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NIST TN 2256

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NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
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Stephen M. Zimmerman
*Building Energy and Environment Division*
*Engineering Laboratory*

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**NIST Author ORCID iDs**

Andrew Persily: 0000-0002-9542-3318
Marylia Duarte Batista: 0000-0002-5200-7963
William Healy: 0000-0001-7711-7301
Mark Kedzierski: 0000-0001-5051-1819
Lingnan Lin: 0000-0002-0813-7613
Tania Ullah: 0000-0001-6588-8977
David Yashar: 0000-0002-8532-8501
Stephen M. Zimmerman: 0000-0002-5254-278X

## Abstract

Premise plumbing systems need to meet a range of performance goals including occupant health and comfort, energy and water efficiency, and reduced environmental impacts. Pressures to improve water efficiency and building water quality, combined with the use of new plumbing technologies and designs, have led to the recognition that significant knowledge gaps exist in plumbing system design, installation, operation, and maintenance. The research needed to address these gaps was summarized in a 2020 NIST report *Measurement Science Research Needs for Premise Plumbing Systems*. NIST also initiated an effort in 2020 to study several key research topics identified in that report including: the pressure versus flow relationships of plumbing fittings, the factors contributing to pathogen growth in residential hot water systems, the development of standard plumbing systems for comparing different design and operational approaches, and the improvement of existing premise plumbing system simulation software. To obtain feedback from industry and others in the premise plumbing community, NIST held a one-day workshop in November 2022 to discuss these research efforts, strengthen ongoing dialogues among the plumbing community, and develop a shared understanding of the research needs.

## Keywords

Measurement science; premise plumbing; research needs; water; workshop.

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# 1. Introduction

Premise plumbing systems constitute an essential component of the built environment by providing access to clean, potable water and a safe, reliable means of removing wastewater from homes, businesses, and other institutions. Plumbing systems evolved throughout the 20th century in response to concerns about cost, water availability, environmental impacts, and safety. The National Bureau of Standards (NBS), the predecessor to the National Institute of Standards and Technology (NIST), performed research that supported and informed these advancements throughout most of the 20th century.

A series of policy actions including the Safe Drinking Water Act of 1974, the Energy Security Act of 1980, and the Energy Policy Act of 1992 sought to improve water quality, water use efficiency, and energy efficiency. These policies led to notable achievements including the reduction of lead in plumbing products and the introduction of high-efficiency fixtures. These and other realities have led to a situation in which plumbing systems are being designed, installed, and operated in vastly different ways from what is supported by the technical data and understanding embodied in current codes, standards, and practice (Persily et al. 2020). For example, a typical single-family, detached home today uses 22 % less water for indoor purposes than it did two decades ago (DeOreo, Mayer et al. 2016). Consequently, the flow rates within the piping networks and the corresponding residence times are significantly different than those assumed under current design methods. This situation has in turn led to questions regarding the assumptions surrounding the effectiveness of water treatment practices and concerns regarding the potential for decreased water quality.

In response to these realities and in recognition of the need for research needed to provide new data and technical understanding of plumbing system performance, NIST, the U.S. Environmental Protection Agency (EPA), and the Water Research Foundation (WRF) jointly hosted a workshop in August 2018. The objective of this workshop was to identify and discuss research needs to support the design and operation of new premise plumbing systems and the management of existing systems given the realities of lower water consumption and the needs for increased water and energy efficiency and for improved water quality. This event was attended by 46 representatives from industry, academia, government, utilities, and standards and codes organizations. The workshop proceedings were published in Pickering, Onorevole et al. (2018).

Subsequent to the 2018 workshop, NIST solicited additional input through a request for information (RFI) that was published in the Federal Register in October 2018. This RFI generated 26 responses from a broad array of interested parties, including over 140 pages of text on the most important issues to design and operate safe, healthy, reliable, and efficient plumbing systems and the research needed to address these issues. Additional discussions with other organizations provided another important source of information. For example, the International Association of Plumbing and Mechanical Officials (IAPMO) and the International Code Council (ICC) are the two major model code development organizations within the premise plumbing community, and discussions with both provided important information to NIST. Follow up discussions with the WRF, EPA, numerous advocacy groups, and academic researchers were also a key resource.

NIST used the information obtained through these mechanisms to identify measurement science research needs that are critical to the design of new premise plumbing systems and the operation and retrofit of existing systems to achieve the goals of water and energy efficiency and water quality in an integrated manner (Persily et al. 2020). The 59 research needs published in that 2020 report were categorized into 1) Foundational Measurement Science and 2) Applied Research. The Foundational Measurement Science needs include topics such as metrics, test methods, and data that are critical to understanding and characterizing the physical, chemical, and biological performance of plumbing systems. Applied Research builds on the findings of the Foundational Measurement Science to develop guidance and design approaches to improve the efficiency of the water delivery systems while also improving water quality.

Shortly after that report was published, NIST initiated a research program to pursue a subset of the research needs in the 2020 report. A workshop was held on November 15, 2022 to present and discuss the NIST research efforts with industry and others in the premise plumbing community. In addition, this workshop was intended to continue ongoing dialogues within the plumbing community and develop a shared understanding of the research needs. This report contains the material presented during that workshop and summarizes the discussion that took place. Section 2 of this report reviews the workshop agenda and the topics discussed. Section 3 summarizes input obtained from the participants prior to the workshop in combination with the discussion that took place during the event. Section 4 contains a summary of the workshop findings and describes next steps to continue the dialog and maintain the interest expressed during the workshop. This report also contains two appendices: A – a list of attendees and their affiliations, and B – the presentation materials from the workshop speakers.

## 2. Workshop Agenda

The workshop agenda is shown in Table 1. Most of the morning was devoted to presentations on the NIST premise plumbing research efforts, including tours of two laboratories designed and instrumented over the previous 2 years. After the tours, Steven Buchberger of the University of Cincinnati described his work funded by NIST under a cooperative agreement. All other research projects were conducted by NIST staff and research associates based at the NIST Gaithersburg, MD campus. Following the NIST project presentations, there were discussions of related activities being pursued by other federal agencies or with EPA funding. During the afternoon, the attendees discussed industry trends and activities and research priorities.

**Table 1.** Workshop Agenda.

**NIST Premise Plumbing Research Workshop**
**15 November 2022**
**National Institute of Standards and Technology**
**Building 226, Room B205**
**Gaithersburg Maryland**

| **Time** | **Agenda Item** |
|---|---|
| **7:30** | Registration starts at NIST visitors center.<br>Optional tour of Net-Zero Energy Residential Test Facility. |
| Transition to Building 226, Room B205 (NIST staff escort required from lobby of Building 226) | |
| **8:30 to 9:00 a.m.** | **Welcomes and introductions** |
| **9:00 to 9:40 a.m.** | **NIST premise plumbing research (Part 1)**<br>Water heaters and pathogen growth<br>Water Heater Laboratory – Marylia Duarte Batista<br>Testing at NIST Net Zero Energy House – Tania Ullah<br>Pressure v. flow of plumbing fittings – Lingnan Lin |
| **BREAK** | |
| **9:55 to 10:45 a.m.** | **Lab tours:**<br>Pressure v. flow of plumbing fittings<br>Water heaters and pathogen growth (Water Heater Laboratory) |
| **10:45 to 11:25 a.m.** | **NIST premise plumbing research (Part 2)**<br>Non-residential Water Use – Steven Buchberger<br>Model Development – Mark Kedzierski<br>Standard Plumbing System Designs – Stephen Zimmerman |
| **11:25 a.m. to Noon** | **Premise plumbing research activities under other federal agencies**<br>Jonah Schein, US EPA, Office of Water<br>Jeff Szabo, US EPA, Office of Research and Development<br>Michael Blanford, HUD<br>Patrick Gurian on EPA-Funded research program – Drexel University<br>Andrew Whelton on EPA-Funded research program – Purdue University |
| **LUNCH** | |
| **1:00 to 2:00 p.m.** | **Discussion of plumbing industry trends and activities**<br>Andrew Whelton on disaster impacts on plumbing – Purdue University<br>Christoph Lohr on industry trends - IAPMO |
| **2:00 to 3:00 p.m.** | **Discussion of research priorities** |
| **3:00 to 4:00 p.m.** | **Wrap-up and Follow-up** |

The six NIST presentations are summarized as follows, with the slides from each in Appendix B of this report.

Water Heaters and Pathogen Growth: Water Heater Laboratory

A new laboratory facility was built at NIST to study the response of opportunistic premise plumbing pathogens (OPPP) to water use patterns and temperature settings in electric storage water heaters. OPPP are waterborne microorganisms in potable water that can persist and grow in building plumbing, increasing the likelihood of infections in immunocompromised and elderly individuals. The experimental design consists of three steps: tank cleaning, in which tanks are disinfected and heavily flushed; an acclimation phase, in which the heaters operate at low temperature and low usage to allow microbial growth; and an experimental phase, in which each tank temperature is raised to a different setting [49 °C (120 °F) and 60 °C (140 °F)] and a planned water use pattern is implemented. Water samples are collected for analysis of bench-scale physical/chemical water quality parameters, molecular analysis of OPPP through ddPCR, and culturing of heterotrophic microorganisms. Future expansion of the test setup will include testing of different types of water heaters and components, such as pipes, fixtures, and thermostatic mixing valves.

Water Heaters and Pathogen Growth: Testing at the NZERTF

This project is investigating the effects of water heater setpoint temperatures and water use patterns on the occurrence and concentrations of OPPP in an automated test home on the NIST campus. This residence is equipped with a heat pump water heater and a PEX-manifold plumbing system to provide hot and cold water for a 4-person building occupancy. Chemical and physical water quality parameters and concentrations of OPPP such as *L. pneumophila*, *P. aeruginosa*, *M. avium*, and *N. fowleri* were measured at the building water supply line, the cold and hot water plumbing systems, and the fixtures. Preliminary results show that *L. pneumophila*, the bacterium that causes Legionnaires' disease, had the highest number of detects (25 % of n = 60 samples), though the frequency of detection of any pathogen was small. Results of this study will aid researchers and policy makers in identifying strategies to reduce OPPP growth in buildings and their associated health impacts.

Pressure v. Flow of Plumbing Fittings

Pressure loss characterization of plumbing fittings has been identified as a fundamental measurement science gap. However, there is no standardized method of test to develop pressure-flow curves in fittings, and existing data are not sufficiently accurate to support the increasingly demanding design processes to improve water and energy efficiency. The lack of a scientific, standardized method to quantify pressure losses through plumbing components also confounds efforts to address oversized water supply systems, which can support the growth of OPPP and lead to delayed hot water delivery. NIST reviewed available data and published a summary of that review (Lin et al. 2022). NIST also designed and constructed a new laboratory facility to establish a standardized and precise means of establishing pressure-flow relationships of plumbing fittings. This laboratory includes state-of-the-art instrumentation to accurately measure water flow and pressure drop for a range of fittings using approaches identified in collaboration with NIST's Fluid Metrology Group in the Physical Measurement Laboratory. Data will be acquired in this laboratory for a range of fittings and components, and a draft method of test will be submitted to an appropriate standards development organization for further development and consideration as an industry consensus standard.

Model Development

Models of premise plumbing temperatures and mycobacteria dynamics have been improved in two separate efforts. First, EPANET, which was developed for outdoor water distribution systems, could be improved by including heat transfer and corresponding local temperature prediction. To support these improvements, NIST paid a royalty-fee to the TRNSYS developer to allow inclusion of its Type604 pipe heat transfer model into EPANET. Inclusion of the TRNSYS model in EPANET is being pursued by the EPA's Water Infrastructure Division, which oversees the distribution of EPANET. The second effort has produced a promising model for nontuberculous mycobacteria (NTM) dynamics in plumbing systems, which was developed by modifying an existing NIST model derived to predict the thickness of the contaminant excess layer on piping surfaces. The original model was developed using in-situ measurements obtained from a fluorescence-based measurement technique and accounts for turbulent convection and diffusion of contaminant from the surface. The original model was modified by converting the contaminant thickness to a rate of reduction in the contaminant excess layer as the pipe is flushed. The modified model captures the rate of NTM colonization in a pipe during a prescribed stagnation period as a function of diameter, velocity, disinfectant residual, and other parameters.

