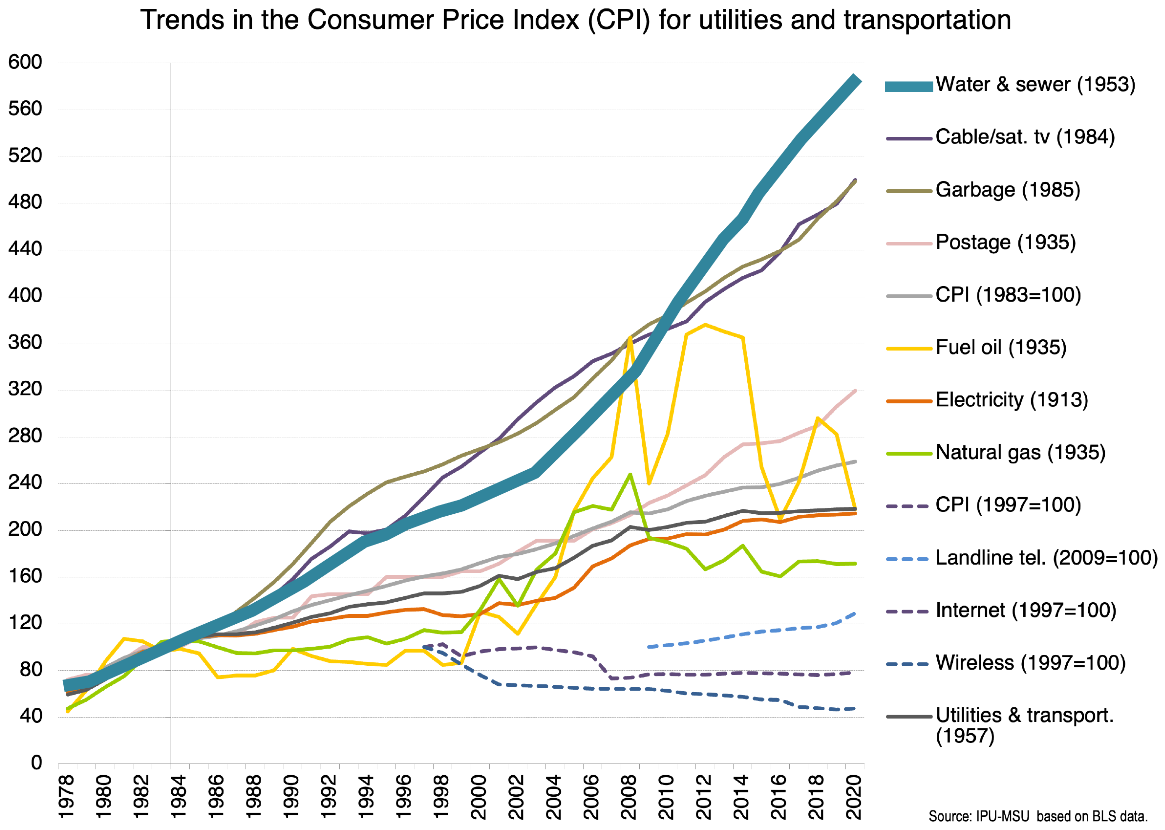
Best Practices Guide
Water Efficiency in Laboratories

MAY 2022

Table of Contents

Contact I²SL: www.i2sl.org • info@i2sl.org • 703.841.5484

I²SL is dedicated to advancing sustainable laboratories globally.



Source: IPU-MSU based on BLS data.

Figure 1. Trends in the Consumer Price Index for Utilities and Transportation. Figure courtesy of Janice A. Beecher of the Institute of Public Utilities at Michigan State University.

Introduction

Most laboratory buildings in the United States use significantly more water per square foot than typical commercial buildings do. Compared to commercial buildings of a similar size, a laboratory can use five times as much potable water (Daniel Watch and Deepa Tolat, 2016). However, that means there are a variety of opportunities for laboratories to make cost-effective improvements in water efficiency, whether in special lab process equipment, cooling towers, steam boilers, or other building systems. With more frequent and intense droughts and water shortages, some states and local jurisdictions have adopted aggressive water reduction targets, and laboratories are responding with water-saving efforts that also reduce energy and operating costs—and even increase resiliency.

Water efficiency can also help laboratories offset rising water and sewer costs. Since 2001, water and sewer costs have increased at a rate nearly three times greater than the rate of inflation (Black and Veatch Management Consulting, 2021). As shown in Figure 1, this rate of increase far outpaces that of other public utilities, including electricity, natural gas, and waste disposal.

Developed in collaboration with the U.S. Environmental Protection Agency's (EPA's) WaterSense® program, this document is one of a series of best practices guides the International Institute for Sustainable Laboratories (I^2SL) published to provide information about technologies and practices to use in designing, constructing, and operating safe, sustainable, high-performance laboratories. This guide highlights best practices for laboratory water management in particular and potable water use reduction in general, including:

- Water management and monitoring;
- Understanding and targeting efficiency in specialized laboratory equipment;
- Designing for efficiency;
- Minimizing cooling demand and optimizing cooling tower and boiler operations;
- Improving efficiency within other building water systems; and
- Reusing water or identifying alternative sources.

For more information about saving water in offices and other facilities, review [WaterSense at Work: Best Management Practices for Commercial and Institutional Facilities](), a comprehensive guide for building owners and managers pursuing water efficiency (EPA).

PART I: LAB-SPECIFIC WATER SAVINGS OPPORTUNITIES

Water Management

In laboratories, water management planning involves understanding current water use, identifying and implementing efficiency measures, and sustaining long-term savings through the following steps:

- Assessing major water uses within the facility and lab processes
- Establishing a water balance
- Establishing water reduction goals
- Creating and implementing an action plan
- Dedicating staff and resources to pursue efficiency
- Metering and monitoring water use, including benchmarking
- Communicating goals and educating staff on water-efficient behaviors

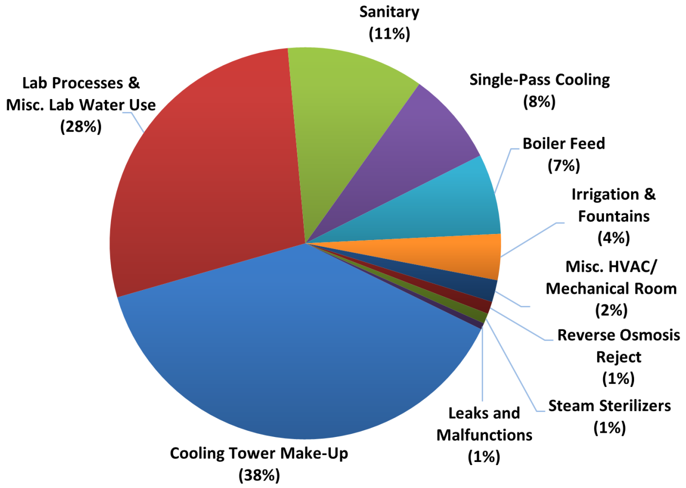


Figure 2. Typical EPA laboratory building water use, based on data collected during water assessments conducted at EPA's laboratories between 2011 and 2019.

Conducting a Water Assessment and Establishing a Water Balance

A water assessment is a good place to start to: establish annual water use; collect detailed information on major water-using fixtures, equipment, systems, and processes; create a facility water balance that shows the sources and uses of water on a site; and identify water conservation measures that can be pursued to reduce laboratory water and energy use and operating costs. Figure 2 shows water usage for a typical EPA-operated laboratory. However, laboratories have unique water usage characteristics based on their size, function, and research needs; therefore, a water assessment is beneficial in understanding end uses of water of a specific laboratory.

A lab water assessment should collect specific equipment or process information (e.g., flow rates, operating frequency, set points, nameplate capacity) that will help estimate water use. The water quality required for each use can also be included, since certain processes and systems do not require potable water and can present opportunities for reuse.

To develop a water balance, determine whether known water purchases equal known usage. If these two are in balance, look for opportunities for greater efficiency in each major usage category and determine whether water from one process can be used elsewhere cost effectively. If purchases and usage do not balance, however, more investigation is needed. A thorough review can help laboratory managers fill in any missing information and discover the source of the imbalance.

> Well-managed facilities can usually account for 85% to 95% of the water they purchase.

Following are some tips for determining where a lab's water use may be out of balance:

- Check grounds and facilities for water or steam leaks in piping, distribution, condenser water, irrigation systems, or other equipment.
- Check the facility's main water meter at night and again in the morning to see if there is a large amount of unexplained usages that indicates a leak in the system.
- Review utility bills (about 2 years' worth) to understand trends in water use over time.
- Complete a detailed survey of staff and equipment to identify or verify the principal water users and water-using equipment.
- Ask researchers and facility staff how their equipment is being used to determine if actual usage is higher than original estimates.
- Understand the lab's water use from cooling tower and boiler blowdown and reverse osmosis treatment, which can be significant sources. Water-quenching devices used for hot condensate and blowdown can also use a lot of water, especially if they operate continuously without a temperature-controlled solenoid to limit use.

Goal-Setting and Staff Planning

Following a water assessment, you can create an action plan with goals and targets to reduce water use. Once you have a plan in place, it's important to assign staff who will be responsible for supporting water management activities, such as: collecting and tracking water meter and utility billing data; inventorying water-using systems and laboratory equipment; managing the execution of water efficiency projects; and handling communications and education of researchers and other lab staff.

Assigned staff, such as operations and maintenance workers, should check water-using systems and appliances on a regular basis as part of daily or weekly facility walk-throughs. This can help identify leaks or other malfunctioning equipment. For example, cooling tower make-up or boiler tempering valves that are stuck open are common problems that can be identified during frequent facility walks of mechanical spaces and labs, while leaking irrigation system pipes can be spotted during an exterior walk-through. The Federal Energy Management Program (FEMP) has developed water evaluation tools, including data collection forms and a water balance tool, to assist facility staff with water management.

Metering and Monitoring Water Use

Water use should be monitored regularly to establish use trends and identify potential leaks or other inefficiencies. Water meters should be installed at the facility level. Submeters should be installed on major water-using systems (e.g., cooling towers, steam boilers, irrigation systems, specialized water treatment systems) and on alternative water systems (e.g., reclaimed water systems). A good rule of thumb is to submeter any process using more than 10% of total annual water consumption, or, in larger labs, 1,000 gallons or more per day or 100,000 gallons or more per year.

Water use data from meters and submeters should be collected and tracked regularly. ENERGY STAR® Portfolio Manager® is a free utility management tool that can assist with tracking water consumption. If feasible, meters and submeters should be integrated into a centralized building management system or building automation system, which allows more frequent data collection and analysis. These systems allow facility management staff to set alarms if leaks or excessive use is detected. Make sure staff are assigned to review data at least monthly to understand trends, look for anomalies, and respond to preset alarms or notifications that may indicate a leak.

Use the water use information to compare your lab's water performance to other facilities of the same type or function. Benchmarking requires that overall laboratory or process water use be divided by some meaningful denominator, such as conditioned square feet or output. Lab managers can use I²SL's [Laboratory Benchmarking Tool (LBT)](https://lbt.i2sl.org) to evaluate how their water use compares to other similar facilities in terms of gallons of water per square foot of laboratory space per year (also referred to as water use intensity or WUI), or gallons per researcher and employee per day. If facility data are already collected in ENERGY STAR Portfolio Manager, it can be imported into the LBT. Over time, this benchmarking tool will become more robust as more laboratories enter their water data at https://lbt.i2sl.org.

Figure 3 shows the spread of laboratory WUI from two datasets. The bar to the left represents average WUI from 2015-2017 for 34 buildings with "good" and fully metered data from the Cambridge Compact Net Zero Labs Work Group's *Lab Benchmarking Report: Phase 2*. One laboratory with reported WUI greater than 200 gallons/square foot/year was removed. The bar to the right shows average WUI for laboratories that submitted data to the LBT (as of November 10, 2021). One laboratory with reported WUI greater than 800 gallons/square foot and one laboratory with reported WUI of 0 were omitted.

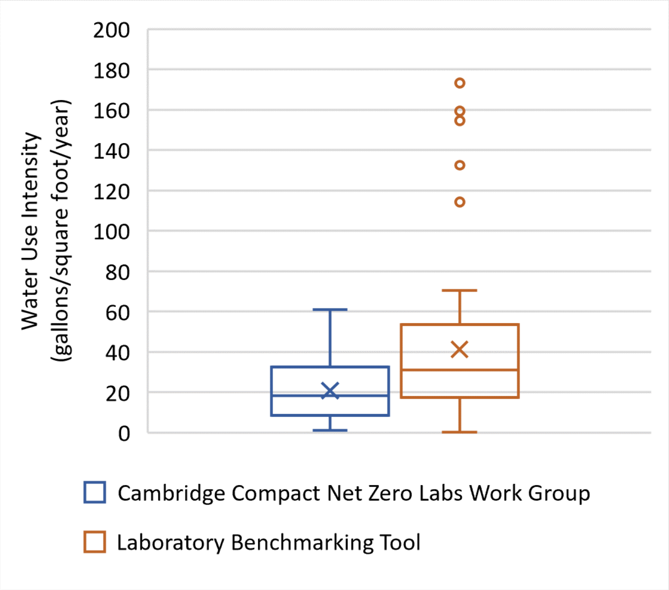


Figure 3. Chart showing laboratory water use intensity from two datasets. The boxes represent the upper and lower quartiles around the median. The "X" shows the mean. The lines extending from the boxes indicate variability outside of the upper and lower quartiles. Additional data points beyond the lines are considered outliers.

Communicating With Employees

Since the behavior of researchers and other staff can affect a facility's water use, it's important to communicate your overall water reduction goals and specific steps staff can take to help meet them. For example, outreach materials, building signage, and training should emphasize the importance of reporting any leaks occupants see in the building, and include a point of contact (facility or maintenance management staff) who can resolve the leak quickly. Leaks are the ultimate water waste, so communicating to building occupants, custodial staff, and others who interact frequently with different water-using systems will help demonstrate that water management is important within the facility.

