Residential Water Heating Energy in California's Title 24

Jim Lutz
jdlutz@hotwaterresearch.net

ACEEE Hot Water Forum
February 28, 2017

What is Title 24

- Title 24 of California Code of Regulations, Part 6 - California Energy Code
- Energy conservation standards for all residential and non-residential buildings throughout California
- Since 1978, updated every three years by the California Energy Commission
- Requires building permit applicants submit energy efficiency compliance documentation with permit

Performance Compliance

- Calculations to show proposed design uses less energy than it would if it met the Prescriptive requirements.
- Uses state-certified, free, open source energy modeling software: CBECC-Res
  - Simulation as a rating tool, not a forecasting tool
  - Time Dependent Valuation (TDV) – different "price" of electricity every hour of year based on PUC cost model
  - Typical Meterological Year (TMY) – 16 weather files for state

Title 24
(from the beginning)

- proposed building energy use < standard budget
- standards based on minimum life cycle cost
- water heating included
- water heaters meet appliance standards
- electric only if LCC < equivalent gas WH
- certified computer programs can be used

1982

- residential water heating budgets
  - vary by CTZ
  - not by building size
  - not by number of bedrooms
- annual energy calculation
- based on 50 GPD (35 GPD for MF)

Residential Water Heating Study

- Davis Energy Group
- finished 1991
- HWSIM computer model of distribution systems
- surveyed plumbers
- developed new compliance method

1992

Alternative Calculation Method (ACM) Approval Manual

For the 1992 Energy Efficiency Standards for Residential Buildings

April 1992

California Energy Commission

Pete Wilson, Governor

CEC Contract no. 400-89-015

1992 Compliance Method

- default water heater (automatically complies)
  - 50 gallon gas-fired
  - meeting Federal standards
  - with R12 external insulation
- methodology includes credits and penalties for energy impacts of non-standard hot water distribution (piping) systems.
- still an annual calculation
- worksheet based (with computer option)
- based on CFA, not CTZ

Equations (1992)

- Basic Energy Use

  for storage tanks: $BEU = ARL / LDEF$ for tankless: $BEU = ARL / \mathrm{RE}$

- Adjusted Recovery Load

$$ARL = SRL * DSM * SSM$$

- Standard Recovery Load

$$SRL = 0.0855347\left(CFA/1000\right)^2 + 3.61307\left(CFA/1000\right) + 6.036$$

- DSM - Distribution system multiplier
  - credits/penalties for non-standard hot water distribution systems
- SSM - Solar savings multiplier
  - from f-Chart
- LDEF - Load Dependent Energy Factor (storage tanks)

$$LDEF_j = \ln\left(\frac{ARL_j \times 1000}{365}\right)\left(a \times EF_j + b\right) + \left(c \times EF_j + d\right)$$

- credits for
  - tank wrap
  - wood stove boilers

Time Dependent Valuation (2005)

- TDV energy accounts for the energy
  - used at the building site
  - consumed in producing energy
  - in delivering energy to a site, including:
    - power generation
    - transmission
    - distribution losses
- varies **hourly** for electricity, monthly for gas
- major policy tool

hourly energy use
residential water heating systems

- Hourly Adjusted Recovery Load

$$HARL = HSEU \times DLM \times SSM + HRDL$$

- water delivered at the fixture

$$HSEU = 8.345 \times GPH \times \Delta T$$

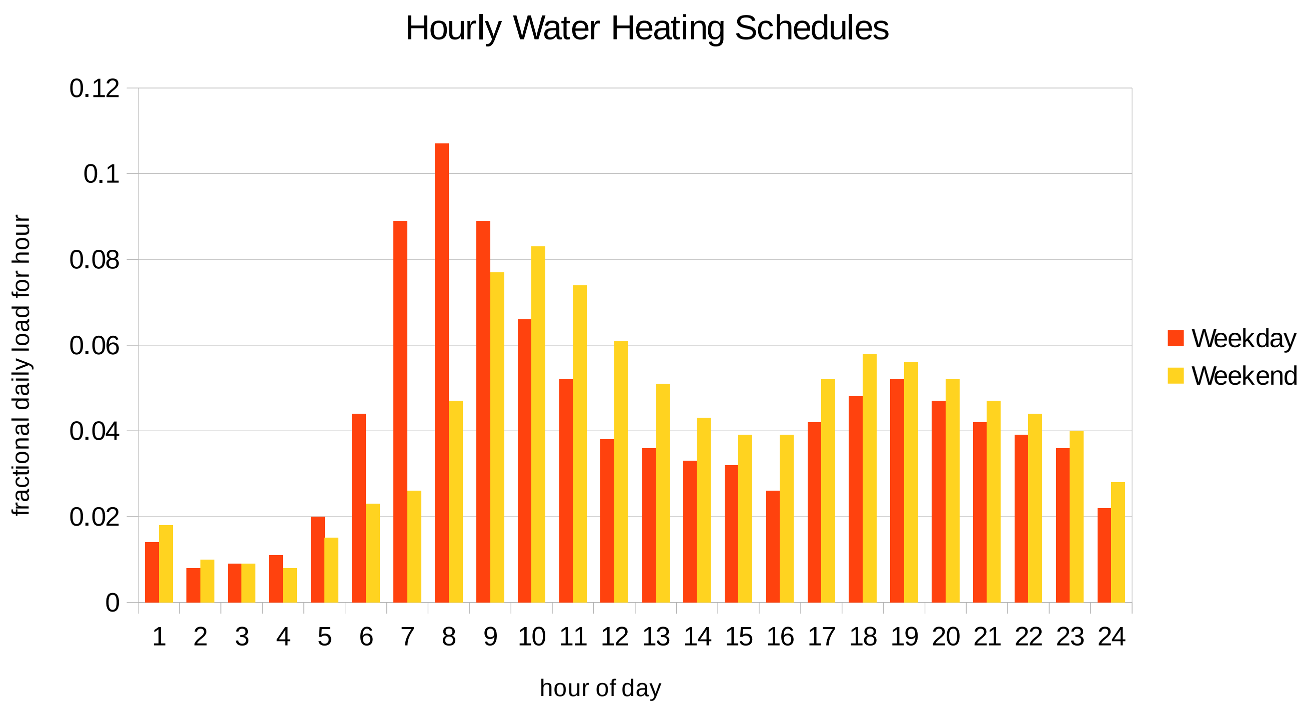
- distribution loss multiplier

$$DLM = 1 + (SDLM - 1) \times DSM$$

- standard distribution loss multiplier
  - SDLM = 1.064 + 0.000084 × CFA (single story)
  - SDLM = 1.023 + 0.000056 × CFA (2 or 3 story)
- solar savings multiplier (SSM)
  - from SRCC OG-300 and SRCC OG-100
- Hourly Recirculation Distribution Loss for Central Water Heating Systems (HRDL)

hourly water consumption

- GPH = GPD × SCH
- GPD = 21.5 + 0.014 × CFA



Hot Water

- $\Delta T = T_s - T_{inlet}$
- Cold Water Inlet Temperature
  - monthly ground temperature (2005)
- Hot water supply temperature of 135 ^oF.

