WATER

(AKA "THE BATHROOM LECTURE")

No rocket science here!
Only an organized synthesis of the relevant considerations
with useful numbers and numerical illustrations

ENGS 44 Sustainable Design
Benoit Cushman-Roisin
1 May 2017

After irrigation for agriculture,
most human water usage occurs in buildings.

We use water daily for:
- washing, showering,
- laundry, dishwashing,
- food preparation,
- flushing toilets.

Water is also used domestically for:
- watering gardens and lawns,
- indoor climate control (humidifiers),
- growing food and raise fish.

In the United States, residential water consumption accounts for about three-fourths of the total urban water demand.
(https://www3.epa.gov/watersense/our_water/water_use_todaty.html)

Currently, domestic water consumption is:

USA: More than 1,130 liters per household per day (>300 gallons per household per day)
70% indoor, 30% outdoor
World average: 22 liters per person per day (6 gallons per person per day)

In designing buildings, current practice in the United States calls for:
70 gallons per person per day in a home, of which 25 gallons are hot water,
and 35 gallons per day per employee in an office building.
But, this amount is only the portion that we use directly. There is also an indirect water usage caused by each of us to produce the food that we eat and the things that we buy. Our total, direct+indirect water footprint is a lot higher.


Water consumption in the home

US average domestic Indoor water consumption: 37.2 $n + 69.2$ gallons/day with $n =$ number of people (Mihelcic & Zimmerman, 2010)

Water consumption in office buildings

The average daily domestic demands in commercial/industrial settings range between 20 and 35 gallons per day (gpd) per employee.
Confronting Water Issues:
From where? For what? To where?

1. Harnessing of water
   ● from rain (or dew or snow)
   ● from surface streams
   ● from ground

2. Water use and conservation
   ● what engineers can do
     - toilets, faucets, appliances
     - indoor climate control
   ● how individuals can behave

3. Treatment and recycling after use
   ● at the level of a single building
   ● at the level of a community

Harnessing water from buildings for buildings

Simplest and most economic approach:
Collect rain water from roof and store it in a cistern.
The cistern may or may not be buried (“below grade” or “above grade”).

Limitations:
- The system is at the mercy of the local precipitation.
- Local air pollution may contribute heavy metals and other impurities.
- Where there is water scarcity, it may be illegal to collect rain water (ex. Denver).

Installation in Portland, Oregon
Notes: Not all the water needs to be purified, only that fraction that goes to sinks and showers. Greywater from sinks and showers can be reused in toilets before treatment.
In Hanover, rainfall is 3.2 inches per month in average → 3.2 ft/year, which means that a building with 32,000 ft² of footprint (about the size of MacLean Engineering Science building) can collect about 766,000 gallons annually on its roof.

Now, consider that the average water consumption of the same building by its ~55 occupants is about
35 x 50 = 1,925 gallons per day.
Usage for 360 days a year creates an annual demand of about 693,000 gallons of water.

On the Dartmouth campus, the new Life Sciences Center stores and reuses roof water for toilet flushing. The roof is roughly 1 acre in size and collects about 1 million gallons of water per year, most of which is captured in 60,000-gallon tanks and then used in the building after minimal treatment.

Planning a water harnessing system

1. Know the local precipitation, say $P$ (in inches/month)
   For this, go to www.city-data.com/ or www.weather.com

2. Determine the roof collection area, say $A$ (in ft², projected on the horizontal)

3. Calculate the amount of water that can be captured and take 10% off to account for evaporative and other losses.
   [Quick calculation: gallons/month = 0.561 x roof area (ft²) x precipitation (inches/month)]

4. Determine the expected water demand:
   # people x consumption per person (37.2 n + 69.2)
   or itemize
   - Top-loading washer: 30 gallons (113L) per cycle
   - Front-loading washer: 10 gallons (3.78L) per cycle
   - Dishwasher: 3-5 gallons (11-19L) per cycle
   - Low-flow shower head: 3-7 gallons (11-26L) per shower
   - Sink use (handwashing, toothbrushing, etc.): 1 gallon (3.78L) per average use
   - Lawn sprinkler: 480 gallons per hour

5. Is the capture able to meet the demand?

6. Size the storage tank so that it can hold approximately two weeks worth of water.
Water Use & Conservation

1. What building designers can do – Good engineering practices

2. What individuals can do – Good personal behavior

Good engineering practices:

- Installation of plumbing fixtures that conserve water
- Installation of pressure reduction (ex. from 100 to 50 psi)
  less pressure → slower flow
- Greywater reuse
  indoor, for toilets
  outdoor, for landscaping

The City of Corpus Christi, Texas has estimated that an average three-member household can reduce its water use by 54,000 gallons annually and can lower water bills by about $60 per year if water-efficient plumbing fixtures are used (Jensen, 1991; https://www3.epa.gov/watersense/pubs/indoor.html).

