3. Results

Tables 2–4 present the results of the three analyses for factors shaping premature mortality, self-reported health, and life expectancy in US counties, respectively. The OLS model results are also presented for reference; the results of the independent variables are nearly the same. The SEM results are discussed hereafter. All three models highlight a consistent—and significant—relationship between energy burden and health. Communities that have more LMI households experiencing higher energy burdens also have poorer health outcomes. As energy burden increases so too do premature mortality rates within a county (Table 2). Across US counties, each unit of increase in LMI energy burden is associated with an average 240 more premature deaths per 100,000 people between 2016 and 2018. Similarly, as the energy burden increases across counties, each unit increase is associated with a seven percent increase in county residents that report experiencing fair or poor health (Table 3). Finally, each unit increase in energy burden is significantly associated with more than a five year decrease in county average life expectancy (Table 4).

Table 2. The results of spatial error models of factors shaping premature mortality in US counties.

Premature Mortality	OLS Model				Spatial Error Model			
	Coefficient	Std Error	95 % CI		Coefficient	Std Error	95 % CI	
Energy Burden	267.58	(25.42) ***	217.73	317.42	239.63	(26.45) ***	187.79	291.48
Social Capital	−3.28	(1.55) *	−6.31	−0.25	−2.10	(1.53)	−5.10	0.90
Environmental Quality	0.30	(1.43)	−2.50	3.11	−0.06	(1.65)	−3.30	3.17
Income Inequality	28.36	(2.36) ***	23.72	33.00	24.37	(2.27) ***	19.92	28.83
Inadequate Housing	99.70	(78.17)	−53.58	252.99	293.91	(77.68) ***	141.65	446.16
Non-Hispanic Black	71.31	(14.91) ***	42.08	100.54	102.38	(16.48) ***	70.08	134.67
Healthy Food Access	172.15	(22.34) ***	128.34	215.96	163.53	(21.54) ***	121.31	205.75
Access to Physicians	−15,557.55	(4773.23) **	−24,916.94	−6198.15	−16,171.95	(4485.64) ***	24,963.65	7380.25
Education	−277.47	(17.33) ***	−311.46	−243.48	−266.10	(16.86) ***	−299.15	−233.04
Constant	423.13	(23.07) ***	377.90	468.35	428.31	(25.85) ***	377.64	478.97
Lambda, λ					0.48	(0.03) ***	0.42	0.54
n	2871				2871			
R^2	0.60							
Adjusted R^2	0.59							
pseudo R^2					0.60			

Standard errors in parentheses; state fixed effects not shown. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 3. The results of spatial error models of factors shaping self-reported health in US counties.

Self-Reported Health	OLS Model				Spatial Error Model			
	Coefficient	Std Error	95 % CI		Coefficient	Std Error	95 % CI	
Energy Burden	7.65	(0.66) ***	6.27	8.87	7.39	(0.68) ***	6.06	8.73
Social Capital	−0.42	(0.04) ***	−0.54	−0.38	−0.42	(0.04) ***	−0.50	−0.35
Environmental Quality	−0.11	(0.04) **	−0.20	−0.05	−0.05	(0.04)	−0.14	0.03
Income Inequality	1.15	(0.06) ***	1.08	1.32	0.99	(0.06) ***	0.88	1.11
Inadequate Housing	37.03	(2.00) ***	33.72	41.70	34.31	(1.94) ***	30.50	38.11
Non-Hispanic Black	8.57	(0.39) ***	7.74	9.27	9.79	(0.43) ***	8.94	10.64
Healthy Food Access	4.41	(0.52) ***	3.69	5.97	3.55	(0.49) ***	2.59	4.51
Access to Physicians	−117.50	(119.80)	−498.17	−2.05	−133.27	(109.09)	−347.09	80.55
Education	−11.00	(0.43) ***	−11.60	−9.83	−10.25	(0.41) ***	−11.05	−9.45
Constant	19.00	(0.60) ***	17.63	20.00	18.71	(0.69) ***	17.37	20.06
Lambda, λ					0.58	(0.03) ***	0.53	0.64
n	2925				2925			
R^2	0.84							
Adjusted R^2	0.83							
pseudo R^2					0.84			

Standard errors in parentheses; state fixed effects not shown. ** $p < 0.01$, *** $p < 0.001$.

