Estimating heating and other end uses in the 2020 *Residential Energy Consumption Survey* (RECS)

Webinar

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U.S. Energy Information Administration | *Independent Statistics and Analysis* | www.eia.gov

Agenda

- Introduction

- Consumption, expenditures, and end-use data highlights

- New ArcGIS dashboard

- Overview of methodology and end-use estimation process
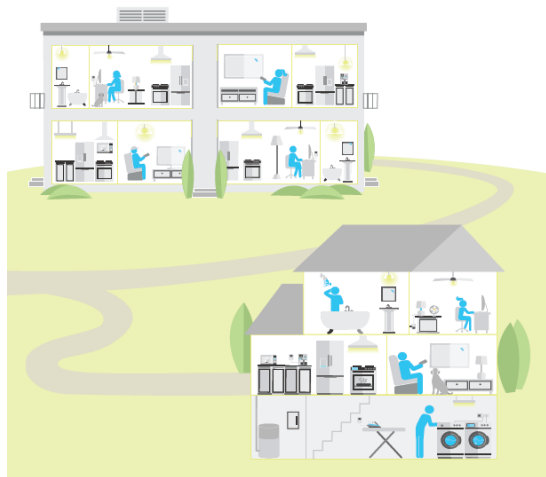
- What's next for RECS?

- Q&A

Introduction

RECS has three phases: the Household Survey, the Energy Supplier Survey, and the end-use estimation process

- RECS Household Survey

  - Measures the characteristics that contribute to energy consumption in primary, occupied housing units

  - Fielded September 2020 through April 2021

  - Used self-administered web and paper modes

  - 18,496 completed surveys

  - Completed in collaboration with IMG-Crown and RTI International

RECS has three phases: the Household Survey, the Energy Supplier Survey, and the end-use estimation process

- RECS Energy Supplier Survey (ESS)

  - Collects household energy billing information directly from energy suppliers for responding households

  - Fielded July 2021 through March 2022

  - Billing records collected for almost 30,000 energy accounts from electricity, natural gas, propane, and fuel oil suppliers

  - Completed in collaboration with Leidos and Westat

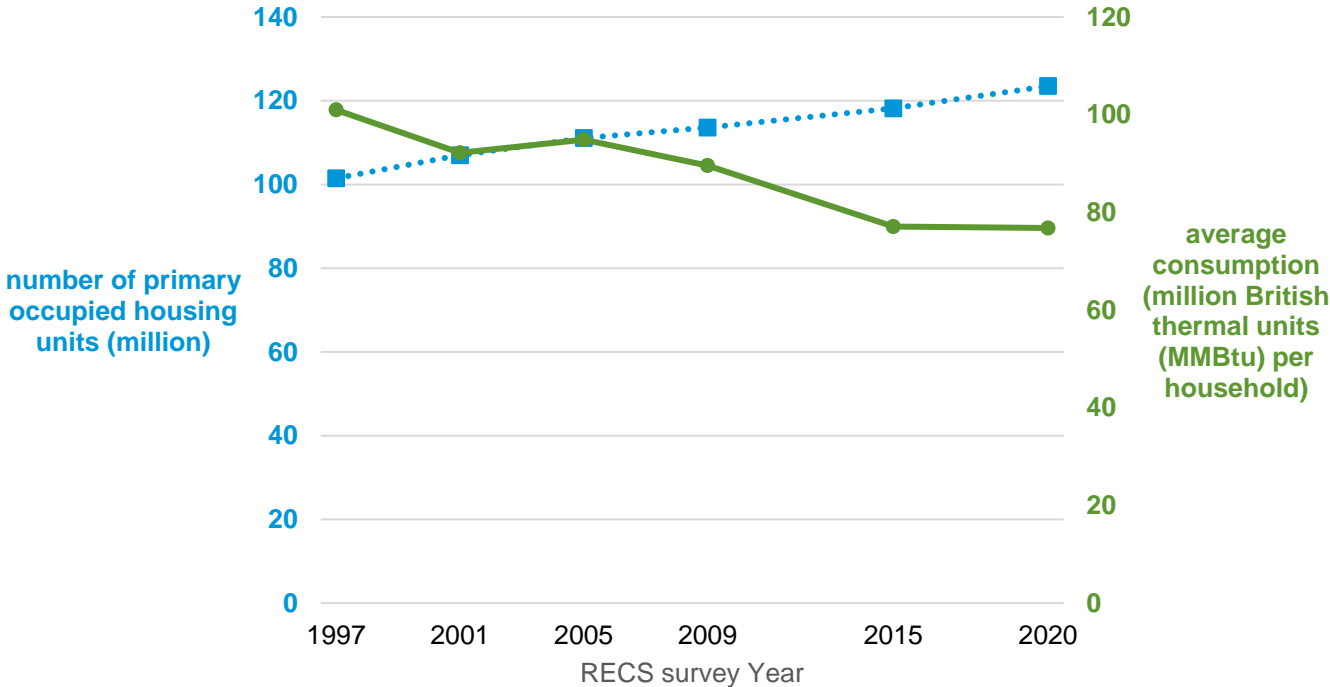# RECS has three phases: the Household Survey, the Energy Supplier Survey, and the end-use estimation process

- End-use estimation process

  – Took the characteristics from the RECS household survey and the energy bills from the ESS and calculated estimates for end uses.

  – Created over 100 fuel end-use combinations (for example, electric space heating).

  – We published a subset of these of end uses, including space heating, air conditioning, water heating, and 23 other end uses.

Consumption, Expenditure, and End-Use Highlights

In 2020, the nation's 123.53 million households consumed 76.8 million Btu of energy on average
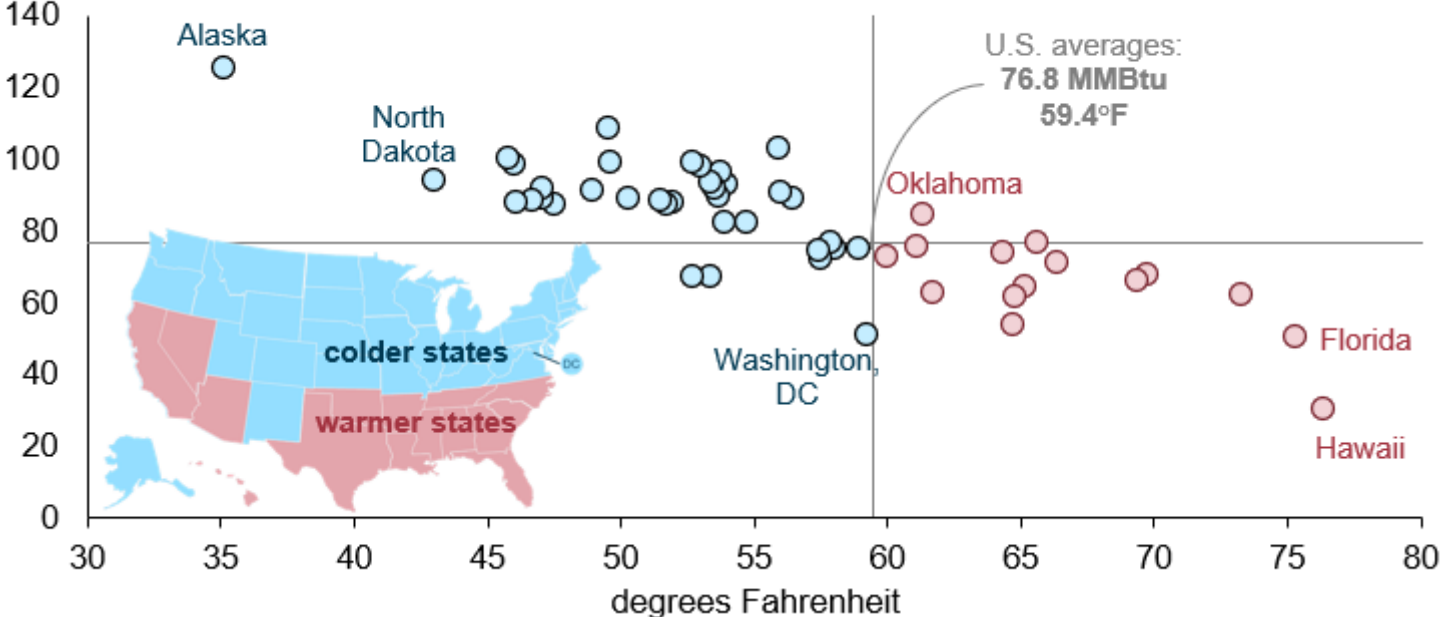

number of primary occupied housing units (million)

average consumption (million British thermal units (MMBtu) per household)

