Peak Water Demand Study: *Development of Metrics and Method for Estimating Design Flows in Buildings*

ACEEE 2016 HOT WATER FORUM: PORTLAND, OR

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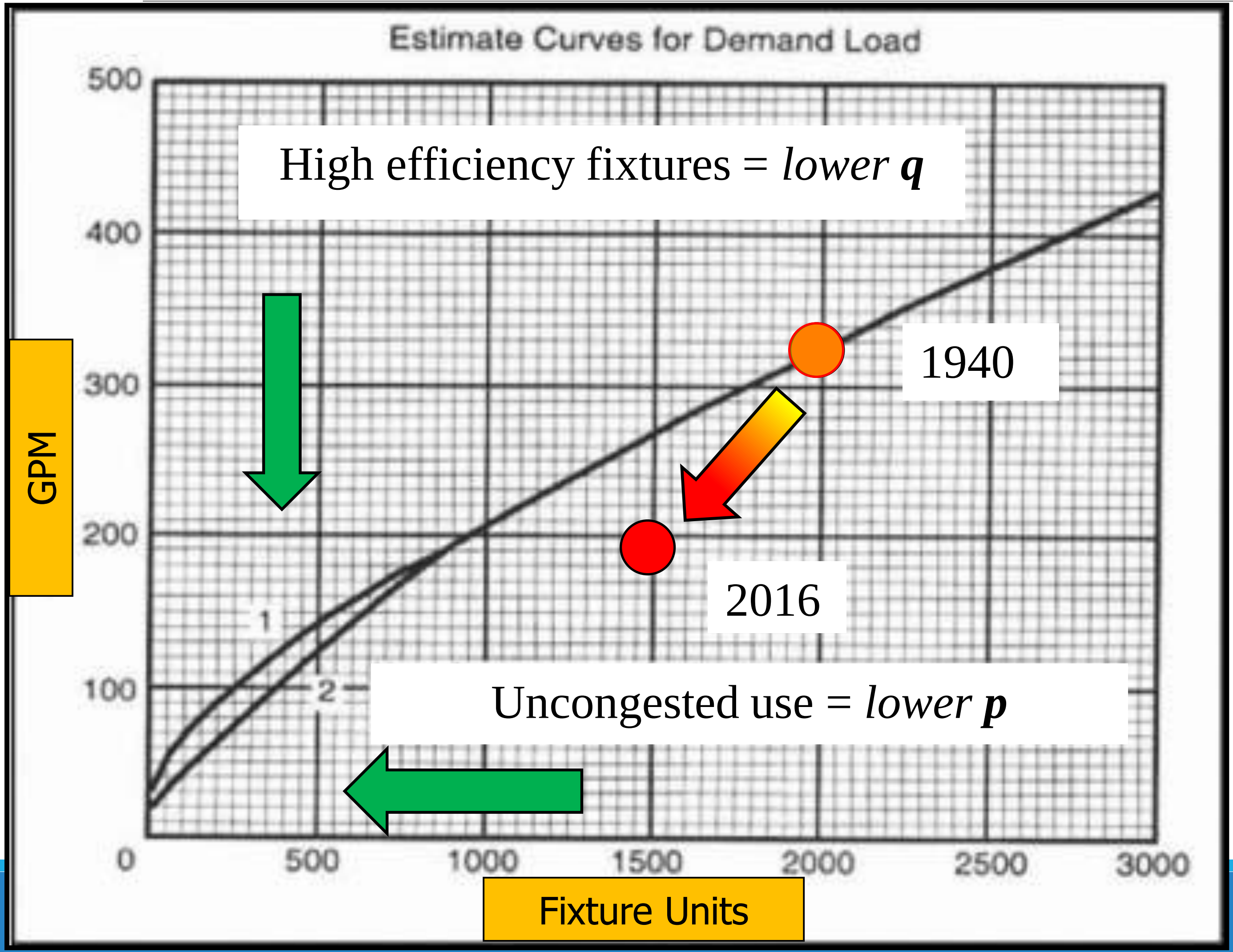
Outline

- Background
- Task Group
- Water Use Database
- Key Parameters and Considerations
- Application
- Conclusion

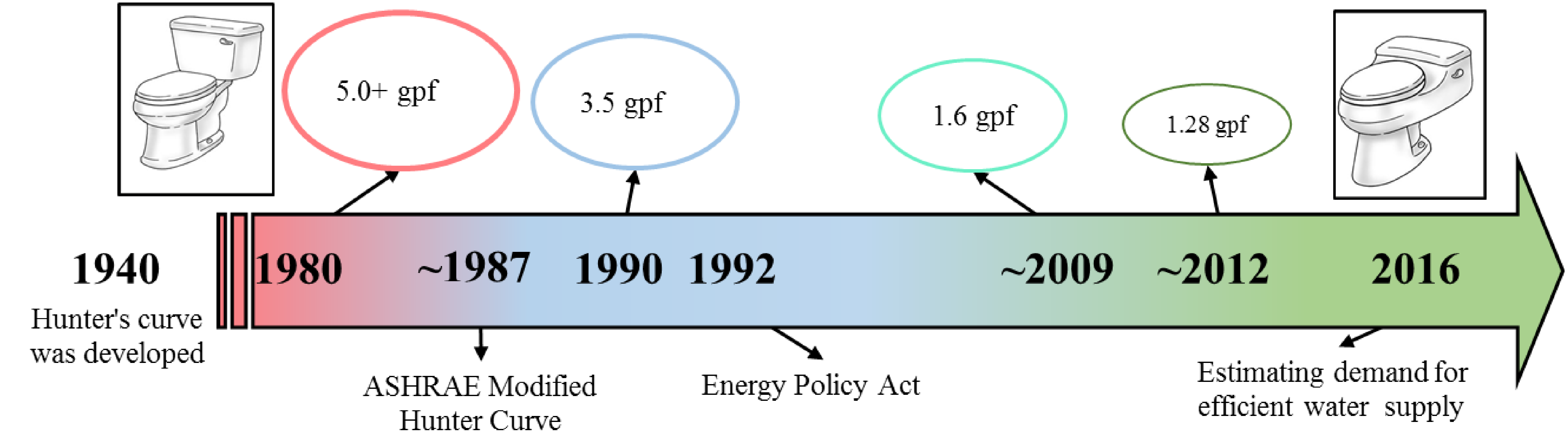
BACKGROUND

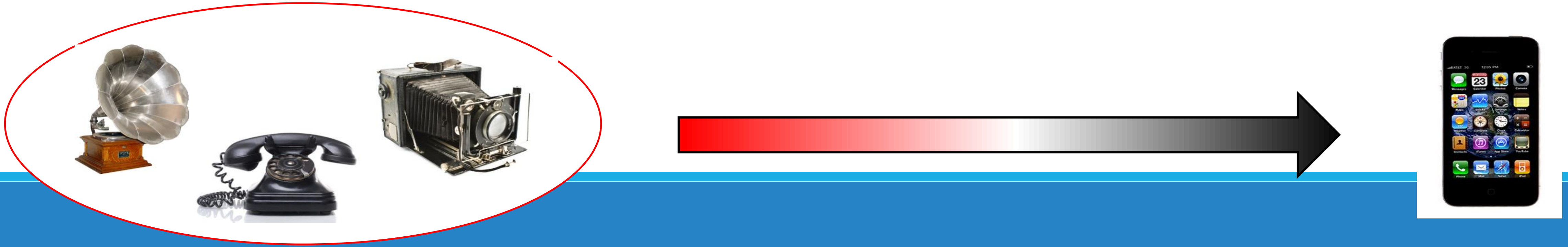
Hunter's Curve



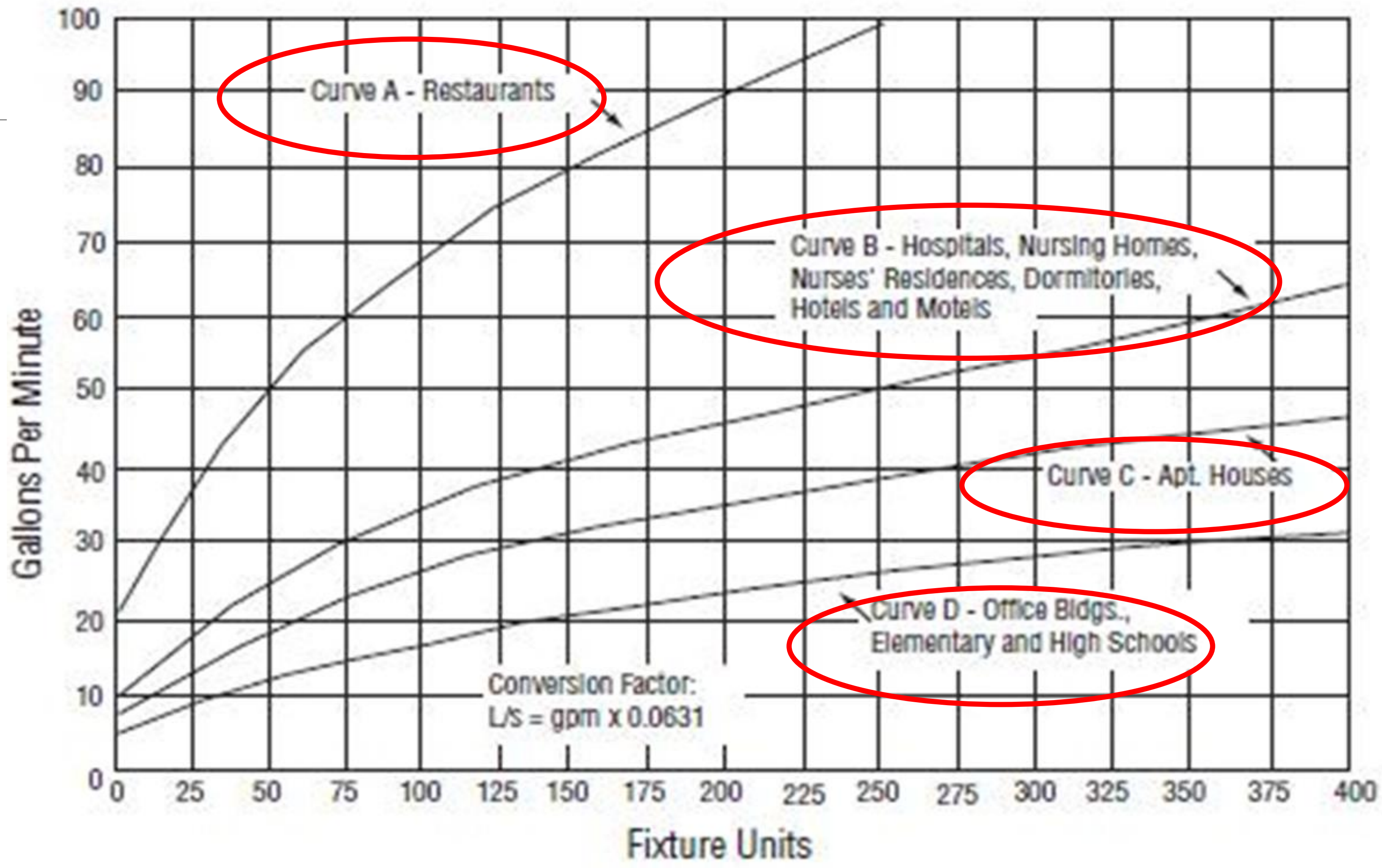
Today, **Hunter's curve** is often faulted for giving overly conservative design….Why?

Changing Times





Modified Hunter's Curve(s)



Different curve for different end users

ASPE
American Society of Plumbing Engineers™

Water Quality Association®

IAPMO®
International Association of Plumbing and Mechanical Officials

TASK GROUP

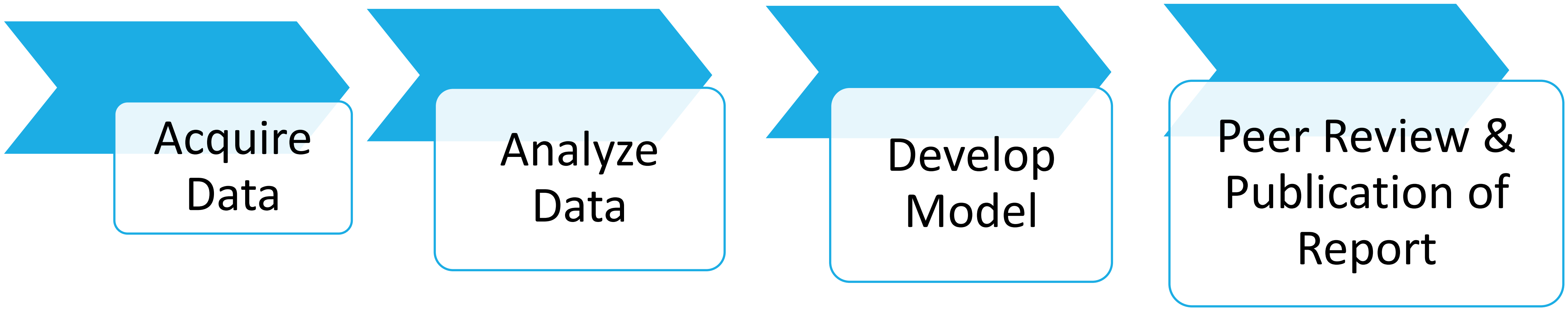
IAPMO Task Group Orders

International Association of Plumbing and Mechanical Officials

“….will work singularly to develop the probability model to predict peak demands based on the number of plumbing fixtures of different kinds installed in one system.”

