

Article

Energy Consumption Analysis and Characterization of the Residential Sector in the US towards Sustainable Development

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Abstract: In 2023, residential and commercial sectors together consumed approximately 27.6% of total United States (U.S.) energy, equivalent to about 20.6 quadrillion Btu. Factoring in the electrical system energy losses, the residential sector represented approximately 19.7% of total U.S. energy consumption during that time. There were approximately 144 million housing units in the United States in 2023, which is increasing yearly. In this study, information on energy usage in the United States residential sector has been analyzed and then represented as energy intensities to establish benchmark data and to compare energy consumption of varying sizes and locations. First, public sources were identified and data from these previously published sources were aggregated to determine the energy use of the residential sector within the US. Next, as part of this study, the energy data for seven houses/apartments from five different United States climate zones were collected firsthand. That data were analyzed, and the energy intensity of each home was calculated and then compared with the energy intensities of the other homes in the same states using Residential Energy Consumption Survey (RECS) data. The energy intensity for each facility was calculated based on the actual energy bills. Finally, the study evaluated the carbon footprint associated with residential energy consumption in all 50 states to reinforce the importance of sustainable development initiatives.

Keywords: residential energy consumption; climate zones; heating-degree days (HDD); cooling-degree days (CDD); sustainable development; energy intensity analysis



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1. Introduction

The United States residential sector uses more energy than the commercial sector. Historical data on energy consumption in the United States by end sector, based on the most recent data in [1,2], are presented in Figure 1.

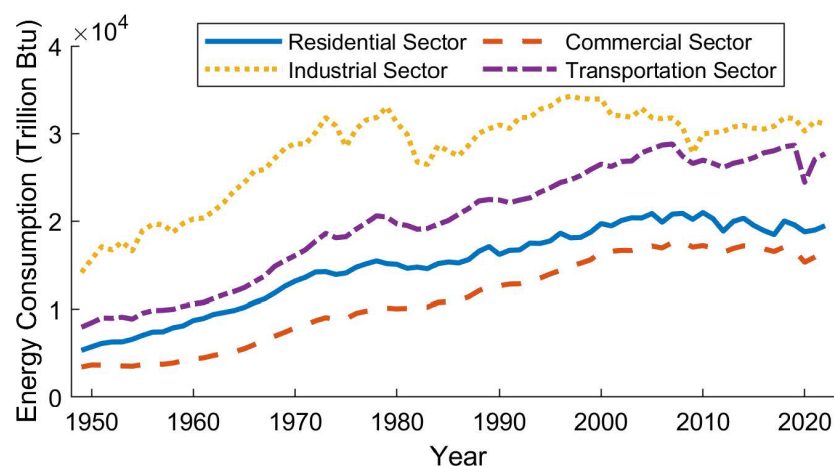


Figure 1. U.S. total energy consumption by end sector.

As in the other sectors, there has been significant and relatively consistent growth in the energy consumed in the US residential sector in the last 60 years. The residential sector consumed more than 10 quadrillion Btu (3.1 trillion kWh) in 2019 and 11.6 quadrillion Btu (3.36 trillion kWh) in 2021. This is equivalent to more than 11% of U.S. energy consumption. In 2022, the residential sector used 1.56 trillion kWh of electricity, which is approximately 38.4% of the total electricity use in the United States [3]. In 2022, the US used about 100.41 quadrillion British thermal units of energy. Most of this energy, around 38%, was used by the electric power sector. Transportation followed, using 27% of the total energy, while industries used 23% [4]. In 2023, the residential and commercial sectors consumed about 27.6% of total U.S. energy, totaling approximately 20.6 quadrillion Btu. The energy consumed by these sectors includes both end-use consumption and electrical system energy losses associated with retail electricity sales. When considering these losses, the residential sector alone accounted for around 19.7% of the total U.S. energy consumption in 2023 [5]. There were approximately 144 million housing units [6] in the United States in 2023, which is increasing yearly. The energy used in homes (residential sector) represented 7% of the total, and commercial buildings used 5%. This breakdown shows how energy is distributed across different parts of the economy, highlighting areas where efficiency improvements could have a big impact. The percentage share of total power consumption is shown in Figure 2 [7]. As shown in the figure, the electric power usage resulted in 38% of the total primary energy consumption.

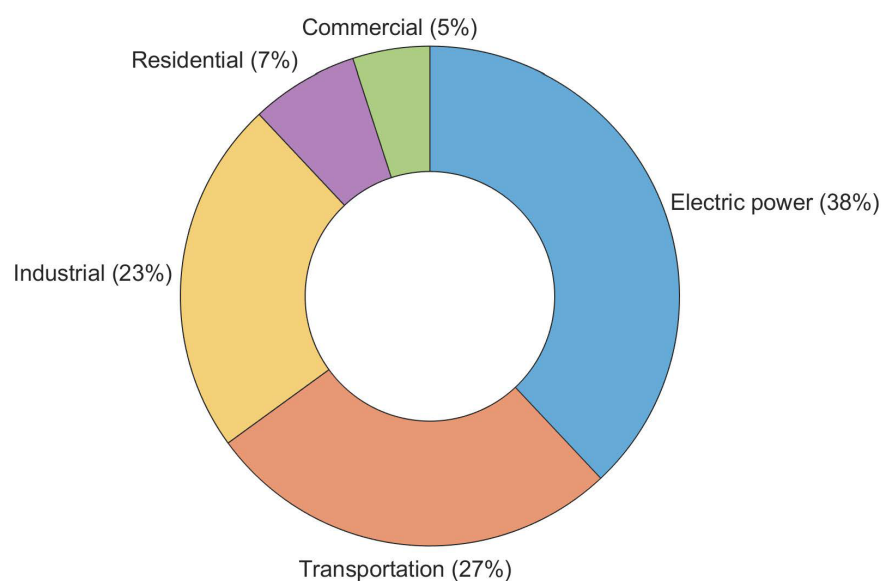


Figure 2. Percentage share of total primary energy consumption by the U.S. energy use sector, 2022.

The annual energy consumption of the residential sector for five US climate zones with different cooling degrees days (CDD) and heating degrees days (HDD) is shown in Figure 3 [8]. Knowing these zones helps to identify the energy management strategies.

The amount of energy needed to heat indoor places during colder months is measured in heating-degree days (HDD). Both HDD and CDD are determined by deducting a base temperature (often 18.3 °C or 65 °F) from the average outside temperature for a given day.

As seen in Figure 3, zone 1 represents the cold states, while zone 5 represents the hot states in the country. According to the most recent Residential Energy Consumption Survey (RECS) conducted by EIA in 2020, on average about 77 million British thermal units (MMBtu) were consumed by the total U.S. households. The results also indicated that the energy used by a household is correlated with the average zone temperature; homes in colder zones, where heating is used more intensely, consume more energy than houses in the warmer zones [9]. Sekar et al., in their study, found that Americans are now spending

more time at home than before, which means that more residential energy is consumed than before [10].

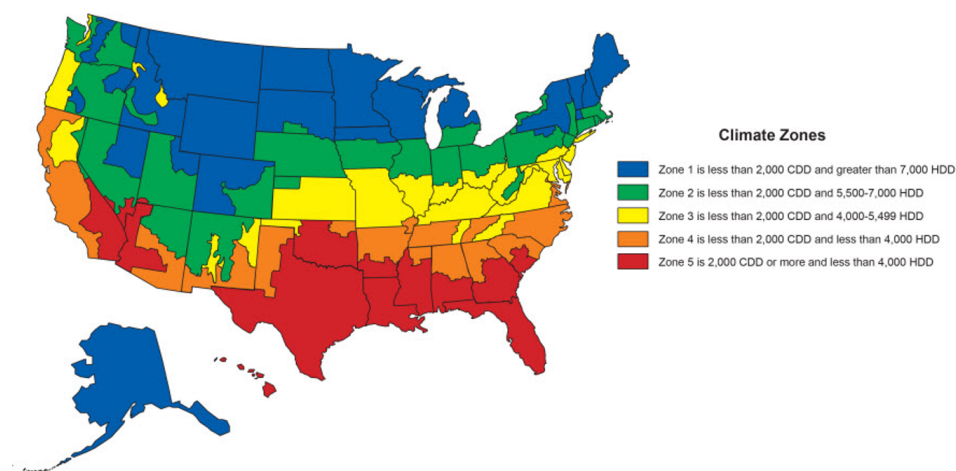


Figure 3. Different climate zones in the United States [11].

