Heat Pump Water Heaters: Basic Operation and Market Scenario

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Overview

- Part I
  - History of Heat Pump Water Heaters (HPWH)
  - Basic operation of HPWH
  - Advantages and disadvantages
  - Field data
- Part II
  - Electrical source efficiency impact
  - HPWH market overview
  - Consumer user survey
  - Comparisons with other water heating systems
  - Conclusions

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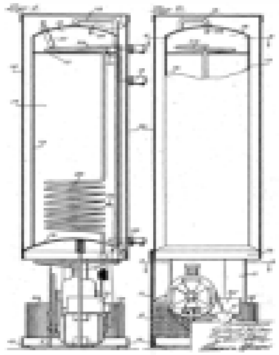
History of HPWH



Source: Wilkes and Reed 1937

1935

1st US Patent for a HPWH. The tank was split into an upper and lower chamber to prevent the electric resistance element rom heating the entire storage volume.

1950s

First mass market HPWH developed by Hotpoint Company.

1960s

Electricity price declines reduced the interest in HPWHs.

1970s

Emerging energy crisis and spike in retail electricity rekindled interest in HPWHs.

Popular Science trumpeted HPWHs as a way to achieve "solar savings—without the cost" (Powell 1980), and became eligible for state tax credits. By 1984, ~17 HPWHs were on the market (Calm 1984). While sales reached over 10,000 units per year in the 80s, the HPWH market soon collapsed because "these early machines suffered from high purchase prices, high maintenance costs, excessive noise, poor longevity, and limited installation options." (Bodzin 1997)

mid/late 1970s

The National Rural Electric Cooperative Association and the U.S. DOE provided funding to develop a prototype HPWH. Through this funding, Energy Utilization Systems manufactured 100 HPWHs—85 integrated units and 15 add-on units—which were tested by 20 electric utilities. While the add-on units were unsuccessful, the integrated units showed significant promise with COPs averaging around 2.0 (Calm 1984).

1980s

ECR International and Oak Ridge National Labs developed the WatterSaver™ HPWH. Achieved good COPs but had reliability issues.

1995

HPWH market dropped and only two manufacturers remained with sales of roughly 2,000 HPWH per year

1999

2010

New push for HPWHs with major manufacturers supporting the technology.

