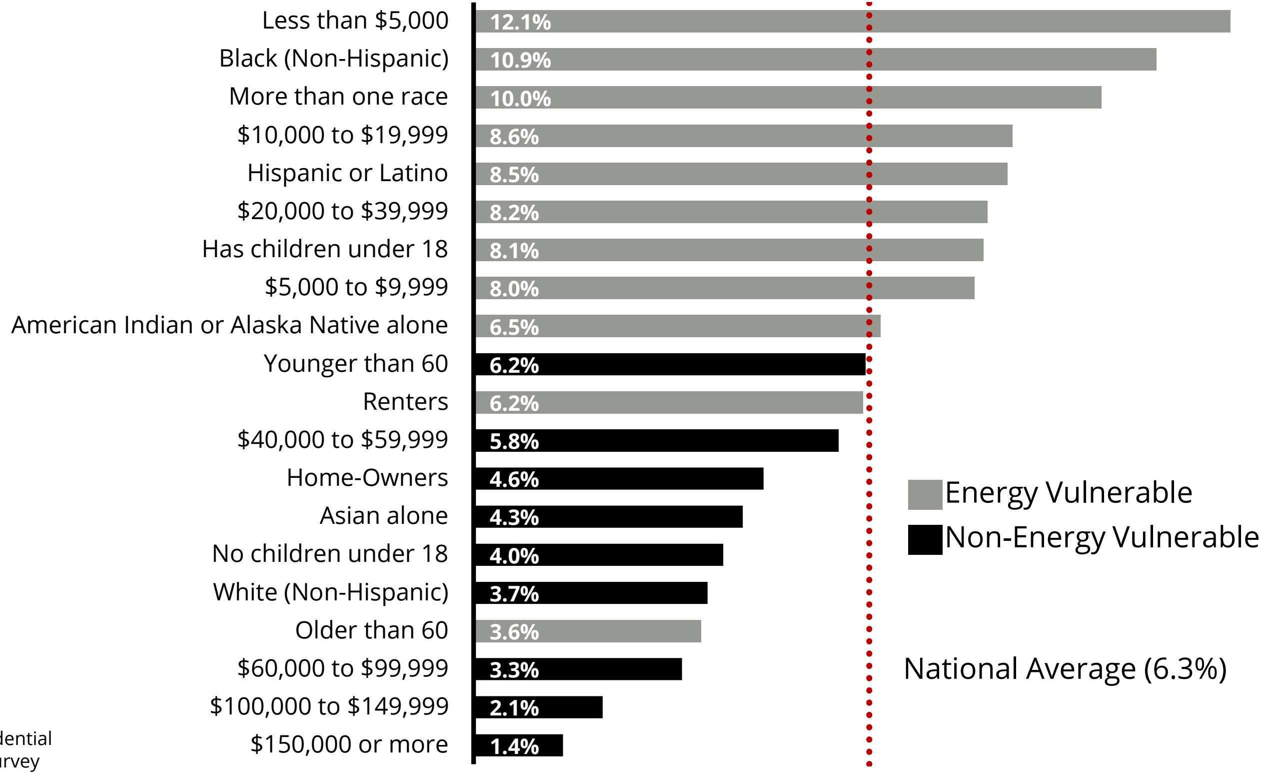
Majority of the households unable to use their ACs are from the energy vulnerable sub-populations.

Percentage of households that were unable to use their AC units



Data source: 2020 Residential Energy Consumption Survey

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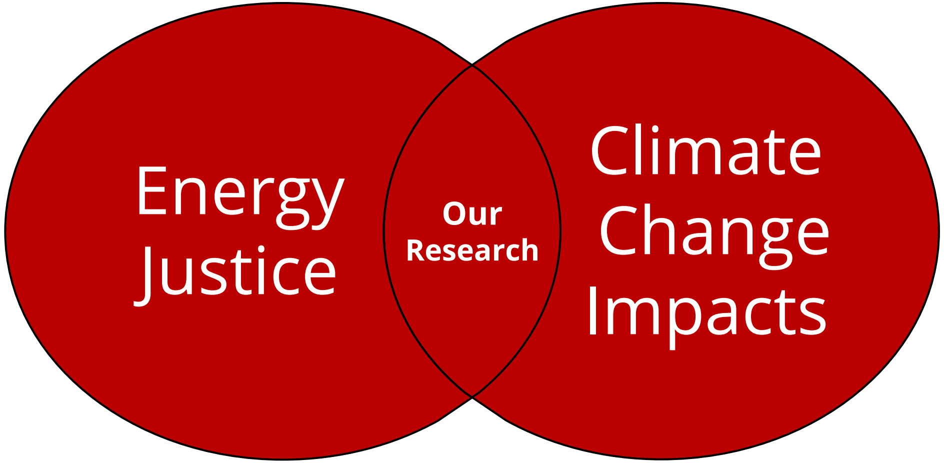
Our work is at the intersection of future climate impacts, household adaptation, and energy justice

1. How will increasing temperatures due to climate change affect residential electricity cooling consumption among vulnerable groups?

2. What effect does improving AC efficiency have on reducing consumption and energy inequalities?



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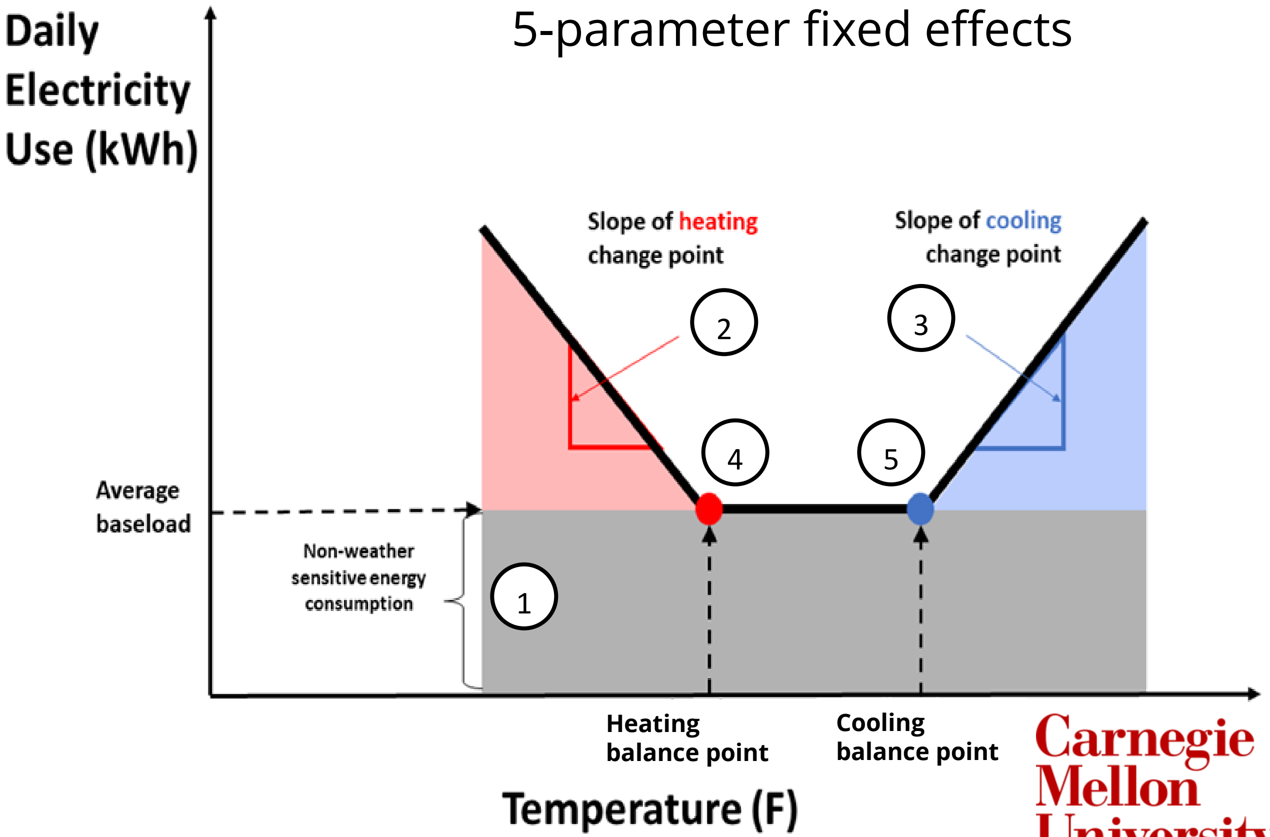
Temperature Response Function: Load Disaggregation

A household's temperature dependent electricity usage falls under three electricity demand categories: **baseload (BL)**, heating (HL), and cooling (CL) (De Cian et at., 2017; Li et al., 2014; Sailor et al., 2003).



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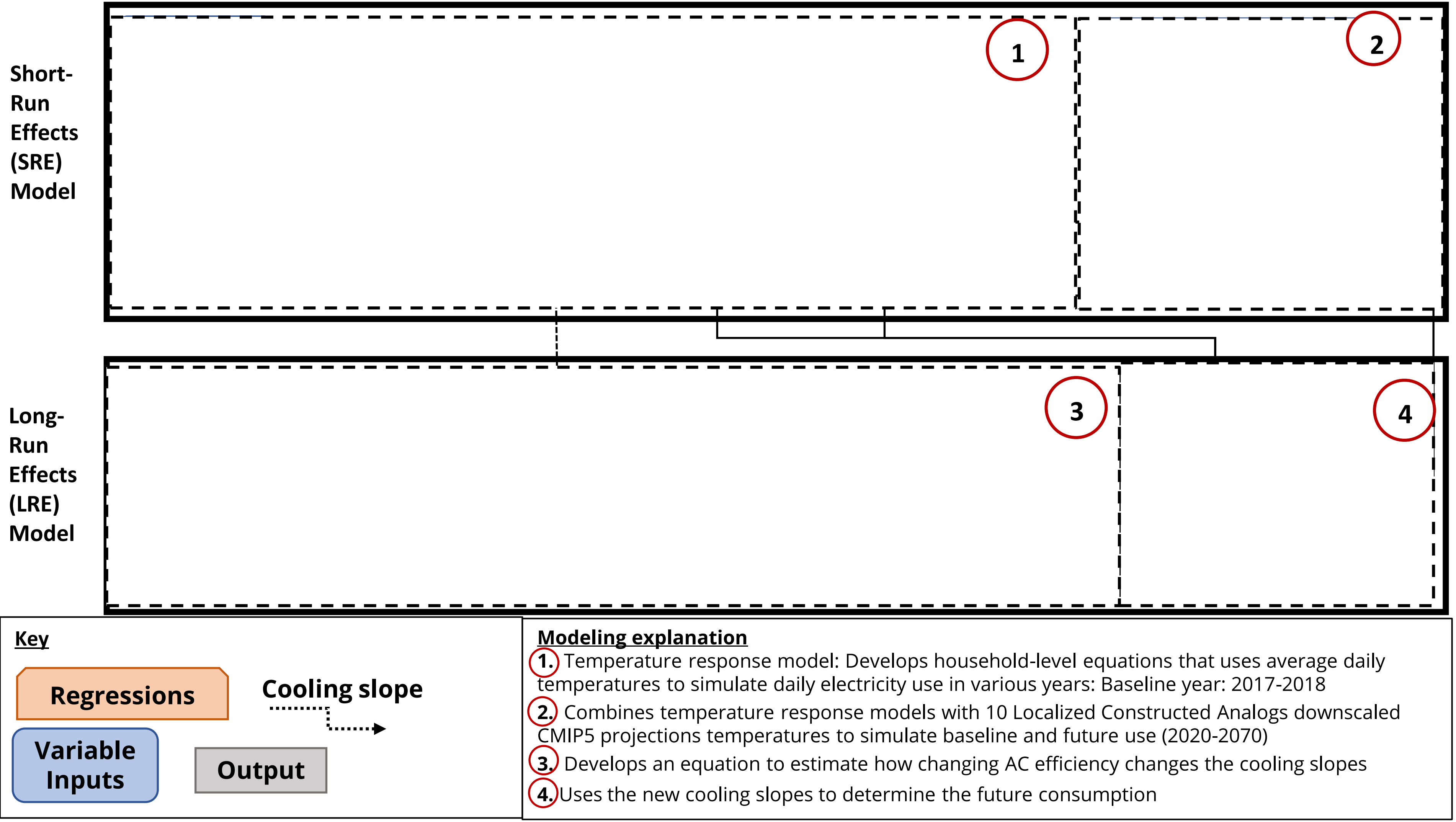

