The Art and Science of Domestic Hot Water Design

Bob Barrett
Sr. Sales Engineer, CEM, LEED AP
rbarrett@wea-inc.com
Wallace Eannace Associates
www.WEA-INC.com
The Art and Science of Domestic Hot Water Design

Part I - Equipment
How to select the right DHW system

It’s good to know what your options are… and there are many

- **Traditional – Residential**: Tube-in-tank style
- **Traditional – Commercial**: Standard DHW tank with remote water heater
- **Instantaneous – Point of Use**: Small water heaters placed at each fixture
- **Traditional Indirect**: Indirect coil-in-tank DHW heater feed by boiler
- **Distributed Instantaneous / Inverted Indirect**: Tank used as instantaneous / Indirect heat source, DHW tubes piped inside.
- **Plate HXR piped as Traditional Indirect**: Plate HXR used as indirect source of heat for the standard DHW storage tank; boiler used as primary heat source (2-config’s).
- **Distributed Instantaneous with Indirect Plate HXR**: Boiler with Buffer tank used as primary source of heat, Plate HXR provides instantaneous source of heat to a distributed DHW system
Traditional - Residential: Tube-in-tank style

1st Hour Rating: Storage Capacity + Heater Capacity
2nd Hour Rating: Heater Capacity Only

Hot water storage ~ 2/3 to 3/4 of tank volume
Cold water storage ~ 1/3 to 1/4 of tank volume

Note: Heating operates at Full Fire (100%) and off
Traditional - Residential: Tube-in-tank style

**ADVANTAGES** | **DISADVANTAGES**
---|---
Inexpensive | Difficult or Impossible to maintain
Small Footprint | Lime build-up is a major and unavoidable issue
| Limited venting options
| Limited efficiency *
| Short Lifespan

* There are some high efficiency models of tube-in-tank DHW heaters. These have higher rated efficiencies but have the same disadvantages otherwise.

In addition, they can have issues with cycling that greatly reduce their actual efficiencies. When these units cycle, they undergo a purge cycle that introduces cold outside air which cools the warm water in the tank.
Traditional - Commercial: Standard DHW tank with remote water heater

- Domestic Hot Water supply 140F
- Domestic Cold Water fill (Non-condensing) 40F
- Domestic Cold Water fill (condensing) 147F 140F 133F

**ADVANTAGES**
- Longer lifespan
- Mitigates lime issues
- Higher efficiencies *
- Greater venting options
- Separate from boiler plant

**DISADVANTAGES**
- Higher first cost
- Bigger foot print **
- Separate from boiler plant

* This configuration represents the highest possible efficiency set-up for DHW generation (when condensing boilers used). In addition, water-tube design water heaters provide better efficiency due to minimal purge cycle losses.

** The water heater can be mounted on top of the storage tank (select sizes), providing the performance advantages of this set-up, while providing the small foot print advantages of a Traditional tube-in-tank style water heater.

- Water heaters typically fire at Full Fire (100%) until they hit the set-point (140F), then they modulate the burner down as they approach the upper range +7F, and shut off.
How much storage do you need?

If you select the system with:
1/3-GPH (boiler) & 2/3-GPH (tank), then you should be good…but what happens if you flip that ratio?

<table>
<thead>
<tr>
<th></th>
<th>2/3 Storage</th>
<th>1/3 Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank Capacity:</td>
<td>1,400-gallons</td>
<td>350-gallons</td>
</tr>
<tr>
<td>~ Hot storage (2/3):</td>
<td>924-gallons</td>
<td>231-gallons</td>
</tr>
<tr>
<td>~ Equiv. Capacity:</td>
<td>770-MBH</td>
<td>192-MBH</td>
</tr>
<tr>
<td>~ Cold storage (1/3):</td>
<td>462-gallons</td>
<td>116-gallons</td>
</tr>
<tr>
<td>~ Cold load (1/3):</td>
<td>206-MBH</td>
<td>51.5-MBH</td>
</tr>
<tr>
<td>Ave. Cold Temp:</td>
<td>87F</td>
<td>87F</td>
</tr>
</tbody>
</table>

DHW Capacity @ 100F delta-T: 700-GPH

- DHW Equivalent flow: 11.6-gpm
- Water Heater Flow: 53-gpm
- Water Heater 1-pass Delta-T: 22F
- Instantaneous capacity: 9,691-Btu/min.
- Time to satisfy minimum tank load: 21.2 minutes

Wallace Eannace Associates
**Instantaneous – Point of Use:**
Small water heaters placed at each fixture

- With point of use instantaneous heaters, there is no diversity factored into the sizing of the units, so you end up with very large gas or electrical demand loads.
- Note, actual loads do take into account a diversity of usage charges, but the utility demand charge would still be high.
- These systems are great for “off-grid” electric systems, or any system where a far flung area needs to be served. They also make sense in areas with low energy demand charges.