(Bring Hunter into 21st Century)

Project Activities

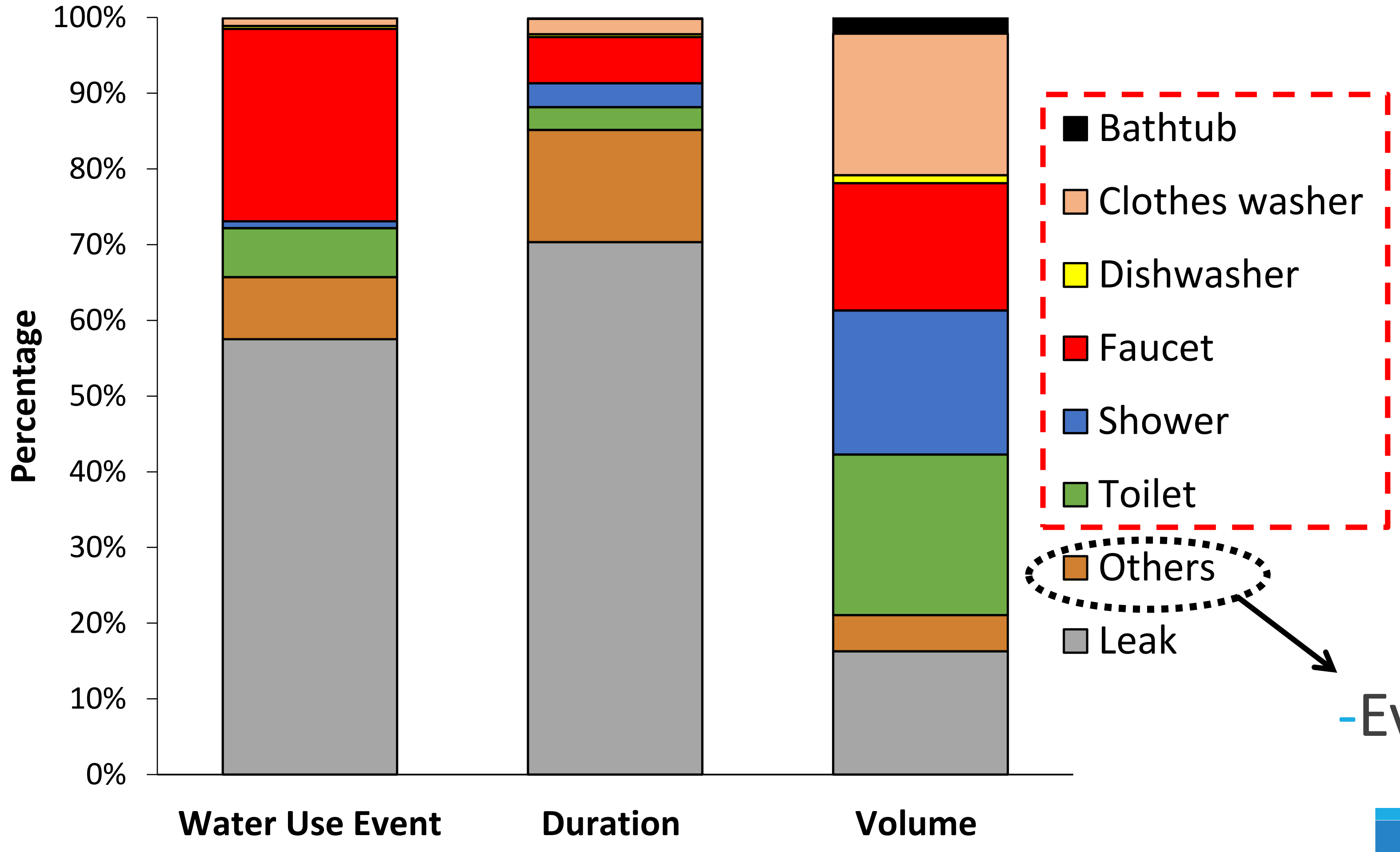


WATER USE DATABASE

Database: Location of Homes

- Over 1000 households
- Surveyed between 1996 -2011
- 2,800 residents
- 11,350 monitoring days

Database: Summary of Measured Data

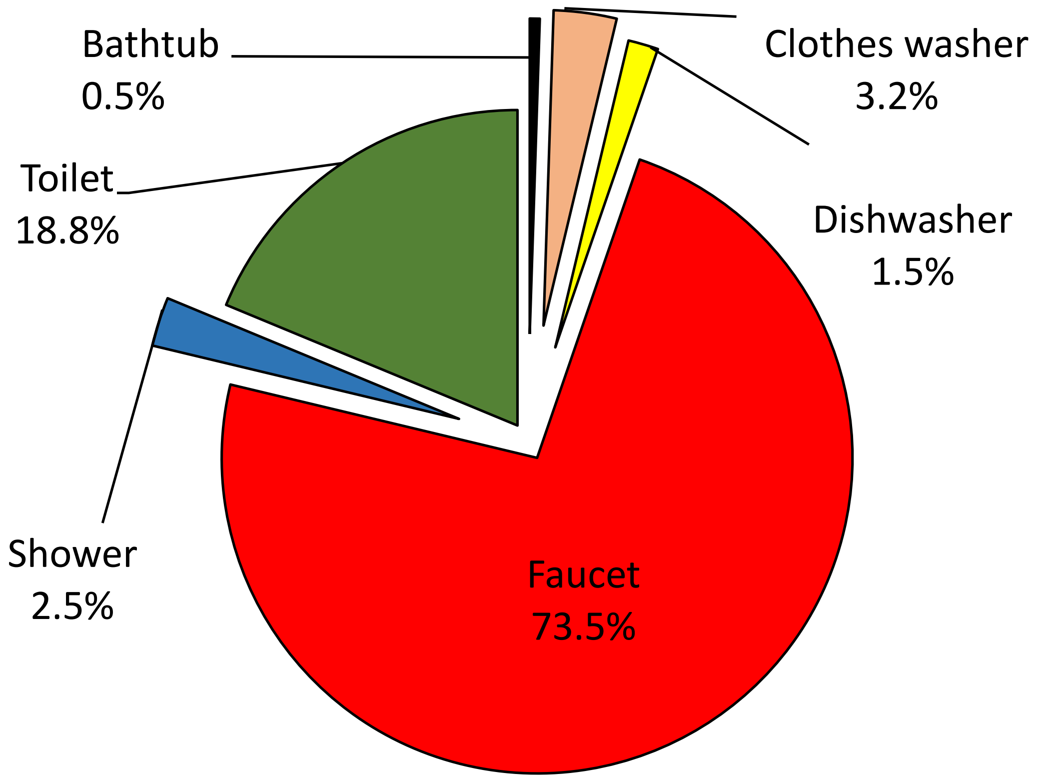


- Six unique fixtures
- 862,900 water use events (excluding leaks)
- 1,591,700 gallons
- 889,700 minutes

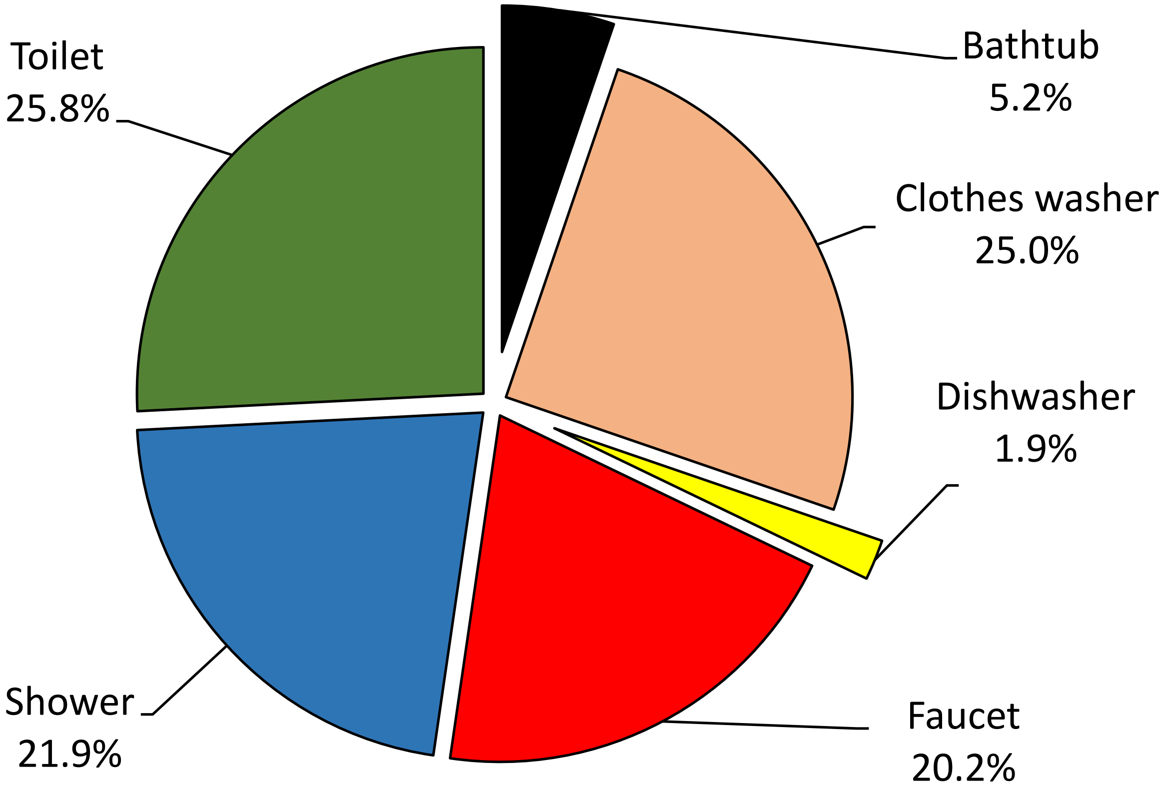
-Evaporative Cooler

Database: Details of Water Use at Fixture

FREQUENCY OF FIXTURE USE PER CAPITA PER DAY



VOLUME OF WATER USE PER CAPITA



Database: Residential Fixture Classification

Fixture*	Ultra-Efficient	Efficient	Inefficient
Clothes washer (gallons /load)	< 20	20 – 30	> 30
Dishwasher (gallons/cycle)	< 1.8	1.8 – 3.0	> 3.0
Shower (gallon/minute)	< 2.2	2.2 – 2.5	> 2.5
Toilet (gallon/flush)	< 1.8	1.8 – 2.2	> 2.2

***Bathtubs and faucets were excluded**

KEY PARAMETERS & CONSIDERATIONS

Key Fixture Characteristics

1 - ***n*****:** Fixture Count

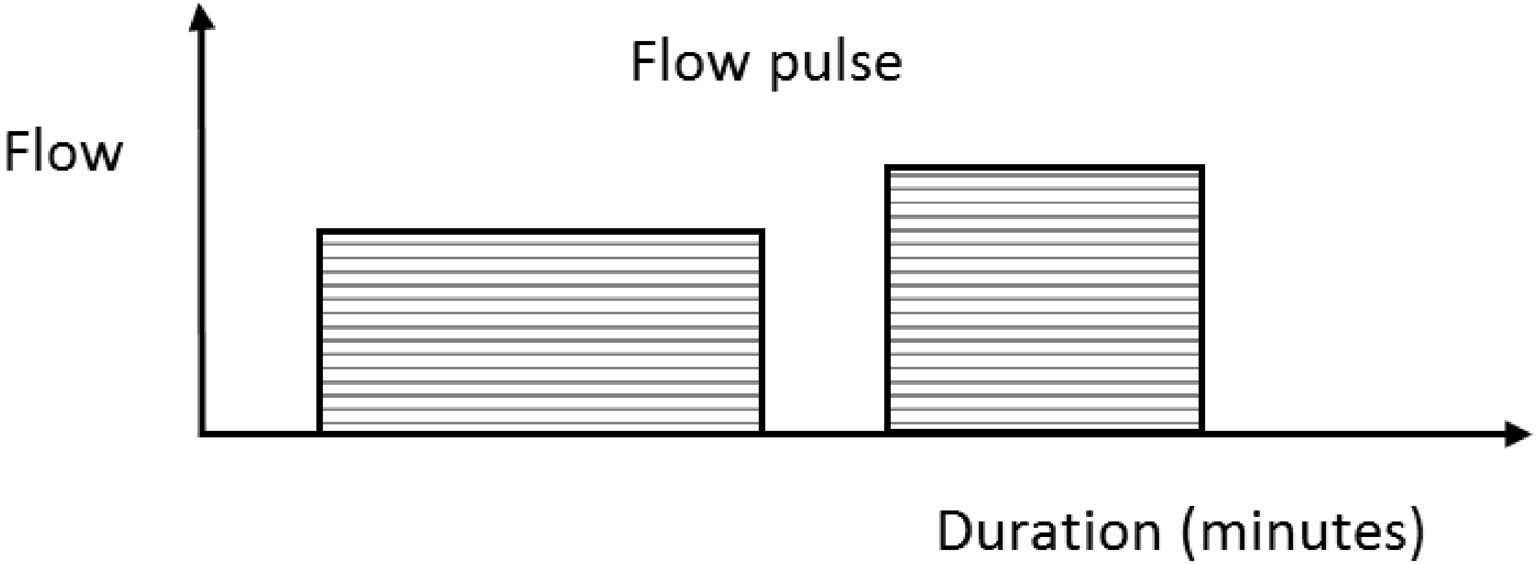
$1 \quad 2 \quad 3 \; . \; . \; . \; x \; . \; . \; . \; . \quad n$

