

HIGH PERFORMANCE DOMESTIC HOT WATER MODELING: FIXTURES, FMIX AND OCCUPANCY

By SEAN ARMSTRONG of
REDWOOD ENERGY

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PROJECT MANAGER SEAN ARMSTRONG

- Founded Redwood Energy in 2011 to provide building science consulting for Zero Net Energy design
- Project Manager for 2005-2011 with affordable housing developers
- Co-directed an off-grid demonstration house in 1999 with solar, wind, biodiesel and human power at HSU, volunteer for 1995-2015
- Second generation farmer specializing in grass-fed Kunekune pigs



PURPOSE, PROCESS AND PEOPLE

Purpose: To create a model for housing that includes:

- fixture efficiency
- behavioral and structural waste
- occupancy
- impact of DHW mix

Process:

- Spring of 2012 began building DHW model for USDA's ZNE projects
- Technical supervision by Jonah Schein (EPA) and Martha Brook (CEC)
- Research based— “show me the paper please”

People: Sean Armstrong, Peter Mayer, Bill De Oreo, Peter Parker, Gerald Van Decker, Jonah Schein, Jim Lutz, Yanda Zhang, Gary Klein, Troy Sherman, Craig Selover, Bill Dakin, Martha Brook, Adrian Ownby,

DR. YANDA ZHANG
SHOWS MULTIFAMILY USE BELOW CA TITLE 24 ASSUMED
BASELINE OF 21.5 GPD +.14*SF
(2013)

An Assemblage of Tables 5, 6, 8 and 9 from "Multifamily Central Domestic Hot Water Distribution Systems" (Zhang, 2013)

Average Daily DHW per Residence at a Multifamily Complex (Gallons)	Site Index	Occupancy Type	Number of Units	Average Unit Area
4	E-DAE	College	250	150
7	A-SAM	Senior	87	600
9	16-DAR	College	60	100
12	14-HOC	Market Rate	16	550
12	13-HOL	Affordable	25	580
15	2-BKS	Senior	27	475
16	B-SFD	Affordable	98	787
19	1-SFB	Senior	40	712
19	8-OAL	Affordable	22	643
24	G-LAB	Market Rate	20	550
25	5-SAC	Market Rate	16	650
25	12-HOB	Market Rate	12	700
26	H-LAR	Market Rate	20	685
31	9-OAL	Affordable	28	643
33	3-BKU	Affordable	35	995
34	17-SAP	Market Rate	16	700
35	4-SAP	Market Rate	11	700
38	D-SFF	Affordable	82	900
39	11-HOB	Market Rate	20	550
53	6-DAK	College	88	200
54	7-DAL	College	88	200
55	C-SFH	Senior	87	600

The Average Daily DHW Consumption of Various Multifamily Housing Residence Types (Zhang, 2013)

Housing Type	College Residence (4 complexes, 486 residences)	Market Rate Residence (7 complexes, 131 residences)	Affordable Residence (6 complexes, 290 residences)	Senior Residence (4 complexes, 241 residences)	Average for All Housing Types (22 complexes, 1148 residences)	Average for All Non-College Housing Types (18 complexes, 662 residences)
Gallons/residence/day	30.0	27.7	24.8	24.0	26.6	25.8
Average Square Footage	163	657	758	597	576	668
Gallons/Square Foot/Day	0.185	0.042	0.033	0.040	0.046	0.039

A Comparison of DHW in CA Affordable Housing: Title 24 ACM vs. Zhang

Residence Type (by bedroom)	Median Square Footages of 74 CTCAC funded projects (M. Winkler, Redwood Energy)	T-24 Domestic Hot Water Demand (Gallons/Day = 21.5 + (.014 x Residential Square Footage)	Proposed CUAC Algorithm for DHW Demand at Affordable Multifamily Housing = .033 Gal/SF/Day x Residential Square Footage
Studio	378	26.8	12.4
1-Bed	616	30.1	20.2
2-Bed	850	33.4	27.8
3-Bed	1092	36.8	35.8
4-Bed	1336	40.2	43.8


**OCCUPANCY DATA PER BEDROOM:
DR. DANNY PARKER
AND LIHTC POLICY**

Occupancy Assumptions: 2009 RECS Data, CTCAC Housing Survey + Policy

Housing Type	Occupancy Formula	Studio	1 Bed	2 Bed	3 Bed	4 Bed	5 bed
Single Family in California	$1.75 + (\# \text{ of Bedrooms} * .430)$	1.75	2.18	2.61	3.04	3.47	3.9
All Multifamily-California	$1.935 + (\# \text{ of Bedrooms} * .432)$	1.935	2.367	2.799	3.231	3.663	4.095
All Multifamily-National	$1.49 + (\# \text{ of Bedrooms} * .453)$	1.49	1.943	2.396	2.849	3.302	3.755
Multifamily-California Tax Credit funded housing (CTCAC)	Studios = 1, and # of Bedrooms * 1.5	1	1.5	3	4.5	6	7.5
Multifamily 100% below poverty level-California	$2.49 + (\# \text{ of Bedrooms} * .623)$	2.49	3.113	3.736	4.359	4.982	5.605
Multifamily 100% below poverty level-National	$1.69 + (\# \text{ of Bedrooms} * .57)$	1.69	2.26	2.83	3.4	3.97	4.54