**ADVANTAGES**
- Low first cost
- Unlimited hot water
- No line or storage losses
- High efficiencies **
- Failure of unit limited to only one fixture

**DISADVANTAGES**
- Very high demand load*
- Limited venting (if gas)
- Cycling issues (if gas)

*DHW = 110F
*DCW = 40F

**The theoretical efficiencies for electric POU are 99%. Many of the electric POU units lime-up quickly, decreasing their effectiveness and efficiency.**
Instantaneous – Point of Use:
Small water heaters placed at each fixture

DHW = 105F
DCW = 40F

Q = 2.8-gpm * 70F * 8.33-lb/gal
= 1,633-Btu/min. (output) / 82%
= 1,991-Btu/min (input)
= 119-MBH (output) / 82%
= 146-MBH (input)

A 10-min shower at 2.8-gpm (large flow fixture) ~ 19,910-Btu’s
While 146,000-Btu/hr would likely never be used, it is still a connected load; so may affect Demand charges
**Traditional Indirect w/DHW storage:**
Indirect DHW tank with remote boiler heater

*This set-up eliminates the need for a DHW heater; so it eliminates the venting for the DHW heater.*

If piped up like a **HVAC zone** (which requires controls capable of that arrangement), then multiple boilers can service the DHW load, adding to the redundancy of the DHW heat source. Note: This changes the Burner operation as well (**H to L becomes L to H**)

**Indirect coil input is usually quite high, so the storage volume may be able to be reduced; but still allows for a more conventional DHW storage volume**

---

**ADVANTAGES**

- Longer lifespan
- Mitigates lime issues
- Less venting required*
- Smaller tank size**
- Connected to boiler plant

**DISADVANTAGES**

- Operates in Non-Condensing range
- Single/Double wall options
- Connected to boiler plant

---

The Art and Science of Domestic Hot Water Design

Wallace Eannace Associates
Traditional Indirect w/DHW storage:
Indirect DHW tank with remote boiler heater

Boiler acts like DHW heater when there is a call for DHW.

The boiler pump turns off, the DHW pump turns on, and the burner fires at Full Fire (100%) until the DHW tank set-point is satisfied.

If Indirect tank is piped up as a HVAC zone, then the boiler acts like a boiler, ramping from low to high.
Distributed Instantaneous / Inverted Indirect:
Tank used as instantaneous/indirect heat source, DHW tubes piped inside

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inexpensive</td>
<td>Operates in Non-Condensing range</td>
</tr>
<tr>
<td>Less venting required</td>
<td>Limited cold storage*</td>
</tr>
<tr>
<td>Smaller tank size***</td>
<td>Short cycling issues*</td>
</tr>
<tr>
<td>Provides Instantaneous heat</td>
<td>Single wall const.**</td>
</tr>
<tr>
<td></td>
<td>Very high demand loads</td>
</tr>
<tr>
<td>Connected to boiler plant</td>
<td>Connected to boiler plant</td>
</tr>
</tbody>
</table>

* Small volumes of cold domestic water plus an operating range of 20°F on the boiler size result in very little cold storage. This leads to boiler short cycling which reduces the boiler’s lifespan.

** Single wall construction can be a health issue in larger boiler plants that use chemical treatment.

*** Vendor claims to be able to use smaller tanks but does little to address issues related to boiler short cycling as a result of both limited volume and limited delta-T.
Distributed Instantaneous / Inverted Indirect:
Tank used as instantaneous/indirect heat source, DHW tubes piped inside

Are you protecting your boiler?  
...think about summer operation.

