

Residential Cooling Energy Efficiency During Heatwaves in South Texas

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ABSTRACT

Heatwaves have become increasingly intense and frequent in recent years. As a result, residents are forced to rely on air-conditioning systems, a major contributor to high energy consumption. South Texas is one of the regions that has been affected by historically extreme heat. This paper explores the challenges this region has faced due to heatwaves and the strategies adopted to mitigate their effects. It investigates the use of cooling technologies, energy-related habits, and investment in home construction to reduce indoor heat and manage electricity bills. A literature review is performed to help identify relevant factors related to maximizing energy efficiency. Additionally, a survey is conducted to collect and analyze data on how heatwaves have affected residents economically, socially, and in terms of health, as well as the behaviors and measures they have taken. The findings suggest that while residents employ behavioral measures and energy-efficient retrofits, building materials can influence electricity costs. Overall, the results highlight the need to combine building improvements with behavioral adaptations to enhance resilience and reduce energy consumption in heat-prone regions.

INTRODUCTION

In recent years, extreme weather events such as heatwaves have become more frequent and intense, and the rapid rise in Earth temperature has become a major sign of climate change (Aizebeokhai 2009; Zuo et al. 2015). A heatwave is typically defined as an event lasting several days where the temperature rises to an uncommon level compared to the rest of the season, often intensified by high humidity (Marx et al. 2021). Heatwaves have a significant impact on public health, quality of life, and socioeconomic stability.

According to the US National Oceanic and Atmospheric Administration (NOAA 2025), the U.S. experienced its warmest year on record: the average annual temperature across the U.S. was 55.5°F, 3.5°F above the 20th-century average, making it the hottest in 130 years of climate records. Texas was one of the seventeen states that experienced its warmest year on record (NOAA 2024). In terms of energy consumption, the Residential Energy Consumption Survey (RECS) reported that in 2020, air conditioning accounted for approximately 19% of residential electricity use in the U.S. (EIA 2024). During heatwaves, most people tend to remain indoors and rely heavily on air-conditioning to maintain thermal comfort, leading to extended use of cooling systems. This prolonged operation of cooling systems elevates electricity demand across large regions, increasing the risk of power outages. This increased usage not only places strain on the power grid but also leads to higher electricity bills (Vogel, Martha M. et al. 2020; Wang et al. 2021).

For several decades, energy efficiency has remained a central focus in the design and construction of buildings (Baniassadi et al. 2022). Improving the energy efficiency of residential

cooling systems is essential for environmental sustainability and public health resilience. However, as climate change drives higher temperatures, residential energy consumption has continued to rise (Karimi et al. 2022), underscoring the urgency of energy-efficient solutions. Within climate adaptation, energy retrofitting has gained attention because it can significantly help reduce building energy consumption and offer multiple benefits, they are categorized into three types: Passive, active, renewable retrofits (Amaripadath and Sailor 2024; Liyanage et al. 2024; Webb 2017). National Weather Service seasonal summaries indicate that in summer 2025, parts of the region frequently experienced daily maximum temperatures above 100°F. (Goldsmith 2025).

This study focuses on the Rio Grande Valley (RGV) in South Texas, a region of counties: Cameron, Hidalgo, Starr and Willacy, characterized by hot-humid climate and faces vulnerability to the impacts of climate change. While previous studies have explored the impact of heatwaves in different regions, South Texas remains underrepresented. Existing studies often emphasize technical or climatic dimensions but provide limited insight into how household characteristics and behavioral adaptations impact in this specific regional context.

GOAL AND OBJECTIVES

The goal of this paper is to investigate the impact of heatwaves on communities, focusing on residential energy efficiency. Specifically, how residents in South Texas have been affected by heatwaves and how they respond in terms of behaviors, technologies, and home improvements. To achieve this goal, the following objectives are investigated: investigate the cooling technologies commonly implemented, evaluate changes and habits in energy-related behaviors, analyze social, economic, and health impacts of extreme heat events, and identify the strategies to improve residential energy efficiency and resilience.