distribution loss multiplier

$$DLM = 1 + (SDLM - 1) \times DSM$$

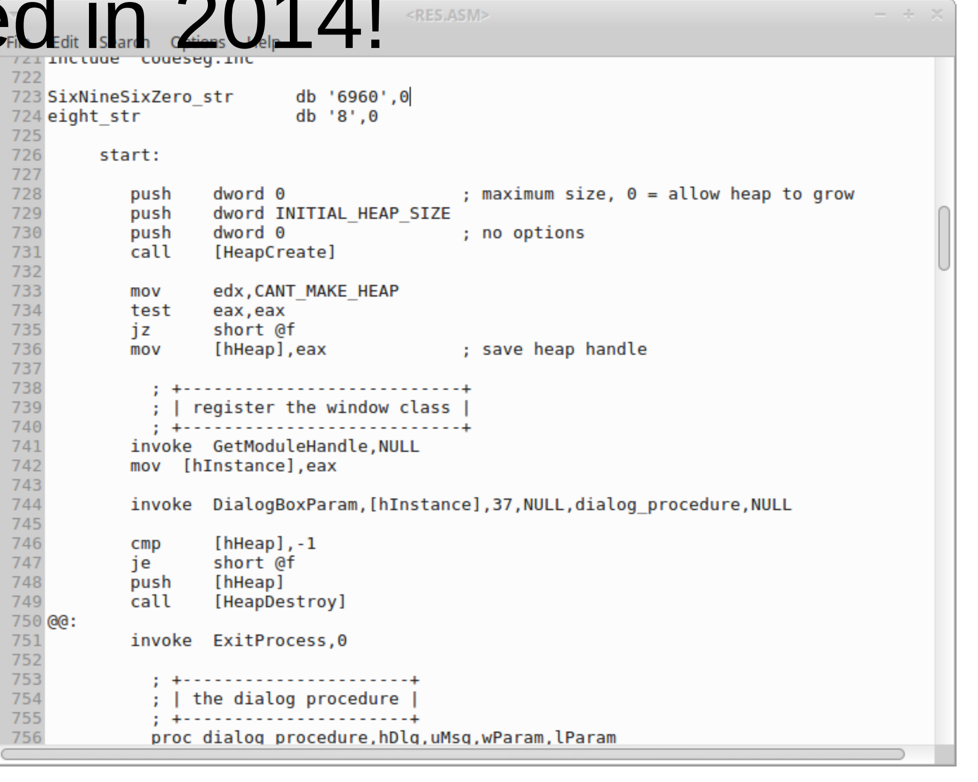
- standard distribution loss multiplier
  - single story $SDLM = 1.064 + 0.000084 \times CFA$
  - 2 or 3 stories $SDLM = 1.023 + 0.000056 \times CFA$

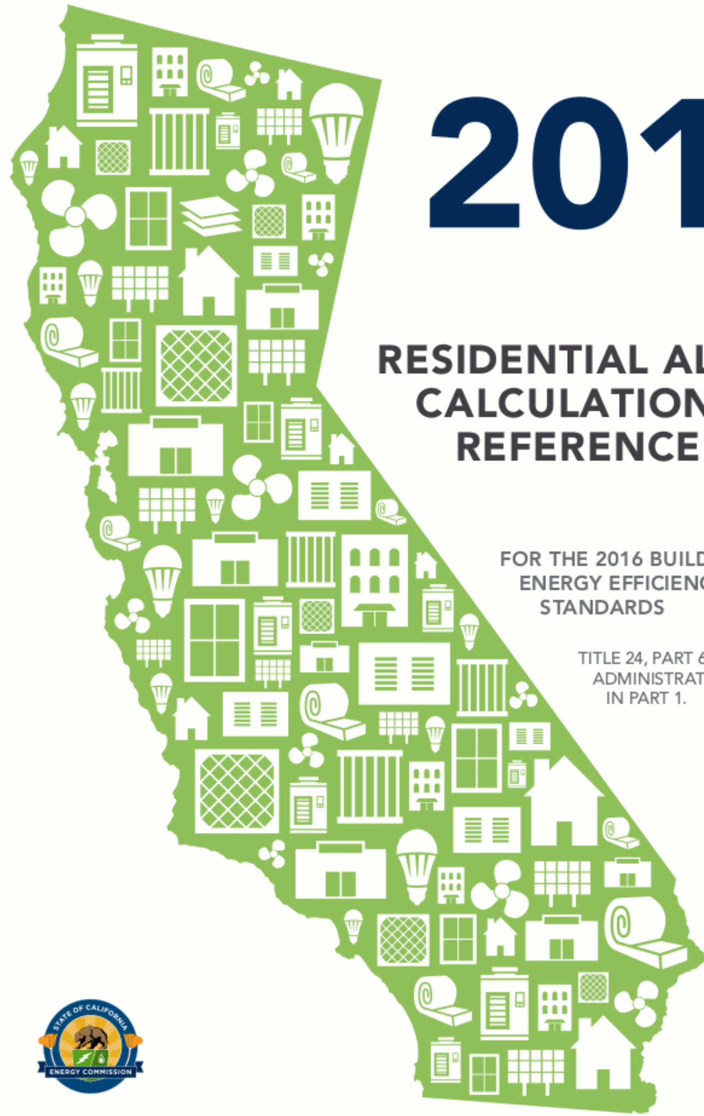
Distribution System Multiplier (2005)

Distribution System Measure	**Code**	**DSM**
Standard Case	STD	1.00
Pipe Insulation (all lines)	PIA	0.90
Point of Use	POU	0.00
Standard pipes with no insulation	SNI	1.19
Parallel Piping	PP	1.04
Recirculation (no control)	RNC	4.52
Recirculation + timer control	RTm	3.03
Recirculation + temperature control	RTmp	3.73
Recirculation + timer/temperature	RTmTmp	2.49
Recirculation + demand control	RDmd	1.31

Legacy Code

- slow computers → assembly language
- hard to make changes
- programmer retired in 2014!





2016

RESIDENTIAL ALTERNATIVE CALCULATION METHOD REFERENCE MANUAL

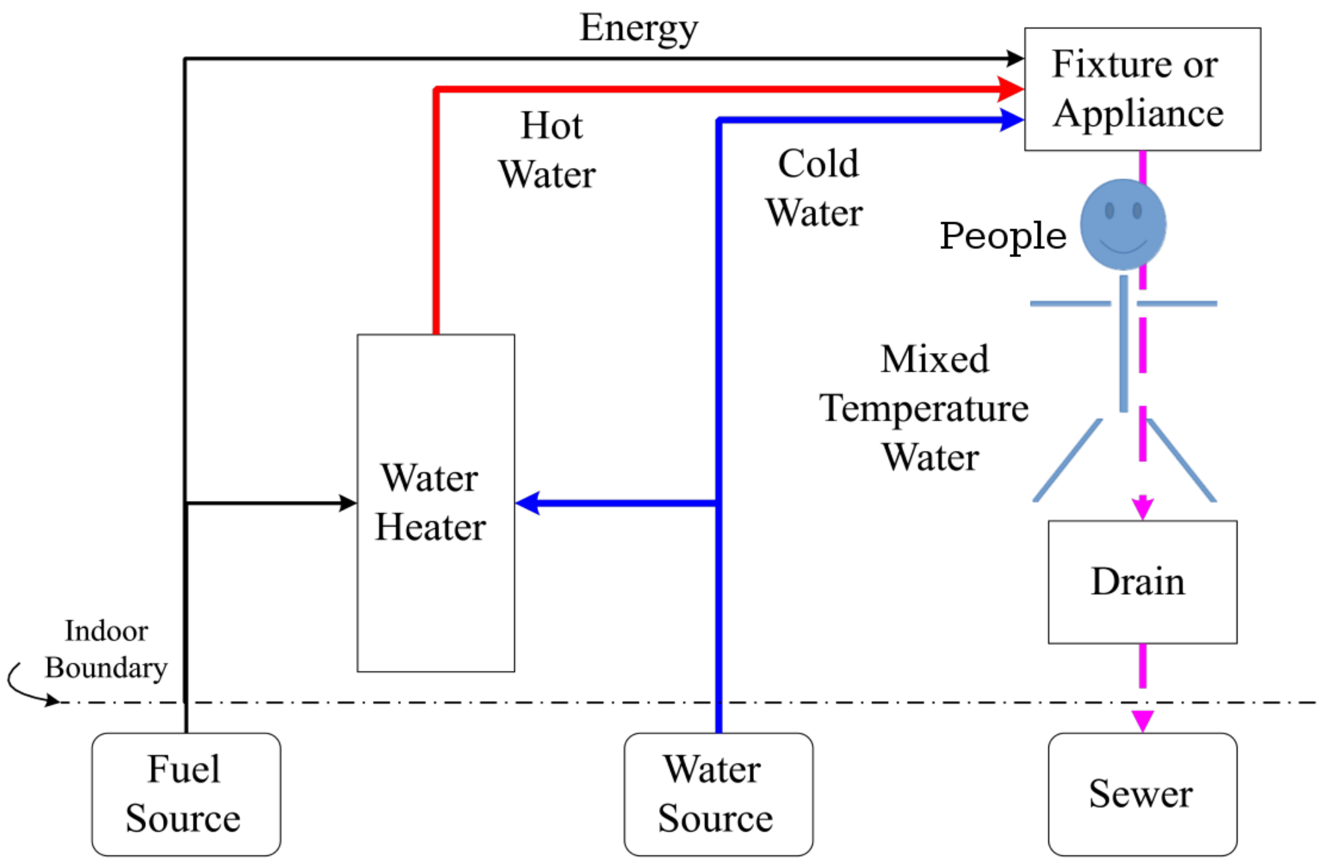
FOR THE 2016 BUILDING ENERGY EFFICIENCY STANDARDS

TITLE 24, PART 6, AND ASSOCIATED ADMINISTRATIVE REGULATIONS IN PART 1.