<table>
<thead>
<tr>
<th>Tank capacity:</th>
<th>119-gallons</th>
</tr>
</thead>
<tbody>
<tr>
<td>~ Hot storage</td>
<td>119-gallons</td>
</tr>
<tr>
<td>~ Equiv. Capacity:</td>
<td>19.8-MBH</td>
</tr>
<tr>
<td>~ Cold storage:</td>
<td>0-gallons</td>
</tr>
<tr>
<td>~ DHW Delta-T:</td>
<td>100F</td>
</tr>
</tbody>
</table>

DHW Capacity @ 100-F delta-T: 700-GPH
Equivalent flow: 11.6-gpm
DHW Capacity: Input: 600-MBH  Output: 581-MBH
DHW rated flow: 53-gpm
DHW 1-pass delta-T: 22F
Inst. Capacity: 9,691-Btu/min.
Time to satisfy minimum tank load: 2 minutes
Plate HXR piped as Traditional Indirect:
Plate HXR used as indirect source of heat for the standard DHW storage tank
Boiler used as primary heat source

**ADVANTAGES**
- Longer lifespan
- Higher efficiencies*
- Quasi-Instantaneous heat**
- Smaller tank size***
- True double-wall const.
- Connected to boiler plant

**DISADVANTAGES**
- Takes up more space
- Can require additional relays for extra pump

* Plate HXR’s allow for closer approach temperatures (cooler boiler water), and larger delta-T’s (35°F to 40°F, as opposed to 20°F for standard indirects)... this can result in condensing operation as a result of a call for DHW demand.

** Plate HXR can heat incoming water from 40°F up to 140°F (although this may not be beneficial from a flow scale perspective).

*** If you size the plate HXR as a quasi-instantaneous heat source, then you can downsize the storage requirements.... the minimum storage volume should allow for 1/3 of volume of the tank of “cold storage” to run the boilers for at least 5-minutes during summer operation.

---

The Art and Science of Domestic Hot Water Design

Wallace Eannace Associates
Plate HXR piped as Traditional Indirect:
Plate HXR used as indirect source of heat for the standard DHW storage tank
Boiler used as primary heat source

Example with redundant Plate DHW HXR’s
Plate HXR piped as Traditional Indirect:
Plate HXR used as indirect source of heat for the standard DHW storage tank
Boiler used as primary heat source

Simple & Effective
Distributed Instantaneous with Indirect Plate HXR:
Boiler with Buffer tank used as primary source of heat, Plate HXR provides instantaneous source of heat to a distributed DHW system.

**ADVANTAGES**
- Buffer tank provides instant source of hot water
- Buffer tank provides for decent cold storage
- Instantaneous heat
- Smaller tank size
- True double-wall const.
- Connected to boiler plant

**DISADVANTAGES**
- Takes up more space
- Can require additional relays for extra pump
- Very high demand load*
- Oversized HXR**
- Limited storage for variable loads
- Connected to boiler plant

---

* Instantaneous generation of DHW requires larger loads... much larger (by a factor of 5 to 10-times); to cover the same building diversity factors services by a conventional arrangement.

** HXR’s are sized to meet service peak loads (flows); which makes them grossly oversized for normal operation. Temperature control issues and lime issues can result.

*** Boiler short cycling can result; especially in the summer months if the buffer tank is undersized.
Distributed Instantaneous with Indirect Plate HXR:
Boiler with Buffer tank used as primary source of heat, Plate HXR provides instantaneous source of heat to a distributed DHW system.

Does the Distributed Instantaneous concept affect your DWH source load requirements?

**ABSOLUTELY!**

<table>
<thead>
<tr>
<th>Source of DHW Load (Showers)</th>
<th>100-people</th>
<th>50-Shower Instantaneous</th>
<th>50-Shower Instantaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHW Flow/Fixtures</td>
<td>1.85-gpm</td>
<td>1.85-gpm</td>
<td>1.85-gpm</td>
</tr>
<tr>
<td>Usage (minutes)</td>
<td>10-min.</td>
<td>1-min.</td>
<td>1-min.</td>
</tr>
<tr>
<td>Diversity Factor (peak hr %)</td>
<td>0.35</td>
<td>0.116</td>
<td>0.35</td>
</tr>
<tr>
<td>Total DHW Demand:</td>
<td>648-GPH</td>
<td>10.7-GPM</td>
<td>32.4-GPM</td>
</tr>
<tr>
<td>Water Heater (%)</td>
<td>33%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Water Heater capacity</td>
<td>214-GPH</td>
<td>644-GPH</td>
<td>1,934-GPH</td>
</tr>
<tr>
<td>Water Heater capacity</td>
<td>178-MBH</td>
<td>420-MBH</td>
<td>1,294-MBH</td>
</tr>
<tr>
<td>DHW Storage Tank (%)</td>
<td>66%</td>
<td>Buffer</td>
<td>Buffer</td>
</tr>
<tr>
<td>DHW Storage Tank</td>
<td>434-gallons</td>
<td>200-gal</td>
<td>200-gal</td>
</tr>
<tr>
<td>Effective Tank capacity</td>
<td>361-MBH</td>
<td>66-MBH</td>
<td>66-MBH</td>
</tr>
</tbody>
</table>

Large increases in plant load if Distributed Instantaneous used!