Table 4. The results of spatial error models of factors shaping life expectancy in US counties.

Life Expectancy	OLS Model				Spatial Error Model			
	Coefficient	Std Error	95 % CI		Coefficient	Std Error	95 % CI	
Energy Burden	−6.32	(0.71) ***	−7.72	−4.92	−5.63	(0.75) ***	−7.09	−4.17
Social Capital	0.23	(0.04) ***	0.13	0.31	0.21	(0.04) ***	0.12	0.29
Environmental Quality	−0.16	(0.04) ***	−0.24	−0.08	−0.19	(0.05) ***	−0.29	−0.10
Income Inequality	−0.63	(0.07) ***	−0.76	−0.50	−0.56	(0.06) ***	−0.68	−0.43
Inadequate Housing	4.07	(2.20)	0–0.24	8.40	−0.63	(2.19)	−4.93	3.66
Non-Hispanic Black	−1.23	(0.42) **	−2.06	−0.41	−1.88	(0.46) ***	−2.79	−0.97
Healthy Food Access	−2.58	(0.66) ***	−3.86	−1.29	−2.45	(0.63) ***	−3.68	−1.21
Access to Physicians	133.52	(134.45)	−130.10	397.15	114.98	(126.61)	−133.17	363.14
Education	8.05	(0.49) ***	7.08	9.01	7.87	(0.48) ***	6.94	8.81
Constant	77.47	(0.65) ***	76.19	78.74	77.85	(0.73) ***	76.42	79.28
Lambda, λ					0.48	(0.03) ***	0.42	0.54
n	2859				2859			
R^2	0.54							
Adjusted R^2	0.54							
pseudo R^2					0.55			

Standard errors in parentheses; state fixed effects not shown. ** $p < 0.01$, *** $p < 0.001$

As noted earlier, prior research has established that social capital is an important determinant of health [25,28,29]. The results here are consistent with that past research. Social capital is statistically significant in the models of self-reported health and life expectancy. Higher levels of social capital are systematically related to lower percentages of residents reporting fair or poor health (Table 3). A county with a 10-point higher social capital score relative to another county experiences roughly 4 percent fewer residents reporting fair or poor health. Counties with higher levels of social capital also have significantly higher levels of life expectancy (Table 4). Each 10-point increase in social capital was associated with an increased average life expectancy of 2 years.

The measure of environmental quality (the annual average level of $PM_{2.5}$ in a county in 2014) is significant in only one of the three models, and the result is as expected. Changes in environmental quality are no more or less associated with rates of premature mortality or self-reported health across counties. Higher levels of $PM_{2.5}$ are associated with statistically significant lower rates of life expectancy (Table 4). Each 10-point increase in $PM_{2.5}$ across US counites is associated with a two year decrease in average life expectancy.

Overall, the remaining control variables suggest strong support for the SDoH framework. Income inequality—measured here as the ratio of household income at the 80th percentile to household income at the 20th percentile—is systematically related to poor health outcomes. This is in keeping with previous research findings; growing income inequality is significantly associated with all three measures of health [69–72]. Higher income inequality is linked to higher rates of premature mortality. Similarly, counties where the gap between the 80th and 20th percentile of household income is high also have systematically higher percentages of residents reporting fair or poor health. Finally, higher levels of income inequality within a county are linked to lower levels of life expectancy.

Inadequate housing (measured as the percentage of households that are overcrowded or lack plumbing or kitchen facilities) is significant in predicting increased premature mortality and self-reported poor health. In keeping with the large and growing literature that documents racial health disparities, the results indicate that race matters in shaping health. Counties that have a higher percentage of residents identifying as Non-Hispanic Black also have statistically higher rates of premature mortality, a higher percentage of residents reporting fair or poor health, and lower life expectancy. Similarly, access to healthy food is an important predictor of all three measures of health. Recall that this is the percentage of low-income residents who do not have access to a grocery store. As this percentage increases across counties, there are corresponding increases in rates of premature morality, increases in percentages of residents who report fair or poor health and declining rates of life expectancy.