Several studies suggested that during winter, places with higher HDD use more natural gas, underscoring the importance of effective insulation and heating systems in cold climates. The study in [12] investigated how demand response events might be used by local aggregators to provide energy savings to residential customers. Local aggregators are organizations that maximize the overall energy usage by coordinating energy consumption across several households. The authors provided a technique for evaluating local aggregators' potential for energy savings by an examination of the climate, energy usage trends, and building energy efficiency in the area.

The data from EIA provide insights into the energy consumption patterns in the U.S. residential sector from 1960 to 2020. Over these decades, fluctuations were observed in the consumption of various energy sources. Coal, natural gas, petroleum, renewable energy, and electricity have all played significant roles in meeting residential energy needs. Initially, coal was a dominant energy source, but its usage gradually decreased over the years. Conversely, the consumption of natural gas has shown a steady increase, reflecting its growing popularity as a cleaner and more efficient alternative. Petroleum usage has fluctuated, influenced by factors such as economic conditions and energy policies. The rise of renewable energy sources, including solar and wind power, is evident in the data, although the data start from a relatively small base. Electricity, as a versatile energy carrier, witnessed consistent growth, reflecting technological advancements and lifestyle changes. The data highlight the dynamic nature of residential energy consumption and the evolving energy landscape in the United States. The energy consumption of the US residential sector by energy source from 1960 to 2020 is shown in Figure 4 [13]. Although natural gas dominated as a source of energy for a long period of time, the use of electricity is now taking its place and has started to move to the top position.

Guo et al. emphasized how crucial it is to comprehend household power usage trends to guide local decarbonization initiatives [14]. Data on state energy-related carbon dioxide (CO₂) emissions by sector in 2021 shed light on the carbon footprint associated with residential energy consumption in different states [15]. A closer analysis reveals significant variations in CO₂ emissions between states, reflecting differences in energy sources, consumption patterns, and efficiency measures. States with high residential CO₂ emissions, such as California, Illinois, New York, and Pennsylvania, often coincide with densely populated areas and extensive urbanization, where the energy demand is inherently high. On the contrary, states with lower emissions, such as Hawaii, Vermont, and the District of Columbia, tend to have smaller populations and may rely more on renewable energy sources or have implemented energy efficiency initiatives. For instance, Hawaii has

abundant solar resources. It has made substantial investments in solar energy production, leading to lower reliance on fossil fuels and subsequently lower CO₂ emissions from residential energy use. These variations underscore the importance of regional considerations in addressing carbon emissions from residential energy use. State energy-related carbon dioxide emissions by residential use are shown in Figure 5 [16]. Based on this data, New York tops in energy-related CO₂ emission. New York is actively pursuing significant CO₂ emission reductions through several initiatives under the Climate Leadership and Community Protection Act (CLCPA). This law mandates a reduction of statewide greenhouse gas emissions to 60% of 1990 levels by 2030 and to 15% of 1990 levels by 2050, aiming for economy-wide carbon neutrality by mid-century. California, on the other hand, is actively working to reduce CO₂ emissions through various comprehensive measures. The state aims to achieve carbon neutrality by 2045, with significant investments in renewable energy and nature-based solutions.

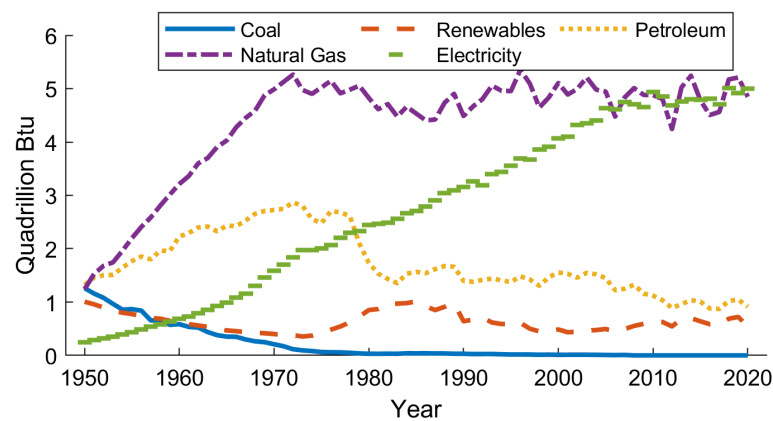


Figure 4. The U.S. residential sector energy consumption by energy source, 1960 to 2020.

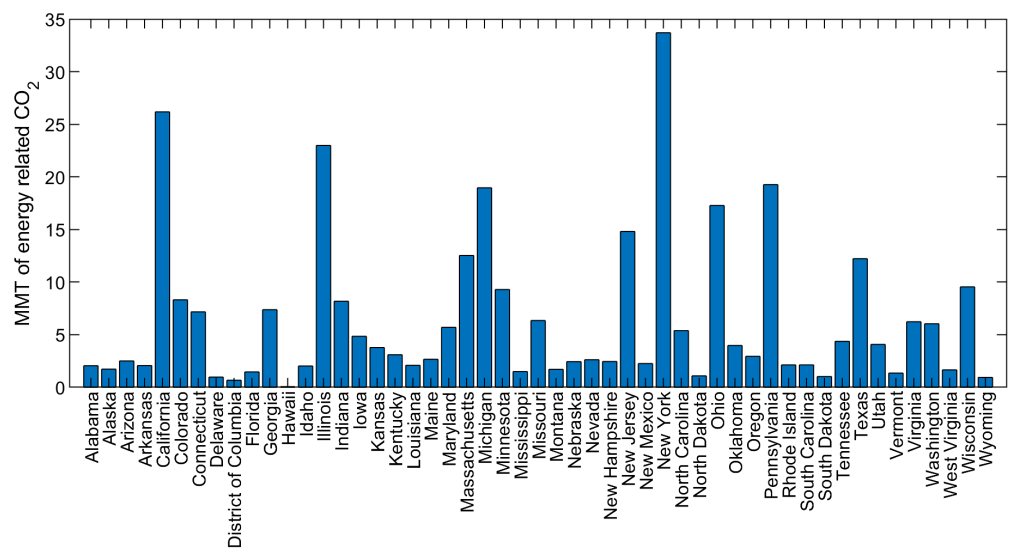


Figure 5. State energy-related carbon dioxide emissions in Million Metric Tons (MMT) by sector.

The average electricity cost for the residential sector in the U.S. was 16.19 cents per kWh in 2023 [17]. Assuming an average annual income of USD 68,703 per household [18], and an average electricity consumption of 877 kWh per month [19], the average electricity cost per dollar of income would be approximately 1.97 cents. Adding taxes and other surcharges would mean that households in the United States spend about 2 cents for each dollar of income on electricity. The Residential Buildings Integration program by the Department of Energy (DOE) focuses on developing and scaling energy-efficiency technologies and approaches that improve the affordability and comfort of the nation’s

120 million residential buildings while reducing their carbon footprint and energy consumption. It is, thus, important that a benchmark for the energy consumption is established in terms of Energy Intensity (kWh/ft²) instead of just expressing energy consumption in kWh or Btu [20].