Standard Plumbing System Designs

Standardized reference buildings have been developed for evaluating energy and indoor air quality performance of residential and commercial buildings by the U.S. Department of Energy and NIST, which have been very useful for conducting a wide range of research studies and for developing revisions to existing standards (Persily et al., 2006; Ng et al. 2019). Under this project, NIST developed premise plumbing system designs for a subset of these reference buildings under a contract with an architectural and engineering firm. These designs include two single-family detached homes, a four-story multi-family residential building, a medium sized office building, a stand-alone retail building, a primary school, and a full-service restaurant. These plumbing system designs and the associated documentation will be made available to the public on NIST's website to support consistent analyses of plumbing system performance and the impacts of different technologies, design approaches, and operating strategies.

Non-Residential Water Use

This effort involved three sub-tasks performed by the University of Cincinnati (UC) under a cooperative agreement funded by NIST:

**Task 1** - Develop a wireless sensor network to monitor use of individual fixtures in buildings. Extending the Water Demand Calculator (Buchberger et al. 2017) to non-residential buildings requires realistic estimates of the probability of use of individual water fixtures (i.e., "p-values"). To acquire these p-values, an innovative wireless sensor network with distributed modules, routers and a gateway was developed. The non-intrusive sensor network was designed to record all instances when water was flowing at a particular fixture. Field testing was conducted at two buildings on the UC campus, demonstrating the technical feasibility of this novel data collection scheme for estimating fixture p-values.

**Task 2 -** Identify non-residential building stock, determine sample size, and estimate fixture p-values. Based on surveys from several federal agencies, five types of non-residential buildings were recommended for peak flow monitoring: education, healthcare, lodging, office, and food sales/service (DOE 2018, EPA 2017). The number of building fixtures to be sampled to achieve statistically significant results was identified using sampling theory. A procedure was then proposed for archiving field observations from the wireless sensor network. Methods were explored to analyze these data and extract representative estimates of the fixture p-values. Finally, Monte Carlo techniques were used to simulate fixture use and confirm that estimated fixture p-values converged to a steady-state result.

**Task 3** – Corroborate predictions of the Water Demand Calculator (WDC). The Water Demand Calculator predicts the 99$^{th}$ percentile of the peak flow during the busy hour of water use in residential buildings fitted with water-conserving fixtures. Indoor water use at 20 newly constructed residential buildings totaling 1267 apartments in California (12 sites), New York (6 sites) and Washington (2 sites) was monitored for an extended period. Results showed that predictions of peak water use from conventional methods (e.g., Uniform Plumbing Code-Hunter's Curve) were, on average, 12 times higher than instantaneous peaks measured in the field. In contrast, WDC predictions of the peak water use were only three times higher, on average, than the peak water demands observed at the residential sites. This field verification exercise showed that, compared to the conventional Uniform Plumbing Code approach, the WDC provided more accurate estimates of the actual peak water demand, while still affording a comfortable margin of safety.

The presentations under the agenda item "Premise plumbing research activities under other federal agencies" are provided in Appendix B of this report.

## 3. Pre-Workshop Input and Workshop Discussion

This section of the report summarizes the input submitted to NIST before the workshop as well as the discussion that took place during the workshop. This material is organized around the 59 research needs published in the 2020 NIST report with additional needs that were discussed noted as such. After the presentations of NIST research efforts and research efforts under other federal agencies, there was a broader discussion of industry trends and activities, which are captured in Section 3.2 Other Trends, Activities and Needs.

### 3.1. Input and Discussion on Research Needs

Prior to the workshop, NIST contacted the attendees with questions for them to consider in preparation for the discussion, and some individuals sent their thoughts to NIST in advance. The specific questions were:

- Which of the research needs in the 2020 NIST research needs report do you think are most pressing?
- Are there new research topics that need to be addressed since that report was published?
- What do you see as the major trends in the premise plumbing field that need to be addressed through research or guidance development?

This section merges the pre-workshop input with the discussion that took place during the meeting itself. That material is organized using the research needs and their numbering in the 2020 report, starting with Foundational Measurement Science (identified by F) and followed by Applied Research (identified with an A). Research needs that were identified as "most pressing" are in **bold font**, along with any comments provided, noted with an *, **, + or ++ symbol. However, the fact that specific research needs were not identified as pressing by the attendees does not necessarily mean they are not important. After each table of research needs, additional input, discussion, and potential research topics are noted in ***bold italics***. These comments and suggestions for additional research topics were generated by the workshop participants and do not reflect NIST positions or the results of NIST research efforts.

**Areas #F1 and #F2:** No response on either.

| |
|---|
| **AREA #F1: TERMINOLOGY** |
| Standardized definitions of key terms |
| Taxonomy of plumbing system design and layout |
| **AREA #F2: METRICS** |
| Metrics for long-term durability and resilience |
| Chemical and biological attributes of influent water |
| Chemical and biological attributes of wastewater |
| Water quality targets specific to facility type |
| Metadata development |

**AREA #F3: DATA:**

| |
|---|
| **Data on water demand patterns for various building types*** |
| Water use data to update Hunter's Curves |
| Water quality data at point of entry and point of use |
| **Occupant behavior and preferences**** |
| **Data on biofilm and scale development** |
| Data on water conditions to support design and operation for OPPP control |
| Data quantifying system impacts on dissipation of chlorine and other disinfectants |
| Data on the effects of residence times on scaling and water quality |
| **System design information following disease outbreaks** |

*Need to update and validate methods to predict demand

*Also need to understand plumbing system performance under various conditions of use (pressure changes, lower flows, etc.).

*Field surveys to acquire representative, high-accuracy, high-resolution data in a variety of commercial, residential, and institutional buildings as well as multi-building campuses, including multi-family, mixed-use, hospitals, schools, daycare, and assisted living.

*Need to consider income ranges to help target research efforts and implementation actions. See the Census Bureau's American Housing Survey's (AHS) data on household income, which is crossed with other important factors, including units in structure and year built.

**Consideration of occupant behavior and water usage must address building occupancy changes in response to the pandemic, many of which will remain in place for the long term.

***Impact of pressure drop on biofilms.***

**AREA #F4: FLOW AND TRANSPORT FUNDAMENTALS:**

| |
|---|
| Hydrodynamic flow regimes and transport |
| Pressure losses as a function of materials and fitting geometry |
| Chemical processes in plumbing systems |
| **Biological processes in plumbing systems** |
| Plumbing material leaching |
| Material and chemical impacts on biofilms, pathogens, and scaling |
| **Impacts of residence time on water quality*** |
| **Impacts of water source on water quality** |
| **Impacts of reduced flow rates on drainage systems** |
| **Improved venting requirements based on modern system demands** |

*Water age as a metric, including impacts of system sizing and piping layout, e.g., dead ends.

***Understanding how transitioning to plastic materials may or may not impact short- and long-term water quality.***

***Impacts of smaller pipe sizes on pipe longevity and noise.***

**AREA #F5: METHODS AND MEASUREMENT:**

| |
|---|
| Methods to collect end use data |
| Test methods for water quality in supply and distribution systems |
| **Performance of fittings and pipes*** |
| Protocol to describe plumbing design of existing buildings |
| Improved and less expensive meters |

*Pressure losses as a function of materials and fitting geometry are critical for modern materials and fittings, particularly given the need to right-size the piping

**AREA #F6: MODEL DEVELOPMENT:**

| |
|---|
| Simulation tools of water flow, supply, and drainage |
| **Reference buildings and plumbing systems** |
| Data to validate plumbing models |
| **Expansion of plumbing models to include thermal analysis** |
| **Expansion of chemical and biological models** |
| **Models to estimate reduced drainage loads*** |

*If the WDC predicts smaller supply demands and the need for smaller pipe, then something very similar should be true on the drainage side.

***Improved ability to model water distribution systems, including updating Hunter's method into a computer program that can be used in building design.***

***A robust public-domain user-friendly computer program to simulate the detailed and stochastic operation of premise plumbing systems with output linked to BIM platforms that can be used to fine-tune the hydraulic design of new buildings. Such a program could also generate information on water residence times, maintenance (flushing) plans and identify locations in premise plumbing systems that may be susceptible to water quality problems.***

**AREA #A1: SYSTEM DESIGN**

| |
|---|
| New plumbing system designs and technologies |
| **Validation of alternative sizing models and methodology for integration with plumbing codes*** |
| **Potential side-effects of water and energy-efficient systems** |
| **Hot water plumbing design**** |
| Multipurpose residential piping and sprinkler systems |
| Comparison of trunk-branch and series distribution systems |
| **Impacts of alternative water use+** |
| **Impacts of design, reuse, reduced flows, materials, and water quality on wastewater systems++** |

* Codes are on 3-year cycles, followed by additional time for local adoptions; we need to get ahead of this schedule through research and education.

** Not all designs are equal. For example, recirculation system designs may be single- or multi-zone, one heater may be used for hot water needs or there may be distributed and clustered heaters. Must consider water delivery, not just water heating.

+ Specifically, technical assessment of alternative water systems is needed to address rainwater harvesting and on-site reuse.

++Water age and pipe right sizing, as well as drainage and venting design.

***Reducing plumbing system "footprint" can lead to lower water volume, which could improve water quality, and will reduce material costs.***

***Methods to predict peak water demands to properly design systems in new buildings.***

***Bringing the Water Demand Calculator into non-residential construction.***

**AREA #A2: INSTALLATION, OPERATION AND MAINTENANCE**

| |
|---|
| Impact of current plumbing codes and standards |
| **Best practice guidelines for installation** |
| **Recirculation lines and temperature maintenance** |
| Water management protocols for existing buildings |
| **Water management strategies to control *Legionella* and other pathogens** |
| Best practices for maintenance of emergency fixtures |
| Best practices for scheduled shutdowns and resiliency to unplanned disturbances |
| Metering for low-flow systems |
| Eliminating domestic galvanized iron pipe |

***Microbial water quality indicators for non-legionella premise plumbing pathogens.***

***Mycobacteria are not as well understood as Legionella.***

***Impacts of disinfection strategies on biological growth and plumbing materials.***

***The use of building intelligence to reduce water age and repurpose water for other on-site applications, such as irrigation and laundry.***

***Impact of wording in the Safe Drinking Water Act of 1974 that considers a building owner who treats potable water in their building to control Legionella to be a public water system.***

***Scalding management for safety, public health, and energy; knowledge exists but improved guidance needed.***

***The typical plumbing system has two key control variables - temperature and flushing. We understand temperature well, but not the impact of flushing frequency, volume, and rates.***

***State Codes are being pushed by commercial entities to include water management plans, testing and certification before research is finished.***

**AREA #A3: TRAINING AND GUIDANCE**

| |
|---|
| **Guidance for homeowners, facility managers and other practitioners*** |
| Training for designers on water efficiency |
| Training and certification for design, operation, and maintenance |
| **Training for building water system assessments*** |
| Maintenance and monitoring guidance for control of *Legionella* and other OPPPs |

*Training should also include assessments of water-based fire suppression systems for overall performance with specific attention to water quality issues including risks of OPPP growth.

## 3.2. Other Trends, Activities and Needs

Several other topics were discussed during the workshop under the agenda item on industry trends and activities, and that discussion is captured below. These comments were made by the workshop participants and do not reflect NIST positions or the results of NIST research efforts.

