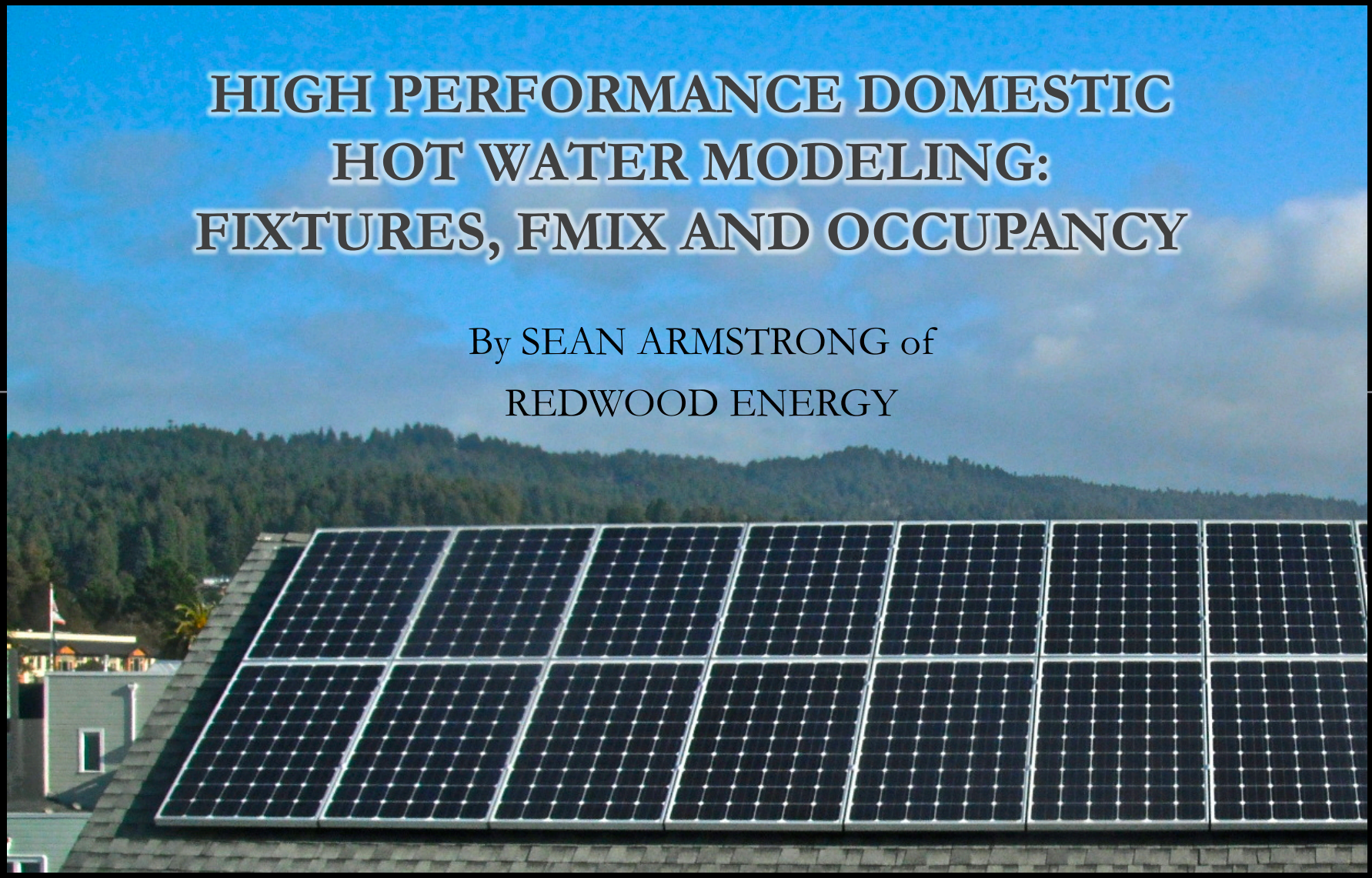
HIGH PERFORMANCE DOMESTIC HOT WATER MODELING: FIXTURES, FMIX AND OCCUPANCY

By SEAN ARMSTRONG of

REDWOOD ENERGY

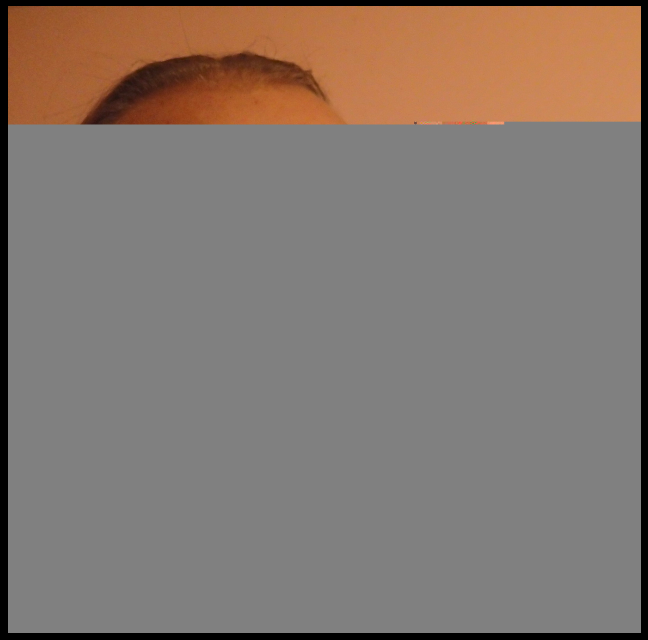


sean@redwoodenergy.net

707.826.1450 (o)

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, Martha Brook, Jim Lutz, Yanda Zhang, Gary Klein, Troy Sherman, Craig Selover, Amy Dryden, Bill Dakin, Adrian Ownby,

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

An Asseblage 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

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

Technical Papers supporting SAP 2009

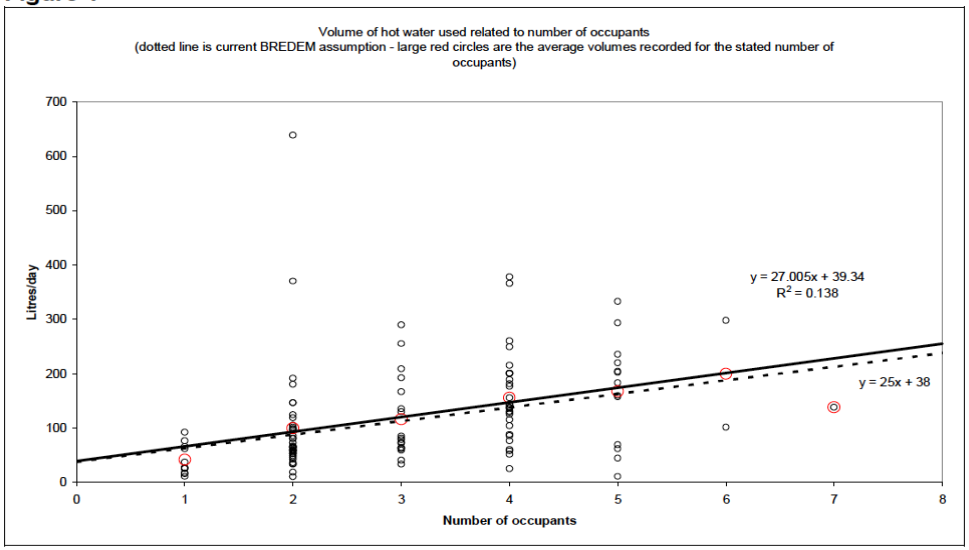
SAP

Analysis of the EST's domestic hot water trials and their implications for amendments to BREDEM and SAP

Reference no.	STP09/DHW01
Date last amended	04 June 2008
Date originated	19 March 2009
Author(s)	Les Shorrock, BRE

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.

Building AMERICA
U.S. Department of Energy

Fixture hot water use:

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

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

Where:

F_{mix} = the fraction of fixture water consumption that is hot

Nbr = Bedrooms (or occupants)

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 + (# of Bedrooms * .430)	1.75	2.18	2.61	3.04	3.47	3.9
All **Multifamily**-California	1.935 + (# of Bedrooms * .432)	1.935	2.367	2.799	3.231	3.663	4.095
All **Multifamily**-National	1.49 + (# of Bedrooms * .453)	1.49	1.943	2.396	2.849	3.302	3.755
Multifamily-CaliforniaTax 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 + (# of Bedrooms * .623)	2.49	3.113	3.736	4.359	4.982	5.605
Multifamily 100% below poverty level-National	1.69 + (# 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

"Rent Restrictions

All units receiving LIHTCs have rent restrictions based on number of bedrooms, imputed household size and AMI.