2 - ***q*****:** Fixture flow rate

3 - ***p*****:** Fixture Probability of use

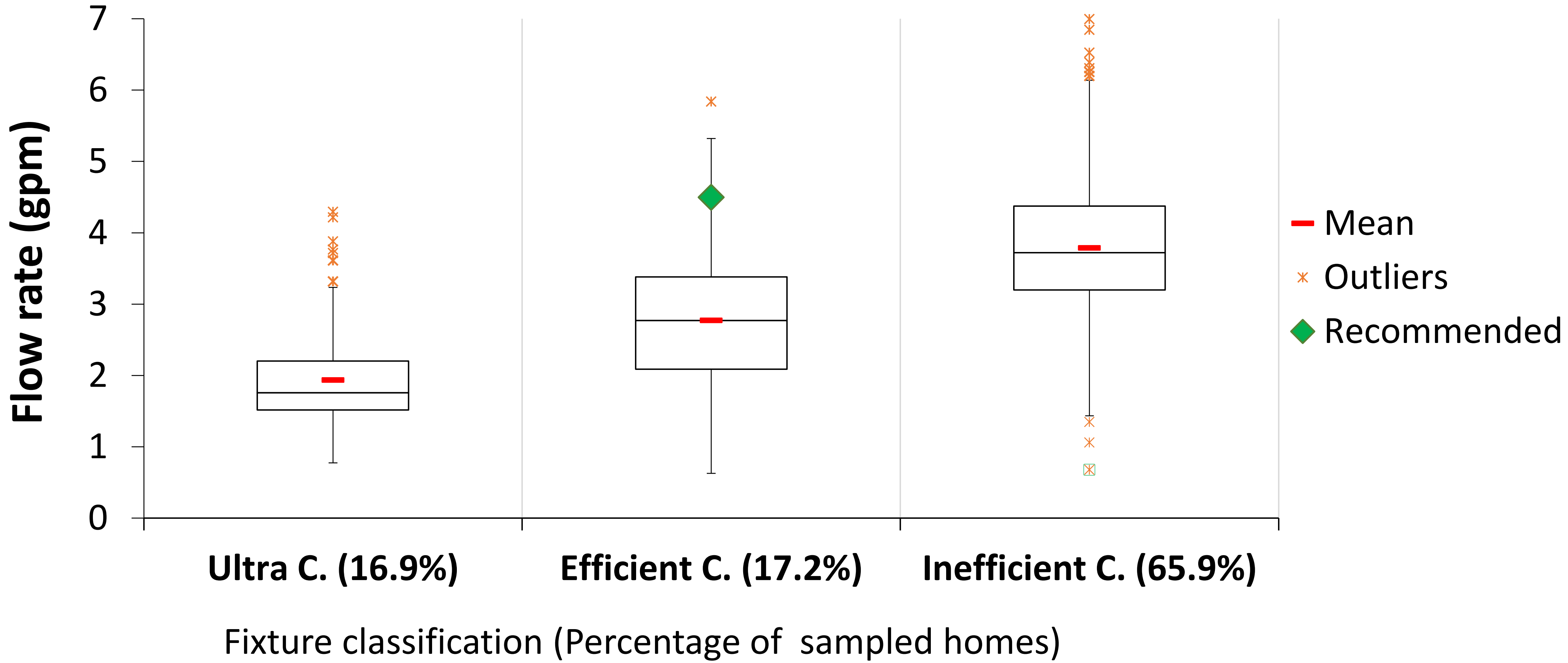
$$p = \frac{\sum t_i}{T}$$

Computed Fixture Flow Rate; *q*



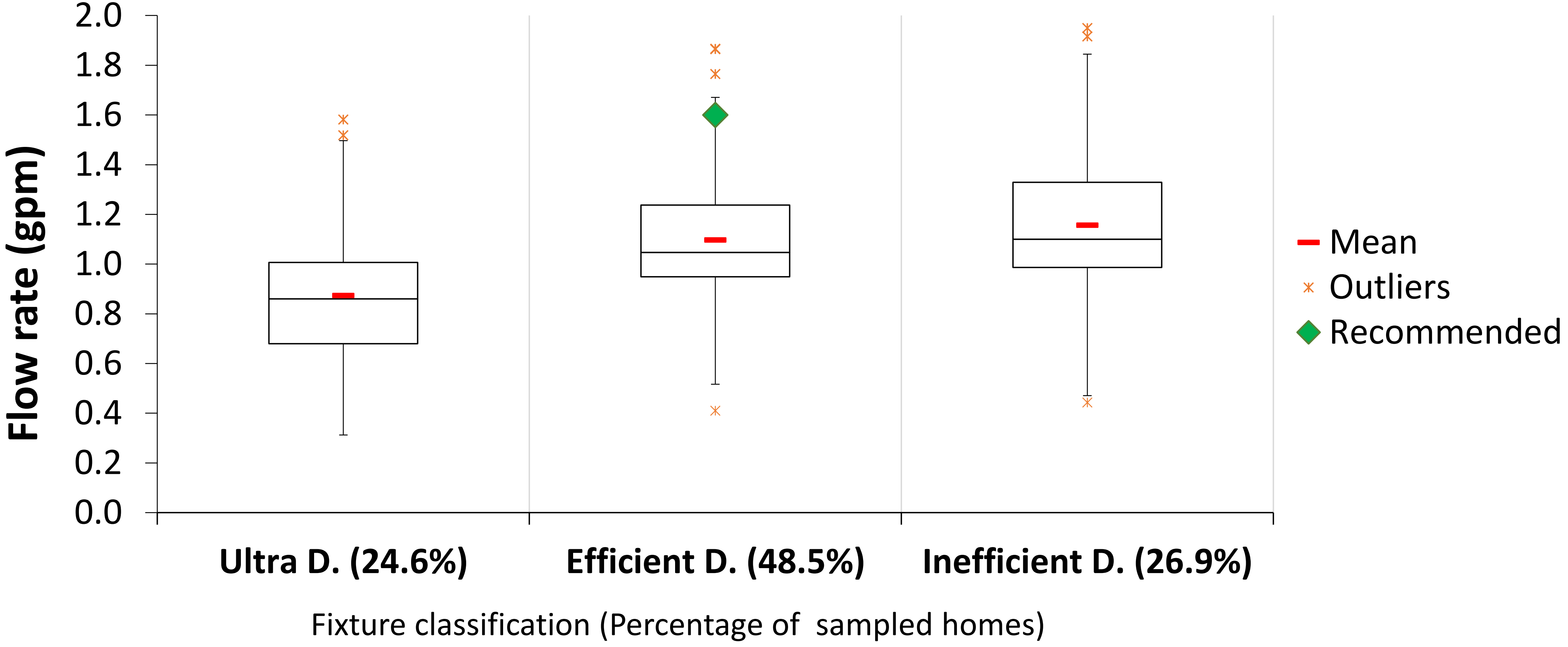
$$q = \frac{\sum Volume\ of\ each\ pulse\,(gallons)}{\sum Duration\ of\ each\ pulse\,(minutes)}$$

Clothes Washer Flow Rate



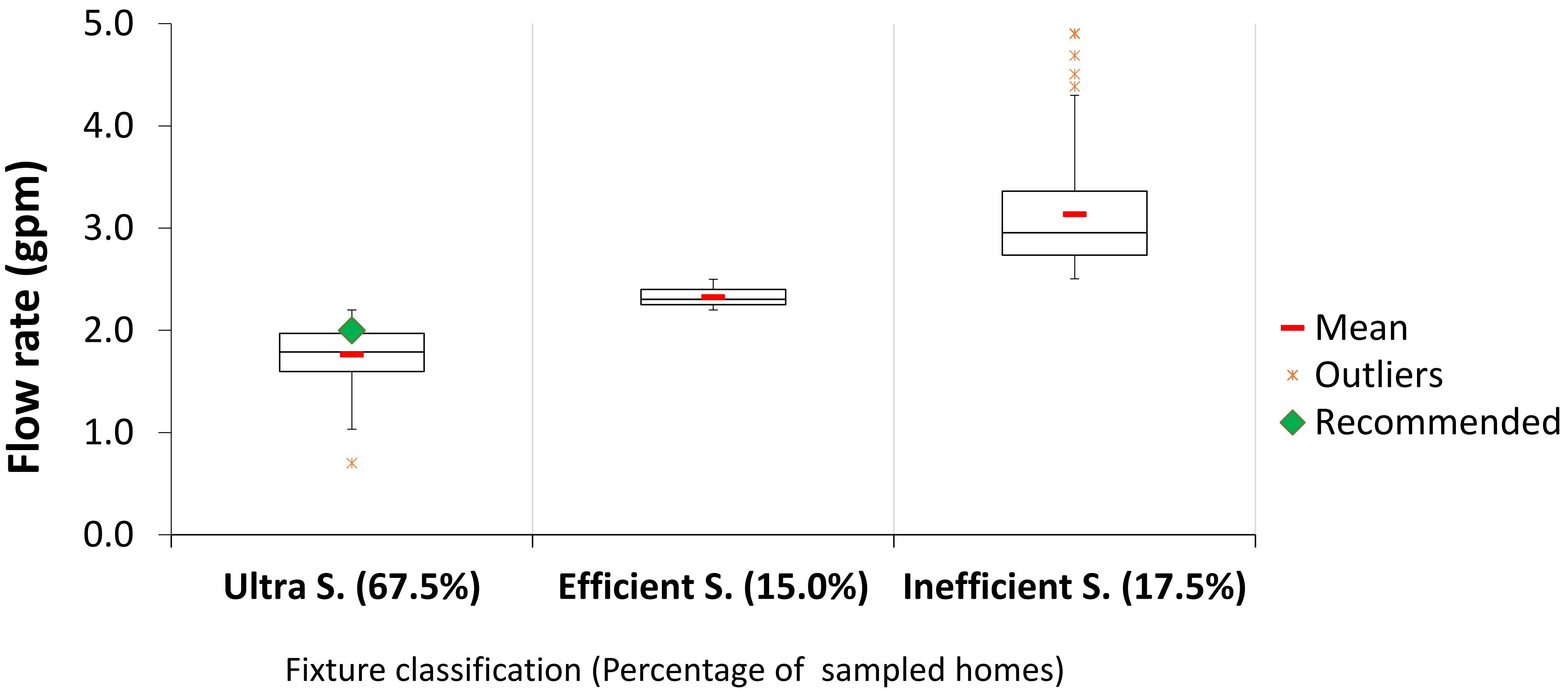
Clothes washer efficiency measured in gallons/load

Dishwasher Flow Rate



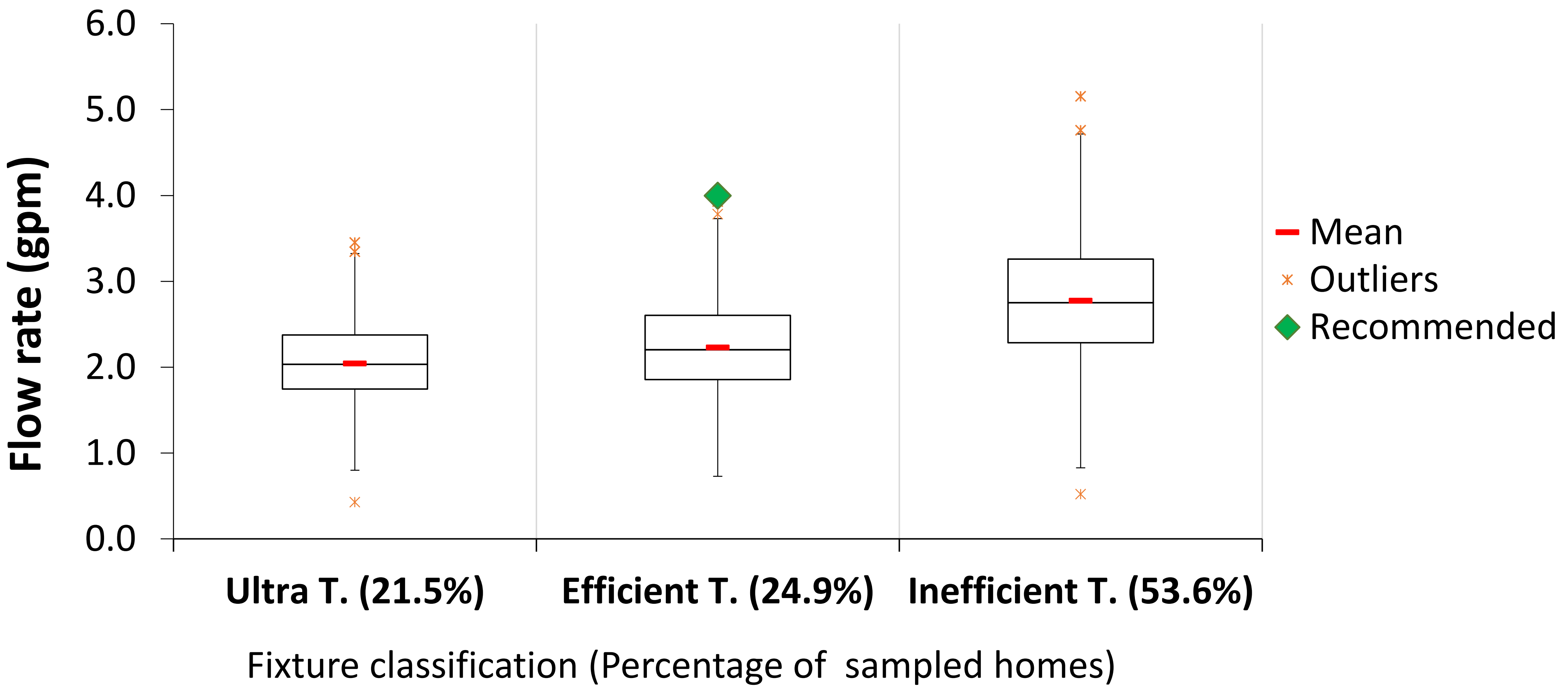
Dishwasher efficiency measured in gallons/cycle

