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Tool for Generating Realistic Residential Hot Water Event Schedules

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SimBuild 2010

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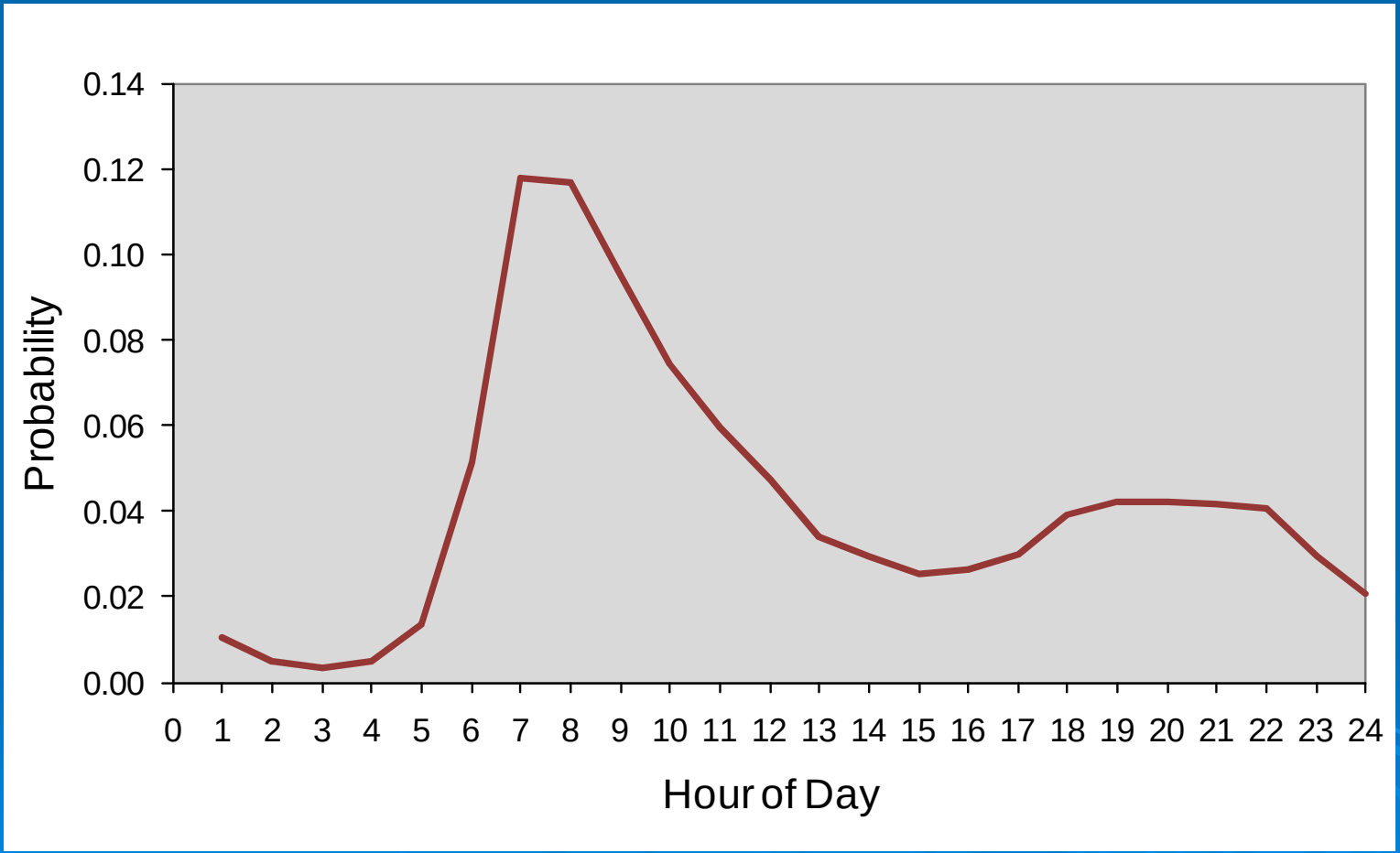
Objective

- Artificially reproduce statistically valid, realistic hot water draw patterns based on a series of user inputs, to improve the accuracy of simulation and testing of residential hot water systems
  - Flow rates
  - Durations
  - Fixtures
  - Time of day
  - Clustering
  - Vacation periods

Why are Realistic Draw Patterns Needed for Simulations?