Laboratory Equipment Best Practices

Laboratories have unique missions that often require special processes and equipment, many of which can be water-intensive, including: water treatment systems; sterilization equipment; vacuum systems; glassware, instrument, cage, and/or rack washers; vivarium watering systems; fume hoods; humidification systems; and photography/x-ray equipment.

Equipment Cooling

Single-pass systems use approximately 40 times more water than a cooling tower operating at five cycles of concentration to remove the same heat load.

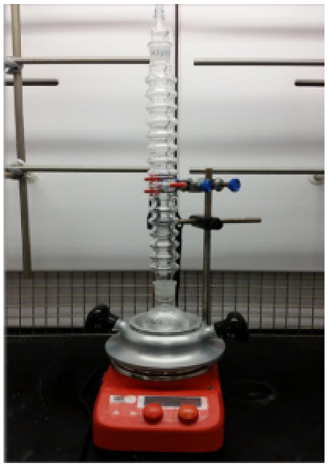
Eliminating single-pass cooling offers laboratories a significant opportunity for water and cost savings.

Lab equipment associated with single-pass cooling using potable water includes: point-of-use chillers or other refrigeration systems; condensers; air conditioners; air compressors; vacuum pumps; ice machines; electron microscopes; gas chromatographs; mass spectrometers; and CAT scanners and X-ray equipment. Sometimes, research staff order and install equipment that requires cooling without consulting facility management, and therefore overlook opportunities for tie-in to centralized chilled water systems. The best way to reduce water associated with single-pass cooling is to either switch to air-cooled systems or use a process or cooling water loop. Laboratory facilities with water-side heat recovery such as a heat recovery heat pump/chiller can even reclaim waste heat from lab equipment for reheat elsewhere in the building.

EFFICIENCY AND SAFETY GAINS FROM AIR-COOLED CONDENSERS

Using air-cooled (also known as waterless) condensers within chemistry labs for synthetic experiments that require reflux and distillation can provide a multitude of benefits. Air-cooled condensers eliminate up to 1 gallon of water per minute compared to a water-cooled condenser unit. (Grist, Perkins, and Barber, 2013). Because many labs require multiple condensers, the volume of water and associated water and sewer costs to support these research activities can add up!

Air-cooled condensers also reduce risk of laboratory flooding, which can have costly consequences for the facility and research team. (University of Colorado [CU] Boulder). They can also be easier to set up, as they do not require tubing or connectors for water cooling. This leaves more time and lab space for other research activities (Radleys).



Example waterless condenser from CU Boulder.

Air Cooling

Many types of equipment used in laboratories (e.g., vacuum pumps, ice machines, condensers) have air-cooled models readily available. Laboratories should evaluate the life-cycle energy and water costs of these alternatives to calculate the payback period for eliminating single-pass cooling. If air-cooled equipment is used for equipment with high heat loads, explore options for rejecting heat to the outside air rather than to conditioned laboratory space (which would increase inside temperatures and the amount of energy needed for space cooling).

Packaged, air-cooled point-of-use chillers can also be used for equipment cooling. Packaged chillers work in somewhat the same way that large comfort-load chillers do. The packaged unit recirculates temperature-controlled fluid (i.e., refrigerant) to a laboratory application to remove heat and maintain a constant temperature. The recirculating fluid picks up heat from the application and returns it to the chiller to be cooled to a specified set point before circulating back to the application. Air-cooled chillers are conventionally thought to be less energy-efficient than water-cooled chillers; however, when considering the energy and water use of the cooling tower system needed to support a water-cooled chiller, this may not be the case. Laboratory managers may want to compare the amount of energy and water used by different packaged chillers at both part and full loads and select the most efficient and cost-effective model to meet lab needs.

Chilled Water Cooling

With a chilled water cooling system, a cooling loop provides recirculating water at a preset temperature to cool the laboratory equipment. Chilled water systems are closed loop, meaning they should not lose water when operating properly. As heat is transferred to the chilled water loop, it must be removed by a chiller system.

Chilled water loops dedicated to cooling a single piece of laboratory equipment are typically cooled by an air-cooled, point-of-use chiller. Air-cooled, point-of-use systems provide more precise control of temperature, which is an advantage in many laboratory operations. Larger chilled water loops supporting multiple pieces of equipment or the entire laboratory are cooled by central chillers that may be air-cooled, or water-cooled using a cooling tower. See the Cooling Towers section on page 21 in Part II for more information on efficiently operating a cooling tower in association with a chilled water system.

If eliminating single-pass cooling is not possible, consider the following best practices for single-pass cooled equipment: use the minimum flow rate required to cool the system recommended by the manufacturer; or install and maintain an automatic control system (e.g., solenoid valve) that only permits cooling water to flow when equipment is operating and a heat load is present. There may also be opportunities for collecting and reusing single-pass discharge water for other uses. This water is typically the same quality as the incoming water supply, so there are ample opportunities for reuse, such as for initial rinse cycles, toilet flushing, irrigation, and cooling tower and boiler make-up.

Water Treatment and Purification Systems

Laboratories require high-quality water for both research and operations. The various water purity levels (i.e., types or grades) required depend on what the lab is used for and how it operates. Because higher purity water is more expensive and resource-intensive to produce, laboratories should evaluate what grade of water is needed to support the majority of their operations, and design centralized treatment systems to supply that grade. If higher-purity water is needed for certain applications, polishers or point-of-use treatment equipment can be used only as necessary (National Institutes of Health [NIH], 2013).

Water treatment and purification systems within laboratories can use a range of technologies; some of the following technologies are often used in

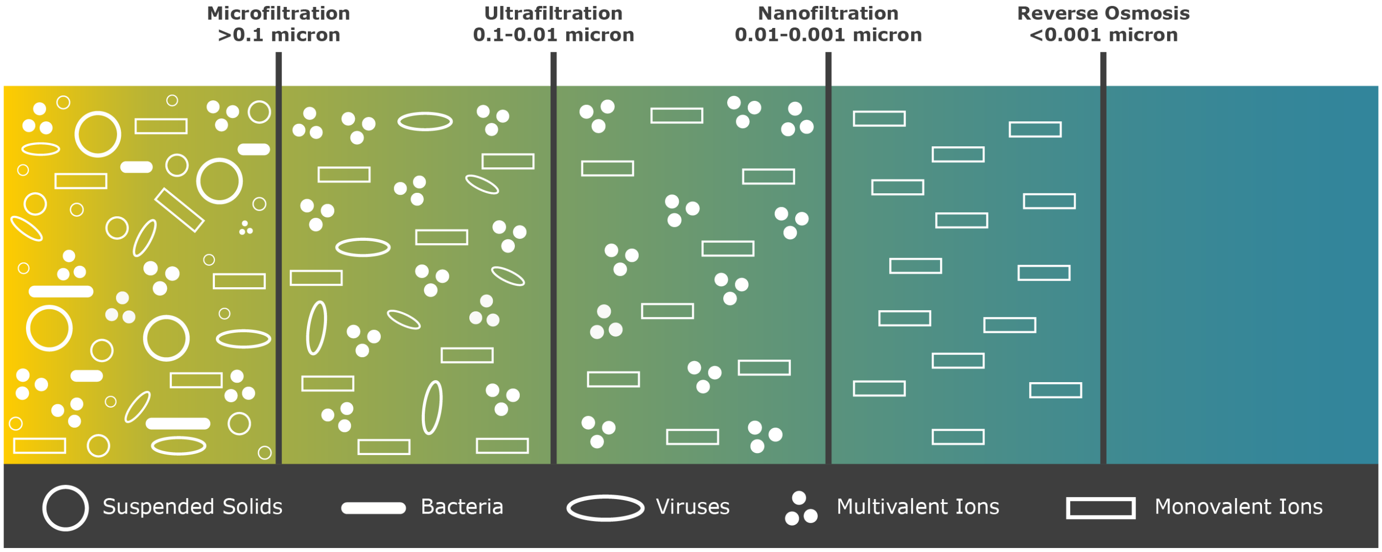


Figure 4. Water contaminants removed by different levels of water treatment.

sequence to provide the desired level of water quality:

- Microporous and carbon filtration
- Reverse osmosis and other membrane processes
- Water softening
- Deionization
- Distillation

Sediment, Microporous, and Carbon Filtration

Sediment and microporous filtration (e.g., microfiltration, ultrafiltration) are common types of water purification. Sediment filters physically remove suspended solids greater than the filter's rated pore size, with filters typically available that can filter down to 1 micron. As shown in Figure 4, microfiltration can remove particles down to 0.1 micron in size, and ultrafiltration can remove particles down to 0.01 micron. Most of the water use comes from backwashing, which is required when too much particulate matter builds up within the filter. To reduce water used during filtration, laboratories should conduct filter backwashing as infrequently as possible and deploy pressure sensors to determine when the pressure drop in the filter is significant enough to warrant a backwash. Single-use cartridge filters that do not need to be backwashed are also available, but they must be disposed of after each change.

Activated carbon filtration uses adsorption to remove chlorine and dissolved organics. Once the adsorptive capacity of the carbon has been used up, the filters need to either be discarded and replaced, or regenerated offsite. While offsite regeneration does not impact water usage within an individual facility, laboratories are still encouraged to regenerate only as needed.

Sediment, microporous, and carbon filtration are commonly used in laboratories for pretreatment prior to water undergoing additional treatment, such as through reverse osmosis (DOE/EERE/FEMP, 2013).

Reverse Osmosis (RO) and Other Membrane Processes

Membrane processes filter water to remove impurities at a smaller level than microporous filtration. Nanofiltration can remove particles down to 0.001 micron in size, followed by ROs (>0.0001 micron). Nanofiltration and RO are capable of removing more and finer particles and cations and anions, but in return use more water during the process.

RO is the most water-intensive membrane process. Two streams exit an RO system: the concentrate stream and filtered, purified water. The concentrate is rejected water containing a high level of dissolved minerals that is typically sent to a drain, or a portion of it is recycled back to the feed stream to increase the system's overall water recovery. The recovery rate, which is defined as the ratio of the purified water (i.e., permeate) volume to the total incoming water volume, is used to represent the efficiency of the RO system. Commercial units can typically achieve 50% to 75% recovery ratings. However, carefully designed and optimized systems that include appropriate pretreatment, advanced membrane technologies, and configurations that make use of the concentrate stream can achieve recovery rates exceeding 90% (DOE/EERE/FEMP, 2013).

In general, higher throughput production systems have higher recovery rates than smaller, point-of-use systems. However, while treatment systems with higher capacities may be more efficient, laboratories should avoid installing oversized systems. Oversized systems are not only costlier, but require more space and can lead to other inefficiencies, such as the energy required to recirculate water within large storage tanks. Assuming that all use points and systems will be operated at once can lead to an oversized system that may not provide the expected level of performance or efficiency (Bosley, 2012).

While RO reject water includes higher levels of contaminants than utility-supplied water, it can often be collected and used within other systems or processes. See the Alternative Water Sources section on page 32 for more information.

WATER TREATMENT EFFICIENCY PRINCIPLES

To summarize, major water-saving principles for water treatment systems include:

- Identify the minimum quality of water required for laboratory research and operations and use treated water only when necessary.
- Avoid oversizing treatment systems. Consider use of point-of-use treatment systems where highly purified water use is limited.
- Backwash filters based on pressure drop and regenerate carbon, ion, and resin beds only when necessary (e.g., based on volume of water treated or conductivity readings) rather than on a set schedule.
- When purchasing new RO or membrane-based treatment systems, select systems with higher recovery ratings and look into optimizing system design to achieve efficiency.
- Explore opportunities for reject water to be reused for other processes.

Water Softening

Laboratories often use water softeners to generate boiler feed water and to otherwise pretreat water prior to additional forms of purification. Cation exchange is a common method for softening water, as the process replaces calcium and magnesium ions with sodium ions. As the sodium ions get used up, the water softening beds need to be regenerated by backwashing with a brine solution. Regeneration can cause excess water use in ion exchange systems, but unlike activated carbon filters, this regeneration typically happens onsite and therefore impacts a lab's overall water use. Laboratories should select demand-initiated water softeners, meaning that regeneration occurs based on incoming water's hardness, the volume of water softened, or treated water conductivity rather than on a set schedule (EPA).

Beyond how regeneration is initiated, important considerations for selecting a water softener include a system's water consumption during regeneration and its salt efficiency. With respect to water consumption, look for systems that use 4 gallons of water or less per 1,000 grains of hardness removed. For salt efficiency, look for systems that can achieve at least 3,500 grains of hardness per pound of salt (ASHRAE and ICC, 2020).

Deionization (DI)

DI is a treatment process commonly used in laboratories that is similar to water softening. Water is sent through resin beds of cations and anions, which bind to the ions in the water supply to provide deionization. Similar to activated carbon filters, resin beds have a limited binding capacity and must be regenerated periodically to ensure effectiveness (NIH, 2013). Regeneration typically occurs offsite and therefore does not impact facility-level water use (EPA).

Distillation

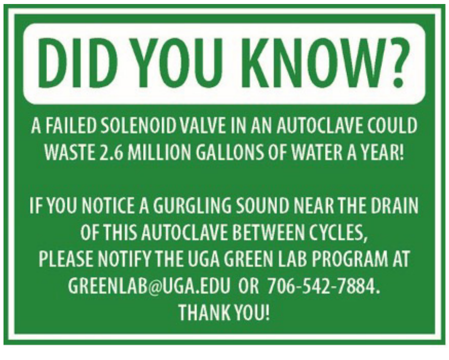
Distillation separates water from impurities by heating water to vapor and condensing it back into a liquid in a separate vessel. Smaller units are often more water-efficient, as they can have no discharge, whereas larger stills reject about 15% to 25% of water that enters the system. However, a major source of water use that may occur during distillation is through condenser cooling. Some labs still use single-pass cooling water for this purpose, which can use a substantial amount of water during the distillation process. Replacing distillation equipment that uses single-pass cooling with air-cooled models or using recirculating chilled water to provide condenser

Autoclave Awareness Helps Contribute to Long-Term Water Savings

Education, outreach, and researcher awareness are critical components of a successful laboratory water efficiency program. Signage, email reminders, and staff incentives can help catch leaks or other water waste.