Shower Flow Rate



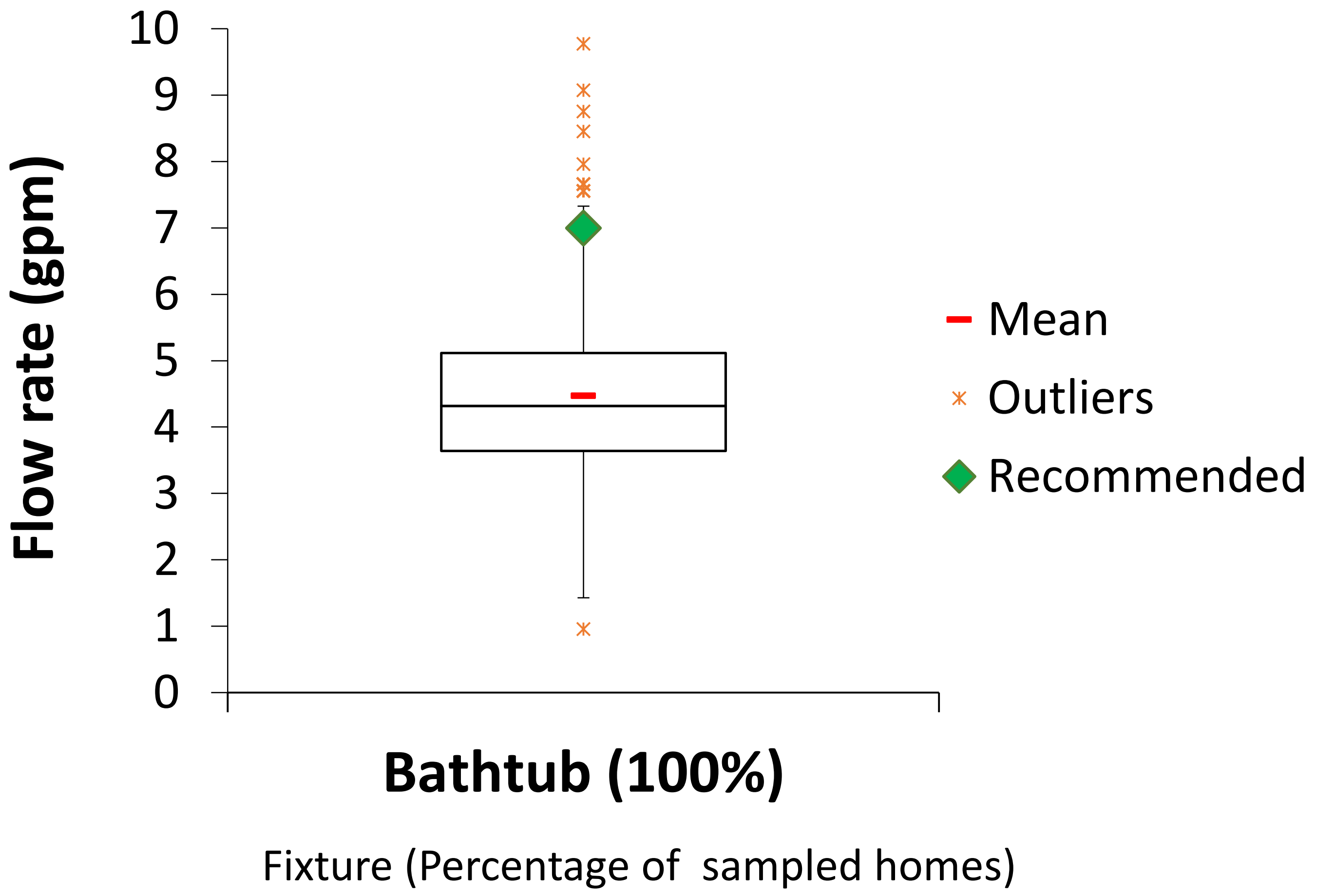
Shower efficiency measured in gallons/minute