To achieve the goal, a literature review was conducted to collect relevant factors related to residential energy efficiency during heatwaves, and a survey was designed and distributed to learn how heatwaves have affected residents' lives and their energy consumption.

The research questions this study aims to answer are:

1. What are the perceived social, economic, and health impacts of extreme heat events?
2. What kinds of home characteristics and cooling systems are most used by residents in South Texas?
3. What measures are residents adopting to improve energy efficiency and indoor comfort?
4. Which of these features and systems are residents most satisfied with in terms of comfort and performance?

By achieving its objectives, the study can inform future planning and policymaking by identifying cost-effective strategies that enhance energy resilience. The findings may support passive cooling, targeted retrofits, and community interventions to strengthen household comfort in the face of rising temperatures.

METHODOLOGY

For this paper, a two-phase approach was designed to capture the context of residential cooling energy during heatwaves in South Texas: (1) a systematic literature review and (2) a quantitative household survey.

First Phase: Literature Review. The first phase involved a systematic literature review following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) technique to identify key factors most applicable to the South Texas hot climate context that

enhance household energy efficiency, reduce energy consumption, and highlight the current state of residential cooling efficiency and adaptation. A broad search was performed using Google Scholar and supplemented with other academic databases. The keywords used in search included “residential cooling”, “energy efficiency”, “heatwaves”, and “South Texas”. Duplicate articles were removed and limited to records published from 2021 to the present. Titles and abstracts were screened to exclude records not related to residential buildings, energy efficiency, or cooling strategies. Full texts were reviewed to confirm relevance, and articles were excluded if they didn’t address residential energy efficiency, extreme heat, or residential cooling strategies. Publications were categorized thematically, emphasizing: (1) Cooling technologies applicable to hot climates; (2) Passive and active retrofits for thermal comfort. The studies that were included in the literature review provided insight into effective cooling technologies in hot climates, strategies for thermal comfort, behavioral and socioeconomic factors impacting residential cooling, and building practices relevant to South Texas.

Second Phase: Survey. The second phase consisted of quantitative data collection through a survey that was designed for residents and homeowners in the Rio Grande Valley area, to understand how they experience heatwaves and adopt cooling strategies.

Structure. The survey consisted of 74 questions and was divided into the following sections:

1. Demographic and household: collected data on age of householders, employment status, and annual income to identify potential social and economic factors influencing their behavior.
2. Home characteristics: gathered information on materials from exteriors and interior walls and roofs, which affect heat retention and energy efficiency.
3. Heatwave perception: based on their experience of changes in heat intensity, frequency of heatwaves, and any related health impacts or discomfort.
4. Cooling method and habits: asked about types of cooling systems used, thermostat use patterns, and daily cooling practices to recognize energy consumption.
5. Electricity bills: monthly bill ranges, type of electricity rate, seasonal variations, and potential financial stress during heatwaves.
6. Simple Habits for a More Energy-Efficient Home: Adoption of low-cost or no-cost measures, such as using fans, running AC economically, performing regular maintenance, minimizing direct sunlight, exterior and interior shading, and incorporating green spaces.
7. Investments to Reduce Energy Consumption: willingness to adopt energy-efficient upgrades.

Questions employed a 5-point Likert scale (e.g., Extremely Satisfied, Somewhat Satisfied, Neither Satisfied nor Dissatisfied, Somewhat Dissatisfied, and Extremely Dissatisfied), along with yes/no, multiple-choice, and short open-ended responses to facilitate statistical analysis.

Distribution and participation. The survey was developed using Qualtrics software and distributed via email lists, social media platforms, and QR codes on flyers. Participation was voluntary and anonymous, and most respondents were residents of the Rio Grande Valley region, which is an area regularly affected by extreme heat.

Data analysis. Survey data were analyzed through statistical methods, including:

- Descriptive statistics: frequencies, percentages, means, and standard deviations were calculated to summarize key variables, including demographics, perception of heatwaves, satisfaction with cooling systems, electricity bill ranges, household characteristics, and adoption of strategies.