The results also suggest that access to a physician matters, but not for all measures of health. In particular, this control variable is significant in only one of the models, namely premature mortality (Table 2). More per capita access to physicians is associated with lower rates of premature mortality in a county. The final control variable, education, is statistically significant across all three models and the results are consistent with prior research on the link between education and health. Counties that have more educated residents have lower rates of premature mortality, lower percentages of residents reporting fair or poor health, and higher life expectancy.

4. Discussion

Modeling three different measures of health provides an opportunity to compare more fully the relationships between health on the one hand, and energy burden, social capital, and environmental quality on the other hand. A challenge of this study was controlling for multiple determinants of health; nonetheless, strong patterns emerged across all three measures of health. Finding patterns of significance across models explaining different measures of health surely increases confidence in the results. Indeed, most of the variables had similar and expected relationships with health measures across the three models.

A limited number of studies have empirically explored the relationship between energy burden and health in the U.S while controlling for other variables known to have either positive or negative effects on public health. It was anticipated that higher energy burdens would be associated with poorer health outcomes. Across nearly all US counties, the analysis supports this expectation. Moreover, modeling results suggest this is an influential determinant of health across all three models, with only education and race having stronger influences on the health outcomes. Energy poverty is thus an important addition to the broader SDoH framework. High energy burdens for LMI households are particularly detrimental for population health. For instance, in the US, recipient families of the Low-Income Home Energy Assistance Program (LIHEAP) which provides financial assistance with energy bills, report often choosing between paying their energy bill or buying food, a situation commonly referred to as "heat or eat" which poses high health risks of malnutrition for children [73]. Recall also that the US Energy Information Administration also found that more that 25 million households reduce or forgo food or medicine in order to pay their energy bills [13]. If energy burdened households are unable to afford medical treatments, it is to be expected that the communities in which they live would experience increased levels of premature mortality, reduced life expectancy, and higher percentages of the population reporting they are in poorer health. Many state and local governments are beginning to consider the health implications of energy unaffordability and are launching programs that focus on improving energy efficiency and/or access to renewable energy in order to reduce energy consumption, improve housing quality, and reduce energy bills.

Social capital exhibits a significant positive effect on two of the three health measures, even when controlling for the effects of energy burden, environmental quality and other social determinants. Thus, to some degree it may be possible for the trust-based networks to compensate some for the negative health effects of energy burden. If greater energy burden produces an environment that either directly or indirectly is likely to lead to lower public health levels, the collective resource of social capital may produce some counterweight to energy burden's negative health influence. The trust and reciprocity embedded in social capital's foundation may be likely to spill over into some reservoir of support. However, it is important to note that social capital—while durable in some settings—is nonetheless dynamic and if depleted or low, is likely to take considerable time to develop. As social capital varies across counties, the resources associated with that capital also vary. A strategy to advance health by investing in social capital is a longer-term investment in community health and well-being.

Surprisingly, after accounting for spatial clustering, environmental quality was statistically associated with only one measure of public health, life expectancy. But measures of air pollution also can introduce complications. In this study, a single, annual average value of $PM_{2.5}$ at the county level is used; as a result, variability in air quality across a county is not well accounted for. Particulates may be directly emitted from a source such as engine exhaust fumes or formed in the atmosphere as a result of chemical reactions such as industrial activity. Therefore, PM2.5 tends to be higher in more urban areas with a higher level of traffic. Thus, the association between air pollution and health outcomes may need to be assessed at a smaller spatial scale than the county-level, such as zip code or census tract. However, other studies have found that higher $PM_{2.5}$ exposure was not associated with perceptions of higher concern about pollution-related health risks [74].

To be sure, this study is constrained by its character as an aggregate, observational analysis that does not directly observe the pathways through which energy burdens operate to shape health outcomes. However, other more limited previous observational studies suggest that theses pathways are present and provided the foundation for the hypotheses guiding this aggregate level study. The explicit analysis of pathways across large numbers of counties is an area for future study. It is also important to note that this study is confined to a single country, the US. While the nation-wide county-level database used here provides substantial variation in the size and cultures of the energy burden context, at the same time these findings may or may not be replicated in other national contexts. Results in other countries may vary based on different conjunctions of energy burden and health, as well as energy economies that are supported by different patterns of wealth, energy governance, or by energy sources that impinge on public health to a significantly different degree.