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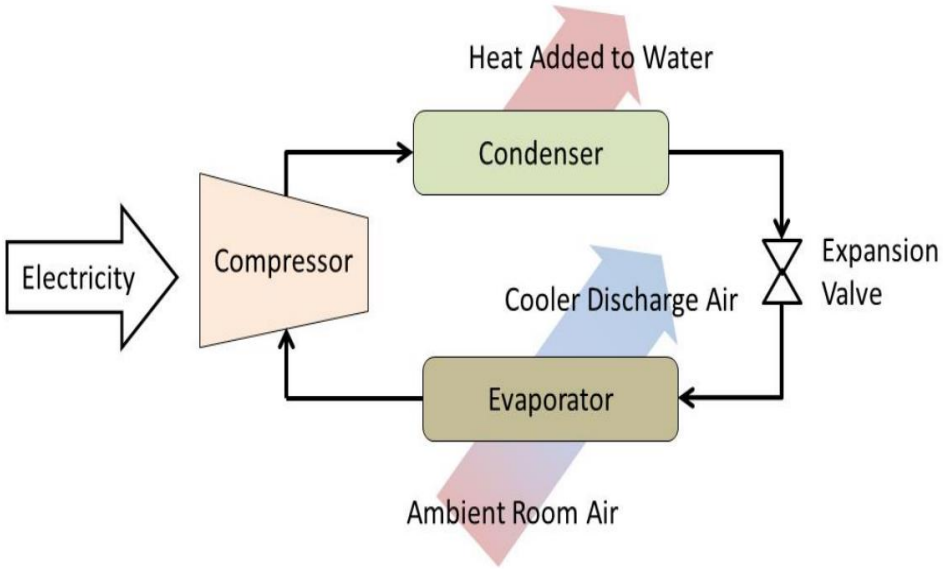
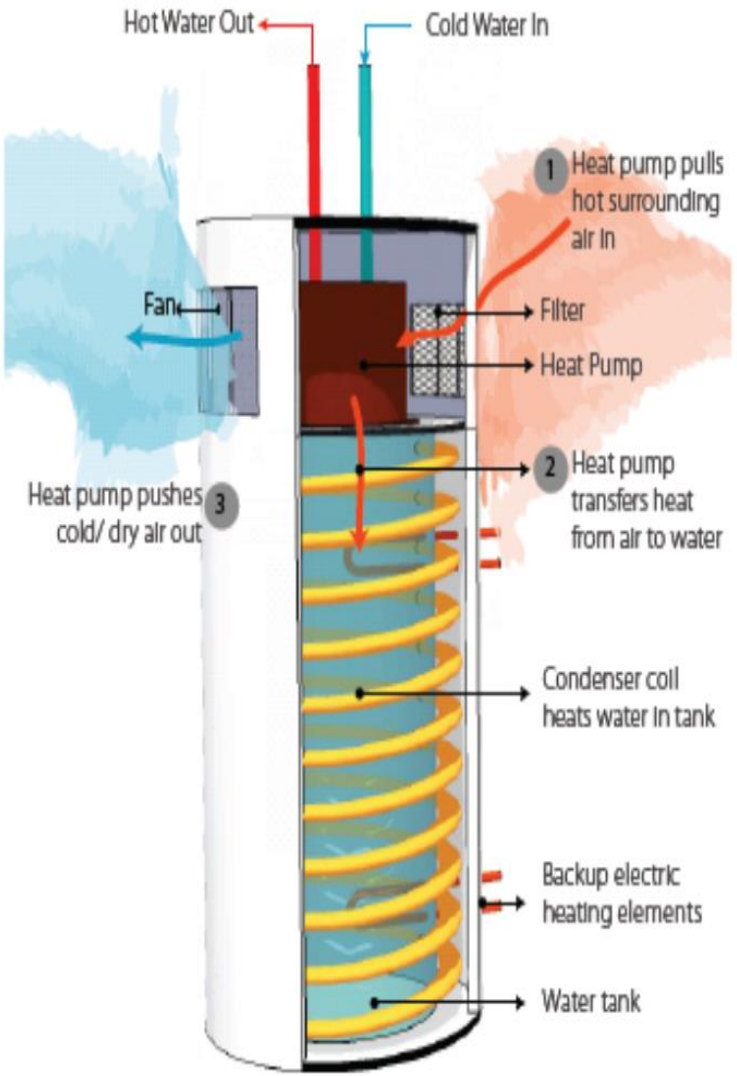
HPWH: Method of Operation



CEE HPWH study, 2015

DOE HPWH study, 2016



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[1]Common Operation Modes

- *Mode 1 (known mostly as Hybrid mode):*
  - Most common; heat pump used as primary source of heating
  - [2]Electrical resistance available only as back up; kicks off when:
    1. Weighted average of water temp falls below certain threshold
    2. Ambient temperature is outside safe operating range
    3. High water usage
- *Mode 2:*
  - Similar to above, but controls further limit use of electric back up
- *Mode 3:*
  - Operation with electrical resistance only

[1] Most common features but not necessarily available in all units
[2] Some or all control methods are utilized in most common units

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Advantages of HPWHs

- Higher efficiencies since heat is being “moved” instead of being created (rated Energy Factor higher than 100%, nominally around 200 – 250%)
- Conditions space in summer months
- Available rebate (both Federal and State)

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Disadvantages of HPWH

- Requires large spaces to operate (usually at least 1000 ft^3)
- Long recovery periods (Bock direct vs. Stiebel Eltron)
- Extra load on heating system in winter months by consuming heat from space
- Ambient must be in a certain “safe” temperature range for proper operation
- Lifespan of 10 years compared to 20-30 for tankless coil boilers
- To ensure proper operation of a HPWH, filters need to be cleaned regularly, condensate drains need to be checked periodically, and water should be drained to flush the tank of potential sediment deposits per manufacturer’s specifications

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Field Studies

- DOE study (Puttagunta and Shapiro, 2016) of 14 homes with various conditions of HPWH operation in RI and MA, lasted over a year

- Center for Energy and Environment, MN study (Schoenbauer 2015) on 29 homes which looked at HPWH performance and their effects on home heating

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Ambient Temperature Comparison: Warm Boiler Room (~80°F)