- To analyze beyond description, chi-square tests of independence were conducted to examine associations between categorical variables such as income level and financial impact, home characteristics, income groups, and electricity bill levels. Spearman’s rank correlation was applied to explore relationships between income and perceptions of financial impact. These methods helped identify patterns and associations linking household, behavioral, and construction factors.

RESULTS AND ANALYSIS

Results from Literature Review. The literature selection process was conducted using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), which provides a detailed approach for identifying and screening relevant studies. Figure 1 Presents the PRISMA flow diagram summarizing the process. The diagram begins with the identification phase; records were retrieved through a database search. Only studies that were published after 2021 and removed from the ones that were duplicates, as well as considering their relevance, were excluded. In the screening stage, titles and abstracts were carefully reviewed, and records were excluded for being unrelated to residential cooling, energy efficiency, or extreme heat. For the eligibility assessment, the full texts of these studies were examined in greater detail. Here, articles were excluded because they did not meet the criteria: some focused on non-residential buildings or general climate adaptation. Finally, the review included 56 articles that directly addressed residential cooling energy efficiency and adaptation during heatwaves. It clearly illustrates how the body of literature was narrowed down from an initial broad set of records to a focused collection of relevant studies.

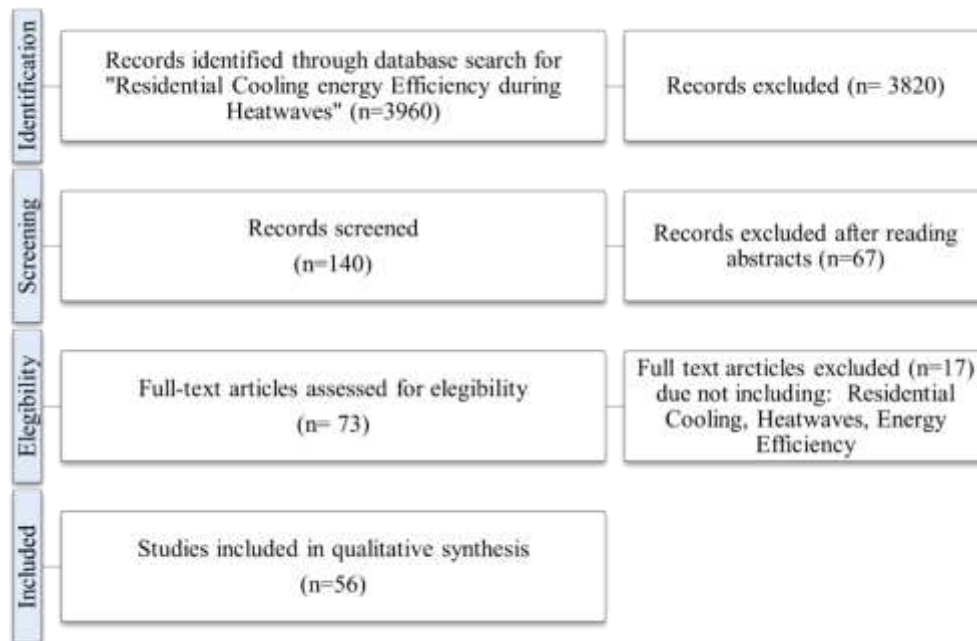


Figure 1 PRISMA flow diagram for the literature review

Based on the literature review, several key factors were collected that influence residential energy efficiency during heatwaves. These are summarized in Figure 2. It included and highlighted six major categories: Socioeconomic, Building Characteristics, Thermal Comfort, Cooling Systems, Energy Consumption, Passive Cooling Strategies, and Investments. Each category branches into specific elements.