- Imputed household size equals number of bedrooms multiplied by 1.5 persons per bedroom (one person for a 0-bedroom unit)."

http://ntcicfunds.com/tax-credit-basics/lihtc-basics/

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

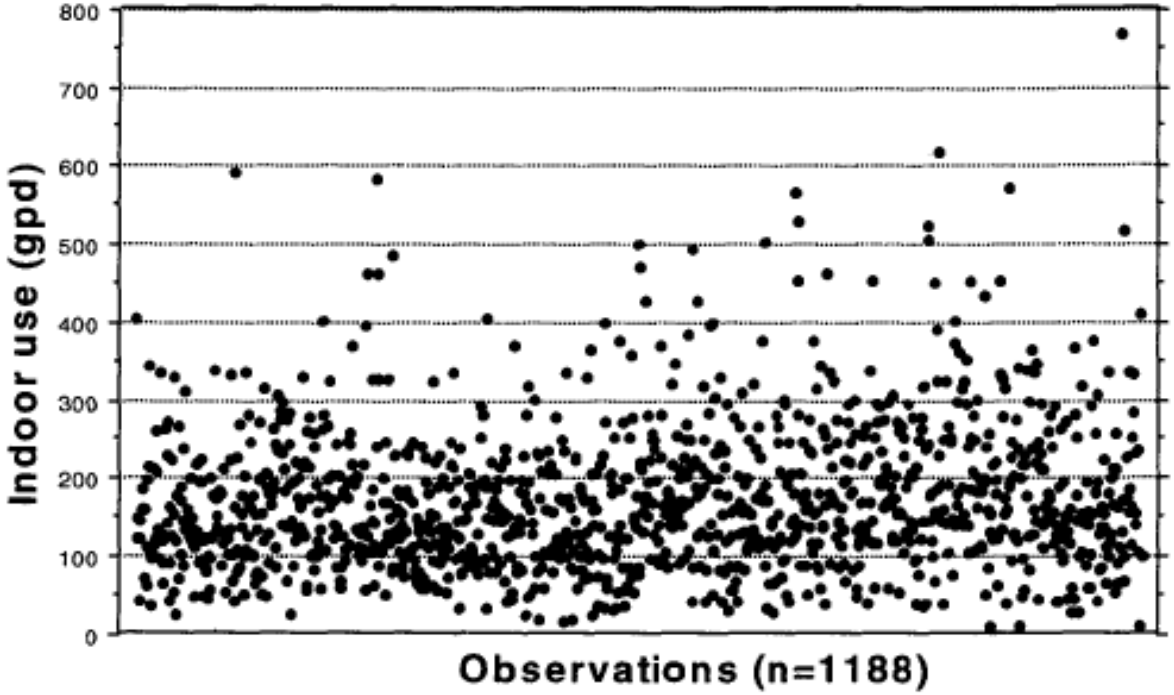


Figure 5.3 Scatter diagram of average daily indoor water use, 1,188 study homes

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

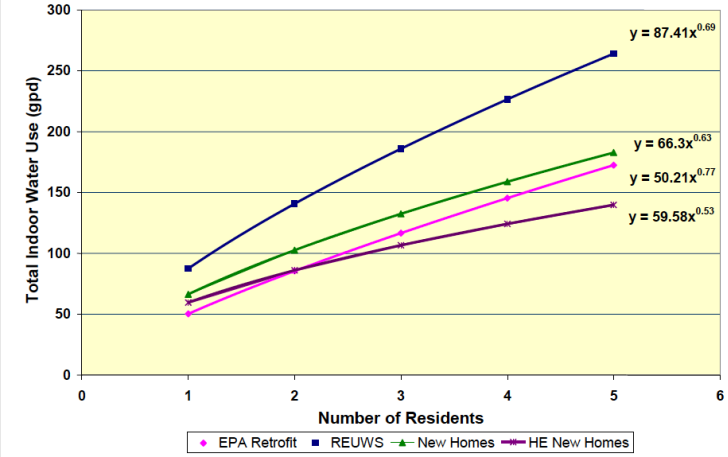


Figure ES 5: Indoor use versus residents for four research study groups

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 anomolously 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
Aquacraft, Inc. Water Engineering and Management