After the above discussions, it can be said that studying the energy consumption of residential customers is essential for a range of reasons. It offers insightful information on resource management, helping to maintain the sustainability of limited energy sources. Assessing the effects on the environment is also made possible by an understanding of consumption patterns, especially concerning carbon dioxide emissions. This information is essential to create energy-efficient policies, such as those that encourage the use of renewable energy sources and energy-efficient technologies. Furthermore, assessing household energy use helps with financial decision making, effective grid management, consumer education on energy efficiency, and solving differences in energy availability and cost between various areas.

The significance of this study is to investigate the energy consumption of the residential sector in the United States to establish a benchmark and to compare the energy consumption of varying sizes and locations. In addition, the paper emphasizes the need for more state and federal regulations of energy efficiency and the adoption of renewable energy, new technologies, and sustainability policies. This should include the construction of new buildings and homes to ensure energy efficiency, resource use, and the importance of sustainable development. There is also a need for stakeholder collaboration to achieve sustainable development targets and social issues of residential buildings. According to the U.S Energy Information Administration, the United States generated more than 4178 billion kilowatt-hours (kWh) of electricity in 2023 [21]. About 60% of this electricity was generated from fossil fuels and 19% was generated from nuclear energy. Only about 21% was generated from renewable energy sources, which is projected to increase to 42% in 2050. Increasing the generated renewable electricity will significantly reduce greenhouse gases and it is a great step toward sustainable development. Previous analysis of residential energy use is often expressed as a percentage of total energy but without clear values of actual monthly energy consumption. This information is of low value since energy consumption cannot be used for benchmarking and sustainable development. In this article, we address the lack of a methodology for assessing and quantifying residential energy consumption by calculating the energy intensity for use as a metric for sustainable development.

2. Residential Energy Consumption Data

Since the residential sector has been responsible for more than 19.7% of total U.S. energy consumption in the last decade, residential energy consumption in the United States is considered a significant contributor to greenhouse gas emissions, environmental impacts, and total energy usage. Studying the characteristics of residential energy consumption helps to determine the potential reduction and look for efficient ways for energy management. There is a need for more governmental programs for people to promote green living and to increase understanding of energy-efficient products, the use of renewable energy systems, and eco-friendly construction materials. Currently, there are several home energy efficiency-saving programs, such as the Federal Investment Tax Credit (ITC) program and the Federal Solar Tax Credit program. These programs are available to homeowners in the United States. Homeowners can receive a credit of up to 30% of the renewable energy system's cost. However, these programs are available for homeowners and not for rental properties, and these programs are voluntary, not mandatory. Also, many Americans are unaware of energy efficiency incentives, and some do not know how to save energy. According to the American Council for an Energy-Efficient Economy (ACEEE) report, only three states have targets for energy savings among low-income households [22]. There are several challenges to energy efficiency when new technologies are not implemented. These challenges include ignorance, lack of technical, demographics, and economic barriers [23]. According to

the American Council for an Energy-Efficient Economy report, common challenges that residential energy programs face are: low population density, lack of broadband access, high costs, inefficient marketing, residents being skeptical and unfamiliar with energy efficiency programs, and shortage of qualified local energy efficiency workers [24]. More attractive programs with higher tax credits can be offered to increase the rapid adoption of new sustainable technologies by customers and overcome economic challenges to reach more homeowners.

Energy intensity analysis is crucial for assessing and enhancing energy efficiency in processes. It helps quantify energy consumed per unit of output, aiding in cost reduction, environmental impact mitigation, and competitive advantage. This analysis targets areas of high energy intensity for optimization, facilitates cost reduction through efficiency upgrades, and supports environmental goals by cutting greenhouse gas emissions. It also informs policy development by revealing consumption patterns, allowing targeted interventions for sustainable energy use and risk mitigation in volatile markets.

The typical energy use of a 2000-square-foot house is roughly 10,400 kWh per year. This equates to an annual energy intensity of 5.2 kWh/ft². However, the energy intensity varies greatly by geography, and dwellings in colder regions often require more energy due to greater heating demands. On the other hand, warmer-climate homes may have higher cooling demands, resulting in higher energy intensity during the summer months. The Energy Information Administration (EIA) study on 2020 residential energy consumption in the United States provides crucial insights into usage patterns. This national sample survey gathered data from nearly 18,500 households, representing 123.5 million primary residences. The 2020 RECS, the 15th iteration, released its first microdata file in July 2022 with preliminary household characteristics. The second file, from March 2023, includes final housing and square footage data, with differences outlined in the Housing Characteristics documentation's Appendix A.

According to the report, residential energy consumption increased slightly in 2020 compared to the previous year, largely due to the impacts of the COVID-19 pandemic on energy use patterns. With more people staying home due to lockdowns and work-from-home arrangements, energy consumption for space heating, water heating, and cooking increased [25].

In contrast, energy use for transportation and commercial activities decreased. This trend highlights the dynamic nature of energy demand in response to societal shifts, emphasizing the need for flexible energy policies and infrastructure to meet evolving needs and challenges. The data show that in 2020, the total site energy consumption in the U.S. was 9481 trillion Btu, with an average of 76.8 million Btu per household, 31.3 million Btu per household member, and 42.2 thousand Btu per square foot. Total energy expenditure was 232.76 billion dollars, with an average of 1884 dollars per household, 768 dollars per household member, and 1.04 dollars per square foot. Understanding the energy consumption patterns in buildings worldwide is crucial for effective management and sustainability efforts. This involves examining various factors that influence energy usage, such as urbanization, income levels, population growth, initiatives aimed at improving efficiency, and prevailing climate conditions. By comprehensively analyzing these determinants, policymakers, urban planners, and stakeholders can develop targeted strategies to address energy challenges and promote more sustainable building practices on a global scale [26]. The study in [26] identified heating equipment type and home size as primary contributors to energy consumption across most climate zones, with variations observed in different regions. Additionally, the influence of on-site solar power generation was found to be limited, suggesting the need for further research and policy considerations [27].

There are some methodologies for estimating and improving energy efficiency in residential buildings, covering aspects like window replacement, insulation, and shading. They provide rough estimations and exact calculations, emphasizing the importance of factors such as climate conditions and building characteristics for accurate assessments [28].

When looking at the census region and division, the Northeast had the highest energy consumption and expenditures per household, with an average of 89.2 million Btu and 2263 dollars, respectively. The Midwest had the highest energy consumption and expenditures per square foot, with an average of 48.3 thousand Btu and 0.94 dollars, respectively. The South had the lowest energy consumption and expenditures per household member, with an average of 27.2 million BTU and 753 dollars, respectively. The West had the lowest energy consumption and expenditures per square foot, with an average of 39.1 thousand Btu and 1.00 dollars, respectively.

The report also highlights the continuing importance of energy efficiency measures in reducing energy consumption and costs for homeowners. By improving insulation, upgrading appliances, and using energy-efficient lighting and heating systems, homeowners can save money on energy bills and reduce their carbon footprint. The table displays data from the 2020 Residential Energy Consumption Survey by the U.S. Energy Information Administration, detailing the main heating fuel sources in U.S. households. Natural gas leads at 62.71%, followed by electricity at 42.57%. Fuel oil kerosene and propane hold smaller shares at 4.93% and 5.21%, respectively, while wood is used by 2.25% of households. Some other fuels, such as coal and district steam, represent a negligible share. Additionally, 5.79% of households do not use heating equipment. These data are based on a sample of primarily occupied housing units across the 50 states and the District of Columbia, classified by the U.S. Census Bureau using 2010 Census data, covering energy consumption, expenditures, climate regions, and household characteristics.

To reduce power consumption, we need to implement various measures to reduce power consumption in residential buildings, including improving energy efficiency through better building materials and construction methods, promoting the adoption of smart devices for energy management, and using economic incentives to encourage households to adopt energy-saving behaviors [29]. The report highlights electricity as the primary energy source for residential buildings, followed by natural gas and propane, although there is a growing trend towards renewable sources like solar and wind power. The 2020 Residential Energy Consumption Survey (RECS) recently released data on state household characteristics, offering insights into energy consumption patterns nationwide and facilitating trend analysis [30].