Relationship of Occupants to Bedrooms for Single Family and Multi-family occupancy ↓ 🖨️ ↗️

Inbox x

 **Danny Parker** 📧 Nov 15 ☆ ↶ ▾
to me, Bill ▾

DR. PETER MAYER AND DR. BILL DE OREO: RESIDENTIAL END USES OF WATER

Residential End Uses of Water

Prepared by:
Peter W. Mayer and William B. DeOreo
Aquacraft, Inc. Water Engineering and Management
2709 Pine St., Boulder, CO 80302

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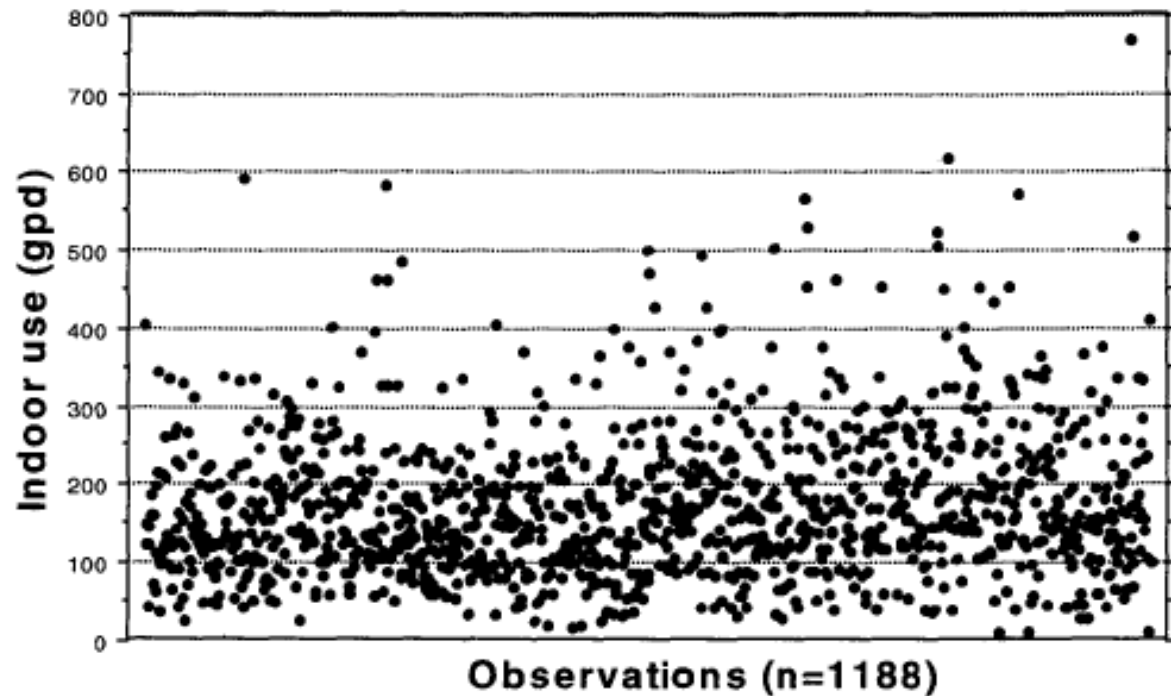