The Art and Science of Domestic Hot Water Design
Wallace Eannace Associates
Conventional DHW design VS Distributed Instantaneous design

- Inst. Dist. w/1,934-GPH heater (35% of max fixture flow)
- Inst. Dist. w/644-GPH heater (35% of peak GPH)
- Conventional (434-gal storage w/ 214-GPH heater)

Number of showers served @ 2-gpm vs Time (minutes)
The Art and Science of Domestic Hot Water Design

Part II – “Right Sizing”
The Art and Science of Domestic Hot Water Design

Accounting:  Tedious but relatively easy

Engineering:  Application of Knowledge

Science:  Understanding human factors of usage

Artistry:  Understanding the equations allows for manipulation

Mastery:  Wisdom - A full understanding of the system that allows you to be creative
Knowledge is “know-how”
Most Engineers Know-how

Understanding is “know-why”
This presentation gets into the “why”
Fundamentals

What is a BTU? It is a statement of energy.
   It’s the energy required to raise 1-pound of water, 1F
   If we provide a timeframe, say 1-hour, we get Btu/hr
   Energy/Time -> Power (so we can convert Btu/hr -> kW/hr)

What is a GPH? Is it a statement of mass flow.
   100-GPH is 100-gallons (volume) per 1-hour (mass flow)
   If we tie the GPH to a delta-T, its and expression of energy
   1-gallon of water (volume) = 8.33-lbs. (mass)
   1-GPH @ 1F delta-T = 1-lb*F = (Btu)

So GPH ~ Btu, when GPH is tied to a delta-T
Fundamentals

\[ Q = 500 \times \text{Flow (gpm)} \times \text{Delta-T (F)} \]

What is 500?

500 ~ GPH of Water = 8.33-lbs/gal * 60-min/hr. = 499.8~gal/hr

Ex: \[ Q = 8.33\text{-lbs/gal} \times 60\text{-min/hr} \times 100\text{-gal/min} \times 100\text{F} \]

Ex: \[ Q \sim 5,000,000\text{-}(\text{lbs*F})/\text{hr or Btu/hr} \]

Remember: GPH ~ Btu/hr, when GPH is tied to a delta-T / hr

*Artistry:* Understanding the equations allows for manipulation
Apartment
2-Bedroom, 2-bathroom, Laundry room with washer and dryer, Kitchen with dishwasher

What’s the Domestic Water Load?

Step 1: ACCOUNTING

<table>
<thead>
<tr>
<th>FIXTURE TYPE</th>
<th>LOCATION</th>
<th>QTY</th>
<th>TOTAL FLOW (GPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHOWER</td>
<td>BATHROOM</td>
<td>2</td>
<td>1.75</td>
</tr>
<tr>
<td>SINK</td>
<td>BATHROOM</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>TOILET</td>
<td>BATHROOM</td>
<td>2</td>
<td>2.0</td>
</tr>
<tr>
<td>TUB</td>
<td>BATHROOM</td>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td>SINK</td>
<td>KITCHEN</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>DISHWASHER</td>
<td>KITCHEN</td>
<td>1</td>
<td>3.0</td>
</tr>
<tr>
<td>REFRIG (ICE MACKER)</td>
<td>KITCHEN</td>
<td>1</td>
<td>0.10</td>
</tr>
<tr>
<td>REFRIG (WATER FOUNTAIN)</td>
<td>KITCHEN</td>
<td>1</td>
<td>0.25</td>
</tr>
<tr>
<td>WASHING MACHINE</td>
<td>LAUNDRY RM</td>
<td>1</td>
<td>3.0</td>
</tr>
<tr>
<td>HOSE FAUCET</td>
<td>VERANDA</td>
<td>1</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Step 2: SCIENCE - Human Factors -
Think about how people interface with equipment

How many people occupy a space?