According to the survey findings, the average household size in the U.S. stands at 2.5 people. Utah and South Dakota have the largest households, averaging 3.1 people, while Maine and Vermont have the smallest, at 2.2 people. The average number of rooms per household is 5.5, with Mississippi and New Mexico leading at 6.4 and 6.2 rooms, respectively, and Delaware and Rhode Island having the fewest at 4.3 and 4.5 rooms, respectively. In terms of energy consumption, Hawaii tops the charts with an average of 22,100 kWh of electricity per year, while Maine has the lowest at 6900 kWh. Wyoming records the highest average natural gas consumption at 791 therms, whereas Hawaii has the lowest at 17 therms. For fuel oil or kerosene, Maine leads with 501 gallons per year, contrasting Hawaii's mere 3 gallons. Propane consumption averages 461 gallons annually, with Maine at the top with 766 gallons and Hawaii at the bottom with 3 gallons. Wood consumption remains the lowest among all fuel sources, averaging 1.1 cords annually. According to the U.S. Housing Statistics and Facts, the total space of homes in the United States was estimated to be 256.7 billion square feet in 2023. From 2015 to 2023, as shown in Figure 6, the total space of homes in the U.S. increased from 237.40 billion square feet in 2015 to 254.21 billion square feet in 2022 [31].

As shown in Table 1, between 2015 and 2022, there was a general trend of fluctuation in energy consumption, measured in trillion Btu [2], across billions of square feet of space [32], with a corresponding change in energy intensity, measured in kWh per square foot. Despite variations, there was an overall increase in energy consumption from 2015 to 2022, with peaks in 2018 and 2022, while energy intensity showed a slight fluctuating trend but remained relatively stable.

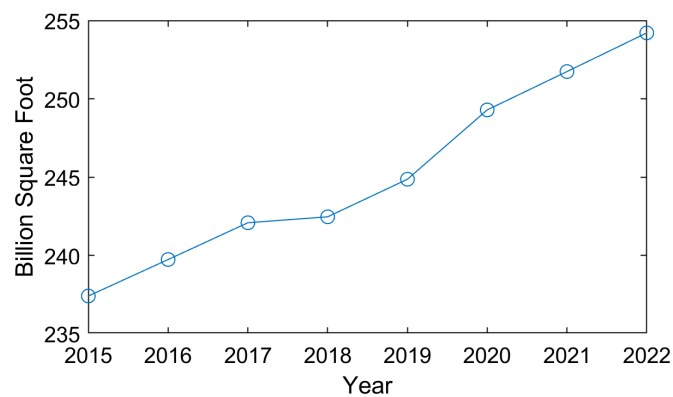


Figure 6. Total home space between 2015 and 2022.

Table 1. U.S. residential energy vs. total space of homes.

Year	Trillion Btu	Billion Square Foot	Energy Intensity kWh/ft ²
2015	19,520.28	237.40	25.10
2016	18,928.66	239.73	23.14
2017	18,471.13	242.08	23.36
2018	20,023.104	242.46	24.20
2019	19,574.9	244.86	23.43
2020	18,795.068	249.29	22.10
2021	18,990.718	251.74	22.11
2022	19,495.784	254.21	22.48

Residential buildings are one of the major contributors to climate change and account for more than 19% of the U.S.'s CO₂ emissions by source. According to the annual energy outlook report for the year 2023, the residential sector is responsible for more than 0.9 billion metric tons of CO₂ emissions [33–35]. The CO₂ equivalent for different fuel types is shown in Table 2 [30]. Based on this table, various fuels emit different amounts of CO₂. Propane emits 12.68 pounds of CO₂ per gallon, while diesel emits 22.45 pounds per gallon. Coal is the most CO₂-intensive, emitting 3876.61 pounds per short ton. Natural gas is the least CO₂-intensive per million Btu, emitting 116.65 pounds.

Table 2. Carbon dioxide emissions coefficients by fuel.

CO ₂ Factors	Pounds CO ₂ Per Unit of Volume or Mass	Unit	Kilograms CO ₂ Per Unit of Volume or Mass	Unit	Pounds CO ₂ Per Million Btu	Kilograms CO ₂ Per Million Btu
Propane	12.68	gallon	5.75	gallon	138.63	62.88
Diesel and Home Heating Fuel (Distillate Fuel Oil)	22.45	gallon	10.19	gallon	163.45	74.14
Kerosene	21.78	gallon	9.88	gallon	161.35	73.19
Coal (All types)	3876.61	short ton	1758.40	short ton	211.87	96.10
Natural Gas	120.96	thousand ft ³	54.87	thousand ft ³	116.65	52.91
Finished Motor Gasoline	17.86	gallon	8.10	gallon	148.47	67.34
Motor Gasoline	19.37	gallon	8.78	gallon	155.77	70.66
Residual Heating Fuel (Businesses only)	24.78	gallon	11.24	gallon	165.55	75.09

In summary, the above discussions highlight the importance of energy efficiency measures, such as improved insulation and upgraded appliances, in reducing consumption and costs. It also details the main heating fuel sources in U.S. households, with natural gas leading, followed by electricity, and a small percentage not using heating equipment. The report emphasizes electricity as the primary energy source for residential buildings, with a trend towards renewable energy. The survey findings show variations in household size, room number, and energy consumption across states, with Hawaii having the highest electricity use and Wyoming the highest natural gas use. Fuel oil, kerosene, propane, and wood have varying usage rates, with Maine leading in fuel oil and propane consumption.

3. Methodology

A major goal of this research is to undertake a comprehensive analysis of energy use in the United States residential sector. This investigation takes a multifaceted approach, integrating existing data from the literature and government publications with firsthand data acquired from updates in different parts of the United States. The study focuses on quantifying energy intensity, which is defined as the electricity consumption in kWh per square meter (kWh/f²) of the building's footprint. This statistic provides a standardized way to compare energy consumption across various residential constructions. We explain the process in more detail in this section.

1. Literature Review and Data Compilation: The first phase in this research is a thorough examination of available literature and official records about energy consumption patterns in the United States residential sector [36]. This procedure includes studies, surveys, and reports from reputable sources, such as the United States Department of Energy (DOE), the Energy Information Administration (EIA), and academic research. We ensure the analysis is founded on the most recent and credible information accessible by pulling from these reputable sources. This overview of the literature serves as the foundation for comprehending the broader context of household energy usage.
2. Calculation of Energy Intensity: Energy intensity, a key metric in this study, is computed for each residential building by dividing the annual energy consumption (in kWh) by the total floor area (in square meters) of the respective house. This calculation is expressed mathematically as:

$$\text{Energy Intensity} = \frac{\text{Annual Energy Consumption}}{\text{Total Area}} \quad (1)$$

The energy intensity metric normalizes energy consumption, enabling meaningful comparisons between residential buildings of varying sizes and layouts. This approach aligns with established standards for energy benchmarking and performance assessment [37].

3. Data Collection from Sample Residential Homes: In addition to relying on published data, this study collects and analyzes energy-related information for seven residential homes located in different regions of the United States. This includes acquiring utility bills that detail the energy consumption patterns over a year and recording the total floor area of each house. The data collected from these homes provide a real-world perspective on energy use and allow for in-depth scrutiny.
4. Energy Intensity Calculation for Sample Homes: To assess the energy performance of the selected residential homes, the energy intensity is computed for each dwelling using the actual annual energy consumption data obtained from utility bills and the recorded total floor area. These calculations provide insight into the energy efficiency of these specific homes and enable the comparison of consumption trends across the sample.