Short-Run Effects (SRE) Model
1
2
Long-Run Effects (LRE) Model
3
4
Key
Regressions
Cooling slope
Variable Inputs
Output
Modeling explanation
1. Temperature response model: Develops household-level equations that uses average daily temperatures to simulate daily electricity use in various years: Baseline year: 2017-2018
2. Combines temperature response models with 10 Localized Constructed Analogs downscaled CMIP5 projections temperatures to simulate baseline and future use (2020-2070)
3. Develops an equation to estimate how changing AC efficiency changes the cooling slopes
4. Uses the new cooling slopes to determine the future consumption

Short-run effects

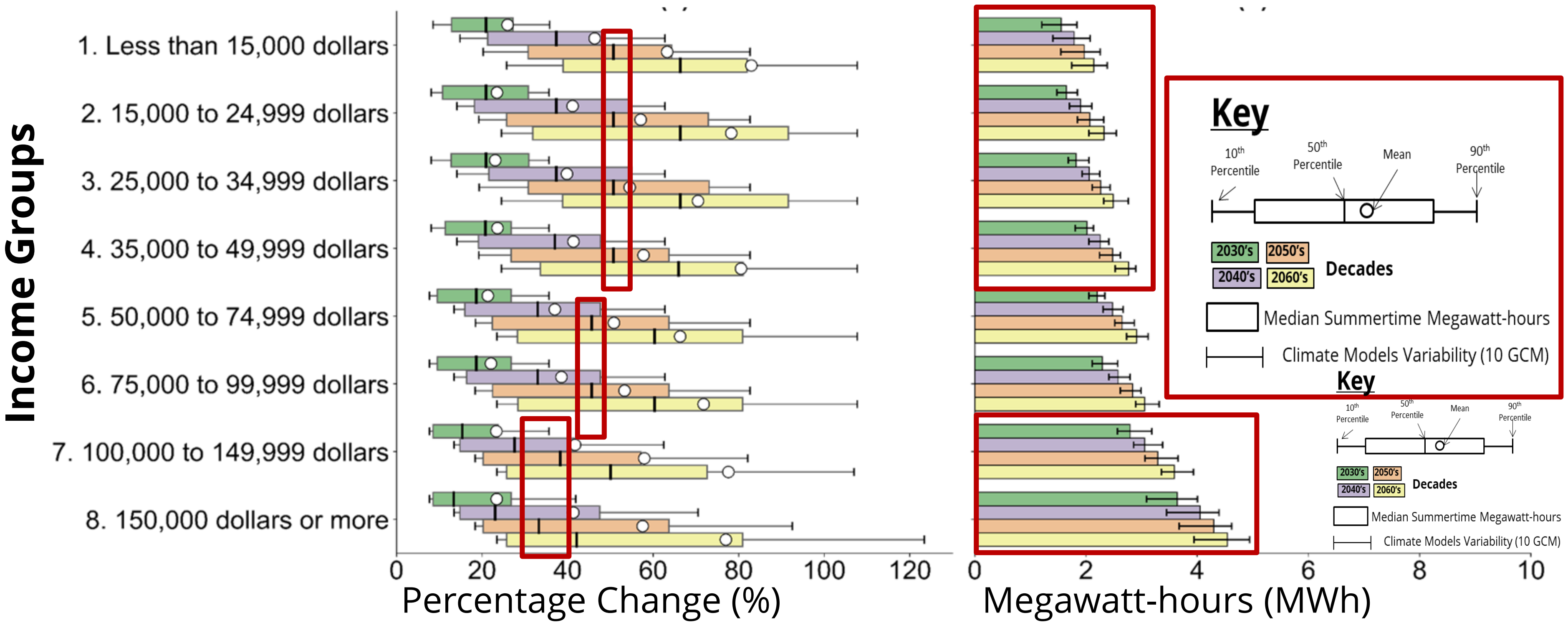
Only changes in temperature

We focus our discussion of the results under **<u>RCP 8.5</u>**

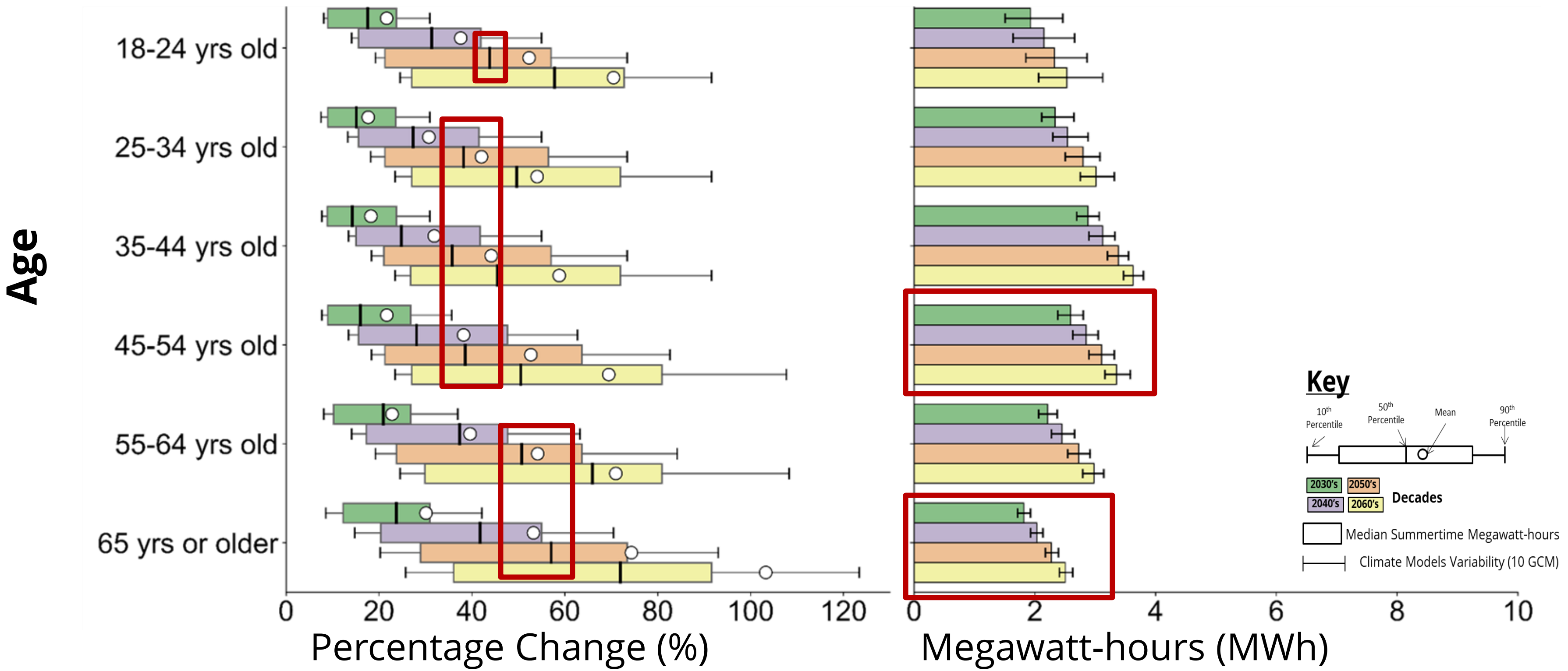
Looks at the **<u>consumption</u>** from May to September

Focuses only on **<u>2,432</u>** households

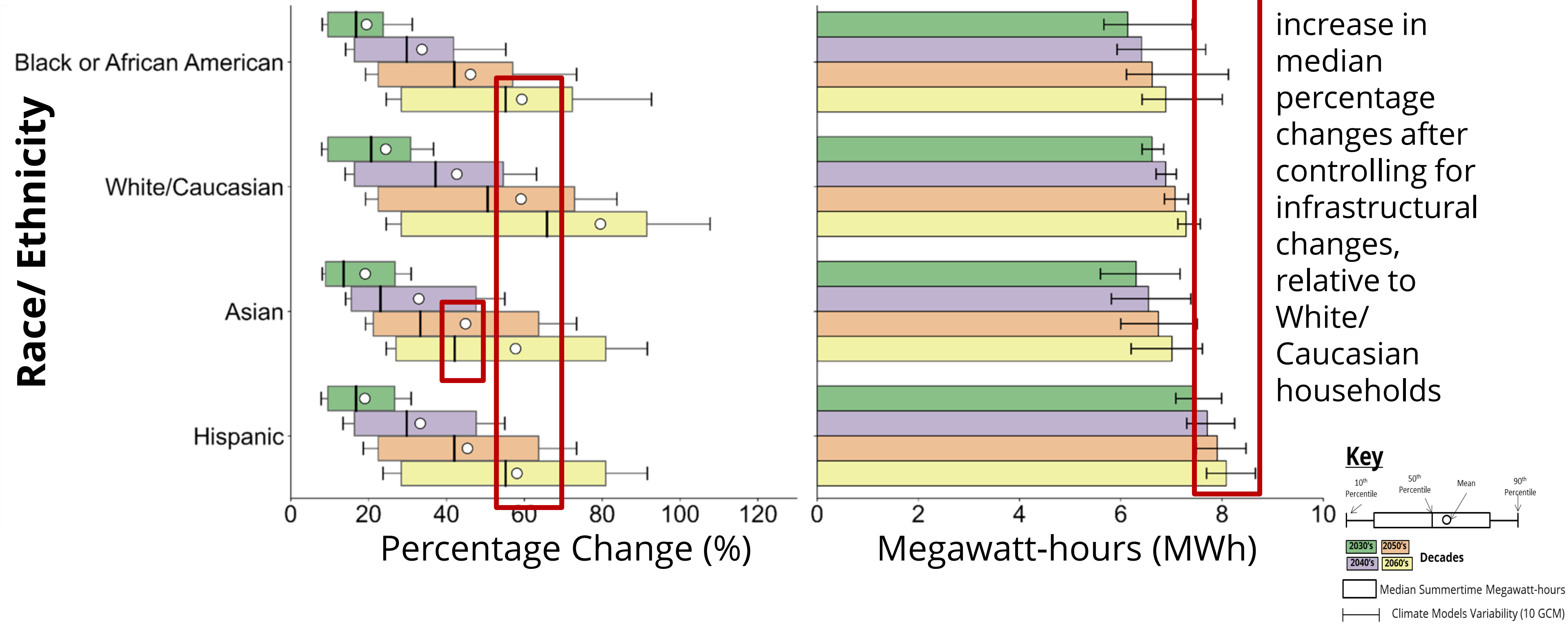
During the 2050's low-income groups may experience a 33% difference in cooling behavior compared to higher income groups, despite consuming 20% less megawatt-hours.