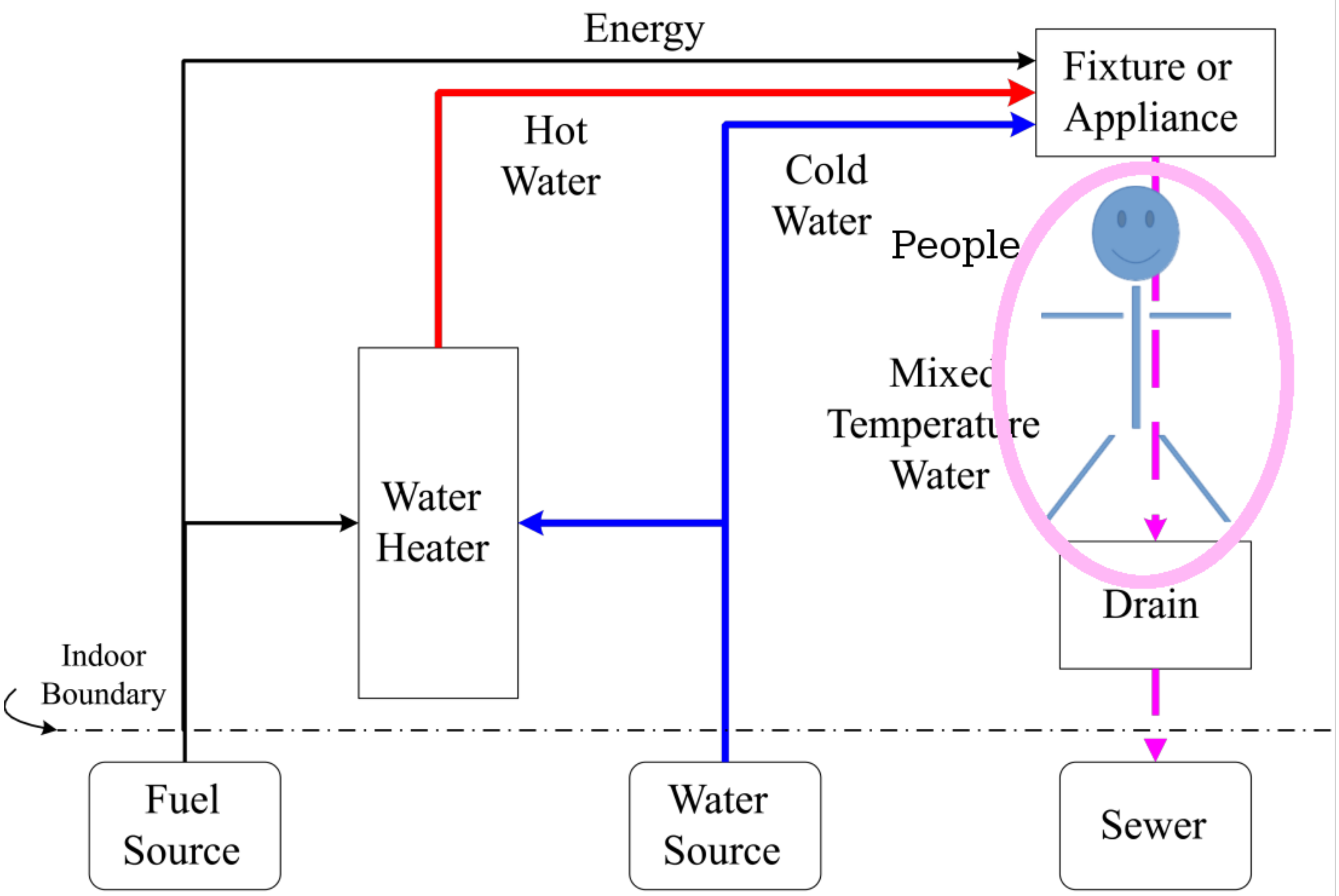
NOVEMBER 2015 • REVISED JUNE 2016
CEC-400-2015-024-CMF-REV

CALIFORNIA ENERGY COMMISSION
Edmund G. Brown Jr., Governor

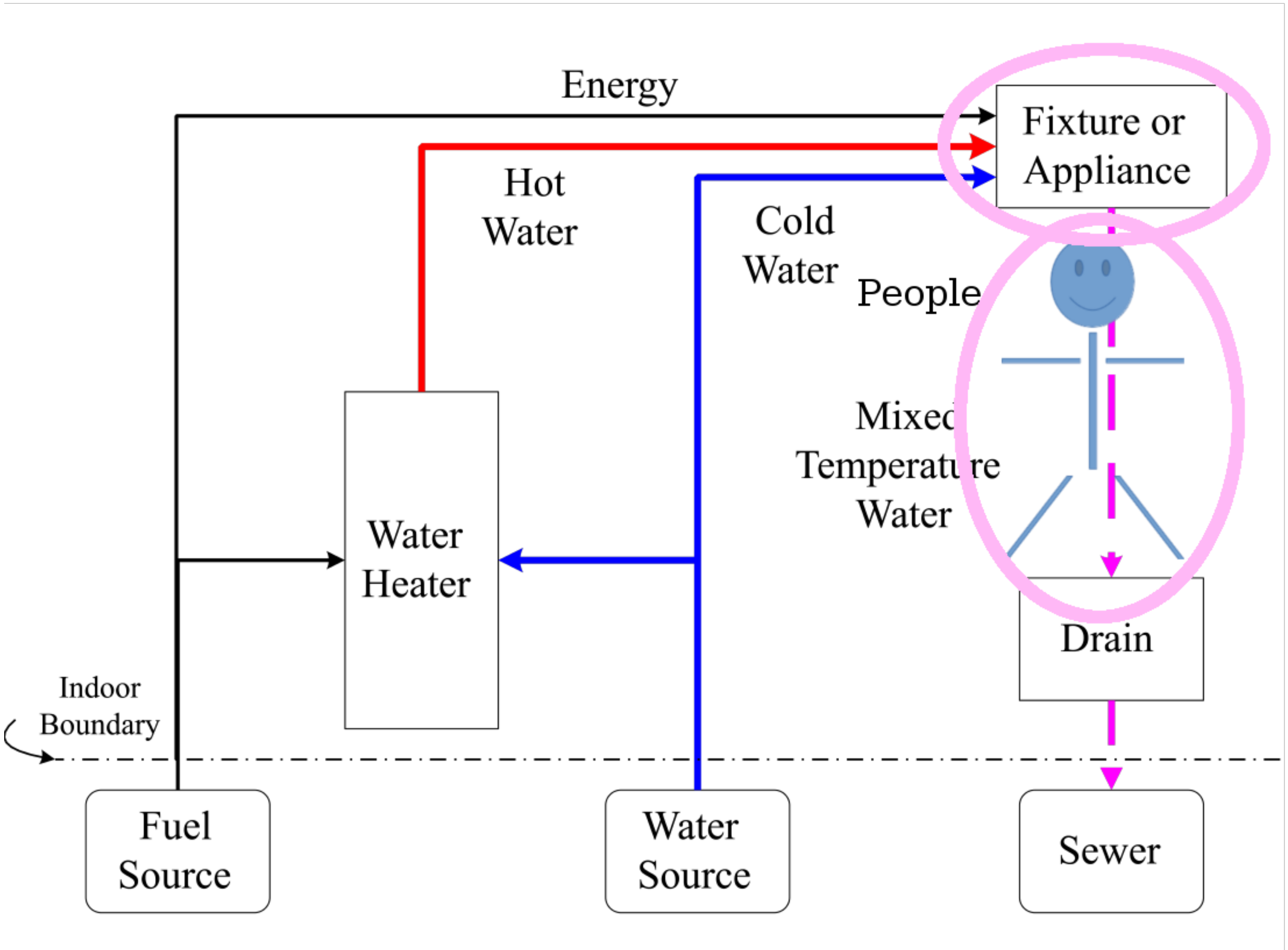
Schematic of Residential Domestic Hot Water System



