Estimating Peak Water Demands in Buildings with Efficient Fixtures

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INTERNATIONAL EMERGING TECHNOLOGY SYMPOSIUM

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Outline

- [1] Background/Motivation
- [2] Water Use Database
- [3] Water Use Parameters
- [4] Water Use Model
- [5] Application
- [6] Conclusion
[1] BACKGROUND / MOTIVATION
Today, **Hunter’s curve** is often faulted for giving overly conservative designs....Why?

High efficiency fixtures = lower $q$

Uncongested use = lower $p$
Changing Times

1940
Hunter's curve was developed

ASHRAE Modified Hunter Curve Energy Policy Act Estimating demand for efficient water supply

5.0+ gpf 3.5 gpf 1.6 gpf 1.28 gpf
Modified Hunter’s Curve(s)

Different curve for different end users
Task Group Sponsors and Members

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IAPMO Task Group Orders

“….will work singularly to develop the probability model to predict peak demands based on the number of plumbing fixtures of different kinds installed in one system.”

(Bring Hunter into 21st Century)
Project Activities

- Acquire Data
- Analyze Data
- Develop Model
- Peer Review & Publication of Report
[2] WATER USE DATABASE
Database: Location of Homes

- Survey 1996-2011
- 1,038 households
- 2,800 residents
- 11,350 monitoring days
- MS Access DB
Database: Summary of Measured Data

- Six unique fixtures
- 862,900 events*
- 1,591,700 gallons*
- 889,700 minutes*

*excluding leaks

Evaporative Cooler
Database: Details of Water Use at Fixture

**NUMBER OF “HITS”**

- Bathtub: 0.5%
- Toilet: 18.8%
- Shower: 2.5%
- Faucet: 73.5%
- Dishwasher: 1.5%
- Clothes washer: 3.2%

**VOLUME OF WATER USE**

- Faucet: 20.2%
- Toilet: 25.8%
- Shower: 21.9%
- Dishwasher: 1.9%
- Clothes washer: 25.0%
- Bathtub: 5.2%
## Database: Residential Fixture Classification

<table>
<thead>
<tr>
<th>Fixture*</th>
<th>Ultra-Efficient</th>
<th>Efficient</th>
<th>Inefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clothes washer (gallons/load)</td>
<td>&lt; 20</td>
<td>20 – 30</td>
<td>&gt; 30</td>
</tr>
<tr>
<td>Dishwasher (gallons/cycle)</td>
<td>&lt; 1.8</td>
<td>1.8 – 3.0</td>
<td>&gt; 3.0</td>
</tr>
<tr>
<td>Shower (gallons/minute)</td>
<td>&lt; 2.2</td>
<td>2.2 – 2.5</td>
<td>&gt; 2.5</td>
</tr>
<tr>
<td>Toilet (gallons/flush)</td>
<td>&lt; 1.8</td>
<td>1.8 – 2.2</td>
<td>&gt; 2.2</td>
</tr>
</tbody>
</table>

*Bathtubs and faucets were excluded*
[3] WATER USE PARAMETERS
Key Fixture Characteristics

1 - $n$: Fixture Count

2 - $q$: Fixture Flow Rate

3 - $p$: Fixture Probability of Use

\[ p = \frac{\sum t_i}{T} \]
Computed Fixture Flow Rate; $q$

$$q = \frac{\sum \text{Volume of each pulse (gallons)}}{\sum \text{Duration of each pulse (minutes)}}$$
Summary of “Efficient” Fixture Flow Rate

“Efficient” = Ultra-efficient and Efficient Fixtures
Hourly Fixture Use (Volume)

Average hourly volume of water use at a fixture per home per day
Single Home 12 Day Water Use Profile (10S761)

Peak Hour

Volume (gallons)

Hour of Day

Clothes washer
Dishwasher
Faucet
Shower
Toilet
Total Volume
Multiple Homes Water Use Profile (by Volume)
Distribution of Peak Hour of Water Use

(N = 1,038 Homes)
Probability of Fixture Use at Individual Homes

- Focused on only efficient fixtures

\[ p = \frac{\sum_{i} t_i}{n \cdot D \cdot T} \]