Similarly, elderly households see more than a 49% - 66% increase during the 2040s through 2060s, equating to more than 2 MWh.



Racial/ethnic groups percentage changes are more equal among the other groups



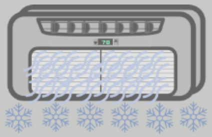
Hispanic households see a 0.24 increase in median percentage changes after controlling for infrastructural changes, relative to White/ Caucasian households

Long-run effects

Changes in temperature

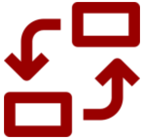
&

Changes in AC efficiency

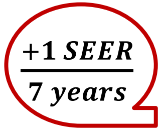


Assumptions

Purchases an AC efficient unit (SEER 15) in 2020



Replaces their AC units every 20 years

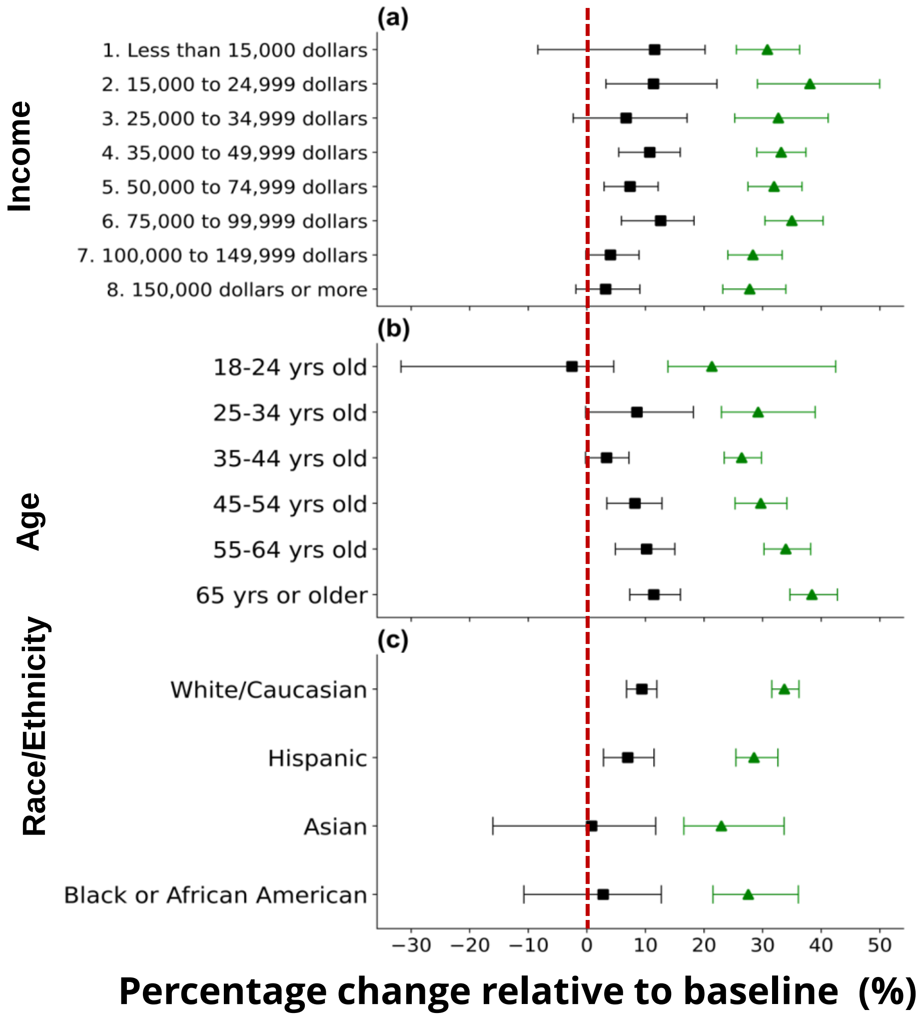


SEER standards increases by 1 SEER every seven years

Year of upgrade	SEER Rating
2020	15
2040	18
2060	21

Focuses only on **333 households**

The elderly and low-income households benefit at a slightly lower percentage (60% reduction) than their counterparts' (80%) reduction, which totals to a saving of more than 26 MWh from upgrades.



Only Temperature changes (Median)

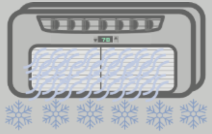
AC Efficiency + Temperature Changes (Median)

Household Variability

Effects on energy burden

Changes in temperature

Changes in AC efficiency



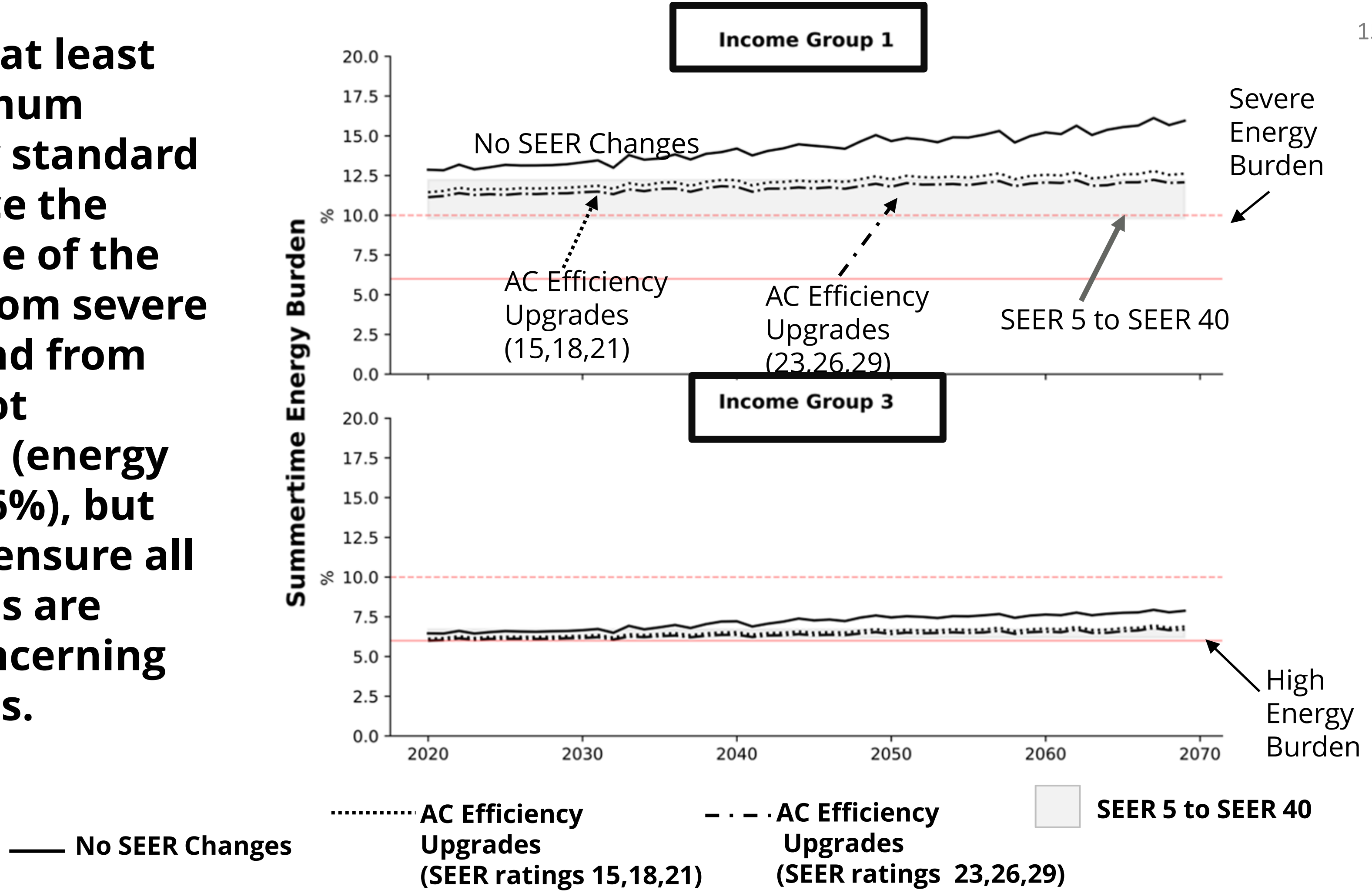
Focus on the income groups closes to the affordability thresholds

Energy Burden

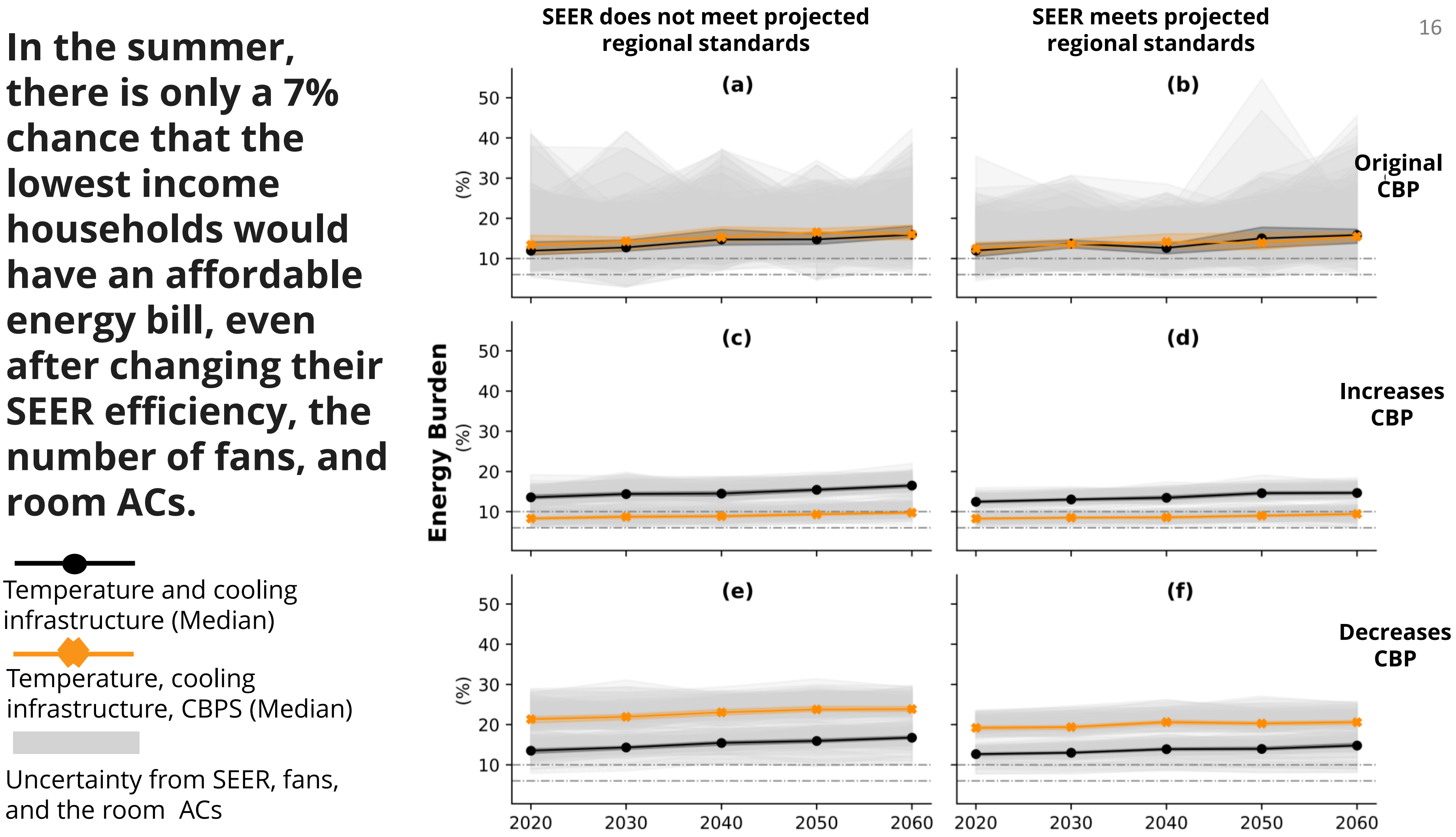
$$\frac{\text{Energy expenditures}}{\text{Income}}$$