5. Conclusions

This study supports the social determinates of health framework and suggests that energy poverty should be included as a central component. To better understand how multiple, overlapping social determinants shape health, this study examined three different health outcomes across the majority of US counties: age-adjusted premature mortality, self-reported health, and life expectancy. In particular, this research examined the impact of energy burden, social capital, and environmental quality and their influence on all three health outcomes.

The research reported here clearly leads to the conclusion that the aggregate cost and availability of energy relative to the wealth capacity of individuals to pay for it has a significant effect on the health of those individuals. Those health effects of energy burden maintain across a range of health measures, from self-assessment to life expectancy to premature mortality. Moreover, those independent effects of energy burden emerge even when controlling for the well-established effects of social capital, environmental quality, and a broader set of social determinants of health. However, it also is clear that identifying the health effects of energy burdens does not erase the health effects of social capital and the social determinants of health more broadly. Thus, this energy burden analysis enhances both the understanding of the complexity of the causes of public health when aggregated at the county level and expands knowledge in a way that should provide new and innovative pathways through which public health can be enhanced, or at least can be protected. The implications of this paper contain a dynamic that may travel beyond the boundaries of health or energy burdens themselves. Additional concerns with energy justice may reside in a location external to energy burdens when those burdens themselves are disproportionately distributed among vulnerable populations, or when the negative health effects of those burdens are likewise inequitably distributed. If so, energy burden mitigation can provide a separate pathway toward the goal of public health equity.

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Appendix A

Table A1. Descriptive Statistics.

	Mean	Std Dev	Min	Max
Premature Mortality	407.05	111.18	127.77	1216.80
Self-Reported Health	17.94	4.65	8.12	40.99
Life Expectancy	77.43	2.92	61.63	104.74
Energy Burden	0.13	0.09	0.02	0.67
Social Capital	−0.05	1.17	−3.18	21.81
Environmental Quality	9.15	1.90	3.00	19.70
Income Inequality	4.52	0.74	2.54	11.97
Inadequate Housing	0.03	0.02	0.00	0.38
Non-Hispanic Black	0.09	0.14	0.00	0.85
Healthy Food Access	0.08	0.06	0.00	0.72
Access to Physicians	0.00	0.00	0.00	0.01
Education	0.58	0.11	0.20	0.90
n	2853			

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Attachment JAH - 3

Understanding Energy Affordability

How Energy Efficiency Can Alleviate High Energy Burdens

According to the US Energy Information Administration (EIA), nearly one-third of US households in 2015 struggled to pay their energy bills.[1] For many low-income families the issue is more acute as they tend to live in older homes with less-efficient appliances and heating and cooling equipment. High energy bills can put a strain on families and lead to difficult trade-offs between paying for energy and other necessities. According to EIA, one-fifth of Americans in 2015 reported reducing or forgoing necessities such as food and medicine to pay an energy bill. In addition, 11% of households reported keeping their home at an unhealthy or unsafe temperature to lower energy bills and 14% received a disconnection notice.

A household's energy burden—the percentage of household income spent on energy bills—provides an indication of energy affordability. Researchers define households with a 6% energy burden or higher to experience a high burden.[2] Factors that may increase energy burdens include the physical condition of a home, a household's ability to invest in energy-efficient upgrades, and the availability of energy efficiency programs and incentives. See the table below for more examples of the drivers of high energy burdens.

1 www.eia.gov/todayinenergy/detail.php?id=37072

2 The 6% affordability threshold is based on Fisher, Sheehan and Colton's Home Energy Affordability Gap Analysis. This affordability percentage is based on the assumption that an affordable housing burden is less than 30% of income spent on energy, and 20% of housing costs should be allocated to energy bills. This leads to 6% of an affordable housing burden spent on energy costs, or a 6% energy burden. For more information, see www.homeenergyaffordabilitygap.com/.

