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Field Test of a DHW Distribution System: Temperature and Flow Analyses

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Scope of This Presentation

Field test of a DHW distribution system in an occupied townhome

(Previous presentation by Lee Magnusson et al., ACEEE 2008)

Additional data, further analysis:

Measured fixture flows and temperatures

(Some surprising results)

Tested recirculation system

(Surprising result)

Evaluated disaggregation of flow by:

- Measured Temperatures
- Aquacraft Trace Wizard analysis
- Comparison.

Description of Home

Credit: Paul Norton/NREL

Solar Row, in Boulder, Colorado

3-story, 1,700 finished ft^2

+ Semi-finished basement, 587 ft^2

3 bedrooms, 2 occupants.

Solar DHW/space combination system

Condensing boiler backup

Description of Data Acquisition System

Flow meters:

- Each fixture hot
- Total DHW and total water
- (Cold water flow = total water – total DHW)

Thermocouples:

- Hot at each fixture
- Master shower pipe
- Cold at kitchen sink (enables mixed water temperature calculation)

Campbell CR1000 datalogger with TC and pulse multiplexers

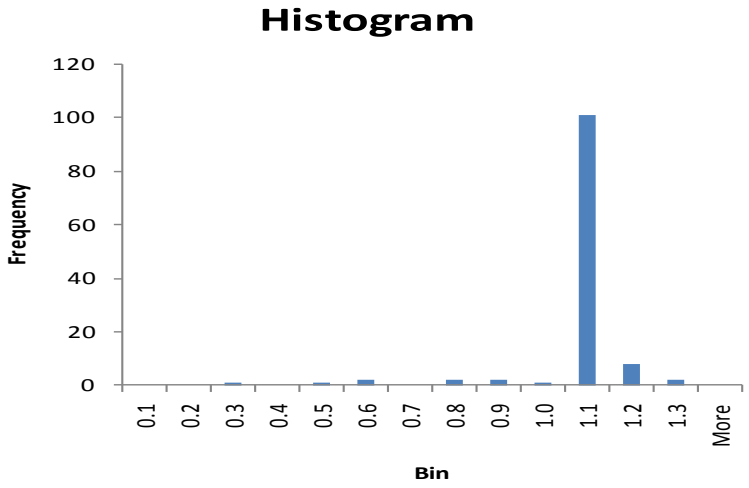
5-second records during flow events

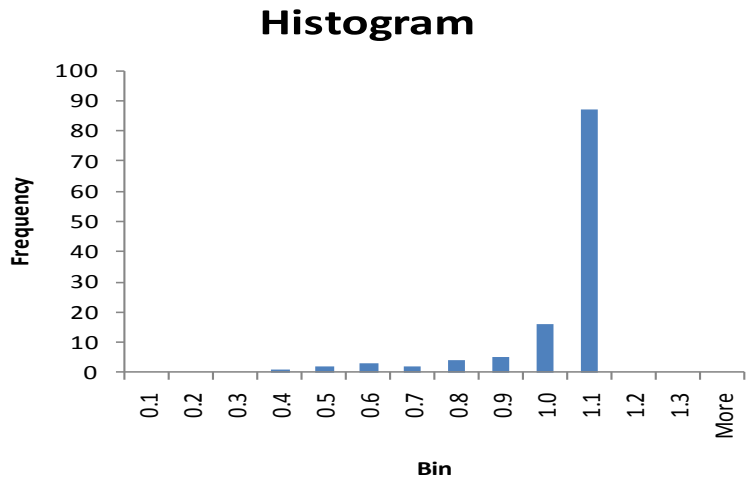
Flow Results: All Fixtures

Fixture	Daily Volume, Gal		Event Duration, s		Event Volume, Gal		Flow Rate, Gal/m	
	Avg	%	Avg	SDV	Avg	SDV	Avg	SDV
Master bath shower	10.4	46.4	372	158	6.21	2.80	0.98	0.14
Kitchen sink	5.0	22.2	30.9	33.7	0.33	0.54	0.46	0.31
Dishwasher	3.0	13.2	65.2	42.5	0.96	0.71	0.78	0.17
Master bath sink	1.8	8.0	28.2	32.5	0.35	0.61	0.50	0.31
Washing machine	1.8	7.9	49.9	34.1	0.96	0.69	1.10	0.29
2nd bath sink	0.3	1.4						
1st floor bath sink	0.1	0.5						
2nd bath shower	0.1	0.5						
TOTALS:	**22.5***	**100.0**						