Sustainability (which includes water and energy efficiency, and decarbonization)

- Pipe layout, which impacts energy use and water age, is driven to a large degree by the architectural layout of a building. Better training is needed for architects to understand the importance of layout for minimizing piping lengths and system footprint.
- Holistic research and design are needed to support system optimization.
- Hot water sides of systems are increasing in size (i.e., storage volume) and temperature setting, which has energy implications.
- Better information is needed on the relationships between scalding risk, energy costs, and OPPP growth.
- Decentralized water treatment and reuse has potential that needs to be better understood.
- Solar PV and sanitary venting are competing for space on residential rooftops.
- Policy initiatives to decarbonize water heating are promoting the installation of heat pump water heaters instead of other water heating technologies. These systems are very different and require different design strategies and space considerations.
- These same initiatives are also addressing reduced water storage volumes in pipes, which can adversely impact plumbing safety.

Resilience and Other Infrastructure Issues

- Guidance needed to decontaminate plumbing systems, including remediation strategies for buildings of different size, e.g., single-family homes, larger commercial buildings, etc.
- Research to help provide uniform and scientifically sound guidance to deal with contamination by per- and polyfluorinated substances (PFAS).
- Better understanding of the impacts of nitrification, which may be widespread but not always harmful in terms of pH reduction.
- Evaluation of methods to reduce the number of non-flood water loss insurance claims.
- Wastewater treatment infrastructure needs to be improved.
- The need for water efficiency is expected to become more pressing because of population growth, climate change and infrastructure challenges. Resilience needs to be acknowledged as key to these realities.
- Infrastructure and guidance to plan for intermittent water supply.
- What to do when plumbing systems are contaminated, i.e., what chemicals are most persistent and how to decontaminate?
- Wildfire Issues: After fires, contaminated water can get into the treatment plants, and they are not equipped to treat it. Recommendations are not always based on science. For example, benzene has been found in water systems, which raises questions of how much time is needed to flush the system or does it need to be replaced?

Water Quality/Water Safety

- Low flow becomes efficient flow if the whole building is designed for low flow, not just the fixtures. Many other elements of premise plumbing systems are still grossly oversized.

- Water quality requirements are needed for indoor potable and non-potable use that are safe for the occupants and do not jeopardize the performance of a plumbing system and its components.
- Improved hydraulic designs are needed for efficiency and cost effectiveness, while managing the risk from OPPP.
- Flushing/increasing flow rates often is the chosen solution to water quality issues but without necessarily fully understanding the problem.

Innovation, Design, Affordability and Other Technical Needs

- The U.S. requires more vent piping than many other countries, even with the same performance goals.
- Drainage systems are also currently oversized.
- Simplified plumbing fixtures and systems are needed to reduce pressure losses, surface area available for potential biofilm growth, and stagnant water conditions that increase water age and the likelihood of OPPP growth.
- Reducing plumbing system "footprint" can lead to lower water volume, which could improve water quality and reduce material costs.
- The design of modern devices can create areas at risk of increased microbial activity. Also, it can be difficult to take some components apart without breaking pipe. We need fixtures that can be repaired easily.
- Right-sizing supply piping saves money and reduces the volume of plumbing systems. And while the use of the WDC is growing slowly, it is expected to ramp up rapidly. We need data to extend its use to other occupancies, and we need to teach the industry that it is safe to use and how to know whether it is being done correctly.
- While there is a lot of focus on new construction, there are millions of buildings that were built before 1992; how do we cost-effectively manage water quality risks and deliver the expected service in these buildings?
- The modeling of plumbing systems for building design needs to be improved. Digitization of plumbing design, along with the entire design process, would be helpful in meeting this need.
- Continuous commissioning is needed for premise plumbing, but best practices are needed to support these processes.
- Building insurance/warranties could include mechanisms to pay for commissioning.

Specific technologies

- Vacuum water closet technology, urine separating water closets, and onsite wastewater composting technology are receiving attention in the international plumbing community as the need for net zero water and nutrient recovery increases.
- Questions exist regarding the impact of wastewater separation (from different streams within building, e.g., so called greywater) on horizontal drain line transport. It was noted that some international approaches, such as those used in Germany, the Netherlands and China, may be able to provide some useful insight.
- The airflow around heat pump water heaters and the associated performance impacts needs to be better understood to improve installation guidance.
- The technical understanding of the effectiveness and impacts of thermostatic mixing valves needs to be improved. For example, some have raised concerns about "collateral heating" of cold water lines associated with mixing valves and the potential for water quality issues.

- Point-of-use water heaters and electric water heaters with tanks may benefit from new design features driven by new and anticipated research findings. These new features may lead to the need for design standards and certification processes that are evidence-based.
- Better guidance is needed on target hardness levels for water softeners.

## 4. Summary and Next Steps

As is evident in the above material, the workshop discussion covered a wide range of topics related to the ultimate goals of improving energy and water efficiency and water quality in premise plumbing systems. The discussion on research needs and other issues facing the industry and others involved in premise plumbing are summarized below.

Several key trends, both new and old, that are affecting premise plumbing system design and operation were identified and discussed including energy efficiency, reduced greenhouse gas emissions, decarbonization, infrastructure, resilience and natural disasters, and population growth and movement.

The key priorities for research and other activities that were highlighted include the following:

Data on water usage patterns in buildings and microbial growth in plumbing systems.

Models of building water use, as well as biological growth, thermal performance, flow and pressure, and water age in premise plumbing systems. Also, standard reference plumbing system designs.

Water heating energy performance; water temperature management to balance energy use, safety, and pathogen growth; and existing and new technologies.

New technologies that hold promise for improved performance, but which also lead to questions on implementation and actual performance.

Science-based guidance and standards for design, installation, maintenance, and system assessment; including guidance that specifically targets homeowners.

Tables 2 and 3 are drawn from the 2020 NIST Research Needs report (Persily et al. 2020), with topics that were identified as important during the workshop highlighted in **bold**. Additional research needs discussed during the workshop are added and highlighted in ***bold italics.***

**Table 2.** Updated Research Needs in Foundational Measurement Science.

| |
|---|
| **Area #F1: Terminology** |
| Standardized definitions of key terms |
| Taxonomy of plumbing system design and layout |
| **Area #F2: Metrics** |
| Metrics for long-term durability and resilience |
| Chemical and biological attributes of influent water |
| Chemical and biological attributes of wastewater |
| Water quality targets specific to facility type |
| Metadata development |
| **Area #F3: Data** |
| **Data on water demand patterns for various building types** |
| Water use data to update Hunter's Curves |
| Water quality data at point of entry and point of use |
| **Occupant behavior and preferences** |
| **Data on biofilm and scale development** |
| Data on water conditions to support design and operation for OPPP control |
| Data quantifying system impacts on dissipation of chlorine and other disinfectants |
| Data on the effects of residence times on scaling and water quality |
| **System design information following disease outbreaks** |
| ***Impact of pressure drop on biofilms.*** |
| **Area #F4: Flow and Transport Fundamentals** |
| Hydrodynamic flow regimes and transport |
| Pressure losses as a function of materials and fitting geometry |
| Chemical processes in plumbing systems |
| **Biological processes in plumbing systems** |
| Plumbing material leaching |
| Material and chemical impacts on biofilms, pathogens, and scaling |
| **Impacts of residence time on water quality** |
| **Impacts of water source on water quality** |
| **Impacts of reduced flow rates on drainage system** |
| **Improved venting requirements based on modern system demands** |
| ***Understanding how transitioning to plastic materials may or may not impact short- and long-term water quality.*** |
| ***Impacts of smaller pipe sizes on pipe longevity and noise.*** |
| **Area #F5: Methods and Measurement** |
| Methods to collect end use data |
| Test methods for water quality in supply and distribution systems |
| **Performance of fittings and pipes** |
| Protocol to describe plumbing design of existing buildings |
| Improved and less expensive meters |
| **Area #F6: Model Development** |
| Simulation tools of water flow, supply, and drainage |
| **Reference buildings and plumbing systems** |

| |
|---|
| Data to validate plumbing models |
| **Expansion of plumbing models to include thermal analysis** |
| **Expansion of chemical and biological models** |
| **Models to estimate reduced drainage loads** |
| ***Improved ability to model water distribution systems, including updating Hunter's method into a computer program that can be used in the design process.*** |
| ***A robust public-domain user-friendly computer program to simulate the detailed and stochastic operation of premise plumbing systems with output linked to BIM platforms that can be used to fine-tune the hydraulic design of new buildings. Such a program could also generate information on water residence times, maintenance (flushing) plans and identify locations in premise plumbing systems that may be susceptible to water quality problems.*** |

**Table 3.** Updated Applied Research Needs.

| |
|---|
| **Area #A1: System Design** |
| New plumbing system designs and technologies |
| **Validation of alternative sizing models and methodology for integration with plumbing codes** |
| **Potential side-effects of water and energy-efficient systems** |
| **Hot water plumbing design** |
| Multipurpose residential piping and sprinkler systems |
| Comparison of trunk-branch and series distribution systems |
| **Impacts of alternative water use** |
| **Impacts of design, reuse, reduced flows, materials, and water quality on wastewater systems** |
| ***Methods to predict peak water demands to properly design (right-size) premise plumbing systems in new buildings.*** |
| ***Bringing the Water Demand Calculator into non-residential construction*** |
| **Area #A2: Installation, Operation and Maintenance** |
| Impact of current plumbing codes and standards |
| **Best practice guidelines for installation** |
| **Recirculation lines and temperature maintenance** |
| Water management protocols for existing buildings |
| **Water management strategies to control *Legionella* and other pathogens** |
| Best practices for maintenance of emergency fixtures |
| Best practices for scheduled shutdowns and resiliency to unplanned disturbances |
| Metering for low-flow systems |
| Eliminating domestic galvanized iron pipe |
| ***Microbial water quality indicators for non-legionella premise plumbing pathogens.*** |
| ***The use of building intelligence to reduce water age and repurpose water for other on-site applications, such as irrigation and laundry.*** |
| **Area #A3: Training and Guidance** |
| **Guidance for homeowners, facility managers and other practitioners** |
| Training for designers on water efficiency |
| Training and certification for design, operation, and maintenance |
| Training for building water system assessments |
| Maintenance and monitoring guidance for control of *Legionella* and other OPPPs |

Major themes that arose repeatedly during the workshop were the need to right-size plumbing systems, impacts of water source, the need to address system drainage and venting in addition to water supply, and approaches to deal with the many challenges in existing buildings as opposed to focusing exclusively on new building designs. The need for research to reflect real plumbing systems and to employ a holistic approach was another important theme during the discussion.

The workshop closed with a discussion of next steps and follow-on activities. The attendees were all committed to continuing the dialog at conferences and other venues, and to identifying and pursuing vehicles to advance the discussion and move the field forward.

## 5. References

Buchberger, S.G., Omaghomi, T., Wolfe, T., Hewitt, J., and Cole, D/. (2017). Peak Water Demand Study - Probability Estimates for Efficient Fixtures in Single and Multi-Family Residential Buildings, Executive Summary, IAPMO, Chicago, IL.

DeOreo, W.B., Mayer, P.W., Dziegielewski, B. and Kiefer, J. (2016). Residential End Uses of Water, Version 2. Report #4309B. Water Research Foundation.

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Lin, L., Duarte Batista, M., Milesi Ferretti, N. (2022). State-of-the-art Review on Measurement of Pressure Losses of Fluid Flow through Pipe Fittings. NIST Technical Note 2206. National Institute of Standards and Technology.

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Persily, A., Yashar, D., Milesi Ferretti, N., Ullah, T., Healy, W. (2020). Measurement Science Research Needs for Premise Plumbing Systems. Technical Note 2088. National Institute of Standards and Technology.