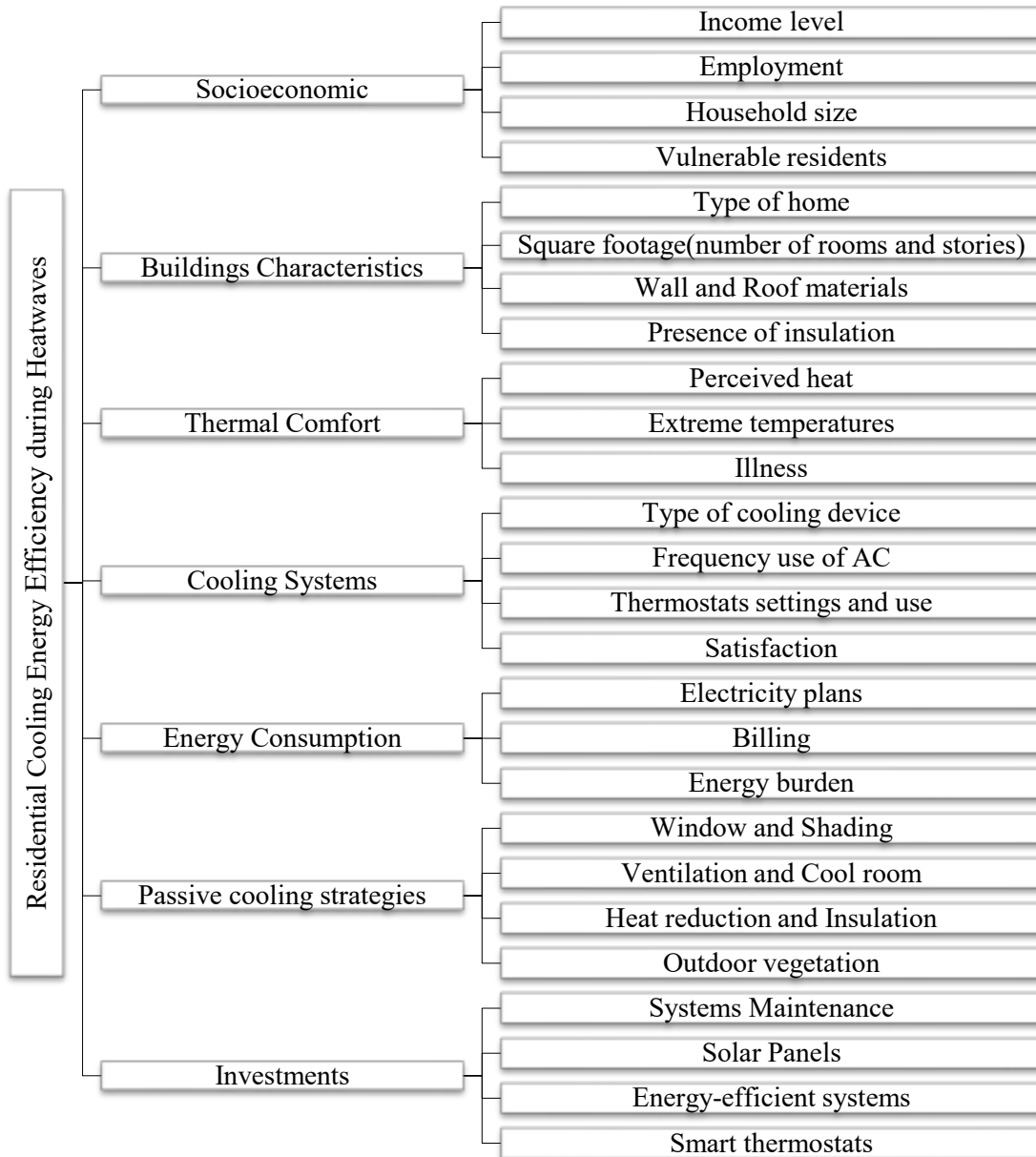


Figure 2 Factors from Residential Cooling Energy Efficiency during Heatwaves

Demographics. A total of 125 responses were recorded, of which 102 were fully completed, and between 102 and 109 responses were considered valid depending on the analysis. In terms of income, 43% of the respondents reported annual household income between \$100,000 and \$249,999, followed by 18% in the \$60,000 - \$99,999 range. **Perception of heatwaves.** Respondents experienced significant heat during the previous year, with perceived temperature ranging from 100–110°F (38–43°C). 79% of the respondents noticed an increase in heat last summer. 57% agreed that heatwaves were more intense compared to previous years, while 32% responded “maybe” and 10% disagreed.

