Plumbing Practices on the International Space Station

Apply the techniques used in space to develop sustainable plumbing systems on Earth.

By Winston Huff, CPD, LEED AP

Imagine a facility that sustains itself without water, waste, or energy connections to the outside world. Science fiction, right? In reality, such a facility currently exists: the International Space Station (ISS). If the ISS can sustain itself in space's harsh environment, why can't we build facilities on Earth that are self-sustaining, safe, comfortable, and off the grid? We can, by applying the technologies used on the ISS to sustainable building here on Earth. Studying the ISS' sustainable abilities accentuates the importance of biospherics research and the development of environmental systems that sustain life as well as the Earth's biosphere.

Author's Note: *This is the third in a series of articles covering plumbing biospherics. These articles are intended to spark plumbing engineers' imaginations on how future plumbing system technology will develop—by copying the Earth's sustainable biosphere and, as a result, increasing our basic sustainable standard of living. In this article, I explore the International Space Station's water-efficient sustainable systems and how their principles can benefit Earth-based water efficiency practices.*

Photo: NASA

ISS Background

According to the June 1997 edition of *NASA Facts,* "Space stations have long been seen as laboratories for learning about the effects of space conditions and as a springboard to the moon and Mars." One of the earliest references to a space station was Edward Everett Hale's science fiction story "The Brick Moon," published in 1869 in the *Atlantic Monthly,* in which a manned satellite served as a navigational aid for ships at sea. After the mid-20th century Apollo and Skylab programs proved that people could live in space, the U.S. Space Station Program Office was established in 1984. In the mid-1990s, the project became known as the International Space Station after Russia agreed to merge its space station program with NASA's. ISS assembly began in space in June 1998, and the first crew arrived in January 1999. Permanent human residence and operations on the ISS are expected to last well into 2013.

The ISS orbits approximately 235 miles away from Earth, racing by at 17,000 miles per hour in near 0 gravity (0-G). These conditions raise many questions regarding needed plumbing systems such as toilets, showers, and lavatories. Can toilets flush in 0-G? What is the crew's water source? Where does the plumbing waste go? How does water boil? What happens to water outside a container?

Basics of Water in Space

Water reacts very differently in space than it does on Earth. The environment outside the ISS technically has no temperature (very close to absolute zero, -460°F or -273°C), but it does make things very cold. Space is a type of "temperature sink," meaning it sucks heat out of things. As a result, the temperature of an object in space theoretically will get close to absolute zero; in reality, stray particles and radiation will heat things to 5°F above absolute zero.

The simple task of boiling water is very different in space than on Earth. In a laboratory on Earth (1-G), water boils at room temperature when a vacuum is applied. When air pressure decreases, so does the boiling point. What does this mean for water released out of the ISS?

Early space flights and some shuttle flights expelled the crew's urine out to space. When this occurs, the urine liquid boils violently, and the vapor immediately passes into the solid state, a process known as desublimination. The end result is a cloud of very fine frozen urine crystals. In 0-G, a large object such as the ISS creates a small gravity force that attracts such particles. Thus, if this plumbing practice was used for the ISS, the space station eventually would create its own exterior atmosphere of frozen urine particles.

Much like a sustainable building on Earth, a primary concern on the ISS is maintaining the exterior environment's natural state. Many experiments planned for the ISS require a clean exterior environment, which is another reason to recycle and reuse.

In 0-G, strange things also happen inside the ISS. Objects do not fall; liquids do not pour; and flames form balls that float. On Earth, gravity plays an important role in transferring heat. For example, body heat causes exhaled carbon dioxide to rise away from the body, allowing oxygenated air to rise. In space, a crew member can suffocate when sleeping if no system to move air exists, so fans are used to constantly move air around the cabin. Remember, there is no up and down in space.

Boiling water also exemplifies a strange heat transfer characteristic in space. On Earth, gravity causes warm liquid to rise and cool and denser liquid to sink. Called convection, this process is what causes the rolling motion in boiling water.

Without gravity, convection, currents, and buoyancy do not work. The liquid next to the heat source rises in temperature but does not move, so the liquid farthest away remains relatively cool. The liquid near the heat source becomes very hot and boils much quicker than it does in 1-G.

On Earth, the boiling creates bubbles of steam that rise to the surface of the liquid. In space, one large bubble usually either remains near the heat source or floats in the middle of the liquid (see Figure 1). The end result is that water must be handled differently in space than on Earth.

Water Efficiency Procedures on the ISS

During ISS construction in space, contingency water containers holding about 90 pounds each were stored on the Russian module Zarya. However, transporting water to ISS is expensive, so water must be recycled. Without a water-recycling program, a crew of four would use 40,000 pounds of water per year, according to "Water on the Space Station," a Science@NASA article.