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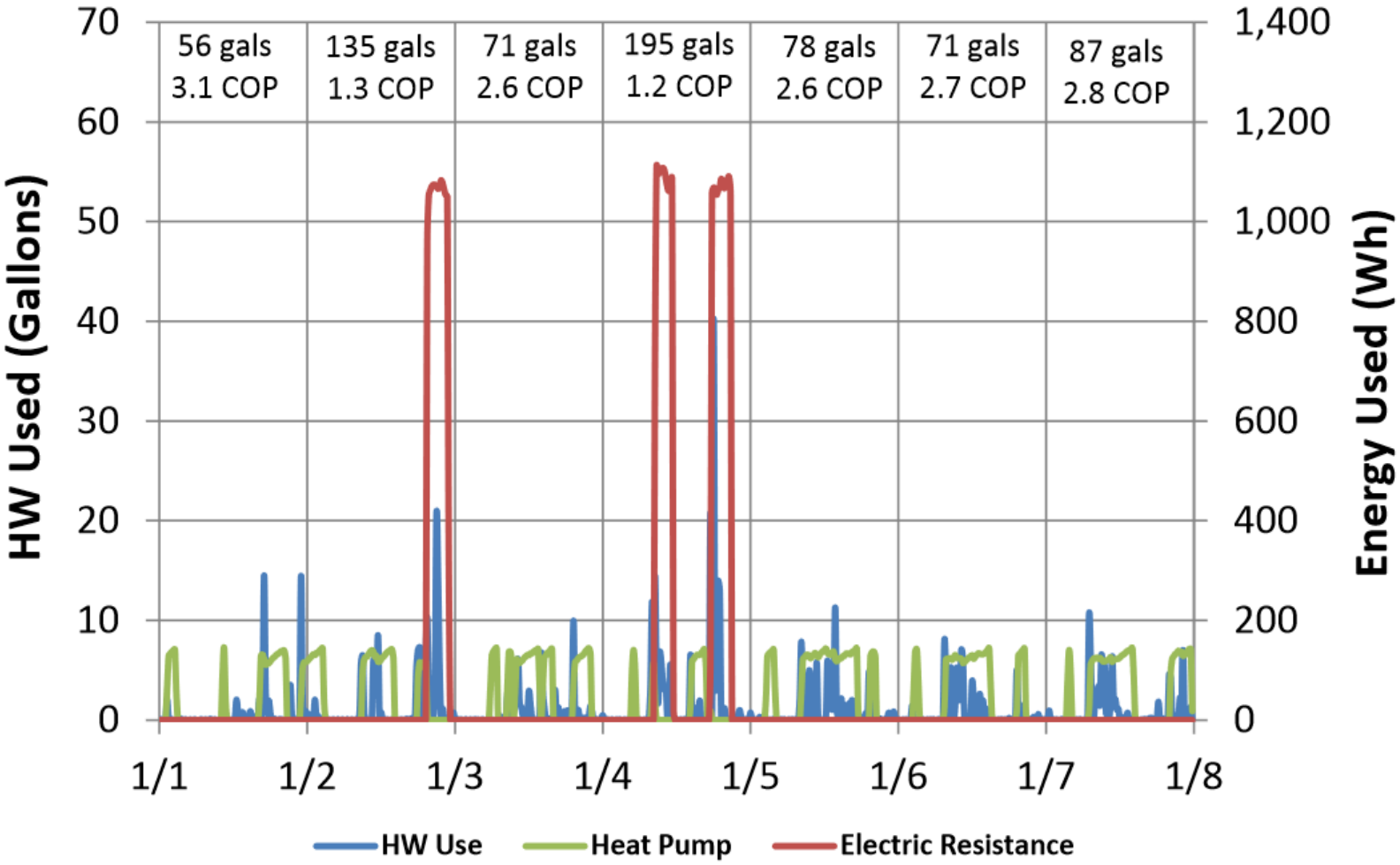

Average COP = 2.5 for total use of 693 gallons of DHW

* DOE HPWH study, 2016

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Ambient Temperature Comparison: Cold Basement (< 50°F)