Toilet (Water Closet) Flow Rate

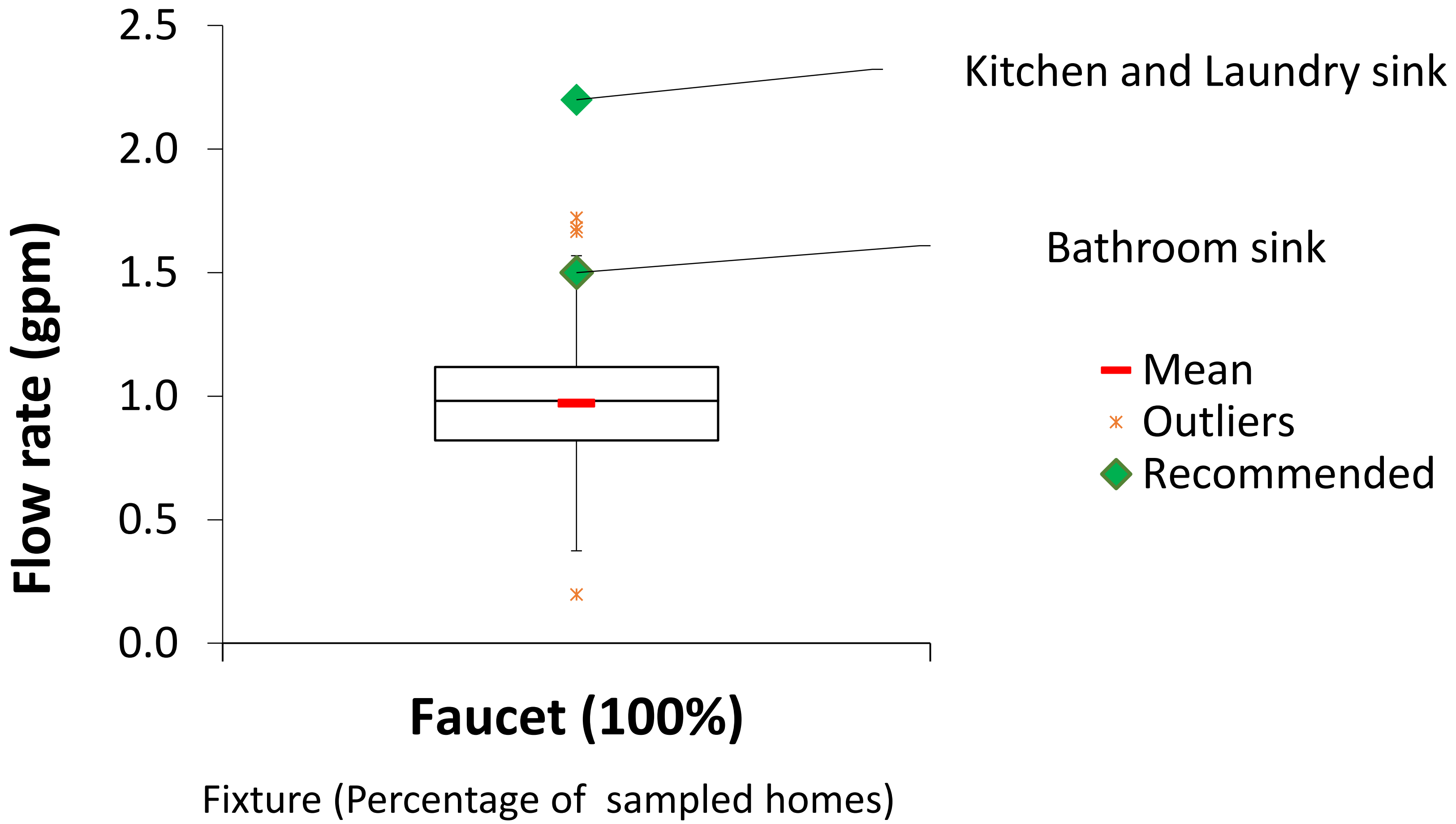


Toilet efficiency measured in gallons/flush

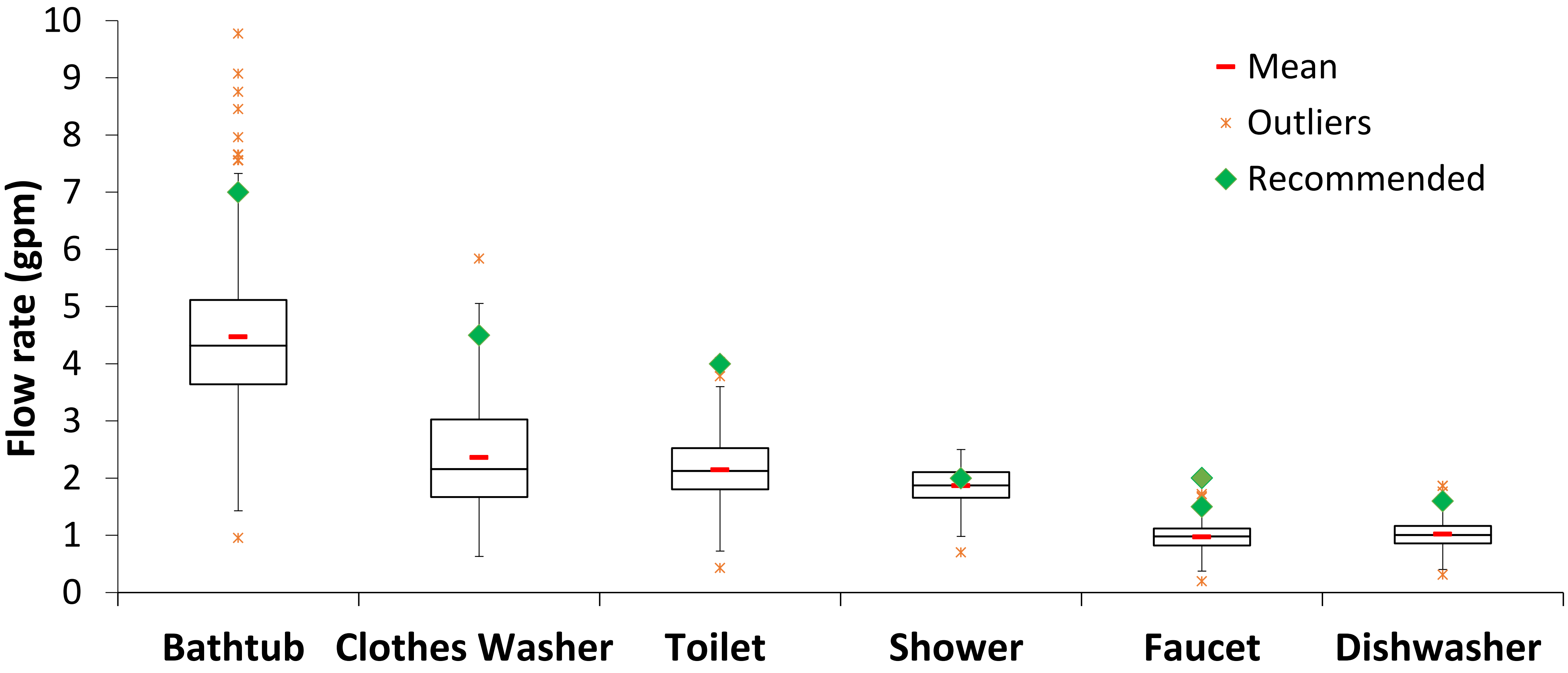
Bathtub Flow Rate



Faucet Flow Rate

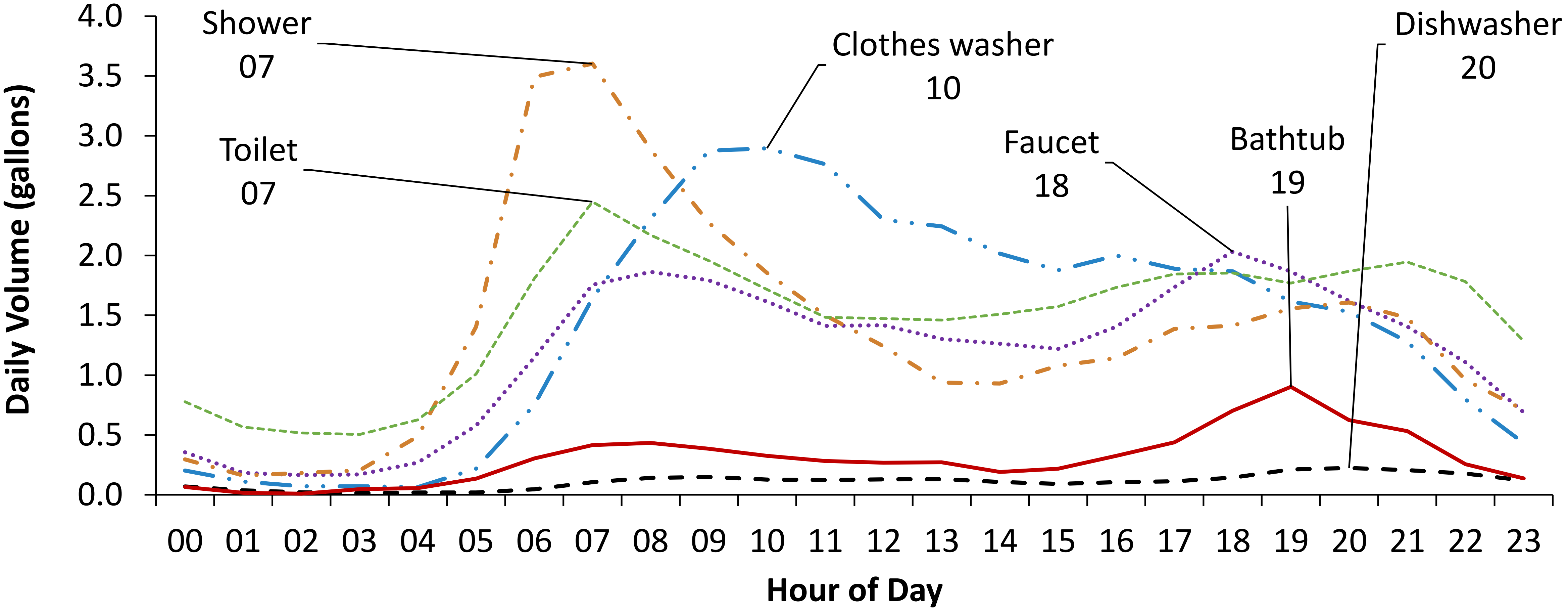


Summary of “Efficient” Fixture Flow Rate



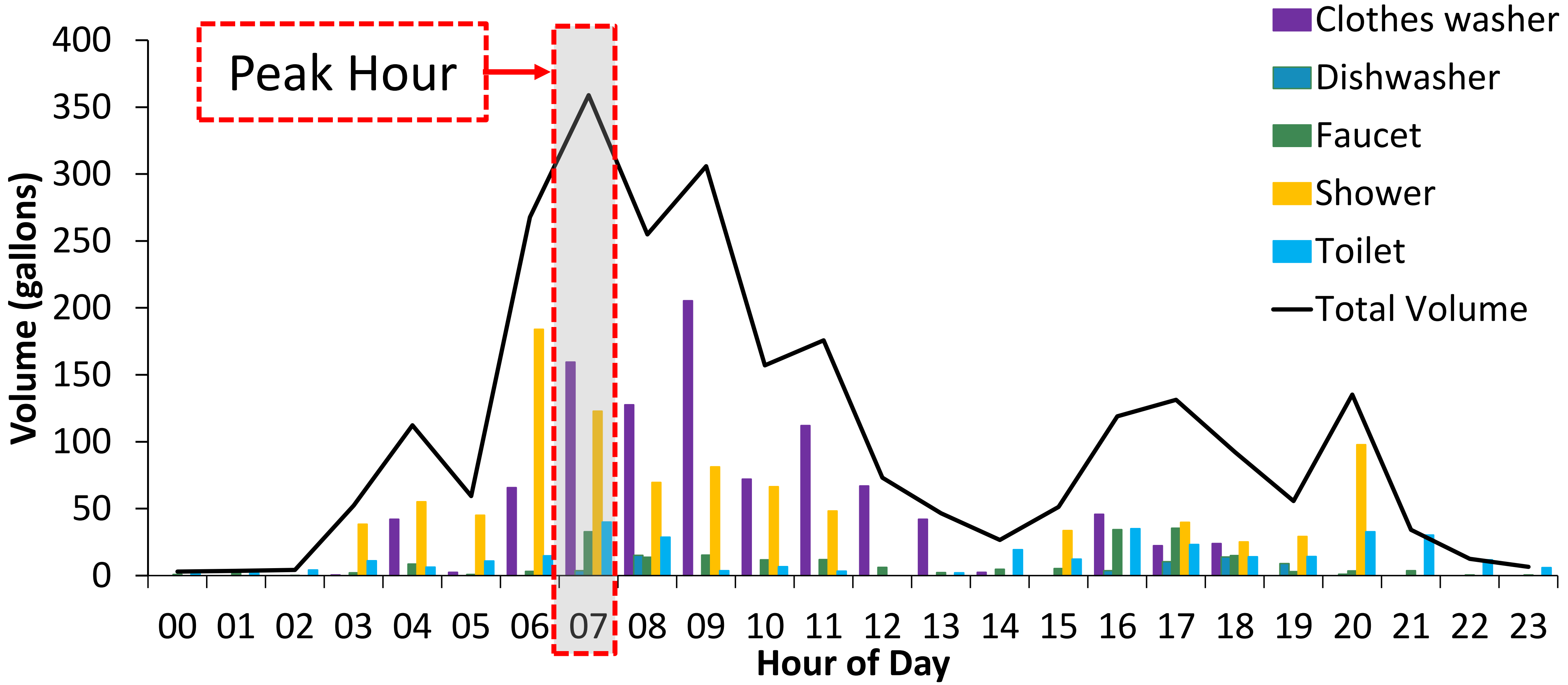
“Efficient” = Ultra-efficient and Efficient Fixtures

Peak Hour of Fixture Use (by Volume)

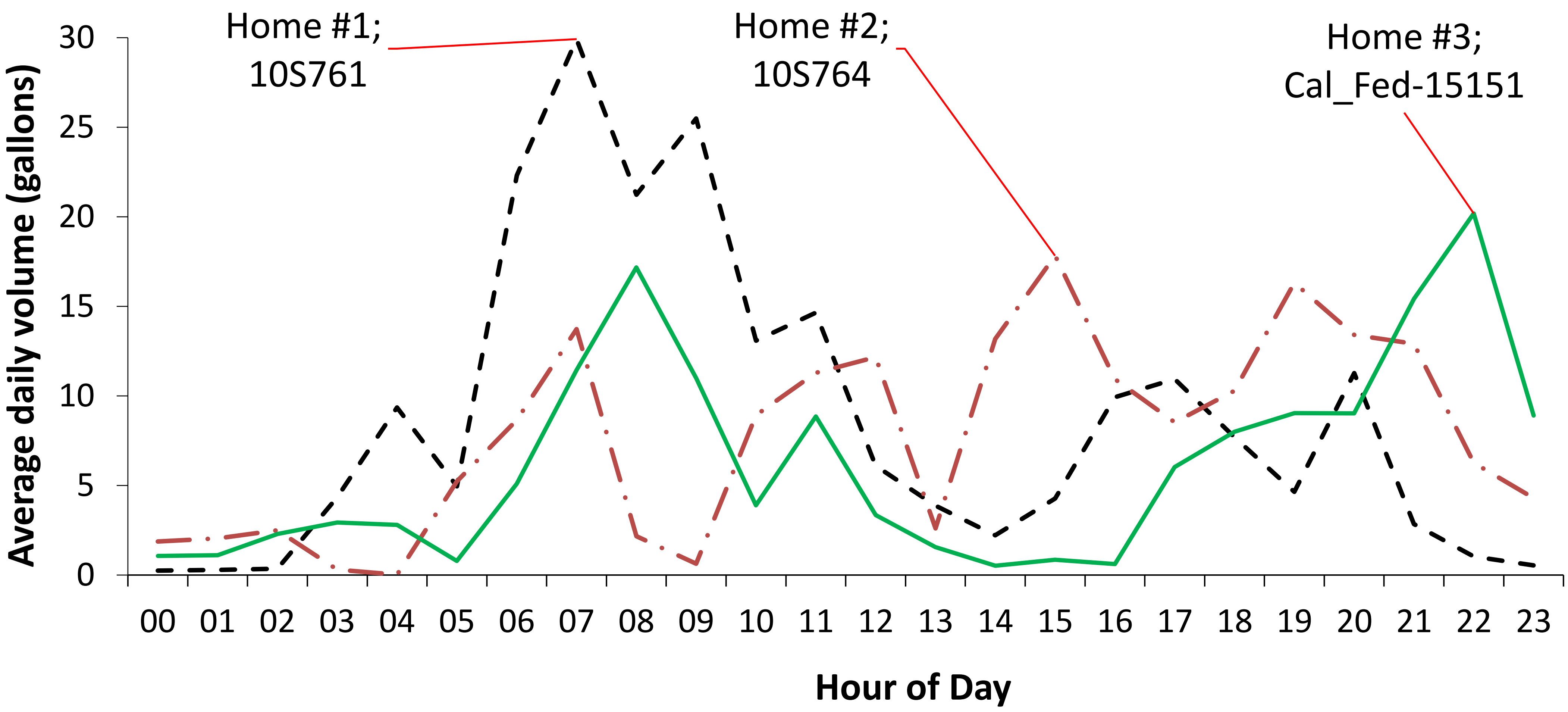


Average hourly volume of water use at a fixture per home per day

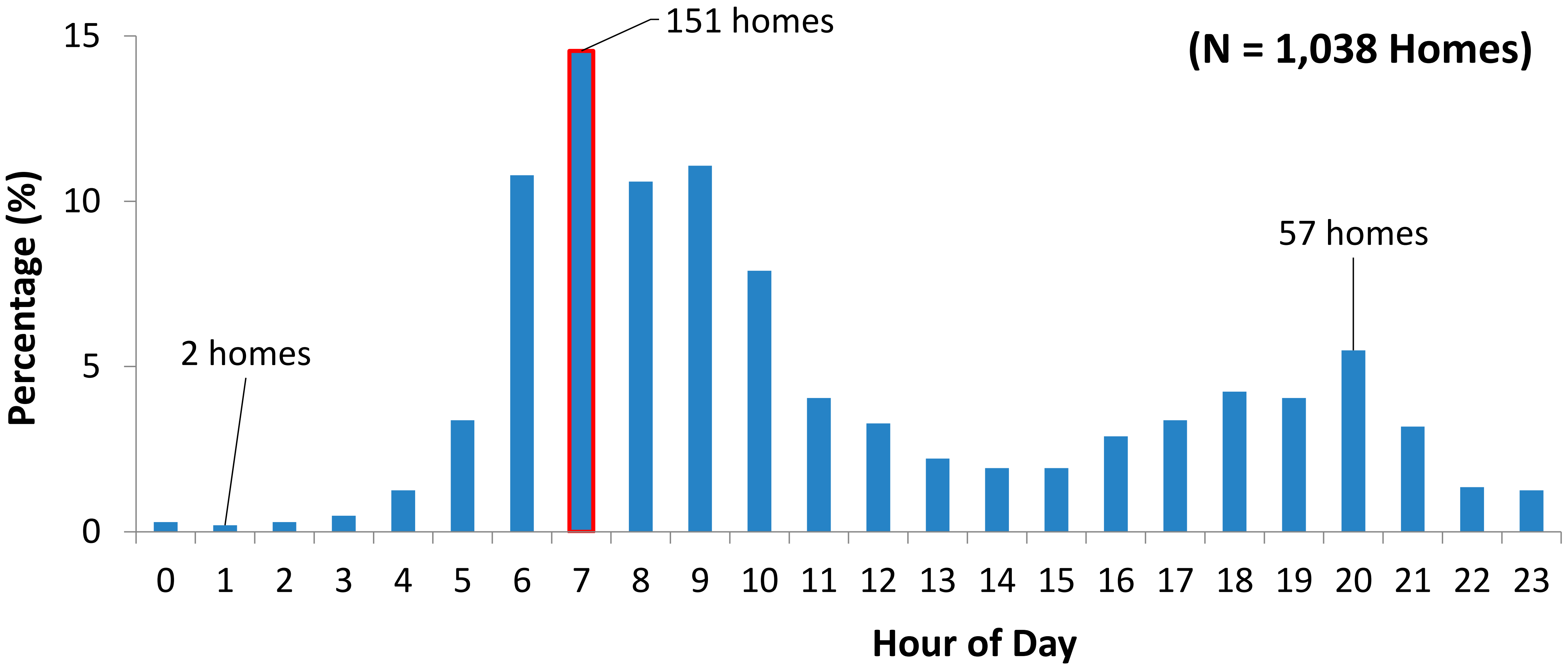
Single Home 12 Day Water Use Profile (10S761)



Multiple Homes Water Use Profile (by Volume)



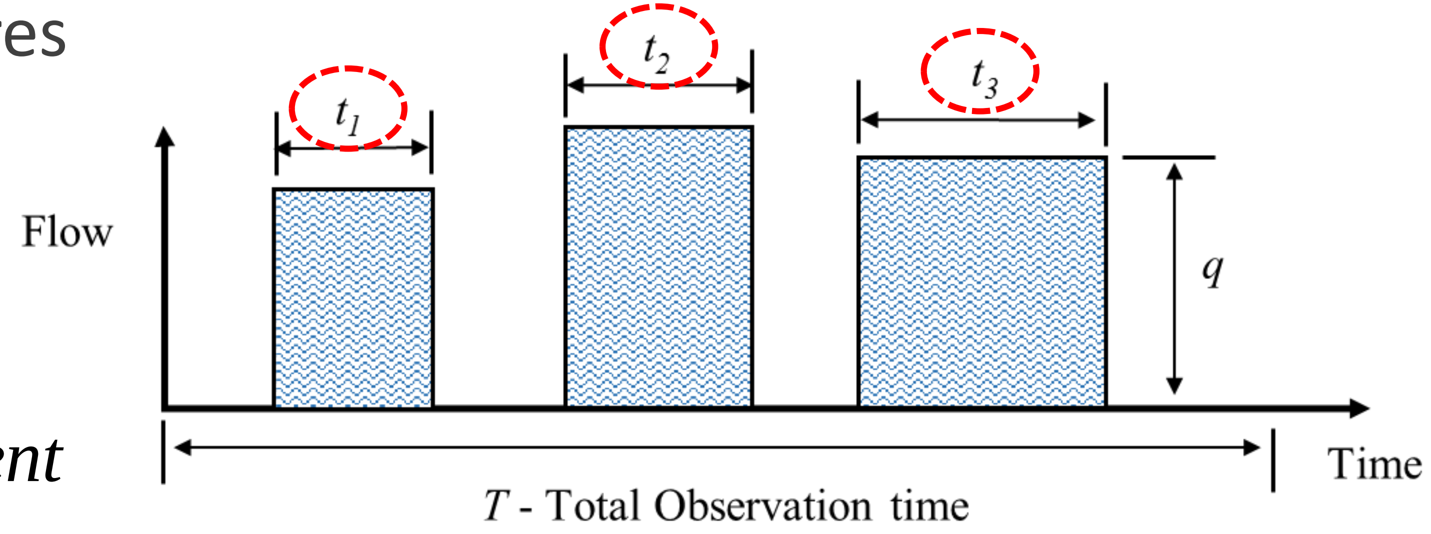
Distribution of Peak Hour of Water Use



Peak Hour Probability of Fixture Use

- Focused on only efficient fixtures

$$p = \frac{\sum_i t_i}{n \cdot D \cdot T}$$



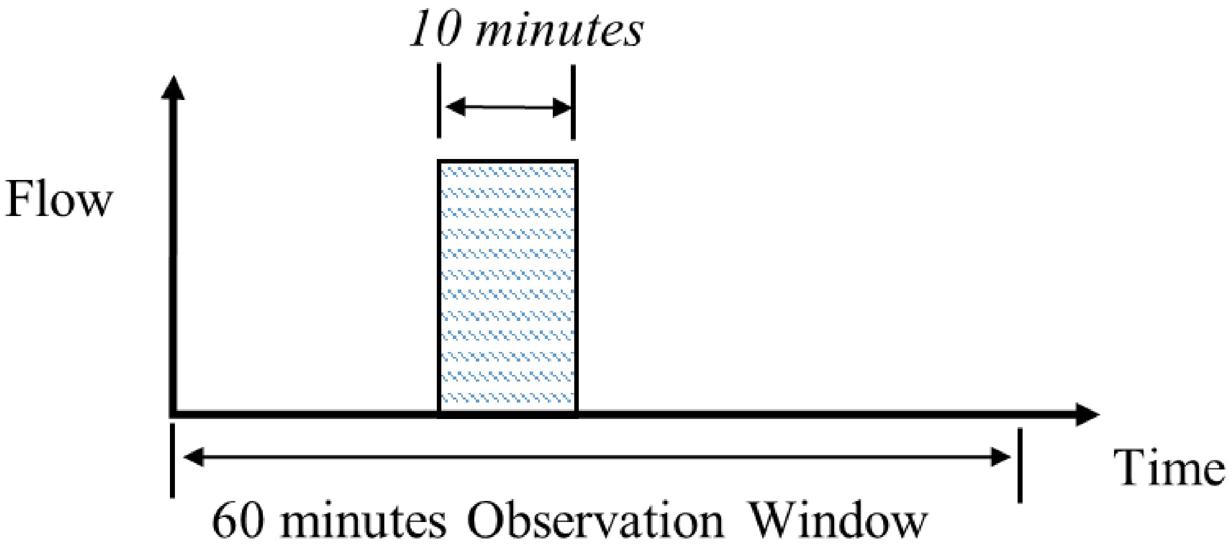
t_i – Duration of i^{th} water use event

n – Number of fixtures

D – Number of observation days

T – 60 minutes (1 hour observation window)