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

Residential
End Uses
of Water

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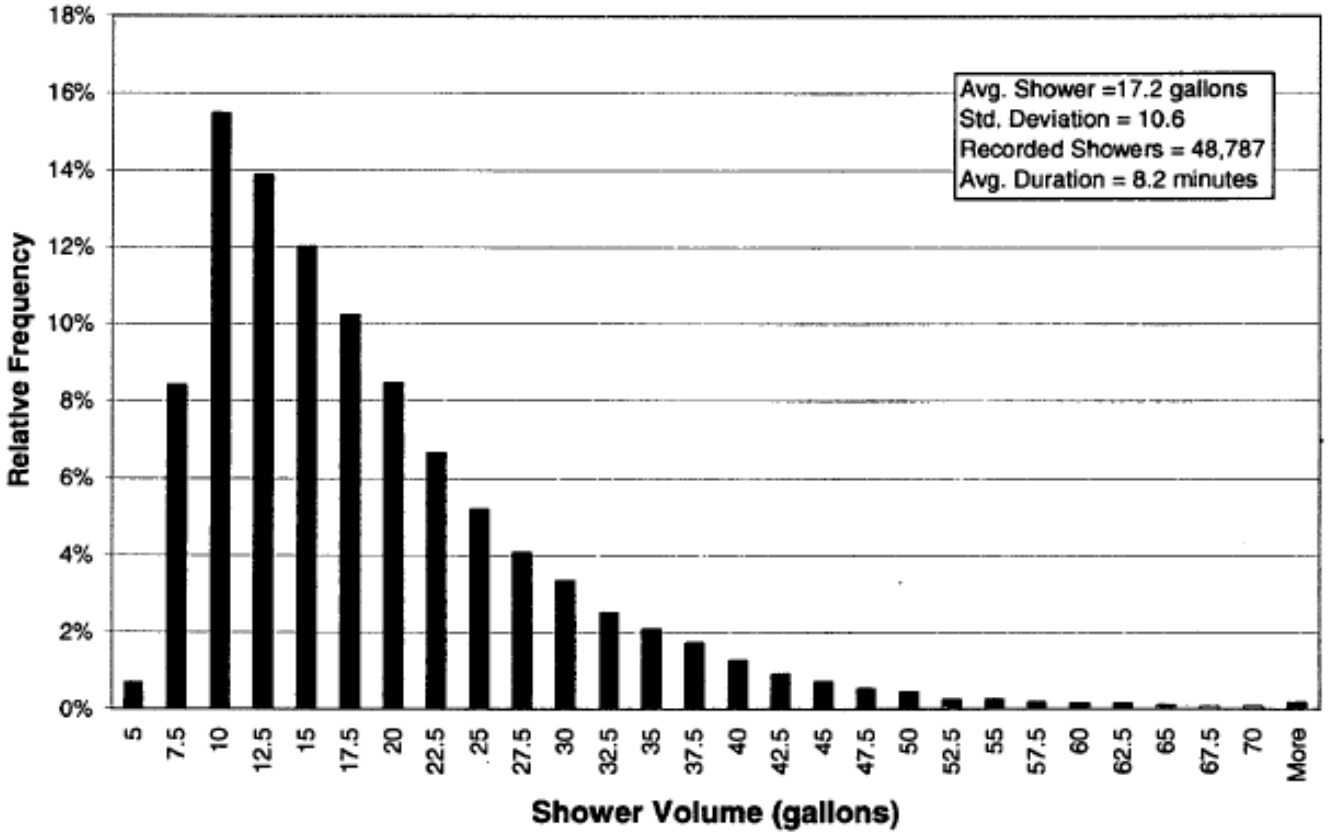