Water savings kits made up of a solenoid valve reduce the amount of water consumed in older autoclave models. These solenoid valves can eliminate the continuous flow of water used for condensate tempering. Once the valve is installed, tempering water is only applied when the autoclave is operational and cooling is required. However, these kits have a lifespan of 5 to 7 years, much shorter than the lifespan of the autoclave itself. When these kits fail, they fail open, thus allowing the constant flow of cold water to pour down the drain. At 3.0 gpm, that's more than 1.5 million gallons per year! Because autoclave users aren't necessarily responsible for maintaining the equipment, it is unlikely that a failed solenoid valve is discovered and replaced in a timely manner.

All lab autoclave users should be trained in identifying what a failed valve sounds like and understand the need to report it immediately. For example, the University of Georgia (UGA) placed awareness stickers on every campus autoclave to ensure users are aware of the valves and can identify what a failed valve sounds like. In the first week the stickers were placed, two units with failed valves were identified by users, saving UGA up to $48,000 in annual water and sewer costs. UGA conducted education and outreach on the program, replaced failed solenoid valves for free, and engaged with manufacturers and service vendors to bring awareness to these water savings efforts.



DID YOU KNOW?

A FAILED SOLENOID VALVE IN AN AUTOCLAVE COULD WASTE 2.6 MILLION GALLONS OF WATER A YEAR!

IF YOU NOTICE A GURGLING SOUND NEAR THE DRAIN OF THIS AUTOCLAVE BETWEEN CYCLES, PLEASE NOTIFY THE UGA GREEN LAB PROGRAM AT GREENLAB@UGA.EDU OR 706-542-7884. THANK YOU!

Example signage posted by the UGA Green Labs program. Source: Star Scott, Green Lab Program Coordinator at UGA cooling can save water. More information on alternatives to single-pass cooling can be found in the Equipment Cooling section on page 6.

Steam Sterilization

Steam sterilizers (sometimes referred to as autoclaves) are used for disinfection in laboratories. Table-top units are typically small and do not use significant amounts of water. However, larger stand-alone sterilizer models can use a substantial volume of water to produce steam and to cool wastewater before discharge. Some sterilizers also use water to create a vacuum to expedite drying, either through a venturi-based water-ejector or a liquid ring vacuum pump.

In older steam sterilizer models, the majority of water use results from condensate cooling. Prior to being discharged to a sanitary sewer, condensed steam from the sterilizer must be cooled to 140°F (60°C) or less. This is done by adding cold water (typically from the main water supply) to the condensate to temper it before discharges, as much as 1 to 3 gallons per minute. Many older models apply tempering water continuously, even when the equipment is idle or turned off and does not require the same level of condensate cooling.

In general, newer steam sterilizers are designed to apply cooling water only when necessary. These models include a cooling reservoir to assist with condensate cooling prior to discharge and/or a temperature-actuated valve to only apply tempering water when the condensate discharge is above 140°F. Older models without these features incorporated into their design can be retrofitted with a water savings kit that includes a solenoid valve. These retrofits can reduce condensate cooling water use by up to 90% (Koeller et al., 2004). Another solution that can eliminate once-through tempering water is to provide condensate cooling through a heat exchanger connected to a building chilled water loop (Consolidated Sterilizer Systems, 2021).

Newer, stand-alone sterilizers commonly include their own boiler system that can capture and reuse the condensate from within the sterilizer, saving both energy and water.

Steam sterilizers can also be designed or retrofitted with a water recirculation system to reduce the amount of water necessary to draw a vacuum through the sterilization chamber. In a conventional steam sterilizer, the vacuum is generated by passing water at a high velocity through an ejector at a flow rate of 5.0 to 15.0 gallons per minute (gpm) and discharging it directly to the sanitary sewer (Koeller, 2004). A recirculation system can be used to capture and reuse some of the water. Some newer steam sterilizer models offer an electric liquid-ring vacuum pump or a dry vacuum that can reduce water used to establish a vacuum significantly. Dry vacuum systems should be selected for all new equipment.

Following are ideas for reducing water use from steam sterilizers:

- Turn off the steam sterilizer when not in use or program the sterilizer to turn off at the end of the workday, on weekends, or after being idle for an extended period.
- Retrofit older steam sterilizer models to include a temperature-actuated valve and/or cooling tank to reduce the frequency that tempering water is applied, particularly during periods when equipment is idle.
- Periodically inspect temperature-actuated valves to make sure they are functioning properly and that tempering water is only being applied while the steam sterilizer is operating.
- Identify alternative sources of cooling water, such as RO system reject water, that may be

available in the lab that can be collected for use as tempering water (Stanford University, 2013).

- Consider installing a system to recover and recirculate water used to create the vacuum.
- Select sterilizer models that use a dry vacuum system rather than a water-ejector or liquid ring vacuum pump.
- Consider sterilizer models that include a stand-alone boiler system that recovers its condensate.
- Replace older units with newer models that are designed to reduce energy and water use through the technologies described above.

Vacuum Systems

Laboratories use vacuum systems to collect waste gases, liquids, or debris from a vessel or enclosure. Historically, "wet" vacuums pumps (which use water to create the vacuum) have been used. There are two types of wet vacuum pumps: liquid ring and aspirator (i.e., venturi) vacuum systems; aspirators in particular waste large amounts of water. Liquid ring vacuum pumps use water to form a vacuum seal, which gathers impurities. The seal and cooling water needs to be discharged and replenished with fresh water to remove impurities and heat. Water requirements for wet vacuum systems range from 0.5 to 1.0 gpm per horsepower (EBMUD, 2008). Water can also be used to cool dry vacuum systems. If water is being used for cooling of either wet or dry vacuum systems, consider connecting the vacuum system to a recirculating water loop.

Where feasible, replace existing wet or water-cooled vacuum systems with dry, air-cooled models. Aside from use in explosive or extremely corrosive environments, dry vacuums can be used in most laboratory settings. While they can be more expensive to procure, these newer dry vacuum systems are more energy-efficient and eliminate the use of water, reducing long-term operating costs. As with water treatment systems, centralized vacuum systems can often be oversized. If vacuum needs can be supported by smaller, point-of-use electric-powered vacuum pumps rather than a larger, centralized system, a lab can save significant amounts of energy and water.

Other tips for saving water in vacuum systems include:

- Turn off the vacuum pump when not in use.
- Ensure the vacuum pump is operating according to the manufacturer's specifications with respect to seal and cooling water.
- Consider installing a system to recover and recirculate seal and cooling water, which can reduce water use by 50% to 80%.
- Replace older, wet or water-cooled vacuum systems with dry, air-cooled models to improve both energy and water efficiency.

Glassware Washers

Glassware washers are used to remove chemicals and other material from laboratory glassware. A common misconception is that glassware washers use more water than hand washing, but in reality, glassware washers are much more efficient and effective. Laboratory glassware washers are often supplied with potable water as well as purified (e.g., DI or RO) water. In these instances, potable water is used for initial pre-rinse and washing stages, whereas purified water is used in the final rinse stage to make sure no residual contaminants or minerals are left on the glassware.

Newer glassware washers use less water than older models, as they include flow control and sensing capabilities. With newer models, the operator can also select the number of rinse

Glassware washer image courtesy of Labconco Corporation.

cycles. Fewer cycles should be selected whenever possible, as long as this would not affect the laboratory's desired level of cleanliness. Because water used in glassware washers is typically heated to high temperatures, operating more water efficiently will save energy too.

When purchasing new glassware washers, choose a size (e.g., undercounter, free-standing) that fits the needs of the laboratory without oversizing. Compare similar models based on water and energy use and select more efficient models. Consider add-ons like "cool-down" tanks, water recycling systems, or heat recovery systems that can reduce water and/or energy use.

Vivarium Systems

Vivaria use specialized equipment related to the care and housing of animals such as cage, rack, and bottle washers and animal watering systems.

Cage, Rack, and Bottle Washers

All vivaria must wash cages, racks, bottles, and other items used for the care and feeding of animals. There are two basic types of systems for washing cages: batch-type washers and continuous tunnel washers. Hot water use from cage, rack, and bottle washing is also a major contributor to laboratory energy use.

Batch-type cage, rack, and bottle washers function similarly to a residential dishwasher. Cages, racks, and/or bottles are loaded into the washer, which then completes a wash cycle. Cleaned equipment is then removed and prepped to be used again for animal care. Batch-type washers include multiple cycles (i.e., pre-rinse, wash, final rinse), although additional cycles may be selected for more specialized cleaning requirements. Each additional cycle increases water used per batch. Newer washers use between 12 and 50 gallons of water per cycle (up to 150 gallons per load for a conventional three-cycle wash); however, older units can use nearly 500 gallons per load (EPA).

Tunnel washers are typically found in laboratories that require large amounts of cage and rack washing. Tunnel washers use a conveyor system, with staff stationed at each end to feed dirty cages and racks and remove them once clean. Tunnel washers use a counter-current washing process, meaning water used for each subsequent rinse cycle is recycled within the previous cycle (i.e., the cleanest water is only needed for the final rinse phase; water for early rinsing tasks, when the quality of water is not as important, is recycled from later in the process). Tunnel washers typically vent into the workspace continuously during operation, which results in higher air conditioning requirements.

Comparing these two washer options, one study found that batch-type cage and rack washer operations were more water- and energy-efficient and could result in fewer hours of labor to operate. For the same throughput, the study found tunnel washers would use, on average, 21% more water and 69% more steam, although would use 11% less electricity (Zynda, 2015).

Various types of water (e.g., softened, RO/DI, heated) can be used for washing, depending on each laboratory's specific needs. High-quality, treated water should only be used if necessary. See the Water Treatment and Purification Systems section on page 7 for more information on efficiently operating these systems. If hot water greater than 140ºF is used, tempering water might also be used to cool water prior to sewer discharge.

Reducing water use within cage, rack, and bottle washing operations can also result in commensurate energy and chemical savings. To summarize, major water saving principles for cage, rack, and bottle washers include:

- Wash only full loads for batch washers and schedule wash runs for tunnel washers to maximize the equipment washed during each run.
- Use high-quality water only for the final rinse cycle.
- Choose the minimum number of wash and rinse cycles necessary to effectively clean equipment.
- Minimize or eliminate tempering water use by installing a heat exchanger to cool washer effluent prior to discharge.
- When purchasing new washers:
    - Consider batch-type washers over tunnel washers to reduce utility costs and labor requirements;
    - Avoid oversizing equipment;
    - Select models that use less water per cycle;
    - Select models that allow users to specify the number of rinse cycles; and
    - Choose equipment capable of recycling final rinse water for the first wash.

Animal Watering Systems

Automatic watering systems supply drinking water to animals within laboratory settings. Although these systems are a less labor-intensive alternative to manual bottle filling, they can result in greater water use. Systems should be selected and operated with the primary goal of providing adequate volumes of water for animal care while preventing transmission of pathogens or other bacterial buildup; however, water efficiency should also be considered.

Animal water systems can be either flushing or recirculating systems. Flushing systems use either a continuous or periodic water flow to maintain water quality and flush watering piping and bottles, but then it goes right down the drain to the sewer system. Recirculating systems use a constant flow of recirculating water flow that is treated using ultraviolet or other methods of disinfection, and are much more water-efficient.

If the water supplied to your lab's animal watering systems requires pretreatment, make sure to optimize system efficiency. Eliminate continuously flushing systems and automate flushing systems to reduce the occurrence of flush cycles to only when water quality considerations dictate. Before purchasing new or replacing automatic animal watering systems, consider whether manually filling water bottles is feasible. If your laboratory decides to move forward with an automatic system, consider selecting one that is recirculating, provided the necessary disinfection can be provided in a cost-effective manner.

See the Water Treatment and Purification Systems section on page 7 for more information.

Laboratory Fume Hoods

Most fume hoods—which contain and remove harmful air from the lab—simply exhaust the fumes through duct work to the outside. For low concentrations of hazardous substances, filtered fume hoods may eliminate the need for exhaust completely. These filtration systems use inert adsorbents (e.g., activated carbon, activated alumina) or chemically active adsorbents (e.g., potassium permanganate). These dry filtration systems effectively contain and trap low concentrations of contaminants. Owners must make sure to replace adsorbent as indicated by sensors or time logs.

A few laboratory operations (e.g., those involving acid fumes, toxic materials, and perchlorate) require hoods that remove contaminants through special treatment prior to the air being exhausted to the atmosphere. They require wet scrubbers or special wash-down equipment to remove potentially combustible products.

Wet Scrubbers

Within wet scrubbers, contaminated air from the fume hood passes through a spray or wetted packed column, where it comes in contact with water (and sometimes additional scrubber reagents), which absorbs water-soluble gases, vapors, aerosols, and particulates. The scrubbing liquid should be recirculated back though the scrubber with monitoring for saturation by the contaminants. A portion of the liquid will eventually need to be discharged (blown down) to control total dissolved solids and other contaminants, and make-up water is added to maintain scrubber circulating water quality. Mist eliminators installed in the discharge from the scrubber both prevent the release of the scrubber fluid and save water.

Other water-saving suggestions for fume hood scrubbers include:

“Shut the Sash” Efforts Contribute to Water Efficiency

“Shut the Sash” campaigns, which encourage researchers to close the window (or “sash”) on laboratory fume hoods to promote safety and energy savings, can contribute to water efficiency, too. Reducing the amount of conditioned air needed within a laboratory will reduce the load on a cooling tower, therefore reducing the tower’s water consumption. For labs that use a wet scrubber system on fume hoods, eliminating unnecessary air flow through the fume hood will also reduce evaporation that occurs from the wet scrubber.