By combining data from published sources with real-world measurements from the selected residential homes, this research offers a comprehensive and data-driven analysis of energy use within the U.S. residential sector. The calculated energy intensities facilitate the identification of trends, the evaluation of energy efficiency measures, and the formulation

of recommendations for optimizing residential energy consumption and sustainability. This methodology aligns with established practices in energy analysis and provides a robust framework for understanding and addressing energy-related challenges in the residential sector.

4. Sample Data Collection and Discussions

Electricity consumption is a key metric for analyzing residential energy use because it is straightforward to measure and provides a good overview of how much energy homes are using. It shows which appliances and devices are running and how energy needs change with the seasons. By looking at electricity usage, a user can see where they might be using too much energy and find ways to be more efficient. In this section, case studies from five different zones in the United States are presented. The data collection was performed in 2022–2023. Monthly energy consumption is affected by the weather and the type of building insulation. To understand the energy characteristics of the building, the utility bills and building information were gathered. Then, the energy intensity was calculated. The electricity intensity is calculated based on the total energy (in kWh) divided by the area (in square feet or square meters) as in Equation (1).

4.1. Denton, Texas, Climate Zone 5

The data for zone 5 came from a single-story house in Denton, Texas, with a zip code of 76210. This is a 2200 ft² house with brick walls and equipped with central HVAC. As shown in Table 3, the monthly energy consumption for this house ranges from 232 kWh in December to 1055 kWh in August. August marked the peak energy consumption period for this household, as illustrated in Figure 7, a trend commonly observed in residences within this zone due to the region's hot climatic conditions.



Figure 7. High energy consumption months for case 1, as visualized with a word cloud.

By analyzing utility bills and building specifications, the annual electricity consumption was determined to be 5710 kWh, resulting in an energy intensity value of 2.60 ft². The monthly electricity use and the average temperature for case 1 are presented graphically in Figure 8.

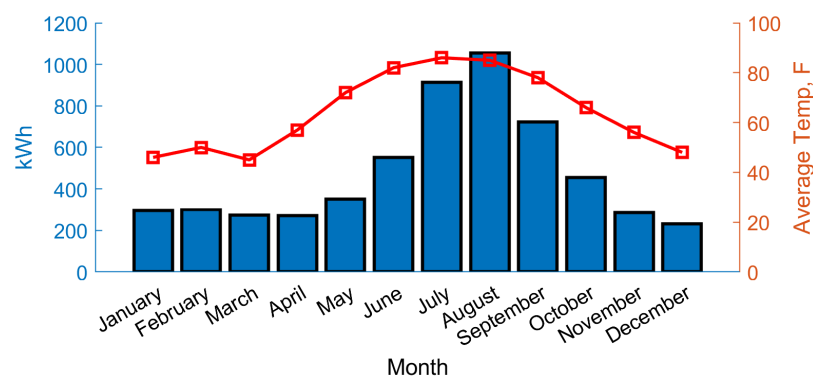


Figure 8. Monthly electricity use and average temperature for case 1. The red line with squares represents temperature in Fahrenheit, and the bars represent energy consumption in kWh.

Table 3. Monthly energy consumption for case 1.

Month	kWh	Average Temp, F
January	297	46
February	300	50
March	273	45
April	272	57
May	351	72
June	551	82
July	914	86
August	1055	85
September	723	78
October	455	66
November	287	56
December	232	48
Total	5710	

4.2. Atlanta, Georgia, Climate Zone 4

In this case study, data from a 2072 ft² apartment built in 1995 are presented from Atlanta, Georgia, zip code 30005. The apartment is front-brick type, second floor, and vinyl-sided with standard R-18 for walls. The house uses electricity for heating and water heating. As shown in Table 4, the monthly energy consumption of this house ranges from 1074 kWh in October to 4010 kWh in January. The most energy consumption happens during the months of January, February, and December, as depicted in Figure 9.



Figure 9. High energy consumption months for case 2, as visualized with a word cloud.

The annual electricity consumption for this apartment was recorded as 28,226 kWh. The energy intensity of this house was found to be 13.62 kWh/ft². Monthly electricity use and the average temperature for case 2 are presented in Figure 10.

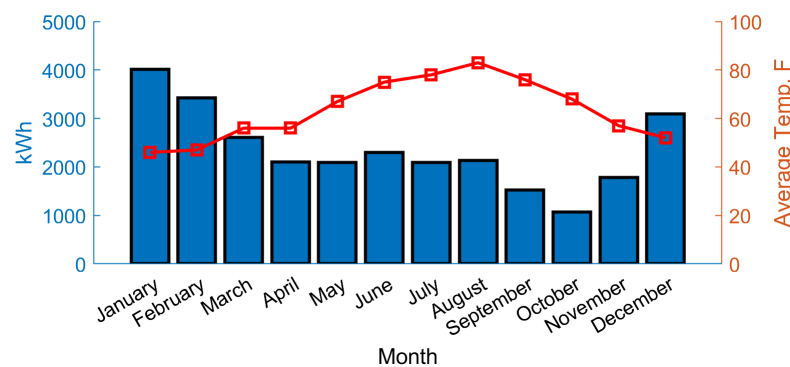


Figure 10. Monthly electricity use and average temperature for case 2. The red line with squares represents temperature in Fahrenheit, and the bars represent energy consumption in kWh.

Table 4. Monthly energy consumption for case 2.

Month	Electricity, kWh	Average Temp, F
January	4010	46
February	3429	47
March	2604	56
April	2104	56
May	2090	67
June	2300	75
July	2087	78
August	2130	83
September	1525	76
October	1074	68
November	1781	57
December	3092	52
Total	28,226	

4.3. LA, California, Climate Zone 4

The previous data from Atlanta, GA are from the moist area, whereas the data collected in Los Angeles, California, reflect marine weather conditions. This is a 1400 square foot apartment constructed in 2002 located in Los Angeles, California, with zip code 92563. Energy consumption data were gathered for this two-bedroom apartment, situated on the second floor of a brick-front, vinyl-sided building with standard R-18 insulation for walls. As illustrated in Table 5, monthly energy consumption for this residence varies from 248 kWh in January to 642 kWh in September. The highest energy consumption for this apartment happened in September, Figure 11. As anticipated for this particular region, the months characterized by higher temperatures corresponded to increased energy consumption periods in this case study. This result aligns with the common expectation that warmer weather typically leads to greater demand for cooling systems, thereby driving up energy usage.

Table 5. Monthly energy consumption for case 3.

Month	kWh	Average Temp, F
January	248	53
February	293	54
March	313	56
April	280	60
May	320	64
June	420	68
July	571	72
August	518	74
September	642	72
October	385	65
November	281	58
December	254	52
Total	4525	



Figure 11. High energy consumption months for case 3, as visualized with a word cloud.

The annual electricity consumption for this apartment is 4525 kWh. The energy intensity of this apartment is 3.23 kWh/ft². The monthly electricity use and the average temperature for case 3 are presented graphically in Figure 12.

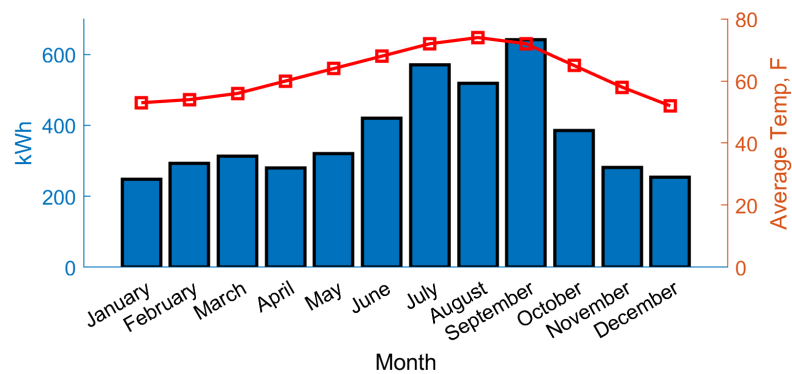


Figure 12. Monthly electricity use and average temperature for case 3. The red line with squares represents temperature in Fahrenheit, and the bars represent energy consumption in kWh.