Figure 5.11 Shower volume distribution diagram

DISAGGREGATED FAUCETS: DR. BILL DE OREO WITH REUWS 1999

Aquacraft inc
WATER ENGINEERING & MANAGEMENT

March 17, 2005

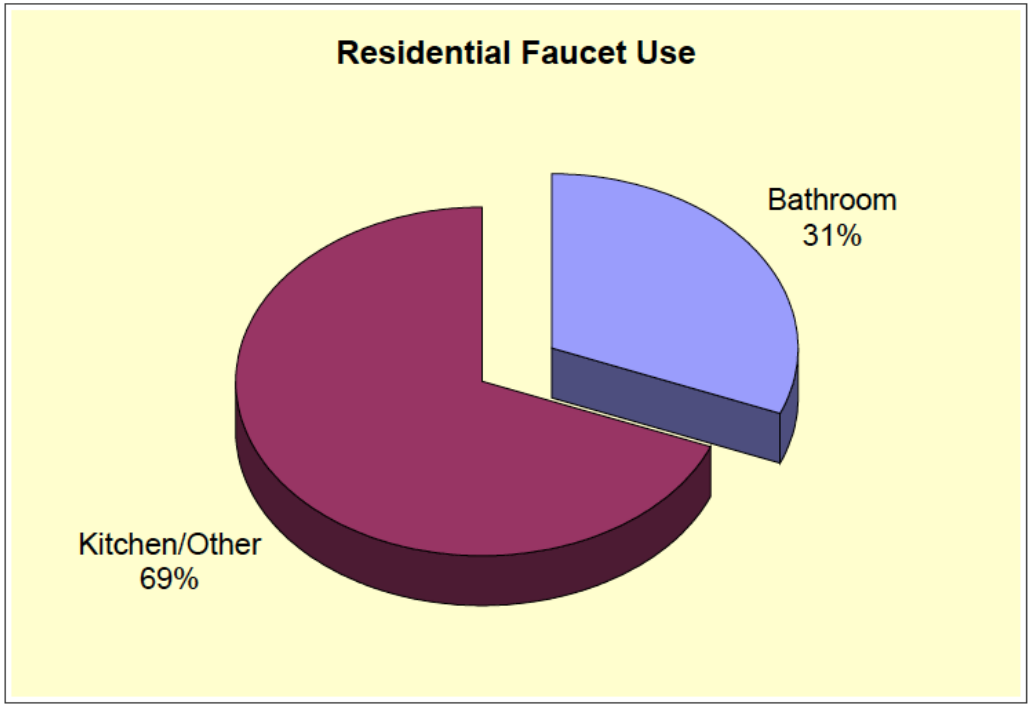
Tom Reynolds, President
Mark Sanders, Chairman
Barnacle Water Saver, LLC
13450 US Highway 42
Suite 214
Prospect, KY 40059

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 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.