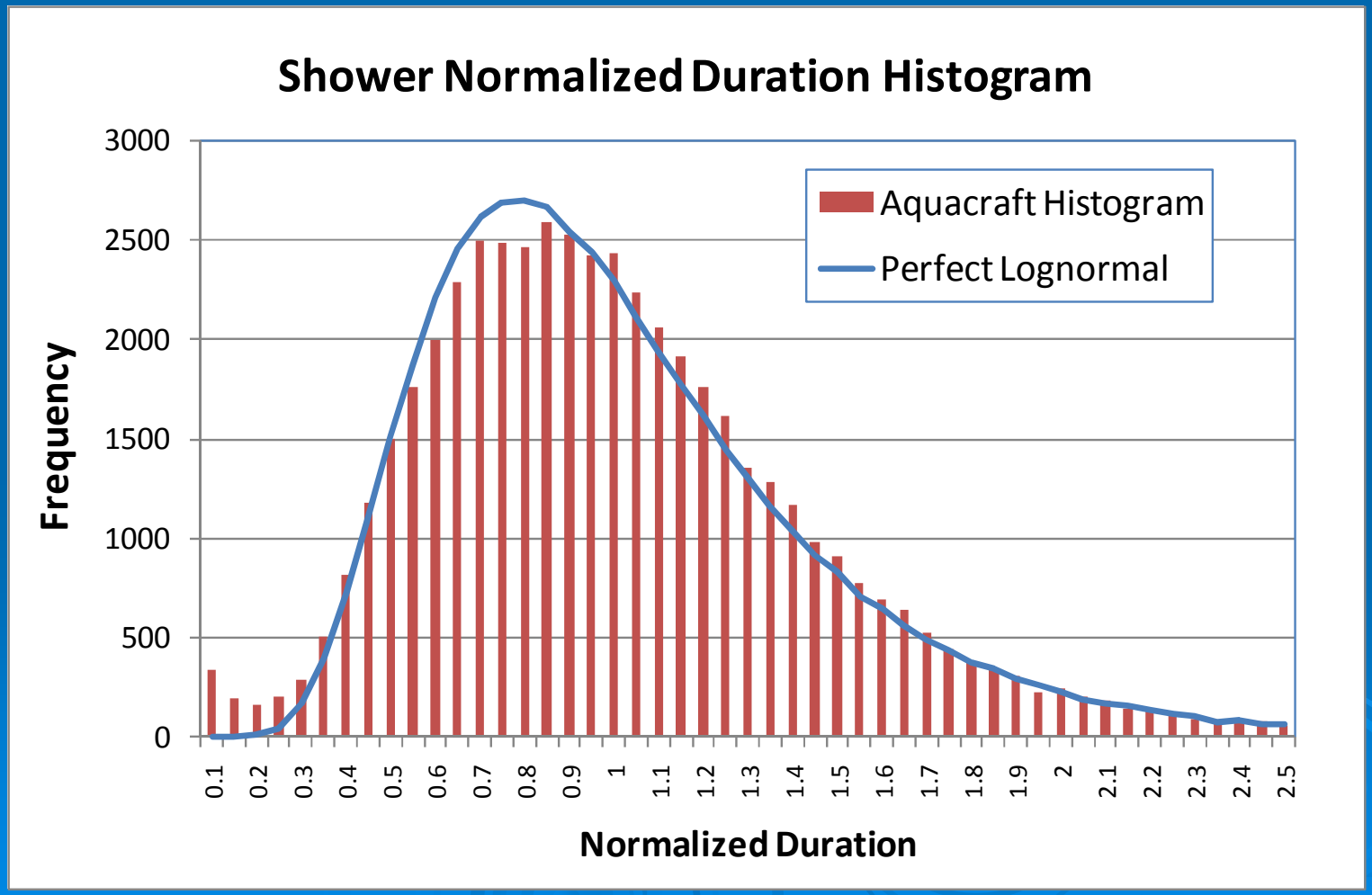
- Distribution system losses
- Tankless water heaters
- Solar systems w/ load-side heat exchanger
- Sizing of storage tanks and ICS systems
- Heat recovery systems

Example Probability Distribution – Shower Start Time



- From Building America Benchmark

Example Probability Distribution – Shower Duration



Characteristics of Probability Distributions

Characteristics	Sink	Shwr	Bath	CW	DW
Average Duration (min)	0.62	7.81	5.65	3.05	1.53
Standard Deviation for Duration (min)	0.67	3.52	2.09	1.62	0.41
Probability Distribution for Duration	Expo-nential	Log-Normal	Normal	Discrete	Log-Normal
Average Flow Rate (gpm)*	1.14	2.25	4.40	2.20	1.39
Standard Deviation for Flow Rate (gpm)*	0.61	0.68	1.17	0.62	0.20
Probability Distribution for Flow Rate	Normal	Normal	Normal	Normal	Normal
Average Event Volume (gal)*	0.76	16.73	23.45	6.95	2.13