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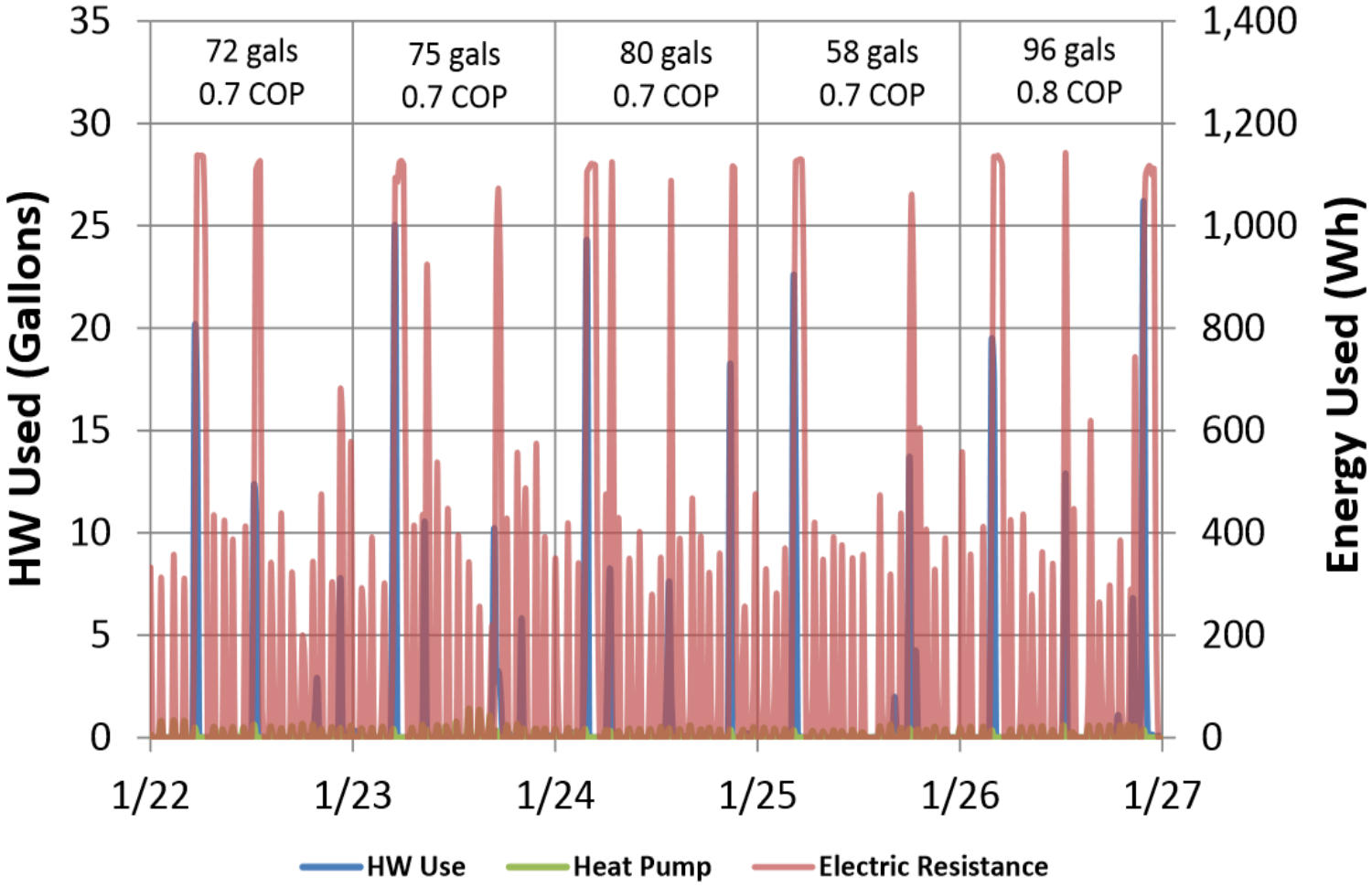

Average COP = 0.72 for total use of 381 gallons of DHW

* DOE HPWH study, 2016

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Effect of DHW and Backup Usage