Figure 2: Faucet use pie chart



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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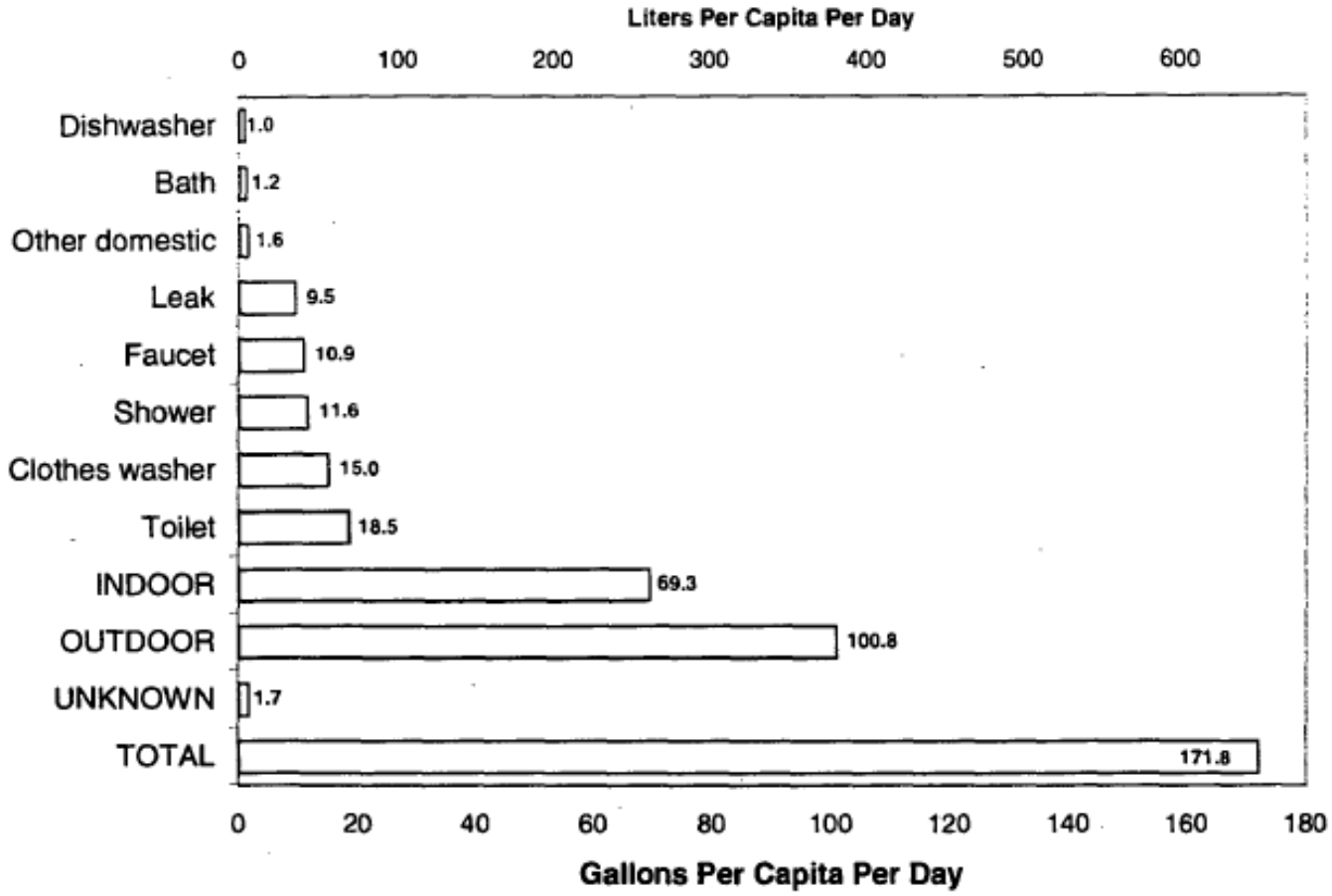
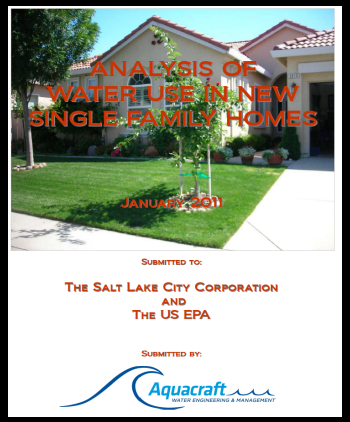