RECS survey Year

Households in colder states consume more energy on average than those in warmer states

Average U.S. household energy consumption versus average state temperature (2020)
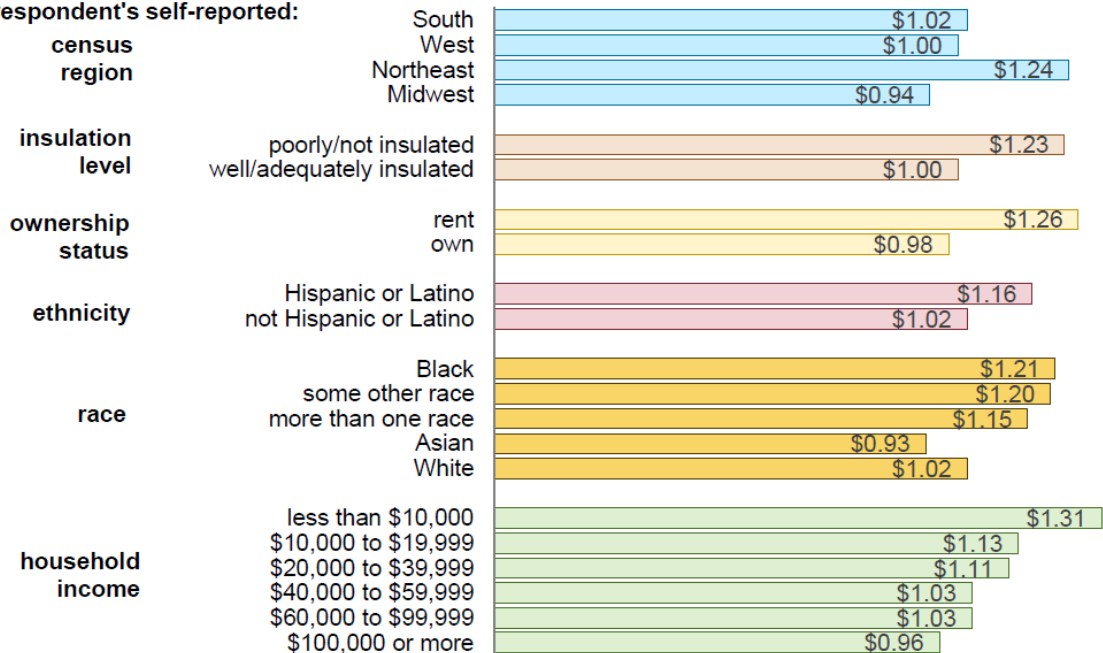million British thermal units (MMBtu) per home

Data source: U.S. Energy Information Administration, 2020 *Residential Energy Consumption Survey* (RECS)

Average household energy expenditures per square foot were $1.04 - but varied by household characteristics

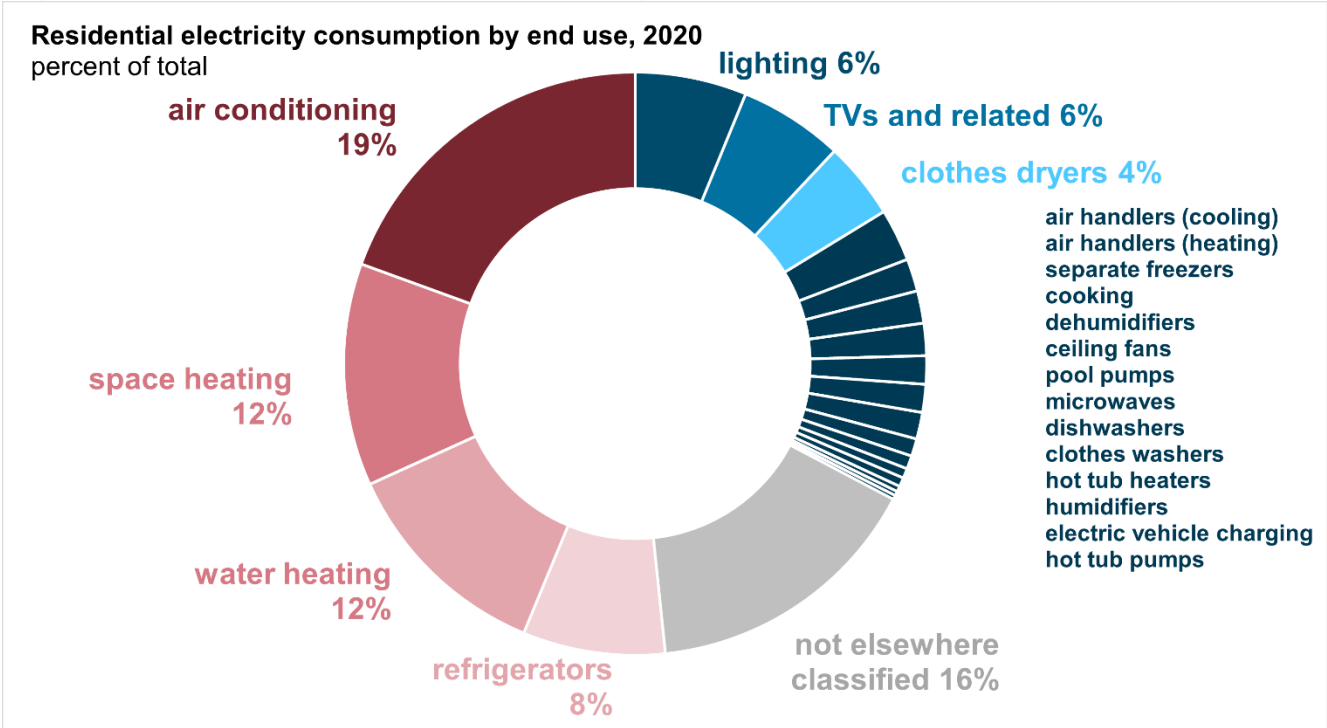**Average U.S. household energy expenditures per square foot by select attributes (2020)**
U.S. dollars per square foot
respondent's self-reported:

Attribute	Category	Value
census region	South	$1.02
	West	$1.00
	Northeast	$1.24
	Midwest	$0.94
insulation level	poorly/not insulated	$1.23
	well/adequately insulated	$1.00
ownership status	rent	$1.26
	own	$0.98
ethnicity	Hispanic or Latino	$1.16
	not Hispanic or Latino	$1.02
race	Black	$1.21
	some other race	$1.20
	more than one race	$1.15
	Asian	$0.93
	White	$1.02
household income	less than $10,000	$1.31
	$10,000 to $19,999	$1.13
	$20,000 to $39,999	$1.11
	$40,000 to $59,999	$1.03
	$60,000 to $99,999	$1.03
	$100,000 or more	$0.96

eia Data source: U.S. Energy Information Administration, 2020 *Residential Energy Consumption Survey* (RECS)

Air conditioning, space heating, and water heating were the primary residential electricity end uses