Persily, A.K., Musser, A., Leber, D. (2006). A Collection of Homes to Represent the U.S. Housing Stock. NISTIR 7330. National Institute of Standards and Technology**:** 31.

Pickering, R., Onorevole, K., Greenwood, R., and Shadid, S. (2018). Measurement Science Roadmap Workshop for Water Use Efficiency and Water Quality in Premise Plumbing Systems: August 1-2, 2018. NIST GCR 19-020, National Institute of Standards and Technology.

## Appendix A. List of Workshop Attendees

Julius Ballanco, Self
Michael Blanford, HUD
Steven Buchberger, University of Cincinnati
Richard W. Church, CM Services
Dan Cole, IAPMO
Michael Cudahy, PPFA
Peter De Marco, IAPMO
James E. Dipping, ESD
Marcus Elmer, Copper Development Association
Mark Fasel, ICC
Patrick Gurian, Drexel University
David A. Hewitt, HUD
Timothy M. Keane, Legionella Risk Management
Gary Klein, Self
Cliff Kornegay, HUD
Jasen Kunz, CDC
John Lansing, PAE
Christoph Lohr, IAPMO
Mia Catharine Mattioli, CDC
Toritseju (Toju) Omaghomi, University of Cincinnati
Jonah Schein, US EPA
Matt Sigler, ICC
Kerry Stackpole, PMI
Jeffrey Szabo, US EPA
Kyle Thompson, PMI
Andrew Whelton, Purdue University

**NIST Staff**
Marylia Duarte Batista
Joannie Chin
William Healy
Mark Kedzierski
Lingnan Lin
Lisa Ng
Natascha Milesi Ferretti
Denise Nyangwechi
Andrew Persily
Tania Ullah
David Yashar
Stephen Zimmerman

## Appendix B. Workshop Presentations

**NIST presentations**

NIST Agenda and Discussion

Design and operation of a NIST laboratory facility to study opportunistic premise plumbing pathogen (OPPP) occurrence in hot water systems; Marylia Duarte Batista

Impacts of Water Demand and Water Heater Delivery Temperatures on Opportunistic Premise

Plumbing Pathogens in a Single-Family Residence, Tania Ullah

Measuring Pressure Losses in Modern Plumbing Fittings, Lingnan Lin

Non-Residential Water Use, Steven Buchberger and Toju Omaghomi (University of Cincinnati)

Comparing Measured Peak Flow Rates to WDC Estimates, Gary Klein

Enhanced Plumbing System Simulation Tools, Mark Kedzierski

Standardized Plumbing System Models, Stephen Zimmerman

**Non-NIST presentations**

U.S. EPA WaterSense Update, Jonah Schein

U.S. EPA Premise Plumbing Research, Jeff Szabo

Water Quality in Buildings (Results of EPA sponsored study), Patrick Gurian

Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health (Results

of EPA sponsored study), Andrew Whelton

Disaster Impacts on Plumbing, Andrew Whelton

21st Century Water Needs, Christoph Lohr

# NIST Premise Plumbing Workshop
# 15 November 2022


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# Workshop Agenda

| Time | Agenda Item |
|---|---|
| 8:30 to 9:00 a.m. | Welcomes and introductions |
| 9:00 to 9:40 a.m. | NIST premise plumbing research (Part 1)<br>Water heaters and pathogen growth<br>Testing at NIST Net Zero Energy Residential Test Facility – Tania Ullah<br>Basement Water Heater Lab – Marylia Duarte Batista<br>Pressure v. flow of plumbing fittings – Lingnan Lin |
| BREAK | |
| 9:55 to 10:45 a.m. | Lab tours:<br>Pressure v. flow of plumbing fittings<br>Water heaters and pathogen growth (basement lab) |
| 10:45 to 11:25 a.m. | NIST premise plumbing research (Part 2)<br>Non-residential Water Use – Steven Buchberger<br>Model Development – Mark Kedzierski<br>Standard Plumbing System Designs – Stephen Zimmerman |
| 11:25 a.m. to Noon | Premise plumbing research activities under other federal agencies<br>Jonah Schein, US EPA, Office of Water<br>Jeff Szabo, US EPA, Office of Research and Development<br>Michael Blanford, HUD<br>Patrick Gurian on EPA-Funded research – Drexel University<br>Andrew Whelton on EPA-Funded research – Purdue University |
| LUNCH | |
| 1:00 to 2:00 p.m. | Discussion of plumbing industry trends and activities |
| 2:00 to 3:00 p.m. | Discussion of research priorities |
| SHORT BREAK | |
| 3:00 to 4:00 p.m. | Wrap-up and Follow-Up |

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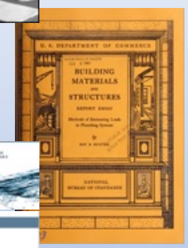
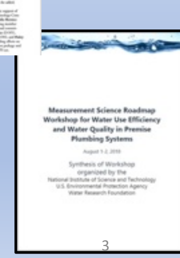
## Background on NIST Premise Plumbing Research Efforts








**Long history of plumbing research at NBS/NIST**

**Outside interest in NIST re-engaging**
Discussions with stakeholders since 2015
Bring back the plumbing tower!!!
Legislation calling for NIST involvement

**NIST Premise Plumbing Roadmap Workshop**
Aug 2018, NISTGCR 19-020

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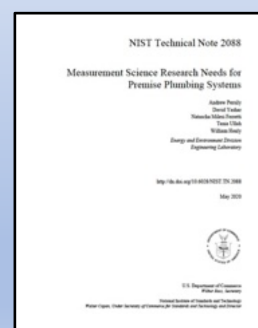
## 2020 NIST Research Needs Report


**NIST Technical Note 2088: Measurement Science Research Needs for Premise Plumbing Systems**

**Goal**: To identify measurement science research needs critical to the design of new premise plumbing systems and the operation and retrofit of existing systems to achieve water and energy efficiency and water quality

**59 Research Needs:**
<u>Foundational Measurement Science</u>
e.g., metrics, test methods, data
<u>Applied Research</u>
e.g., guidance, design approaches

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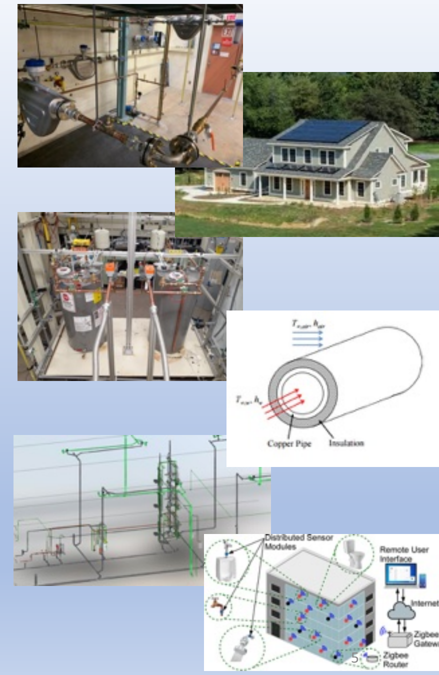
## More recently

**One-time NIST funding:**
Summer of 2020 through September 2022

**New premise plumbing research efforts**
Pressure-flow relationships of plumbing fittings
Water heater temperatures and opportunistic pathogens
Non-residential building water usage survey
Enhanced plumbing system simulation tools
Standardized plumbing system models

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## Input requested before workshop

**Which of the research needs in the 2020 NIST research needs report do you think are most pressing?**

**Are there new research topics that need to be addressed since that report was published?**

**What do you see as the major trends in the premise plumbing field that need to be addressed through research or guidance development?**

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## Research Priorities from 2020 NIST report

https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2088.pdf

**FUNDAMENTAL**
**Area #F1: Terminology and Area #F2: Metrics**

**Area #F3: Data**
Occupant behavior and water usage patterns for different building types
Data on biofilm and scale development
Plumbing system design info following disease outbreaks

**Area #F4: Flow and Transport Fundamentals**
Biological processes in plumbing systems
Data to support updated vent sizing requirements in drainage systems, based on modern system demands
Data on the impact of water sources on water quality in plumbing systems
Impacts of reduced flow rates on drainage systems

**Area #F5: Methods and Measurement**
Performance of fittings and pipes

**Area #F6: Model Development**
New probabilistic models to estimate drainage loads
Reference buildings and plumbing systems
Expansion of plumbing models to include thermal analysis
Expansion of chemical and biological models





## Research Priorities from 2020 NIST report

https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2088.pdf

**APPLIED**
**Area #A1: System Design**
Validation of alternative sizing models and methodology for integration with plumbing codes
Hot Water Plumbing Design
Potential Side Effects of Water and Energy Efficient Systems
Technical assessment of alternative water systems, e.g., rainwater harvesting and on-site reuse
Water age and pipe right sizing.
Drainage and venting design with lower flow fixtures.

**Area #A2: Installation, Operation and Maintenance**
Best practices in general
Recirculation lines and temperature maintenance, installation and operation

**Area #A3: Training and Guidance**
Guidance for homeowners, facility managers and other practitioners
Training, Education and Guidance for Homeowners, Facility managers and the Public on water efficiency with respect to the plumbing system.

## Overarching Research Themes

### OPPP

Risk management of *legionella* and mycobacteria; water quality indicators for non-legionella pathogens
Scalding management for safety, public health and energy

### Modeling and Design

Ability to model the water distribution systems
Updating and revising Hunter's method into a computer program that can be used in a building design
Bringing the Water Demand Calculator into non-residential construction
Public-domain computer program to simulate operation of premise plumbing systems linked to BIM platform

### Resilience Issues

Infrastructure decontamination; remediation strategies for different size buildings
Better understanding of the impacts of nitrification
Evaluation of methods to reduce the number of water loss insurance claims.

### Specific Technologies

Vacuum water closet technology, urine separating water closets, onsite wastewater composting
Heat pump water heaters; point-of-use water heaters; electric water heaters with tanks: better data, improved designs, standards and certification
Thermostatic mixing valves: need a better evidence base; alternative designs may be better
Water softeners, better guidance on target hardness levels

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## Most "Popular" Research Needs

**Data on water demand patterns for system design**

**Venting and drainage requirements for modern systems**

**Simulation tools for design and analysis**

**New design and operation guidance, especially for hot water systems**

**Code updates based on data and design tools**

**Impacts of water source and incoming water quality**

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# Wrap-up and Follow-Up

**1 GREAT DISCUSSION! THANKS TO ALL!**

**2 PRIORITIES**

DATA – usage, microbial growth, …
MODELS – biological, thermal, flow/pressure, water age, …
RESEARCH YES! – but also science-based guidance, tools, codes and O&M
REALITIES, NEW & OLD – Energy/GHG emissions, Infrastructure, Resilience, Decarb
NEW TECHNOLOGIES - Both promise and questions
WATER HEATING!!!

**3 MISC**

Right sizing; Terminology, e.g., "~~low flow~~"; More focus on appliances; Drainage & sanitary; Silos in research and practice; Existing buildings

**4 NEXT STEPS**

Summarize pre-workshop input and workshop discussion
Share presentations: NIST and non-NIST
Pursue vehicles for ongoing input and discussion

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NIST Premise Plumbing Research Workshop
15 November 2022

# Design and operation of a NIST laboratory facility to study opportunistic premise plumbing pathogen (OPPP) occurrence in hot water systems

Marylia Duarte Batista, Alshae' Logan, Tania Ullah, William Healy

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

Building Energy and Environment Division, National Institute of Standards and Technology
100 Bureau Dr, Gaithersburg, Maryland 20899

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# Introduction

- After the service connection, most drinking water standards are not enforced or monitored.
- Pipes, water heaters, and fixtures are critical premise plumbing components.
  - increased water age,
  - increased temperature range,
  - greater surface area-to-volume ratios,
  - presence of a variety of materials.
- Consequence to public health:
  - OPPPs can benefit from disinfectant decay and warm temperature in buildings to proliferate, and ultimately cause diseases to exposed immunocompromised people.