* Note:
The measured total daily hot water flow is only 41% of the Building America Benchmark value of 54.7 gal/day for a 2-bedroom (2-person) home.

Flow Results: Dishwasher





Ratio of hot-to-total water flow rate,

before T_{hot}=105 F.

Average value = 1.03.

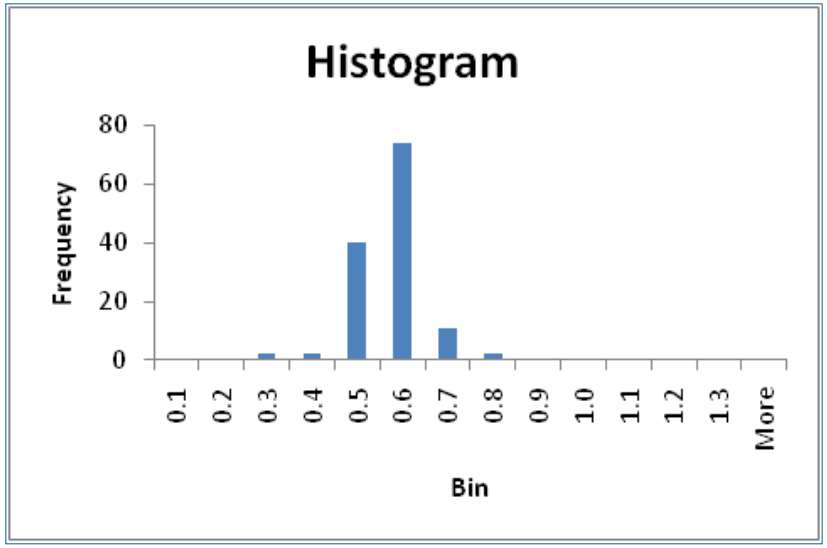
- Ratio should be =1 consistently.
- Note size of measurement errors (single cold water measurement).
- Note simultaneous usage.

Ratio of hot-to-total water flow rate,

after T_{hot}=105 F.

Average value = 0.97.

Flow Results: Washing Machine



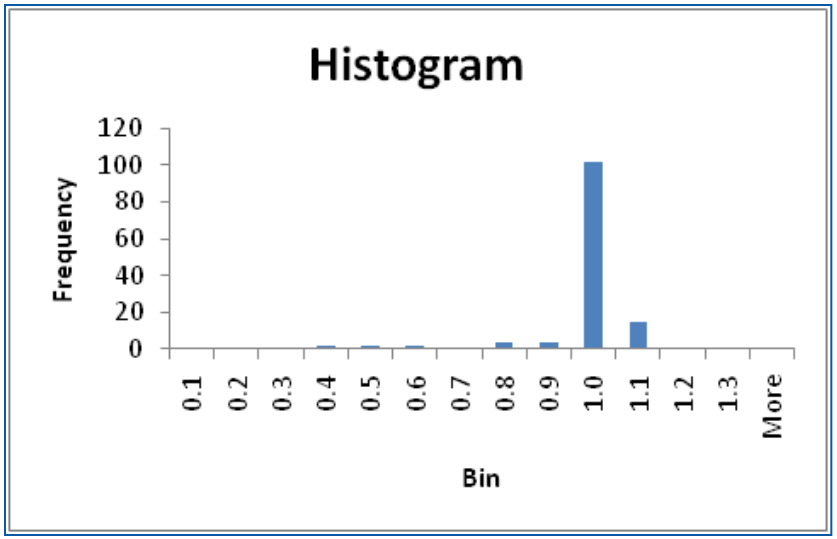
Ratio of hot-to-total water flow rate,

before T_{hot}=105 F.