Residential electricity consumption by end use, 2020
percent of total

- air conditioning 19%
- space heating 12%
- water heating 12%
- refrigerators 8%
- not elsewhere classified 16%
- lighting 6%
- TVs and related 6%
- clothes dryers 4%
- air handlers (cooling)
- air handlers (heating)
- separate freezers
- cooking
- dehumidifiers
- ceiling fans
- pool pumps
- microwaves
- dishwashers
- clothes washers
- hot tub heaters
- humidifiers
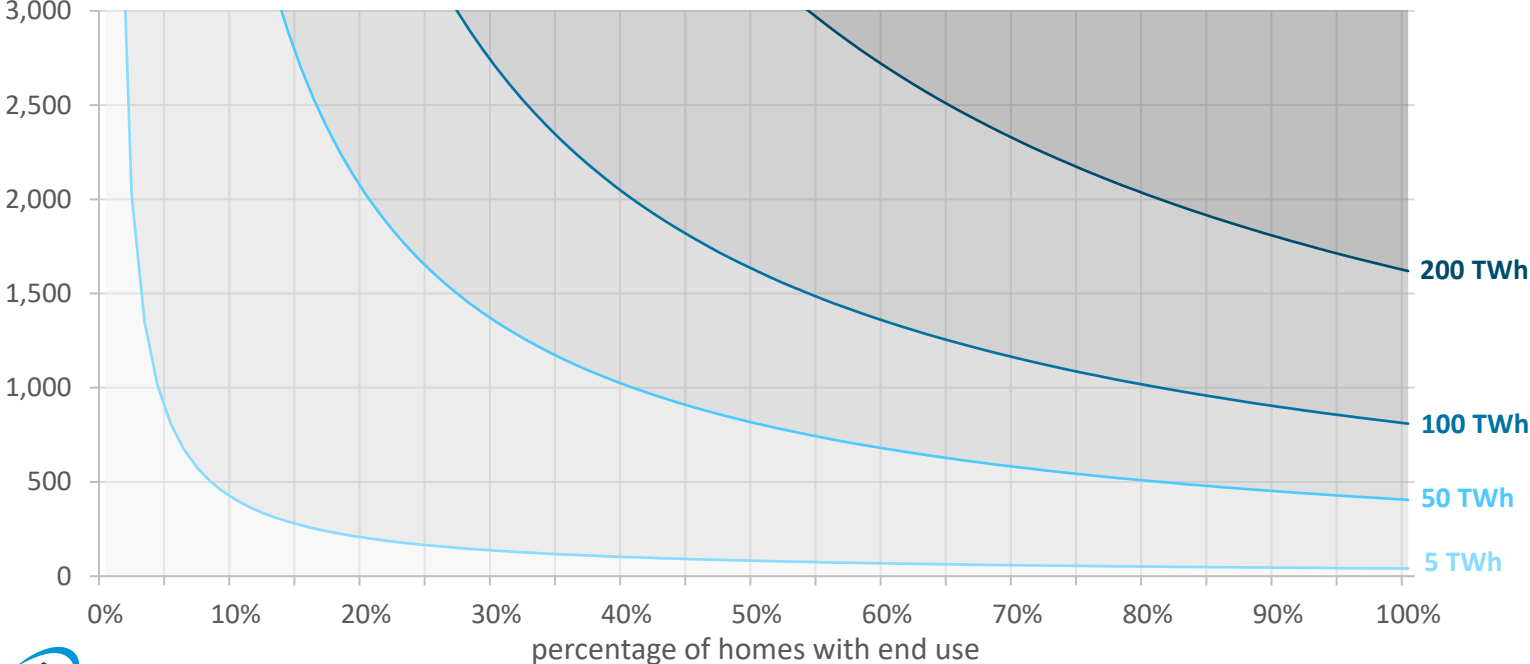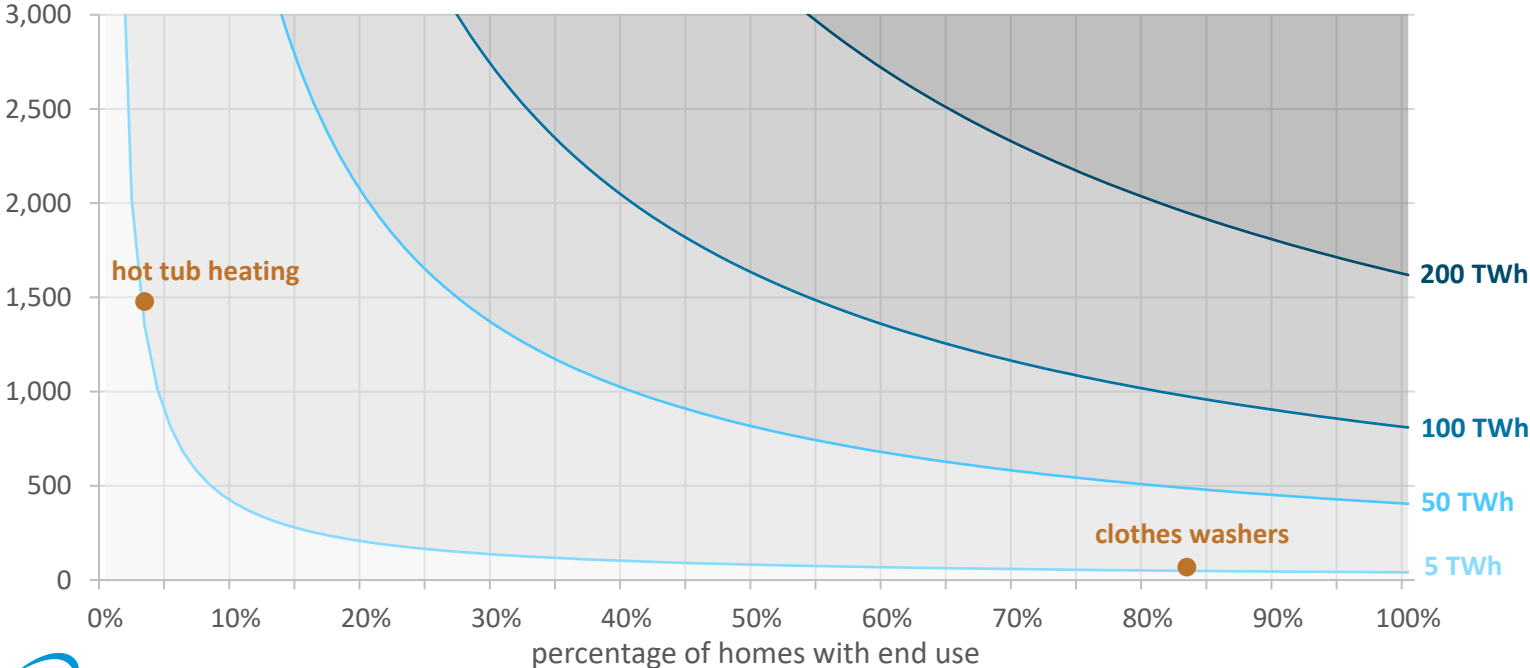- electric vehicle charging
- hot tub pumps

Data source: U.S. Energy Information Administration, 2020 *Residential Energy Consumption Survey* (RECS)

Total household site consumption for an end use is determined by share of households using it and its intensity