People Use Hot Water



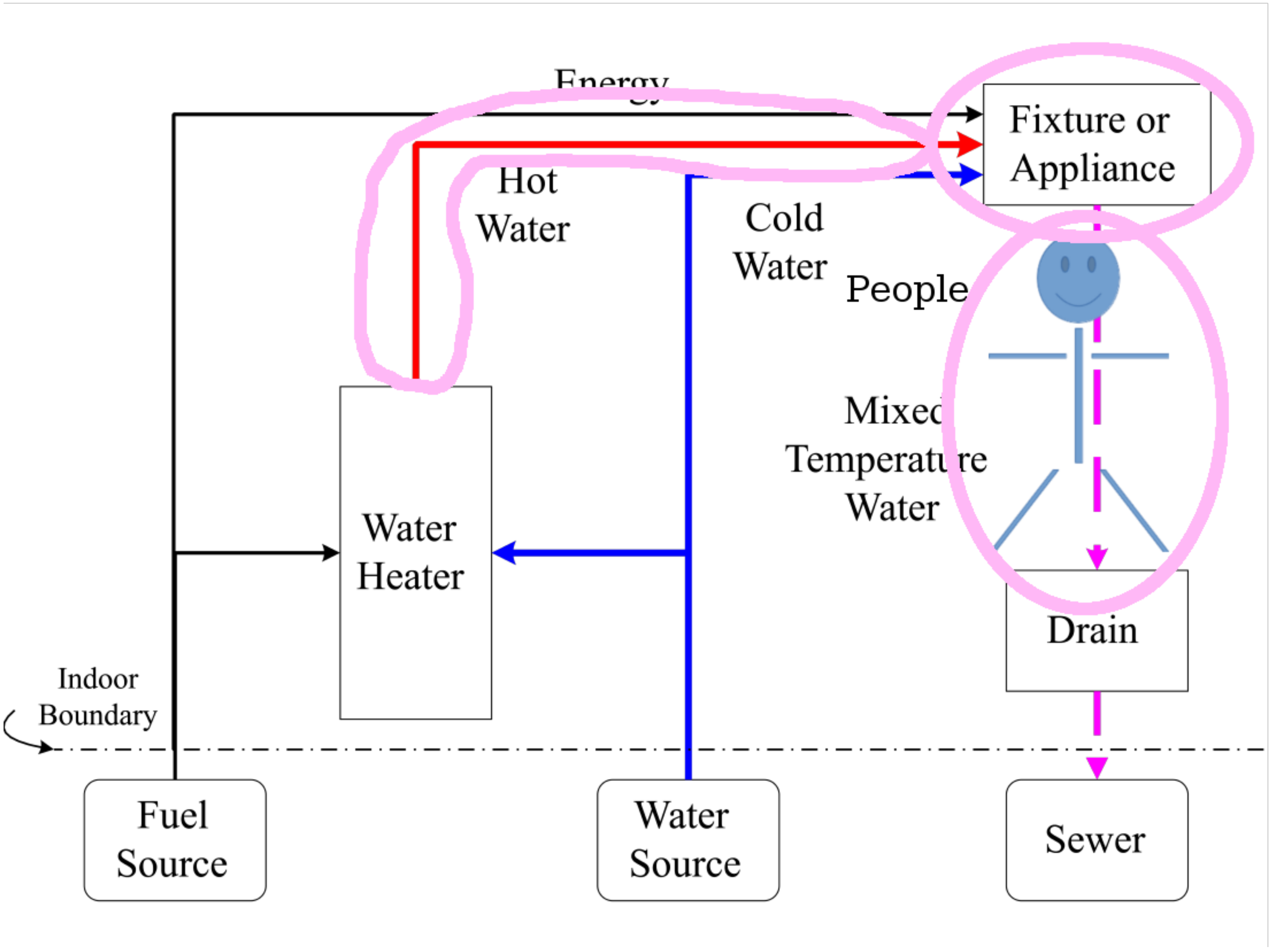
Fixtures and Appliances



Shortcomings of 2016 ACM
People and Draw Patterns

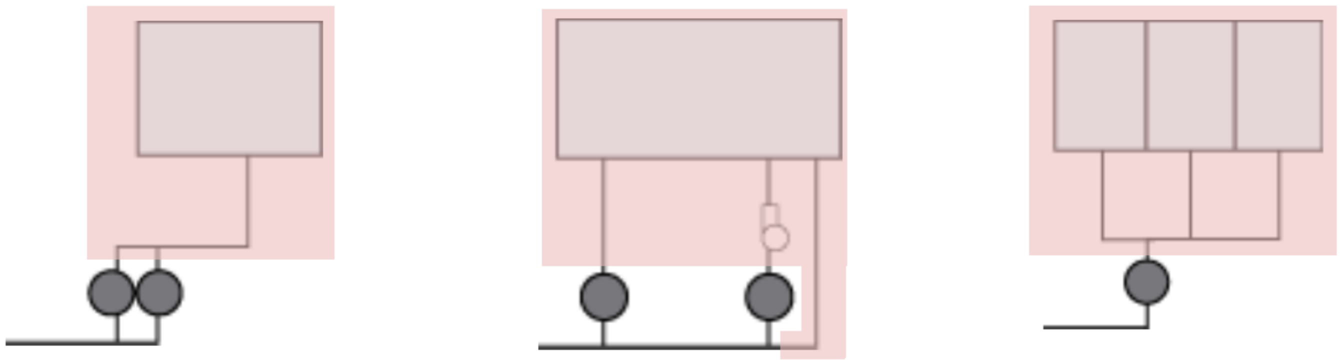
- Aquacraft California data set lacking hot water
- faucet or clothes washer draws all mixed, no cold only
- age bins of people Aquacraft vs RASS
  - teenagers use more
  - seniors use less
- draw patterns not transparent
  - assembled as used
  - events are total mixed water flow rate
  - flow rates depend on
    - efficiency standards
    - cold water temperatures
- shower draw patterns include warmup
  - structural waste not separated
  - behavioral waste not separated
- water heating energy at the dishwasher not counted

Hot Water Distribution System

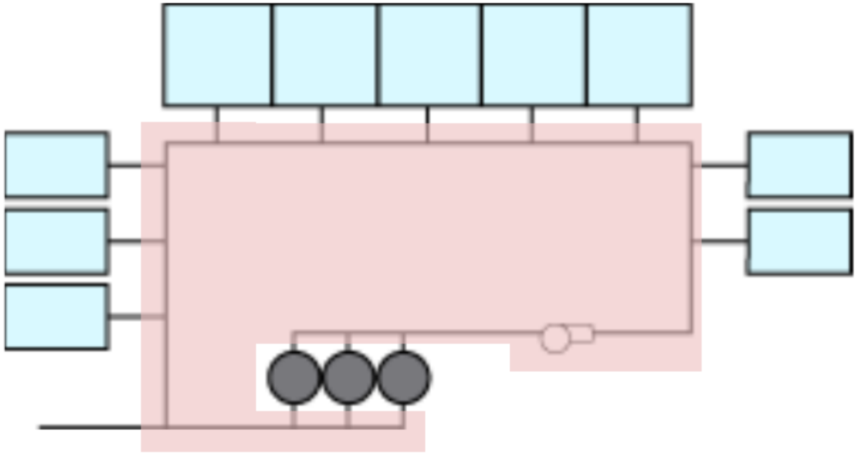


Hot Water Distribution System

Within Dwelling Unit Distribution System (DLM)



Multifamily Central DHW w/ Recirculation (HRDL)



Within Dwelling Unit
Hot Water Distribution System

- hot water draw pattern changes because of:
  - heat losses from pipes during use
  - cool down between draws
  - volumetric waste above pipe volume during clearing draws
  - human behavior to compensate

Showering Habits
(audience survey)

- #1 “How do you clear the pipes?”
  - turn tubspout to full hot
  - turn showerhead to full hot
  - turn shower to remembered setting
- #2 “How long before you get in?”
  - ≤ 5 seconds
  - ≤ 15 seconds
  - ≤ 30 seconds
  - ≤ 1 minute
  - ≤ 2 minutes
  - ≤ 5 minutes
- #3 “What do you do while you wait?”