Probability of Fixture Use at Individual Homes

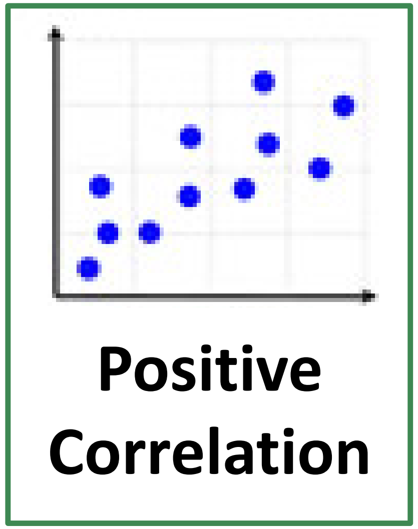


$$p = \frac{\sum_i t_i}{n \cdot D \cdot T}$$

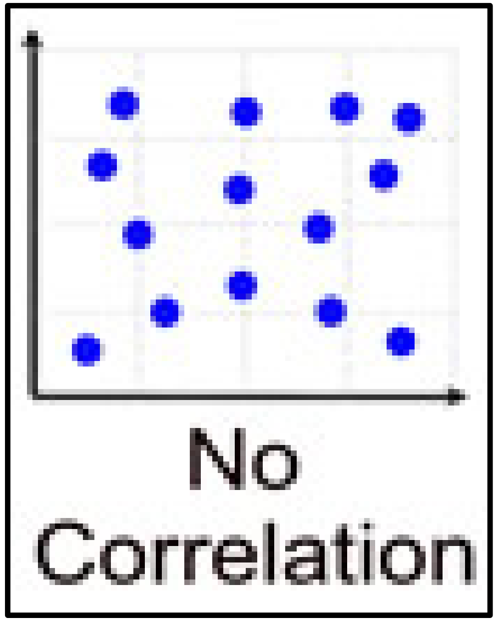
$$p = \frac{10\,minutes}{1\,fixture \cdot 1\,day \cdot 60\,minutes} = 0.17$$

Considered only efficient fixtures

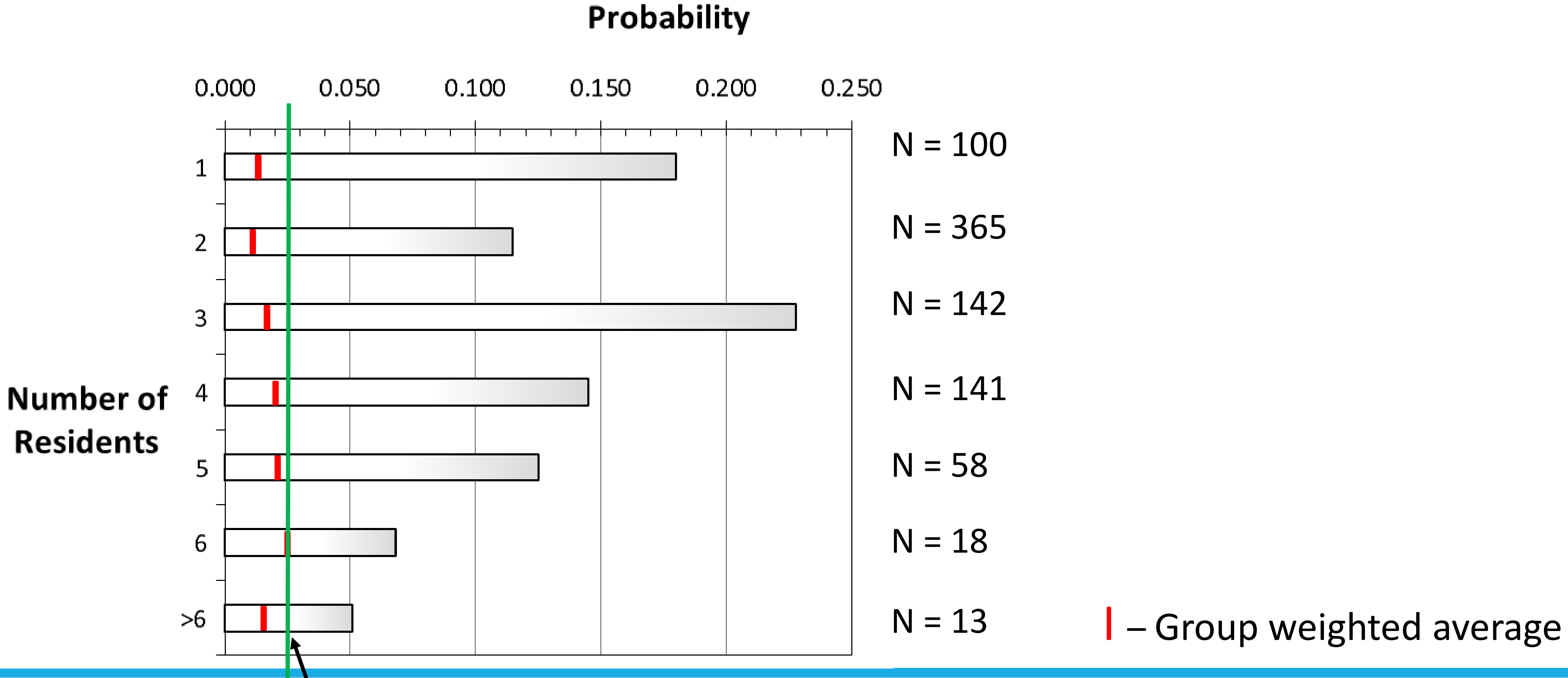
Probability of Fixture Use – Group of Homes



- Number of residents
- Number of bathrooms
- Number of bedrooms

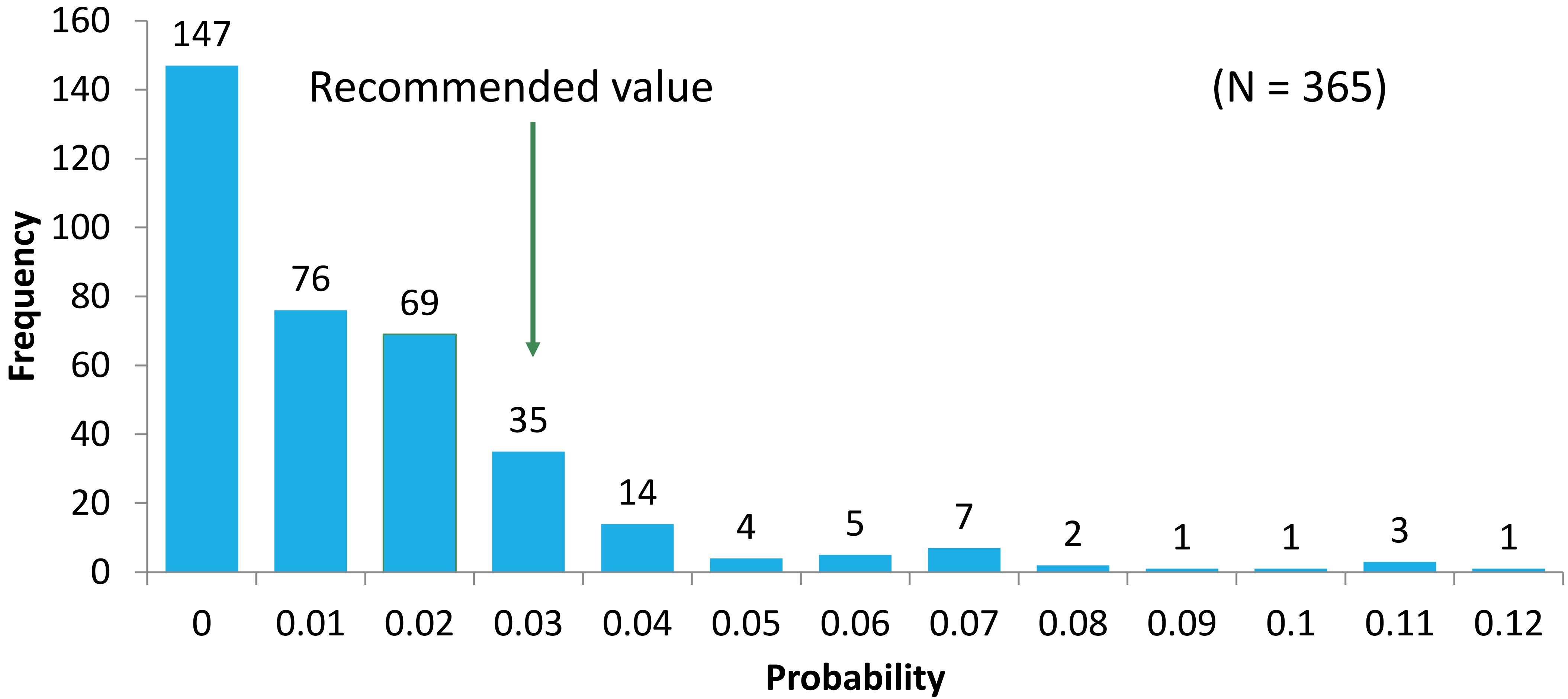


Probability of Shower Use



Recommended Value = 0.025

Distribution of Shower *p* values for Homes with 2 residents



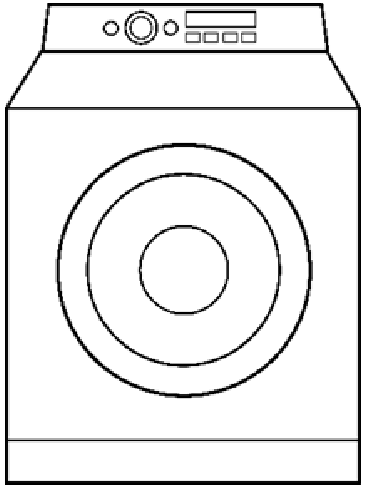
Summary Probability of Fixture of Use

- Each fixture has a unique water use profile.

- Probability of fixture use does not dependent on how frequent a fixture used.

- Probability of fixture use increased as the number of residents increased.