Average value = 0.53.

Washing machine control strategy:

- Hot & cold for 40 sec, then hot only.
- Results in $T_{mix} \approx 92$ F (not 76 F)

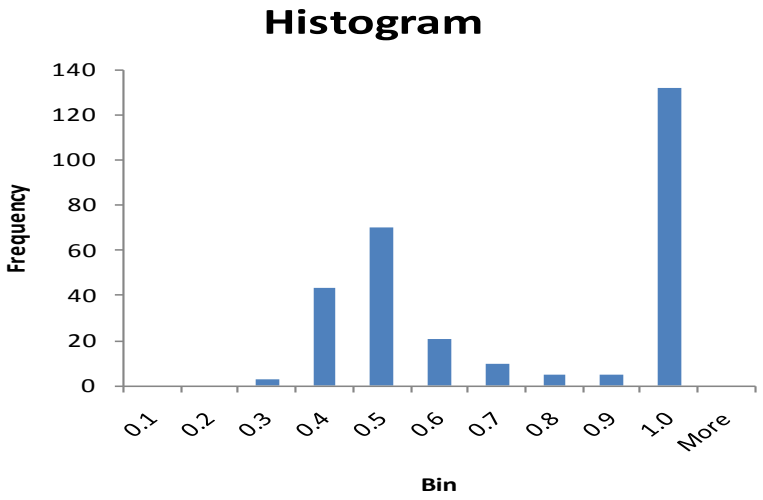


Ratio of hot-to-total water flow rate,

after T_{hot}=105 F.

Average value = 0.95.

Flow Results: Master Bath Shower

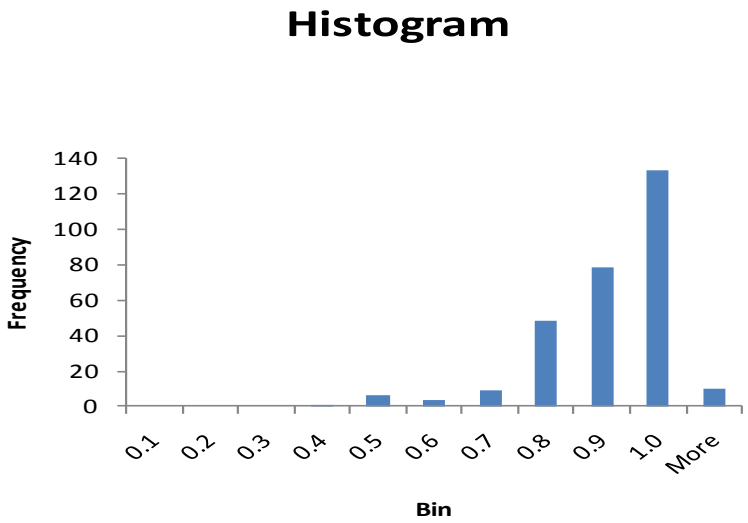


Ratio of hot-to-total water flow rate,

before T_{hot} = 105 F.

Average value = 0.69.

- Was cold water run in the shower while waiting for warm-up?
- Was cold water run elsewhere?
- Single cold water measurement is ambiguous.