4.4. Cape Girardeau, MO, Climate Zone 3

In this case study, data from a 1090 ft² apartment built in 2003 are presented. These data were collected in Cape Girardeau, Missouri, zip code 63701. The apartment is on the third floor and vinyl-sided with standard R-18 for walls. The house uses electricity for heating and water heating. The monthly energy consumption for this case is shown in Table 6.

Table 6. Monthly energy consumption for case 4.

Month	Electricity, kWh	Average Temp, F
January	1071	39
February	985	31
March	1094	37
April	791	49
May	672	58
June	702	70
July	833	78
August	989	81
September	843	76
October	796	70
November	682	58
December	974	46
Total	10,432	

The months with the most energy consumption are depicted in Figure 13. While January and March are highlighted with larger words, it is important to note that February maintained an average daily consumption of 35.18 kWh, consistent with the other two months, as previously mentioned. It is worth highlighting that February had 28 days in 2022. The total kWh consumed each month varied throughout the year, ranging from a low of 672 kWh in May to a high of 1094 kWh in March. The highest consumption occurred during the winter months, which is expected due to the increased use of heating systems.



Figure 13. High energy consumption months for case 4, as visualized with a word cloud.

The annual electricity consumption of the apartment was based on the utility bills for 12 months and amounted to 10,432 kWh. The yearly energy intensity value obtained for this building was 9.57 kWh/ft². Monthly electricity use and average temperature for case 4 are depicted in Figure 14.

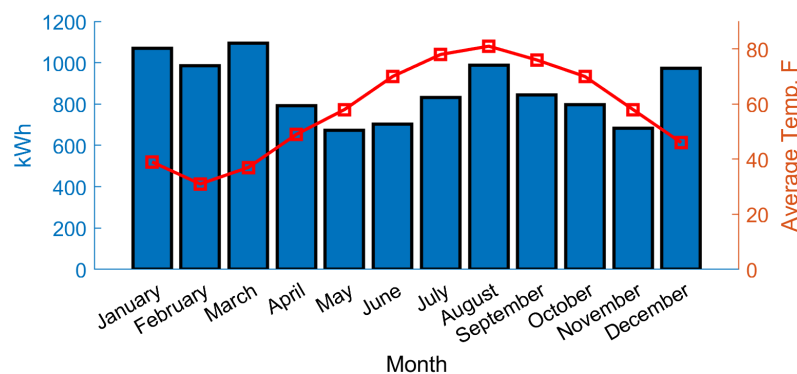


Figure 14. Monthly electricity use and average temperature for case 4. The red line with squares represents temperature in Fahrenheit, and the bars represent energy consumption in kWh.

4.5. Beaverton, Oregon, Climate Zone 2

This is an 1890 ft² apartment built in 2002 and is in Beaverton, Oregon, zip code 97003. The energy data for this single-family house were collected. The house is vinyl-sided with a standard R-18 for walls. The house uses electricity for heating and water heating. As shown in Table 7, the monthly energy consumption for this house ranges from 1753 kWh in October to 4233 kWh in February. The word cloud data visualization in Figure 15 shows that the month of February had the highest electricity consumption for this apartment, which is not quite consistent with the given average temperature data for this month. Energy consumption data for this particular month can be considered an anomaly, possibly influenced by factors beyond temperature alone.



Figure 15. High energy consumption months for case 5, as visualized with a word cloud.

Table 7. Monthly energy consumption for case 5.

Month	kWh	Average Temp, F
January	3100	40
February	4233	42
March	2450	47
April	2000	51
May	1767	56
June	2134	62
July	2151	67
August	2131	68
September	1987	62
October	1753	53
November	1878	45
December	2021	39
Total	27,605	

The annual electricity consumption for this apartment is 27,605 kWh. The energy intensity value for this house was found to be 14.61 kWh/ft². Monthly electricity use and average temperature for case 5 are presented graphically in Figure 16.

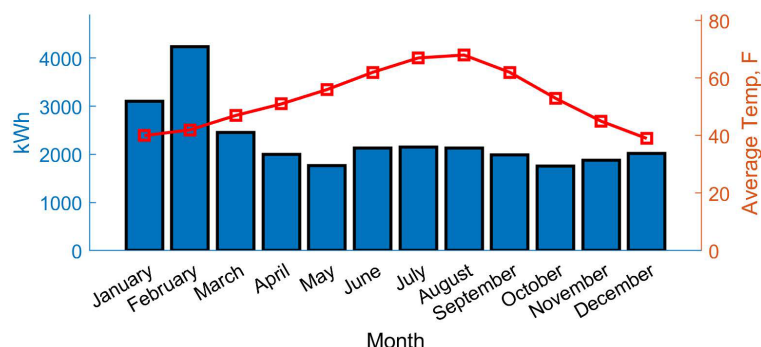


Figure 16. Monthly electricity use and average temperature for case 5. The red line with squares represents temperature in Fahrenheit, and the bars represent energy consumption in kWh.

4.6. MA, Chelmsford, Climate Zone 2

A second data point from climate zone 2 was also gathered, this time from a 1275 square foot apartment constructed in 1991, located in Chelmsford, Massachusetts, with zip code 01824. Unlike the data from OR, which represent a cold and dry area, this dataset reflects the conditions of a moist region within Zone 2. The energy data were collected for this single-story apartment, with an additional room in the basement, and it features central HVAC for temperature control. As presented in Table 8, the monthly energy consumption for this residence varied from 322 kWh in April to 527 kWh in September, with the maximum consumption happening in September, Figure 17.



Figure 17. High energy consumption months for case 6m as visualized with a word cloud.

Table 8. Monthly energy consumption for case 6.

Month	kWh	Average Temp, F
January	410	27
February	412	29
March	347	32
April	322	47
May	347	59
June	422	65
July	408	72
August	391	71
September	527	66
October	437	50
November	420	42
December	353	34
Total	4796	

The collected data revealed a total annual electricity consumption of 4796 kWh for 2022–2023. The energy intensity for this household is 3.76 kWh/ft². The monthly electricity use and the average temperature for this case are presented graphically in Figure 18.

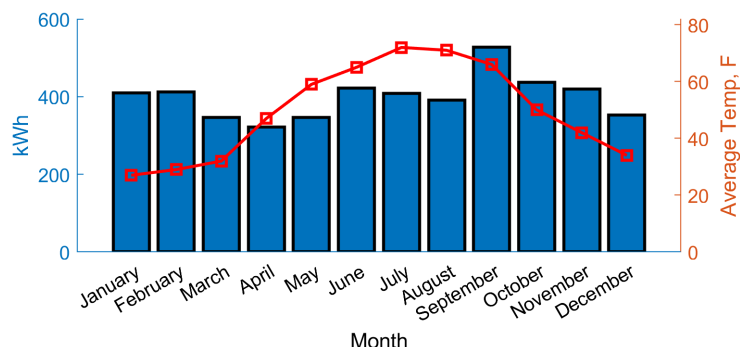


Figure 18. Monthly electricity use and average temperature for case 6. The red line with squares represents temperature in Fahrenheit, and the bars represent energy consumption in kWh.

4.7. WI, Oak Creek, Climate Zone 1

The data for this case study are from climate zone 1 with zip code 53154. This is a 1110-square-foot apartment located in Oak Creek, Wisconsin. The energy data were collected for this single-story apartment, with a central HVAC for temperature control. As presented in Table 9, monthly energy consumption for this residence varied from 211 kWh in June to 411 kWh in August, see Figure 19. The energy consumption was high during the months of higher average temperature days.



Figure 19. High energy consumption months for case 7, as visualized with a word cloud.

Table 9. Monthly energy consumption for case 7.