How many people occupy a 1-bedroom?  \( X = \text{or} > 1 \)

How many people occupy a 2-bedroom? or a 3-bedroom?

Does the wealth of the tenants matter?
YES.

Does the location matter? City or Suburb?
YES.

High Income Tenants
1-Bedroom: 1.5
2-Bedroom: 2.5
3-Bedroom: 3.5

Average Tenants
1-Bedroom: 2.5
2-Bedroom: 3.5
3-Bedroom: 5.5

Low Income Tenants
1-Bedroom: 3.5
2-Bedroom: 5.0
3-Bedroom: 8.0

These factors will change your load
Apartment
2-Bedroom, 2-bathroom, Laundry room with washer and dryer, Kitchen with dishwasher

Step 3: SCIENCE – Human Factors & ENGINEERING – Applied Knowledge

What’s the Domestic Water Load?

**Domestic Cold Water: 40F**
**Domestic Hot Water: 120F**

<table>
<thead>
<tr>
<th>Fixture Type</th>
<th>Location</th>
<th>Qty</th>
<th>Total Flow (GPM)</th>
<th>DHW Flow (GPM)</th>
<th>CW Flow (GPM)</th>
<th>Mixed Temp (F)</th>
<th>Time per Usage (min)</th>
<th># of Usage per hour</th>
<th>DHW Usage (GPH)</th>
<th>Diversity Factors</th>
<th>Peak DHW Usage (GPH)</th>
<th>Total Load (Btu/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shower(s)</td>
<td>Bathroom</td>
<td>2</td>
<td>2.00</td>
<td>1.75</td>
<td>0.3</td>
<td>110.0</td>
<td>12</td>
<td>4</td>
<td>168.0</td>
<td>1.00</td>
<td>168.0</td>
<td>97,961</td>
</tr>
<tr>
<td>Sink(s)</td>
<td>Bathroom</td>
<td>2</td>
<td>0.50</td>
<td>0.41</td>
<td>0.1</td>
<td>105.6</td>
<td>1</td>
<td>6</td>
<td>4.9</td>
<td>1.00</td>
<td>4.9</td>
<td>2,689</td>
</tr>
<tr>
<td>Tub</td>
<td>Bathroom</td>
<td>1</td>
<td>2.50</td>
<td>2.00</td>
<td>0.5</td>
<td>104.0</td>
<td>2</td>
<td>1</td>
<td>4.0</td>
<td>1.00</td>
<td>4.0</td>
<td>2,132</td>
</tr>
<tr>
<td>Sink</td>
<td>Kitchen</td>
<td>1</td>
<td>1.00</td>
<td>0.90</td>
<td>0.1</td>
<td>112.0</td>
<td>4</td>
<td>4</td>
<td>14.4</td>
<td>1.00</td>
<td>14.4</td>
<td>8,637</td>
</tr>
<tr>
<td>Dishwasher</td>
<td>Kitchen</td>
<td>1</td>
<td>3.00</td>
<td>3.00</td>
<td>0.0</td>
<td>120.0</td>
<td>4</td>
<td>1</td>
<td>12.0</td>
<td>1.00</td>
<td>12.0</td>
<td>7,997</td>
</tr>
<tr>
<td>Wash. Mach.</td>
<td>Laundry</td>
<td>1</td>
<td>3.00</td>
<td>3.00</td>
<td>0.0</td>
<td>120.0</td>
<td>5</td>
<td>1</td>
<td>15.0</td>
<td>1.00</td>
<td>15.0</td>
<td>9,996</td>
</tr>
</tbody>
</table>

**Note:** We don’t sum the flow (gpm) & multiply by 60-min -> 794-GPH

**Note:** Total CW usage is calculated in the same manor as DHW except you use the Total Flow of the fixtures times the limiting factors - (hot water is supplied by cold water).... And you add the cold water only figures (toilets, hoses, etc.)

**Total DHW Peak Load:** 129,411-Btu/hr

**Total DHW Peak Load:** 155-GPH @ 100F delta-T

**Total DHW Peak Load:** 222-GPH @ 70F delta-T
Gut Check - Does this make sense?

How have you been figuring out DHW demand in the past?

“Fixture Unit” per fixture

What is a “Fixture Unit”?

How is it determined?