Photo: Marcela Gara, Resource Media

Drivers of High Burdens	Examples
Physical	▪ Housing age and type (e.g. manufactured homes) ▪ Heating system, fuel type, and fuel cost ▪ Poor insulation, leaky roofs, inefficient and/or poorly maintained HVAC systems or inadequate air sealing ▪ Inefficient large-scale appliances (e.g. refrigerators, dishwashers) and lighting sources ▪ Weather extremes that raise the need for heating and cooling
Economic	▪ Chronic or sudden economic hardship ▪ Inability to afford (or difficulty affording) up-front costs of efficiency investments ▪ Difficulty qualifying for credit or financing options to make efficiency upgrades
Behavioral	▪ Lack of access to information about bill payment assistance or efficiency programs ▪ Lack of knowledge about energy conservation measures and impacts/costs ▪ Increased energy use due to age, number of people in household, or disability
Policy	▪ Insufficient or inaccessible policies and programs for bill assistance and/or efficiency and weatherization ▪ Certain utility rate design practices, such as high fixed customer charges, that limit customers' ability to respond to high bills through energy efficiency or conservation

Energy affordability is a national, state, and local priority across the country. The Department of Energy manages a Clean Energy for Low-Income Communities Accelerator, which developed an energy affordability toolkits and data analysis tool. States and local governments are also setting energy affordability targets, such as New York's goal of achieving a 6% statewide energy burden[3] and Portland's Ten-Year Plan to Reduce Energy Burden in Oregon Affordable Housing.[4]

A Closer Look at Energy Burdens

Over the past few years, ACEEE has researched energy affordability. We have calculated energy burdens nationally, regionally, and locally through several research reports, direct assistance, and other projects. We have consistently found that households with lower incomes, communities of color, elderly households, renters, and multifamily building residents tend to have higher energy burdens, on average, than other households.

3 www.governor.ny.gov/news/governor-cuomo-announces-expansion-financial-benefits-low-income-utility-customers

4 www.oregon.gov/energy/Get-Involved/Documents/2018-BEEWG-Ten-Year-Plan-Energy-Burden.pdf

National Burdens

ACEEE analyzed data from the US Census Bureau's American Housing Survey to provide a national snapshot of energy affordability for 2017. We measured what percentage of Americans experience an "high" energy burden, i.e. spending more than 6% of income on energy bills. Using the same methodological considerations as our 2018 rural energy burden analysis, we estimate the percentage of certain groups that experience high energy burdens (> 6%) nationally:[5 6]

- 67% of low-income households (200% of Federal Poverty Level)
- 36% of African American households
- 34% of elderly households (65+)
- 29% of renting households
- 27% of Latino households
- Compared to 24% of all households nationally

These findings suggest that about one-fourth of all households and more than two-thirds of low-income households live with a high energy burden. In fact, low-income households experience high energy burdens almost three times more than the average household and thirteen times more than non-low-income counterparts. This highlights that energy affordability is a national issue, and one that policymakers can prioritize at national, state, and local levels.

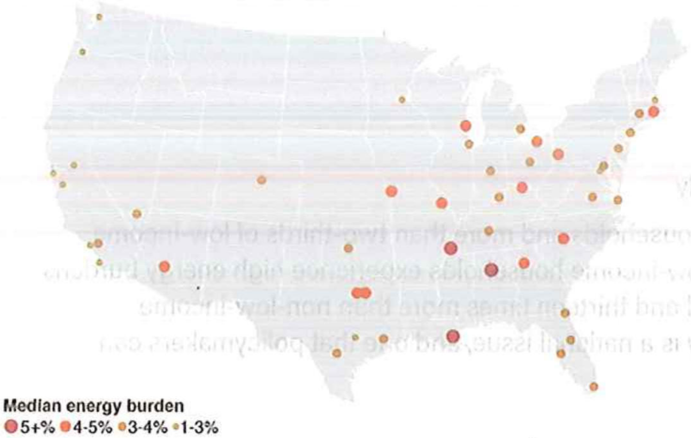
5 ACEEE used the same methodological considerations when calculating energy burdens in our urban and rural energy burden reports, as well as in our national energy burden calculations. Using household-level data from the US Census Bureau's American Housing Survey, we calculated energy burdens by defining energy costs as including electricity and heating fuel costs (not including water and transportation costs). We filtered out cases where individuals either: (1) did not pay for their electric bill, (2) did not pay for their heating bill, and/or (3) did not report positive income. These three factors are needed to calculate a household-level energy burden. We then calculated median energy burdens at the household level and for subgroups. At the national level, we also calculated the percentage of households with a high energy burden (>6%).

