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Built Environment

Residential Buildings

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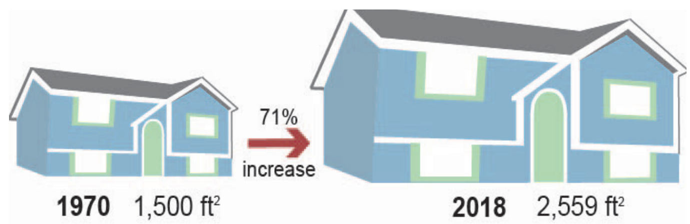
Patterns of Use

Although climate-specific, resource-efficient house design strategies exist, per capita material use and energy consumption in the residential sector continue to increase. From 2000 to 2018, the U.S. population increased by 16.3%, while the number of housing units increased by 19.5%.[1,2,3] Between 2000 and 2010, urban land area increased by 15%.[1] The following trends demonstrate usage patterns in the residential building sector.

Size and Occupancy

Average Size of a New U.S. Single-Family House, 1970 and 2018[5,6]



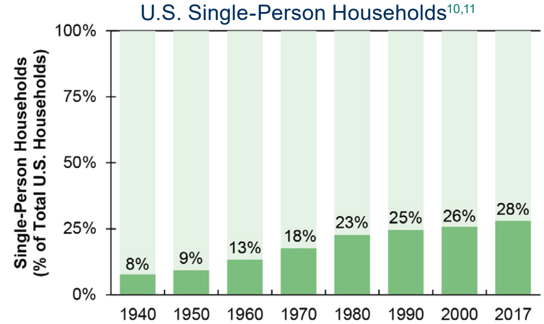
- Increased average area of U.S. homes:[4,5]
  1970s **1,767 ft^2**; 1990s **2,185 ft^2**; 2018 **2,559 ft^2**
  45% increase from 1970s
- Decreased average number of occupants in U.S. households:[7,8]
  1970s **2.96**; 1990s **2.64;** 2018 **2.53**
  15% decrease from the 1970s

Increased average area per person in U.S. homes:
  1970s **597 ft^2**; 1990s **828 ft^2**; 2018 **1011 ft^2**
  69% increase from the 1970s

- A majority of Americans live in single-family houses. In 2017, 69% of the 122 million U.S. households were single family.[9]
- In 1950, 9% of housing units were occupied by only one person.[10] By 2017, this value had increased to 28%.[11]

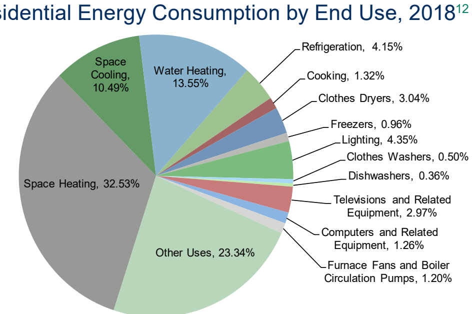
Energy Use

U.S. Single-Person Households[10,11]



- A 1998 study by the Center for Sustainable Systems of a single-family house in Michigan showed an annual energy consumption of 1.3 GJ/m^2.[13]
- A study of 3 houses in Sweden built in the 1990s estimated annual energy consumption from 0.49–0.56 GJ/m^2, less than half the energy consumed by the Michigan house.[14]
- Electricity consumption increased 16-fold from 1950 to 2018. In 2017, the residential sector used 1.46 trillion kWh of electricity, 38.5% of U.S. total electricity sales.[15]
- In 2018, the U.S. residential sector consumed 21.6 quadrillion Btu of primary energy, 21% of U.S. primary energy consumption.[16]
- Miscellaneous loads per household doubled from 1976 to 2006.[17] These are appliances and devices outside of a buildings core functions (HVAC, lighting, etc.) such as computers, fire detectors, fitness equipment, computers, TVs, and security systems.[18] In 2018, miscellaneous loads consumed more electricity than any other residential end use (lighting, HVAC, water heating, and refrigeration), accounting for 43% of primary energy and 51.3% of a household's electricity consumption.[12,15]
- Wasteful energy uses include heating and cooling of unoccupied homes and rooms, inefficient appliances, thermostat oversetting, and standby power loss.[19] Together, these uses account for at least 43% of the total energy use in the residential sector.[12]
- Home energy management systems display energy use via in-home monitor or mobile application and enable remote control of devices. Home energy management systems can reduce a house's energy use by an estimated 4-7%.[20]

U.S. Residential Energy Consumption by End Use, 2018[12]



Material Use

- The average U.S. single-family house built in 2000 required 19 tons of concrete, 13,837 board-feet of lumber, and 3,061 ft^2 of insulation.[21]
- From 1975 to 2000, the consumption of clay for housing and construction more than quadrupled, due to use in tiles and bathroom fixtures.[22]
- In 2012, around 24% of all wood products consumed in the U.S. were used for residential construction.[23]
- Approximately 10 million tons of waste was generated in the construction of new residential buildings in 2003—4.4 lbs per ft^2.[24]
- U.S. average recycling rate of waste from construction and demolition (C&D) is 20-30%.[25] Seattle recycled 57% of its C&D waste in 2017.[26]