U.S. Green Building Council
Leadership in Energy & Environmental Design
LEED 2010

For new building operation and maintenance

Water – Prerequisite: Water Use Reduction by minimal plumbing fixture efficiency
Water – Credit 1: Water Performance Measurement (1 to 2 points)
Water – Credit 2: Water Use Reduction (1 to 5 points)
Water – Credit 3: Efficient Landscaping (1 to 5 points)
Water – Credit 4: Cooling Tower Water Management (1 to 2 points)

• Intent:
  Increase water efficiency within buildings to reduce the burden on municipal water supply and wastewater systems.

• Requirements:
  Employ strategies that in aggregate use less water than the water use baseline calculated for the building (not including irrigation). “Baseline” numbers follow.
Indoor use accounts for roughly 70% of all residential use. Toilets, showers, and faucets combined represent 60% of all indoor water use.

Of this, toilets (at 1.6 gallons per flush) use 26%; sometimes more. Older toilets use 5 gallons per flush.

The average American uses about 9,000 gallons of water to flush 230 gallons of waste down the toilet per year, so that more than 4.8 billion gallons of water is flushed down toilets each day in the United States, and all of this is water that was treated to drinkable standards and conveyed over some distance.

In new construction and building remodeling there is great potential to reduce water consumption by installing low-flush toilets.

This is a low-hanging fruit.

(https://www3.epa.gov/watersense/pubs/indoor.html)

An additional way of saving water

Dual-flush European toilet

Big flush after an act of congress
1.6 gallons

Little flush after a small contribution
0.8 gallons

Photo taken by Benoit Cushman-Roisin in Groningen, The Netherlands
Other water-saving toilets

**Pressure-assisted 1.0 gpf toilet**

Manufactured by Flushmate, a division of Sloan Valve Company

**The 3 oz. foam-flush toilet**

Manufactured by ClivusMultrum Corp.

Ultra-low-flow foaming toilet that uses about 3 oz. of water and a foam solution to flush.

The Vermont Law School in South Royalton, VT has some of these on the lower level of Oakes Hall.

---

For urinals (no solids), technology exists to reduce water down to ZERO

**Caroma's H2Zero waterless cube urinal**

www.gizmag.com/go/7273/

*Waterless urinal making a splash!*
How does it work?

A non-volatile liquid lighter than water (like oil, depicted in blue below) is used as a seal against odors. When urine flows, it falls below this liquid and into a U-tube, leaving the non-volatile liquid on top acting as an odor-blocking barrier. The U-tube is there to keep the non-volatile liquid at a constant level.

Laundry machines: Top-loading (USA) vs. Front-loading (Europe)

In a top-loading washer, the clothes go around horizontally and need to be immersed all the time. Besides the extra water that it needs, such a washer also consumes more energy as it needs more warm water.

Advantage? No need for a seal around the door → lower price at purchase time.

Top-loading washer: 30 gallons per cycle → savings of 67%!

In a front-loading washer, the clothes tumble as in a dryer and take turn at being immersed in the water near the bottom. This saves water and energy (less warm water).

Disadvantages? Need for a seal around the door → higher price at purchase time, chances of leak after many uses.

Front-loading washer: 10 gallons per cycle
From the perspective of the clothes, rather than that of the home:

Life-cycle analysis of a woman polyester blouse.

Ways to reduce laundering:
- Design fabric that needs no laundering (Silver nanoparticles?)
- Cold wash, air dry
- Front loading wash machine (using less water and therefore less hot water)

So, energy saving goes hand in hand with water saving.

A life-cycle inventory for a woman's polyester blouse.
Energy consumption comparison for one load of home laundry.
(Bishop, 2000, page 279 - adapted from Franklin Associates, Ltd., 1993)
Taking a quick 5-minute shower can use up to 40 gallons of water. (FlexYourPower.org)

Showers account for about 20% of total indoor water use. (http://www.epa.gov/owow/NPS/chap3.html)

By replacing standard 4.5-gallon-per-minute showerheads with 2.5-gallon-per-minute heads (>40% reduction), which cost less than $5 each, a family of four can save approximately 20,000 gallons of water per year. (Jensen, 1991)

Some manufacturers of low-flow showerheads claim savings up to 64% of water per shower (with 1.6 gpm showerheads by Delta Faucets).