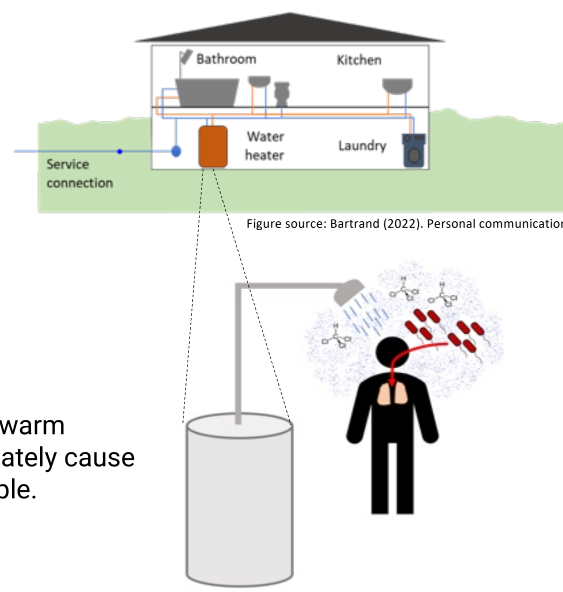


Figure source: Bartrand (2022). Personal communication.

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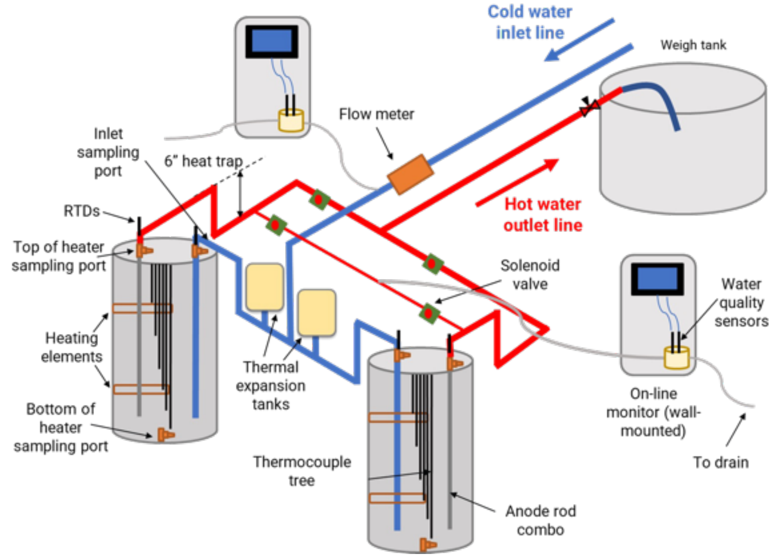
# Experimental design

NIST

- 190 L (50-gal) electric storage water heaters

**Factors:**
- Four **water use** patterns
  - Two daily draw volumes
  - Two stagnation times
- Two **temperature** settings

**Sampling ports:**
- Cold-water inlet (pre- and post- flush)
- Bottom (pre-flush)
- Top (pre-flush)

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# Experimental design

NIST

**1) Cleaning:** Disinfect tanks with bleach and flush.

**2) Acclimation:** Operate heaters at low temperature [37.8 °C (100 °F) ± 3 °F] and a small daily flush to encourage microbial growth.

**3) Experiment:** Increase tank temperature, implement water use profiles and collect water samples.

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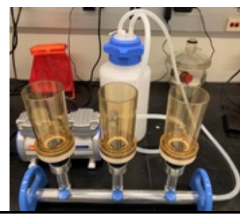
# Measurement science

- **Bench-scale measurements:**
  - Physical/chemical: chlorine residual, pH, turbidity, conductivity, hardness
  - Microbial: heterotrophic plate counts (HPCs)
- **On-line tests:**
  - same as bench tests, total organic carbon (TOC), UV254, color.
- **Molecular measurement:**
  - droplet digital PCR – ddPCR: *Legionella pneumophila*, *Pseudomonas aeruginosa*, *Mycobacterium avium*, *Naegleria fowleri*, and genus *Legionella* and *Mycobacteria*.
- **Temperature measurement:**
  - six tank heights (thermocouples), tank inlets and outlets (RTDs).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# Preliminary results

**<u>Current simulation</u>**

**Profile 1**

- **Water use pattern**
  - 5 gallons/use
  - 4 times/day
  - 6-hour stagnation
  - Total = 20 gallons/day
- **Temperatures**
  - Tank A = 49 °C (120 °F)
  - Tank B = 60 °C (140 °F)

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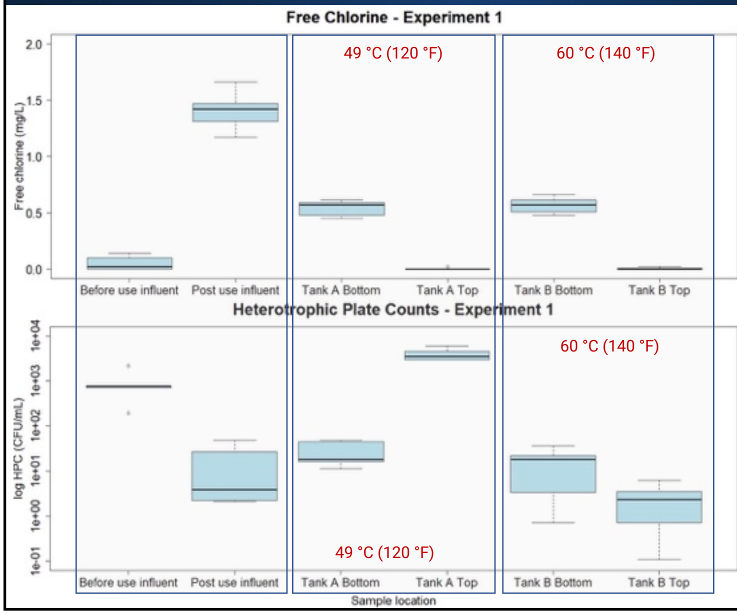
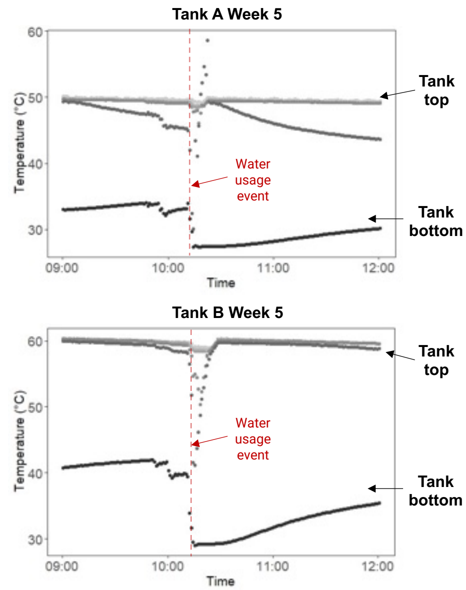
# Preliminary results

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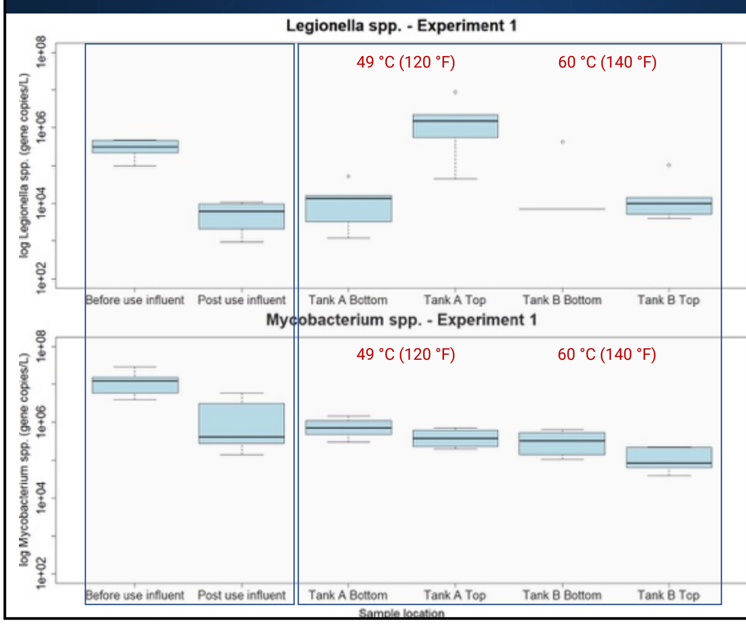
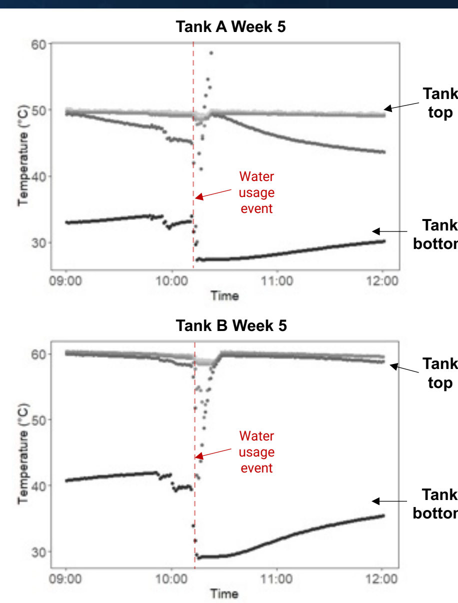
# Preliminary results

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# Next steps

NIST

**Phase 1:**

- Simulate three other water use profiles

| Draw pattern | Volume removed per day [L (gal)] | Stagnation time (hours) | Draws per day | Volume per draw [L (gal)] |
|---|---|---|---|---|
| **1** | 75.7 (20) | 6 | 4 | 18.9 (5) |
| **2** | 75.7 (20) | 24 | 1 | 75.7 (20) |
| **3** | 151.4 (40) | 6 | 4 | 37.9 (10) |
| **4** | 151.4 (40) | 24 | 1 | 151.4 (40) |

Completed

- Implement on-line water quality monitoring

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National Institute of Standards and Technology
U.S. Department of Commerce

# Impacts of Water Demand and Water Heater Delivery Temperatures on Opportunistic Premise Plumbing Pathogens in a Single-Family Residence

Alshae' Logan, Marylia Duarte Batista, Tania Ullah, William Healy

Nov 15th, 2022

1

## Introduction

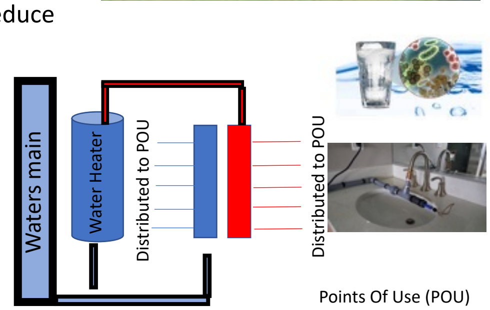
***Lead:*** *Alshae' Logan-Jackson, PhD (NRC Post-doc)*

**Objective:**

- Examine water quality parameters and OPPPs for an entire residential premise plumbing system, from the water main to tap.
- Understand the effects of **water heater temperature** and **water use patterns** on the occurrence and concentration of OPPPs throughout hot- and cold-water systems in order to identify strategies to reduce their growth and associated public health impacts.