Fixture Draws Converted to Water Heater Draws

- VS = hot water draw at water heating system delivery point (gal) (source of hot water)
- VF = mixed water draw at appliance or fixture (gal)
- f_{hot} = fraction hot
- f_{wh} = wasted heat factor

$$VS = VF \times f_{hot} \times f_{wh}$$

Fraction Hot

Shower	$\frac{105 - T_{inlet}}{T_s - T_{inlet}}$
Bath	
Faucet	0.5
Clothes washer	0.22
Dish washer	1

T_{inlet} = cold water inlet temperature (°F)

T_s = hot water supply temperature (115 °F)

Wasted Heat Factor
(Fudge Factors)

- Applies to Shower and Bath draws
- Depends on:
  - floor area (up to 2,500 ft^2)
  - distribution system type
  - within-dwelling-unit pumped circulation

Wasted Heat Factor

WF = hot water waste factor

0.9 for within-dwelling-unit pumped circulation

1.0 otherwise

DLM = distribution loss multiplier

SDLM = standard distribution loss multiplier

DSM = distribution system multiplier

CFA = dwelling unit conditioned floor area (ft^2)

capped at 2,500 ft^2

Wasted Heat Factor

$$f_{wh} = WF \times DLM$$

$$DLM = 1 + (SDLM - 1) \times DSM$$

$$SDLM = 1.004 + 2.02 \cdot 10^{-4} \times CFA + 2.31 \cdot 10^{-8} \times CFA^{2}$$

WF = hot water waste factor

0.9 for within-dwelling-unit pumped circulation

1.0 otherwise

DLM = distribution loss multiplier

SDLM = standard distribution loss multiplier

DSM = distribution system multiplier

CFA = dwelling unit conditioned floor area (ft^2)

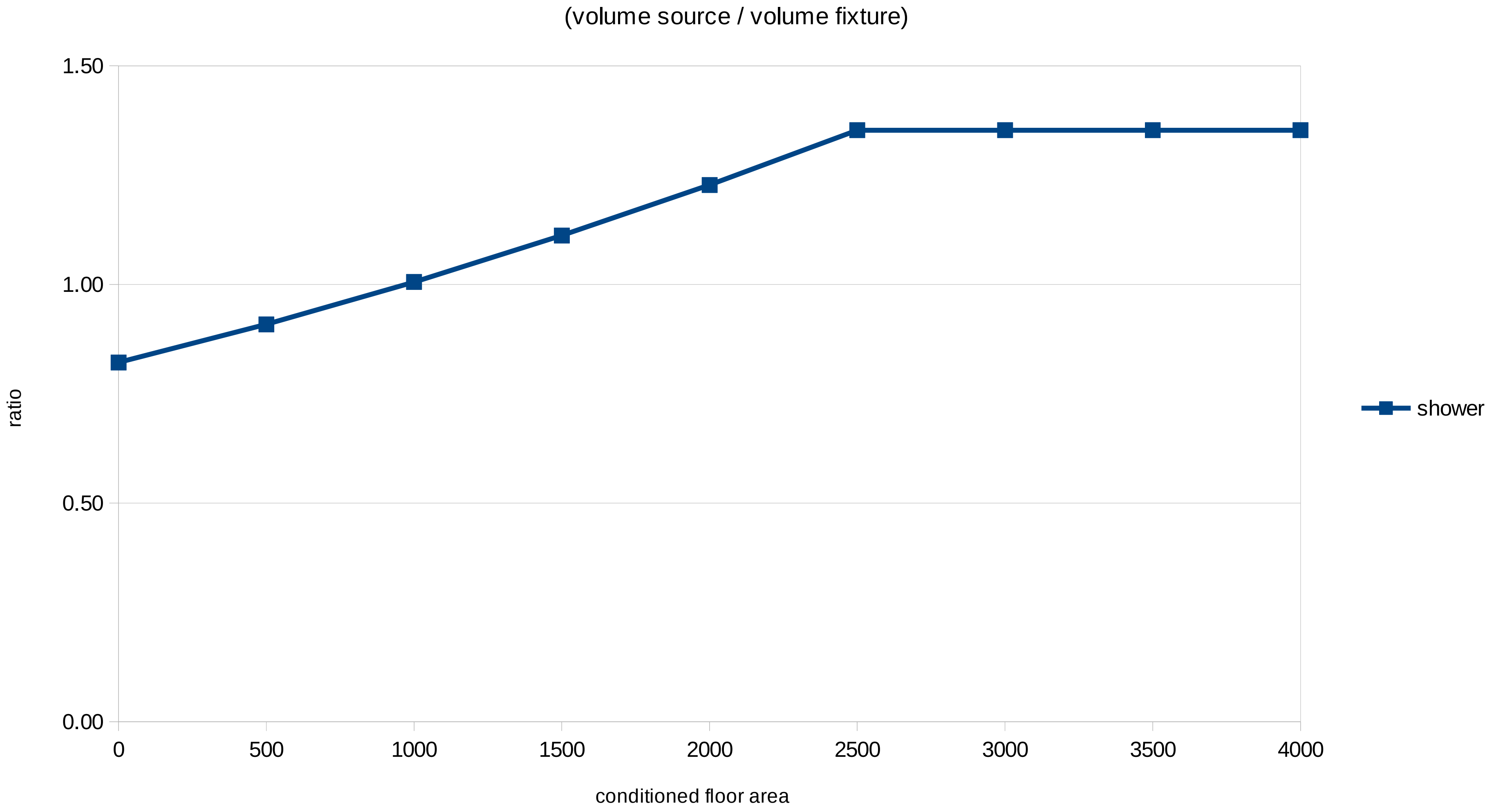
capped at 2,500 ft^2

Distribution System Multipliers

Distribution System Types	Assigned Distribution System Multiplier
No HERS Inspection Required	
Trunk and Branch -Standard (STD)	1
Pipe Insulation (PIC)	0.9
Central Parallel Piping (PP)	1.05
Point of Use (POU)	0.3
Recirculation: Non-Demand Control Options (R-ND)	9
Recirculation with Manual Demand Control (R-DRmc)	1.6
Recirculation with Motion Sensor Demand Control (R-DRsc)	2.4
Optional Cases: HERS Inspection Required	
Pipe Insulation (PIC-H)	0.8
Central Parallel Piping with 5' maximum length (PP-H)	0.95
Compact Design (CHWDS-H)	0.7
Recirculation with Manual Demand Control (R-DRmc-H)	1.45
Recirculation with Motion Sensor Demand Control (RDRsc-H)	2.2
Non-Compliant Installation Distribution Multiplier	1.2

Fraction of Draw from Water Heater

trial calculation of VS and VF for typical shower
(10 gallons, Tinlet 60°, Ts 115°)



preliminary calculations, need to be confirmed!

Shortcomings of 2016 ACM
Hot Water Distribution System

- more water out of shower than water heater?
- Plumbing
  - energy effects not accounted if:
    - reduce water volume from source to use (smaller pipes)
    - reduce water wasted while waiting for hot water
- end uses not assigned to locations
- end uses not assigned to water heaters

Problems Modeling Plumbing

- pipes usually not shown on plans
- plans may not be followed even if shown
- architects not concerned or aware this
- plumbing codes oversize pipes
  - Hunter curves

    Hunter, Roy B. Methods of Estimating Loads in Plumbing Systems. US Department of Commerce, National Bureau of Standards, 1940.
  - pipe and fitting losses

    Freeman, John Ripley. Experiments Upon the Flow of Water in Pipes and Pipe Fittings: Made at Nashua, New Hampshire, June 28 to October 22, 1892. The American Society of Mechanical Engineers, 1941.
  - Moody Chart

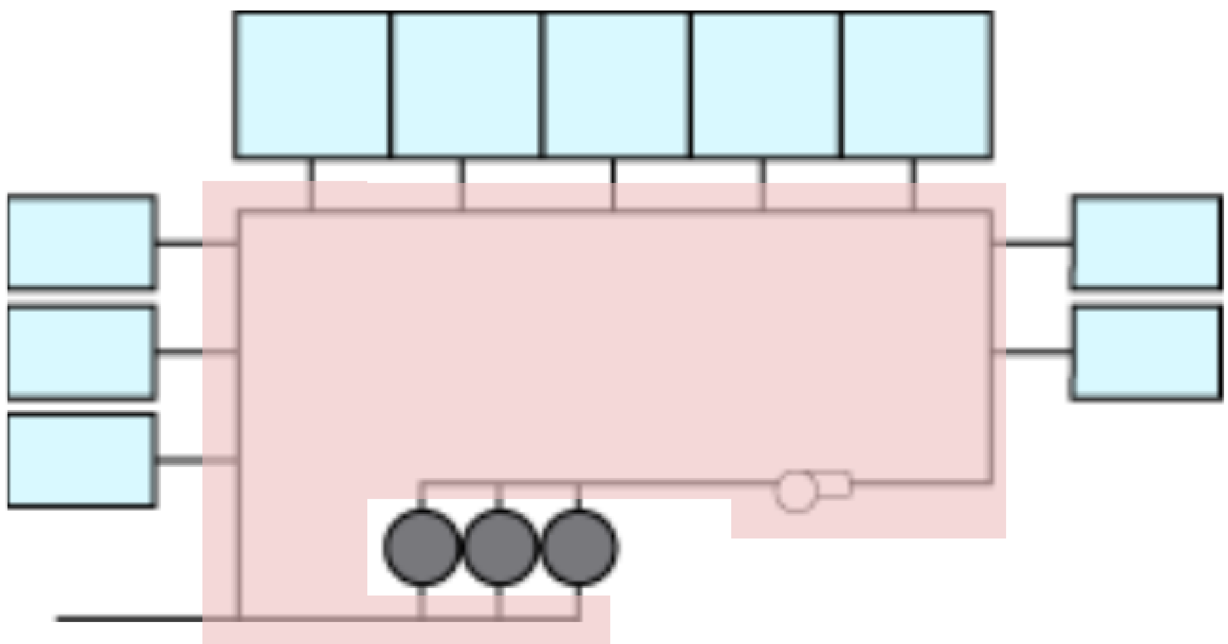
    Moody, Lewis F. “Friction Factors for Pipe Flow.” Trans. Asme 66, no. 8 (1944): 671–84.