Maintains the same assumptions as the long-run

Adopting at least the minimum efficiency standard can reduce the magnitude of the burden from severe to high and from high to not burdened (energy burden ≤6%), but does not ensure all reductions are below concerning thresholds.



In the summer, there is only a 7% chance that the lowest income households would have an affordable energy bill, even after changing their SEER efficiency, the number of fans, and room ACs.



Findings

1. The ***median household can experience a 27.7%*** increase in cooling demand under RCP 8.5, whereas the ***elderly sees a 35.5%*** and ***low-income sees between a 31-32%*** increase relative to 2017-2018

2. Improving AC efficiency ***reduces the short-run cooling consumption by 70%***

3. Low-income groups can see as high as a ***12.2% - 14.4% in median summertime energy burden*** without AC efficiency upgrades

4. AC efficiency can ***lower energy burden by 1-2 ±0.2 percentage points***

5. Vulnerable groups are ***disproportionately more energy burdened*** than their counterparts

Race/Ethnicity	Share of households
White/Caucasian	9%
Asian	12%
Black or African American	18%
Hispanic	21%

Recommendations

We encourage

The continuation of regional efficiency standards along with additional infrastructural subsidies for low-income households to ensure they can purchase, maintain, and replace their AC system.

Stronger local policies and ordinances with cities, utilities, property owners and residents to share energy data for better informed decisions.

Working alongside at-risk groups and communities to develop resources and supports to maximize savings and other efficiency improvements (i.e., energy audits and workshops).

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Conclusions

- At-risk groups have the potential to see higher climate impacts relative to their counterparts without intentional support, in addition to improving AC efficiency

- Our findings suggest that additional infrastructural improvements and support are needed to ensure vulnerable groups have adequate resources to meet their cooling needs.

Thank you!

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We note that this paper was initiated while Constantine Samaras was affiliated with Carnegie Mellon, and the views of this presentation do not represent the United States Government or any other organization.

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ABSTRACT

Transitioning to an equitable electricity sector requires a deep understanding of a warming climate's impacts on vulnerable populations. A vital climate adaptation measure is deploying air-conditioning (AC), but AC use can increase household energy costs. We evaluate how a warming climate will affect regional energy equity by tying temperature projections with household temperature response functions derived from smart-meter electricity data in Phoenix, Arizona. We simulate future consumption changes under two climate change scenarios from 2020 to 2070, with and without AC efficiency upgrades.

We find that the median elderly and low-income household percentage changes are nearly 5 percentage points higher than their counterparts after controlling for decadal, housing, and cooling infrastructural differences. Improving AC efficiency reduces cooling consumption by up to 70% for vulnerable groups. However, a disproportionate share of racial minorities (Hispanic (21%), Black (18%), Asian (12%)) have energy burdens above 6%, indicating affordability challenges.

The energy justice implications of this work suggest that intentional considerations of how technology adoption will affect energy affordability and cooling needs are imperative for households to adapt to a warming climate. Such insights are essential for mitigating risk in vulnerable populations, given that policies often rely on ACs as a primary extreme-heat adaptation strategy.

If you want to learn more about this analysis

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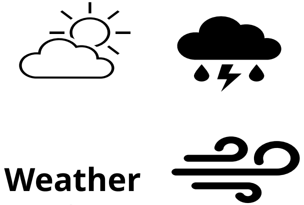
Limitations

Data availability

- Survey results are based on 2017 responses
- Using CMIP6 can provide the most recent temperature scenarios and assumptions

Spatial & temporal granularity

- Point-in-time analysis versus multiyear averages
- Analysis is limited regarding spatial implications which can address more of the racial differences



Weather confounders

- Humidity and other climate variables (rainfall, wind speed, or solar radiation) may affect both temperature and daily consumption

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Terminology

1. Temperature response function – the relationship between a household’s electricity consumption and outdoor temperature
2. Inflection temperature – the temperature that is related to the minimum electricity consumption
3. Energy Burden – the percentage of a household’s income spent on electricity bill
4. Energy insecurity – an inability to adequately meet basic household energy needs [1]
5. Energy Justice - as a framework that evaluates (a) where injustices emerge, (b) which affected sections of society are ignored, and (c) which processes exist for their remediation in order to (i) reveal and (ii) reduce such injustices [2]
6. Energy vulnerable households- householder who are low-income, African American/black, of Hispanic origin, or above the age of 65-year-old.

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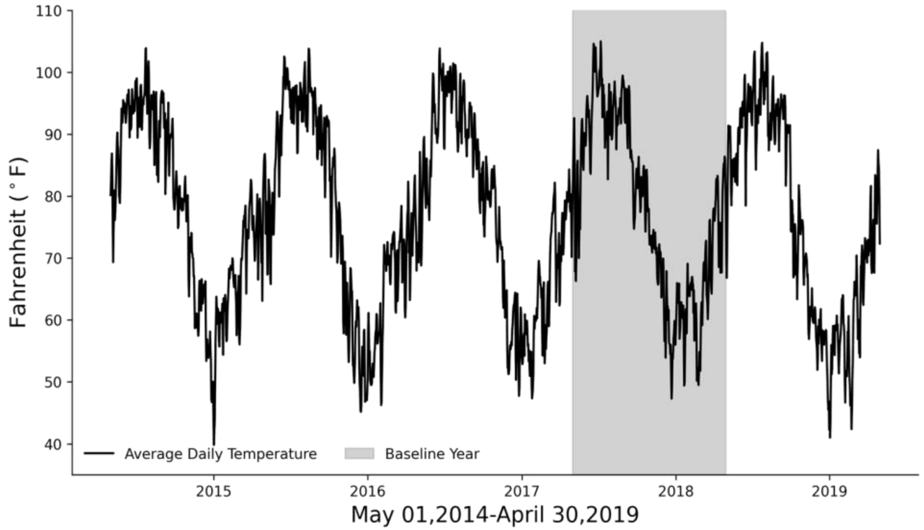
Case Study Region: Phoenix, Arizona

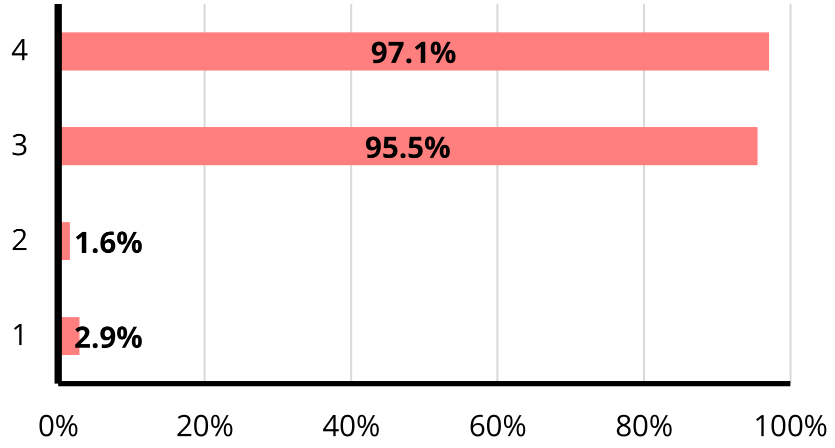
Temperatures



Average Daily Temperature

Focus Range of study (May 2017-April 2018)

AC Penetration



Data Source: American Housing Survey

Data

Description	Time Frame	Source
Total daily electricity consumption [kWh]	May 2015 to April 2019	Salt River Project (Arizona)
Survey results	June 2017	Salt River Project
Daily temperature average	May 2015 to April 2019	National Oceanic and Atmospheric Administration
Localized Constructed Analogs (LOCA) downscaled CMIP5 projections	May 2020 to April 2069	US Geological Survey Data Portal

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Table A.1: Survey variables used for AC efficiency model (Numerical)

	count	mean	std	min	max
Numerical Variables					
Seasonal Energy Efficiency Ratio (SEER)	723	14	4	1	96
Number of fans	5512	4.31	2.12	0	16
Housing unit age	4233	25.47	16.63	0	99

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Table A.2: Survey variables used for AC efficiency model (Categorical)

	count
Dwelling Type	
No Response	747
Apartment/Condo/Townhouse	896
Mobile home	244
Single family home	3994
Dwelling Size	
No Response	761
1,500 - 2,999	2703
3,000 or more	477
Less than 1,500	1940
Number of AC units	
No response	401
3 or more	177
One	4203
Two	1100
Types of AC units	
No response	448
Central-Gas	1096
Central-Heat pump	3334
Central-Separate AC	532
Central-Unknown	471

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Household temperature response function

$$E_{h,t,y} = \beta_{0_{h,y}} + \beta_{1_{h,y}}(T_{h,y}^{HBP} - \bar{T}_t) + \beta_{2_{h,y}}(\bar{T}_t - T_{h,y}^{CBP}) + \gamma \overline{EleC}_{t,h} + \theta_{h,t,y} + \varepsilon_{h,t,y} \quad \textbf{(1)}$$

E is the total electricity consumption on day t for household h, in year y

$\bar{T}$ is the average outdoor temperature in degrees Fahrenheit on day t

T^{CBP} is the temperature that household, h, during year, y, begins to cool their homes

T^{HBP} is the temperature that household, h, during year, y, begins to heat their homes

$\overline{EleC}$ is the average electricity price on day, t, for household, h

θ are the fixed effects for the month, day of the week, and holidays

ε is the random error term for household h on day t

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AC efficiency and cooling slopes

$$\beta_2 = \alpha + \beta_3 SEER + \varsigma Share + \kappa Col + XHH + \varepsilon_2 \qquad \textbf{(2)}$$

β_2 is the slope of the household's cooling demand

$SEER$ is the Seasonal Energy Efficiency Ratio rating

$Share$ is the percentage of the number of days the temperature is above the household's cooling balance point, ranging from 0 to 1.