Figure 5.3 Scatter diagram of average daily indoor water use, 1,188 study homes

BRITAIN, DOE-BUILDING AMERICA, AND NEW RESNET ALGORITHMS ALSO USES OCCUPANCY FOR DHW MODELING

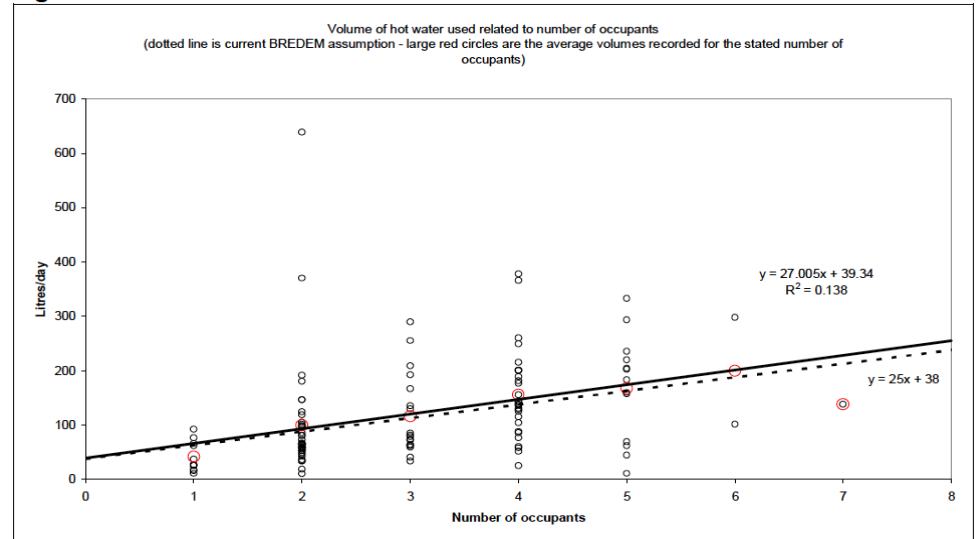
Technical Papers supporting SAP 2009



Analysis of the EST's domestic hot water trials and their implications for

How does the volume of hot water used relate to the number of occupants?

Figure 1



¹ Measurement of Domestic Hot Water Consumption in Dwellings. Prepared by Chris Martin, Energy Monitoring Company for the Energy Saving Trust. March 2008.



Fixture hot water use:

In the Building America procedure, the fixture gallons per day is obtained versus household bedrooms.

$$\text{Fixture Gallons per day} = F_{\text{mix}} * (30 + 10.0 * \text{Nbr})^5 \quad [6]$$

Where:

F_{mix} = the fraction of fixture water consumption that is hot
 Nbr = Bedrooms (or occupants)

BUILDING AND SCALING UP ONE PERSON'S WATER WITH REUWS 1999 AND 2014

Daily Indoor Residential Water Use for a One Occupant Household

Type of Fixture	Percentage of Fixture Flow that is DHW (REUWS 2014)	Baseline Flowrates (REUWS 1999 and 2014)	Duration of use, in minutes (REUWS, 1999)	Daily Uses per Occupant (REUWS, 1999)	Total Domestic Hot Water	Total Domestic Unheated Water	Total Blended Daily Water Use
Shower - Actual Use and Structural Waste	66%	2.20	7.57	0.75	8.2	4.2	12.5
Shower - Behavioural waste	72%	2.20	0.63	0.75	0.8	0.3	1.0
Bathroom Faucets	57%	1.3	8.1	0.31	1.9	1.4	3.3
Kitchen Faucets	57%	1.3	8.1	0.69	4.1	3.1	7.3
Toilets	0%	2.6	---	5.0	0.0	13.0	13.0
Dishwasher	100%	--	---	1 gal/day	1.5	0.0	1.5
Leaks	12%	--	---	9.5 gal/day	1.1	8.4	9.5
Clothes Washer	20%	27	---	0.37	2.0	8.0	10.0

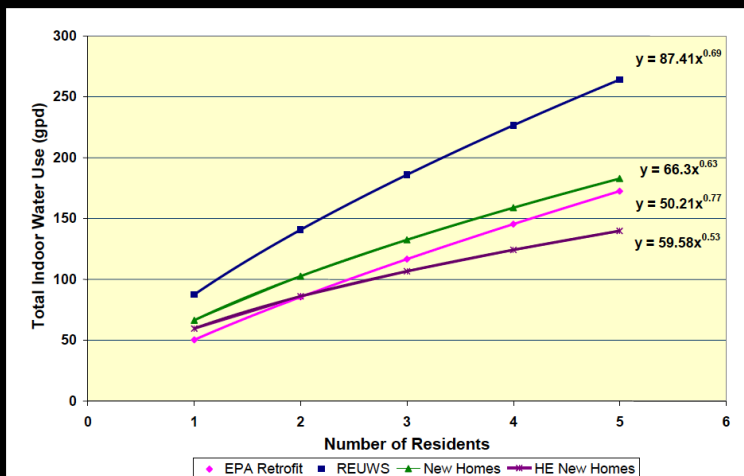


Figure ES 5: Indoor use versus residents for four research study groups

HOT WATER RATIOS

Showers

Percentage of Flow that is Domestic Hot Water	City				
77%	Denver, CO				
52%	Clayton County, Georgia				
59%	San Antonio, TX				
69%	Fort Collins, CO				
65%	Waterloo, Canada				
66%	Regional Municipality of Peel, including Brampton, near Toronto, Canada				
67% REUWS 2014 Recommendation from Peter Mayer					

Clothes Washers

Percentage of Clothes Washer Flow that is Domestic Hot Water					
Clothes Washer					
21%	Denver, CO				
19%	Clayton County, Georgia				
17%	San Antonio, TX				
13%	Fort Collins, CO				
26%	Waterloo, Canada				
16%	Regional Municipality of Peel, including Brampton, near Toronto, Canada				
20% REUWS 2014 Recommendation from Peter Mayer					

Faucets

Percentage of Flow that is Domestic Hot Water	City				
69%	Denver, CO				
52%	Clayton County, Georgia				
49%	San Antonio, TX				
56%	Fort Collins, CO				
52%	Waterloo, Canada				
59%	Regional Municipality of Peel, including Brampton, near Toronto, Canada				
57% REUWS 2014 Recommendation from Peter Mayer					

Leaks

Percentage of Leaks Flow that is Domestic Hot Water					
Leaks					
47%	Denver, CO *				
17%	Clayton County, Georgia				
5%	San Antonio, TX				
12%	Fort Collins, CO				
8%	Waterloo, Canada				
5%	Regional Municipality of Peel, including Brampton, near Toronto, Canada				
9.4%					
12% REUWS 2014 Recommendation from Peter Mayer (4/22/14)					

* Mayer believes this anomalously high leak rate in Denver is due to the leaks in the baseboard heating recirculation loops commonly used in Denver and the wintertime data collection period.