Average U.S. residential end-use consumption of electricity, 2020
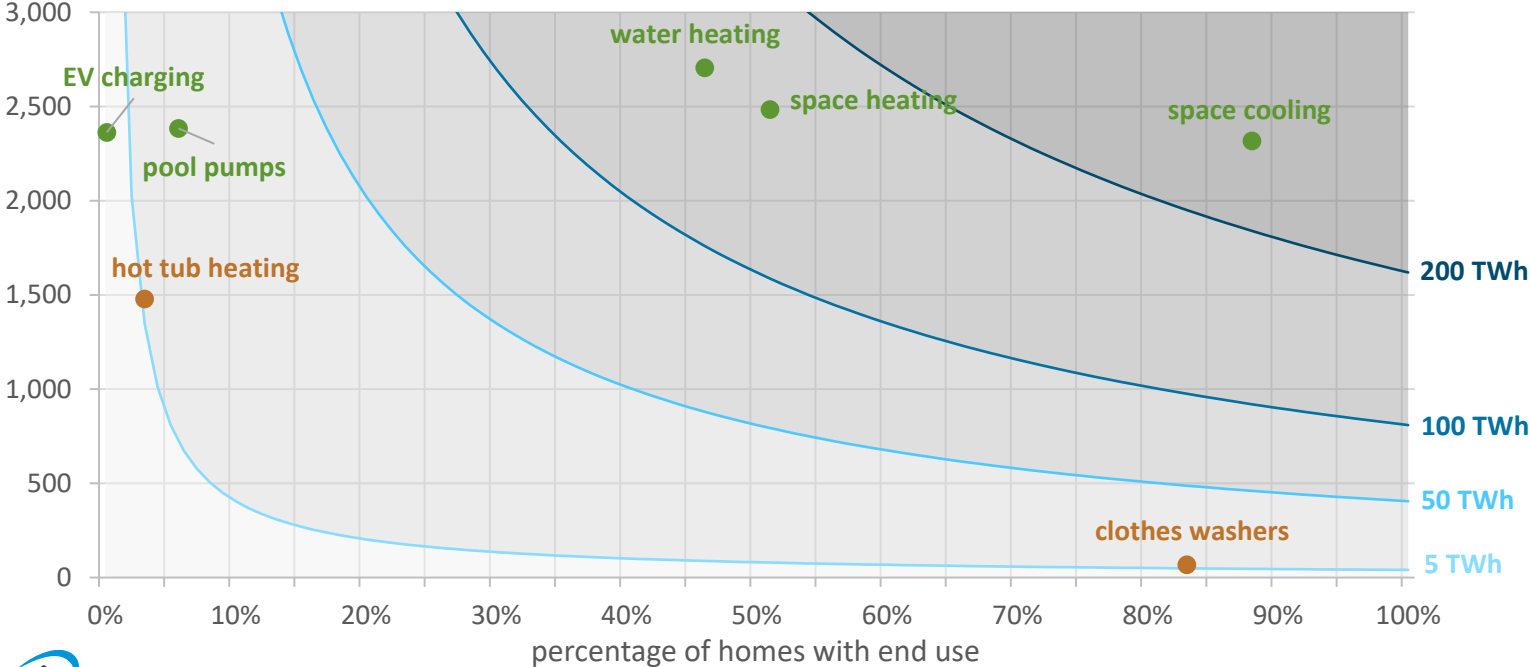kilowatthours

Data source: U.S. Energy Information Administration, 2020 *Residential Energy Consumption Survey* (RECS)

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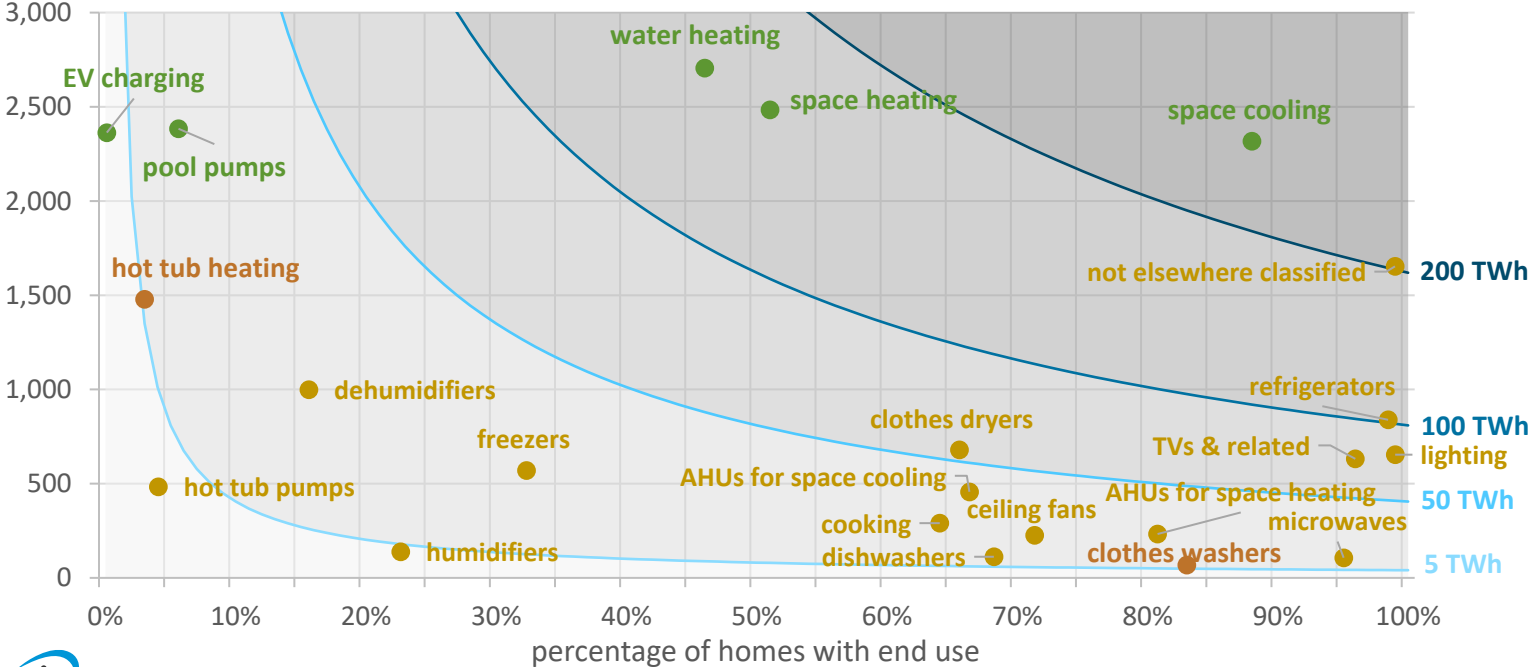kilowatthours

Data source: U.S. Energy Information Administration, 2020 *Residential Energy Consumption Survey* (RECS)

Total household site consumption for an end use is determined by share of households using it and its intensity

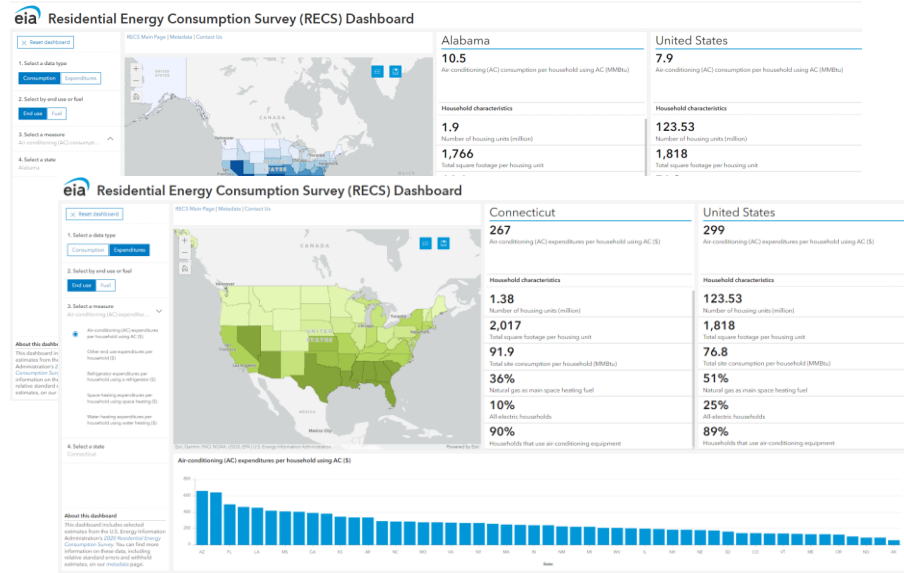**Average U.S. residential end-use consumption of electricity, 2020**
kilowatthours