Col is cooling infrastructure variables such as, (i) number of fans, (ii) type of AC unit, and (iii) Number of AC units

XHH is housing infrastructure variables including (i) dwelling type, (ii) age of the unit, and (iii) size of the residence.

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Simulated daily electricity

$$E^*_{h,t,y} = \beta_{0_{h,y}} + \beta_{1_{h,y}}\left(T^{HBP}_{h,y} - \boldsymbol{T^*_t}\right) + \beta_{2_{h,y}}\left(\boldsymbol{T^*_t} - T^{CBP}_{h,y}\right) + \gamma \overline{EleC}_{t,h} + \theta_{h,t,y} \quad \textbf{(3)}$$

E^* is the total electricity consumption on day t for household h, in year y

$\overline{\overline{\boldsymbol{T}}}{}^*_{\boldsymbol{t}}$ is the average outdoor temperature in degrees Fahrenheit on day t **(from GCMs)**

All coefficients are unique to each household and derived from Equation (1)

Monte Carlo Assumption

Sensitivity analysis inputs table. Uniform distributions were selected to model scenarios that are all equally likely to occur, and to capture household behavior and infrastructural changes **along with future warming scenarios** impact on our estimates.

Parameters	Ranges	Units	Distribution
Heating balance points	30 - 60	°F	Uniform
Cooling balance points	60 - 105	°F	Uniform
AC efficiency (SEER)	3-35	SEER	Uniform
Fans	0-10	Count of fans	Uniform
Room AC units	0-15	Count of room ACs	Uniform
Income	833 -1,250	$ per month	Uniform

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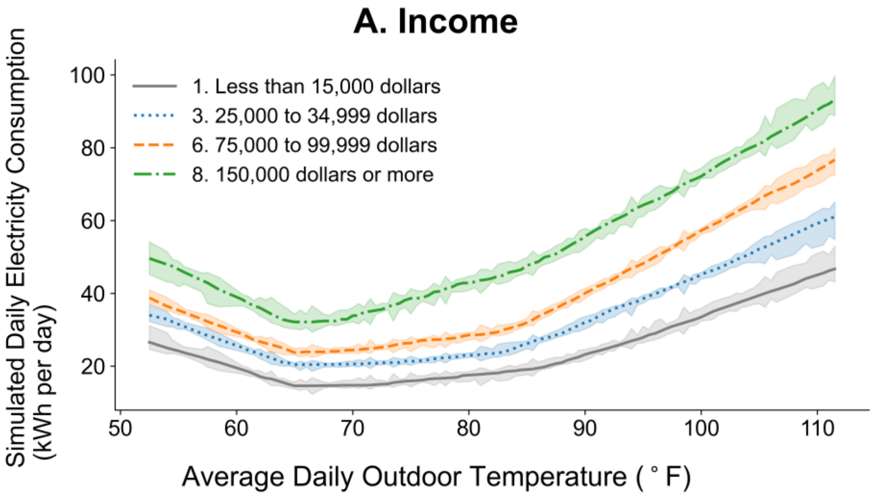
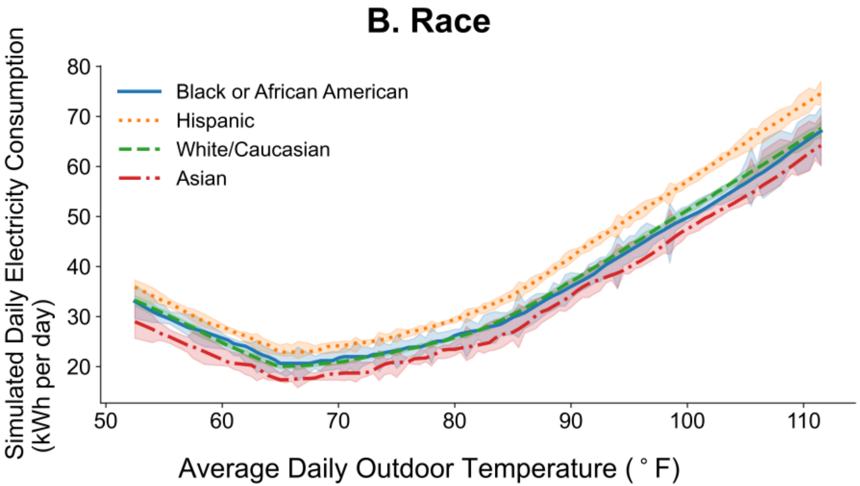
Baseline Analysis

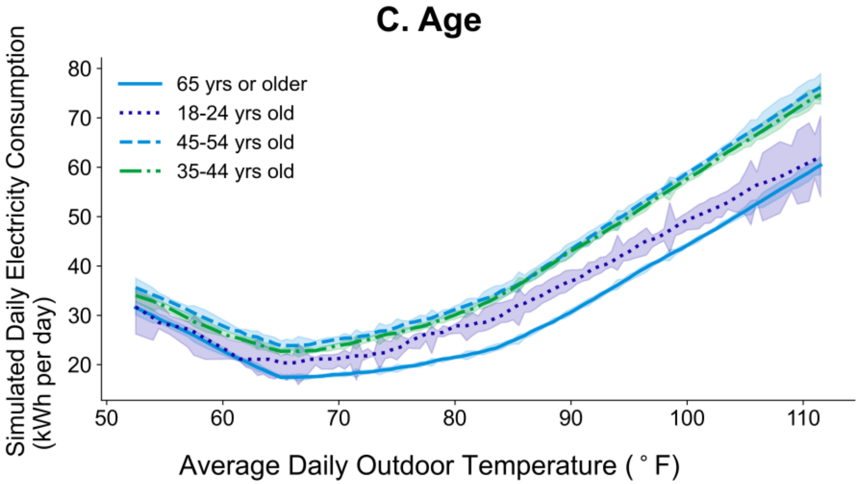
Table 1: Household-level model evaluation for daily consumption

	Household (N)	In-sample RMSE (±kWh)			Adjusted R^2 (%)		
	Count	Mean	Minimum	Maximum	Mean	Minimum	Maximum
2015-2016	3484	7.96	0.79	33.98	77.51	8.72	97.87
2016-2017	3593	7.80	0.52	41.79	78.16	13.57	97.44
2017-2018*	3048	7.76	0.67	43.39	79.58	12.04	98.17
2018-2019	2244	7.70	0.44	53.54	80.54	16.10	97.53

*Our baseline model estimate only considers the 2017-2018 household models







Racial/ethnicity temperature response is less dispersed than other at-risk groups at the extremes

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Table D.2: Median and 95% confidence interval for three of the five parameters within the 2017-2018 baseline 5-parameter regression

	Count (N)	β_0: Baseload (kWh)			T^{CBP}: Cooling Balance Points (°F)			β_2: Cooling Slopes (kWh per 1VCDD)		
		Median	95% CI		Median	95% CI		Median	95% CI	
			Lower	Upper		Lower	Upper		Lower	Upper
Overall										
All households	4377	21.62	20.95	22.24	81.0	80.0	81.0	1.39	1.37	1.42
Age										
18-24 years old	122	20.2	17.4	**24.7**	79.0	77.0	**83.0**	1.18	1.07	1.32
25-34 years old	405	**22.0**	**21.0**	**24.5**	79.0	78.0	80.0	1.30	1.25	1.39
35-44 years old	936	**23.8**	**22.3**	**25.2**	79.0	78.0	80.0	**1.42**	1.34	**1.46**
45-54 years old	718	**24.7**	**23.5**	**27.0**	80.0	78.0	81.0	**1.44**	1.36	**1.50**
55-64 years old	821	**23.0**	**21.2**	**24.6**	**82.0**	**82.0**	**82.0**	**1.44**	1.37	**1.51**
*65 years or older	1249	18.9	18.0	19.9	**83.0**	**82.0**	**83.0**	**1.41**	1.36	**1.46**
Income										
*Less than $15,000	227	14.6	12.5	17.1	**82.0**	**81.0**	**82.5**	1.05	0.93	1.18
*$15,000 to $24,999	330	16.1	14.8	17.1	**82.0**	**81.0**	**83.0**	1.21	1.12	1.28
$25,000 to $34,999	341	20.3	19.1	22.1	**82.0**	**81.0**	**83.0**	1.29	1.22	1.37
$35,000 to $49,999	534	19.3	17.8	20.5	81.0	80.0	81.0	1.34	1.27	1.40
$50,000 to $74,999	758	**21.7**	20.4	**23.3**	**82.0**	**82.0**	**83.0**	1.32	1.27	1.41
$75,000 to $99,999	515	**23.7**	**21.7**	**25.2**	**82.0**	**81.5**	**83.0**	**1.56**	**1.49**	**1.64**
$100,000 to $149,999	467	**28.8**	**27.2**	**30.7**	81.0	80.0	**82.0**	**1.57**	**1.46**	**1.64**
$150,000 or more	284	**32.1**	**27.7**	**35.2**	79.0	77.0	81.0	**1.87**	**1.74**	**2.03**
Race/Ethnicity										
*American Indian/ Alaska Native	54	**25.6**	**22.9**	**28.1**	81.0	80.0	**87.0**	**1.48**	1.17	**1.87**
Asian	112	18.7	16.0	20.6	80.0	77.0	**83.0**	**1.43**	1.35	**1.52**
*Black or African American	114	20.6	17.2	**24.3**	80.5	79.0	**82.5**	1.30	1.12	**1.52**
*Hispanic	581	**24.4**	**23.3**	**26.7**	80.0	79.0	81.0	**1.47**	**1.41**	**1.55**
Native Hawaiian or Other	6	**26.7**	**25.0**	**28.3**	68.0	65.0	71.0	**1.40**	0.96	**1.84**
Other	102	**22.4**	18.4	**27.9**	81.0	80.0	**84.0**	1.35	1.16	**1.48**
Pacific Islander	7	**40.1**	-12.4	**70.0**	75.5	66.5	**85.5**	**2.14**	**1.52**	**3.18**
White/Caucasian	2695	20.9	20.0	21.7	**82.0**	**82.0**	**82.0**	1.37	1.34	1.40

**Denotes the demographic groups that are at-risk of energy-insecurity. The bolded values represent groups that are above sample medians.*

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Table D.3: Cooling slopes regression summary table

Dependent variable: Cooling slopes	AC Efficiency only Model (1)	AC Efficiency and share of days Model (2)	AC Efficiency, share of days, and cooling infrastructure Model (3)	AC Efficiency, share of days, and cooling & housing infrastructure Model (4)	AC Efficiency ,share of days, cooling & housing infrastructure, and income Model (5)
SEER Rating	-0.026* (0.015)	-0.026* (0.014)	-0.033** (0.016)	-0.021** (0.009)	-0.025* (0.014)
Proportion of days AC was used		-1.741*** (0.597)	-1.945*** (0.615)	-1.655*** (0.259)	-1.667*** (0.264)
Intercept[1]	2.002*** (0.236)	2.976*** (0.509)	2.817*** (0.568)	2.185*** (0.246)	2.271*** (0.411)
Cooling Infrastructure[2]	**NO**	**NO**	**YES**	**YES**	**YES**
Housing Infrastructure[3]	**NO**	**NO**	**NO**	**YES**	**YES**
Income	**NO**	**NO**	**NO**	**NO**	**YES**
Observations	284	284	278	235	212
Adjusted R^2	0.006	0.114	0.268	0.450	0.399

Notes. The robust standard errors are shown in parentheses. * p<0.1, ** p<0.05, ***p<0.01
1. Coefficients are relative to single-family homes that is less than 1,500 square feet, and has one central AC.
2. Cooling Infrastructure includes the number of fans, AC units in the household, and the type of central AC unit they are using to cool
3. Housing infrastructure includes the dwelling type (i.e., apartment/condo/townhome, or a mobile), the age of the housing unit, and square feet of the residence.