DISAGGREGATED DHW USES

Residential End Uses of Water

Prepared by:
Peter W. Mayer and William B. DeOreo
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2709 Pine St., Boulder, CO 80302

Table 5.3 Fixture utilization per capita per day, mean and standard deviation, 12 study sites

Study site	Toilet flushes per capita per day		Showers & baths per capita per day		Clothes washer loads per capita per day		Dishwasher loads per capita per day		Faucet minutes per capita per day	
	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
Boulder	4.79	2.25	0.81	0.53	0.34	0.22	0.13	0.10	8.4	4.9
Denver	5.10	2.71	0.80	0.48	0.37	0.26	0.11	0.10	7.5	4.4
Eugene	5.62	3.40	0.90	0.65	0.40	0.32	0.13	0.14	9.1	6.6
Seattle	4.49	2.28	0.75	0.51	0.30	0.17	0.10	0.11	6.9	4.4
San Diego	5.20	2.39	0.63	0.32	0.42	0.27	0.10	0.08	8.1	4.0
Tampa	4.85	2.61	0.70	0.54	0.36	0.24	0.06	0.10	9.4	6.5
Phoenix	5.31	3.00	0.77	0.49	0.40	0.29	0.08	0.07	6.7	3.6
Tempe & Scottsdale	5.12	2.67	0.82	0.73	0.36	0.24	0.11	0.08	8.6	7.2
Waterloo & Cambridge	5.51	3.31	0.63	0.64	0.35	0.21	0.08	0.11	8.0	6.0
Walnut Valley WD	4.69	2.50	0.74	0.37	0.34	0.20	0.07	0.07	9.0	6.1
Las Virgenes MWD	4.73	2.38	0.74	0.44	0.40	0.28	0.09	0.07	8.2	5.4
Lompoc	5.19	2.82	0.71	0.43	0.38	0.20	0.09	0.10	7.5	5.1
12 study sites	5.05	2.69	0.75	0.51	0.37	0.24	0.10	0.09	8.1	5.3

SHOWERS

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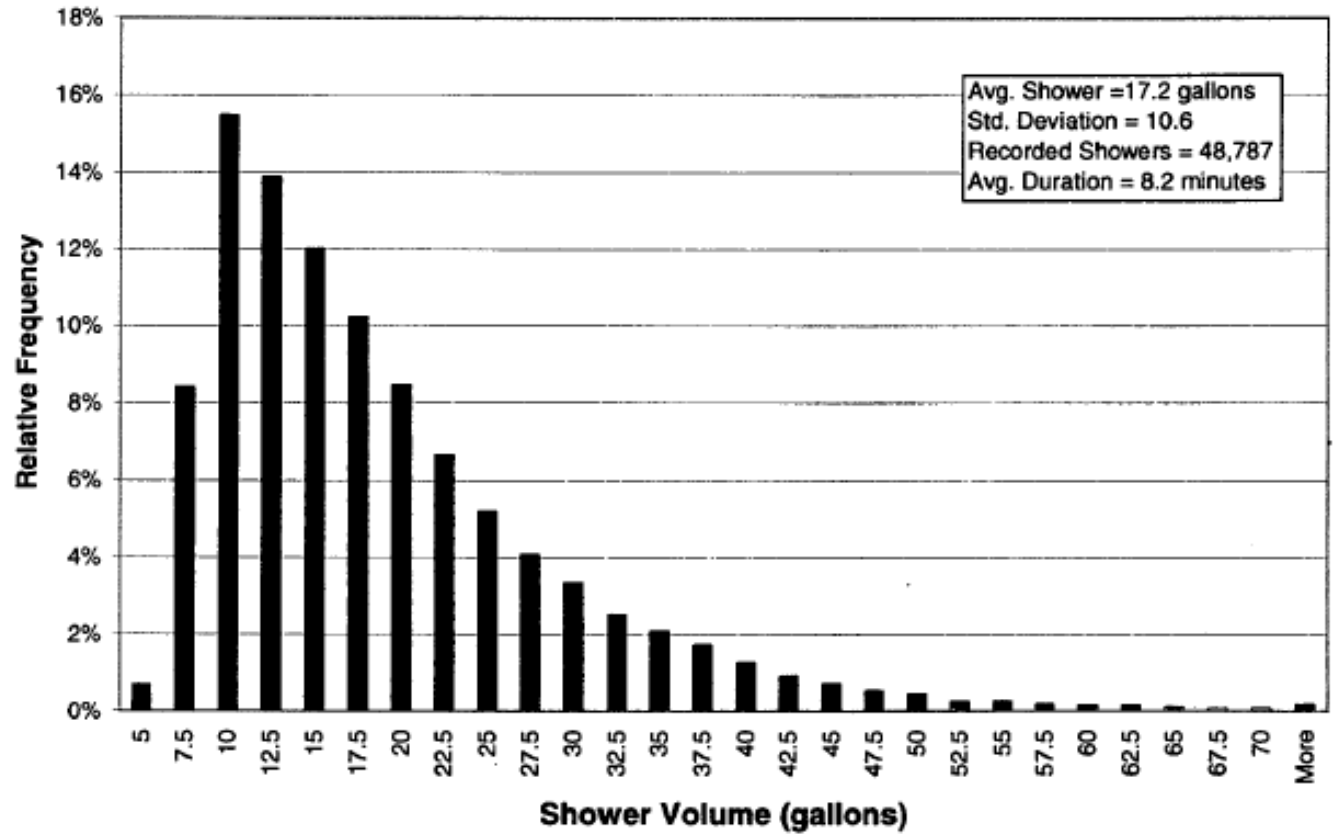