Data source: U.S. Energy Information Administration, 2020 *Residential Energy Consumption Survey* (RECS)

New Dashboard

- Maps for 20 Consumption and Expenditure estimates, by
  - Fuel
  - End use
- Selected household characteristics
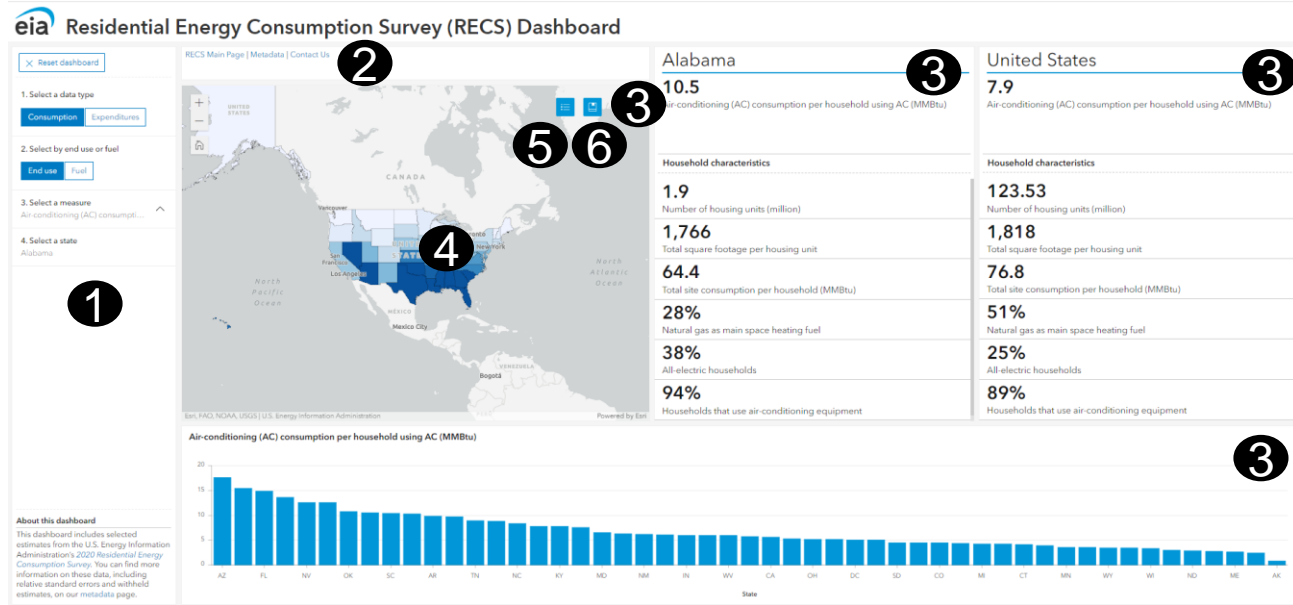
Access the dashboard from the RECS website (right sidebar) or go directly to the 2020 RECS Dashboard.

Please send us your feedback.

Dashboard Overview

1. Navigation
2. Contact us
3. Expand panels
4. Individual state selection
5. Legend
6. Bookmark/Zoom

May need to adjust zoom settings for optimal viewing

End-use Estimation Methodology
from the 2020 RECS

# Because we cannot *measure* end-use consumption in a nationally representative way, we must *estimate* it

Use **Calibration** to synthesize available information:

- **Expectations**, quantified by *Models*

  – Housing characteristics data

  – Weather data

  – Wider community knowledge

- **Measurements**

  – Billing data from energy suppliers

- Work at the individual housing-unit level

MD pop-wgt daily average temperature for 2020
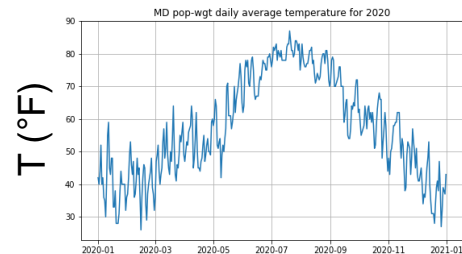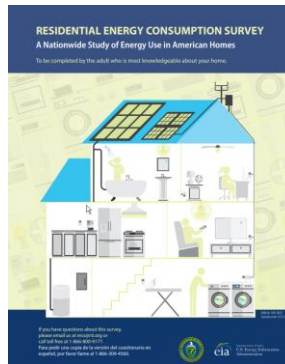
Billing Date	kWh	Cost
1/7/2020	813	$194.44
2/5/2020	627	$133.11
3/9/2020	615	$122.90
4/7/2020	758	$143.89
5/7/2020	689	$149.44
6/8/2020	703	$148.03
7/8/2020	965	$228.99
8/6/2020	1302	$335.73
9/4/2020	1467	$386.86
10/6/2020	1584	$387.18
11/5/2020	1191	$300.21
12/8/2020	963	$223.40
Total	**11,677 kWh**	**$2,754**
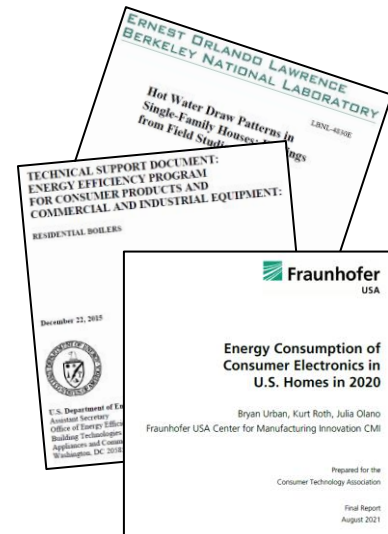
Most billing data require simple proration at the beginning and end of 2020

Billing data				Annualization			
end date	Amount	Cost		duration	factor 2020	Amt 2020	Cost 2020
12/11/2019	103	$119.15					
1/8/2020	134	$150.19		28	8/28	38.29	$42.91
2/12/2020	222	$238.29		35	1	222	$238.29
3/11/2020	152	$168.21		28	1	152	$168.21
4/8/2020	99	$115.14		28	1	99	$115.14
5/13/2020	81	$97.11		35	1	81	$97.11
6/10/2020	25	$41.05		28	1	25	$41.05
7/8/2020	12	$27.80		28	1	12	$27.80
8/12/2020	1	$17.00		35	1	1	$17.00
9/9/2020	6	$21.91		28	1	6	$21.91
10/14/2020	45	$60.18		35	1	45	$60.18
11/11/2020	102	$116.11		28	1	102	$116.11
12/9/2020	136	$149.47		28	1	136	$149.47
1/11/2021	141	$154.38		33	22/33	94.00	$102.92
					Totals	1,013.29	$1,198.10

Simple addition accounts for:

- 83% of electricity totals
- 76% of natural gas totals

→ both about 95% of cases with bills

(other cases were imputed)

End-use expectations for a particular home depend on the information we can collect for that home

- For something small such as, a toaster, our survey asks a single question:

73. **Are any of the following small kitchen appliances <u>used at least once a week</u> in your home?**

		Yes	No
a.	Toaster	○	○
b.	Toaster oven	○	○
c.	Crock Pot or slow cooker	○	○

- Which leads to a very simple model based on an end-use's presence:

```
if TOASTER = 1
    Toaster_Consumption = UEC_toaster
else
    Toaster_Consumption = 0
```

For something larger such as a refrigerator, we ask more questions:

40. How many refrigerators are plugged-in and turned on in your home? Include compact refrigerators and refrigerators in basements or garages, even if they are only used occasionally. *If none, please enter "0."*

[ ] refrigerators → *If you answered "0": Go to #50*

RFG1 size

41. What is the size of your most used refrigerator?
- ○ Half-size or compact → *Go to #43*
- ○ Small (17.5 cubic feet or less)
- ○ Medium (17.6 to 22.5 cubic feet)
- ○ Large (22.6 to 29.5 cubic feet)
- ○ Very large (bigger than 29.5 cubic feet)

RFG1 configuration

42. Which of the following best describes your most used refrigerator?
- ○ One door
- ○ Two doors, freezer next to the refrigerator
- ○ Two doors, freezer above the refrigerator
- ○ Two doors, freezer below the refrigerator
- ○ Three or more doors

RFG1 age

43. About how old is your most used refrigerator? Your best estimate is fine.
- ○ Less than 2 years old
- ○ 2 to 4 years old
- ○ 5 to 9 years old
- ○ 10 to 14 years old
- ○ 15 to 19 years old
- ○ 20 or more years old
- ○ Don't know

RFG1 ice service

44. Does your most used refrigerator have through-the-door ice service?
- ○ Yes
- ○ No

# Most end-use models are now based on efficiency standards

- For example, for a refrigerator with a top-mounted freezer, automatic defrost, and no ice service:

  - **Test procedure** specifies ambient room temperature of 72°F and "normal" door openings.