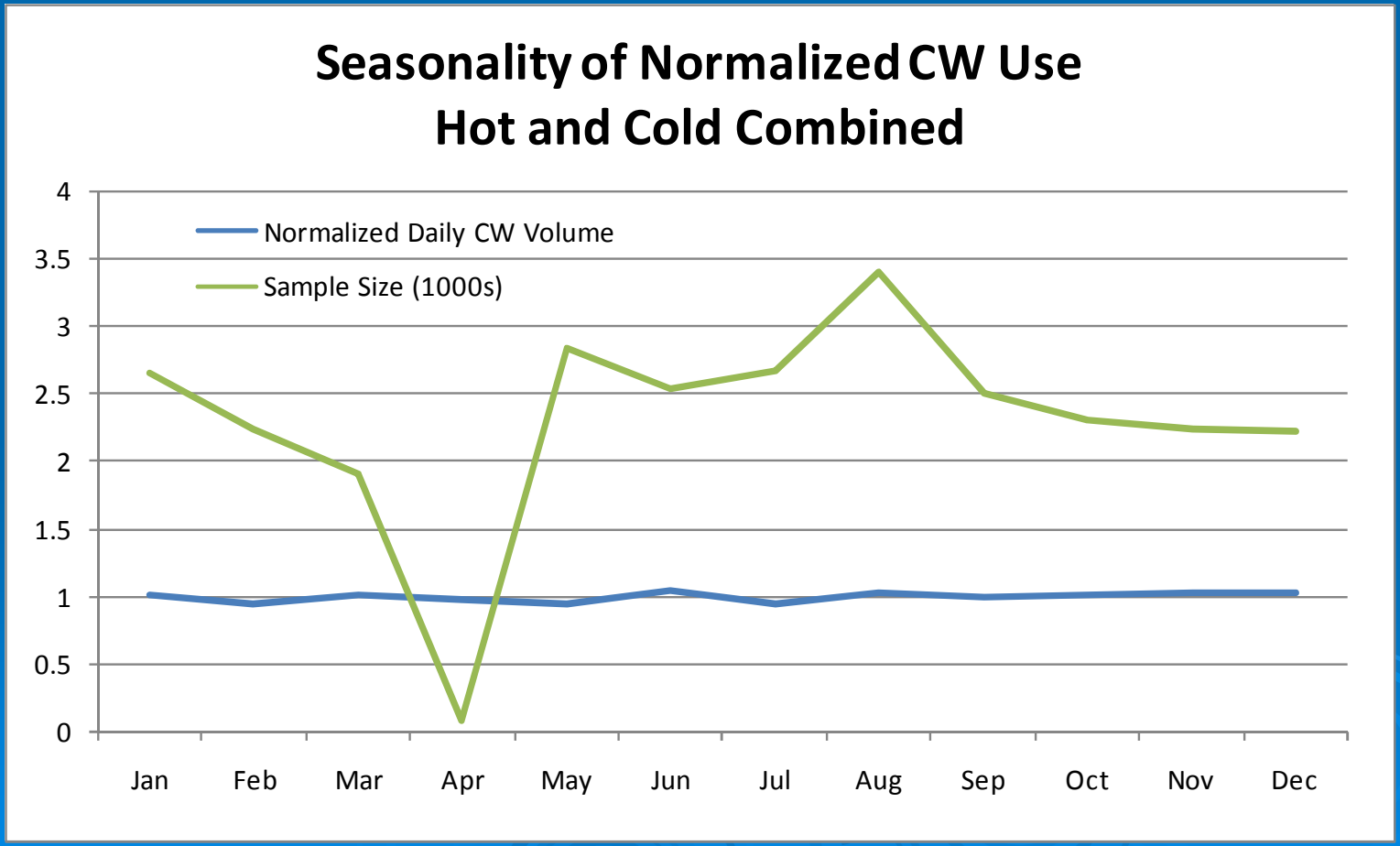
* Hot and cold water combined for sinks, showers, baths

Probability Multipliers

Probability Multipliers:	**Sink**	**Shwr**	**Bath**	**CW**	**DW**
Weekend	1.15	1.05	1.05	1.26	1.04
Weekday	0.94	0.98	0.98	0.90	0.98
Vacation (May 26-28, Aug 12-18, Dec 22-25)	0	0	0	0	0
Not Vacation	1.04	1.04	1.04	1.04	1.04

Seasonal Probability Adjustments

- Minimal seasonality for all 5 end-uses



Fixture Distribution

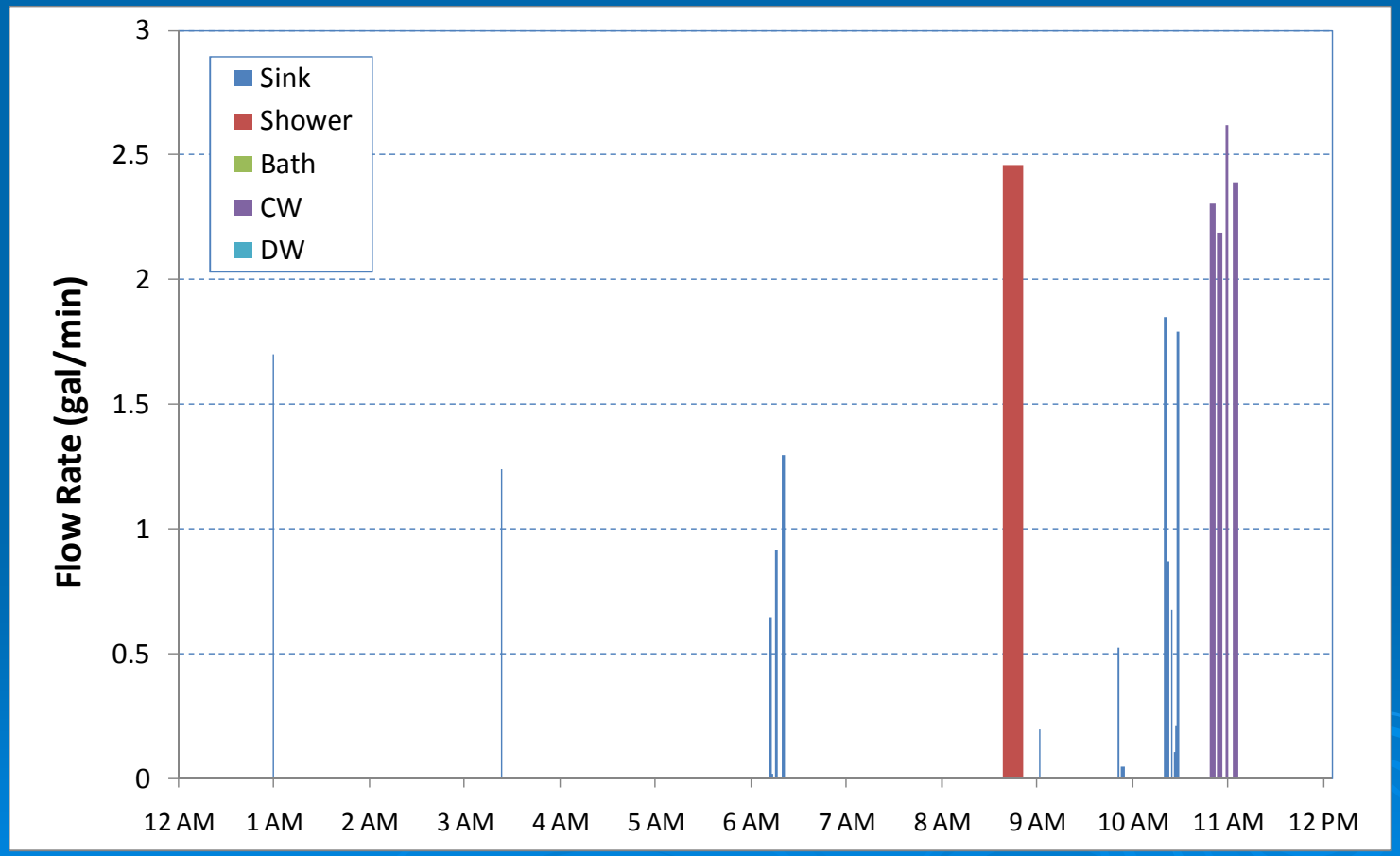
Probability Distributions:	**Sink**	**Shwr**	**Bath**	**CW**	**DW**
Kitchen Sink, Master Bath Shower/Tub, Primary DW or CW	0.70	0.75	0.75	1.00	1.00
Master Bath Sink, 2nd Bathroom Shower/Tub	0.10	0.25	0.25		
3rd Bathroom Sink	0.10				
4th Bathroom Sink	0.10				