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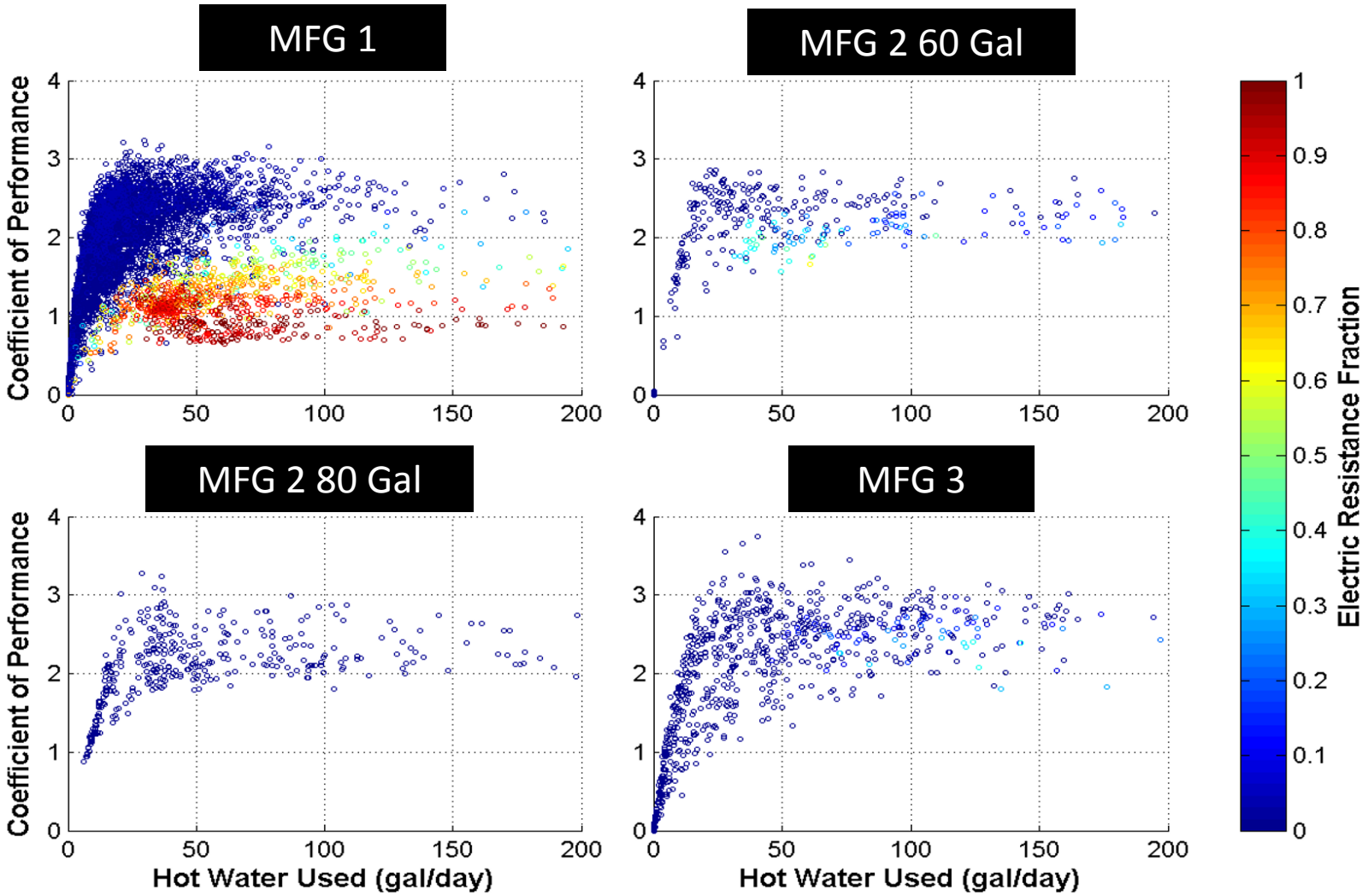