When asked about how these heatwaves affected their health, 5% reported experiencing illness due to heatwaves. Vulnerable populations, such as the elderly and children, 4% of them indicated health issues within these groups. While this percentage appears low, it is important to note that

limited reported cases can represent a significant public health risk, as they are less resilient and suffer consequences.

Cooling systems and behavior. The respondents who use central AC reported an average satisfaction of 3.69 (N=107, SD=1.28), which indicates moderate to high satisfaction. Other systems, such as mini-splits and portable AC, showed higher satisfaction, but with a very small sample size; therefore, since Central AC is the most used type of cooling device, this satisfaction level should be considered as the primary reference. Regarding air conditioning control, 64% stated they set one temperature and leave it there most of the time, 20% reported using programmable or smart thermostats that automatically adjust the temperature, and 12% indicated they manually turn equipment on or off as needed. This pattern was more pronounced among those who spent most days at home, who were more likely to maintain a constant setting compared to those who spent fewer days with combined control behaviors.

Financial impact. Respondents were asked how they usually pay for the electricity bills, and 98% reported that they are all paid by the household, in Figure 3 Electricity bills were analyzed across three groups of seasonal period to capture annual variations, during normal weather months respondents reported average bills within the \$101-\$200 range, in contrast during summer conditions, they reported having paid higher with bills falling within the \$201-\$400 range, for the winter months respondents reporting average payments within the \$101-\$200 range, similar to normal conditions. When asked about satisfaction with their electricity plans, the mean obtained was 3.25, meaning that they have a neutral to slight level of satisfaction. When asked if the extreme heat has made electricity bills harder to afford, as shown in Figure 4 46% of respondents expressed agreement, compared to 27% who expressed disagreement and 27% remained neutral, representing the largest individual category.

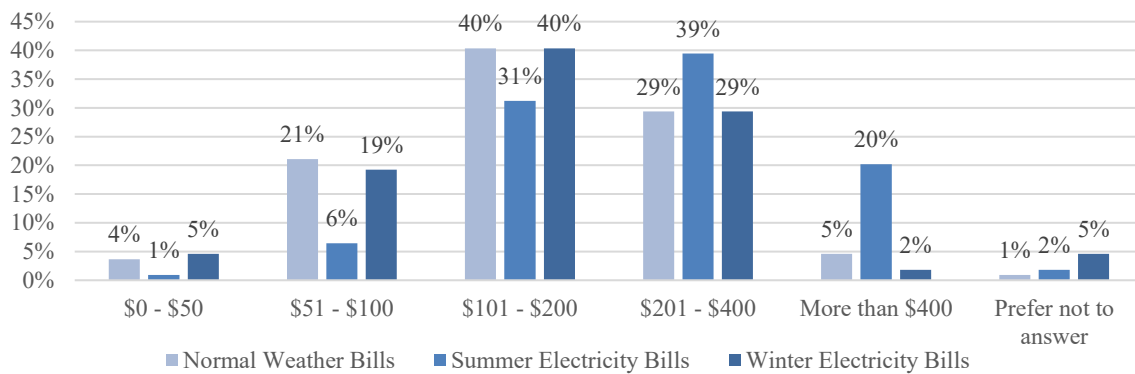


Figure 3 Reported average monthly electricity bill (USD) under different conditions (N=109)

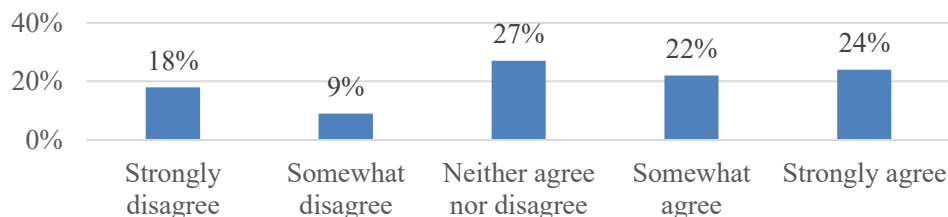


Figure 4 Respondents agreement regarding difficulty in affording electricity bills. (Percent of respondents, N=109)

A Chi-square test revealed no significant association between income and the affordability of bills ($p=0.49$), likely due to small group sizes and concentration around “Neutral” responses. Spearman’s rank order correlation coefficient indicated a weak, negative correlation between income level and financial difficulty ($p 0.195$). While higher income respondents may experience slightly less difficulty, this was not statistically significant. A low percentage, especially low-income levels, may still face financial strain.