  - *Adjusted volume* is **AV = Fresh Volume + 1.63 × Freezer Volume** (in cubic feet).

  - Efficiency standards specify these equations for **maximum annual energy use** at test conditions, based on adjusted volume:

    - Sep 2014 :: max energy use = **233.7 + 8.07 × AV** kWh

    - July 2001 :: max energy use = **276.0 + 9.80 × AV** kWh

    - Jan 1993 :: max energy use = **355 + 16.0 × AV** kWh

  - End-use model also accounts for:

    - Aging effects from insulation degradation

    - ENERGY STAR sales data and relative performance values

    - Varying ambient room temperatures

Space conditioning end uses are the largest and most complicated to model

- Energy consumption depends on many aspects:

  – Building size and materials

  – Building location and weather

  – Occupant behavior

  – Space conditioning equipment type and fuel

- We model the **heating or cooling load** of a home based on estimated heat losses or gains through a season.

- We model the energy used by **particular equipment** to meet that load based on the equipment's efficiency, which we also get from efficiency standards.
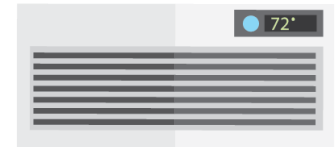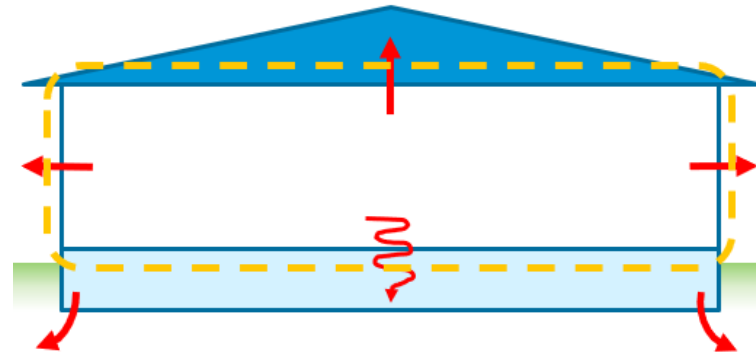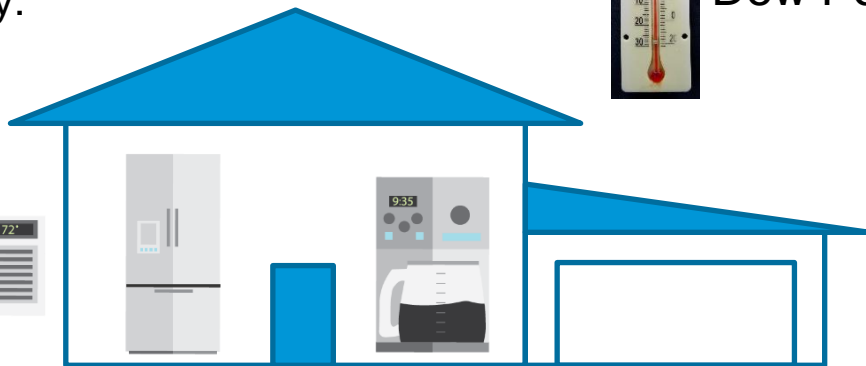
A simple home: calibration

- Consider a hypothetical RECS housing unit

  - **Household Survey**
    Only **three** end uses for electricity:
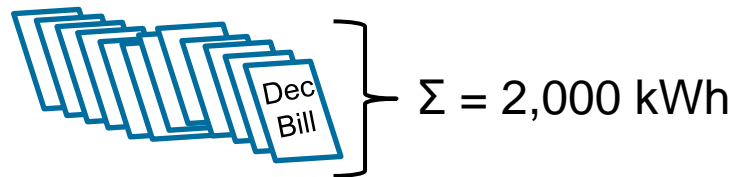
    - AC

    - Refrigerator

    - Coffee maker

  - **Administrative data**
    Weather data, etc.

  - **Energy Supplier Survey**
    Annualized billing total of **2,000 kWh**

Temperature, Dew Point

$\Sigma = 2{,}000$ kWh

Dec Bill

A simple home: possible disaggregations

- What are the end-use estimates of consumption?

$$1{,}900 + 50 + 50 = 2{,}000$$

$$667 + 667 + 666 = 2{,}000$$

$$\ldots$$

$$1{,}300 + 600 + 100 = 2{,}000 \quad ???$$
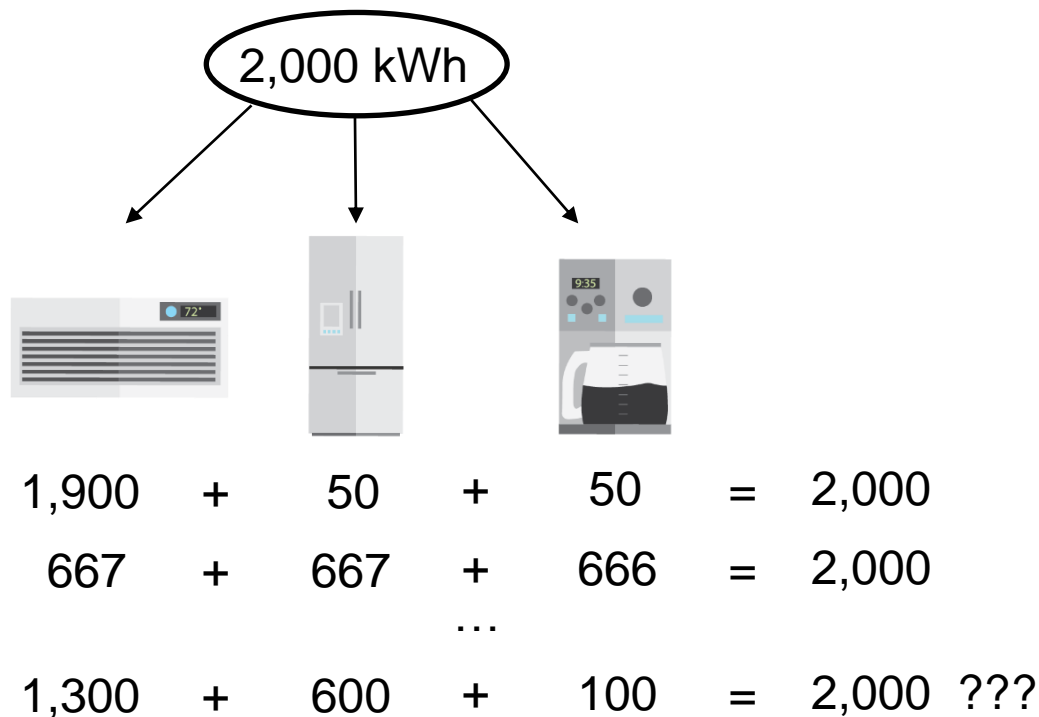
A simple home: end-use energy expectations

- Plausible, hypothetical model estimates for the end uses:

    – AC = **1,000 kWh**

    – Refrig = **500 kWh**

    – Coffee = **60 kWh**

- Sum of model estimates is **1,560 kWh.**

This total is **440 kWh** less than the annualized billing total of **2,000 kWh**

- How to correct the model estimates so they add to 2,000 kWh?