Figure 5.6 Average per capita per day usage (gpcd), 1,188 data logged homes

INDOOR LEAKS



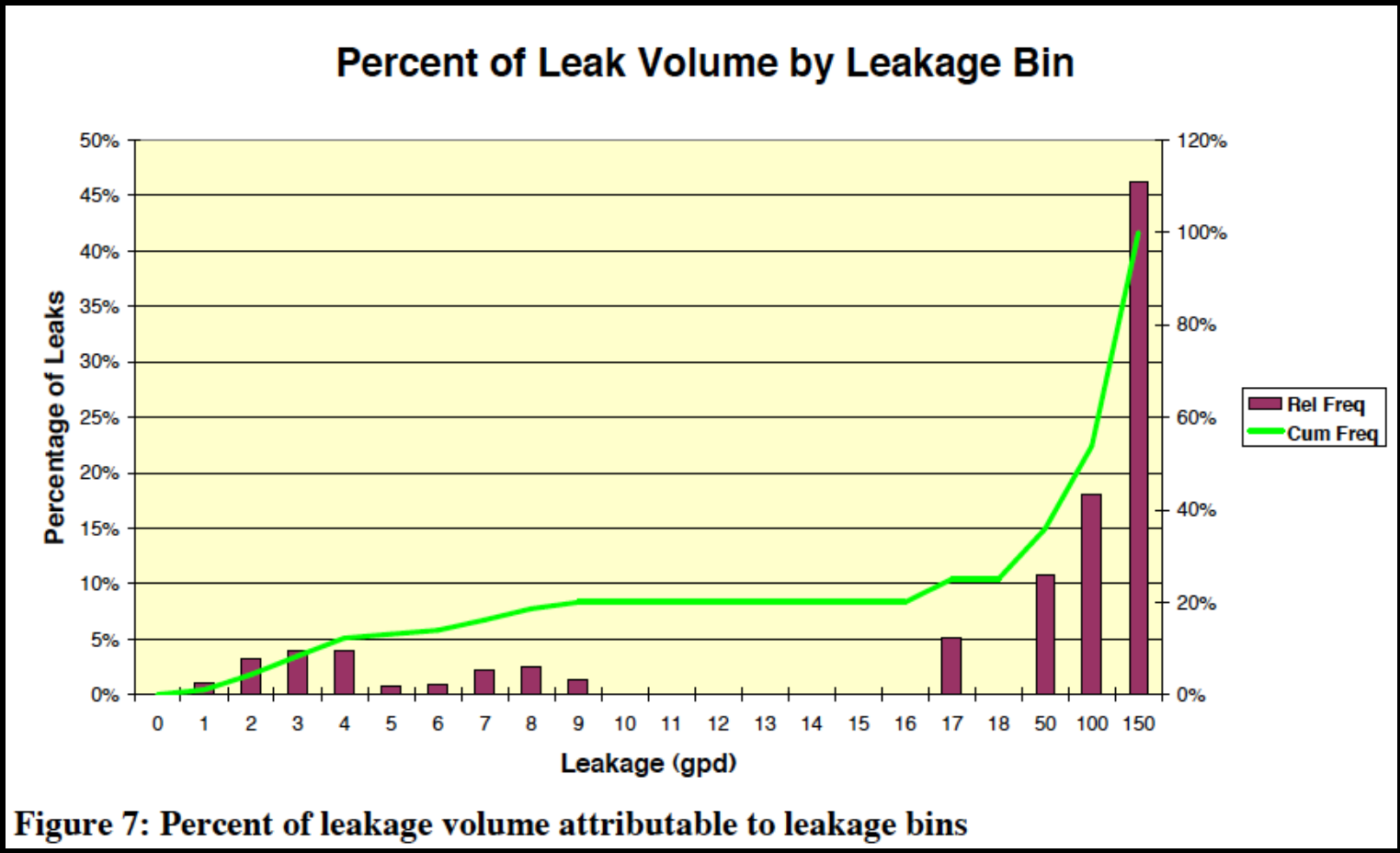


Figure 7: Percent of leakage volume attributable to leakage bins

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

Residential End Uses of Water

Prepared by:
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Aquacraft, Inc. Water Engineering and Management

95

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

iation, 12 study sites

neea

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

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

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

neea

September 5, 2013
Report#13-263

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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	Estimated Energy Use			Cycle/Loads	Estimated Energy Use		
		per Unit per Week	per Cycle	per Week	per Year	per Unit per Week	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

		Housing Type	The number of occupants assumed in each household according to census data or CTCAC management and funding goals					
		Affordable Multifamily	1	1.5	3	4.5	6	7.5
NATIONAL BASELINE WATER LOADS FOR SINGLE FAMILY RESIDENCES FROM RESEARCH	Daily Gallons of Water Used by a Single Occupant	Household Size by Number of Bedrooms	Studio	1 Bed	2 Bed	3 Bed	4 Bed	5 Bed
Total Indoor Water Use (gallons/day)	57.6	Algorithm:Total Flow of a 1 Person Household*Number of Residents^0.69	57.6	76.1	122.8	162.5	198.1	231.1
Domestic Hot Water Use (gallons/day)	18.9	Algorithm:Total Flow of a 1 Person Household*Number of Residents^0.889	18.9	27.2	50.3	72.1	93.2	113.6
	Ratio of Hot Water to Total Water Use		33%	36%	41%	44%	47%	49%