Adaptation strategies and home retrofit. A series of questions was asked regarding the actions householders have implemented to enhance energy consumption. Participants were asked to assess whether these improvements and alternatives helped reduce energy consumption and indoor heat. As shown in Figure 5 most of the measures were implemented by respondents, except for using a designated room for cooling, which had the lowest rate. Overall, in Table 1 The strategies that respondents agreed and strongly agreed were helpful, including having good insulation, blocking sunlight, using a ceiling fan, and maintaining HVAC systems regularly. Since using a designated room for cooling was the least adopted strategy, its effectiveness could not be adequately evaluated.

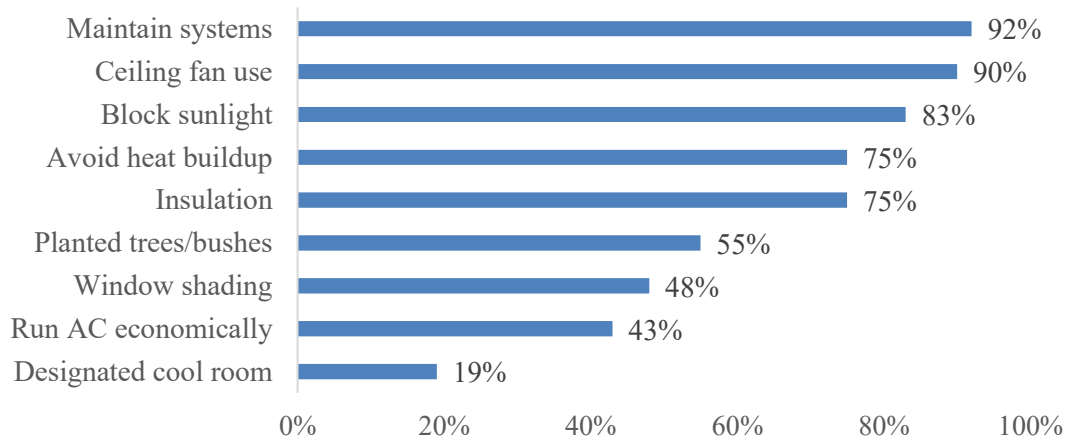


Figure 5 Adaptation strategies and retrofit that have been implemented by respondents. (percent of respondents, N=108)

Table 1 Perceived effectiveness of measures in reducing heat and energy use. (5-pont Likert scale; 1=strongly disagree, 5= strongly agree)

Retrofit/Strategy	Mean	Standard deviation
Ceiling fan use	4.29	0.79
Run AC economically	3.93	0.84
Maintain systems	4.28	0.65
Avoid heat buildup	4.09	0.65
Block sunlight	4.29	0.77
Insulation	4.36	0.73
Designated cool room	3.23	1.09
Window shading	4.10	0.88
Planted trees/bushes	4.22	0.80

Investments. In Figure 6, when asked if they have invested in energy-saving systems or appliances for their homes, 61% of the respondents answered “Yes”. Among those who had not

yet invested, the willingness to adopt expensive systems or appliances to save energy was inconclusive, with 33% “probably not” and 33% selecting “probably yes”. The main options they were given were solar panels, LED light bulbs, smart thermostats, and high-efficiency HVAC systems. Respondents were given the option to write other energy-saving measures they had implemented., from the open-ended question we got diverse responses, such as adding insulation to garage roof and walls, installing tankless electric water heater, using small solar generator, applying fiberglass and cellulose insulation, adding a glass storm, purchasing energy-efficient appliances, such as washer stove and fridge, installing metal reflective roof, and using wraparound for shading. Table 2 presents participants satisfaction with energy-saving investments. Overall, the results show that major system upgrades, specifically HVAC, are perceived to improve comfort and reduce energy costs, while LEDs have been implemented by more participants, they are considered less impactful.