A.

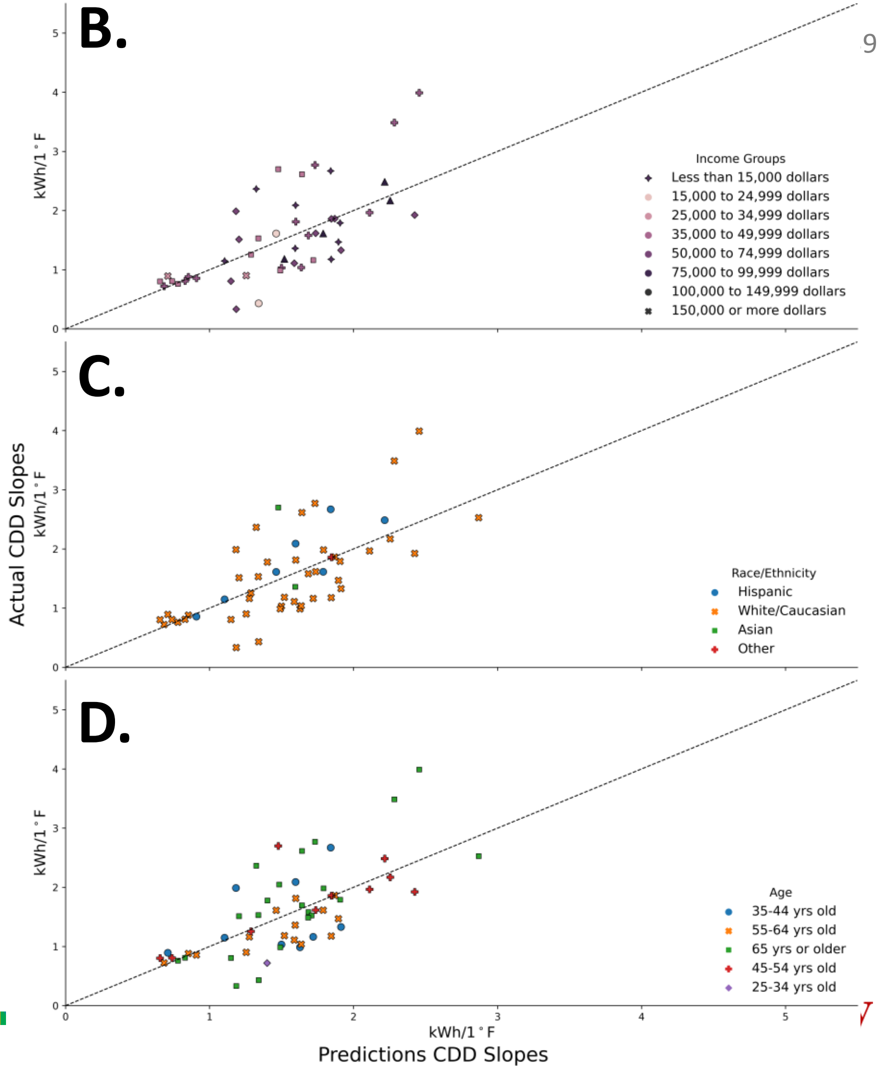
	Count	Mean	RMSE	CV(RMSE)
Training Set	218	1.60	0.27	16.70
Testing Set	61	1.62	0.31	19.29

Figure E.1: SEER efficiency coefficient derived from the testing set (n=61).

(A) describes the training and testing set which shows that the coefficient of variation of the root mean square error is less than 20% for both the in-sample and out of sample estimates.

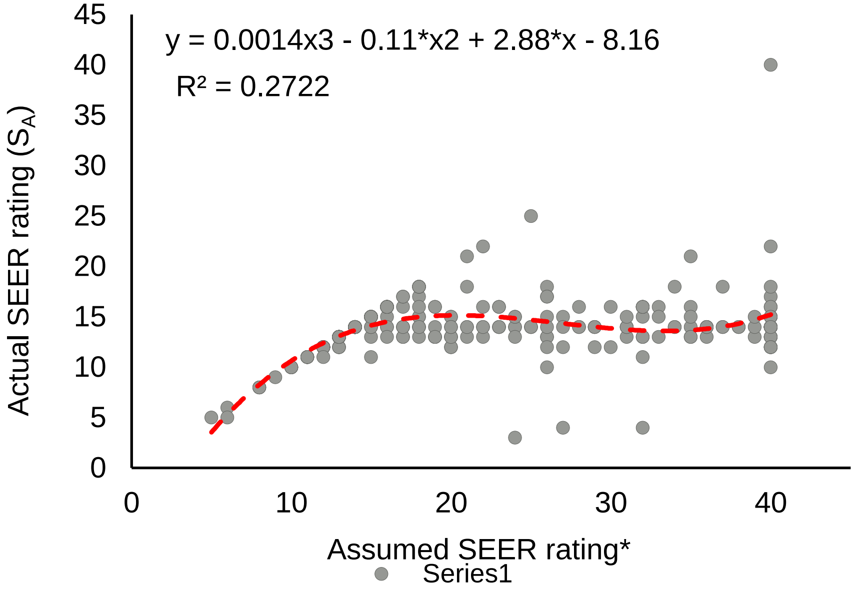
The predictive ability of the actual versus estimated cooling slopes are shown for **(B)** income groups, **(C)** racial/ethnic groups, and **(D)** age groups.

The y-axis represents the actual slopes of the households that reported their SEER, while the x-axis shows the predicted slopes using Equation 4. The diagonal line shows how close these values are to each other.

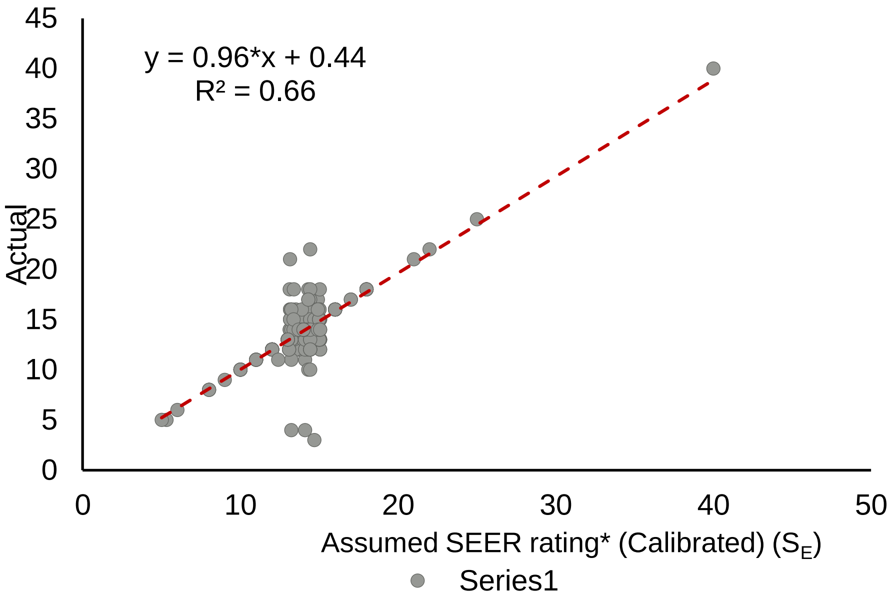


SEER calibration process

Before calibration



After calibration



$$Adjusted\ \ SEER = \begin{cases} S_{E_h} & , \quad S_{E_h} = S_{A_h} \\ 0.0014 * S_{E_h}^3 \; - \; 0.11 * S_{E_h}^2 \; + \; 2.8766 * S_{E_h} \; - \; 8.16, & \quad S_{E_h} \neq S_{A_h} \end{cases} \qquad \text{C.1}$$

Short-run and long-run Analysis

Table E.2: Summertime median decadal household-level cooling percentage change (%) across 10 GCMs and groups under RCP 4.5 and 8.5 (May to September).

	Count N	RCP 4.5					RCP 8.5				
		2020s	2030s	2040s	2050s	2060s	2020s	2030s	2040s	2050s	2060s
All households											
	2432	3.4%	10.0%	15.6%	20.3%	26.9%	6.5 %	15.7%	26.8%	39.6%	52.3%
Age											
18-24 years old	56	3.2%	9.5%	14.8%	19.1%	25.4%	6.1%	14.9%	25.3%	36.8%	48.4%
25-34 years old	169	2.8%	8.9%	14%	17.6%	23.7%	5.5%	13.7%	23.5%	34.2%	43.9%
35-44 years old	536	2.6%	8.7%	13.7%	17.1%	22.8%	5.5%	13.3%	22.7%	33%	42%
45-54 years old	451	2.9%	9.4%	14.7%	18.7%	24.9%	6.1%	14.6%	24.8%	36%	46.2%
55-64 years old	506	3.6%	10.6%	16.4%	21.4%	28.3%	6.8%	16.7%	28.2%	41.8%	56.7%
*65 years or older	705	**4.3%**	**12%**	**18.3%**	**24.1%**	**32%**	**8%**	**19.3%**	**32.7%**	**49.5%**	**66.7%**
Income											
*Less than 15,000 dollars	105	**4.1%**	**11.3%**	**17.2%**	**22.8%**	**30.3%**	**7.3%**	**18.2%**	**30.6%**	**45.1%**	**60.9%**
*15,000 to 24,999 dollars	185	3.8%	11%	16.7%	22%	29.2%	7%	17.3%	29.2%	44.3%	58.9%
*25,000 to 34,999 dollars	176	4.2%	11.3%	17.2%	22.8%	30.2%	7.2%	18.1%	30.5%	45.4%	61.3%
35,000 to 49,000 dollars	280	3.7%	10.6%	16.5%	21.4%	28.4%	6.8%	16.7%	28.3%	41.9%	56.6%
50,000 to 74,999 dollars	408	3.3%	9.9%	15.5%	19.9%	26.4%	6.4%	15.4%	26.3%	38.8%	51.3%
75,000 to 99,999 dollars	298	3.5%	10.1%	15.7%	20.1%	26.9%	6.5%	15.6%	26.8%	39.7%	52.3%
100,000 to 149,999 dollars	296	2.7%	9%	14.2%	17.8%	23.8%	5.9%	13.9%	23.7%	34.4%	43.5%
150,000 dollars or more	193	2.6%	8.8%	14%	17%	23.2%	5.7%	13.5%	23.1%	33%	41.4%
Race/Ethnicity											
*American Indian/Alaska Native	24	3%	9.4%	14.8%	18.8%	25.1%	5.8%	14.4%	24.8%	36.5%	47.5%
Asian	75	2.7%	9%	14.2%	17.5%	23.7%	5.8%	13.8%	23.6%	33.7%	42.4%
*Black or African American	58	3.2%	9.7%	15%	19.4%	26%	6.2%	15.1%	25.9%	37.8%	49.7%
*Hispanic	370	3.2%	9.8%	15.3%	19.4%	25.9%	6.3%	15.1%	26%	38%	50.1%
Native Hawaiian or Other	3	1.2%	4.8%	8.1%	9.9%	14%	2.3%	8%	13.7%	19.3%	24.5%
Other	56	3.5%	10.1%	15.5%	20.4%	27.1%	6.6%	15.9%	27.4%	41%	54.4%
Pacific Islander	3	3.5%	10%	15.7%	22.5%	28.2%	6.6%	16.4%	28.2%	48.6%	66.2%
White/Caucasian	1462	**3.5%**	**10.3%**	**16%**	**20.9%**	**27.5%**	**6.7%**	**16.2%**	**27.5%**	**41%**	**54.9%**

*Notes: *Denotes the demographic groups that are at-risk of energy-insecurity. **Shading** displays each sub-group with the highest percentage changes per decade*

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Table E.3: Summertime median decadal household-level cooling consumption (megawatt-hours) across 10 GCMs and groups under RCP 4.5 and 8.5 (May to September).