A simple home: calibration prior to the 2015 RECS

- Previous calibration: Simple normalization (proration)

  - AC_norm = 1,000 kWh · (2,000 / 1,560) = **1,282 kWh**

  - Refrig_norm = 500 kWh · (2,000 / 1,560) = **641 kWh** Σ = 2,000 kWh

  - Coffee_norm = 60 kWh · (2,000 / 1,560) = **77 kWh**

- These calculations add to 2,000 kWh, but does it make sense to treat all estimates as if they are all equally valid? No!

  - Refrigerators are relatively easy to model.

  - AC is difficult to model.

  - Coffee makers cannot be modeled beyond presence in housing unit.

A simple home: specify uncertainties and correlations

- Beginning in 2015 RECS, we included uncertainties and correlations in calibration

- Plausible, hypothetical estimates for the uncertainties and correlations:

    - AC has 50% relative uncertainty ::   **1,000 ± 500 kWh**

    - Refrig has 20% relative uncertainty ::   **500 ± 100 kWh**

    - Coffee has 100% relative uncertainty ::   **60 ± 60 kWh**

    - All three are uncorrelated ::

        Corr(AC, Refrig) = Corr(AC, Coffee) = Corr(Refrig, Coffee) = 0

    - Uncertainty Propagation :: Sum = AC + Refrig + Coffee = **1,560 ± 513 kWh**

# A simple home: improved calibration in the 2015 RECS

- Uncertainties and correlations lead naturally to *Minimum variance estimation.*

  - Weight model estimates by inverse variance-covariance matrix

  - Optimization problem

  - Assume the billing total has no uncertainty

  - Apply constraints to ensure no negative consumption

- Final estimates in this hypothetical problem:

  - AC_cal = 1,000 kWh + (250,000 / 263,600) · 440 kWh = **1,417 kWh**
  - Refrig_cal = 500 kWh + (10,000 / 263,600) · 440 kWh = **517 kWh**   Σ = 2,000 kWh
  - Coffee_cal = 60 kWh +   (3,600 / 263,600) · 440 kWh = **66 kWh**

A simple home: two calibration solutions

- The Minimum variance estimation and Simple normalization solutions:
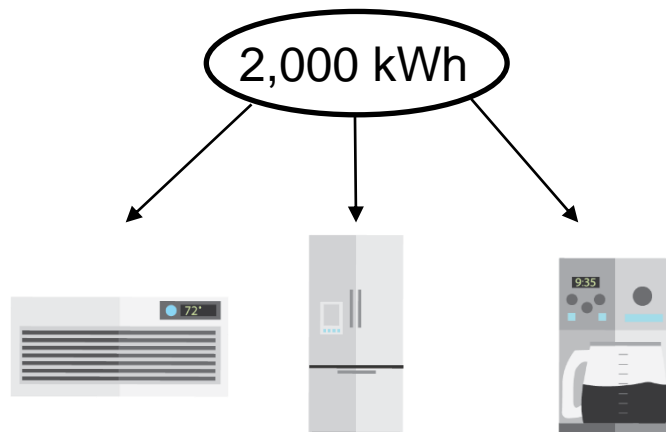
| Minimum variance: | 1,417 | + | 517 | + | 66 | = | 2,000 |
| Simple normalization: | 1,282 | + | 641 | + | 77 | = | 2,000 |

A simple home: comparing results

- Bringing the estimates together

	Modeled	Previous Calibration	Relative Uncertainty	Absolute Uncertainty	Minimum Variance Estimate
AC	1,000	1,282	±50%	±500	1,417
Refrig	500	641	±20%	±100	517
Coffee	60	77	±100%	±60	66
Total	1,560	2,000			2,000

Most of the +440 kWh correction has been given to AC, the end use with the largest absolute uncertainty.

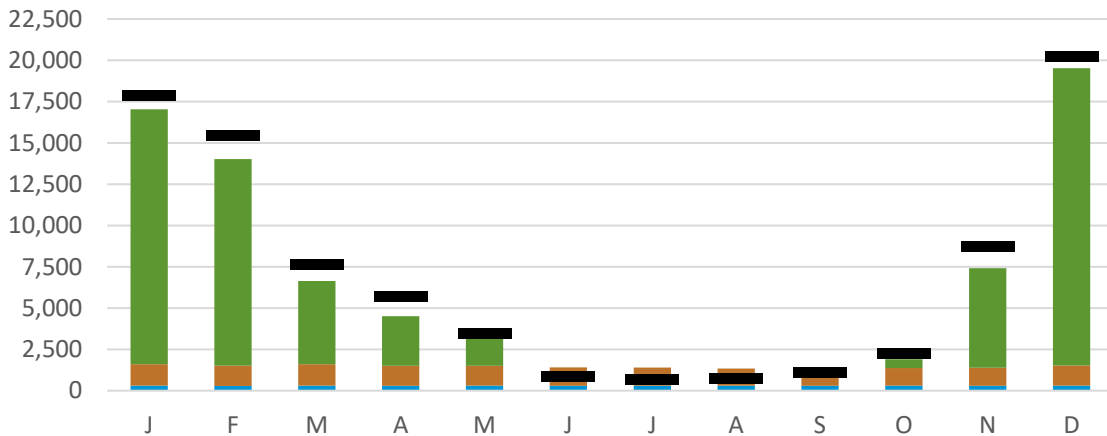# Billing-level calibration for a case with natural gas bills

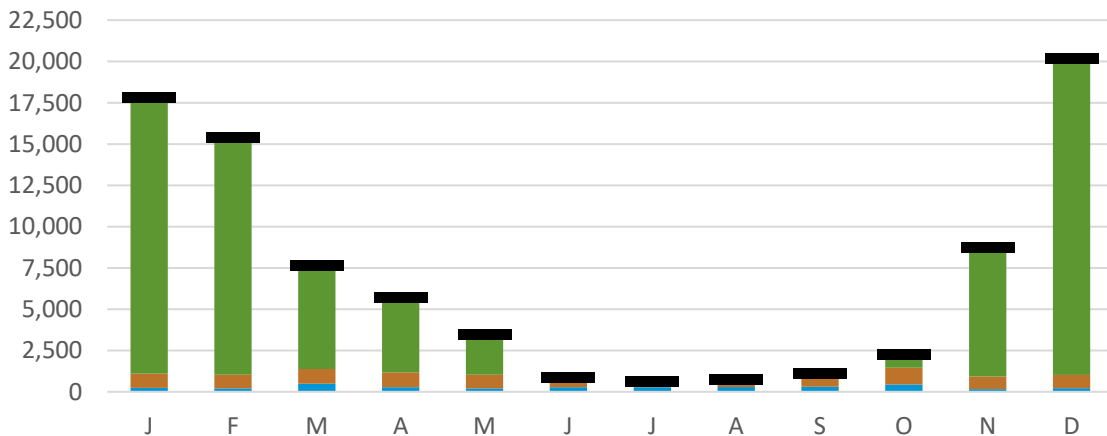| [MMBtu]	space heating	water heating	all other end uses	total
modeled	62.4	13.8	3.6	**79.8**
calibrated	72.4	8.9	3.4	**84.7**
delta	+10.0	-4.9	-0.2	**+4.9**