6 The following are the median energy burdens for each group based on 2017 American Housing Survey data: low-income households (200% FPL) (8%); African American households (4.1%); elderly households (4%); renting households (3.3%); Latino households (3.5%); all households (3%).

Urban Energy Burdens

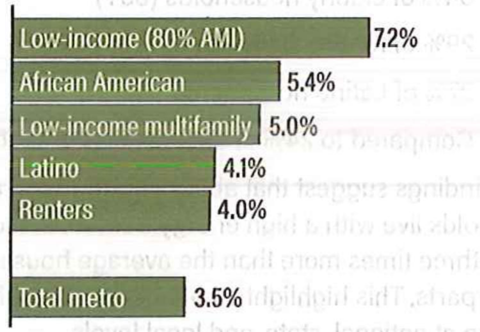
Our first energy burden research report, published in 2016, focused on energy burdens in the 48 largest metro areas in the country. We calculated energy burdens for each major metro area and for certain demographic groups. We found that low-income households were disproportionately impacted by high energy burdens, facing energy burdens three times higher than non-low-income households.

Energy burden in largest metro areas



Energy burden: percent of income spent on energy bills

Metro energy burden by demographic*



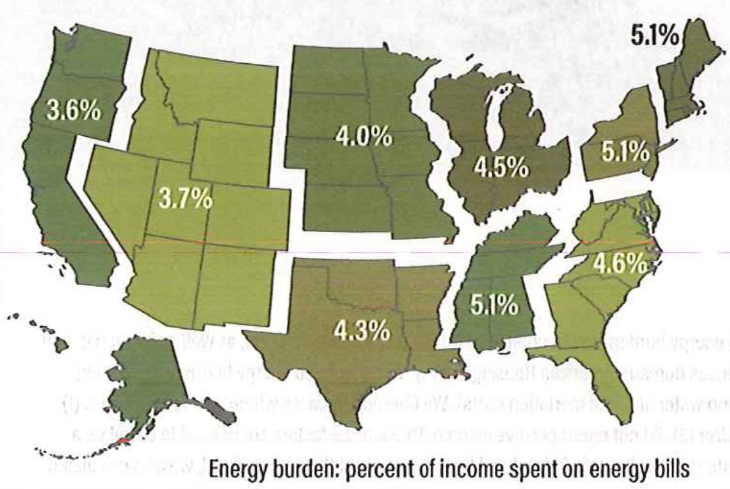
*Based on median across selected cities.

Findings from ACEEE's 2016 urban energy burden study, aceee.org/research-report/u1602

Rural Energy Burdens

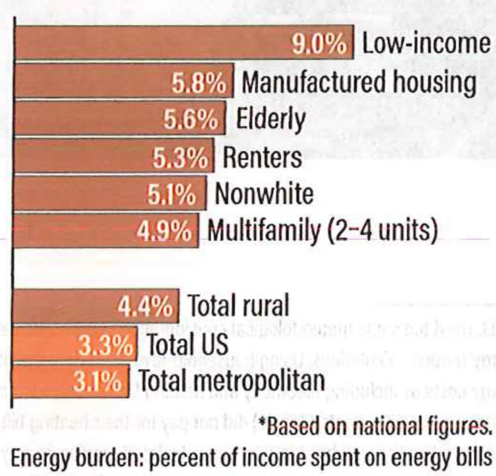
In 2018, we published a second energy burden study focused on rural areas. Rural households make up roughly 16% of all US households and are spread across 72% of the nation's land area. The report calculates energy burdens in rural regions across the country and by demographic groups and housing types. Rural low-income households (200% federal poverty level) experienced energy burdens three times higher than non-low-income households.