Resources for Plumbing Data & Models

- IAPMO/ASPE/WQRF, pipe sizing research
- Gary Klein, fixture & pipe pressure losses
- Davis Energy Group, HWSIM model
- Carl Hiller, time-to-tap lab experiments
- LBNL, wireless field monitoring data

Central Recirculation DHW

- multi-family central systems only
- outside the dwelling units



Hourly Distribution Loss for Central Water Heating Systems

$$HRDL = NLoop \times HRLL + HRBL$$

Hourly Loop Losses

$$HRLL = \sum_n \left[PLWF_n + PLCD_n \right]$$

Hourly Branch Losses

$$HRBL = Nbranch \times HBUL + HBWL$$

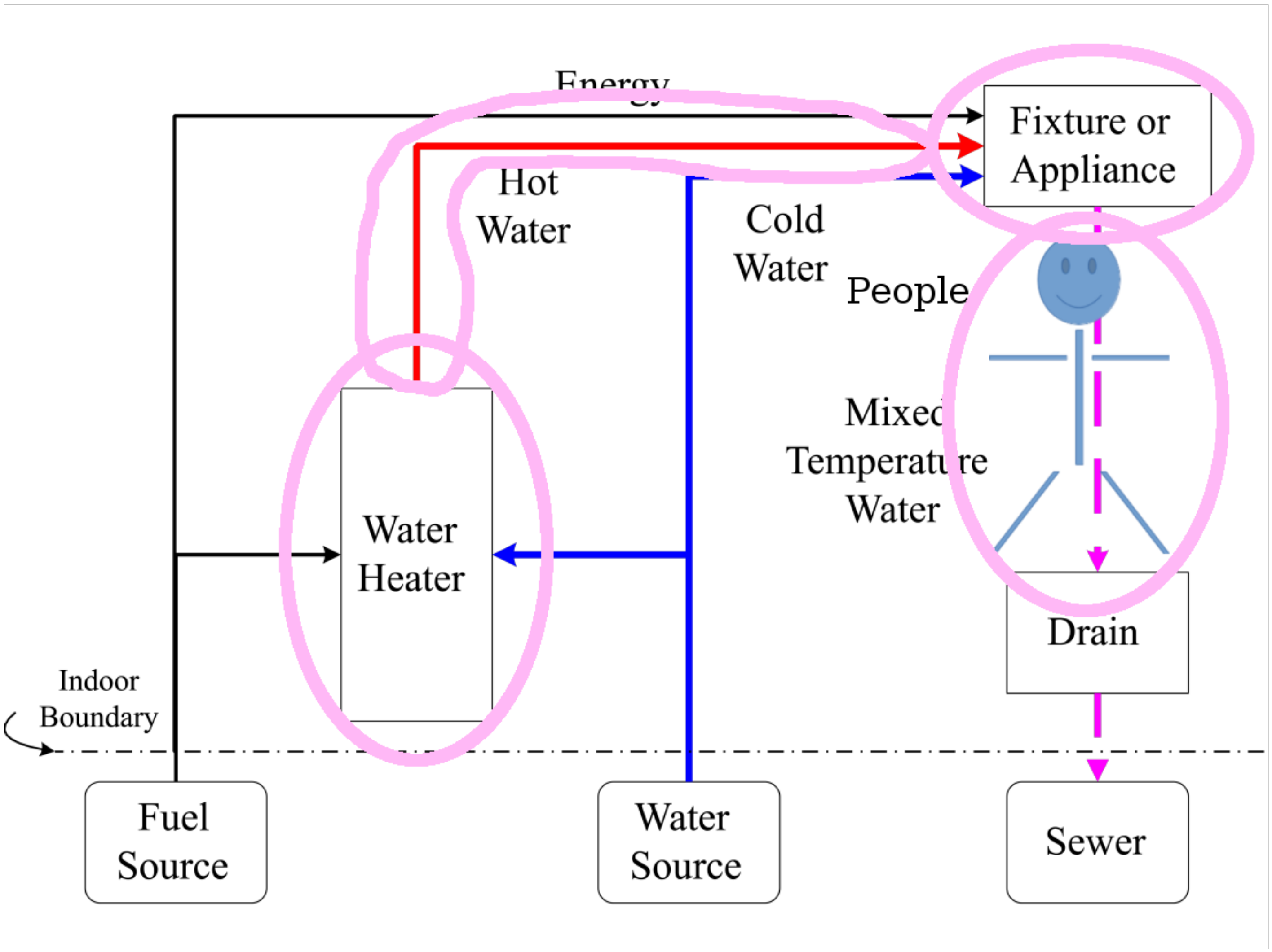
Multifamily Draw Patterns

- different for each dwelling unit
  - 5 different schedules by # bedrooms
- sum dwelling unit draws
- apply algorithms hourly

Shortcomings of 2016 ACM Central DHW

- default configuration extremely simplified
- default vs standard didn't make sense
- model actual plans?
- DHW system (probably)
  - on plans
  - engineered