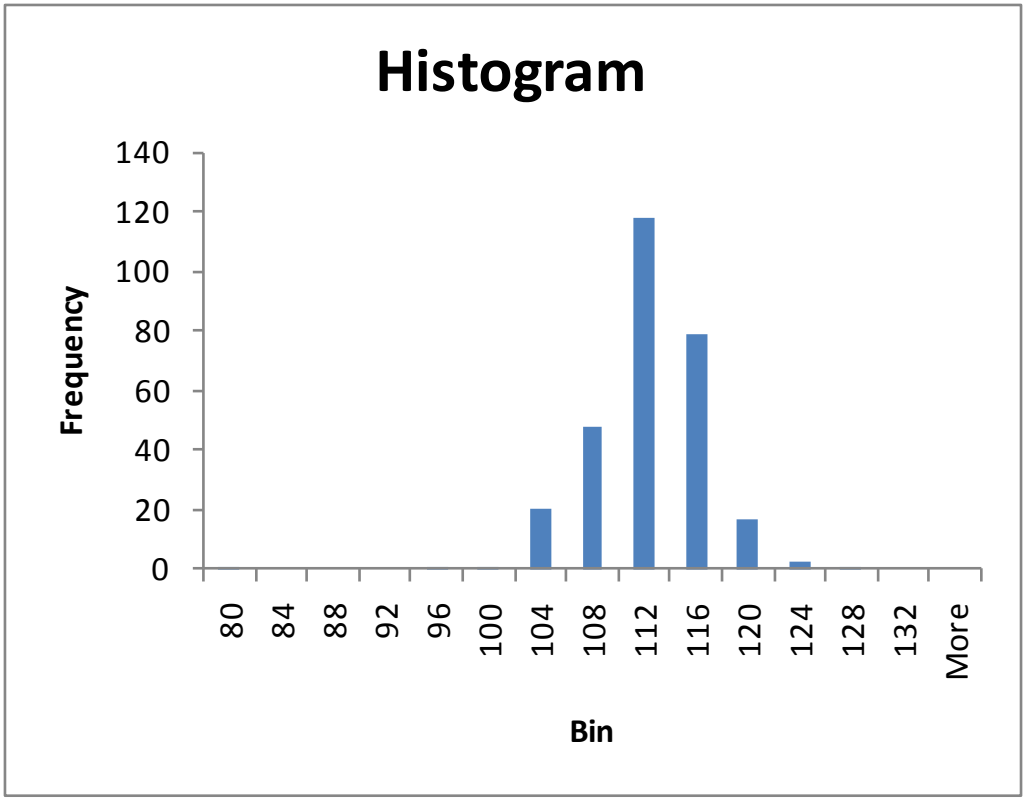


Ratio of hot-to-total water flow rate,

after T_{hot} = 105 F.

Average value = 0.87.