The sash of a laboratory fume hood typically only needs to be open during experiment set up and active use by a researcher. The energy savings and safety benefits of “Shut the Sash” campaigns are well documented. These campaigns can include different strategies for educating researchers on the importance of shutting the sash, including:

- Intuitive and compelling (e.g., colorful) stickers indicating the sash height that provides the most safety and uses the least energy (see right).
- Educational signage, emails, webpages, and informational materials about the safety and energy benefits.
- Periodic compliance evaluations and feedback to researchers and lab managers.
- Periodic competitions and/or rewards.

Energy reductions from “shut the sash” campaigns stem from reducing the air flow through variable air volume (VAV) fume hood systems. When a sash is shut on a VAV fume hood system, the HVAC system doesn’t have to work as hard because it’s removing less air, thus reducing the amount of conditioned air needed to replace it. (FEMP, 2012b; Aldred Cheek and Wells, 2020).

Image courtesy of University of California, Davis.

- Turn off water flow when systems are not in use.
- When a hood must be in continuous operation, but no actual work is occurring, encourage lab users to close the fume hood's sash (see sidebar on page 15). This reduces evaporation in the wet scrubber and reduces air loss from the heated or cooled laboratory space.
- Use water (scrubber fluid) recirculating systems.
- Make sure liquid level controllers and water make-up valves are functioning properly.
- Control blowdown based on scrubber fluid chemistry, rather than allowing continuous blowdown or based on a timer.
- Minimize air flow through the wet scrubbers. Reducing the amount of air passing through the scrubbers will reduce evaporation.
- Size equipment to the task and install mist and drift eliminators.

Perchlorate or Perchloric Acid Wash-Down Systems

Perchlorate or perchloric acid wash-down systems are a specialty type of fume hood used for these unstable, explosive compounds that tend to deposit on hood and ductwork surfaces. Wash-down systems are used to periodically wash these substances from the surface of the fume hood and associated ducts. Water is sprayed onto the hood and ductwork surfaces, then it is drained to the sewer. Fume hood systems and ducts should be designed to minimize surface area, and thus the amount of water needed. This ductwork should be designed to take the shortest path to the outside and remain separate from other ductwork. This both reduces the surface area that needs to be washed (thus saving water) and avoids perchlorate from coming into contact with organic fumes and other combustible substances. Applicable regulatory guidance can be found in ANSI/AIHA/ASSP Z9.5 –Laboratory Ventilation and NFPA 45 Standard on Fire Protection for Laboratories Using Chemicals.

Water-saving principles for perchlorate hoods include:

- Avoid using continuous washers or retrofit them to include automatic shutoff valves when the hoods are not in use.
- Establish operating procedures to schedule wash-downs when necessary to ensure health and safety; however, reducing the runtimes of this equipment will save water.
- Work with the equipment supplier to design an efficient system and operating procedures.

Humidifiers

Humidification of the laboratory working space is often necessary, especially in colder climates, to maintain proper humidity, both for researchers' comfort and to control the growth of harmful organisms such as mold, viruses, bacteria, and mites. Most laboratories try to keep relative humidity between 40% and 60 % and require significant fresh air turnover rates. Two basic types of humidification processes are used in labs:

- Isothermal systems use an internal or external heat source to boil water, which is injected as steam or water vapor directly into the circulating air.
- Adiabatic systems either spray water into the air space (atomizers) or otherwise use the air in the room to evaporate water with the aid of wetted media or mechanical energy.

Table 1 on page 17 includes different humidifier types, as identified by the *ASHRAE Handbook-HVAC Systems and Equipment* (ASHRAE, 2020).

Table 1. Types of Humidifiers

Isothermal	Adiabatic
Hot water heat exchanger	Centrifugal atomizer
Steam heat exchanger	Compressed air atomizer
Direct-injection steam	Pressurized-water atomizer
Electric infrared steam	Ultrasonic atomizer
Electric resistance steam	Hybrid spray/media
Electrode steam	Wetted media
Gas-fired steam	

By design, humidifiers consume water to add moisture to conditioned air. However, additional water use can occur from either 1) blowdown or discharge to prevent a buildup of minerals in the system; or 2) treatment of the humidifier water supply. Blowdown is required in humidifiers to periodically control the levels of total dissolved solids (TDS) and minerals in the system. The only exception to the need for blowdown is an atomizer system that sprays treated water directly into the air. Direct steam injection systems obtain steam from a central boiler system, and therefore do not require additional treatment or blowdown at the point of use, but blowdown and treatment are required at the central boiler.

Very pure water produced by reverse osmosis or deionization is recommended for many types of humidifiers. In particular, atomizers typically require purified water in many laboratories, since tap water contains minerals and other contaminants that would be sprayed into the indoor air. Also, wetted media, ultrasonic, centrifugal, and hybrid spray systems need the water in them to be controlled for bacteriological growth through the addition of biocides, even when high purity water is used. When operating humidifiers or selecting new equipment, laboratories should examine the water that is required for blowdown, as well as waste generated through generation of RO or other treated water.

Energy efficiency is also a consideration when selecting or operating humidifiers. Isothermal humidification requires the generation of steam or hot water, which can be energy-intensive. Since centralized boiler systems are usually operated more efficiently than stand-alone steam boiler humidification systems, direct steam injection tends to be both more energy- and water-efficient. However, laboratories should evaluate steam quality to make sure it is suitable for direct injection and will not negatively impact air quality. Adiabatic systems require the evaporation of water, which has a cooling effect on the air in the space being humidified. This is beneficial in warm, dry climates where cooling is needed in addition to humidification. In colder climates, or in winter, adiabatic systems may not be suitable, and more energy will be required for space heating.

Labs requiring special humidification should be isolated from other labs and non-lab areas with walls, vapor barriers, and sealed doors. Labs with very intensive humidification or tight humidity control may require airlock vestibules to maintain proper control. Lab humidification operations should be properly controlled with instrumentation to measure relative humidity and keep typical levels between 40% and 60%. This ensures that only the water and energy needed to control humidity is used and comfortable, safe conditions are maintained. Often, however, lab areas requiring relative humidity levels above 30% are limited and can be humidified by local trim humidifiers. Therefore, the energy and water consumption of central humidification of the ventilation system for the overall facility can be decreased by maintaining a lower minimum relative humidity setpoint elsewhere in the facility (e.g., 25% or 30%). For older lab buildings located in cold climates, it is sometimes necessary to decrease the humidity levels when outdoor temperatures decrease to reduce condensation on windows, window frames, and walls and mold forming inside the lab from condensing moisture.

Labs should carefully choose humidifier equipment and make sure it is sized for the type of laboratory and operating conditions where it is being installed. Work with a qualified vendor to select equipment and controls designed for energy and water efficiency.

Photographic and X-Ray Equipment

Photographic and X-ray machines in laboratories may require water for film processing or equipment cooling. Many laboratories have switched to digital equipment to eliminate water and chemical use, improve image quality, and generally improve operational efficiency and safety. Put simply, if laboratories are still using traditional film processing equipment, it may be time for a digital upgrade!

Laboratory Design

Initial laboratory design presents a clear opportunity for incorporating water efficiency. Early in the planning and design process, designers should consider opportunities for minimizing water use and incorporate alternative water sources.

Water Mapping and Concept/Schematic Design

As the project team is establishing sustainable design goals and conceiving strategies to achieve them, this is the best time to begin to develop a water mapping study. In new facilities, a water mapping study can help designers plan water system configurations; identify synergies for simultaneous demands and sources; reserve space for equipment; and identify opportunities for greater efficiency. Water mapping, an example of which is shown in Figure 5 on the next page, compares all available sources of water (e.g., potable water, reclaimed water, graywater) to water end uses, based largely on availability and water quality needs. Water mapping can assist designers in identifying opportunities for efficiency and water reuse so they can be designed in from the onset.

The earliest stages of design have the greatest potential to meaningfully reduce the water use intensity of a laboratory.

To complete water mapping, first develop building systems concepts for major water end uses, including: potable water (e.g., drinking, handwashing, showers); sanitary fixtures (e.g., toilets); scientific processes (e.g., humidification, RO/DI); site maintenance (e.g., irrigation); and HVAC systems (e.g., cooling towers, steam boilers). Consider system alternatives that reduce overall water use. Focus particularly on building heating and cooling system options and their overall water use profile. For example, air-source/ground-source heat pumps with heat recovery may be alternatives to cooling towers. Consider the interaction of energy and water demands with HVAC system selection.

Next, identify alternative water source options, including rainwater capture, HVAC condensate recovery, RO reject, other graywater collection, or reclaimed water. Locate potential water storage areas for cisterns or tanks to collect alternative water. Ideally, storage locations would be in close proximity to the proposed end use(s). Finally, determine if alternative water sources are of

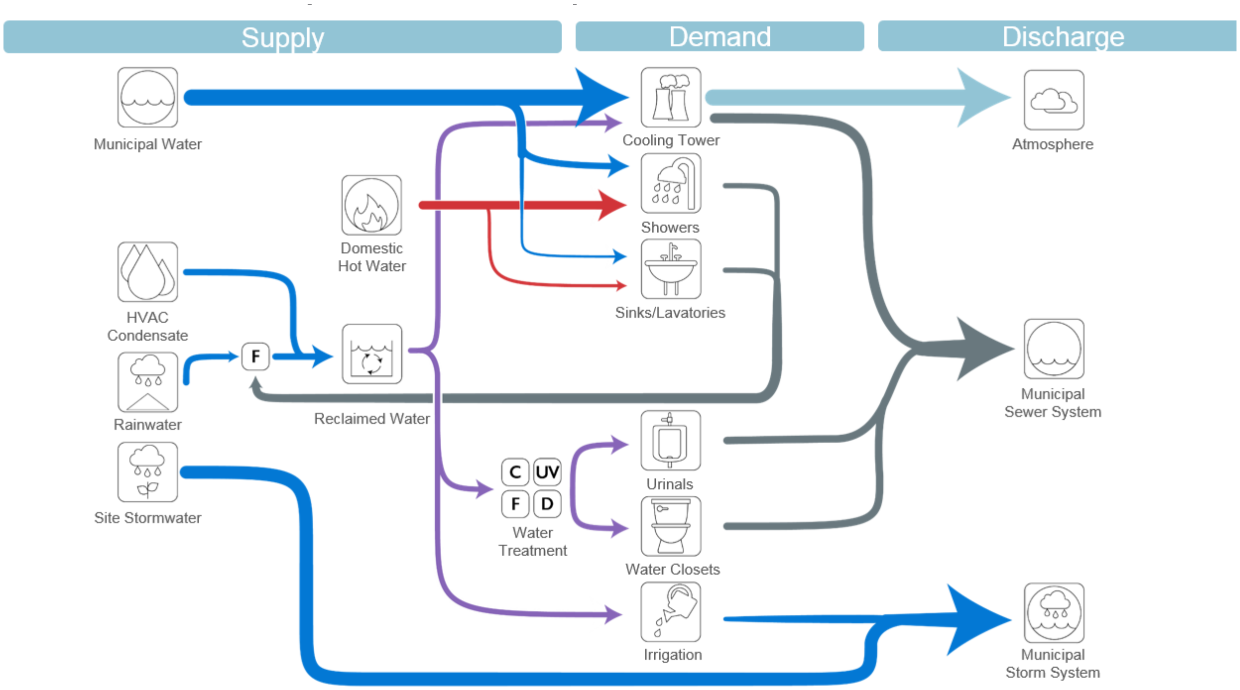


Figure 5. Example water map developed for a typical laboratory. Figure courtesy of Vanderweil Engineers.

sufficient water quality to serve any proposed end uses and/or examine whether water quality must be improved by installing water treatment equipment.

Cost and budget are primary concerns, so project teams should establish budget parameters for potential water efficiency upgrades or alternative water sourcing. Water efficiency or alternative water projects should be evaluated on a lifecycle basis, taking into consideration the per-unit cost of water and sewer service, operations and maintenance costs, and potential energy use or savings. For example, energy recovery strategies that reduce energy consumption may also reduce the demand for water at the cooling tower, so both energy and water cost savings should be quantified.

Design Development

The design development phase is an opportunity to further refine water-saving design options that meet project goals and fit within the budget. The design team can begin to select water-efficient equipment, plumbing fixtures, and irrigation equipment (if applicable); optimize the size of cisterns for alternative water storage; develop more accurate water calculations; and detail the plumbing riser diagrams showing the network of water demands and sources. As the energy model for the project becomes more detailed and representative of the proposed design, extract the cooling loads on the chilled water system or cooling tower to estimate cooling tower make-up more accurately throughout the year and optimize the capacity of heat recovery equipment.

The monthly patterns of water sources and demands may not align, therefore requiring creativity by the design team to assess water loads throughout the year. For example, cooling tower and irrigation loads peak in the summer, but can be much smaller or negligible during the winter. A building that utilizes rainwater or year-round sources (e.g., RO reject) may need to align those winter sources with year-round demands such as toilet flushing. Otherwise, reclaimed water in the winter months may need to be wasted.

Design development is the phase during which scientific equipment requiring cooling should be specified. Design teams should evaluate the lifecycle costs of air-cooled versus water-cooled models, looking carefully at the energy and water needed to operate these systems. If water-cooled systems are used, design teams should investigate opportunities to recapture waste heat for use in the building heating loop via the heat recovery heat pump, thus reducing the evaporation of potable water at the cooling tower.

As plumbing piping main distribution is planned throughout the facility, designers should minimize the length of branch piping between the hot water recirculation loop and hot water outlets at showers and lavatories to reduce the amount of water wasted and length of time to receive hot water. The plumbing design should reduce the size of the branch piping as much as possible within code requirements to further reduce the volume of cooled water between the hot water loop and outlet.