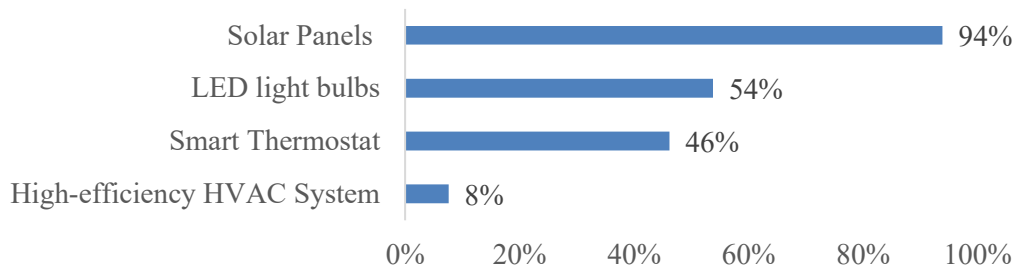


Figure 6 Percentage of respondents that reported investing in energy-efficient systems and appliances. (61% of the full sample, N=66)

Table 2 Perceived satisfaction with different energy-saving investments.(5-point Likert scale; 1 = very dissatisfied, 5 = very satisfied)

Investment	Mean	Standard deviation
Solar Panels	4.20	1.30
LED light bulbs	3.93	1.03
Smart Thermostats	4.07	1.01
High-Efficiency HVAC System	4.26	0.85
Other	4.08	0.86

Residential Characteristics and Electricity Bills. A summary of the most common home characteristics across participants are shown in Table 3. These characteristics reflect typical residential construction in the region and provide important context for analyzing heat exposure and cooling strategies. Chi-square tests were used to examine association between these construction characteristics and monthly household electricity bill level (Table 4). Exterior wall material was the only characteristic that showed a statistically significant association with electricity bills $p=0.0015$. Homes with brick exterior walls were more likely to fall into the high bill category (\$300-\$400), while non-brick homes were more distributed across lower bill category. In contrast, for interior walls, roofing material or roof color were not statistically significant ($p>0.05$), therefore these results are treated as exploratory.

Table 3 Participants most common home characteristics (N=113)

Characteristics	Most Common	Percent
Type of home	Single-family	78%
Size	1,500-1,999 sq ft	27%
Exterior materials	Brick	56%
Interior materials	Drywall	88%
Roofing material	Shingles	78%
Roof color	Dark	81%

Table 4 Results from Chi-square tests

Characteristic	χ^2	df	N	p
Exterior Walls	8.44	2	108	0.015
Interior Walls	2.72	2	108	0.257
Roofing material	1.78	2	108	0.410
Roof Color	1.66	4	108	0.798

CONCLUSION

This study explores how residents in South Texas perceive and respond to extreme heat through a range of building characteristics, cooling behaviors and technological strategies. Using a two-phase approach, a systematic literature review and a household survey, it explored the key factors influencing household energy consumption and overheating risks during extreme heat in Rio Grande Valley, South Texas. The findings show that central air conditioning is the dominant cooling method and that electricity bills increase notably during summer, with some households reporting difficulty affording these costs even though income level was not statistically associated with perceived financial strain. Among the construction characteristics examined, exterior wall material was the only characteristics significantly associated with electricity bill levels, underscoring the importance of building-envelope performance in hot-humid climates. Many passive measures were widely adopted and perceived as effective, such as good insulation, using ceiling fans, blocking direct sunlight and routine HVAC maintenance. Regarding active measures, respondents expressed some willingness to invest, and households that have already adopted major upgrades, particularly solar panels and high-efficiency HVAC systems, often reported improved comfort and perceived energy savings. Limitations include that respondents were recruited mainly through an academic network, and many reported higher incomes, meaning lower income are underrepresented. In addition, the survey relies on self-reported information.