Natural gas end-use expectations for a particular home (single-family detached in NC)
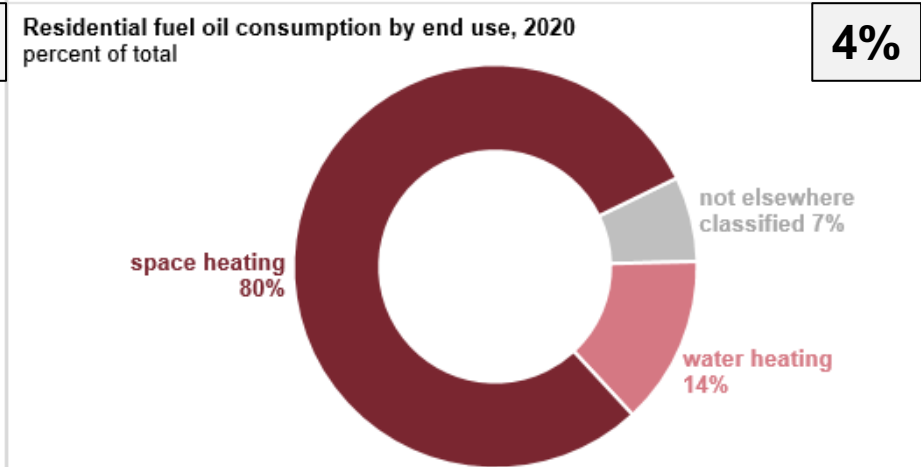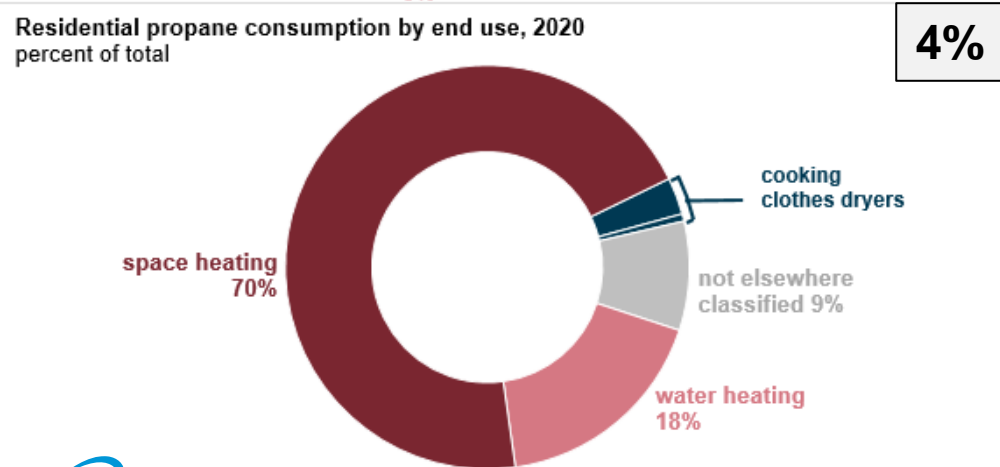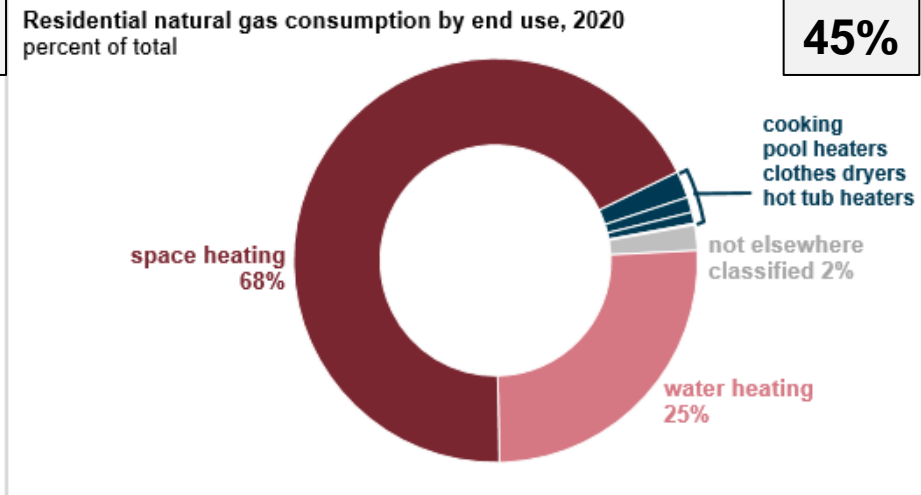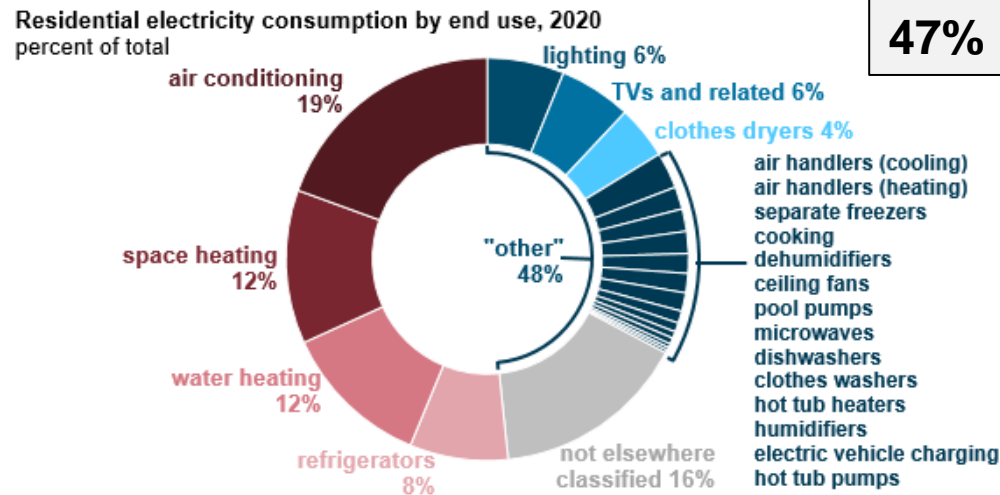thousand British thermal units (MBtu)

Calibrated natural gas end-use estimates for the same home
thousand British thermal units (MBtu)

eia

Residential electricity consumption by end use, 2020
percent of total

47%

- air conditioning 19%
- lighting 6%
- TVs and related 6%
- clothes dryers 4%
- "other" 48%
- space heating 12%
- water heating 12%
- refrigerators 8%
- not elsewhere classified 16%

"other" includes:
- air handlers (cooling)
- air handlers (heating)
- separate freezers
- cooking
- dehumidifiers
- ceiling fans
- pool pumps
- microwaves
- dishwashers
- clothes washers
- hot tub heaters
- humidifiers
- electric vehicle charging
- hot tub pumps

Residential natural gas consumption by end use, 2020
percent of total

45%

- space heating 68%
- water heating 25%
- not elsewhere classified 2%
- cooking
- pool heaters
- clothes dryers
- hot tub heaters

Residential propane consumption by end use, 2020
percent of total

4%

- space heating 70%
- water heating 18%
- not elsewhere classified 9%
- cooking
- clothes dryers

Residential fuel oil consumption by end use, 2020
percent of total

4%

- space heating 80%
- water heating 14%
- not elsewhere classified 7%

Data source: U.S. Energy Information Administration, 2020 *Residential Energy Consumption Survey* (RECS)

What's Next for RECS?

We're preparing for the 2024 RECS!

- Data collection to begin Fall 2024
- Building on 2020 RECS successes—maintaining larger sample, web and mail data collection modes, estimates for all 50 states and DC
- Making updates to questionnaire to account for changes in household energy use
- Option to include small area estimates and collect data on multifamily buildings
- New data products including visualizations

If you have suggestions for new RECS products or new ways to use the RECS data, please email our inbox: eiainfoconsumption&efficiency@eia.gov

Q&A

Contact us

www.eia.gov/recs

- Carolyn Hronis, RECS Survey Manager

- Liz Holland, Program Analyst

- Greg Lawson, Operations Research Analyst

- Email us: eiainfoconsumption&efficiency@eia.gov