**Residential Test Home:**

- Automated scheduling of water use patterns
- PEX manifold hot- and cold-water plumbing systems

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## Experimental Design

NIST

- Profiles: Tank temperatures and water demand over three-week periods (acclimation before sampling)

| Profile |
| --- |
| 1 (Low water usage/Low water temperature) |
| 2 (High water usage/Low water temperature) |
| 3 (High water usage/High water temperature) |
| 4 (Low water usage/High water temperature) |

**Usage:** 1-person (LOW) vs. 4-person family occupancy (HIGH)

**WH delivery temperatures:** 54 ˚C vs. 66 ˚C

- Total of 260 samples were collected from cold- and hot-water pipe
- All points throughout the multi-level plumbing system are sampled
  - Basement: water main, bottom and top of water heater, cold and hot water manifolds
  - First level: kitchen sink
  - Second level: bathroom sink, shower, tubs
- Physical/Chemical Parameters
  - Temperature, chlorine, pH, conductivity, and turbidity



## Methods for Microbial Analysis

NIST

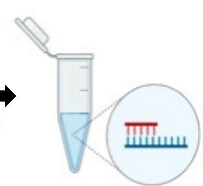
0.5 L Tap Water



N=260 samples

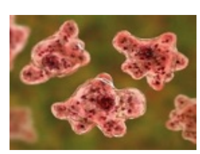
Filter 0.3 L onto 0.45 µM polycarbonate filter

Extract polycarbonate filter by Fast DNA Spin Kit



Assay extraction elute for target species by ddPCR

N=4 total assays



**OPPPs Left to right:**
*Legionella pneumophila*
*Pseudomonas aeruginosa*
*Mycobacterium avium*
*Naegleria fowleri*

## Preliminary Results

NIST

**Profile 1**
Low usage + Low temperature

**Profile 2**
High usage + Low temperature

**Profile 3**
High usage + High temperature

**Profile 4**
Low usage + High temperature

| OPPPs | Profile One N=60 (%) | Profile Two N=70 (%) | Profile Three N=70 (%) | Profile Four N=60 (%) | Total/Species N=260 (%) |
|---|---|---|---|---|---|
| L. pneumophila | 9 (15) | 4 (5) | 5 (7) | 3 (5) | 21 (8) |
| P. aeruginosa | 6 (10) | 3 (8) | ND (0) | ND (0) | 9 (3) |
| M. avium | ND (0) | 2 (2) | 2 (2) | 1 (1) | 5 (1) |
| N. fowleri | ND (0) | ND (0) | ND (0) | ND (0) | ND (0) |
| Total/Profile | 15 (25) | 9 (12) | 7 (10) | 4* (6) | 35 |

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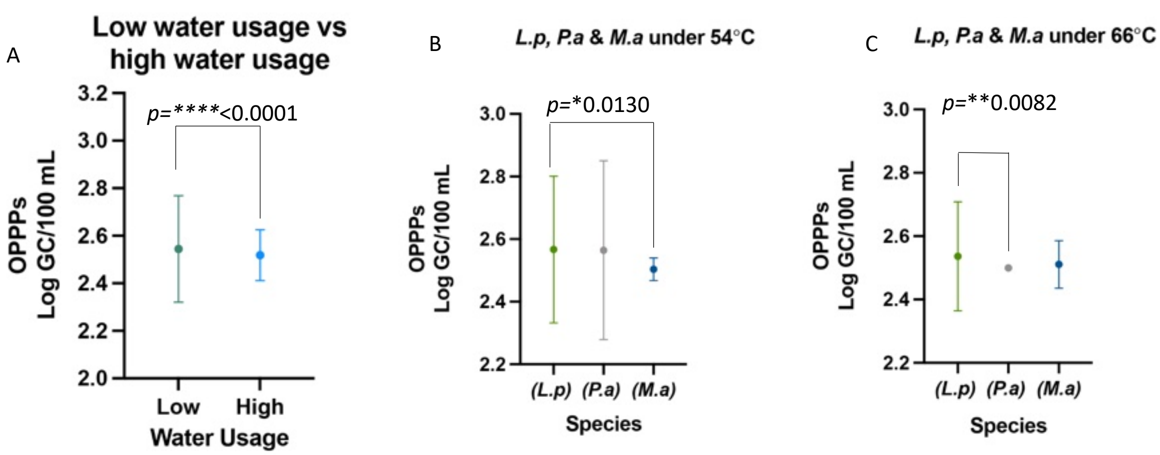
## Preliminary Results

NIST




17 Vs 70
gallons/day

Detection limit is 2.5 $Log_{10}$ GC/100 mL

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## Preliminary Observations

NIST

- *Legionella pneumophila* had the highest detection frequency, but overall low detections across all species
- Increasing the delivery temperature to 66 °C (150 °F) decreased *Pseudomonas aeruginosa*
- Higher water usage may be sufficient to decrease the amplification of OPPPs
- Acclimation period of >2 weeks required to reach steady state
- Lower than expected detections may be attributed to various factors (water heater temperatures, sample volume collected, DNA extraction methods)

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## Future Plans for OPPP Research

NIST

**Ongoing FY23 efforts**

- Net Zero house seasonal study to determine effects of temperature and water quality parameters of mains water on OPPPs detected (*ongoing*)
- Sample volume (1 L vs. 10 L) for optimum OPPPs detection from water heaters

**Outyears**

- Study the impact of commercially available point-of-use and whole home filtration devices on premise plumbing microbial activity
- DNA sequencing methods
- Water heater lab expansion (other fuel types, fixtures, thermostatic mixing valves)

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Premise Plumbing Research Workshop, Nov. 15, 2022

# Measuring Pressure Losses in Modern Plumbing Fittings

Natascha Milesi Ferretti
Lingnan Lin
Marylia Duarte Batista

National Institute of Standards and Technology
U.S. Department of Commerce

engineering laboratory

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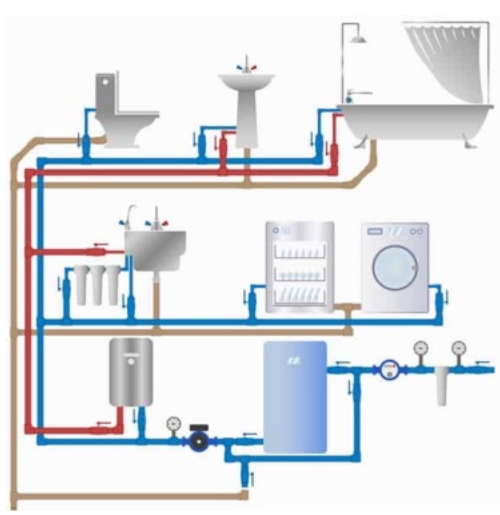
## Pressure Loss in Plumbing Systems
## - necessary to system design

NIST



Straight pipes: $\Delta P_{\text{loss}} = f \frac{L}{D} \frac{\rho V^2}{2}$ (Darcy Equation)

*f* - friction factor, determined by Moody chart or correlations

Fittings: $\Delta P_{\text{loss}} = K \frac{\rho V^2}{2}$

*K* - loss coefficient, a function of D, Re, roughness, geometry

geometry → varies with manufacturer

**Problems:**

- No standard test method for pressure loss in fittings
- Measured data not widely available for specific fittings and configurations,
- Often estimated from literature values that may not be accurate

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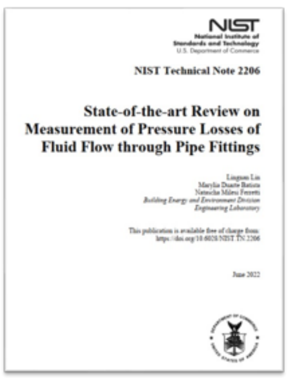
# What about literature data?

- Reviewed literature since 1920, including handbooks and research papers
- A large portion of data are pre-1950, based on iron/steel fittings
- Very limited data for copper, PEX, and CPVC fittings, especially with $D \leq 1$ in.
- Large variation across data for the same type of fitting


National Institute of Standards and Technology
U.S. Department of Commerce

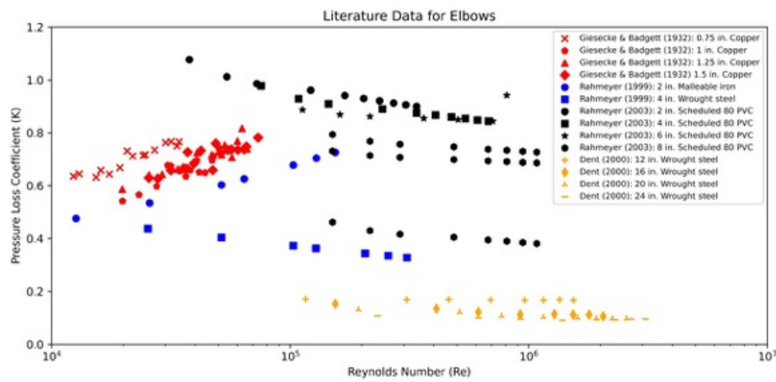
NIST Technical Note 2206

**State-of-the-art Review on Measurement of Pressure Losses of Fluid Flow through Pipe Fittings**

Lingnan Lin
Marylia Duarte Batista
Natascha Milesi Ferretti
*Building Energy and Environment Division*
*Engineering Laboratory*

This publication is available free of charge from:
https://doi.org/10.6028/NIST.TN.2206

June 2022

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# Project Objectives

To develop the **measurement science** needed to establish **standardized** and **precise** <u>means of characterizing pressure loss of modern plumbing fittings</u>

Specifically ...

- Establish a new lab facility to measure pressure loss in fittings
- Provide benchmark data for common fittings
- Develop a test method to be submitted to an appropriate standards organization for consideration as an industry consensus

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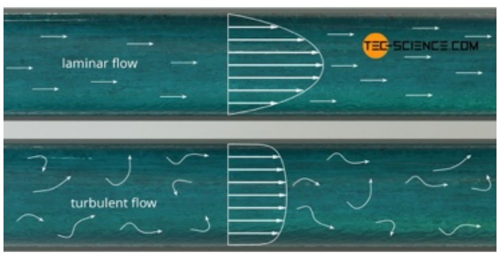
# How Pressure Losses Occur

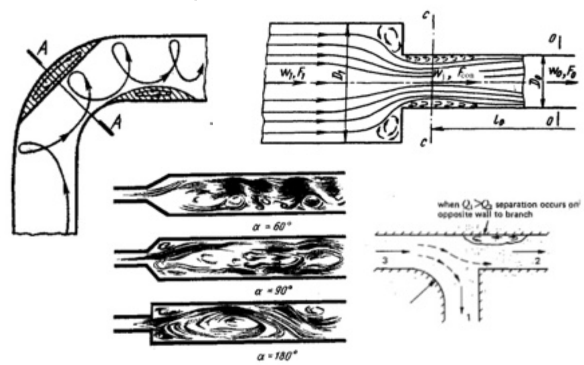
Pressure Loss: irreversible loss of mechanical energy (≠ Pressure Drop)

Root cause: Viscosity & Turbulence

**Straight pipes:**
Friction between fluid and pipe wall




**Fittings:**
Friction; Flow separation; Secondary flow



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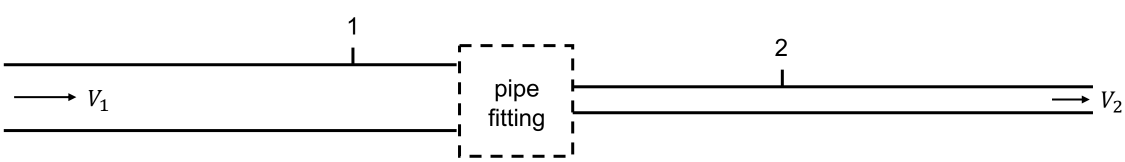
# Pressure Loss Measurement: Traditional Method (two-tapping-location)




$$\Delta P_{\text{loss}} = (P_1 - P_2) - \Delta P_{\text{friction},1} - \Delta P_{\text{friction},2} - \frac{1}{2}\rho(V_2^2 - V_1^2)$$