<table>
<thead>
<tr>
<th>FIXTURE TYPE</th>
<th>COLUMN A</th>
<th>COLUMN B</th>
<th>TOTAL FIXTURE UNIT/FIXTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC/Public - Flush Valve</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>WC/Public - Flush Tank</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Pedestal Urinal/Public</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Stall - Wall Urinal/Public</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Stall - Wall Urinal/Public</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Lavatory/Public</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Bathtub/Public</td>
<td>4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Shower Head/Public</td>
<td>4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Service Sink/Office</td>
<td>3</td>
<td>2.25</td>
<td>2.25</td>
</tr>
<tr>
<td>Kitchen Sink/Hotel, etc.</td>
<td>4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>WC/Private Flush Valve</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>WC/Private Flush Tank</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Lavatory/Private</td>
<td>1</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Bathtub/Private</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Shower Head/Private</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Bathroom Group/Private Flush Valve</td>
<td>8</td>
<td>8.25</td>
<td></td>
</tr>
<tr>
<td>Bathroom Group/Private Flush Tank</td>
<td>6</td>
<td>5.25</td>
<td></td>
</tr>
<tr>
<td>Separate Shower/Private</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Kitchen Sink/Private</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Dishwasher/Private - Public</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Washing Machine/Private</td>
<td>8</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Washing Machine/Hospital</td>
<td>6</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Bidet/Primary</td>
<td>3</td>
<td>2.25</td>
<td>2.25</td>
</tr>
<tr>
<td>Icemaker/Private - Public</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Lawn Hoses/Public</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Lawn Hoses/Commercial</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Equipment Fill Valves/Commercial</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>OTHER FIXTURES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OTHER FIXTURES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OTHER FIXTURES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OTHER FIXTURES</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Used for building pipe sizing only

Are we missing anything? Yes, a diversity factor.

How have you been figuring out the diversity factor in the past?

Usage Factor or Diversity Factor

Small Bldg
Curve 1: Flush valve toilets
Curve 2: Tank Toilets

Large Bldg

0.65
0.42
0.31
0.25
0.15
Usage factors for very large buildings or campuses

These diversity factors are likely good rules of thumb but you should never use them without considering your application AND You should not be afraid to alter them to better suit your project.

Ex: Military Barracks - Is it likely that 100% of its occupants would shower within the same 30-minute window? Yes!
What is a Usage Factor?

Answer: It is simply a diversity factor.

What is it based on?

Think about the ratio of

_Heater : Storage_

Does your heater have enough capacity to charge and meet your second peak?

Do you want enough storage to handle 2-peaks?
The Art and Science of Domestic Hot Water Design

Wallace Eannace Associates

**CW Usage:** about 60% greater than HW

**DHW Peak:** 100% usage of showers in 1-hr.

**Tub drawn + 1-load of Laundry (hot)**
What’s the Domestic Water Load?

**Step 4:** SCIENCE – Human Factors – Think about how the people interface with the equipment

- **Do people shower and wash their hands in the sink at the same time?**
  
  Answer: No, but they may within the same hour

- **Do people do laundry in the morning?**
  
  Answer: Almost never during the week… but yes on the weekend

- **Do people take baths in the morning?**
  
  Answer: Rarely… It’s more of a night activity… apply diversity factor to this activity