Cluster Analysis Results – Derived from Aquacraft Data

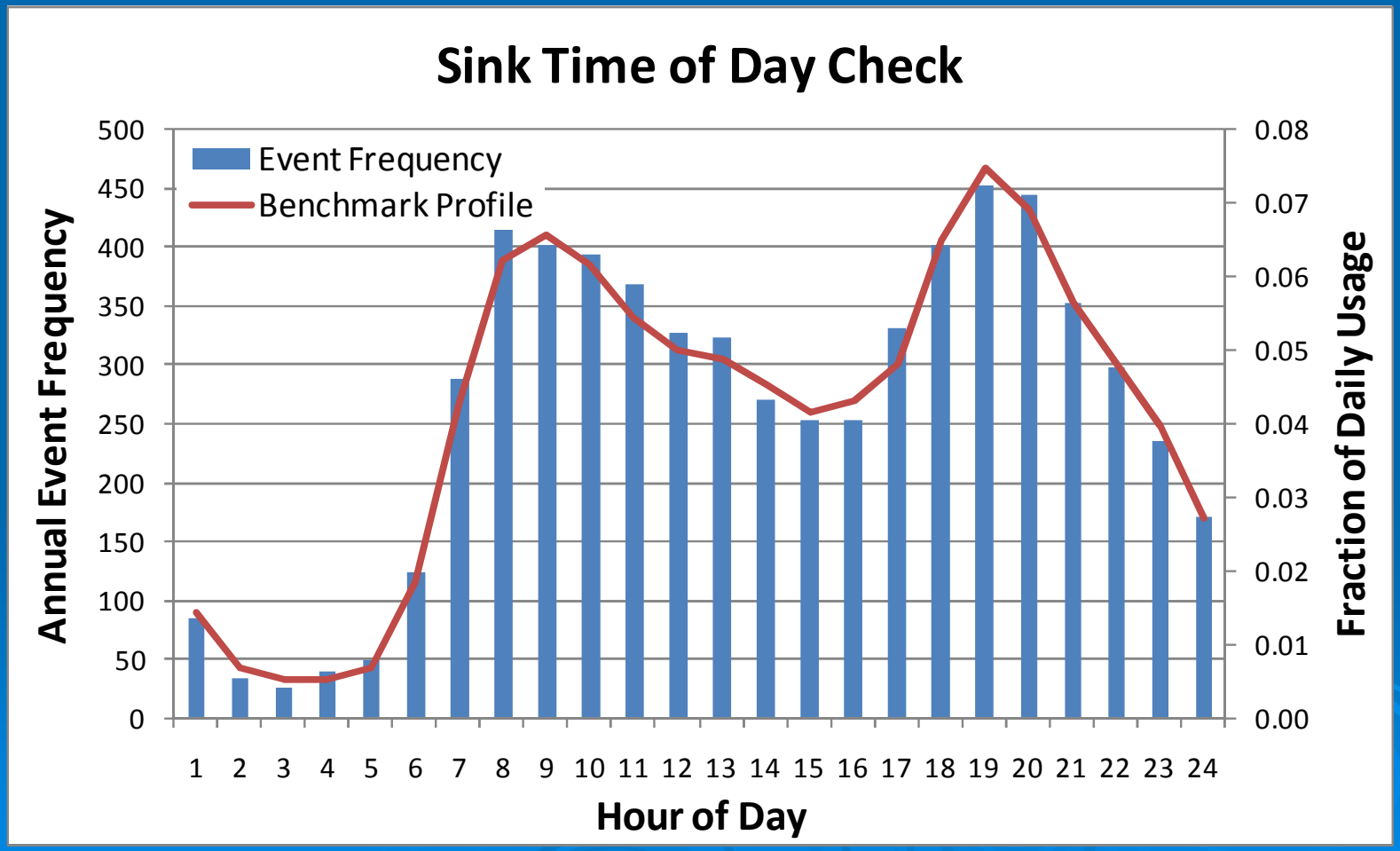
Characteristics	Sink	Shwr	Bath	CW	DW
Average Daily Volume (gal/day, hot and cold)*	25	28	7	15	5
Average Daily Events (events/day)	32.9	1.7	0.3	2.2	2.4
Annual Events (events/year)	12007	611	109	788	858
Maximum Time Between Events in Cluster (min)	15	60	60		60
Average Time Between Events in Cluster (min)	1.93	30.5			9.78
Average Events per Cluster	1.90	1.24	1.00	1.96	4.89
Number of Clusters per Year	6319	493	109	402	176
Maximum Time Between Events in Load (min)				30	
Maximum Time Between Loads in Cluster (min)				240	
Number of Loads per Cluster				1.40	
Average Number of Events per Load				1.40	
Average Time Between Events in Load (min)				4.97	
Average Time Between Loads in Cluster (min)				74.27	