Month	kWh	Average Temp, F
January	271	31
February	255	29
March	217	34
April	308	47
May	227	50
June	211	63
July	392	73
August	411	74
September	299	70
October	297	63
November	321	50
December	324	39
Total	3533	

The total annual electricity consumption for this case is 3533 kWh for 2022–2023. The energy intensity for this household is 3.18 kWh/ft². The monthly electricity use and the average temperature for this case are presented graphically in Figure 20.

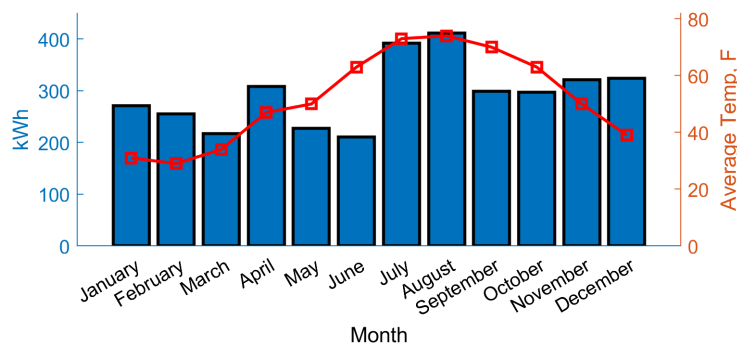


Figure 20. Monthly electricity use and average temperature for case 7. The red line with squares represents temperature in Fahrenheit, and the bars represent energy consumption in kWh.

5. Data Comparison

Energy intensity results vary due to factors such as climate conditions, building design, appliance efficiency, occupant behavior, and the use of renewable energy sources. Regions with extreme temperatures often exhibit higher energy intensity values, as more energy is required for heating or cooling. Well-insulated buildings with energy-efficient features tend to have lower energy intensity values. Additionally, the efficiency of appliances and HVAC systems, along with occupant behavior regarding energy usage, can impact energy consumption patterns. Seven sample cases of energy consumption data are represented in this article. These cases represent residential energy consumption across five different climate zones in the United States. Each case presents the annual electricity usage (in kWh), the area of the residence (in square feet), and the Energy Intensity (EI) value, which indicates the energy consumed per square foot. Case 1, situated in Texas (Climate Zone 5), shows the lowest energy usage with an EI of 2.60 kWh/ft². In contrast, Case 5 in Oregon (Climate Zone 2) exhibits significantly higher energy consumption with an EI of 14.61 kWh/ft², likely due to colder climates necessitating more heating. A summary of the collected data are presented in Table 10. Table 11 is prepared based on [38,39] to list the average energy intensity from the different states as listed in Table 10. This table

includes EI calculations considering both electricity consumption (in kWh) and energy consumption from electricity and other fuel types, e.g., oil, natural gas, and propane (in MMBtu). Interestingly, California (Climate Zone 4) demonstrates relatively lower electricity consumption and energy intensity compared to other states, potentially attributed to energy-efficient practices and regulations.

Table 10. Summary of results for case studies.

Case	State	Climate Zone	Annual kWh	Area (ft ²)	EI (kWh/ft ²)
1	TX	5	5710	2200	2.60
2	GA	4	28,226	2072	13.62
3	CA	4	4525	1400	3.23
4	MO	3	10,432	1090	9.57
5	OR	2	27,605	1890	14.61
6	MA	2	4796	1275	3.76
7	WI	1	3533	1110	3.18

Table 11. Data from the 2020 RECS survey.

State	Climate Zone	Site Electricity Consumption Per Household (kWh)	Total Site Consumption Per Household (MMBtu)	Area (ft ²) Per Housing Unit	EI (kWh/ft ²)	EI (kBtu/ft ²)
TX	5	13,440	66.2	1734	7.75	38.18
GA	4	13,270	73.9	1974	6.72	37.44
CA	4	6482	53.7	1504	4.31	35.70
MO	3	11,983	88.8	2043	5.87	43.47
OR	2	11,132	67.4	1701	6.54	39.62
MA	2	7237	87.7	1853	3.91	47.33
WI	1	8432	91.5	2067	4.08	44.27

The energy data of the 50 states were collected and analyzed to assess their carbon footprint. The CO₂ equivalent for each state was determined, and further analysis was conducted to calculate the CO₂ equivalent per capita and million GDP, providing information on the environmental impact of energy consumption. Table 12 presents a summary of this comprehensive analysis, revealing significant variations in carbon emissions between states. For instance, while Texas exhibits the highest CO₂ equivalent at 206,722,404 tons, Vermont has the lowest at 47,248 tons, indicating diverse energy consumption patterns and sources among states. Moreover, the average CO₂ equivalent per capita was found to be 7.3 tons, based on data provided by the EPA for the year 2021, compared to 5.5 tons per capita for European Union countries, highlighting potential differences in energy efficiency and environmental policies between regions. Detailed information on the energy intensity of each state is tabulated in Appendix A, for an understanding of energy consumption trends and opportunities for sustainability initiatives. A summary of CO₂ emissions is presented in Table 12.

To analyze and visualize the annual energy use distribution in different states, a spreadsheet was used to create a self-organized map (SOM) for annual energy, CO₂/capita, and CO₂ equivalent/GDP for each state. Figure 21 shows the SOM map of the annual CO₂ equivalent per capita by the state of the fifty states and Figure 22 shows annual tons of CO₂ equivalent per million dollars of GDP by state. These states cluster into different groups based on the annual CO₂ equivalent. The darker background color represents states with high annual CO₂ equivalents.

Table 12. Summary of CO₂ emissions by state.

Category	Average	Max	Min	Median
State annual CO ₂ equivalent emissions (tons)	33,952,317.0	206,722,404.5	47,248.9	28,002,997.1
Population	6,636,105.1	39,142,991.0	579,483.0	4,627,098.0
GDP (Million Dollars)	510,853.9	3,373,241.0	37,104.0	368,611.0
CO ₂ equivalent (Ton/Capita)	7.3	69.3	0.1	5.4
CO ₂ equivalent Ton/Millions of USD generated by GDP	108.6	967.1	0.4	75.7
State annual CO ₂ equivalent total output emission rate (lb./MWh)	884.4	1959.4	44.8	828.7

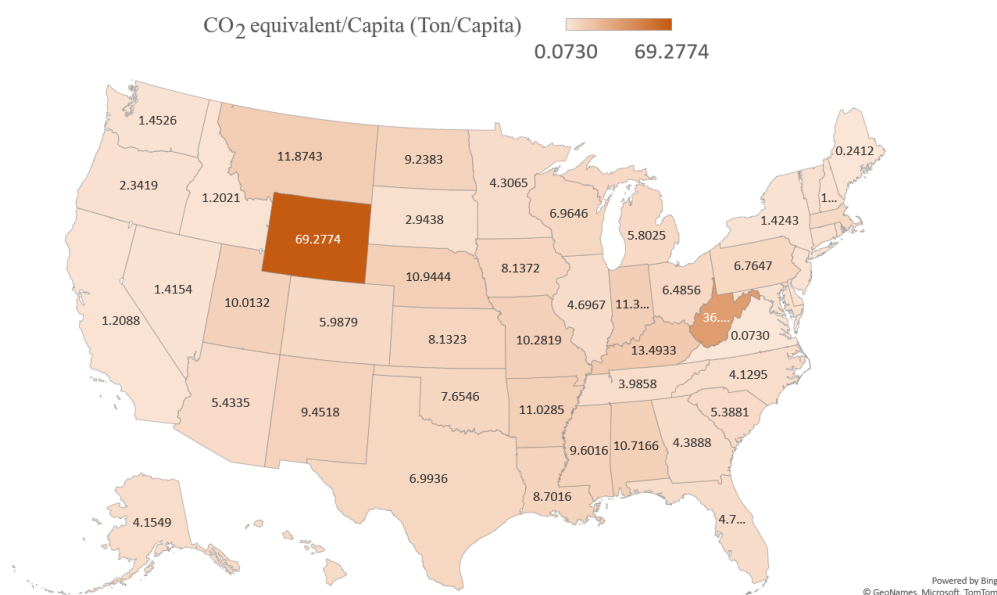


Figure 21. Annual CO₂ equivalent per capita by state.