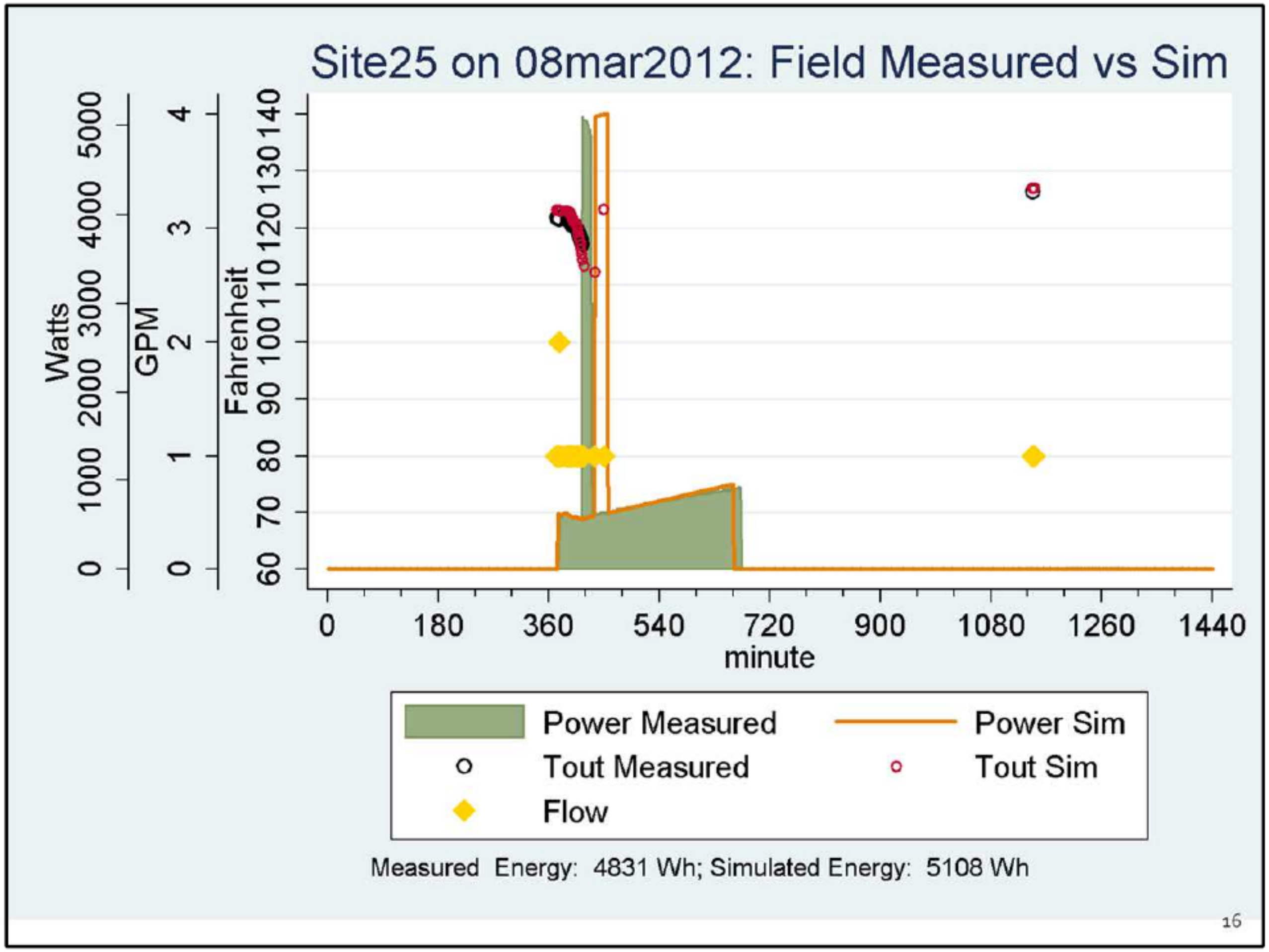
Water Heaters



Heat Pump Water Heaters!

- Ecotope model is now in CBECC-Res
- list of HPWH models from NEEA
- electric resistance is simplified HPWH

Water Heater Simulation Model



source: Larson, Ben and Michael Logsdon, Heat Pump Water Heater - Quick Simulation Approach, ACEEE Hot Water Forum 2013, November 4 2013.

Gas-fired Water Heaters

- draws summed hourly
- 2005 algorithms used
- storage uses LDEF
- tankless derated by .92 factor

Solar Thermal Water Heaters

- annual solar fraction
- applied equally to all draws?!
- PV powered electric water heaters?

Shortcomings of 2016 ACM Water Heaters

- Magical Water Heaters
- Delivery Temperature Issues
- Recirculation Loops vs Water Heaters
- Commercial HPWHs

Magical Water Heaters

- no runouts
- constant delivery temperature
- no cold water sandwiches on tankless
- HPWHs
  - 'magicalized' to match other technologies
  - setpoint 125 °F
  - electric resistance added if temperature drops
  - cold water added if temperature too high
  - fixture source temperatures 115 °F

Delivery Temperature Issues

- water heaters don't deliver constant temperature
- how to prevent undersizing water heaters?
- how should this be modeled?

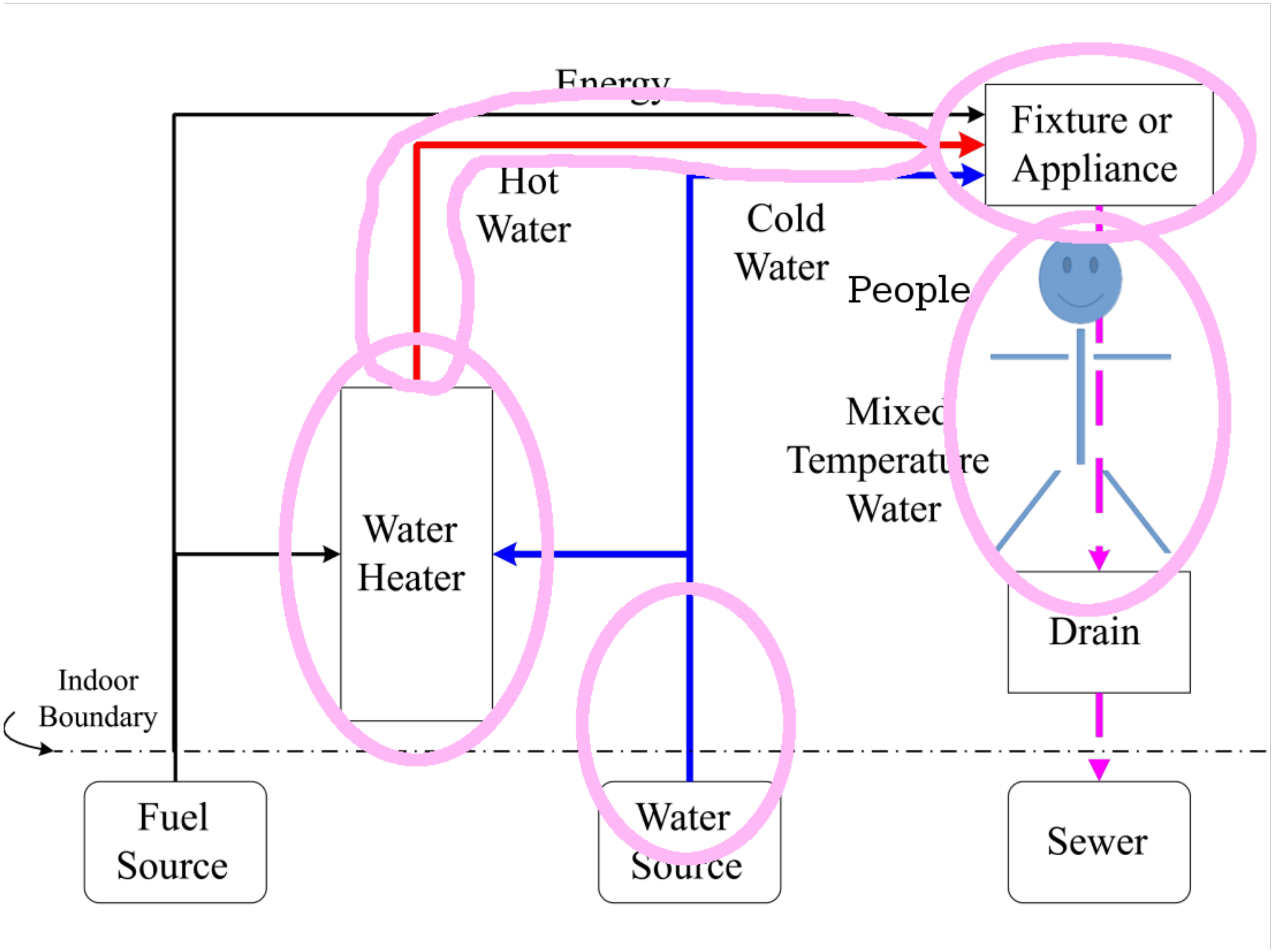
Recirc Loops vs Water Heaters

- warm/hot water back into water heaters
- COP drops for HPWHs
- RE drops for condensing gas WHs
- both within dwelling & central recirc

Commercial HPWHs

- already in multifamily central DHW
- not currently allowed by Title 24

Inlet Water Temperature



Inlet Temperature

$$T_{inlet} = T_{ground} \cdot 0.65 + T_{avg\,31} \cdot 0.35$$

$$T_{ground} = T_{yrAve} - 0.5 \left(T_{yrMax} - T_{yrMin} \right) \times \cos \left(2\pi \left(\theta - \frac{1}{365} \right) - 0.6 - \phi \right) \times \gamma$$

where:

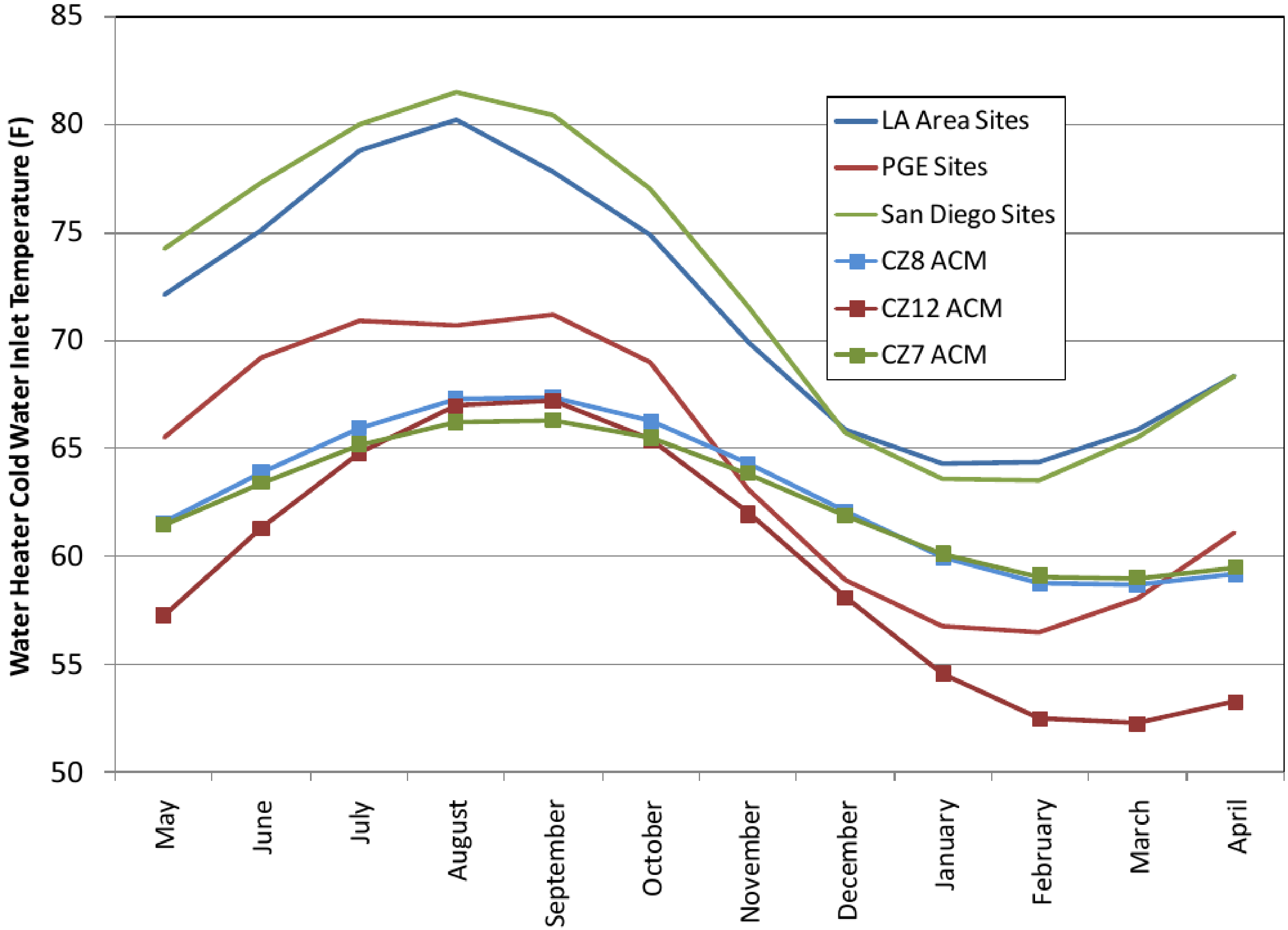
$$\phi = \arctan \left(\frac{1 - e^{-\beta} \left(\cos\beta - \sin\beta \right)}{1 - e^{-\beta} \left(\cos\beta - \sin\beta \right)} \right)$$

$$\gamma = \sqrt{\frac{e^{2\beta} - 2 e^{\beta} \times \cos(\beta) + 1}{2\beta^2}}$$

$$\beta = \sqrt{\frac{\pi}{\left(0.025 * 365 * 24 \right)}} \times 10$$

Ground temperature equation derived from work by National Bureau of Standards for the Office of Civil Defense, U.S. Department of the Army in the mid 1960s to aid in the design of bomb shelters.

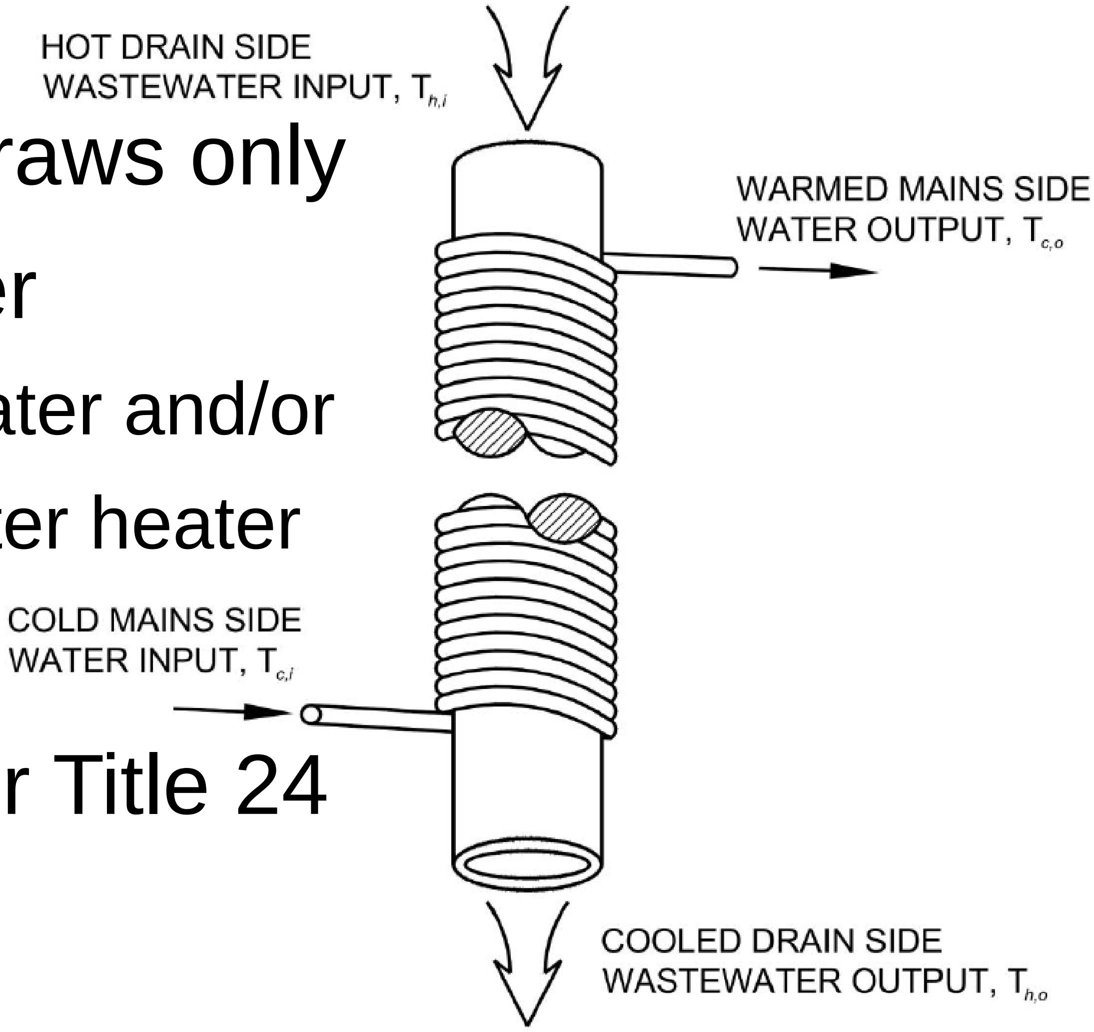
Mains Water Temperature



source: California Utilities Statewide Codes and Standards Team. “Single Family Water Heating Distribution System Improvements 2013 California Building Energy Efficiency Standards,” September 2011. http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Residential/Water_Heating/2013_CASE_R_SEMPRA_Single_Family_DHW_%20Sept_2011.pdf.

Drain Water Heat Recovery

- applied to shower draws only
- impacts water heater
  - lower flow for hot water and/or
  - warmer Tinlet to water heater
- CSA rating
- testing at ATS lab for Title 24



source: Manouchehri, Ramin. "Predicting Steady-State Performance of Falling-Film Drain Water Heat Recovery Systems from Rating Data." Master of Applied Science in Mechanical Engineering, University of Waterloo, 2015. https://uwspace.uwaterloo.ca/bitstream/handle/10012/10035/Manouchehri_Ramin.pdf.

Emerging DWHR Technologies

- horizontal drain water heat recovery
  - no test
  - no ratings
- grey water heat recovery
  - no test
  - no ratings

Water in Title 24?

- not just hot water
- required by legislation/regulation
- driven by drought
- add?
  - toilets
  - landscaping
  - greywater
  - rain water harvesting
- issues of utility pipe sizing
  - on-premise pathogens (water age)
  - neighborhood sewer lines oversized

Jim Lutz
jdlutz@hotwaterresearch.net