* Building America Benchmark values

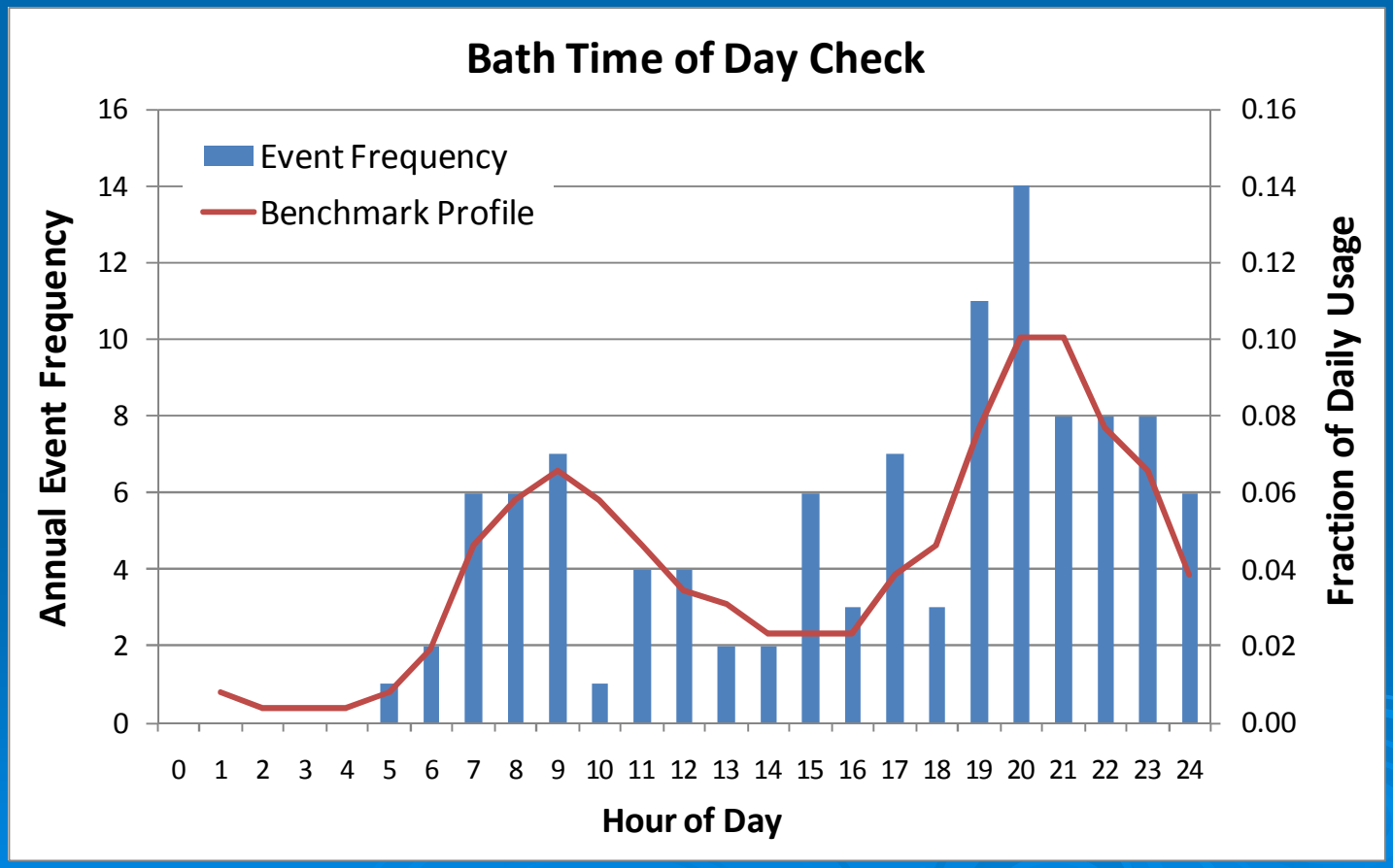
Example Draw Pattern



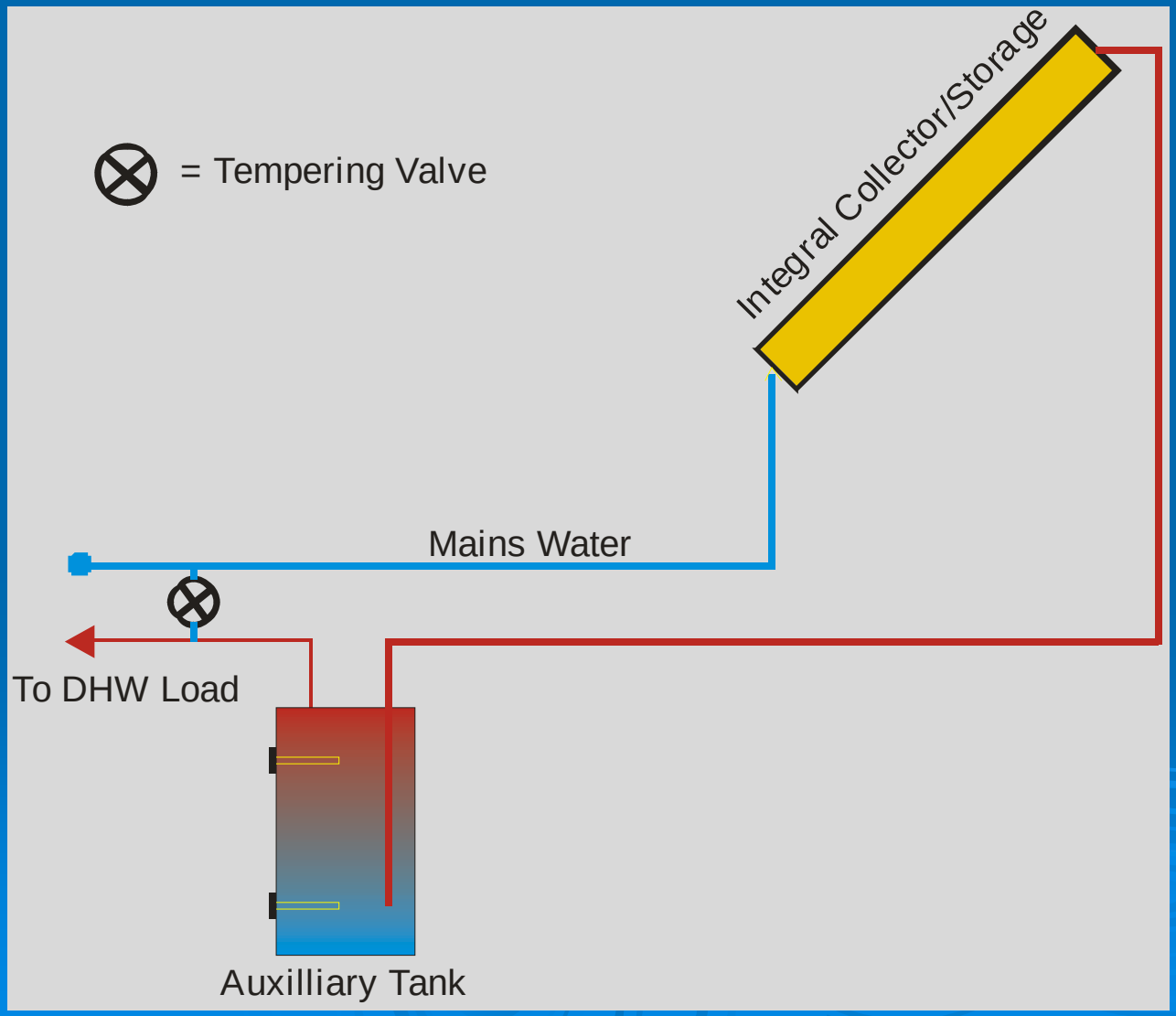
Output/Input Comparison - Sinks



Output/Input Comparison - Baths



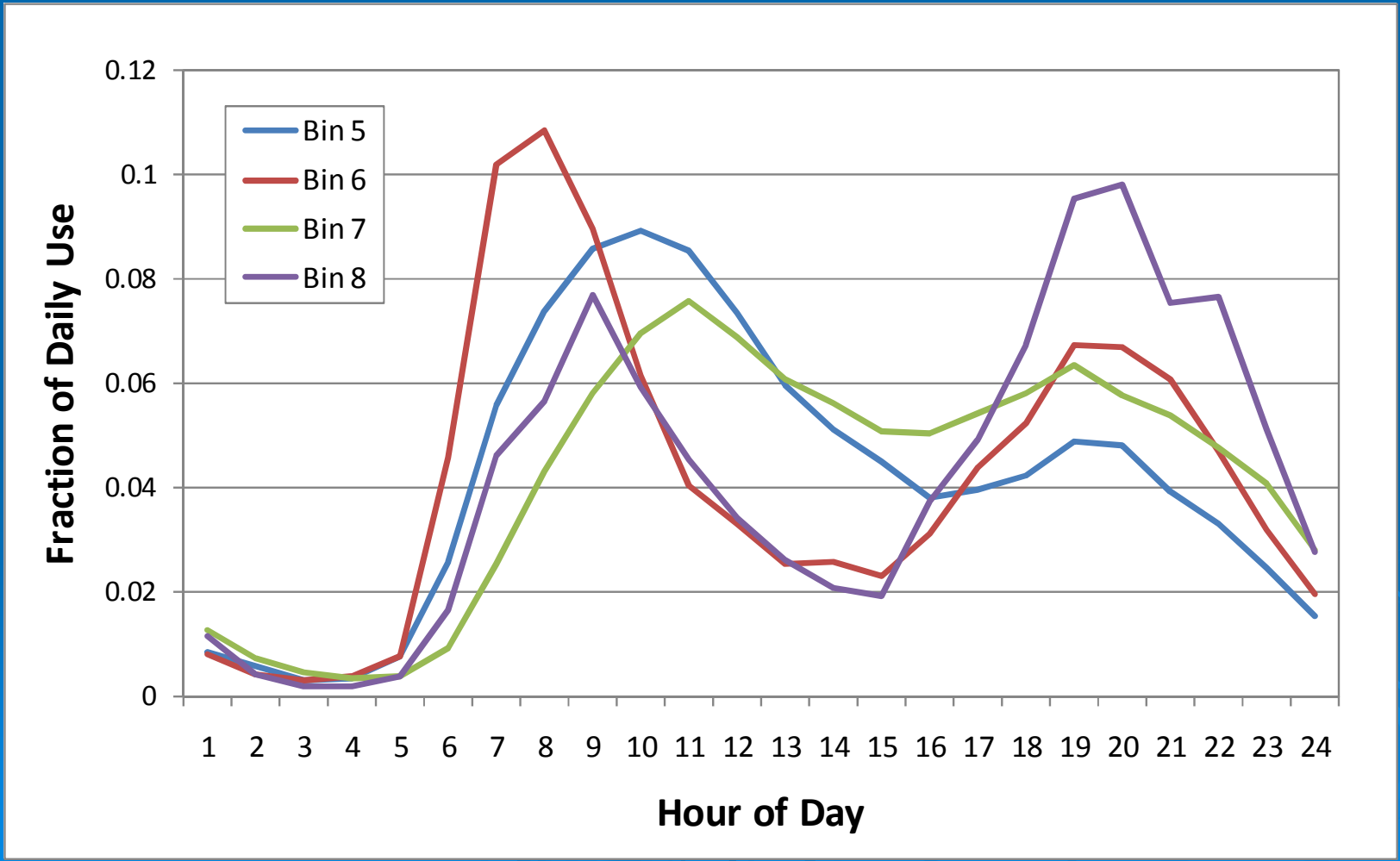
Example Analysis: ICS System



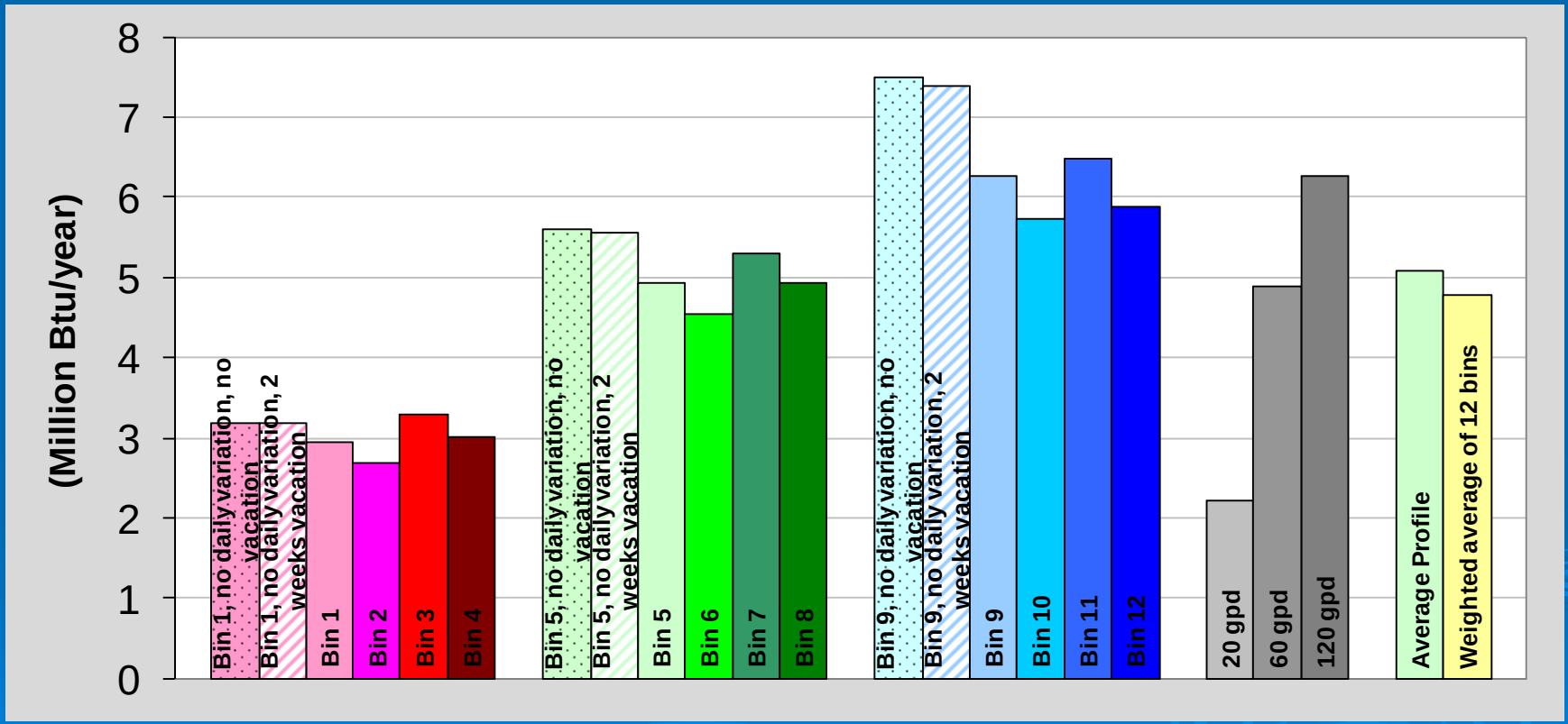
Use Pattern Bin Definitions

Bin #	Bin Categories			Daily Use (gal)	% in Bin