Temperature Results: Shower

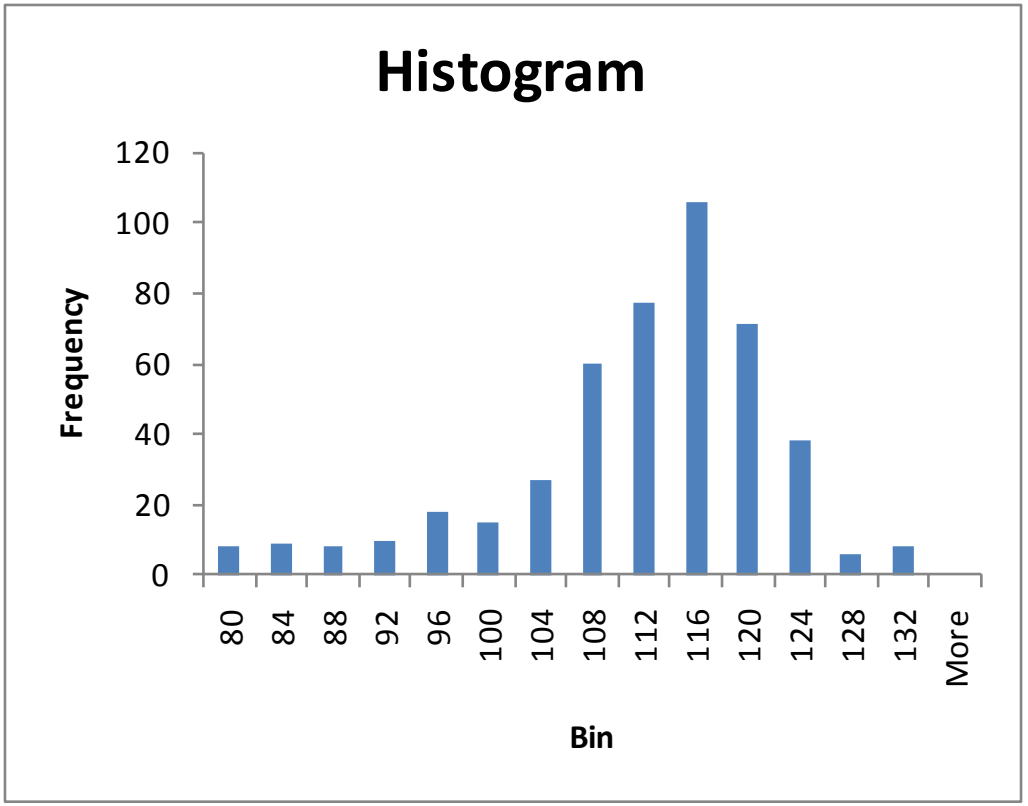


Mixed water temperature* at master bath shower.

Average = 110.4 F. SDV = 4.6 F.

(* Median of 5-second samples after T_{hot} = 105 F)

Temperature Results: Sink



Mixed water temperature* at kitchen sink.

Average = 109.7 F. SDV = 10.6 F.

(* Median of 5-second samples after T_{hot} = 105 F)

Recirculation System: Description

Purpose: To try to measure runoff of water during warm up at the fixtures, by comparing periods with recirculation off and on.

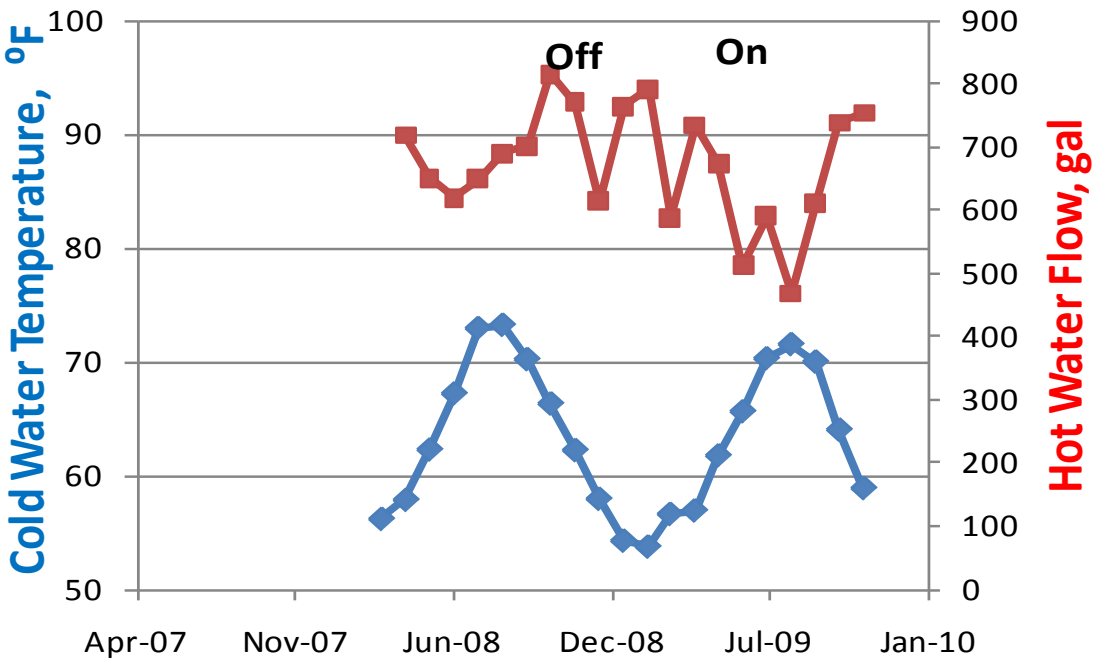
Configuration: Three zones.

Control: Occupant detectors turn pump on.

Temperature sensor on return pipe turns pump off.

Sensitivity set high to avoid false negatives.