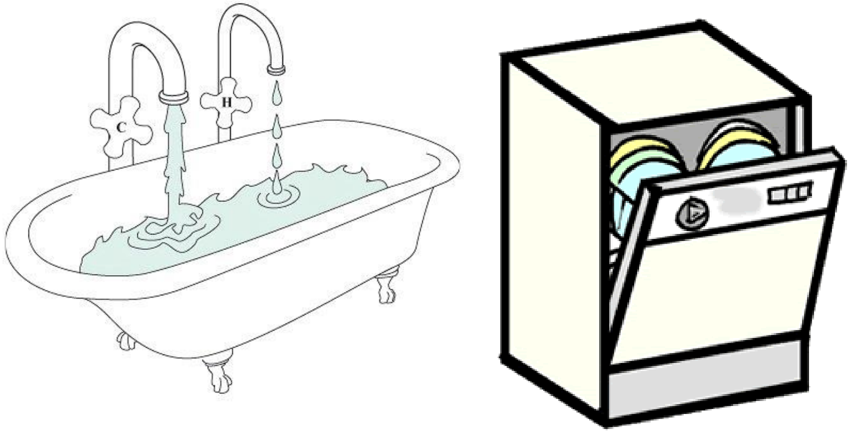
Design Fixture Probability Values



$p = 0.050$

$p = 0.025$

$p = 0.010$

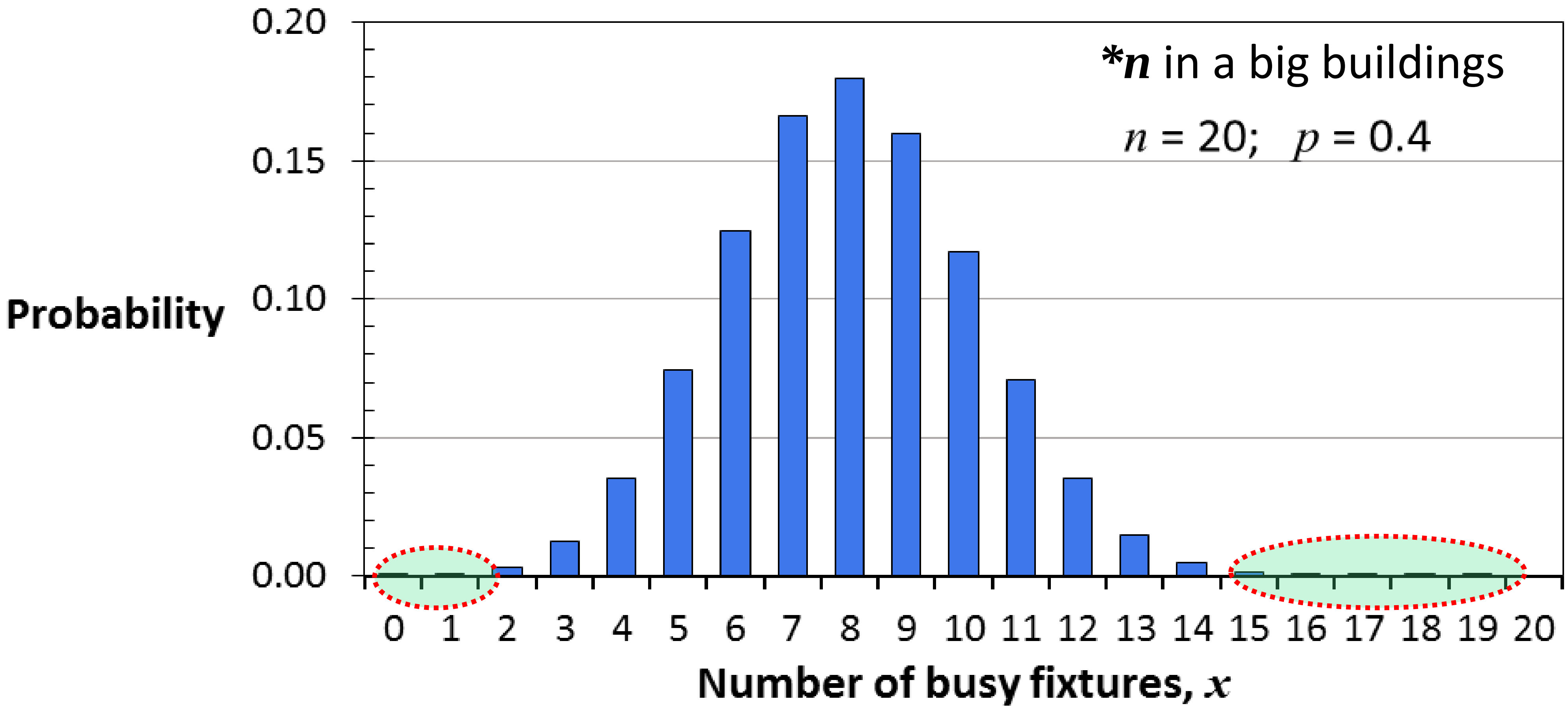


$p = 0.005$

APPLICATION

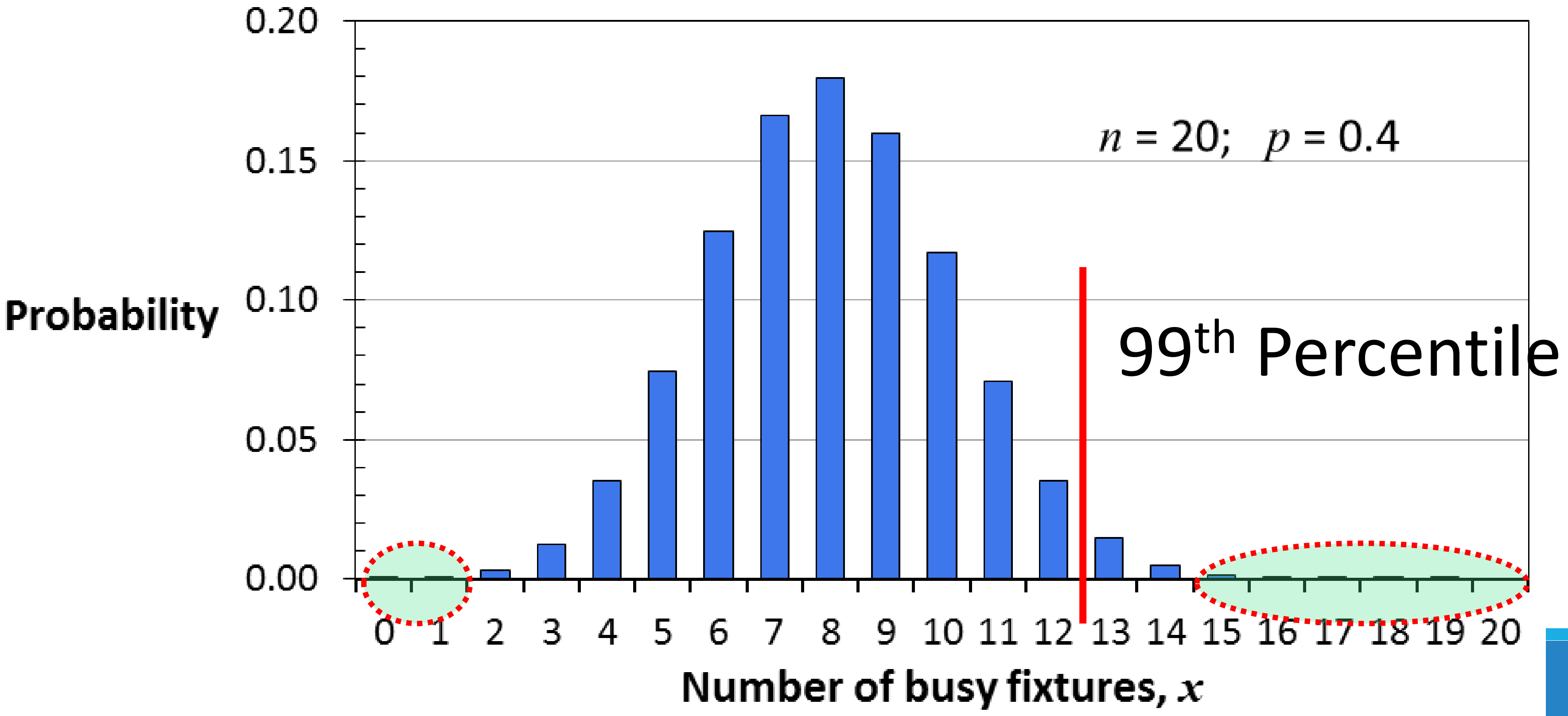
Binomial Model

$$\Pr\begin{pmatrix}\text{exactly } x \text{ busy} \\ \text{out of } n \text{ fixtures}\end{pmatrix} = \binom{n}{x} p^x (1-p)^{n-x}$$



“Frequency Factor” Approach

$$x = Mean + \left(z_{0.99}\right) Standard\ Deviation$$

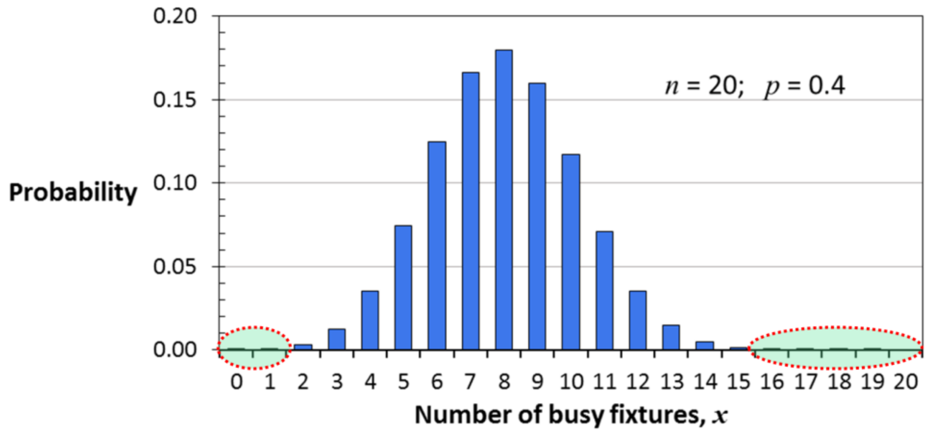


Normal Approximation of Peak Flow

$$Q_{0.99} = \mu_q + \left(z_{0.99}\right)\sigma_q$$

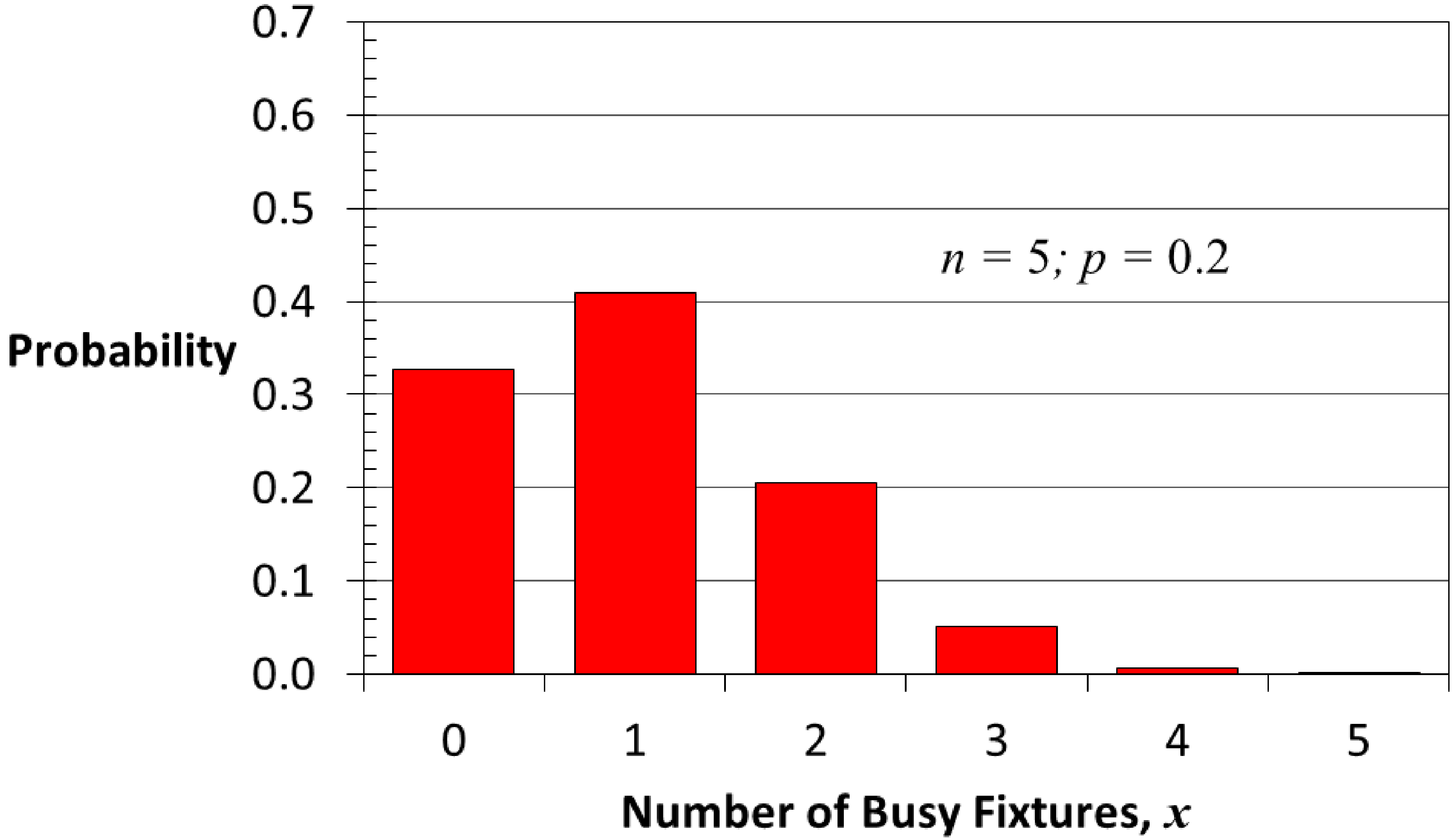
$$Q_{0.99} = \sum_{k=1}^{K} n_k p_k q_k + \left(z_{0.99}\right)\sqrt{\sum_{k=1}^{K} n_k p_k \left(1 - p_k\right) q_k^2}$$

- Wistort (1995)

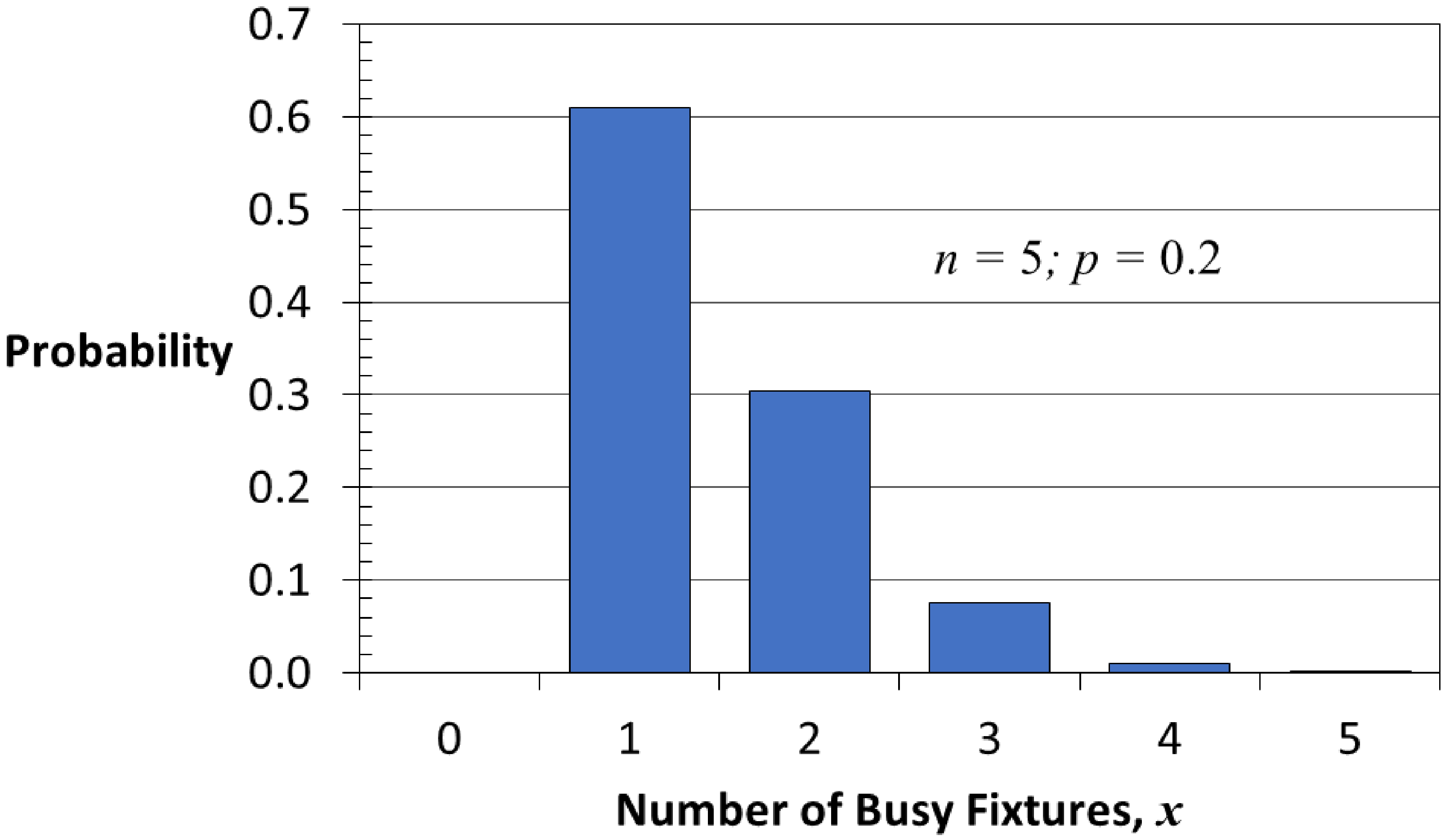


Binomial Distribution

n in a small buildings



Zero Truncated Binomial Distribution (ZTBD)