The current recycling system is a

Figure 1. Water boiling on Earth (top) and in space (bottom).

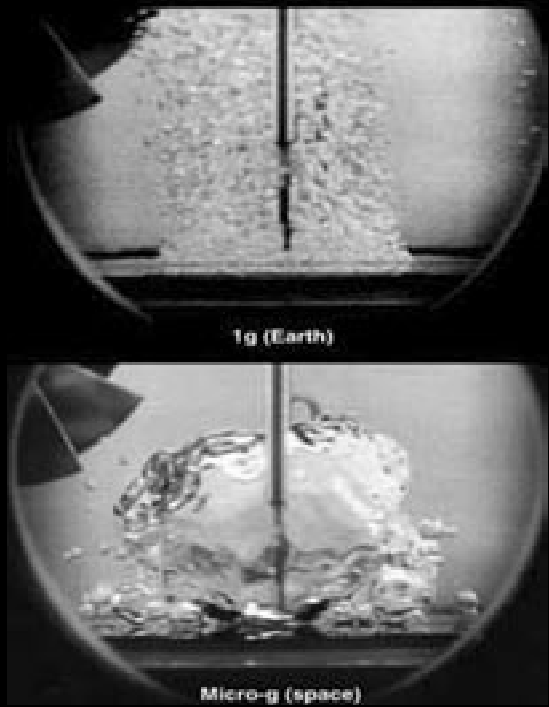
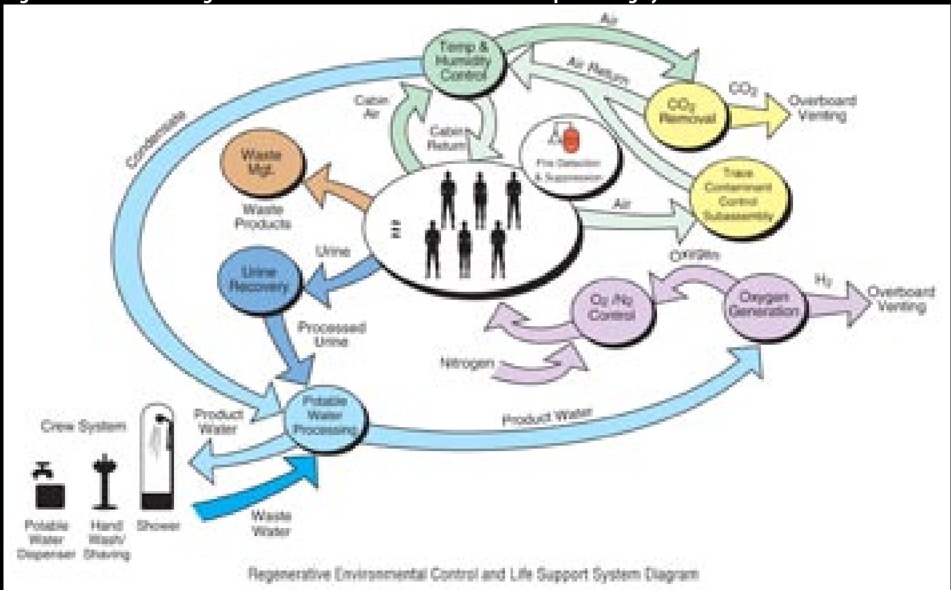


Photo: NASA

Russian-built water processor that collects humidity from the air and cleans it for reuse by the crew. Thus, crew members are subjected to sponge baths using water distilled from the crew's breath and sweat.

NASA currently is creating a more efficient water-recycling system as part of the Environmental Control and Life Support System (ECLSS) being developed at the Marshall Space Flight Center in Huntsville, Ala. When installed, the ECLSS' Water Recycling System (WRS) will reclaim water from ISS fuel cells, urine, oral hygiene, and hand washing. Lab animals are

Figure 2. This flow diagram shows the interconnections of the plumbing systems for ISS.



Source: NASA

not exempt; their waste also will be recycled in the system.

In NASA terms, the environmental system is a "closed loop" in which air and water are recirculated and reused (see Figure 2). The water and air in this closed loop are treated by physical/chemical methods, which means that machines clean the water and air used by the crew.

One part of the WRS under development at Marshall Space Flight Center with Hamilton Sundstrand Space Systems International is the Water Processor Assembly (WPA). Scheduled for delivery to the ISS in 2008, the WPA will be able to produce about 35 gallons of potable recycled water per day, according to Bob Bagdigian, the ECLSS project manager. As a result, the water delivered to the ISS will decrease by approximately 16,000 pounds.

The WPA recycles humidity condensate, reclaimed urine distillate, shower waste, and hand washing and oral hygiene waters. The wastewater first passes through a particulate filter and then goes through ion exchange and carbon absorption filtration systems. A high-temperature catalytic oxidation process removes residual organics and kills microorganisms.