- **Do people wash dishes in the morning?**
  
  Answer: Maybe… usually this is done at night… apply diversity

---

### Diversity factors are probabilities of use during the peak…

So they can be applied on a per fixture basis

<table>
<thead>
<tr>
<th>Fixture Type</th>
<th>Location</th>
<th>Qty</th>
<th>Total Flow (GPM)</th>
<th>DHW Flow (GPM)</th>
<th>CW Flow (GPM)</th>
<th>Mixed Temp (F)</th>
<th>Time per Usage (min)</th>
<th># of Usage per hour</th>
<th>DHW Usage (GPH)</th>
<th>Diversity Factors</th>
<th>Peak DHW Usage (GPH)</th>
<th>Total Load (Btu/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shower(s)</td>
<td>Bathroom</td>
<td>2</td>
<td>2.00</td>
<td>1.75</td>
<td>0.3</td>
<td>110.0</td>
<td>12</td>
<td>350</td>
<td>14700</td>
<td>0.28</td>
<td>4116</td>
<td>2,400,040</td>
</tr>
<tr>
<td>Sink(s)</td>
<td>Bathroom</td>
<td>2</td>
<td>0.50</td>
<td>0.41</td>
<td>0.1</td>
<td>105.6</td>
<td>1</td>
<td>450</td>
<td>369</td>
<td>0.28</td>
<td>103</td>
<td>56,459</td>
</tr>
<tr>
<td>Tub</td>
<td>Bathroom</td>
<td>1</td>
<td>2.50</td>
<td>2.00</td>
<td>0.5</td>
<td>104.0</td>
<td>2</td>
<td>100</td>
<td>400</td>
<td>0.05</td>
<td>20</td>
<td>10,662</td>
</tr>
<tr>
<td>Sink</td>
<td>Kitchen</td>
<td>1</td>
<td>1.00</td>
<td>0.90</td>
<td>0.1</td>
<td>112.0</td>
<td>4</td>
<td>375</td>
<td>1350</td>
<td>0.28</td>
<td>378</td>
<td>226,709</td>
</tr>
<tr>
<td>Dishwasher</td>
<td>Kitchen</td>
<td>1</td>
<td>3.00</td>
<td>3.00</td>
<td>0.0</td>
<td>120.0</td>
<td>4</td>
<td>100</td>
<td>1200</td>
<td>0.20</td>
<td>240</td>
<td>159,936</td>
</tr>
<tr>
<td>Wash. Mach.</td>
<td>Laundry</td>
<td>1</td>
<td>3.00</td>
<td>3.00</td>
<td>0.0</td>
<td>120.0</td>
<td>5</td>
<td>100</td>
<td>1500</td>
<td>0.20</td>
<td>300</td>
<td>199,920</td>
</tr>
</tbody>
</table>

Don’t be afraid to “layer” your diversity factors if it makes sense to do so (a.k.a. – alter quantity of people, their usage per hour, etc.)

Total DHW Peak Load: 3,054-MBH

Total DHW Peak Load: 3,665-GPH @ 100F delta-T

Total DHW Peak Load: 5,237-GPH @ 70F delta-T
ASHRAE Method

Usage (gallons/person/period) with assumptions built in based on:
1. # of beds (Nursing homes)
   # of students (schools)
   # of units (hotels, apartments)
2. High, Medium, Low factors applied based on Demographics
3. System load characteristics (Heater requirements based on type of system; storage based on Demographic factors)

ASHRAE Service Water Heating, Table 8:
Hot Water Demand and Use Guidelines for Apartment Buildings
(Gallons per person delivered at 120° to fixtures)

<table>
<thead>
<tr>
<th>Peak Minutes</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Units</th>
<th>Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.4</td>
<td>0.7</td>
<td>1.2</td>
<td>gal/person/period</td>
<td>12</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>1.7</td>
<td>3</td>
<td>gal/person/period</td>
<td>4</td>
</tr>
<tr>
<td>30</td>
<td>1.7</td>
<td>2.9</td>
<td>5.1</td>
<td>gal/person/period</td>
<td>2</td>
</tr>
<tr>
<td>60</td>
<td>2.8</td>
<td>4.8</td>
<td>8.5</td>
<td>gal/person/period</td>
<td>1</td>
</tr>
<tr>
<td>120</td>
<td>4.5</td>
<td>8</td>
<td>14.5</td>
<td>gal/person/period</td>
<td>0.5</td>
</tr>
<tr>
<td>180</td>
<td>6.1</td>
<td>11</td>
<td>19</td>
<td>gal/person/period</td>
<td>0.33333</td>
</tr>
<tr>
<td>Average Daily</td>
<td>14</td>
<td>30</td>
<td>54</td>
<td>gal/person/day</td>
<td>-</td>
</tr>
<tr>
<td>Maximum Daily</td>
<td>20</td>
<td>49</td>
<td>90</td>
<td>gal/person/day</td>
<td>-</td>
</tr>
</tbody>
</table>

- Maximum Daily

Occupancy

<table>
<thead>
<tr>
<th>Unit Type</th>
<th>Qty</th>
<th># people/unit</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Studio</td>
<td>0</td>
<td>2.25</td>
<td>0</td>
</tr>
<tr>
<td>1 Bedroom</td>
<td>0</td>
<td>3.5</td>
<td>0</td>
</tr>
<tr>
<td>2 Bedroom</td>
<td>100</td>
<td>4</td>
<td>400</td>
</tr>
<tr>
<td>3 Bedroom</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>4 Bedroom</td>
<td>0</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Total:</td>
<td>100</td>
<td></td>
<td>400</td>
</tr>
</tbody>
</table>
### ASHRAE Method