Construction Documents and Construction Phase

As the design team completes the construction documents, this is an opportunity to further refine the design of water savings strategies through submetering, detailed sequences of operation, and specification of water-saving equipment.

Water meters and submeters should be connected to a building automation system (BAS) or other systems used to monitor and report utility consumption. Meter data should be recorded in volume units rather than instantaneous flow; recorded at regular intervals, ideally hourly or every 15 minutes; and stored digitally for at least 3 years. Meters connected to a monitoring-based commissioning (MBCx) system, sometimes referred to as a fault detection and diagnostics (FDD) system, can be used to more quickly identify anomalies in water usage. This can speed up troubleshooting of leaks and other operational problems that result in water waste.

Sequences of operation for alternative water systems and water filtration systems should be detailed on contract documents, including the locations of meters, sensors, and equipment. Design teams should consider how to prioritize where alternative water is directed, and when to utilize backup potable water sources. It’s also important to ensure that heat recovery systems balance energy and emissions reductions with potential water savings, particularly with the operation of heat recovery heat pumps.

During the construction and turnover process, an independent commissioning agent should perform functional testing on plumbing and mechanical systems to ensure that they are operating as intended by the design team, and to facilitate training of the owner’s facility staff to maintain these systems in working order.

Occupancy

The most well-intentioned water saving design means little without producing measurable water savings. Lab operators should monitor water consumption relative to estimates by the design team. While some variability is expected through different seasonal and daily patterns, monitoring water consumption can reveal when significant issues arise, such as too-frequent cooling tower blowdown, a significant water leak, or a malfunctioning alternative water system.

PART II: WATER SAVINGS OPPORTUNITIES NOT SPECIFIC TO LABS

Beyond lab-specific equipment, there are many opportunities for water savings within the plumbing and mechanical systems and equipment commonly found in other commercial building types. In fact, because laboratories typically have high demand for heating and cooling, savings opportunities may be more significant than in other building types. Further, due to the interdependency of energy and water use within facilities (particularly with respect to cooling towers and steam boilers), energy and water efficiency efforts go hand-in-hand. In effect, efforts made to reduce energy demand, process and heat loads, and the use of steam can contribute to laboratory water savings as well.

Cooling Towers

Cooling towers might represent the largest single opportunity for lab water efficiency. Even lab facilities that receive chilled water from central campus chilled water systems indirectly consume large quantities of water for that cooling at the campus plant cooling towers. Laboratories usually have significant comfort-cooling and process loads. They often use 100% outside air for ventilation, making their comfort cooling loads much higher than those of typical office buildings. Additional cooling is often needed for special equipment such as lasers and electron microscopes. Nearly 50% or more of all the water used in multipurpose laboratories can be for cooling (EPA).

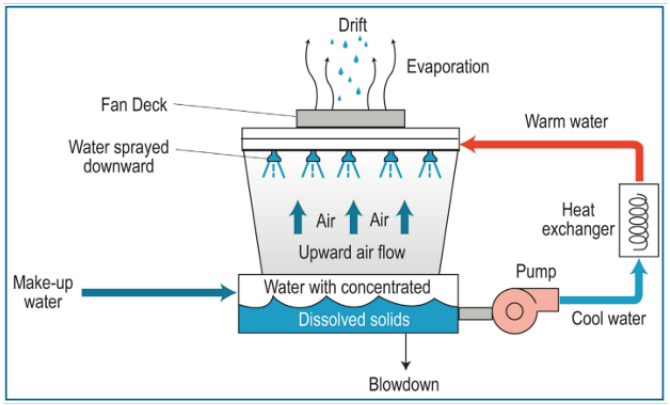


Figure 6. Typical water flow within a cooling tower system. Figure courtesy of the Federal Energy Management Program.

Cooling towers use evaporation to dissipate heat from recirculating water used to cool chillers and other process equipment. By design, condenser water systems and cooling towers help water-cooled lab process equipment be more water-efficient, since water can continue to be recirculated to meet cooling demand rather than being used once and sent down the drain. However, careful management of the cooling tower system is needed to ensure this efficiency is maximized.

Cooling towers use water in three ways: evaporation, blowdown (i.e., bleed-off), and drift. Figure 6 above illustrates water use in a typical cooling tower. Malfunctioning towers may also lose water through overflow and leaks. Evaporation is the primary function of the cooling tower, and opportunities to reduce evaporation focus mostly on strategies that reduce the cooling load on the cooling tower rather than modifications to the tower itself. The quantity of water evaporated is fixed—approximately 1.80 to 1.85 gallons of water are evaporated for every ton-hour of cooling. This includes the ton of heat removed from the facility (one ton-hour = 12,000 British thermal units [BTUs]) as well as the heat from the compressor, air handling units, and pumps used to operate the cooling system. Given this, anything a laboratory can do to improve energy efficiency and reduce the cooling load of the building and equipment supported by the cooling tower will have a commensurate reduction in water consumption from evaporation.

When water evaporates from the cooling tower, dissolved solids (e.g., calcium, magnesium, chloride, silica) are left behind in increasing concentrations.

To control the concentration of dissolved solids, cooling towers blow down a portion of the recirculating water and replace it with make-up water with a lower concentration of dissolved solids.

Blowdown is the primary target of cooling tower water efficiency management efforts once loads on the cooling tower have been optimized.

Cooling towers lose some water through drift and leaks or overflow. Drift, the loss of unevaporated water into the atmosphere, can be controlled by drift eliminators. High-efficiency drift eliminators can be installed or retrofitted onto cooling towers to reduce drift losses to 0.005% or less of the recirculating water flow.

Lastly, while leaks and overflow are not intended by design, cooling tower fill valves can malfunction and should be monitored regularly. Consider retrofitting existing towers with an alarm or sensor that communicates when water is detected in the cooling tower's overflow drain.

Make-up water, which represents the overall consumption of the tower, is the sum of water lost through evaporation, blowdown, drift, leaks, and overflow.

Cooling Tower Water Management

The primary methods for managing water use in cooling towers are operational. To improve the tower's water efficiency, the goal is to increase the cycles of concentration (CoC) to the maximum extent possible without overly concentrating dissolved solids or other constituents in the water,

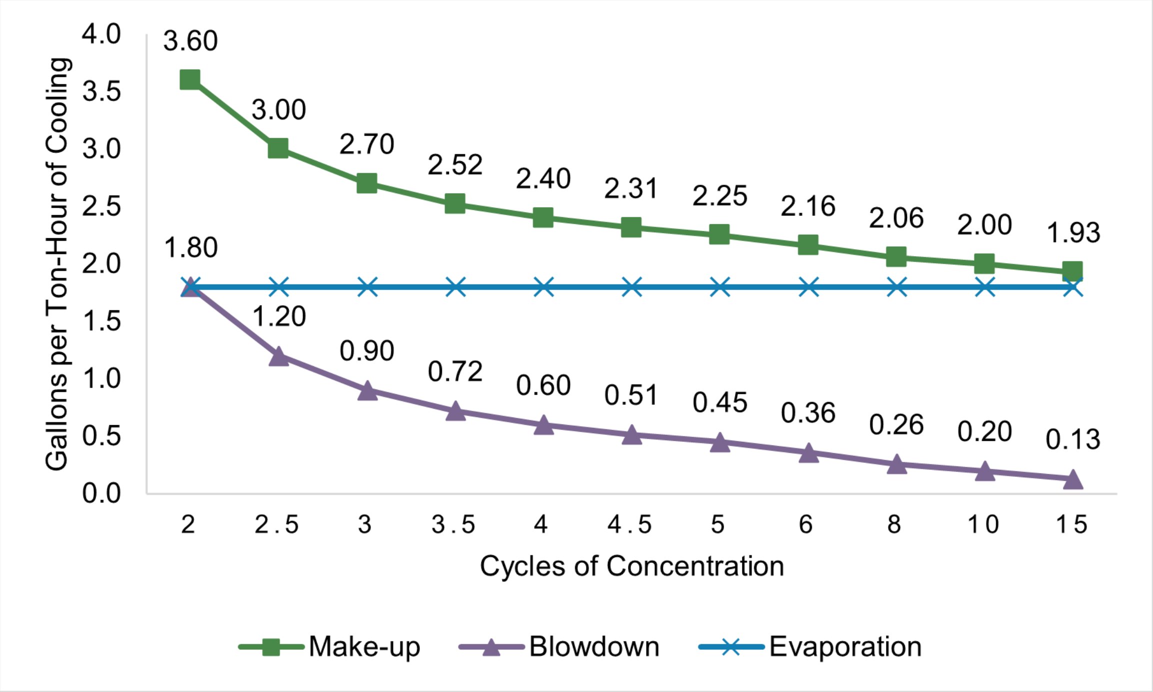


Figure 7. Cooling tower water use per ton-hour of cooling (gallons)

Table 2. Percent of Cooling Tower Make-Up Water Saved by Maximizing Cycles of Concentration

	New Cooling Tower CoC										
Existing Cooling Tower CoC	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
1.5	33%	44%	50%	53%	56%	58%	60%	61%	62%	63%	64%
2.0	—	17%	25%	30%	33%	38%	40%	42%	43%	44%	45%
2.5	—	—	10%	16%	20%	25%	28%	30%	31%	33%	34%
3.0	—	—	—	7%	11%	17%	20%	22%	24%	25%	26%
3.5	—	—	—	—	5%	11%	14%	17%	18%	20%	21%
4.0	—	—	—	—	—	6%	10%	13%	14%	16%	17%
4.5	—	—	—	—	—	—	4%	7%	9%	10%	11%
5.0	—	—	—	—	—	—	—	3%	5%	6%	7%

Table 3. Cooling Tower Maximum Recirculating Water Properties From ASHRAE 189.1 (ASHRAE and ICC, 2020)

Recirculating Water Parameters	Maximum Value
Conductivity (micro-ohms)	3,300
Total dissolved solids (ppm)	2,050
Total alkalinity as $CaCO_3$ (ppm) excluding galvanized steel	600
Total alkalinity as $CaCO_3$ (ppm) galvanized steel (passivated)	500
Calcium hardness as CaCO3 (ppm)	600
Chlorides as Cl (ppm)	300
Sulfates (ppm)	250
Silica (ppm)	150
Langelier Saturation Index (LSI)	+2.8

which can lead to scale, corrosion, or biofouling. CoC is an indication of how many times water recirculates in the tower before blowdown occurs. Therefore, increasing the CoC of the tower reduces the consumption of make-up water and results in greater water efficiency. Figure 7 on page 22 and Table 2 above show the effect of the CoC on make-up water use. Note that increasing the CoC from two to six yields nearly 90% of the savings that can be obtained by increasing the cycles from two to 10. Targeting at least six cycles is therefore a good goal.

Figure 7 on page 22 includes the water required to provide one ton-hour (15,000 BTU) of cooling. For reference, one ton of building cooling is equivalent to 12,000 BTU/hour, but cooling towers require more energy per ton of cooling because the mechanical compressors in chillers and heat pumps also generate heat that must be dissipated.

Perhaps the best way to increase a tower's CoC is through better monitoring and management of the water chemistry. The first step is to understand the quality of the incoming water and what the controlling parameter should be, such as

UNDERSTANDING CYCLES OF CONCENTRATION

Since CoC represents the relationship between the concentration of dissolved solids in the blowdown to the concentration in the make-up water, it can be expressed as:

$$CoC = \frac{\text{Conductivity of Blowdown}}{\text{Conductivity of Make-Up Water}}$$

If a cooling tower is metered for make-up and blowdown, CoC can be calculated based on the volume of make-up and the volume of blowdown.

$$CoC = \frac{\text{Make-Up Volume}}{\text{Blowdown Volume}}$$

The amount of water that can be saved by increasing CoC can be calculated as:

$$\text{Savings} = \text{Initial Make-Up Volume} * \frac{(CoC1 - CoC2)}{CoC1 * (CoC2 - 1)}$$

Where CoC1 is the initial cycles and CoC2 is the target cycles of concentration.

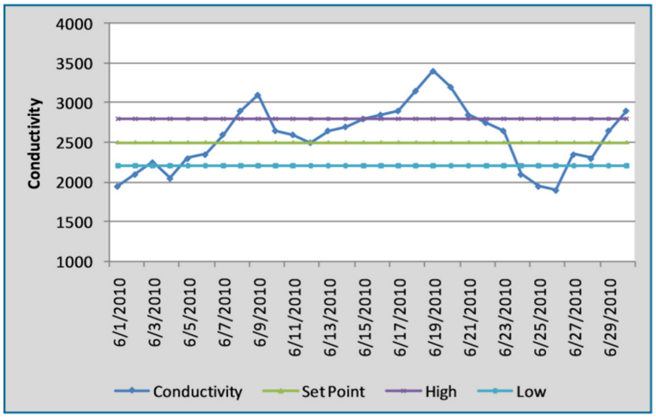


Figure 8. Conductivity trend using manual or timed control. Source: Federal Energy Management Program.

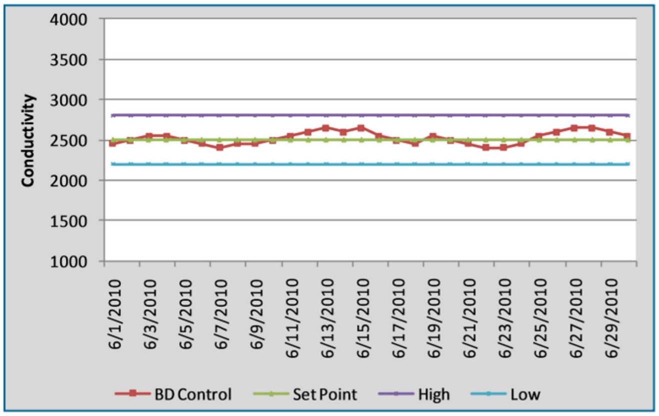


Figure 9. Conductivity trend using a conductivity controller to initiate blowdown. Source: Federal Energy Management Program.

hardness, silica, or TDS. ASHRAE 189.1 Standard for the Design of High-Performing Green Buildings provides guidance on the maximum value of certain recirculating water parameters, shown in Table 3 on page 23. Towers made using Type 316 stainless steel or other materials that protect against corrosion may be able to operate under higher parameters than indicated in Table 3. Laboratories should consult with a qualified treatment vendor and/or the cooling tower manufacturer to understand recommended parameters for their specific tower and water chemistry.