	Count N	RCP 4.5					RCP 8.5				
		2020s	2030s	2040s	2050s	2060s	2020s	2030s	2040s	2050s	2060s
All households											
	2432	2.0	2.1	2.3	2.4	2.5	2.1	2.2	2.5	2.7	3.0
Age											
18-24 years old	56	1.7	1.8	1.9	2	2.1	1.8	1.9	2.1	2.3	2.5
25-34 years old	169	2.1	2.3	2.3	2.4	2.6	2.2	2.3	2.6	2.8	3
35-44 years old	536	**2.6**	**2.8**	**2.9**	**3**	**3.1**	**2.6**	**2.9**	**3.1**	**3.4**	**3.6**
45-54 years old	451	2.3	2.5	2.6	2.7	2.9	2.4	2.6	2.9	3.1	3.4
55-64 years old	506	1.9	2.1	2.2	2.3	2.5	2	2.2	2.5	2.7	3
*65 years or older	705	1.5	1.7	1.8	1.9	2	1.6	1.8	2	2.3	2.5
Income											
*Less than 15,000 dollars	105	1.3	1.4	1.5	1.6	1.8	1.4	1.5	1.8	1.9	2.1
*15,000 to 24,999 dollars	185	1.4	1.6	1.7	1.8	1.9	1.5	1.7	1.9	2.1	2.3
*25,000 to 34,999 dollars	176	1.7	1.8	1.9	2	2.1	1.7	1.9	2.1	2.3	2.5
35,000 to 49,000 dollars	280	1.8	1.9	2	2.1	2.3	1.8	2	2.3	2.5	2.7
50,000 to 74,999 dollars	408	2	2.1	2.3	2.3	2.5	2	2.2	2.5	2.7	3
75,000 to 99,999 dollars	298	2.1	2.3	2.4	2.5	2.6	2.2	2.4	2.6	2.9	3.1
100,000 to 149,999 dollars	296	2.6	2.8	2.9	3	3.2	2.6	2.9	3.2	3.4	3.7
150,000 dollars or more	193	**3.2**	**3.5**	**3.6**	**3.7**	**4**	**3.3**	**3.6**	**3.9**	**4.3**	**4.6**
Race/Ethnicity											
*American Indian/Alaska Native	24	1.5	1.7	1.8	1.8	2	1.6	1.7	1.9	2.2	2.4
Asian	75	2.2	2.4	2.5	2.5	2.7	2.3	2.5	2.7	2.9	3.1
*Black or African American	58	2.1	2.2	2.3	2.4	2.5	2.1	2.3	2.5	2.7	3
*Hispanic	370	**2.2**	**2.4**	**2.5**	**2.6**	**2.8**	**2.3**	**2.5**	**2.8**	**3**	**3.3**
Native Hawaiian or Other	3	6.5	6.7	6.8	7	7.2	6.6	6.9	7.2	7.5	7.8
Other	56	2.1	2.3	2.4	2.5	2.6	2.2	2.4	2.6	2.8	3.1
Pacific Islander	3	2.3	2.6	2.8	3	3.1	2.4	2.8	3.1	3.5	4
White/Caucasian	1462	1.9	2	2.2	2.2	2.4	2	2.2	2.4	2.6	2.9

*Notes: *Denotes the demographic groups that are at-risk of energy-insecurity.* ***Shading*** *displays each sub-group with the highest consumption changes per decade*

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Table E.4: Quantile regression of summertime cooling consumption percentage changes relative to households that make more than $150,000.

	Percentiles		
	10th	50th	90th
Less than $15,000	0.91	4.14	0.94
	(0.13)	(0.18)	(0.47)
$15,000 to $24,999	0.60	3.67	0.84
	(0.11)	(0.15)	(0.39)
$25,000 to $34,999	0.95	5.14	4.89
	(0.11)	(0.15)	(0.39)
$35,000 to $49,999	0.47	1.66	-2.90
	(0.10)	(0.13)	(0.35)
$50,000 to $74,999	0.16	1.24	-2.63
	(0.09)	(0.13)	(0.32)
$75,000 to $99,999	0.25	2.08	-0.39
	(0.09)	(0.13)	(0.33)
$100,000 to $149,999	-0.00	0.72	-0.24
	(0.09)	(0.13)	(0.32)
1,000 - 1,499 sq. ft.	-0.11	-0.63	7.37
	(0.16)	(0.23)	(0.62)
1,500 - 1,999 sq. ft.	-0.10	-0.98	4.57
	(0.16)	(0.23)	(0.61)
2,000 - 2,999 sq. ft.	-0.16	-0.56	7.81
	(0.15)	(0.21)	(0.57)
3,000 - 3,999 sq. ft.	-0.12	-0.99	9.46
	(0.16)	(0.22)	(0.59)
Under 1,000 sq. ft.	-0.63	-1.86	10.39
	(0.18)	(0.25)	(0.68)
2030	7.93	9.71	13.01
	(0.07)	(0.09)	(0.24)
2040	17.74	20.25	35.76
	(0.07)	(0.09)	(0.24)
2050	25.32	31.78	55.32
	(0.07)	(0.09)	(0.24)
2060	30.67	43.67	81.24
	(0.07)	(0.09)	(0.24)
One AC unit	-0.20	-1.01	-7.47
	(0.15)	(0.21)	(0.56)
Two AC units	-0.27	-1.16	-7.79
	(0.14)	(0.20)	(0.53)
AC unit packaged with gas heating	-2.11	-12.98	-23.04
(sometimes called a gas packed)	(0.06)	(0.08)	(0.20)
Don't know AC type	-1.39	-7.75	-9.41
	(0.09)	(0.13)	(0.32)
Separate AC system that only cools	-2.16	-12.91	-22.35
	(0.08)	(0.11)	(0.29)
Occupancy	-0.14	-1.53	-4.19
	(0.02)	(0.02)	(0.06)
Intercept	-9.91	15.80	56.78
	(0.16)	(0.22)	(0.56)
Observations	876100	876100	8761(
Pseudo R-squared	0.133	0.114	0.09

Standard errors are clustered on accounts

Table E.5: Age quantile regression of summertime cooling consumption percentage changes relative to households that are middle aged

	Percentiles		
	10th	50th	90th
65 years old or older	0.61	4.62	11.29
	(0.07)	(0.09)	(0.24)
55-64 years old	0.42	2.05	4.87
	(0.07)	(0.10)	(0.25)
35-44 years old	-0.27	-0.90	-4.50
	(0.07)	(0.09)	(0.23)
25-34 years old	-0.35	-1.62	-5.50
	(0.10)	(0.14)	(0.34)
18-24 years old	-0.20	-1.30	-0.63
	(0.16)	(0.21)	(0.54)
1,000 - 1,499 sq. ft.	0.21	0.34	5.40
	(0.16)	(0.23)	(0.60)
1,500 - 1,999 sq. ft.	0.02	-0.61	3.68
	(0.16)	(0.23)	(0.60)
2,000 - 2,999 sq. ft.	-0.03	-0.23	7.03
	(0.15)	(0.22)	(0.56)
3,000 - 3,999 sq. ft.	-0.11	-1.02	8.91
	(0.16)	(0.23)	(0.58)
Under 1,000 sq. ft.	-0.16	-0.92	9.58
	(0.18)	(0.25)	(0.65)
2030	7.92	9.69	12.40
	(0.07)	(0.10)	(0.24)
2040	17.71	20.27	35.02
	(0.07)	(0.10)	(0.24)
2050	25.31	31.84	54.22
	(0.07)	(0.10)	(0.24)
2060	30.68	43.63	79.94
	(0.07)	(0.10)	(0.24)
One AC unit	-0.13	-0.50	-6.01
	(0.15)	(0.21)	(0.56)
Two AC units	-0.30	-1.31	-7.17
	(0.14)	(0.20)	(0.53)
AC unit packaged with gas heating	-2.13	-12.94	-22.38
(sometimes called a gas packed)	(0.06)	(0.08)	(0.20)
Don't know AC type	-1.25	-6.54	-6.98
	(0.09)	(0.13)	(0.32)
Separate AC system that only cools	-2.19	-12.84	-21.31
	(0.08)	(0.11)	(0.29)
Occupancy	-0.06	-1.05	-2.86
	(0.02)	(0.02)	(0.06)
Intercept	-10.20	14.30	50.87
	(0.17)	(0.23)	(0.57)
N	876100	876100	876100
Pseudo R-squared	0.133	0.115	0.093

Standard errors are clustered on accounts

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Table E.6: Race/Ethnicity quantile regression of summertime cooling consumption percen changes relative to households that are White/Caucasian

	Percentiles		
	10th	50th	90th
American Indian/Alaska Native	-1.23	-4.91	0.05
	(0.21)	(0.28)	(0.73)
Asian	-0.20	-1.23	1.23
	(0.12)	(0.16)	(0.40)
Black or African American	0.35	-0.31	-5.03
	(0.13)	(0.18)	(0.46)
Hispanic	0.15	0.24	-3.84
	(0.06)	(0.08)	(0.21)
Native Hawaiian or Other	-4.27	-18.38	-32.59
	(0.92)	(1.26)	(3.24)
Other	0.53	2.18	-0.10
	(0.14)	(0.19)	(0.48)
Pacific Islander	0.12	6.08	9.46
	(0.53)	(0.72)	(1.86)
1,000 - 1,499 sq. ft.	0.01	-0.06	7.80
	(0.16)	(0.23)	(0.60)
1,500 - 1,999 sq. ft.	-0.11	-0.71	5.07
	(0.16)	(0.22)	(0.59)
2,000 - 2,999 sq. ft.	-0.19	-0.55	8.93
	(0.15)	(0.21)	(0.56)
3,000 - 3,999 sq. ft.	-0.24	-1.25	10.62
	(0.16)	(0.22)	(0.58)
Under 1,000 sq. ft.	-0.48	-1.14	11.60
	(0.18)	(0.24)	(0.65)
2030	7.93	9.74	13.03
	(0.07)	(0.09)	(0.24)
2040	17.74	20.29	35.89
	(0.07)	(0.09)	(0.24)
2050	25.32	31.84	55.38
	(0.07)	(0.09)	(0.24)
2060	30.65	43.77	81.41
	(0.07)	(0.09)	(0.24)
One AC unit	-0.26	-0.80	-8.17
	(0.15)	(0.21)	(0.56)
Two AC units	-0.35	-1.16	-8.47
	(0.14)	(0.20)	(0.53)
AC unit packaged with gas heating (sometimes called a gas packed)	-2.17	-13.22	-22.84
	(0.06)	(0.08)	(0.20)
Don't know AC type	-1.29	-7.14	-8.91
	(0.09)	(0.13)	(0.32)
Separate AC system that only cools	-2.21	-13.11	-21.88
	(0.08)	(0.11)	(0.29)
Occupancy	-0.15	-1.55	-4.08
	(0.02)	(0.02)	(0.06)
Intercept	-9.55	17.36	57.22
	(0.16)	(0.22)	(0.55)
Observations	876100	876100	87610
Pseudo R-squared	0.133	0.114	0.09

Standard errors are clustered on account.