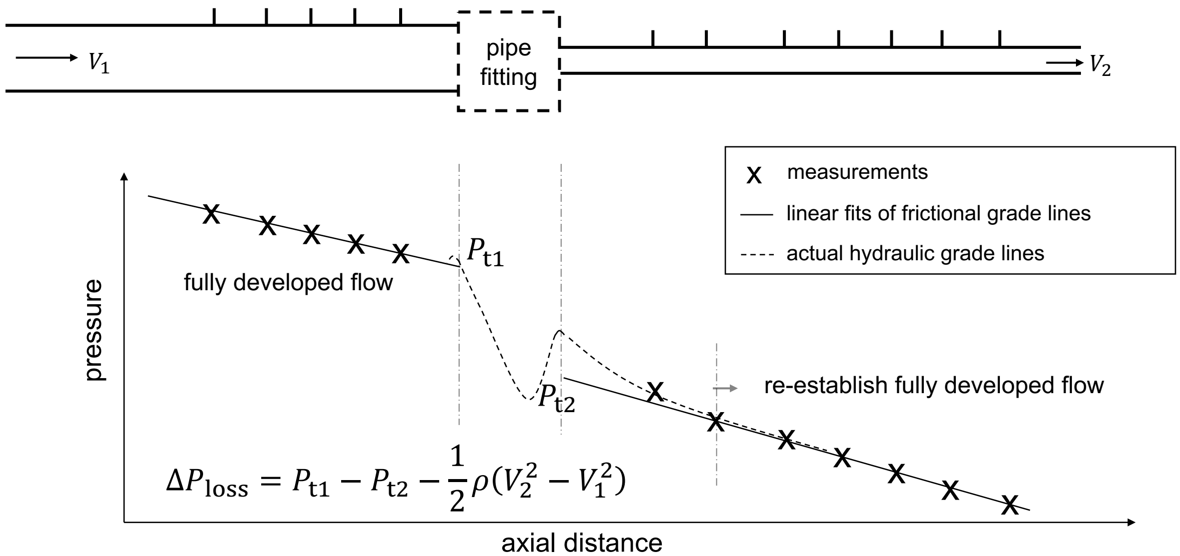
No established predictive method

- Pressure taps 1 and 2 should be located where the flow is fully developed.
- Friction loss in straight pipes need to be measured in a separate experiment.

Introducing additional uncertainties

6

# Pressure Loss Measurement: Alternative Method (multi-tapping-location)

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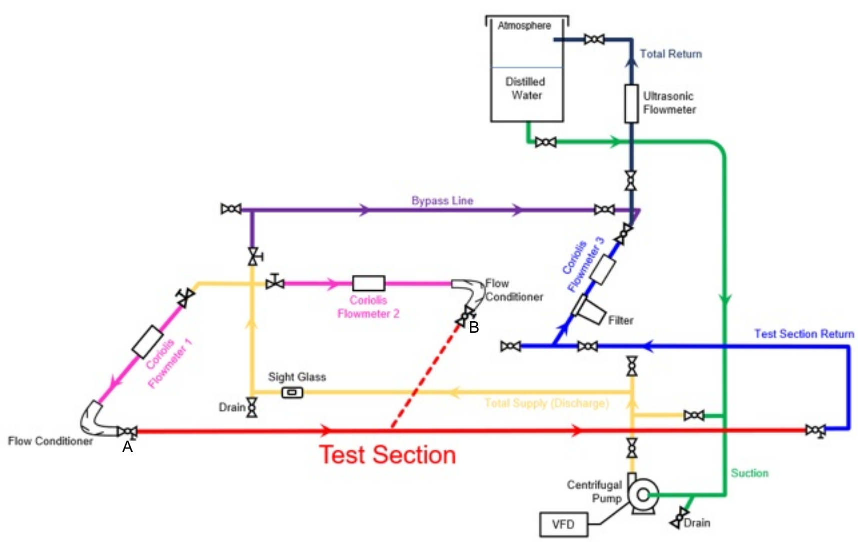
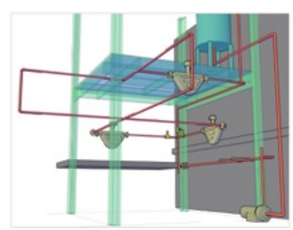
# NIST Pressure-Flow Test Facility



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# Test Section Details

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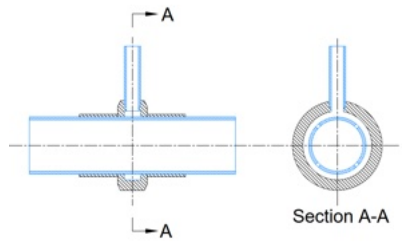
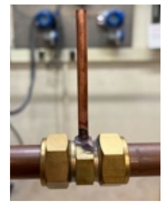
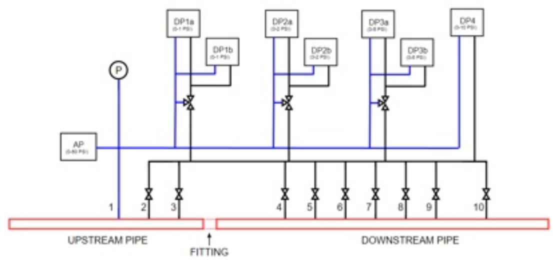
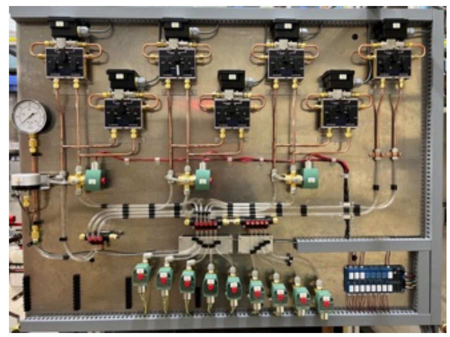
Pressure Tap Design
(piezometer ring)



Automated Pressure Distribution Measurement System



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# Next Plans

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- Quantify the uncertainty of our measurements
- Validate the test rig by measuring the pressure loss in straight copper pipes and comparing with existing data from the literature
- Measure pressure loss in elbows of various materials (e.g., copper, PVC, PEX, and other plastics) from different manufacturers
- Document lessons learned from the development and use of the NIST PvQ test rig
- Seek out collaboration with industry & academia
- Draft test method for consideration by a standards development organization

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# Acknowledgment

SERI Project Team Members:
- Andy Persily
- Natascha Milesi Ferretti
- Lingnan Lin
- Marylia Duarte Batista
- Bill Healy
- Dave Yashar
- Tania Ullah
- Alshae' Logan

Collaborators (University of Cincinnati):
- Steve Buchberger
- Toju Omaghomi
- Gary Klein

NIST Staff:
- Glen Glaeser (Electrical Technician)
- Luis Luyo (Mechanical Technician)
- Tyler Gervasio (Mechanical Technician)
- John Wright (Flow Calibration Lab, PML)
- Steven Bushby
- Mark Kedzierski
- Harrison Skye
- Jeffrey Smith (NIST Pipe Shop)

Other:
- Steve Barfuss (Utah State University)

**Thank you! Questions?**

# Non-Residential Water Use

## NIST Premise Plumbing Research Workshop

November 15, 2022

Steven Buchberger, PE, PhD

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# Acknowledgment

This work was performed under the following financial assistance awards 70NANB21H014 and 70NANB21H181.

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Principal Investigators:
Toju Omaghomi, Tao Li, Gary Klein, Steven Buchberger

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# Two Stages in Two Years

- **Stage 1, Calendar Year 2021** – Research on Estimating Peak Water Demands and Measuring Pressure Losses in Premise Plumbing Systems

- **Stage 2, Calendar Year 2022** - Research on Fixture-Level Peak Probability of Water Use in Non-Residential Buildings

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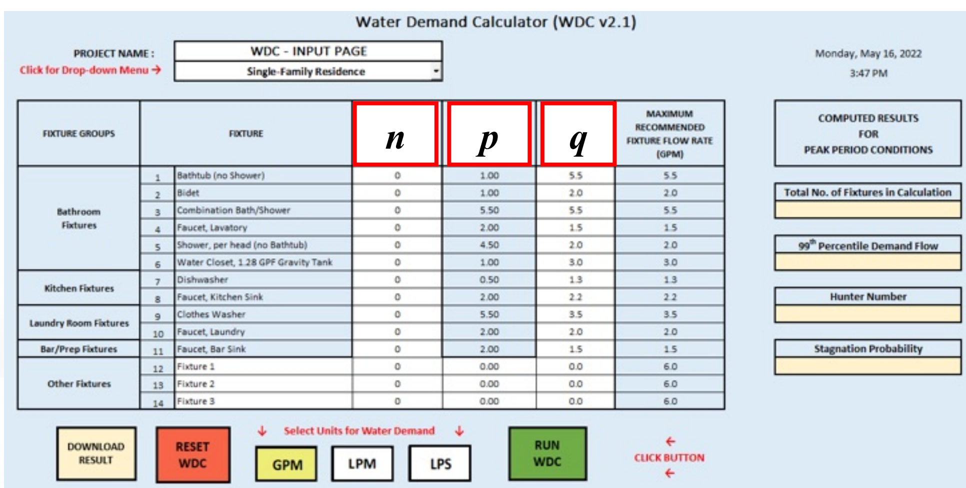
# Water Demand Calculator


Water Demand Calculator (WDC v2.1)

PROJECT NAME : WDC - INPUT PAGE

Click for Drop-down Menu → Single-Family Residence

Monday, May 16, 2022

3:47 PM

| FIXTURE GROUPS | | FIXTURE | $n$ | $p$ | $q$ | MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM) |
|---|---|---|---|---|---|---|
| Bathroom Fixtures | 1 | Bathtub (no Shower) | 0 | 1.00 | 5.5 | 5.5 |
| | 2 | Bidet | 0 | 1.00 | 2.0 | 2.0 |
| | 3 | Combination Bath/Shower | 0 | 5.50 | 5.5 | 5.5 |
| | 4 | Faucet, Lavatory | 0 | 2.00 | 1.5 | 1.5 |
| | 5 | Shower, per head (no Bathtub) | 0 | 4.50 | 2.0 | 2.0 |
| | 6 | Water Closet, 1.28 GPF Gravity Tank | 0 | 1.00 | 3.0 | 3.0 |
| Kitchen Fixtures | 7 | Dishwasher | 0 | 0.50 | 1.3 | 1.3 |
| | 8 | Faucet, Kitchen Sink | 0 | 2.00 | 2.2 | 2.2 |
| Laundry Room Fixtures | 9 | Clothes Washer | 0 | 5.50 | 3.5 | 3.5 |
| | 10 | Faucet, Laundry | 0 | 2.00 | 2.0 | 2.0 |
| Bar/Prep Fixtures | 11 | Faucet, Bar Sink | 0 | 2.00 | 1.5 | 1.5 |
| Other Fixtures | 12 | Fixture 1 | 0 | 0.00 | 0.0 | 6.0 |
| | 13 | Fixture 2 | 0 | 0.00 | 0.0 | 6.0 |
| | 14 | Fixture 3 | 0 | 0.00 | 0.0 | 6.0 |

COMPUTED RESULTS FOR PEAK PERIOD CONDITIONS

Total No. of Fixtures in Calculation

99th Percentile Demand Flow

Hunter Number

Stagnation Probability

DOWNLOAD RESULT | RESET WDC | Select Units for Water Demand: GPM | LPM | LPS | RUN WDC | ← CLICK BUTTON ←

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Download https://www.iapmo.org/water-demand-calculator/