Without additional forms of treatment, the maximum CoC for cooling towers is largely dependent on make-up water quality. Understanding this relationship can help to establish a target CoC. There will be a relationship between these parameters and conductivity, based on the water chemistry specific to a site.

Understanding the target CoC and installing a controller that initiates blowdown based on the associated conductivity are proven techniques to help improve tower water efficiency. The conductivity controller opens a blowdown valve as needed to maintain the controlling parameter within acceptable limits (rather than manually or on a set timer). Figure 8 and Figure 9 above show the impact a conductivity controller can have compared to manual or timer-based blowdown.

In addition to a conductivity controller, flow meters should be installed on make-up and blowdown lines and connected to a building automation system, wherever possible. Meters that display total water use and current flow rate provide useful information about the status of the tower and cooling system, and they should be checked regularly to quickly identify problems. For example, as shown in the Understanding Cycles of Concentration box on page 24, the conductivity of make-up water and blowdown can be compared with the ratio of blowdown volume to make-up volume. If both ratios are not about the same, the tower should be checked for leaks or other unwanted draw-offs. It is worth noting that submetering of the cooling tower make-up and blowdown can be used to document evaporative water consumption (i.e., water that is not being discharged to the sewer). In some municipalities, this information can be used to obtain a reduction in sewer charges.

It is important to select a water treatment vendor carefully—one who understands that water efficiency is a high priority. Vendors should provide estimates of the quantities and costs of the treatment program (e.g., chemical costs), blowdown water volumes, and expected CoC. Criteria for selecting a vendor should include the estimated cost of treating 1,000 gallons of make-up water and the highest recommended CoC for the water system. Treatment vendors may also be able to offer recommendations for filtration, water softening, or other special water treatment, discussed in more detail below, to help improve water efficiency and reduce overall operating costs.

Efficient Cooling Tower Design and Selection

New construction and renovation projects are excellent opportunities to design for greater water and energy efficiency. Labs can employ a number of options to reduce cooling demand or operating frequency of the cooling tower, including non-evaporative cooling equipment, hybrid cooling towers, heat recovery, and economizers.

Non-Evaporative Cooling Equipment

Consider air-cooled chillers, air-source heat pumps, ground-source heat pumps, or dry coolers to produce cooling to meet lab building cooling loads. These systems utilize non-evaporative forms of heat rejection and eliminate the need for cooling towers and their associated water consumption. Given the large cooling load capacity for lab buildings, hybrid systems that utilize non-evaporative cooling strategies as the first form of cooling and utilize cooling towers only for peak cooling capacity can recognize significant savings in cooling tower make-up water. The energy consumption for these systems must be balanced with water savings, though. For example, air-cooled chiller plants typically have lower efficiencies than water-cooled chiller plants serving large lab buildings. On the other hand, recent trends in the building design industry to reduce fossil fuels for heating have led to more labs utilizing air-source heat pumps for both heating and cooling, with the added benefit of reducing or eliminating water consumption for cooling towers.

Hybrid Cooling Towers

Hybrid towers have both a wet and a dry cooling section. The wet cooling section provides evaporative cooling on hotter days, whereas the dry cooling section is used when the outside air temperature is low enough to provide sufficient cooling, operating similar to an air-cooled chiller. Hybrid towers can significantly reduce water consumption compared to typical cooling towers, since water is not consumed when the hybrid tower is operating in dry mode. Hybrid cooling tower performance depends on the location and environmental characteristics of the site. Energy and water costs also play a crucial role in the decision to use hybrid cooling towers, because making some of these towers more water-efficient could have a negative impact on energy efficiency.

Hybrid cooling towers can also help with plume abatement. A cooling tower's plume is the visible column of saturated air exiting a conventional cooling tower. A smaller plume is desirable in many residential areas and in areas where visibility is important, such as near airport runways.

Heat Recovery

The purpose of a cooling tower is to get rid of unwanted heat within the recirculating water loop. However, laboratory facilities commonly include 24/7/365 cooling loads that are simultaneous with reheat or building heating loads, providing a use for the waste heat. A heat recovery heat pump/chiller can be installed to pre-cool chilled water upstream of the building chillers, and reject the waste heat from that first stage of cooling to serve heating loads on the building hot water loop. This directly reduces the cooling load experienced by the water-cooled chillers and cooling towers, thus reducing evaporation, as well as the amount of energy and fossil fuels needed to provide heating to other applications. Newer lab designs attempt to maximize water-cooled process cooling equipment on the chilled water loop to increase these simultaneous heating and cooling loads for energy recovery.

Somewhat related, airside energy recovery systems can reduce the amount of energy needed to heat and humidify or cool and dehumidify ventilation air for a lab, and thus the water consumption for humidification and/or cooling. Non-hazardous lab exhaust can generally be routed through a total energy recovery wheel to transfer both thermal energy and moisture from the exhaust air to the incoming outside air. This type of energy recovery is not permissible from hazardous exhaust airstreams, but the thermal energy from hazardous exhaust can be extracted by heat recovery coils, which can reduce the cooling load to condition outside air in the warmer months. For new construction and major renovations, some form of heat recovery may be required under the International Energy Conservation Code (IECC), which has been adopted by many jurisdictions, depending on the climate zone for your location.

Economizers

Both air- and water-side economizers can be used to reduce both energy and water use. Air- and water-side economizers work by utilizing cold, outside air (when it is available) to provide space or chilled water cooling rather than depending on mechanical cooling. This is often referred to as "free cooling." When mechanical cooling would have otherwise been provided by a chiller and cooling tower, reducing the amount of mechanical cooling has commensurate water savings. ENERGY STAR® provides information on how to use these technologies effectively (ENERGY STAR, 2022a; ENERGY STAR, 2022b).

If pursuing air-side economizers, laboratories should consider humidification requirements, as cold air can often be dry. The energy and water demand from humidification can impact the cost-benefit of using this technology. Note that cooling tower make-up water demands are typically low in the winter, so this strategy may not save as much water as other energy recovery strategies.

Alternative Water for Cooling Tower Make-Up

Another opportunity to reduce water costs associated with cooling tower operation is to identify and utilize appropriate onsite alternative water sources as make-up. Rainwater or condensate from HVAC cooling coils are both good options for supplying water with low dissolved solids to the cooling tower. See the Alternative Water Sources section on page 32 for more information.

Whether pursuing condensate recovery, rainwater collection, or another alternative water source, work with the laboratory's treatment vendor to understand whether additional water treatment or other maintenance will be necessary.

Special Water Efficiency Features

Water-efficient special features that can be incorporated into cooling tower systems include side-stream filtration, water softening, and alternative water treatment systems.

Side-stream filtration systems remove suspended sediment and minerals from a portion of the recirculating water. These systems increase energy and water efficiency and require less chemical treatment because they draw water from the sump, filter out sediment (which reduces microbiological growth that could otherwise lead to issues like corrosion, scaling, and fouling), and return filtered water to the tower. Side-stream filtration is particularly helpful for systems that are subject to dusty atmospheric conditions. Be sure to consider water used to periodically backflush (i.e., clean) the filters when evaluating overall project savings (DOE/EERE/FEMP, 2012a).

If high water hardness limits the CoC that can be achieved, consider using a water softener to treat all or some of the cooling tower make-up water. Water softeners remove scale-forming minerals (e.g., calcium, magnesium) from the incoming water supply, which would allow increased CoC within the tower. It is worth noting that softened water can be more corrosive, so work with the treatment vendor to ensure appropriate corrosion inhibitors are applied to the tower. Also consider ongoing operations and maintenance and salt costs associated with the softener prior to pursuing this project type.

More recently, a number of alternative or innovative cooling tower treatment technologies have become available that can increase cycles of concentration, improve energy and water efficiency, reduce chemical use, and potentially provide ancillary benefits including legionella control and reduced maintenance. These technologies use a variety of treatment mechanisms. The U.S. General Services Administration (GSA) reviewed the efficacy of some of these technologies and confirmed effectiveness and savings claimed (GSA, 2022). Laboratories should consider whether these technologies could be beneficial in reducing water used for cooling.

Steam Boiler Water Efficiency

Both steam and hot water boilers may be present within a laboratory. The operation and maintenance requirements for steam boilers are similar in nature to that of cooling towers and chilled water systems, in as much as periodic blowdown and water treatment are required to maintain water quality and energy efficiency. Steam boilers use (and lose) water primarily from condensate loss and blowdown, as well as the tempering water required for both of these discharges. Given recent trends in the building design industry to move away from utilizing fossil fuels in new designs, steam boilers are often being replaced with lower temperature hot water systems for building heating and local electric steam generators for humidification, sterilization, or other process loads.

In general, hot water boilers are not a target for water efficiency. On open systems used to supply hot water for end uses (e.g., handwashing, cooking, cleaning), water and energy savings should be targeted by reducing hot water use rather than boiler improvements. On closed-loop hot water systems typically used for space heating, water consumption should be minimal. However, consider installing a make-up meter on the closed loop system to help identify leaks.

Steam Condensate Collection

Steam boilers generate steam that is distributed through a laboratory, either for space heating or process use (e.g., within sterilizers). As the steam cools, it recondenses into hot water, which is either discharged to the sewer or captured and returned to the boiler for reuse. Prior to any sewer discharge, condensed steam must be cooled to 140°F or less, often through use of tempering water, which also contributes to the overall water use requirements of boiler operations.

Recovery and return of condensate to the boiler system has substantial potential for reducing both water and energy use. Recovering condensate not only reduces make-up water demand, but it also reduces tempering water requirements, reduces the frequency of blowdown (note that condensate is very low in dissolved solids), and, because it is still hot, requires much less energy to reproduce steam than the cool incoming water supply.

Within a condensate recovery system, leaking steam traps and failed condensate pumps can be a source of water and energy waste. Leaking traps allow steam to pass through to the condensate recovery system. This steam/condensate mix will travel through condensate piping to a condensate receiver. The receiver is intended to collect the liquid condensate and pump it back to the boiler. Pressurized steam in the receiver can damage the pumps; therefore, the receivers are vented to the atmosphere, which wastes energy and water. It is good practice to periodically walk around the outside of the building and look for steam plumes or wisps coming from roof vents (shown in Figure 10 above), especially in winter, which can be an indication of a failed steam trap. Similarly, poorly maintained condensate pumps that are not functioning properly can result in hot condensate overflowing the receiver and discharging to the drain. A good maintenance program should regularly check and repair steam traps and pumps, which can save a significant amount of energy and water. Steam trap repairs and failed condensate pump replacements usually pay for themselves within weeks or months.

Figure 10. Example of steam plume from a roof vent, indicating a failed steam trap.

If condensate recovery is not feasible, laboratories can explore methods for reducing the temperature of condensate prior to discharge without the use of tempering water. In place of tempering water, a flash tank, expansion tank, and/or aftercooler may be able to be used to reduce the temperature of condensate prior to discharge. If tempering water is needed, evaluate whether this can be provided from a non-potable water source and make sure that any valves that supply tempering water cut off cleanly when tempering water is not needed.

Using Heat Recovery in a Boiler Plant to Save Energy and Eliminate Water Used for Tempering

Heat recovery can be used to eliminate the need for tempering water on boiler blowdown or condensate drains. In the schematic below, steam boiler blowdown is initially vented to a small flash tank and flashed down to about 5 pounds per square inch (psi) gauge. The flash steam from a boiler plant operating at 100 psi will be about 10% of the mass flow. Water and embedded energy in the flash steam can be fully recovered by routing this flash steam back to the deaerator. The remaining liquid, now at approximately 230ºF, is directed through a tube-bundle stainless steel heat exchanger inserted into a 350- to 500-gallon pressure vessel. The heat is transferred to the incoming make-up water. The flow of condensate and blowdown are often not simultaneous, so the large tank acts as a thermal flywheel and stores thermal energy. After entering the heat exchanger, the blowdown is cooled to around 85º to 90ºF, completely eliminating the need for tempering water before being discharged to the drain.