The second part of the WRS is the Urine Processor Assembly (UPA), which uses a low-pressure vacuum distillation process to recover water from urine. The process occurs within a rotating distillation assembly that compensates for the absence of gravity and aids in the separation of liquids and gases in space, according to the December 2004 *NASA Facts*.

Electrical conductivity sensors that can detect typical contaminants monitor the water's purity. Mass spectrometers are essential cargo on crewed space missions for closely monitoring the interior and exterior environments for toxins and leaking fluids that could threaten the astronauts' safety, according to "Great Things Come in Small Packages: Miniaturizing Chemical Detection."

Some of the water will be electrolyzed by the Oxygen Generating Assembly (OGA), producing oxygen for the crew and hydrogen that will be vented overboard, according to the December 2004 *NASA Facts*. Another system under development is the Carbon Dioxide Reduction Assembly (CReA), which will cause hydrogen created by the OGA to react with carbon dioxide removed from the cabin atmosphere to produce water and methane. This water then can be added to the crew's water supply.

Space Showers and Toilets

On the Skylab (1973-74) and Russian Mir (1986-2001) space stations, the crews experimented with showers in 0-G. The water did not react as expected. Free-flowing water tended to stay together in one mass. The water wobbled around and remained in one place unless the air movement in the cabin from the fans moved it around. In theory, a fish placed in the water actually could swim outside the water.

In the shower, the water collected on the body and didn't drain off. Crew members could have inhaled water droplets floating in the shower. Another problem was that it took two crew members an entire day to assemble and take apart the shower unit.

In the ISS, the shower is similar to a sponge bath: Water is placed in washcloths and then used to clean the body. As a result, an average ISS shower uses about one gallon of water.

Although plumbing engineers call them water closets, toilets in space use no water. The first space toilets were little more than small plastic bags with adhesive tabs that were stuck to the buttocks and then pulled off and sealed. This method soon proved to be unsanitary and unworkable in long-duration flights, as some of the bags' contents would escape and float around the cabin. The Skylab space station contained the first private space toilet complete with a seat belt to keep users from floating off the seat.

The solid products from the space toilet are not reused in the ISS. The urine is collected in a separate urinal-type device, and the solid waste from the toilet is collected and disposed of on Earth. Because there is no gravity on the ISS, the user first must sit on the seat and pull around thigh bars that hold him in place (see Figure 3). Then he turns on a vacuum that pulls

Figure 3. The toilet scheduled for use on ISS. Note the thigh bars that hold the user in place to keep them from floating off in 0 gravity.

Photo: Hamilton Sundstrand Space Systems International air from the cabin through the toilet seat into the toilet.

At this point, the new ISS toilet design differs from the current shuttle toilet. The early shuttle toilet had a rotating fan that slung feces to the sides of a chamber, where it stuck. Current shuttle toilets don't use a fan, and solids stay in the chamber. After each flight the entire unit is removed, cleaned, and reinstalled.

The ISS toilet improves on the current shuttle design by compacting solid waste in a disposable container that can be removed without taking the entire fixture apart. Also, due to complaints by some users that the holes were not large enough, the ISS toilet has a larger hole in the seat.

Reducing Water Use

With the interconnections of its systems, the ISS is an example of a small-scale biosphere. For example, a waste by-product such as hydrogen from one system is used by another system to create water. Plumbing engineers can apply the same principles to the systems they design to help create self-sustaining buildings on Earth.

For instance, consider the use of water to wash hands. In space, water flowing from a faucet into a lavatory to wash off contaminants is not practical. To solve the problem, washcloths are used to wipe the hands clean. A similar process is becoming popular on Earth with the introduction of waterless hand cleansers. People have discovered that these cleansers are an easy and effective way to clean hands because they do not dry out the skin and are user friendly even for children.

What about showers? Early space stations tried to use showers in the same manner as on Earth. This method was costly and inefficient. The simple method of a modified sponge bath works better in space. Is there an equivalent to the waterless hand soap that would work on the body in place of a shower? Considering the average shower uses 25-50 gallons of water, a waterless shower alternative would save significant amounts of water.

Shampooing is another example. In space, washing hair with shampoo and rinsing with water does not work. The water clings to the hair with the shampoo and dirt and has to be vacuumed off (see the sidebar for an anecdote on washing hair in space). Waterless shampoo products also could work here on Earth.

If such products were available, a typical household would use less water and generate less wastewater, ultimately benefiting the Earth and the environment.

Treating Waste

The way waste elements are treated before they enter the waste stream is another good example of how practices on the ISS can be applied to systems on Earth. For example, when self-contained, refrigerator-size laboratory experiment racks are added to the ISS, the process wastewater will be monitored. If an experiment creates waste products that the ISS wastewater treatment system cannot handle, the rack system operator is required to design and install systems to pretreat the waste stream to remove those elements.