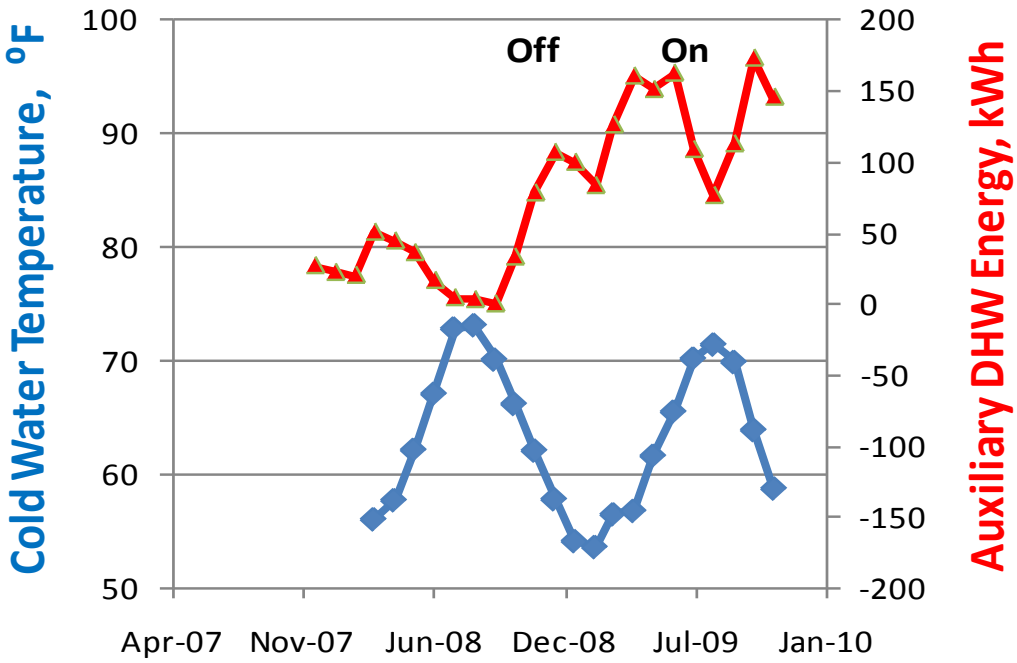
Recirculation System: Effect on Flow



Without recirculation:	3591	255 gal
With recirculation:	3099	328 gal
Difference (14%):	492	416 gal

(90% confidence interval)