* Puttagunta and Shapiro, 2016

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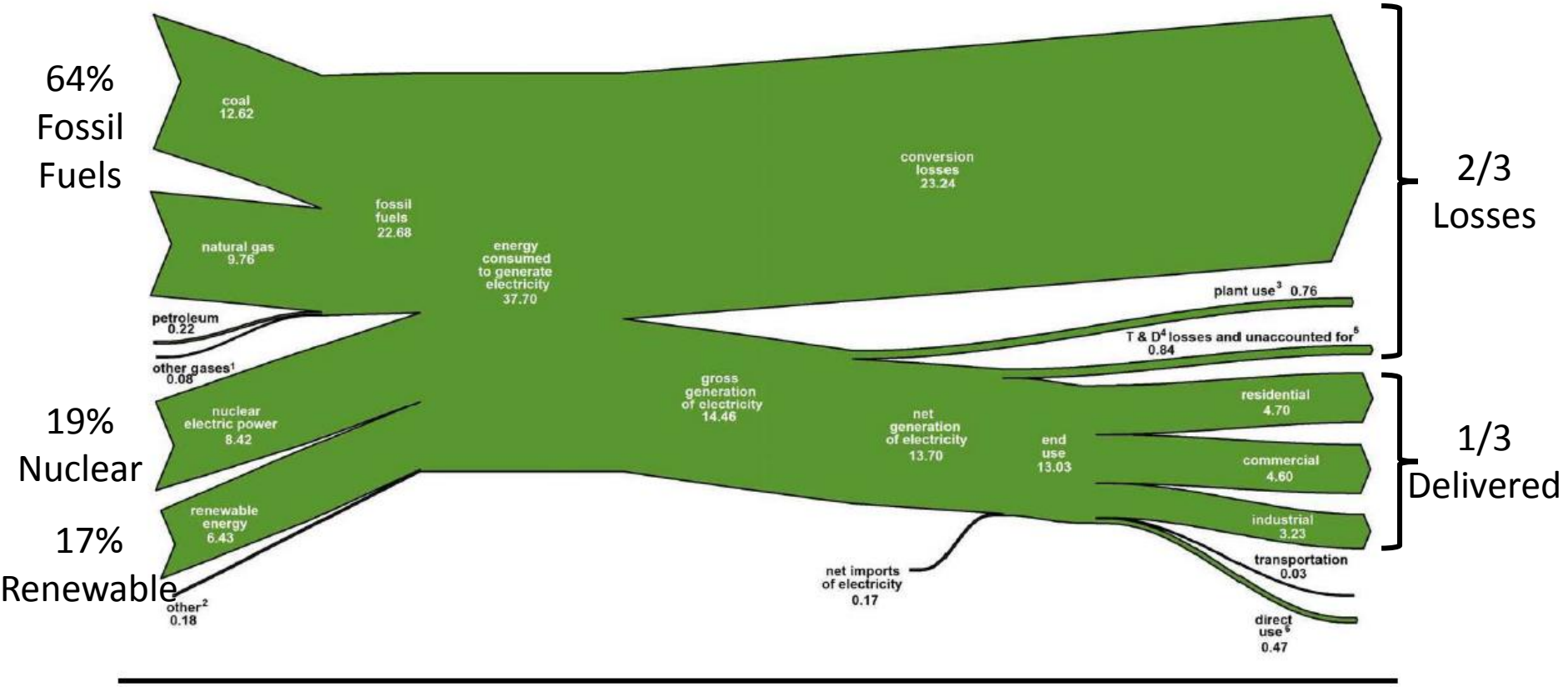
Electrical System Energy Losses

U.S. Electricity Flow

quadrillion BTU



Overall, about <u>two thirds</u> of total energy input is lost in conversion. Currently, of electricity generated, approximately 5% is lost in plant use and 7% is lost in transmission and distribution. (Percentages EIA November 2018, chart 2017)