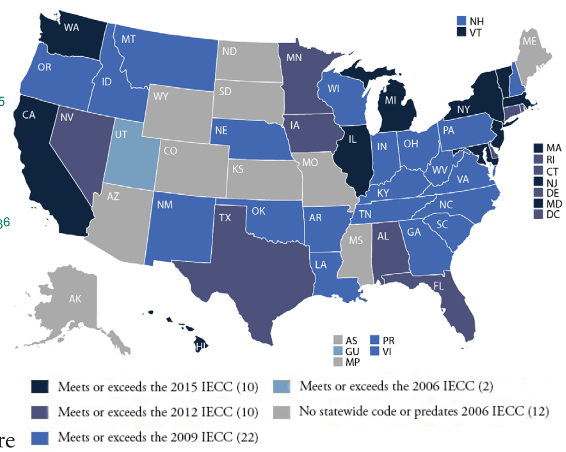
Codes and Standards

- DOE Pacific Northwest National Laboratory estimated cumulative savings from the International Energy Conservation Code (IECC) for 42 states. From 2010-2016, the IECC saved 0.27 quadrillion Btu of primary energy, 1.25% of residential primary energy consumption in 2018.[16,27] Cumulative energy savings generated $3.2 billion (2016 dollars) in cost savings and avoided 17.6 million metric tons of CO_2.[27]
- For most building types, conventional energy efficiency technologies can achieve a 20% reduction in energy use relative to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 90.1-2004 standard.[28]
- Florida's 2007 energy code saved 13% relative to pre-2007 energy consumption through the reduction in heating, cooling and hot water demand. Efficiency gains were offset by increasing house sizes and plug loads.[29]
- The U.S. Green Buildings Council provides Leadership in Energy and Environmental Design (LEED) home rating system and certification.[32]
- Houses built to Energy Star program requirements are 15% more energy efficient than houses built to 2009 IECC or better.[33]

Life Cycle Impacts

- Between 1990 and 2005, total residential GHG emissions increased by 30%. In 2017, GHG emissions were reduced to 964.5 million metric tons, 1% down from 1990 level.[34]
- In 1998, the Center for Sustainable Systems conducted an inventory of the life cycle energy consumption of a 2,450 square foot, single-family house built in Ann Arbor, Michigan.[13]
- Only 10% of the house's life cycle energy consumption was attributed to construction and maintenance; 90% occurred during operation.[13]
- Energy efficiency measures reduced life-cycle energy consumption by 63%. Careful selection of materials reduced embodied energy by 4%.[13]
- Life cycle greenhouse gas emissions were reduced from 1,013 to 374 metric tons CO_2-equivalent over the 50-year life of the house.[13]
- Top contributors to primary energy consumption were polyamide for carpet, concrete in foundation, asphalt roofing shingles, and PVC for siding, window frames, and pipes.[13] Improved HVAC system and cellulose insulation were the most effective strategies to reduce energy costs.[13]
- Substituting recycled plastic/wood fiber shingles for asphalt shingle roofing reduced embodied energy by 98% over 50 years.[13]
- A 900-ft^2 house in Davis, CA, modeled innovative design and technologies to reduce energy consumption. Measures such as LED lighting, efficient appliances, graywater heat recovery and a radiant heating and cooling system brought annual energy consumption to 5,854 kWh, 44% less than a standard house of the same size and location. Electricity generation from rooftop PV made the house energy net-positive.[35]
- Operating energy accounts for 80-90% of a building's life cycle energy consumption and embodied energy accounts for 10-20%. As houses improve energy efficiency and reduce operating phase energy, embodied energy accounts for a larger fraction of life cycle energy. Design and materials selection are key ways to reduce embodied energy.[36]

Residential Building Energy Code Status by State[30,31]



Solutions and Sustainable Alternatives

Reduce Operational Demand

Energy and water consumption during the life of a building contribute more to its environmental impact than do building materials. The following suggestions can significantly reduce operational energy demand:

- Downsizing: build smaller to reduce embodied and operating energy.[37] Tiny houses are designed for the efficient use of space.[38]
- Space heating and cooling made up 43% of residential energy consumption in 2018.[12] Passive heating and cooling can reduce operating energy.[13]
- By adding ceiling fans, air conditioning can be comfortably set about 4ºF higher.[39]
- Adequate insulation can reduce heating and cooling costs. R-value needs differ based on location, building design, and heating methods.[40]
- Water heating accounts for 14% of residential energy consumption.[12] Save energy with a graywater heat recovery system.[41]
- Install low-flow water fixtures (less than 2.5 gallons-per-minute of flow) to save both water and energy.[42]
- Maximize natural lighting with south-facing windows. Properly shade windows to minimize summer heat gain.[43]
- Purchase energy efficient appliances and lighting. Appliances and lighting typically account for 25% of household energy costs.[44]
- Replace incandescent lamps and halogen lamps with compact fluorescent lamps or LEDs to reduce energy costs and GHG emissions.[45]

Select Durable and Renewable Materials

Durable building materials last longer and require fewer replacements than flimsier alternatives. Depending on the materials, building with more durables could lower longterm replacement costs and associated environmental burdens.

- Durables: cork or hardwood floors, standing-seam roofing.
- Renewables: cork, linoleum, wool carpet, certified wood and plywood, strawboard, cellulose insulation, straw-bale.

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