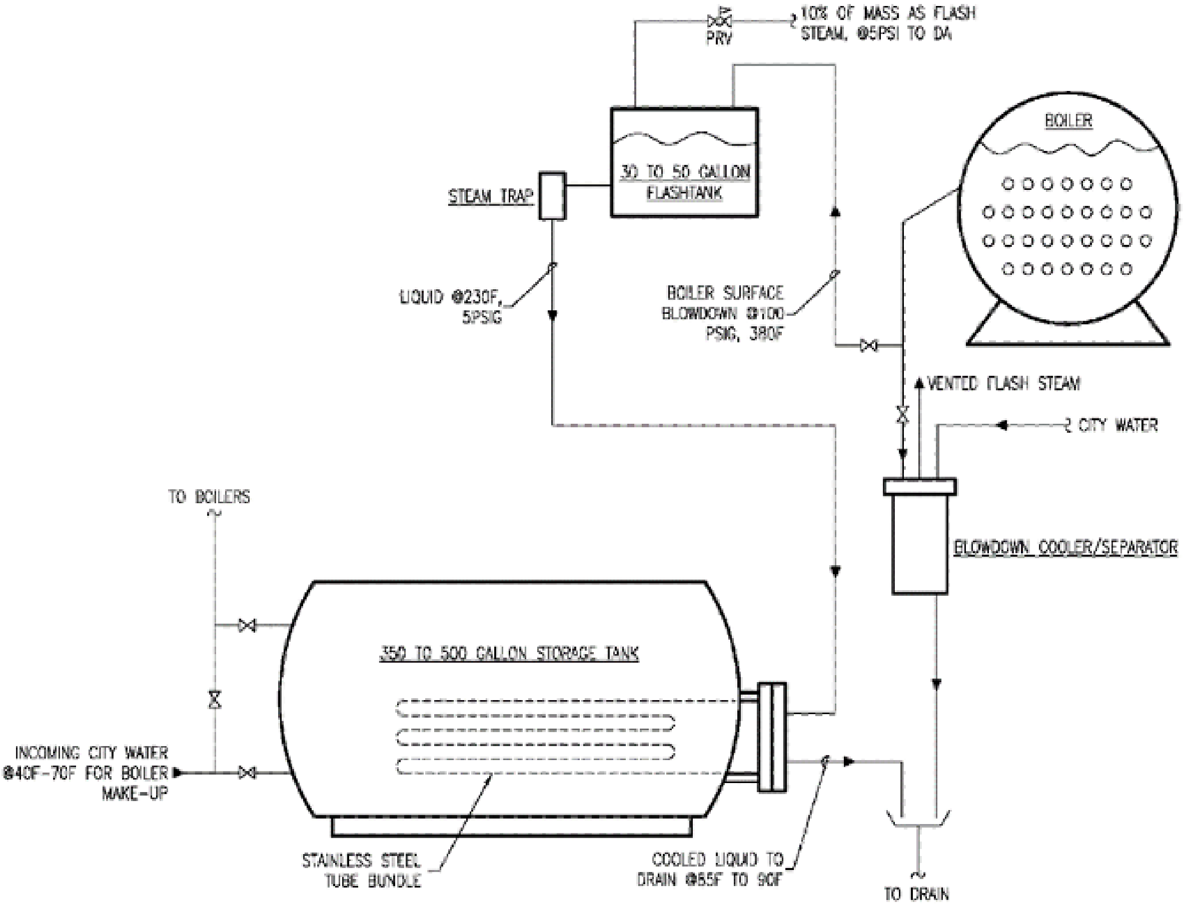


Figure 11. Example design for boiler blowdown heat recovery.

Source: Dan Doyle, Grumman/Butkus Associates

Steam Boiler Blowdown Control and Water Management

As a boiler generates steam, dissolved solids and minerals are left behind in the boiler system (similar to what happens when water is evaporated from a cooling tower). High concentrations of dissolved solids can cause scale and corrosion of the equipment, leading to inefficiencies or other maintenance concerns. Therefore, a portion of the water in the steam boiler system must be periodically blown down. Make-up water is subsequently added to maintain the system's water volume.

First and foremost, metering and monitoring boiler water use and performance should be an integral part of regular operations and maintenance. If possible, meters should be connected to the facility's building automation system or central control dashboard. Beyond metering, work with a water treatment vendor to address water chemistry and help manage the boiler system for efficiency. Blowdown should be activated using a conductivity-based control system rather than continuously or on a set timer. Conductivity controllers only initiate blowdown when dissolved solid concentration reaches a preset threshold. Unnecessary blowdown wastes water, energy, and chemicals.

If tempering water is used to cool blowdown, reducing blowdown can also reduce tempering water use. Similar to with condensate cooling, there may be viable options to reduce the temperature of blowdown prior to discharge without use of tempering water. A flash tank or heat exchanger can be used. Heat exchangers can be used to preheat boiler make-up water, which reduces boiler energy demand (DOE/EERE, 2012).

Another option to reduce blowdown frequency is to improve incoming water quality through pretreatment of make-up water using a water softener or reverse osmosis system. Make sure to consider the additional water or operational costs that may occur during use of pretreatment and pursue efficient operation of these systems. See the Water Treatment and Purification System section on page 7 for more information.

Other Typical Building Water Loads

While cooling towers, boilers, and specialty laboratory equipment can consume significant amounts of water, laboratories often have water loads typical of other commercial buildings, such as those associated with restrooms (sanitary), outdoor (irrigation), and, in some cases, onsite commercial kitchens or laundries. Water use in these areas should not be overlooked when devising a water efficiency strategy. Often measures in these areas can be simple and cost-effective. This section provides a brief overview of sanitary fixture, outdoor, and commercial kitchen and laundry water use and savings opportunities. For more detailed guidance on improving efficiency in these areas, review WaterSense at Work.

Sanitary Fixtures

There are a variety of ways to save water in restrooms; for example, maintenance staff should inspect sanitary fixtures for leaks regularly. They should also check and adjust automatic sensors on toilets, urinals, and faucets, if installed, to ensure they are operating properly to avoid double or phantom flushing or running when unnecessary. Old toilets, urinals, showerheads, and certain lavatory faucets can be replaced with WaterSense labeled models. The faucets used in most commercial lavatories and lab handwashing stations are not able to earn the WaterSense label, but 0.5 gallon-per-minute faucets and aerators are available for this purpose.

EPA Product Labeling Programs Ensure Water Efficiency

The U.S. Environmental Protection Agency's WaterSense program labels plumbing and irrigation products that are independently certified to use at least 20% less water and perform as well as or better than standard products on the market. As applicable, ENERGY STAR certified products are also required to address water efficiency. See the box below to determine which water-using fixtures within a lab can earn the WaterSense or ENERGY STAR labels.

Look for the WaterSense or ENERGY STAR Label on Water-Efficient Indoor and Outdoor Products

Product Category	WaterSense	ENERGY STAR
Plumbing Products		
Toilets	✓	
Flushing Urinals	✓	
Private-Use Lavatory Faucets	✓	
Public-Use Lavatory Faucets		
Showerheads	✓	
Kitchen Faucets		
Irrigation Products		
Irrigation Controllers	✓	
Spray Sprinkler Bodies	✓	
Commercial Kitchen and Laundry		
Clothes Washers		✓
Dishwashers		✓
Commercial Ice Makers		✓
Commercial Combination Ovens		✓
Commercial Pre-Rinse Spray Valves	Now DOE-Compliant	

Outdoor Water Use

Outdoor water use, primarily for landscape irrigation, can be minimized with thoughtful landscape design that includes: regionally appropriate plants; organic compost for healthy soils; mulch; appropriate grading; berms, swales, rain gardens, and vegetated strips that retain stormwater; drought-tolerant species; and limited use of turfgrass. WaterSense has developed several resources to help lab and other facility designers and managers incorporate water-efficient landscaping, including a Water-Smart Landscapes guide.

Proper design, installation, and maintenance of irrigation systems can also have a significant impact on outdoor water use. WaterSense has labeled products and educational resources to assist in identifying water-efficient, high-performing irrigation technologies. For example, WaterSense labels spray sprinkler bodies that adjust the incoming water pressure to match the optimal pressure of the sprinkler nozzles, thus reducing misting, fogging, and overwatering. Replacing clock-timed irrigation controllers with WaterSense labeled models that adjust watering schedules based on weather data or soil moisture levels can also reduce outdoor water waste.

WaterSense also labels certification programs for qualified professionals who demonstrate the ability to design, install, maintain, and audit water-efficient irrigation systems.

Professionals certified by a WaterSense labeled program understand water efficiency concepts and are qualified to design, install, and/or audit irrigation systems. For labs with their own landscape maintenance staff, WaterSense has a design guide for microirrigation and other helpful resources on outdoor water savings. Visit www.epa.gov/watersense/outdoors to learn more.

Commercial Kitchen and Laundry Equipment

Some laboratories may have onsite commercial kitchens or laundries. Water (and energy from generating hot water or steam) used by these types of ancillary operations can be significant.

From food preparation to dish cleaning, common sources of water-using equipment in labs' commercial kitchens include commercial ice machines, combination ovens, steam cookers, steam kettles, dipper wells, pre-rinse spray valves, food disposals, commercial dishwashers, and wash-down sprayers.

Because many of these appliances use heated water, ensuring commercial kitchen equipment uses water efficiently saves the facility energy as well. When specifying or replacing these appliances, look for ENERGY STAR certified ice machines, dishwashers, combination ovens, and steam cookers. For appliances not certified by ENERGY STAR, check typical energy and water use when selecting new equipment.

Some laboratories may also have onsite laundry facilities with equipment such as single- or multi-load washers, washer extractors, and tunnel washers. Recent advances in commercial laundry equipment, including the availability of more efficient equipment, water recycling, and ozone technologies, have provided options for reducing water use in nearly all commercial laundry operations. ENERGY STAR certified clothes washers address both energy and water efficiency.

Other ways to save water in kitchens and laundry facilities in labs include: replace older kitchen appliances, dishwashing equipment, and laundry equipment with ENERGY STAR certified models; replace old pre-rinse spray valves with flow rates of 1.6 gpm or higher with high efficiency, DOE-compliant models; wash only full loads of dishes and laundry; and consider adding ozone or water recycling capabilities to existing laundry equipment.

Alternative Water Sources

Laboratory buildings are good candidates for alternative water sources, because many of their end uses could be supplied by non-potable water.

RESOURCES ON WATER-SAVING EQUIPMENT

Check out ***WaterSense at Work*** for detailed water-efficient practices related to sanitary fixtures, irrigation and landscaping, and commercial kitchen and laundry equipment: www.epa.gov/watersense/best-management-practices.

Learn about **WaterSense and ENERGY STAR product and appliance specifications:** www.epa.gov/watersense/watersense-products; www.energystar.gov/products

Explore **WaterSense's outdoor resources**, including certified irrigation professionals: www.epa.gov/watersense/outdoors

Review **ENERGY STAR commercial kitchen** resources: www.energystar.gov/partner_resources/energy_star_training_center/commercial_food_service

Water used for equipment cooling, cooling tower make-up, irrigation, exhaust air scrubbers, and toilet and urinal flushing does not need to be potable; therefore, there may be opportunities to use alternative sources of water.

Alternative sources of water include those generated onsite (e.g., condensate, rainwater) or supplied by a wastewater utility (e.g., reclaimed water). Following are some ways that laboratories can collect and use alternative sources of water to reduce potable water use, conserve potable water for drinking water, and reduce water and sewer costs.

The two most useful alternative water sources for laboratory buildings are HVAC cooling coil condensate recovery and rainwater harvesting. In certain climates, both can provide fairly steady sources of relatively pure water. Use of these sources is limited primarily by the cost of capturing and storing the water. EPA has developed the Non-potable Environmental and Economic Reuse (NEWR) Calculator as a screening-level assessment of onsite reuse potential. While not specifically targeted to laboratories, the tool can estimate condensate and rainwater collection and reuse potential based on building-specific characteristics.

RO system reject water may also provide relatively consistent quality and quantity of water that can be reused. Lastly, wastewater treatment plants may supply reclaimed effluent, which is often cheaper than potable water and can be used for nonpotable uses.

HVAC Condensate Recovery

In many places in the United States, mechanical space cooling generates significant quantities of HVAC condensate, as warm humid air is cooled and dried for temperature and humidity control. The condensate from HVAC cooling coils in air handling units, fan coils, dehumidifiers, and refrigeration units can provide facilities with a steady supply of relatively pure water for many processes.

Laboratories are excellent sites for condensate recovery, because they typically require dehumidification of a large amount of outside air, and the greatest volumes of reclaimed HVAC condensate are available at the times of greatest nonpotable water demand for cooling tower water make-up.

The potential for condensate recovery depends on many factors, such as ambient temperature, humidity, load factor, equipment, and size. FEMP has developed a map to communicate condensate collection potential across the United States. However, cost-effective implementation of condensate recovery and use can be feasible anywhere given the right circumstances.

Condensate water is relatively free of minerals and other solids. In most cases, it is similar in quality to distilled water. This makes it an excellent source for cooling tower make-up, since there is a good seasonal correlation between condensate supply and cooling tower demand. Due to its lower temperatures and higher quality, utilizing condensate as cooling tower make-up water allows cooling towers to achieve higher cycles of concentration and can reduce chemical usage.

EPA's Collection of Air-Handler Condensate Projects Throughout the United States

EPA owns and operates many research and analysis laboratories throughout the United States that conduct scientific research and analysis supporting national and regional environmental programs. As part of comprehensive water assessments at each facility, staff evaluated potential sites where air-handler condensate recovery was practically feasible and cost-effective. Good candidates were facilities:

- In hot and humid climates with greater condensate generation and higher cooling loads;
- With larger capacity air handlers (rather than smaller units spread throughout the facility), which minimizes the number of collection points;
- Those that had collection points close to the cooling tower basin or recirculating water lines, which reduces the amount of piping; and
- Where major wall or roof intrusions were not required, and other physical obstacles were not an issue.

EPA subsequently implemented air-handler condensate collection and reuse projects at many of these labs. Some examples, including the location, annual gallons collected, and proportion of cooling tower make-up demand, are shown in the table below.

Location	Total Cooling Tower Capacity	Annual Gallons Collected	Aproximate Percent of Cooling Tower Make-Up
Ada, OK	450 tons	200,000	23%
Athens, GA	300 tons	460,000	37%
	780 tons	340,000	23%
Chelmsford, MA	Unknown	140,000	17%
Edison, NJ	400 tons	100,000	10%
Fort Meade, MD	2,400 tons	180,000	8%
Gulf Breeze, FL	450 tons	450,000	18%
Kansas City, KS	1,400 tons	310,000	18%

Condensate can also reduce the temperature of condenser water, allowing chillers to operate more efficiently and save energy as well. Condensate can typically be fed directly into the cooling tower basin as make-up water without any treatment.

Condensate can also be used as boiler make-up, RO feed water, or drip irrigation without special treatment.

Condensate should not be considered potable, as it can contain dissolved contaminants and bacteria, such as legionella, because it is not chemically treated. It is best to use condensate in a process that provides an additional level of biological treatment, namely cooling towers, but could also include boilers or ornamental fountains. Collected condensate can also be used for drip irrigation. If using condensate for spray irrigation or toilet and urinal flushing, however, condensate should be filtered and disinfected. Normal chlorine feed equipment, ozone, or ultraviolet disinfection can be effective (San Antonio Water System, 2013).