Source Efficiency lower than direct fired fossil solutions

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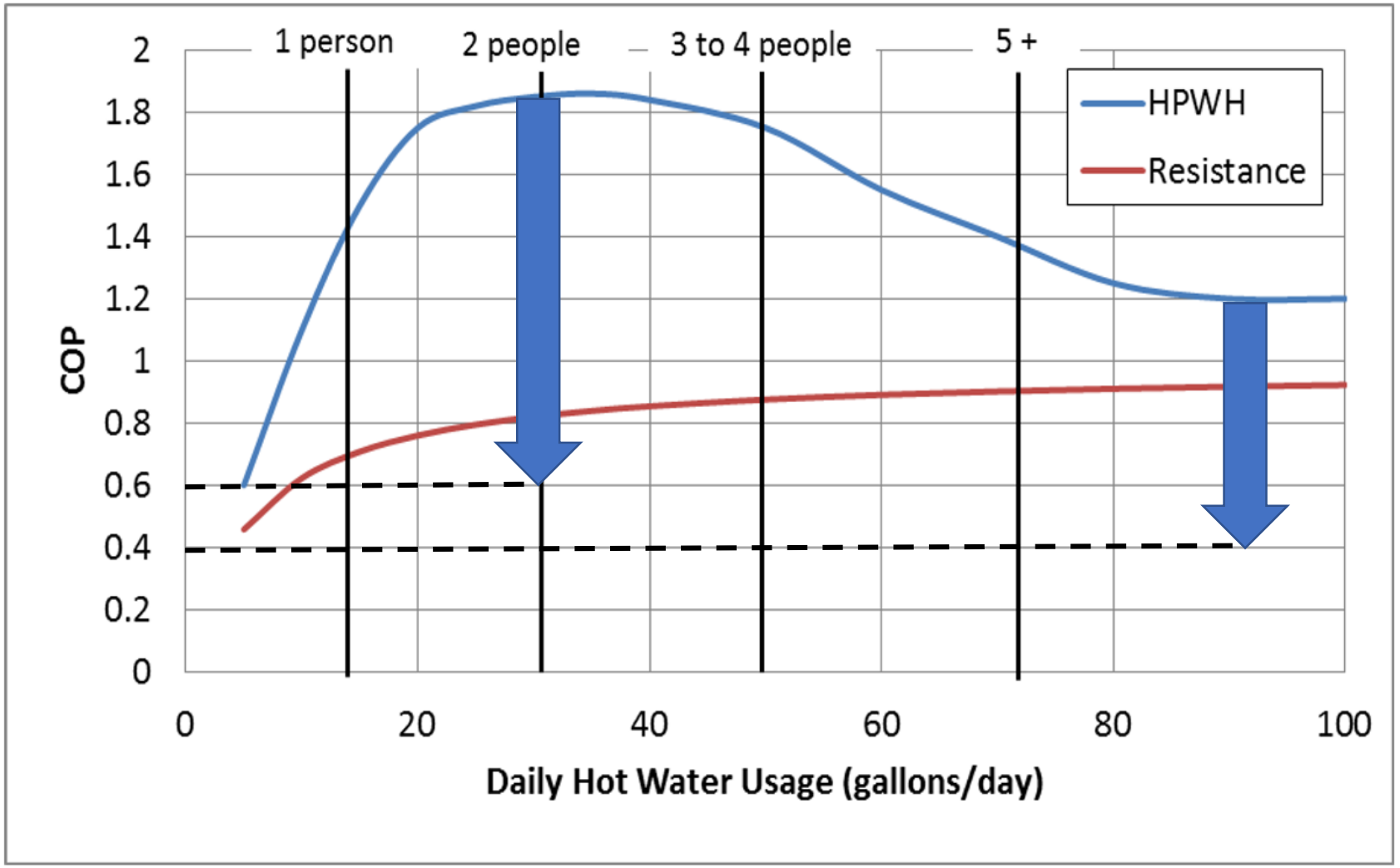

* CEE HPWH study, 2015

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Current US Market

- Gas storage water heater shipments rose 6.3% and their electric counterparts rose 4.3% from Dec ‘17 to Dec ’18 (AHRI)

- Despite growth in electric water heaters, HPWHs account for less than 1% in New England (NEEP)

- Energy Star Market Penetration (2017)

Product Category[2]	2017 Units Shipped (thousand units)	2017 Estimated Market Penetration[3]
Water Heaters		
Gas Storage	278	*6%*
Gas Tankless	387	*N/A*
Heat Pump	72	*2%*
Solar	8	*N/A*

ENERGY STAR:
https://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2017/2017%20Unit%20Shipment%20Data%20Summary%20Report.pdf?7cf2-a6b1

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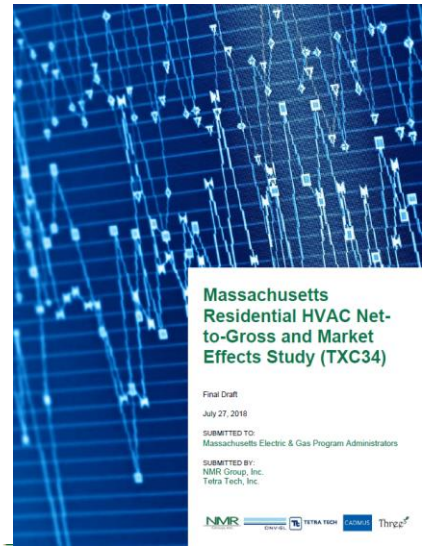
Massachusetts as a Reference

- MassSave Program Review July 27, 2018
- Only those participating in rebate program
- 2016 and first part of 2017 consumers and contractors
- Cost $1000 to $1500 > electric water heater

Heat pump water heater[2]	55 gallons or less, ≥ 2.3 EF	$750
	More than 55 gallons, ≥ 3.0 EF	$150