	Volume (All End-Uses)	Shower	Occupants at Home During the Day		
1	Low	Morning	At Home	27	10%
2	Low	Morning	Not at Home	28	6%
3	Low	Evening	At Home	26	7%
4	Low	Evening	Not at Home	28	3%
5	Medium	Morning	At Home	61	25%
6	Medium	Morning	Not at Home	63	10%
7	Medium	Evening	At Home	60	12%
8	Medium	Evening	Not at Home	63	3%
9	High	Morning	At Home	112	14%
10	High	Morning	Not at Home	117	4%
11	High	Evening	At Home	115	6%
12	High	Evening	Not at Home	119	2%
Avg	-	-	-	66	100%

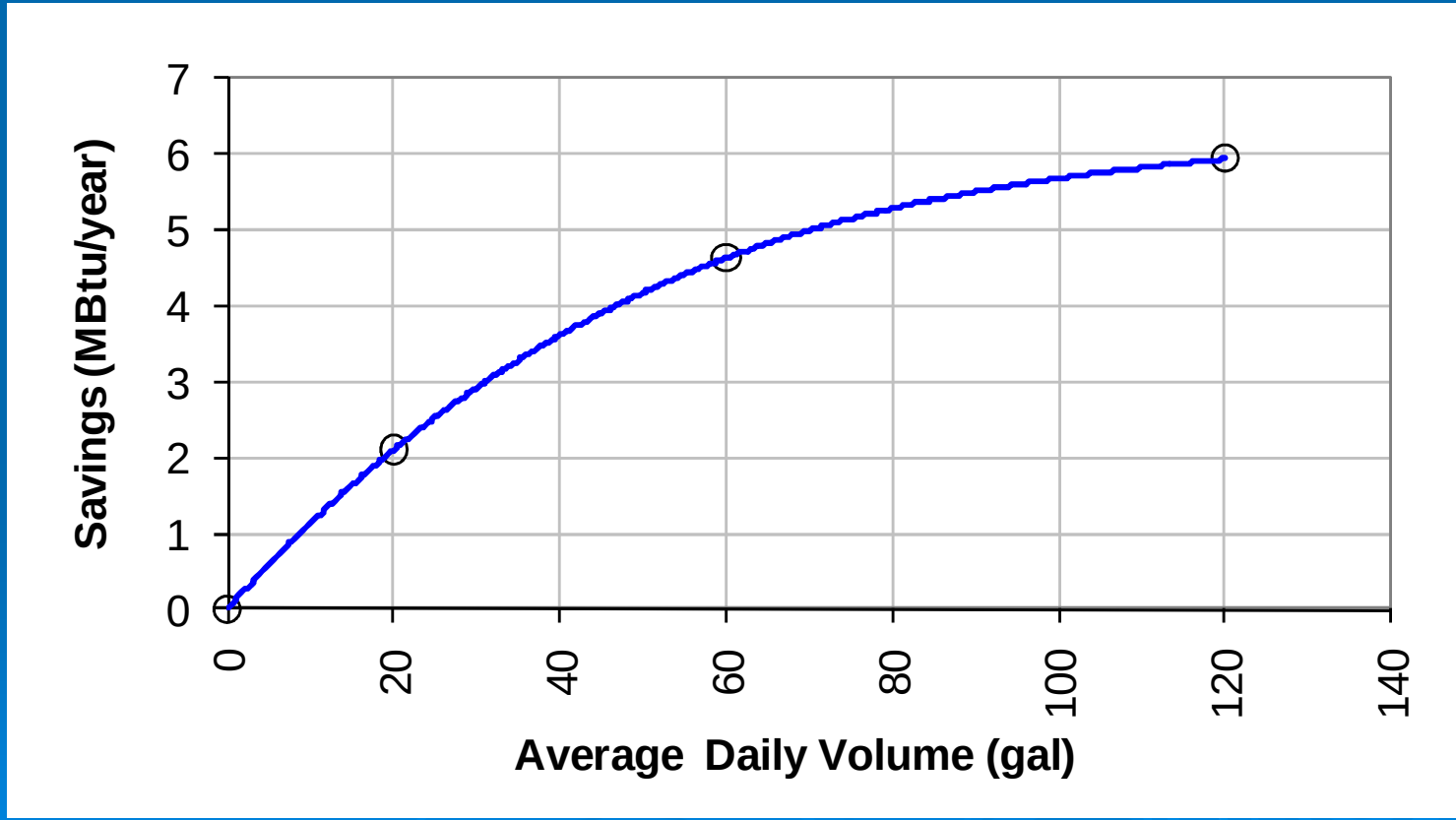
Hourly Profiles for Medium Use Households



Energy Savings for ICS Using Alternative Draw Patterns



Non-Linearity of Energy Savings Relative to Daily Volume



Availability of DHW Tool

- Event generator and several standard profiles are posted on the Building America website
- http://www1.eere.energy.gov/buildings/building_america/perf_analysis.html

Future Work

- Efficiency adjustments
  - Low-flow fixtures
  - EnergyStar appliances
  - Improved distribution systems
- Better empirical data
  - Vacation periods
  - Fixture probabilities
- Clustering across end-uses
- Additional standard profiles
- Improve calculation speed