Figure 5.11 Shower volume distribution diagram

DISAGGREGATED FAUCETS: DR. BILL DE OREO WITH REUWS 1999



March 17, 2005

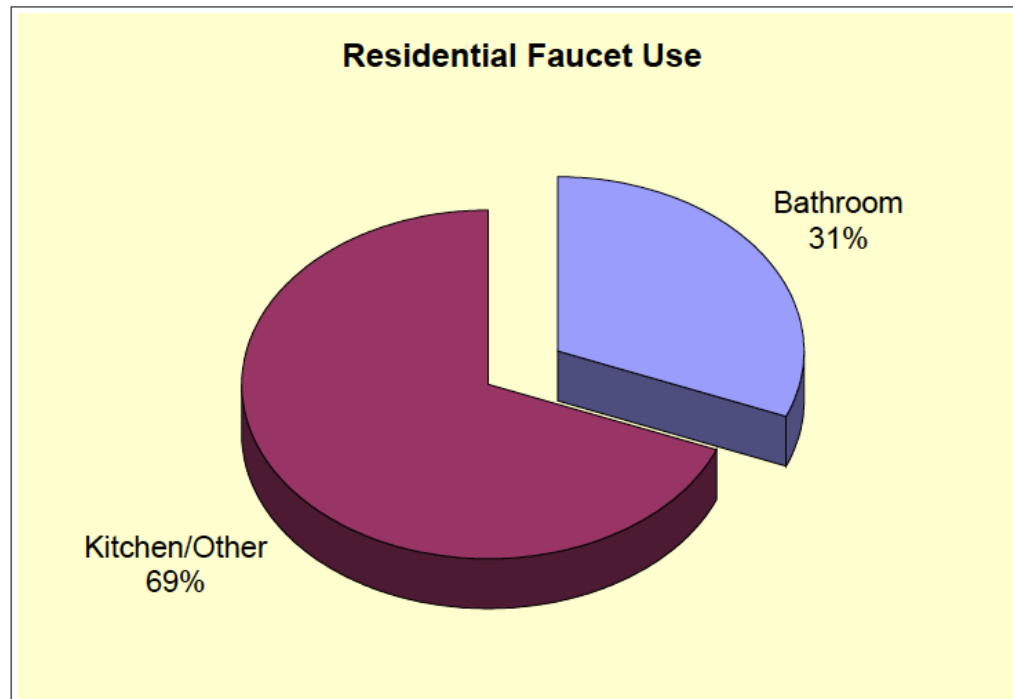
Tom Reynolds, President
Mark Sanders, Chairman
Barnacle Water Saver, LLC
13450 US Highway 42
Suite 214
Prospect, KY 40059

Re: Analysis of bathroom faucet use

Results

Of the 117,987 faucet events associated with the 162 single-bathroom homes, 64,725 (54.9%) events were classified as “bathroom” faucet use and 53,172 (45.1%) events were classified as “kitchen/other” faucet uses. Figure 2 is a pie chart showing the breakdown of total water use

Figure 2: Faucet use pie chart



volume from each faucet category.

Although there were more bathroom faucet events, the volume of those events was substantially less than the events in the kitchen/other category. Bathroom faucet use accounted for 31% of the total faucet volume. Kitchen/other faucet use accounted for 69% of the total faucet volume.