Rural energy burden by region



Energy burden: percent of income spent on energy bills

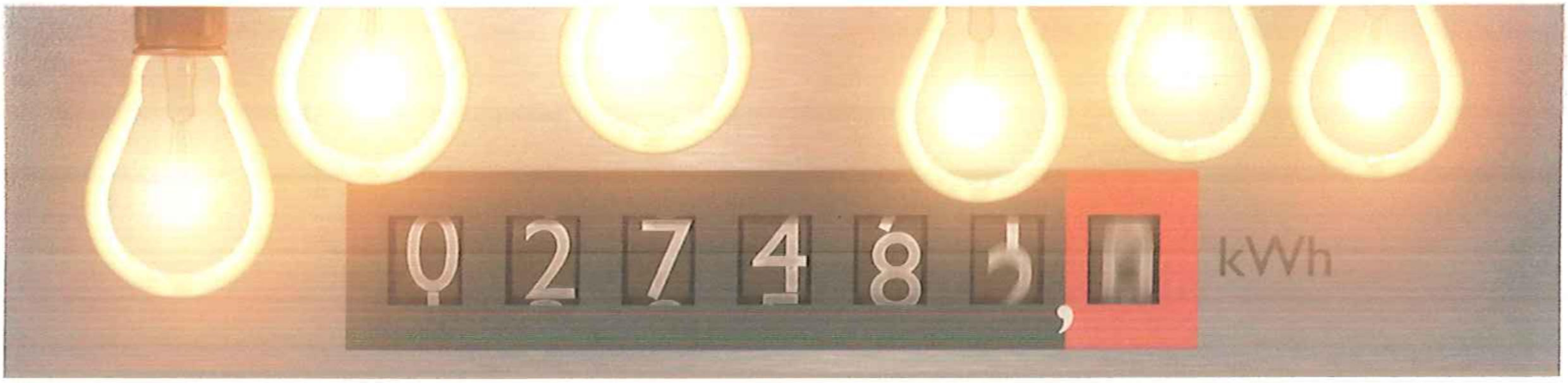
Rural energy burden by demographic*



*Based on national figures.

Energy burden: percent of income spent on energy bills

Findings from ACEEE's 2018 rural energy burden study, aceee.org/research-report/u1806



How Energy Efficiency Can Help

Energy efficiency can offer a long-term solution to high energy burdens. It helps households reduce their energy usage with measures such as heating and cooling system upgrades, insulation, efficient appliances, and behavior change. This lowers energy bills and can also improve home health, comfort, and safety. Efficiency programs targeting low-income households are well suited to addressing high energy burdens. These programs are tailored to the needs of low-income communities and typically provide weatherization and efficiency upgrades at no cost to participants. The following are best practices for increasing energy efficiency and energy affordability for low-income and energy-burdened households.

1. Set state-level spending and savings targets for low-income efficiency programs. Public utility commissions can set requirements for utilities to achieve a certain level of spending or savings on their energy efficiency programs targeted at low-income customers. For up-to-date information on state-level spending and savings targets, see the ACEEE State Policy Database.
2. Utilities can expand and improve their low-income programs. Many utilities have room to ramp up their energy efficiency programs to achieve deeper savings and impact in the low-income sector. Some best practices on program design and delivery include leveraging diverse funding sources, accommodating health and safety measures, partnering with community-based organizations, and prioritizing deep-saving measures. For the most recent reports and data on low-income program best practices, see ACEEE's low-income landing page.
3. Increase Federal support for the Department of Energy's Weatherization Assistance Program (WAP). The FY2019 WAP budget was $257 million, which only allows a small amount of eligible households to participate in the program.
4. Support financing options for multifamily building owners and rural households. On-bill tariff programs that allow customers to pay back energy measures on their bill with their energy savings can help households access efficiency upgrades. For multifamily buildings, one way to address split incentives is to align efficiency incentives with building refinancing and renovation timelines.
5. Conduct equity analysis on program outcomes. Examine the impacts of programs and make changes to ensure that all customers are equitably reached and served by efficiency programs.

ACEEE Research and Future Research

For more information on energy affordability, see ACEEE's Low-Income Programs webpage: aceee.org/topics/low-income-programs. This webpage includes our research related to energy burdens, low-income efficiency programs, and related policy and program design solutions. For more information on state low-income program requirements, visit ACEEE's database or database.aceee.org/state/guidelines-low-income-programs. For information specific to utility low-income and multifamily programs in urban areas, visit database.aceee.org/city/low-income-multifamily.

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