- \( t_i \) – Duration of \( i^{th} \) water use event
- \( n \) – Number of fixtures
- \( D \) – Number of observation days
- \( T = 60 \) minutes (1 hour observation window)
Probability of Fixture Use at Individual Homes

Considered only efficient fixtures
Probability of Fixture Use – Group of Homes

- Number of residents
- Number of bathrooms
- Number of bedrooms
Probability of Toilet Use

Conservative Value

<table>
<thead>
<tr>
<th>Number of Residents</th>
<th>Probability</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>62</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>209</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>82</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>83</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>&gt;6</td>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

- Group weighted average
Design Fixture Probability Values

- Washing machine: $p = 0.050$
- Shower: $p = 0.025$
- Sink: $p = 0.010$
- Bathtub: $p = 0.005$
[4] (PEAK) WATER USE MODEL
Binomial Model

\[ \Pr(\text{exactly } x \text{ busy out of } n \text{ fixtures}) = \binom{n}{x} p^x (1 - p)^{n-x} \]
“Frequency Factor” Approach

\[ Q_{0.99} = \text{Mean} + (z_{0.99}) \text{Standard Deviation} \]
Normal Approximation

\[ Q_{0.99} = \mu_q + (z_{0.99}) \sigma_q \]

\[ Q_{0.99} = \sum_{k=1}^{K} n_k p_k q_k + (z_{0.99}) \sqrt{\sum_{k=1}^{K} n_k p_k (1 - p_k) q_k^2} \]

per Wistort (1995)
Binomial Distribution (small building)

$n = 5; p = 0.2$
Zero Truncated Binomial Distribution

$n = 5; \ p = 0.2$
Modified Wistort’s Model

\[ Q_{0.99} = \frac{1}{1 - P_0} \left[ \sum_{k=1}^{K} n_k p_k q_k + (z_{0.99}) \sqrt{\sum_{k=1}^{K} n_k p_k (1 - p_k) q_k^2} \right] \]

- Note:
  - \( P_0 = \prod_{k=1}^{n} (1 - p_k)^{n_k} \) is probability of stagnation in a home (i.e. no water use)
  - Addresses water demand in single family homes with high \( P_0 \)
  - Transitions back to Wistort’s model as \( P_0 \) approaches 0
[5] APPLICATION
Hypothetical Residential Building Pipe Layout
Peak Flow Calculations

Example: 2.5 bath single family home

<table>
<thead>
<tr>
<th>Section</th>
<th>UPC FU</th>
<th>UPC Method (gpm)</th>
<th>MW Method (gpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25.5</td>
<td>18.0</td>
<td>11.8</td>
</tr>
<tr>
<td>2</td>
<td>10.5</td>
<td>8.5</td>
<td>6.9</td>
</tr>
</tbody>
</table>
Sizing Pipes

Example: 2.5 bath single family home

<table>
<thead>
<tr>
<th>Section</th>
<th>UPC Method</th>
<th>Pipe Size*</th>
<th>MW Method</th>
<th>Pipe Size*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.0 gpm</td>
<td>1”</td>
<td>11.8 gpm</td>
<td>3/4&quot;</td>
</tr>
<tr>
<td>2</td>
<td>8.5 gpm</td>
<td>3/4&quot;</td>
<td>6.9 gpm</td>
<td>3/4&quot;</td>
</tr>
</tbody>
</table>

* Maximum flow rate at 8 f/s
Modified Hunter’s Curve(s)

Different curve for different end users

Universal Dimensionless Design Curve

Glimpse of the Future?
[6] CONCLUSION
Conclusion

- Introduced a new model to estimate peak water demand in single and multi-family dwellings.
- Replaced fixture units with fixture counts.
- Runs on a spreadsheet.
- Recommended fixture $p$ and $q$ values.
- Results are more sensitive to $q$ than to $p$.
- Can be applied to a wide spectrum of buildings.
Questions?

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Demand Sensitivity to $p$ and $q$ values
Distribution of $p$ values for home with 2 residents

(N = 209)
Summary Probability of Fixture of Use

- Each fixture has a unique water use profile.
- Probability of fixture use depends on frequency and duration of use.
- Probability of fixture use increased as the number of residents increased.