Recirculation System: Effect on Energy

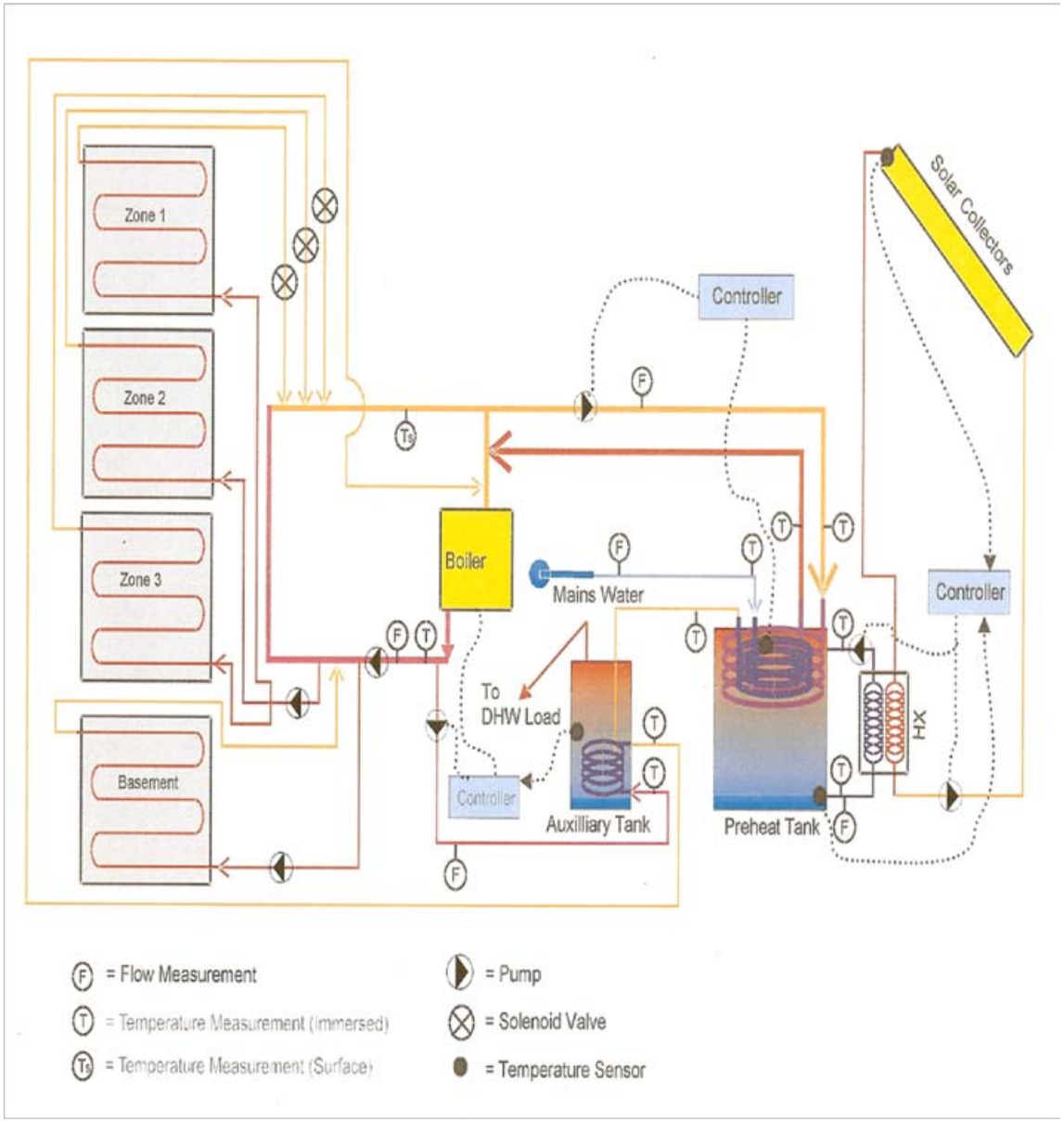


Without recirculation:	222	82 kWh (44% of load)
With recirculation:	709	101 kWh (165% of load)
Difference :	487	131 kWh

(90% confidence interval)

(Note: DHW volume was 3,590 gal when off, 3,060 gal when on.)

Recirculation System: Effect on Energy



Flow Disaggregation Methods: About

Temperature Disaggregation

- Temperatures measured in hot water pipes at the fixtures
- Identify which fixture drew hot water based on temperature rise
- Method described by:

  Weihl, J.S. and Kempton, W. (1985). "Residential Hot Water Energy Analysis: Instruments and Algorithms." Energy and Buildings, Vol. 8, pp. 197-204.

Aquacraft Trace Wizard© Software

- Given sample data from various fixture flows
- Given aggregate hot water usage data
- Identify which fixture drew hot water based on the draw pattern.

Flow Disaggregation Methods: Results

	Percent Error in Fixture ID	
	Temperature[A]	TraceWizard[B]
Sinks	14.1%	17.1%
Shower	2.4%	11.1%
Dishwasher	Not measured	6.5%
Clothes Washer	12.1%	7.2%

% error is based on comparison to fixture flow meter data ("truth").

A: Temperature disaggregation is for single flows only; % error by event.

B: Trace Wizard disaggregation includes multiple flows; % error by volume.

Conclusions

1. In this home, mixed water temperatures average 110 F, unlike the common assumption of 105 F.
2. To measure cold water flow, fixture flow meters are recommended.
3. Our test protocol for the effects of recirculation didn't work very well, because of extraneous variables (noise).
4. Flow disaggregation by temperature:

- Accuracy is comparable to Trace Wizard analysis
- More apparatus is required (thermocouples)
- Useful temperature data are also collected.

(Error Analysis)