In the United States, various energy rebate programs and policies have been implemented across different states to promote energy efficiency and support the transition to cleaner energy sources. The Biden–Harris Administration has opened applications for states and territories to implement USD 8.5 billion in home energy rebates as part of the Investing in America agenda [40]. These rebates, created by the Inflation Reduction Act, aim to lower energy costs and increase efficiency in American homes by making energy upgrades more affordable. Additionally, the Department of Energy provides a map [41] showing the progress of each state’s rebate program, indicating whether they are preparing applications, have submitted applications, or if rebates are already available. Other incentives include electric vehicle laws and incentives by state, as well as financial incentives like grants, loans, and tax credits for renewable energy development tracked by the Database of State Incentives for Renewables and Efficiency [42]. These programs collectively contribute to the nation’s goal of achieving affordable, reliable, and clean electricity for all communities.

Sustainable development in the context of US residential energy consumption necessitates a multifaceted approach to policy making. Policies must address the behavioral aspects of energy use, promoting sustainable consumption through nudges that consider economic and psychological factors [43]. This includes reducing carbon emissions by enhancing energy efficiency and encouraging the adoption of clean energy technologies [44]. Furthermore, policies should aim to bridge the gap between potential energy savings and actual outcomes, often hindered by the rebound effect where increased efficiency leads to higher energy demand. To effectively implement these policies, a behavioral economics

perspective is crucial [45], as it provides a more realistic model of consumer behavior, acknowledging limitations in rationality, willpower, and self-interest. Additionally, international cooperation and technology transfer, along with building human and institutional capacity, are key to supporting sustainable energy systems.

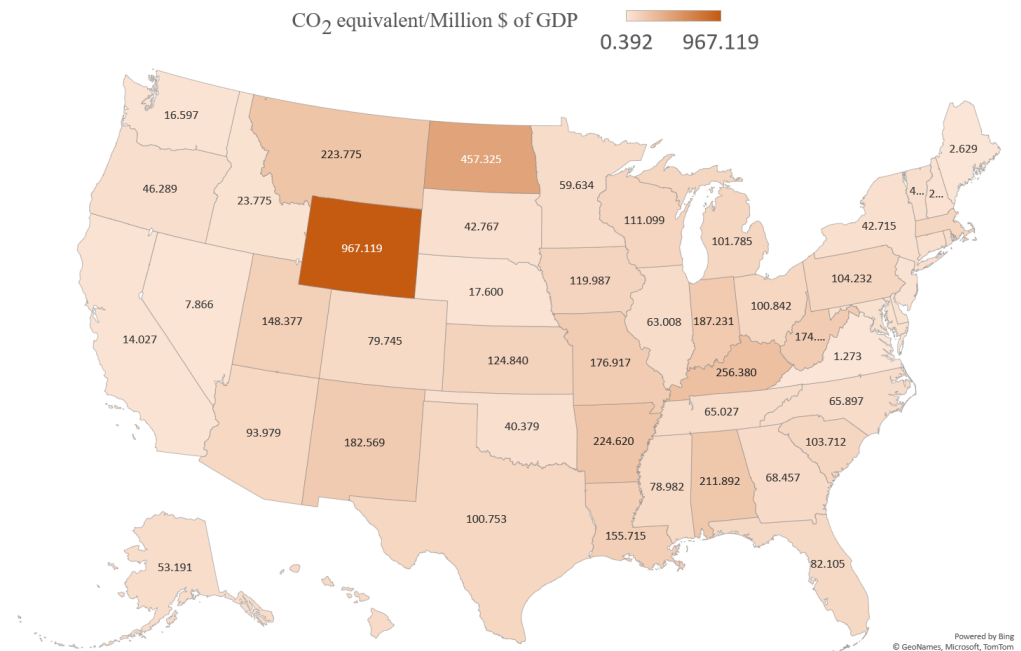


Figure 22. Annual tons of CO₂ equivalent per million USD of GDP by state.

6. Conclusions

The study of home energy consumption in the US offers an important new perspective on the patterns, trends, and environmental effects of energy use. The study shows that energy consumption has been rising steadily over time, with the residential sector using a large share of the country's total energy consumption. Energy intensity and consumption patterns are mostly determined by factors including climate zones, household size, heating fuel sources, and regional variances. Furthermore, the examination of the carbon footprint and CO₂ emissions between states shows the environmental effects of energy use, as distinct regions exhibit different levels of emission. In this study, the residential homes/apartments energy data from five different climate zones were collected, compiled, and analyzed. Energy analysis in this research includes energy intensity (kWh/ft²) and carbon footprint. The energy data for each state were collected and analyzed. The CO₂ equivalent per capita and GDP dollar for each state were estimated.

To reduce the environmental impact of residential energy use, we must adopt sustainable behaviors, promote renewable energy sources, and improve energy efficiency. Policymakers, energy experts, and homeowners can use this information in the future to make informed decisions regarding renewable energy investments, energy efficiency upgrades, and sustainable lifestyle options. By focusing on a more energy-efficient and environmentally conscious residential sector, the United States can reach its goals of sustainable development and a brighter future for future generations.

It is critical to evaluate its merits and identify areas in which further research is still possible. Secondary data sources, which are valuable but may include biases or mistakes, were used in this study. Furthermore, even though residential energy consumption patterns are closely looked at, a thorough investigation of more general socioeconomic issues that can have an impact on how families use energy is necessary. In the future, the current research can be improved by using primary data collection techniques and adopting a more comprehensive strategy that takes the socioeconomic environment surrounding energy usage into account. Another area for investigation would be to explore the impact

of emerging technologies like smart home systems and Internet of Things devices on how households consume energy. Additionally, studies of the effectiveness of various interventions, like behavior change programs and incentives, in encouraging energy-saving habits among different types of households need to be conducted. In addition, exploring energy consumption patterns in different countries or regions could offer valuable insight into the global landscape of sustainability initiatives.

From a policy perspective, the findings of this study emphasize the need for targeted policies that promote energy efficiency and sustainability in the residential sector. Policymakers should consider implementing and enhancing energy efficiency standards for appliances and building codes to ensure new and existing homes are more energy-efficient. Incentive programs, such as tax credits or rebates for energy-efficient upgrades and renewable energy installations, can encourage homeowners to adopt sustainable practices. Moreover, policies aimed at increasing the accessibility and affordability of renewable energy sources, such as solar and wind power, can further reduce the carbon footprint of residential energy consumption.

Educational campaigns and community-based programs can also play a significant role in promoting sustainable energy behaviors. By raising awareness of the environmental and economic benefits of energy conservation and providing practical tips to reduce energy use, these initiatives can help foster a culture of sustainability among residents. Additionally, support for research and development in innovative energy technologies can drive further advancements in the field, ultimately contributing to a more sustainable future.

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Abbreviations

The following abbreviations are used in this manuscript:

BTU	British thermal unit
RECS	Residential Energy Consumption Survey
HDD	Heating Degree Days
CDD	Cooling Degree Days
kWh	Kilowatt hour
MWh	Megawatt Hour
MMBtu	Million British Thermal Unit
EIA	Energy Information Administration
DOE	Department of Energy
HVAC	Heating Ventilation Air Conditioning
EI	Energy Intensity
EPA	Environmental Protection Agency
CLCPA	Climate Leadership and Community Protection Act
SOM	Self-organized Map
GDP	Gross Domestic Product
ITC	Investment Tax Credit
ACEEE	American Council for an Energy-Efficient Economy

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