Rainwater Harvesting

Rainwater from building roofs is another excellent source of nonpotable water. It can be used in many of the applications in which condensate recovery water is used. Typically, however, rainwater contains fewer impurities than potable water from a public drinking water supply. The only cost is the capital cost of equipment to collect and store the water (which can be significant).

Since rainwater and melted snow are collected throughout the year, the demands for rainwater should be year-round as well. Cooling tower and irrigation water demand is usually low in the winter; therefore, collected rainwater can be directed to water closets and urinals during these times. However, utilizing reclaimed water for this purpose typically requires higher levels of filtration and chemical treatment than for uses like cooling towers and irrigation.

Rainwater systems typically consist of six elements: the roof catchment area; gutters, downspouts, or roof drains; leaf screens, vortex filters, and roof washers that remove larger debris and contaminants; cisterns or storage tanks; a pumping and conveyance system; and a treatment system.

Stormwater from impervious surfaces other than rooftops can also be collected. However, because stormwater is not as high-quality as rooftop rainwater, it is best to reuse stormwater reclaimed from surfaces other than rooftops only for irrigation. Run-off from parking lots in northern climates may contain road salt and oil from vehicles; therefore it may not be suitable for irrigation.

The storage tank or cistern requires the most coordination and space of these components. It can be either above or below ground, but should be close to supply and demand points to minimize piping needs. It should have a tight-fitting lid to prevent evaporation and to keep out mosquitoes, animals, and sunlight (which allows algae to grow).

Laboratories considering the use of rainwater should check with local or state governments about possible restrictions. There are some states that restrict rainwater use. The restrictions have to do with water rights laws, which are complex and vary according to the jurisdiction. Some allow facilities to detain water for irrigation and other uses that return the water back to the system, but they do not allow water to be retained permanently onsite. In addition to a Rainwater Harvesting Tool, FEMP has developed a map that summarizes state-by-state rainwater harvesting regulations. The American Rainwater Catchment Systems Association (ARCSA) has helpful documents on the use of rainwater.

Rainwater and condensate recovery systems can be expensive to install as retrofits. Storage capacity and treatment systems in particular can be expensive. However, properly sizing the system to match demand to supply could greatly reduce costs. For example, many condensate recovery systems that are used for cooling tower make-up do not require significant storage, since condensate supply will always be less than cooling tower demand. However, beyond water cost savings, laboratories should consider potential system improvements and other ancillary benefits (e.g., reduced chemical use) from the use of high-quality alternative water sources.

RO Reject Water

Reverse osmosis systems, which use a membrane to remove impurities and create higher purity water, generate a stream of reject water that contains the impurities that were removed during the process. RO systems can achieve a recovery rate of 50% to 75% (with larger, centralized systems commonly used by laboratories likely able to achieve the high end of this recovery range). However, this means that 25% to 50% of water entering the system is part of the reject, which is commonly sent down the drain. Since many laboratories use large volumes of RO water for research and specialized processes, the available quantity of RO reject water has the potential to be significant. Similar to rainwater, RO reject water is available year-round, and is best utilized for year-round demands such as toilet flushing.

While reject water is lower quality than water supplied by a laboratory's water utility, in most cases there may be opportunities to reuse this waste stream for other purposes. End uses can include toilet and urinal flushing, cooling tower make-up, irrigation, or ornamental fountain make-up. If using RO reject as cooling tower make-up, make sure that the concentration of TDS and other constituents of the RO reject water are less than the those of the recirculating water flow.

Similar to condensate and rainwater collection, implementing RO reject water recycling can be more expensive as a retrofit, depending on the storage, treatment (if applicable), and piping needed. If graywater systems exist within a laboratory, RO reject can be diverted to these systems. New lab designs often combine the HVAC condensate, rainwater, and RO reject into the same cistern and treatment system to reduce overall space, complexity, cost, and maintenance of the reclaimed water system.

Reclaimed Wastewater

Reclaimed wastewater (sometimes referred to as recycled or "purple pipe" water) is an option when a laboratory has access to municipal wastewater that has been treated to a secondary disinfection level, or when treated wastewater can be generated cost effectively onsite. Reclaimed wastewater can be used for some nonpotable applications, such as cooling tower make-up, boiler make-up, irrigation, vehicle washing, and fire protection systems (USGS, 2018). While not treated to drinking water quality, reclaimed wastewater can serve as a cost-effective, high-quality, and reliable source of water that can be used to reduce potable water use and costs within a laboratory.

Laboratories should check with their local water and/or wastewater utility to determine the local availability and associated cost of reclaimed wastewater. In addition, before using reclaimed wastewater sourced within the building, it is important to understand local requirements for water quality for the intended uses for that water. Use of reclaimed water often requires the posting of clear signage to indicate reclaimed water is used and is not fit for human consumption. Further, reclaimed water quality can vary by location, and while it is generally fit for nonpotable uses, reclaimed water can be harsher on some fixtures or equipment. The utility providing the reclaimed water, or a laboratory's onsite wastewater treatment plant, should be able to provide insight on different water quality parameters such as conductivity, TDS, alkalinity, biological oxygen demand, and pH. Many plumbing and irrigation manufacturers sell products that are intended for reclaimed water applications. Beyond purple or blue dyes for the water and purple coloration for pipes, signage, and fixtures to indicate reclaimed water use, these products often have added features and are made of materials that can withstand harsher conditions typical of reclaimed water.

When considering the use of reclaimed wastewater within cooling towers, it is important to understand the reclaimed water quality and work closely with a qualified treatment vendor who has experience with reclaimed water. Depending on the type of materials used in the cooling tower, piping, and heat transfer units, there may be special considerations that could impact the ability to use reclaimed water. A qualified treatment vendor should be able to communicate changes to the treatment program and associated cost impacts. In some cases, due to high chlorine and phosphate in reclaimed water, the cost of cooling tower water treatment may actually go down. However, some additional water monitoring, chemical feed systems, or biological control may be necessary (Puckorius, 2013).

Acknowledgements

An earlier version of this guide was published as part of the Laboratories for the 21st Century (Labs21) tool kit. The principal author of the original version was Stephanie Tanner, then of the National Renewable Energy Laboratory (NREL), now the lead engineer for EPA's WaterSense program. Contributors and reviewers included Bill Hoffman, PE, of H.W. Hoffman and Associates; James Kohl of URS Corp; Roy Sieber of Eastern Research Group, Inc. (ERG); and Otto Van Geet, PE, Nancy Carlisle, AIA and Sheila Hayter, PE, of NREL.

Revision Authors

Stephanie Tanner, EPA WaterSense
Robert Pickering and Kim Wagoner, PE, ERG
Bill Hoffman, PE, H.W. Hoffman and Associates, LLC

Other Contributors

Jacob Werner, Perkins & Will and Patrick Murphy, PE, Vanderweil Engineers

Revision Reviewers

Daniel Doyle, PE, Grumman/Butkus Associates
Greg Eades, Ph.D., P.E., EPA Office of Research and Development
Patrick Murphy, PE, Vanderweil Engineers
Otto Van Geet, PE, NREL

References

Aldred Cheek, Kristin and Nancy M. Wells. 2020. Changing Behavior Through Design: A Lab Fume Hood Closure Experiment. *Frontiers in Built Environment*. January 2020. Volume 5. Article 146.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). 2020. 2020 ASHRAE Handbook–HVAC Systems and Equipment. Chapter 22: Humidifiers.

ASHRAE and ICC. 2020. ANSI/ASHRAE/ICC/USGBC/IES Standard 189.1-2020. *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*.

Beecher, Janice A. 2020. Trends in consumer expenditures and prices for public utilities (2020). Institute of Public Utilities, Michigan State University. https://ipu.msu.edu/wp-content/uploads/2020/02/IPU-MSU-CPI-CES-2020-1.pdf

Black and Veatch Management Consulting. 2021. *2021 50 Largest Cities Water and Wastewater Report*. April 2021.

Bosley, Mark. 2012. Reverse Osmosis for Laboratory Use. *International Pharmaceutical Industry*. Summer 2012. Volume 4. Issue 3.

Consolidated Sterilizer Systems. 2021. Eco-Friendly Autoclave Solutions. February 2021. https://consteril.com/wp-content/uploads/2021/02/CSS-Sustainability-Brochure-2021.pdf

Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), Advanced Manufacturing Office. 2012. Recover Heat from Boiler Blowdown. January 2012. www.energy.gov/sites/prod/files/2014/05/f16/steam10_boiler_blowdown.pdf

DOE, EERE, Federal Energy Management Program (FEMP). 2012a. Side Stream Filtration for Cooling Towers. October 2012. www.energy.gov/sites/default/files/2013/10/f3/ssf_cooling_towers.pdf

DOE, EERE, FEMP. 2012b. Fume Hood Sash Stickers Increases Laboratory Safety and Efficiency at Minimal Cost: Success at Two University of California Campuses. March 2012. https://www1.eere.energy.gov/femp/pdfs/sash_stickers_cs.pdf

DOE, EERE, FEMP. 2013. Reverse Osmosis Optimization. August 2013. www.energy.gov/sites/default/files/2013/10/f3/ro_optimization.pdf

East Bay Municipal Utility District (EBMUD). 2008. *WaterSmart Guidebook—A Water-Use Efficiency Plan Review Guide for New Businesses*. www.ebmud.com/water/conservation-and-rebates/commercial/watersmart-guidebook/.

ENERGY STAR. 2022a. Use an Air-Side Economizer. www.energystar.gov/products/use_air_side_economizer. Accessed January 24, 2022.

ENERGY STAR. 2022b. Consider Water Side Economizers. www.energystar.gov/products/consider_water_side_economizers. Accessed January 24, 2022.

Environmental Protection Agency (EPA). *WaterSense at Work: Best Management Practices for Commercial and Institutional Facilities*. www.epa.gov/watersense/best-management-practices.

Grist, Matthew, Dave Perkin, and David M. Barber. 2013. Introducing a Novel and Highly Efficient Water-Saving Condenser. *ACS Sustainable Chem*. Eng. 2013, 1, 12, 1498-1501. September 17, 2013.

Koeller, John, et al. 2004. *A Report on Potential Best Management Practices*. Prepared for the California Urban Water Conservation Council. August 2004. https://calwep.org/wp-content/uploads/2021/03/Steam-Sterilizer-Retrofit-PBMP-2004.pdf

National Institutes of Health (NIH). 2013. Laboratory Water. NIH Office of Research Facilities (ORF) Division of Technical Resources (DTR). March 2013. https://orf.od.nih.gov/TechnicalResources/Documents/DTR%20White%20Papers/Laboratory%20Water-Its%20Importance%20and%20Application-March-2013_508.pdf

Puckorius, Paul R. 2013. “Recycled Water for Cooling Towers: Good Idea or Bad?” *Water Technology*. February 1, 2013. www.watertechonline.com/process-water/article/16212383/recycled-water-for-cooling-towers-good-idea-or-bad

Radleys. UCSD Chemistry standardises on Findenser for safety and sustainability. www.radleys.com/case-studies/ucsd-chemistry-standardises-on-findenser-for-safety-and-sustainability/. Accessed January 24, 2022.

San Antonio Water System. 2013. *San Antonio Condensate Collection and Use Manual for Commercial Buildings*. https://apps.saws.org/Conservation/Commercial/Condensate/docs/SACCUManual_20131021.pdf

Stanford University, Environmental Quality and Water Efficiency Group. 2013. F*act Sheet on Steam Sterilizers at Stanford University*. December 2013. https://suwater.stanford.edu/sites/g/files/sbiybj19876/files/media/file/sem_steamsterilizers_stanford_2013.pdf

University of Colorado Boulder. Waterless Condensers. CU Green Labs Program. www.colorado.edu/ecenter/greening-cu/cu-green-labs-program/lab-water-efforts/waterless-condensers. Accessed December 8, 2021.

U.S. General Services Administration (GSA). 2022. AWT: GSA Guidance for Cooling Towers. www.gsa.gov/governmentwide-initiatives/climate-action-and-sustainability/emerging-building-technologies/published-findings/water/awt-gsa-guidance-for-cooling-towers. Accessed January 24, 2022.

U.S. Geological Survey (USGS). 2018. Reclaimed Wastewater. June 8, 2018. www.usgs.gov/special-topic/water-science-school/science/reclaimed-wastewater. Accessed December 8, 2021

Watch, Daniel and Deepa Tolat. 2016. Sustainable Laboratory Design. August 19, 2016. www.wbdg.org/resources/sustainable-laboratory-design. Accessed January 24, 2022.

Zynda, Jeffrey R. 2015. “A shift in designing cage-washing operations.” *Lab Animal*. Volume 44, No. 4. April 2015.

Additional Resources

American Rainwater Catchment Systems Association (ARCSA). www.arcsa.org/

ENERGY STAR. www.energystar.gov/

EPA. Non-Potable Environmental and Economic Water Reuse (NEWR) Calculator. www.epa.gov/water-research/non-potable-environmental-and-economic-water-reuse-newr-calculator

EPA WaterSense Program. www.epa.gov/watersense

EPA WaterSense Program. 2021. Water-Smart Landscaping. www.epa.gov/watersense/landscaping-tips

EPA WaterSense Program. *WaterSense at Work: Best Management Practices for Commercial and Institutional Facilities*. www.epa.gov/watersense/best-management-practices

FEMP. Alternative Water Sources Maps. www.energy.gov/eere/femp/alternative-water-sources-maps

FEMP. Water Evaluation Tools. www.energy.gov/eere/femp/articles/water-evaluation-tools

International Institute for Sustainable Laboratories (I^{2}SL). Laboratory Benchmarking Tool. https://lbt.i2sl.org/