The multi-year baseline model's cooling demand shows that the 2017–2018 baseline model is higher by 18 percentage points, while lower for consumption by 502 kWh.

This implies that our baseline estimates serve as an upper bound.

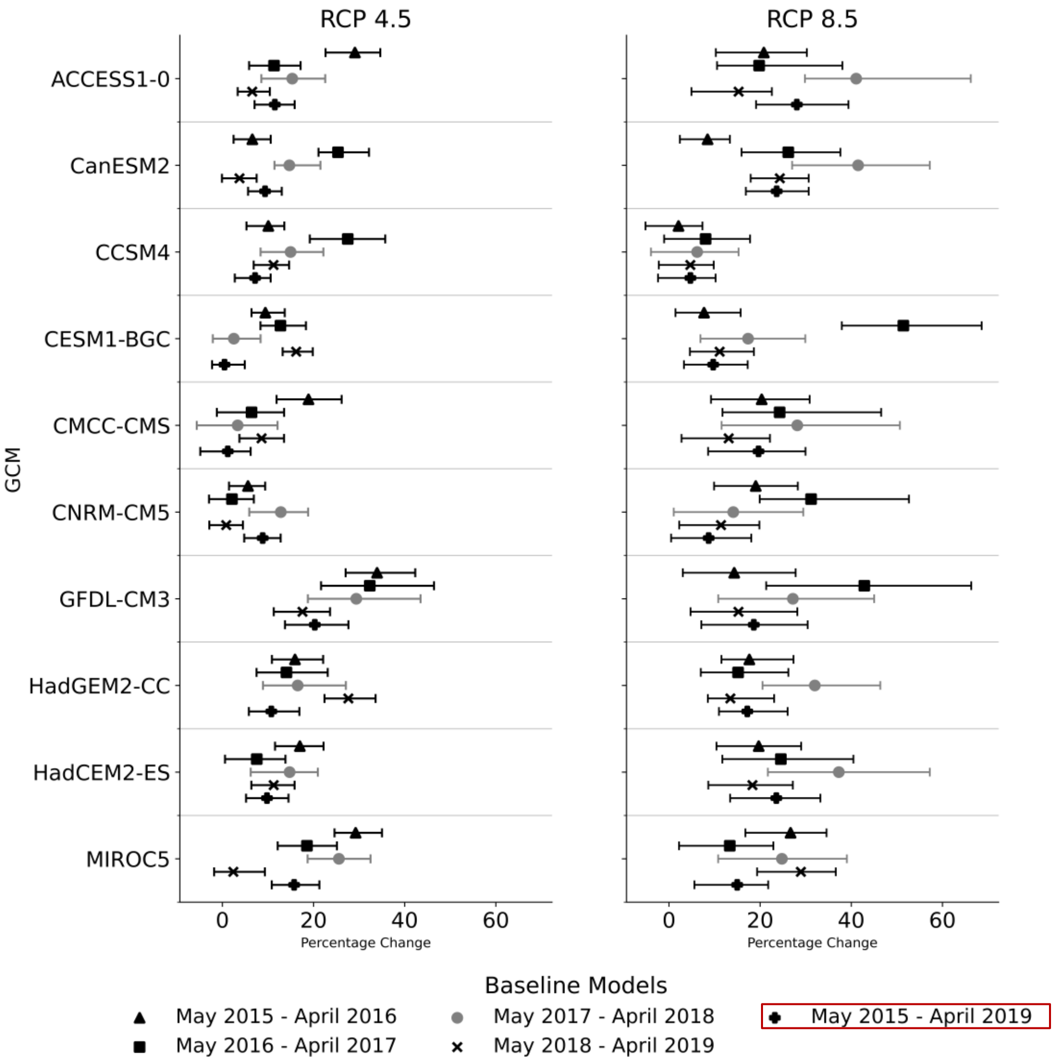

Table E.7: Summertime median decadal household-level cooling consumption percentage change (%) relative to summer 2017-2018 across 10 GCMs and groups under RCP 4.5 and 8.5 (May to September) for the short- and long-run

	Count	RCP 4.5										RCP 8.5									
	N	2020's		2030's		2040's		2050's		2060's		2020's		2030's		2040's		2050's		2060's	
		SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
All households																					
	333	4.3	-11.6	11.9	-5.5	18.2	-0.9	23.6	2.1	31.8	7.5	8.0	-8.0	19.4	0.0	32.8	9.2	48.3	18.4	64.4	28.7
Age																					
18-24 years old	4	2.3	-18.4	8.6	-13.5	13.1	-9.6	16.6	-6.6	22.2	-3.8	5.5	-13.6	13.1	-7.4	21.7	-0.7	31.0	4.2	38.7	8.7
25-34 years old	22	3.8	-9.9	10.7	-4.1	16.6	-0.1	21.1	2.0	28.1	7.5	7.4	-6.0	17.6	1.0	29.6	9.8	44.1	17.3	58.6	26.1
35-44 years old	90	3.5	-12.0	10.2	-6.7	15.5	-3.0	20.3	-0.8	27.0	3.9	6.5	-9.4	15.9	-2.7	27.0	4.8	40.5	12.2	54.1	19.7
45-54 years old	57	4.1	-9.7	11.3	-3.7	17.1	0.5	22.5	3.3	30.0	8.6	7.3	-6.7	18.2	0.9	30.8	9.6	45.2	18.8	61.3	28.8
55-64 years old	77	4.8	-12.1	12.5	-4.9	19.4	0.4	24.9	4.2	33.8	9.5	8.6	-7.9	21.1	1.3	35.3	11.5	50.5	21.6	67.3	33.5
*65 years or older	92	5.2	-12.6	13.7	-5.9	21.5	-0.3	27.1	3.2	37.4	9.7	10.0	-7.6	23.7	1.6	40.4	12.4	56.4	23.0	75.3	34.8
Income																					
*Less than 15,000 dollars	7	4.2	-7.2	12.1	-1.0	17.1	3.7	22.2	6.9	30.8	12.6	7.3	-4.6	18.8	4.3	32.0	13.5	44.7	22.5	58.6	31.2
*15,000 to 24,999 dollars	17	4.9	-11.9	13.3	-5.1	20.7	0.0	26.4	3.8	36.8	9.7	10.0	-6.4	23.6	2.8	41.2	11.6	56.6	22.5	76.7	33.3
*25,000 to 34,999 dollars	27	4.7	-12.9	12.2	-6.8	19.1	-1.7	24.3	1.0	32.4	6.5	8.2	-9.0	20.3	-1.2	34.0	8.5	49.7	19.3	67.5	29.6
35,000 to 49,000 dollars	56	4.4	-10.7	12.2	-4.2	18.8	0.8	24.3	3.8	32.7	9.6	8.6	-6.6	20.8	2.1	34.3	11.9	49.6	21.2	66.3	31.7
50,000 to 74,999 dollars	58	4.3	-12.1	11.8	-6.4	17.9	-2.1	23.5	0.9	31.5	6.0	8.0	-8.3	19.5	-0.2	33.0	8.8	48.3	17.4	64.7	27.6
75,000 to 99,999 dollars	57	4.9	-9.7	12.7	-2.1	20.0	3.2	25.7	6.8	34.2	12.4	9.1	-5.6	21.6	3.9	36.6	14.2	52.4	25.4	70.1	37.7
100,000 to 149,999 dollars	54	3.8	-12.7	11.0	-7.0	16.5	-3.2	21.5	-0.6	29.1	4.5	6.8	-9.9	17.1	-2.8	28.9	5.4	43.6	13.0	58.2	21.5
150,000 dollars or more	41	3.7	-13.8	10.6	-8.4	16.1	-4.2	21.1	-1.8	28.5	3.2	6.8	-10.4	16.8	-3.5	28.3	4.5	41.9	12.5	56.0	21.2
Race/Ethnicity																					
*American Indian/Alaska Native	4	4.9	-21.9	12.1	-16.4	18.6	-12.4	23.8	-10.2	31.4	-4.4	7.9	-19.4	19.0	-12.7	32.2	-4.6	48.1	4.3	68.2	8.3
Asian	8	2.7	-11.8	9.0	-7.4	14.0	-4.0	16.9	-2.3	22.9	1.7	5.7	-10.0	13.8	-3.5	23.4	2.0	33.0	7.0	41.6	11.9
*Black or African American	12	3.7	-14.5	10.6	-8.8	15.7	-4.0	21.3	-1.2	28.9	4.3	6.8	-12.0	16.7	-4.1	28.5	4.7	41.8	13.7	57.4	23.9
*Hispanic	57	4.0	-10.7	11.0	-4.5	16.8	-0.4	21.6	2.5	29.2	7.2	6.9	-8.0	17.3	-0.4	29.3	8.2	43.1	16.4	58.0	24.8
Other	11	2.5	-15.6	8.7	-11.3	13.1	-8.9	17.1	-8.8	22.8	-5.0	6.3	-11.7	14.7	-6.8	24.9	-1.7	35.7	1.4	47.6	5.7
Pacific Islander	2	2.1	-3.5	8.5	2.6	13.5	5.0	16.3	4.4	22.1	10.3	5.1	-1.5	12.1	3.8	20.3	8.5	30.4	18.1	34.2	19.1
White/Caucasian	236	4.6	-11.5	12.4	-5.2	19.1	-0.3	24.6	2.8	33.5	8.5	8.6	-7.5	21.0	0.9	35.2	10.6	51.0	20.3	68.5	31.3

Notes: *Denotes the demographic groups that are at-risk of energy-insecurity.
SR- short-run effects (only temperature changes)
LR: long run effects (temperature changes and AC efficiency improvements)

The intersection of demographic data and energy burden