Faucet aerators are inexpensive devices that break the flowing water into fine droplets and entrain air while maintaining wetting effectiveness.

They can be easily installed in sinks to reduce water use and can reduce the water use at a faucet by as much as 60% while still maintaining (the appearance of) a strong flow.

More efficient kitchen and bathroom faucets that use only 2 gallons of water per minute – unlike standard faucets that use 3 to 5 gallons per minute – are also available. (Jensen, 1991)

With these various devices put together, conservation can reduce water demand by 66%.
Sensor-activated faucet (ex. bathrooms in airports)

Primary advantage: No water running when not needed.
Added advantage: No touch → hygienic

Estimated water savings from low-volume faucets:
40%, from 13.5 gpd to 8.1 gpd, per person.
(Source: Amy Vickers & Associates)

Monitoring the amount of water used can provide baseline information on quantities of overall company water use, the seasonal and hourly patterns of water use, and the quantities and quality of water use in individual processes.

Baseline information on water use can be used to set goals and to develop specific water use efficiency measures. Monitoring can make people more aware of water use rates and makes it easier to measure the results of conservation efforts.

The use of meters on individual pieces of water-using equipment can provide direct information on the efficiency of water use. Records of meter readings can be used to identify changes in water use rates and possible problems in a system. (Brown and Caldwell, 1990).

Some years ago, an ENGS 21 group at Thayer School designed a shower meter, which they installed in a dorm. The device was proven effective in reducing the time that people spend in the shower.

Finally, a significant amount of water can be saved by simple leak detection. Leak detection programs have been successfully implemented in several cities that have large, old and deteriorating municipal water delivery systems. (RMI, 1991)
Double use of water

A water feature entitled “IceFall” flows over a lit and canted cast-glass wall at the center of the lobby. Fed by recycled rainwater, the fall plays a significant role in cooling the lobby in the summer (using chilled water) and humidifying it in the winter.

Water use in buildings for indoor climate control

Hearst Tower
New York City
(LEED Gold)

Masdar, a future city in the desert of Abu Dhabi

Evaporative cooling system with indoor pool and “wind cone” to save energy spent on air conditioning
Conservation of outdoor uses of water

Water is typically used outdoors for:
- landscaping (watering of lawn, flowers and shrubs)
- washing automobiles
- maintenance of swimming pools
- cleaning sidewalks and driveways.

To reduce the amount of water used in landscaping, one should select native plants and/or plants that use little water. (This same measure also saves on fertilizer!)

Failing this, one should:
- cluster plants with similar high-water needs
- schedule lawn irrigation for early morning and late evening to reduce evaporative losses
- use mulches to retain water.

Water Treatment & Recycling

Can it be done at the level of the building? Or, does the treatment need to be pooled and done at the level of a community?

John Todd’s eco-machine
I-89 Welcome Center & Veteran Memorial
Sharon, Vermont
The Living Machine® by John Todd Ecological Design


The first tank is an anaerobic reactor (septic tank – no oxygen in the water) which removes a significant portion of the biological oxygen demand (BOD).

Each subsequent tank is aerobic and contains a carefully selected collection of plants, aquatic insects, snails and worms to accomplish a specific step of the treatment.

The example shown in the picture is located at the Vermont Welcome Center along I-89 near Sharon, VT and treats the wastewater from the facilities at that rest area. Its vegetation includes tropical plants such as ginger, can lily, elephant ear, umbrella and various ivy plants to ensure functioning in all seasons.

Small-scale, local treatment of greywater only

See examples at http://greywater.com/samples.htm
On a slightly larger scale: Sewage solution in an eco-village

Location: Terre d’Enaille (Belgium)
Founded: 1992
Size: 15 residents
Features: gravity flow (houses on top of hill)
series of ponds and wetlands
fish in last pond as monitor of cleanliness
effluent used for irrigation of gardens
clean enough for discharge in local stream

Source: Ecovillages, by Jan Martin Bang
New Society Publishers, 2005

Water-wastewater system envisaged by “Hidden Zero” team (ENGS-44, Winter 2008)

This system was designed for an eco-village with about 700 households and 32 buildings
(incl. some commercial space), next to Centerra in Lebanon, New Hampshire.
Summary Rules & Principles for Water Use in Communities:

- Slow down the water flow on the property.
- Use gravity to move the water to the extent possible.
- Use the same water as many times as possible.
- Filter the water through activated carbon filters or several meters of sandy soil (if water is used for drinking and food preparation).
- Treat the water as close to the source of use as possible.
- Let the water leave the property at a rate equal to its arrival.

(Modified from Ecovillages by Jan Martin Bang, 2005)