Overall, these findings suggest that although residents are taking action, there is limited clear guidance on which combinations of measures most effectively reduce energy use and costs. This motivates the work to develop a decision support tool and other resources that can translate evidence into practical recommendations for residents and local stakeholders. Future work should expand the sample to include more diverse income brackets and housing types, which would offer a clearer understanding of heat vulnerability and help guide interventions that promote thermal comfort and energy affordability for all. In addition, integrating official data could refine and provide more detailed recommendations on the selection of materials and the adoption of

construction systems to enhance thermal comfort. This could contribute to significantly reducing household electricity use.

REFERENCES

- Aizebeokhai, A. P. 2009. "Global warming and climate change: Realities, uncertainties and measures."
- Amaripadath, D., and D. J. Sailor. 2024. "Reassessing energy-efficient passive retrofits in terms of indoor environmental quality in residential buildings in the United States." *Energy and Buildings*, 319: 114564. <https://doi.org/10.1016/j.enbuild.2024.114564>.
- Baniassadi, A., J. Heusinger, P. I. Gonzalez, S. Weber, and H. W. Samuelson. 2022. "Co-benefits of energy efficiency in residential buildings." *Energy*, 238: 121768. <https://doi.org/10.1016/j.energy.2021.121768>.
- Goldsmith, B. 2025. "Summer 2025 Weather Story for the Rio Grande Valley: The Heat Was On, and Rain Fell Just In Time for Many."
- Karimi, A., Y. J. Kim, N. M. Zadeh, A. García-Martínez, S. Delfani, R. D. Brown, D. Moreno-Rangel, and P. Mohammad. 2022. "Assessment of Outdoor Design Conditions on the Energy Performance of Cooling Systems in Future Climate Scenarios—A Case Study over Three Cities of Texas, Unites States." *Sustainability*, 14 (22): 14 848. Multidisciplinary Digital Publishing Institute. <https://doi.org/10.3390/su142214848>.
- Liyanage, D. R., K. Hewage, S. A. Hussain, F. Razi, and R. Sadiq. 2024. "Climate adaptation of existing buildings: A critical review on planning energy retrofit strategies for future climate." *Renewable and Sustainable Energy Reviews*, 199: 114476. <https://doi.org/10.1016/j.rser.2024.114476>.
- Marx, W., R. Haunschild, and L. Bornmann. 2021. "Heat waves: a hot topic in climate change research." *Theoretical and Applied Climatology*, 146 (1): 781–800. <https://doi.org/10.1007/s00704-021-03758-y>.
- NOAA. 2024. "Monthly National Climate Report for Annual 2023." Accessed September 10, 2025. <https://www.ncei.noaa.gov/access/monitoring/monthly-report/national/202313>.
- NOAA. 2025. "2024 was the world's warmest year on record | National Oceanic and Atmospheric Administration." Accessed December 15, 2025. <https://www.noaa.gov/news/2024-was-worlds-warmest-year-on-record>.
- Vogel, Martha M., Zscheischler, Jakob, Fischer, Erich M., and Seneviratne, S.I. 2020. "Development of Future Heatwaves for Different Hazard Thresholds." Accessed November 12, 2025. <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019JD032070#jgrd56198-bib-0037>.
- Wang, Z., T. Hong, and H. Li. 2021. "Informing the planning of rotating power outages in heat waves through data analytics of connected smart thermostats for residential buildings." *Environmental Research Letters*, 16 (7): 074003. IOP Publishing. <https://doi.org/10.1088/1748-9326/ac092f>.
- Webb, A. L. 2017. "Energy retrofits in historic and traditional buildings: A review of problems and methods." *Renewable and Sustainable Energy Reviews*, 77: 748–759. <https://doi.org/10.1016/j.rser.2017.01.145>.
- Zuo, J., S. Pullen, J. Palmer, H. Bennetts, N. Chileshe, and T. Ma. 2015. "Impacts of heat waves and corresponding measures: a review." *Journal of Cleaner Production*, 92: 1–12. <https://doi.org/10.1016/j.jclepro.2014.12.078>.