Measure	Survey Completes[1]		Total Population		Sampling Error (90% CI)	
	Participants	Units[2]	Participants	Units	Absolute	Relative
DMSHP	66	85	8,169	10,539	10%	20%
HPWH	79	80	1,967	2,054	9%	18%
CAC	66	72	2,653	2,920	10%	20%
CHP	35	41	385	423	13%	27%
Furnace	61	68	4,435	4,866	11%	21%
Boiler	60	69	6,181	7,071	11%	21%

Massachusetts Residential HVAC Net to-Gross and Market Effects Study (TXC34), July 27, 2018
http://ma-eeac.org/wordpress/wp-content/uploads/TXC_34_Report_27JUL2018_Final.pdf

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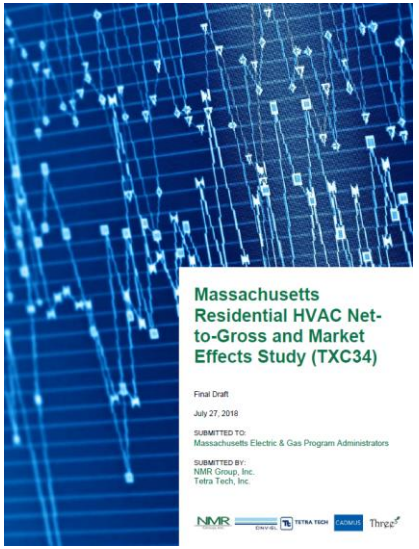
Massachusetts – User Survey

- For those who replaced ERWHs, the primary home heating system fuels cited were fuel oil (49%) and electricity (26%) were the top two.

- Possibly summer hot water use or tankless coils are a target market? Not enough information to tell from survey.



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HPWH Comparison (Minnesota)

Savings vs electric water heater, but not for oil, gas, or propane.

- $175/year savings vs electric water heater at 0.89 EF ($0.12/kWh)
- $415 ($0.21/kWh 3,066 kWh net home impact, 1964 kWh use)

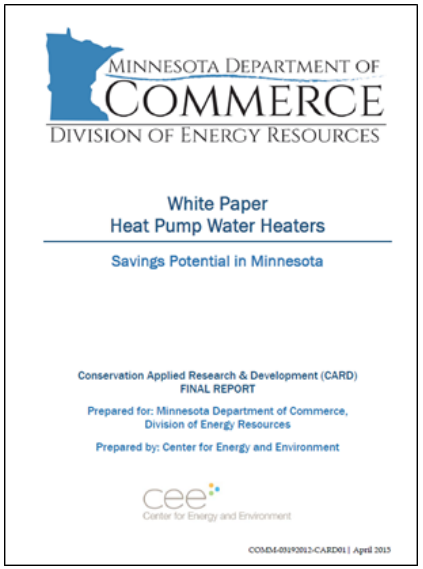
Adjustment for New England at $0.21/kWh (January 2019 EIA)

104 gal/year of oil at $3.17/gallon

- $386/year equivalent direct fired tank 0.68 EF
- $773/year equivalent tankless coil boiler approx. 0.34 EF

NOTE: Cold climate installations that would require installing the HPWH directly in occupied, conditioned space with a thermostat should be avoided. Typical basement installations in Minnesota are good HPWH applications (about 10% of heat "moved" was assumed to impact heat load in this analysis).

GTI tests: For all three manufactures tested, the EF dropped by almost a full point (from 3.0 to 2.2) between the hot/humid (90°F) and cold test (50°F) conditions.



https://www.cards.commerce.state.mn.us/CARDS/security/search.do?documentId={DDE1ED60-6120-4D6B-A272-8B781EDF3B71} Minnesota Department of Commerce Division of Energy Resources, White Paper Heat Pump Water Heaters, Ben Schoenbauer, April 2015

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Conclusions

- Heat pump water heaters have advanced in performance and have growing acceptance in the market
- The theoretical high efficiencies are highly reliant on ambient conditions and can easily be reduced
- From an efficiency and cost standpoint, the EF numbers may be misleading for consumers when comparing water heating methods
- Environmentally, using HPWHs are not as "green" given electricity sources
- "Favored" Technologies are promoted and supported at state and utility levels
- Equipment with high operating or service costs is targeted for replacement by consumers
- HPWHs can be installed without a refrigeration certification or license

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