To expand this concept a little further, compare the space station to a small municipal system. For instance, in the ISS, the experiment racks are connected to the common station electrical, air, water, and waste systems. Backflow devices are installed to protect the ISS station from possible contamination from the racks' water system.

A wide range of experiments can be conducted on each rack. Scientists could conduct research with laboratory animals such as mice in one rack. The adjacent rack could house a small furnace that melts and joins metals in the weightless space environment. In another rack, research concerning compounds' and chemicals' reactions in the weightless environment could be conducted. Similar to a small community, the ISS water and waste systems will supply water to and treat the waste from these racks while protecting against cross contamination from rack to rack.

Photo: NASA

Learning From the WRS

Waste pretreatment and monitoring is a growing industry on Earth and in space, creating new demands on plumbing engineers to be aware of methods to treat wastes before they exit a building. Applying practices being researched for the WRS can help make the Earth-based systems operate more efficiently.

One application on Earth concerns water filtration. The water filtration system on ISS is very reliable and requires a minimal amount of crew involvement to operate. It can filter biological and viral contaminants and can be monitored from a remote location (Earth). Space-based designers have looked into future applications of these devices that could revolutionize the water treatment industry.

The basic technology of today's wastewater and water treatment plants was developed centuries ago. These facilities are very expensive to build and operate, and the distribution piping from them is intrusive on surrounding environments. Because of the cost, many small communities cannot afford clean drinking water.

Older urban areas have antiquated water distribution systems in which contaminants such as lead are a real problem for end users. However, installation of traditional water treatment facilities in highly populated areas is not practical, and the large distribution piping required to supply water and to carry sewer discharge away from these areas cannot be installed under city streets already crowded with other utilities.

For More Information

Follow these links to read the articles referenced in this article.

"Water on the Space Station," Science@NASA
science.nasa.gov/headlines/y2000/ast02nov%5F1.htm

"A History of U.S. Space Stations," *NASA Facts,* June 1997
spaceflight.nasa.gov/spacenews/factsheets/pdfs/history.pdf

"Great Things Come in Small Packages: Miniaturizing Chemical Detection"
exploration.nasa.gov/articles/detection_lite.html

"International Space Station Environmental Control and Life Support System," *NASA Facts,* December 2004
www.nasa.gov/centers/marshall/pdf/104840main_ECLSS%20Fact%20Sheet.pdf

In the future, the technology developed for the ISS' WRS could be used in these congested urban areas to recycle water within neighborhoods or even within buildings, eliminating the need to transport large amounts of sewage out of and large amounts of clean water back into these areas.

Where contaminants such as lead are in old piping distribution systems, WRS technology could be used in buildings or neighborhoods to filter out the lead and deliver clean water to the buildings, which would eliminate the need for expensive pipe replacement projects.

A small WRS-type system could be installed in one or two remote facilities in areas out of the municipal water distribution system's reach with minimal effect on the exterior environment. Larger systems could provide economical, reliable, and safe water to small communities that cannot afford traditional water treatment facilities. WRS technology also could be used in developing countries that have large populations with little access to clean drinking water and the finances necessary to build large water treatment facilities.

Applying practices used on the ISS can help plumbing engineers design systems that don't negatively affect the surrounding environment, while providing safe interior environments. The ISS research will aid in the development of more and more self-sustaining facilities that can operate off the grid for long periods. ■

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Washing Hair in Space

Washing my hair in space was a challenge. There is no shower on the shuttle, and without the help of gravity, it's difficult to contain water and soap. It took me several days to really get the hang of washing my hair and really getting it clean. Astronauts use a shampoo that was designed for people that are confined to the bed and unable to go to the shower. The shampoo does not require rinsing out. Although it's a great concept, I didn't find it worked too well. If I didn't rinse the shampoo out, my hair was very heavy and felt dirty. So, I ended up washing my hair much like I do at home. I would fill up one of our drink bags with warm water and use that to wet my hair down. I held a towel over my head while I carefully squeezed water out of the drink bag into my hair. Once my hair was wet, I'd carefully squeeze shampoo onto my hair and slowly work up a lather. I found that if I didn't get a lather, I didn't get clean hair. The tricky part came trying to rinse the shampoo out. I once again used the drink bag to squeeze water onto my hair and with the help of my towel was able to slowly get the shampoo out. Then I'd use my new daily towel to dry my hair a little. The dry air in the shuttle allowed for very quick drying of my hair. I would typically wash my hair after my daily exercise and the entire process took about 10 minutes. Of course, without the help of gravity, there was no controlling my hair once it was washed.

—"Washing My Hair in Space," by Susan Still, NASA astronaut