Bathroom faucet use was analyzed on the household and the per

FAUCET FLOWS



Water Efficiency Benchmarks
for New Single-Family Homes

Table 4-31: Faucet statistics – high-efficiency new home study group

Parameter	Value
Total number of logged days from standard new home sites	318
Average daily household faucet use (gpd)	18.1
Median daily household faucet use (gpd)	15.1
Average daily duration of household faucet use (min./day)	19.4
Average flow rate from faucet fixtures (gpm)	0.9

1999 REUWS vs. 2014 REUWS Preliminary Data

2014 Average Time	0.5	minute
2014 Average Volume	0.5	gallon
2014 REUWS Derived Flow	1	gpm
1999 REUWS Derived Flow	1.3	gpm

LEAKS

Residential End Uses of Water

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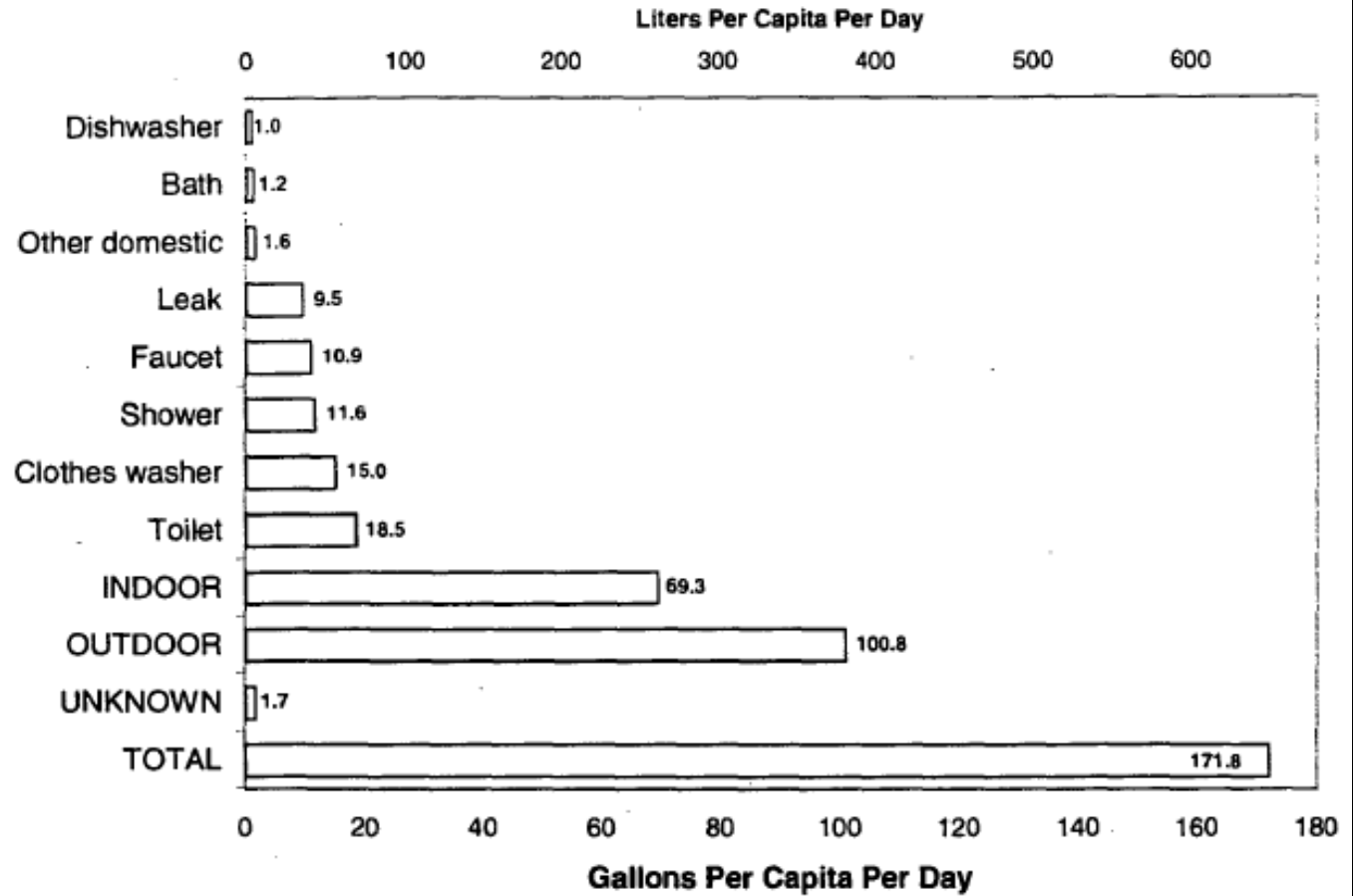
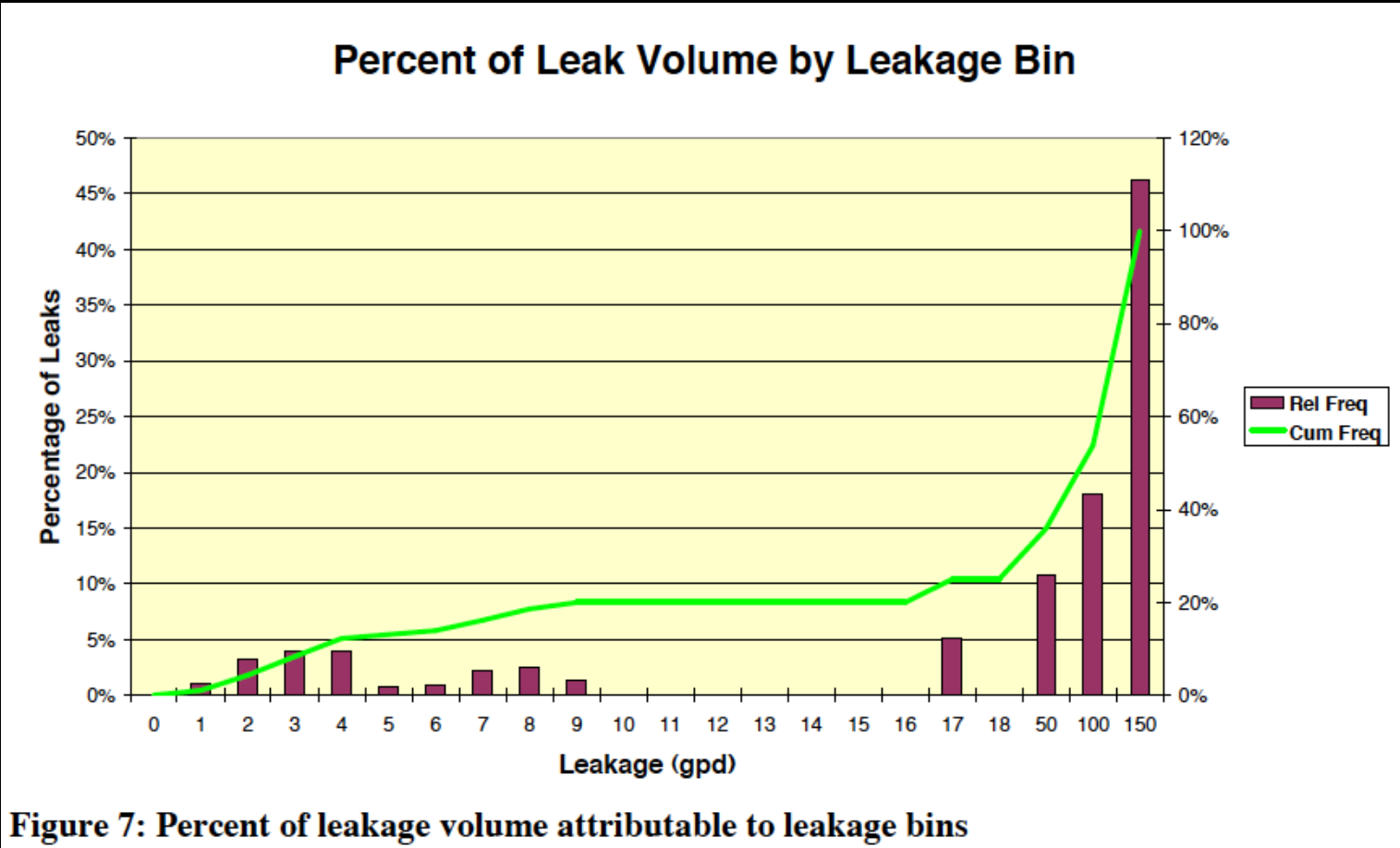