<table>
<thead>
<tr>
<th>DHW Usage Factor</th>
<th>Demographic characteristics</th>
</tr>
</thead>
</table>
| **High**         | No occupants work  
                  | Public assistance and low income (mix)  
                  | Family and single-parent households (mix)  
                  | High percentage of children  
                  | Low income |
| **Medium**       | Families  
                  | Public assistance  
                  | Singles  
                  | Single-parent households |
| **Low**          | Couples  
                  | Higher population density  
                  | Middle income  
                  | Seniors  
                  | One person works, one stays home  
                  | All occupants work |
## System Load Characteristics

<table>
<thead>
<tr>
<th>System Load</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak-5</td>
<td>Instantaneous systems</td>
</tr>
<tr>
<td></td>
<td>No storage</td>
</tr>
<tr>
<td>Peak-15</td>
<td>Separate Boiler</td>
</tr>
<tr>
<td></td>
<td>Storage capacity</td>
</tr>
<tr>
<td></td>
<td>Additional loads</td>
</tr>
<tr>
<td>Peak-30</td>
<td>Separate Boiler</td>
</tr>
<tr>
<td></td>
<td>Storage capacity</td>
</tr>
</tbody>
</table>

## Sizing - Generation

<table>
<thead>
<tr>
<th></th>
<th>“Medium”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak System Demand</td>
<td>30 peak minutes</td>
</tr>
<tr>
<td>Water per person</td>
<td>2.9 gal/period</td>
</tr>
<tr>
<td>Peak Demand</td>
<td>1,160.0 gal/period</td>
</tr>
<tr>
<td>Flow Average (DHW side)</td>
<td>38.7 gpm</td>
</tr>
<tr>
<td>System Load</td>
<td>2,320.0 gal/hr</td>
</tr>
<tr>
<td>Required Boiler Output</td>
<td>1,546.0 MBH</td>
</tr>
<tr>
<td>Combustion Efficiency</td>
<td>0.92 (decimal)</td>
</tr>
<tr>
<td>Required Boiler Input</td>
<td>1680.5 MBH</td>
</tr>
</tbody>
</table>

## Building Characteristics

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Usage Factor</td>
<td>Medium</td>
</tr>
<tr>
<td>Entering Water Temp</td>
<td>40 °F</td>
</tr>
<tr>
<td>Faucet Delivery Temp</td>
<td>120 °F</td>
</tr>
<tr>
<td>Delta T</td>
<td>80 °F</td>
</tr>
</tbody>
</table>

## Storage Sizing

<table>
<thead>
<tr>
<th></th>
<th>“Low”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Volume Load</td>
<td>60 peak minutes</td>
</tr>
<tr>
<td>Storage Required at 120°F</td>
<td>1,920.0 gal</td>
</tr>
<tr>
<td>Actual Storage Required at 120°F</td>
<td>2,742.9 gal</td>
</tr>
<tr>
<td>DHW Storage Temperature</td>
<td>140 °F</td>
</tr>
<tr>
<td>Storage Required at DHW Storage Temp</td>
<td>1,536.0 gal</td>
</tr>
<tr>
<td>Actual Storage Required at Storage Temp</td>
<td>2,194.3 gal</td>
</tr>
</tbody>
</table>
What’s the Domestic Water Load?

Whose method is right?

There is no one right way to calculate DHW Loads...
Only better or worse ways of approaching the task

The engineer with the greatest understanding of the system AND who is making the least amount of assumptions will provide the best system.

REVIEW:
Step 1: Accounting - Create a fixture table, noting actual flow rates for each fixture
Step 2: Determine the correct human factors (this may take some investigative work)
Step 3: Engineering - work through the numbers; apply appropriate human factors & safety factors
Step 4: Pick an appropriate diversity factor
   (judgment call... hopefully based on some investigative work, hard data, and wisdom)
Step 5: Select your DHW equipment
The Art and Science of Domestic Hot Water Design

So how do you calculate a DHW load?

Which DHW system is right for your application?

With proper knowledge and understanding you should be able to design DHW systems with ease.
The Art and Science of Domestic Hot Water Design

It’s as easy as AESAM

Accounting: Tedious but relatively easy

Engineering: Application of Knowledge

Science: Understanding human factors of usage

Artistry: Understanding the equations allows for manipulation

Mastery: Wisdom - A full understanding of the system that allows you to be creative
The Art and Science of Domestic Hot Water Design