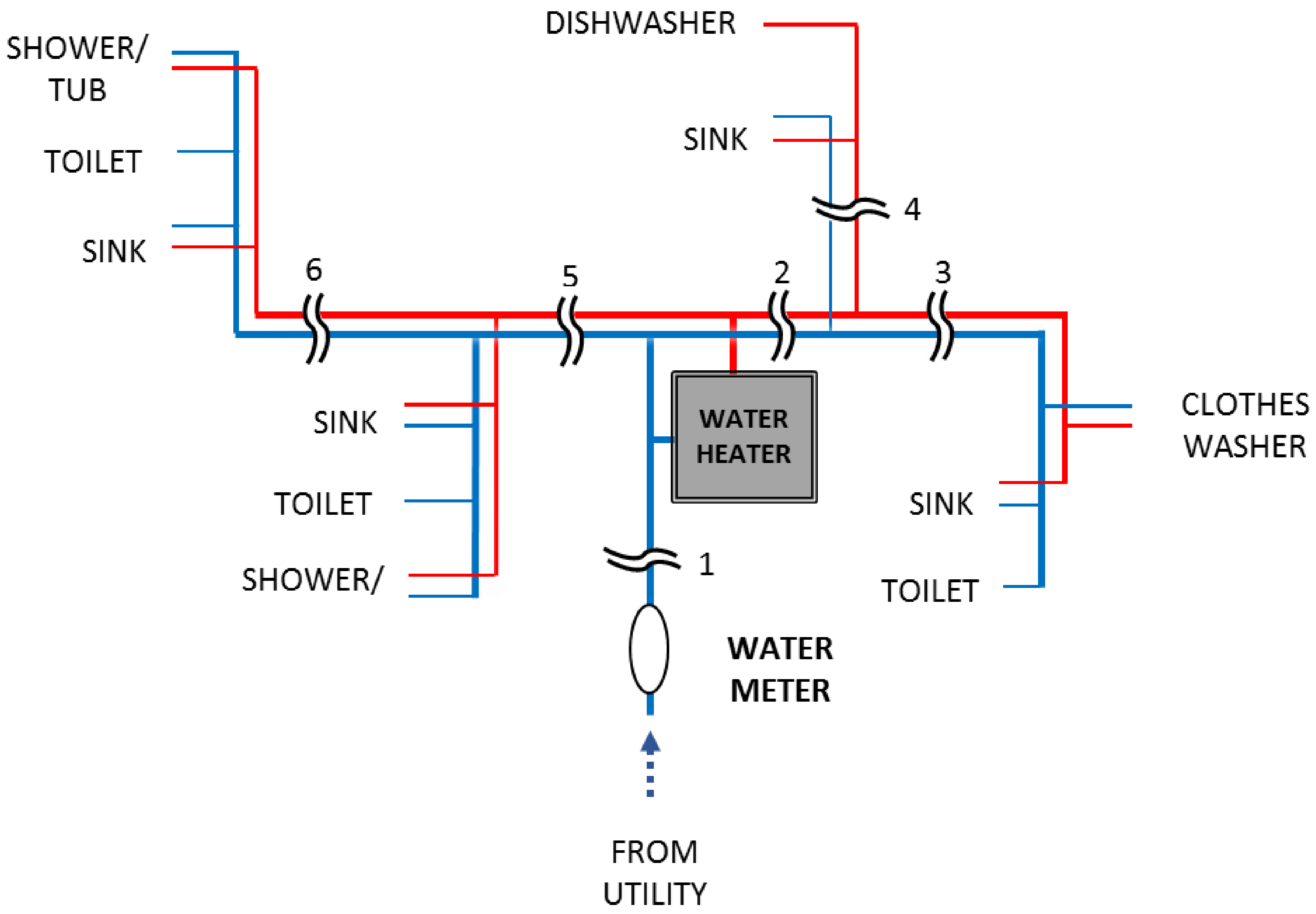
Modified Wistort's Model

$$Q_{0.99} = \sum_{k=1}^{K} n_k p_k q_k + \left(z_{0.99}\right)\sqrt{\sum_{k=1}^{K} n_k p_k \left(1-p_k\right) q_k^2}$$

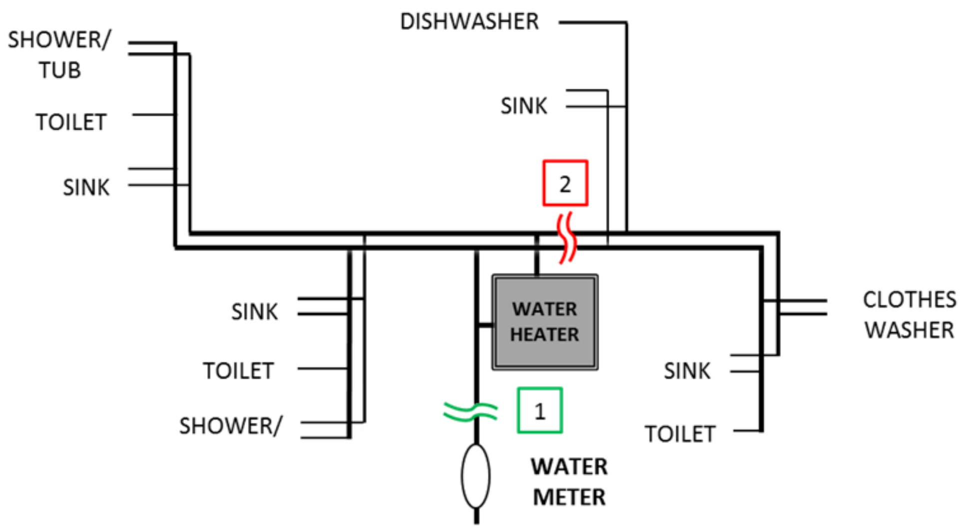
$$Q_{0.99} = \frac{1}{1-P_0}\left[\sum_{k=1}^{K} n_k p_k q_k + \left(z_{0.99}\right)\sqrt{\left[\left(1-P_0\right)\sum_{k=1}^{K} n_k p_k \left(1-p_k\right) q_k^2\right] - P_0\left(\sum_{k=1}^{K} n_k p_k q_k\right)^2}\,\right]$$

- Note:
  - $P_0 = \prod_{1}^{k}\left(1-p_k\right)^{n_k}$ is probability of stagnation in a home (i.e. no water use)
  - Addresses water demand in single family homes with high P_0
  - Transitions back to Wistort's model as P_0 approaches 0

Hypothetical Residential Building Pipe Layout



Peak Flow Calculations

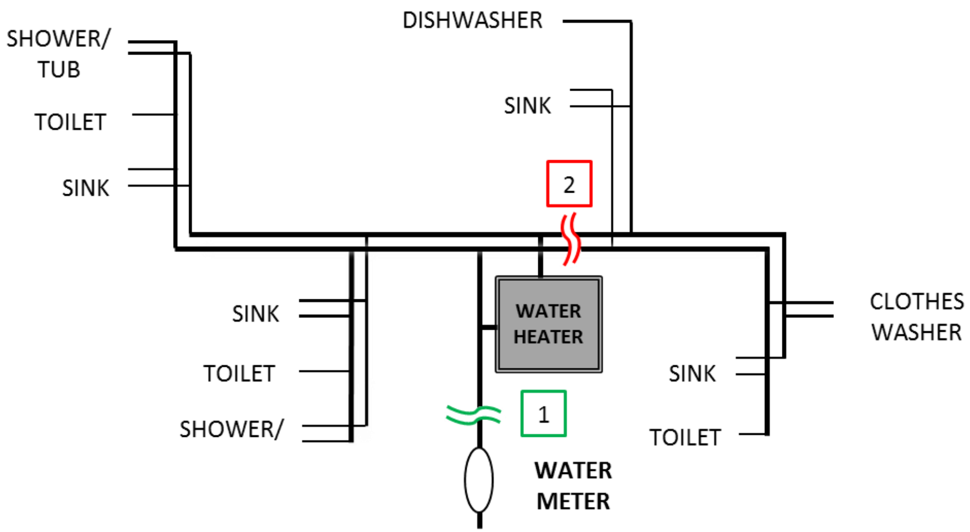


Example: 2.5 bath single family home

Section	UPC FU	UPC Method (gpm)	MW Method (gpm)
1	25.5	18.0	**11.8**
2	10.5	8.5	**6.9**

gpm - gallons per minute

Sizing Pipes

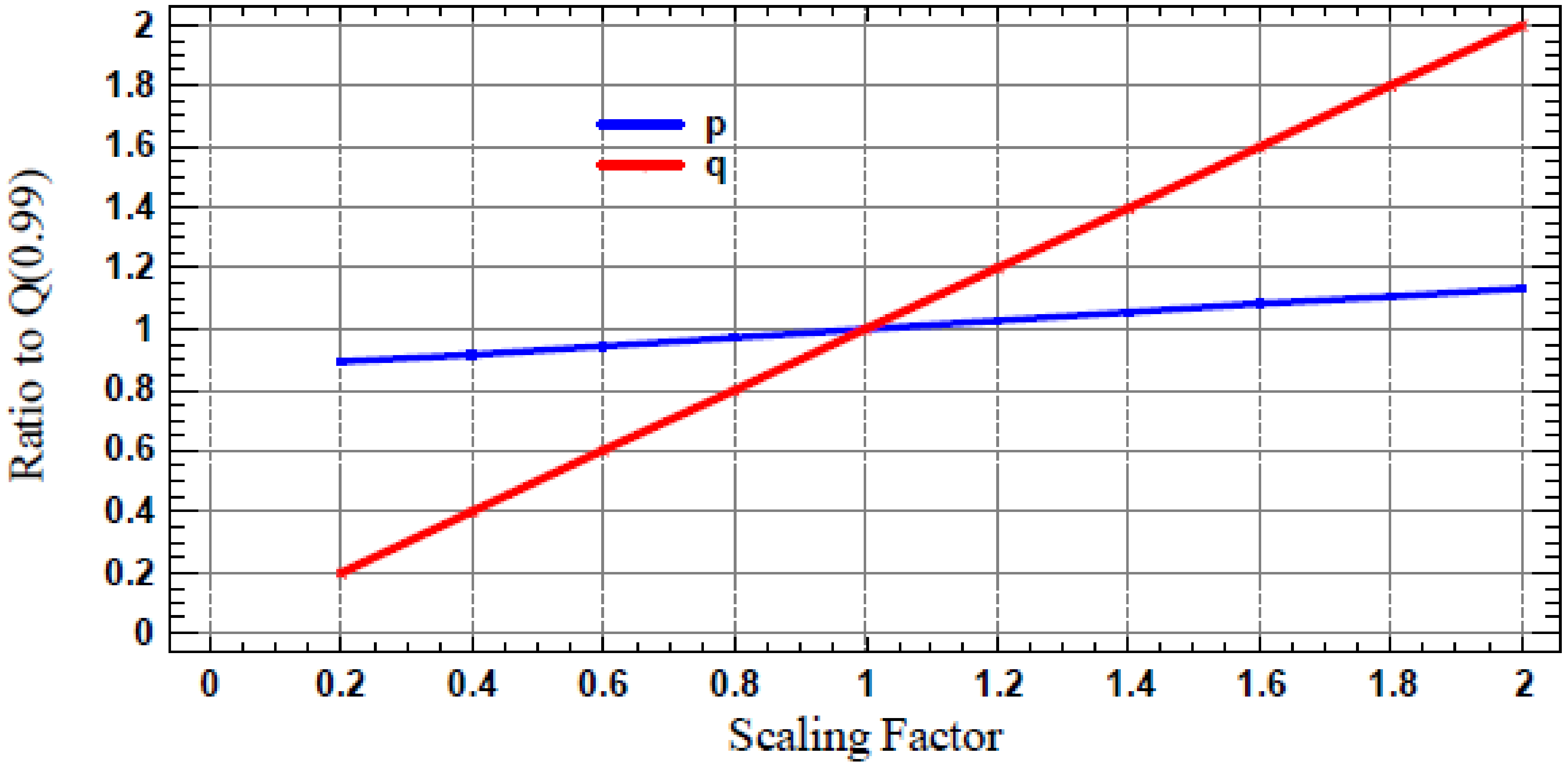


Example: 2.5 bath single family home

Section	UPC Method	Pipe Size*	MW Method	Pipe Size*
1	**18.0 gpm**	**1”**	**11.8 gpm**	**3/4"**
2	8.5 gpm	3/4"	6.9 gpm	3/4"

* Maximum flow rate at 8 f/s

Demand Sensitivity to p and q values



CONCLUSION

Conclusion

- Introduced a computational model to estimate peak water demand in single and multi-family dwellings.

- Recommended fixture $\boldsymbol{p}$ and $\boldsymbol{q}$ values.

- Model applicable to a wide spectrum of buildings.

Questions?

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