Figure 5.6 Average per capita per day usage (gpcd), 1,188 data logged homes

INDOOR LEAKS



DISHWASHERS: .1 TO .16 LOADS/ PERSON/DAY

Residential End Uses of Water

Prepared by:
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Study site	Dishwasher loads per capita per day	
	Mean	St.Dev.
Boulder	0.13	0.10
Denver	0.11	0.10
Eugene	0.13	0.14
Seattle	0.10	0.11
San Diego	0.10	0.08
Tampa	0.06	0.10
Phoenix	0.08	0.07
Tempe & Scottsdale	0.11	0.08
Waterloo & Cambridge	0.08	0.11
Walnut Valley WD	0.07	0.07
Las Virgenes MWD	0.09	0.07
Lompoc	0.09	0.10
12 study sites	0.10	0.09

variation, 12 study sites



September 5, 2013
Report#13-263

RESIDENTIAL BUILDING STOCK ASSESSMENT: MULTIFAMILY CHARACTERISTICS AND ENERGY USE

Prepared by:
David Baylon
Poppy Storm
Benjamin Hannas
Kevin Geraghty
Virginia Mugford

Surveyors also asked the tenants about their use of the dishwasher. The overall average across units with dishwashers was about 2.1 loads per week, as shown in Table 94. This is somewhat less than responses to this question in the other residential sector surveys.

Table 94. In-Unit Kitchen Appliance Characteristics

Category	Kitchen Appliance Characteristics		
	Mean	EB	n
Dishwasher Loads per Week	2.09	0.26	453

IN-HOME CLOTHES WASHER USE

Residential End Uses of Water

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Aquacraft, Inc. Water Engineering and Management
2709 Pine St., Boulder, CO 80302

Table 5.3 Fixture utilization per capita per day, mean and standard deviation

Study site	Toilet flushes per capita per day		Showers & baths per capita per day		Clothes washer loads per capita per day	
	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
Boulder	4.79	2.25	0.81	0.53	0.34	0.22
Denver	5.10	2.71	0.80	0.48	0.37	0.26
Eugene	5.62	3.40	0.90	0.65	0.40	0.32
Seattle	4.49	2.28	0.75	0.51	0.30	0.17
San Diego	5.20	2.39	0.63	0.32	0.42	0.27
Tampa	4.85	2.61	0.70	0.54	0.36	0.24
Phoenix	5.31	3.00	0.77	0.49	0.40	0.29
Tempe & Scottsdale	5.12	2.67	0.82	0.73	0.36	0.24
Waterloo & Cambridge	5.51	3.31	0.63	0.64	0.35	0.21
Walnut Valley WD	4.69	2.50	0.74	0.37	0.34	0.20
Las Virgenes MWD	4.73	2.38	0.74	0.44	0.40	0.28
Lompoc	5.19	2.82	0.71	0.43	0.38	0.20
12 study sites	5.05	2.69	0.75	0.51	0.37	0.24

WASHER USE ~DOUBLES WITH IN-RESIDENCE MACHINES



September 5, 2013
Report#13-263

RESIDENTIAL BUILDING STOCK ASSESSMENT: MULTIFAMILY CHARACTERISTICS AND ENERGY USE

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Table 62. Average Number of Clothes Washer Loads per Week by Laundry Type

Laundry Type	Average Loads per Week		
	Mean	EB	n
Common Only	2.51	0.76	230
In-Unit and Common	3.57	1.90	67
In-Unit Only	4.43	1.24	214
None	2.84	1.88	33
All Types	3.42	0.51	539

A NATIONAL STUDY OF WATER & ENERGY CONSUMPTION IN MULTIFAMILY HOUSING

In-Apartment Washers vs.
Common Area Laundry Rooms

MARCH 2001
NOVEMBER 2002 (revised)

FIGURE 16: Estimates of Laundry Use Energy Consumption

		Type of Laundry Facilities								
		Common Area				In-Unit				
		Cycle/Loads per Unit per Week	Estimated Energy Use			Cycle/Loads per Unit per Week	Estimated Energy Use			
	per Cycle	per Week	per Year	per Cycle	per Week	per Year		per Cycle	per Week	per Year
California	Electricity (in kWh)	2.26	1.048	2.368	123.16	7.74	2.139	16.559	861.05	
	Gas (in therms)	2.26	0.049	0.111	5.79	7.74	0.107	0.824	42.87	
Georgia	Electricity (in kWh)	3.50	1.048	3.668	190.74	4.93	2.139	10.547	548.45	
	Gas (in therms)	3.50	0.049	0.173	8.97	4.93	0.107	0.525	27.31	
Oregon	Electricity (in kWh)	2.65	1.048	2.777	144.41	3.39	2.139	7.252	377.13	
	Gas (in therms)	2.65	0.049	0.131	6.79	3.39	0.107	0.361	18.78	
Texas	Electricity (in kWh)	1.57	1.048	1.645	85.56	4.70	2.139	10.055	522.86	
	Gas (in therms)	1.57	0.049	0.077	4.02	4.70	0.107	0.501	26.03	
Total	Electricity (in kWh)	2.16	1.048	2.264	117.71	5.22	2.139	11.167	580.71	
	Gas (in therms)	2.16	0.049	0.106	5.54	5.22	0.107	0.556	28.91	

ONE PERSON'S WATER: REUWS 1999 AND 2014

Daily Indoor Residential Water Use for a One Occupant Household

Type of Fixture	Percentage of Fixture Flow that is DHW (REUWS 2014)	Baseline Flowrates (REUWS 1999 and 2014)	Duration of use, in minutes (REUWS, 1999)	Daily Uses per Occupant (REUWS, 1999)	Total Domestic Hot Water	Total Domestic Unheated Water	Total Blended Daily Water Use
Shower - Actual Use and Structural Waste	66%	2.20	7.57	0.75	8.2	4.2	12.5
Shower - Behavioural waste	72%	2.20	0.63	0.75	0.8	0.3	1.0
Bathroom Faucets	57%	1.3	8.1	0.31	1.9	1.4	3.3
Kitchen Faucets	57%	1.3	8.1	0.69	4.1	3.1	7.3
Toilets	0%	2.6	---	5.0	0.0	13.0	13.0
Dishwasher	100%	--	---	1 gal/day	1.5	0.0	1.5
Leaks	12%	--	---	9.5 gal/day	1.1	8.4	9.5
Clothes Washer	20%	27	---	0.37	2.0	8.0	10.0