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# Stage 2 Activities

- Calendar Year 2022 - Research on Fixture-Level Peak Probability of Water Use in Non-Residential Buildings

1. Develop Wireless Sensor Network to monitor fixture use (SB)
2. Select buildings, determine sample size, estimate p-values (TO)
3. Corroborate predictions of Water Demand Calculator (GK)

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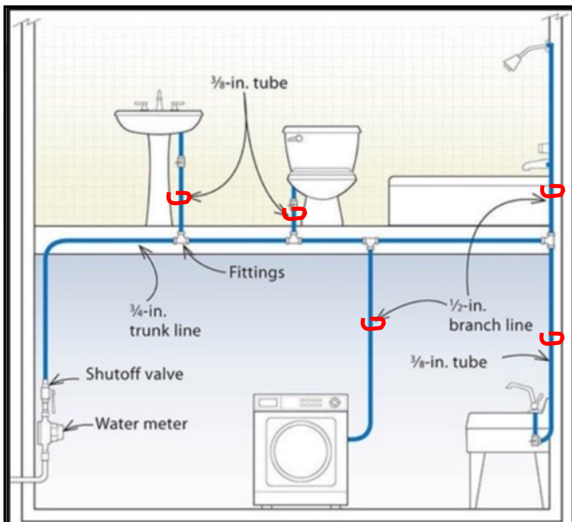


# How to Measure?

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- Select building to be monitored
- Install sensors for sampling
- Data collection, storage and analysis

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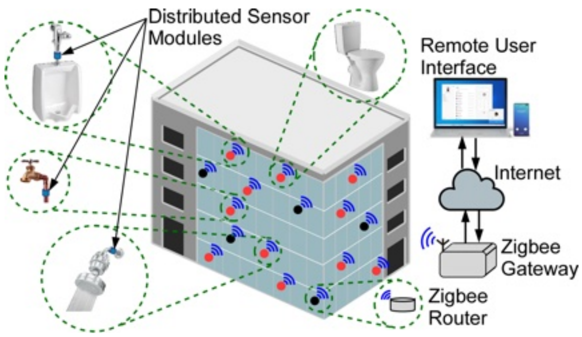
# Our Solution



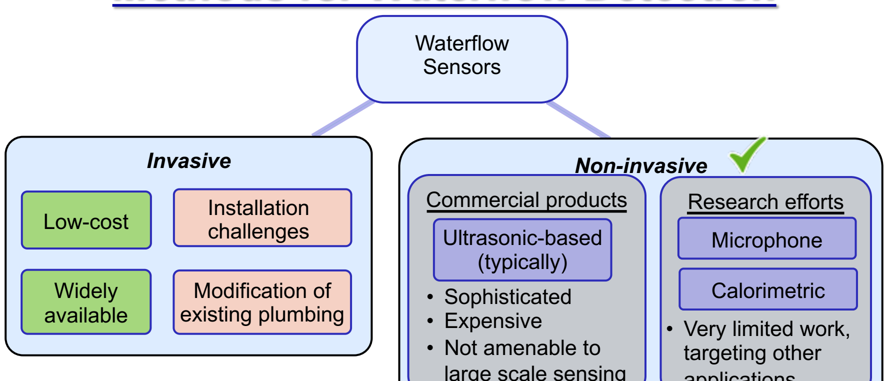

Concept diagram of the wireless sensor network.

- Sensor modules
  - Battery powered
  - Distributed
- Zigbee routers
  - To expand network coverage as needed
- Zigbee gateway
  - Interfaces between sensor modules, Zigbee router, & Internet

- P-value estimation requires large scale water usage data:
  - Time stamped binary (on/off) switching events at individual fixtures
- Currently no solution available
- **Our solution**: Wireless sensor network based on Zigbee with a cluster of distributed sensor modules, routers, and gateway
- Web-based remote user interface accessible from Internet



# Methods for Waterflow Detection

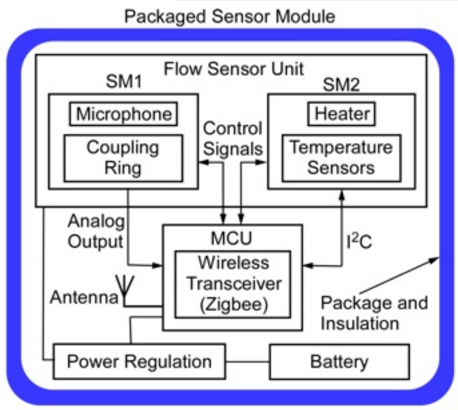



(Invasive) Paddlewheel inline flowmeter

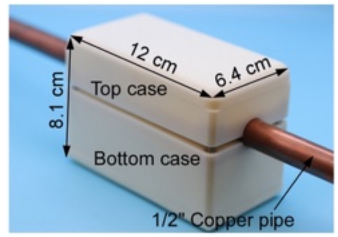
(Non-invasive) Keyence clamp-on ultrasonic flow sensor

- Both SM1 (microphone) and SM2 (calorimetric) sensing modalities included
  - SM1: Fast response, prone to interferences
  - SM2: Slower, more reliable

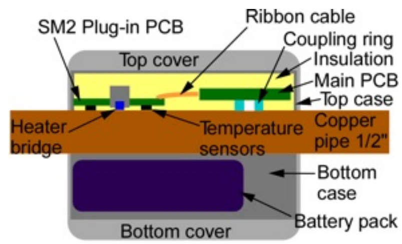
# Sensor Module Hardware




Hardware block diagram of the sensor module.




Assembled & packaged sensor module mounted on 1/2" copper pipe

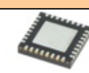
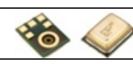
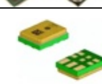


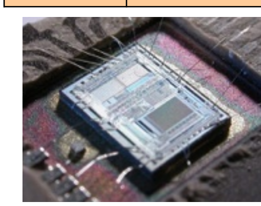

Cross-sectional illustration of packaged sensor module

- Module wakes up only when sound exceeds threshold
- Estimated lifetime >68 days (10,000 mAh battery, 70% usable for conservative est.)

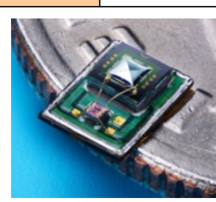


# Microchip MCU and Sensors Used in Solution

| Category | Chip Model | Features | Images |
|---|---|---|---|
| **MCU** | Silicon Labs EFR32MG21A010F1024IM32-BR | - ARM Cortex-M33 core CPU<br>- 1024 KB flash, Zigbee<br>- 3.21 x 3.21 x 0.85 mm$^3$ |  |
| **Microphone** | PUI Audio PMM-3738-VM1010-R | - Analog<br>- Wake-up functionality<br>- 3.76 x 2.95 x 1.3 mm$^3$ |  |
| | Knowles SPH0645LM4H-1 | - Digital<br>- 3.5 x 2.65 x 0.98 mm$^3$ |  |
| | SPK2611HM7H-1-6 | - Digital<br>- Keyword recognition<br>- 4.00 x 3.00 x 1.30 mm$^3$ |  |
| **Temperature sensor** | MAX30208CLB+ | - Digital<br>- 2 X 2 X 0.75 mm$^3$<br>- Resolution 0.005°C |  |



Microcontroller unit (MCU)

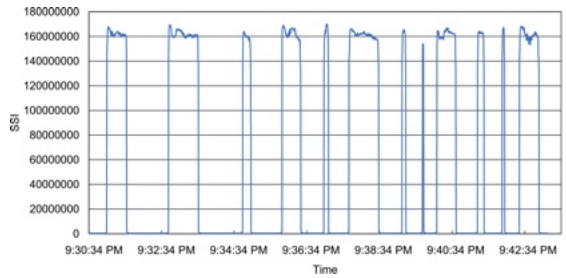


MEMS microphone

- Miniature.
- Low noise.
- Low power consumption.
- Low distortion.
- High sensitivity.
- High signal-noise ratio.

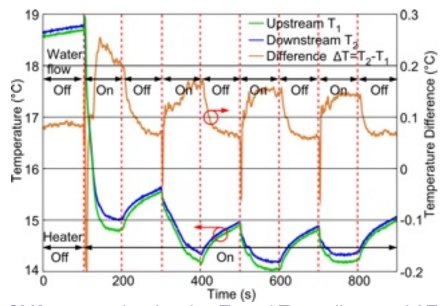
# Example Test Results for Both Sensing Modalities

- SM1 field test at a men's restroom on UC campus
  – Digital microphone and detection algorithm




SM1 detection results – signal strength indicator (SSI)

- SM2 test result on ½" copper waterpipe
  – ΔT≈0.1°C when waterflow on
  – Negligible 0-3 sec delay observed

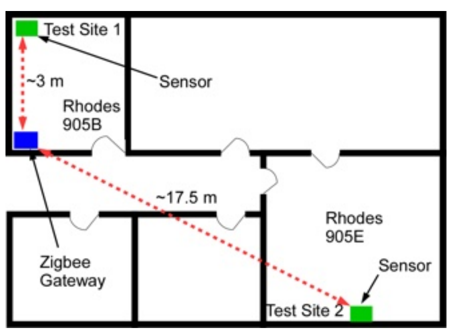



SM2 test results showing $T_1$ and $T_2$ readings and ΔT





# Example Test Results on Wireless Sensor Network




Approximate layout of system test site

Recorded waterflow events with timestamp

| Events | Location | SM1 Timestamps (sec) | | SM2 Timestamps Raw Data (sec) | |
|---|---|---|---|---|---|
| | | On | Off | On | Off |
| 1 | 1 | 0 | 103 | 1 | 103 |
| 2 | 1 | 200 | 303 | 202 | 303 |
| 3 | 1 | 400 | 502 | 401 | 503 |
| 4 | 1 | 600 | 702 | 603 | 702 |
| 5 | 1 | 800 | 903 | 802 | 903 |
| 6 | 1 | 1000 | 1103 | 1003 | 1103 |
| 7 | 1 | 1200 | 1303 | 1201 | 1303 |

- Tests of overall wireless sensor network performed
- Two sensor modules deployed for demonstration; scalable to 100s-1000s
- Both sensing modalities tested concurrently
- Data wirelessly collected and downloaded through Internet via web user interface

- Overall sensor network and both sensing modalities successfully verified
- Future work: Larger scale field tests; machine learning for data interpretation; sensor module optimization for field deployment; etc.

# References for Wireless Sensor Network


C. Choudhary, G. Batra, T. Wang, T. Omaghomi, S.G. Buchberger and T. Li, “Battery-powered wireless sensor network for non-invasive monitoring of water usage events in premise plumbing systems”, IEEE Sensors Conference, Dallas, TX, October 2022

C. Choudhary, G. Batra, S.G. Buchberger and T. Li, “Non-Invasive Calorimetric Sensor for Waterflow Event Detection in Premise Plumbing Systems”, IEEE Sensors Conference, Dallas, TX, October 2022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# Questions?

Steven.Buchberger@uc.edu

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# Probability of a Busy Fixture

NIST Premise Plumbing Research Workshop
November 15th, 2022

Toritseju Omaghomi, PhD

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## Objective

- Update the WDC: Expand its use beyond residential buildings
  - Study and simulate arrivals at fixtures in nonresidential buildings
  - Estimate fixture p-values to predict peak water demand in nonresidential buildings

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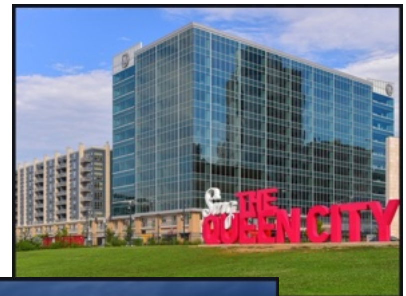
## Types of Nonresidential Buildings?

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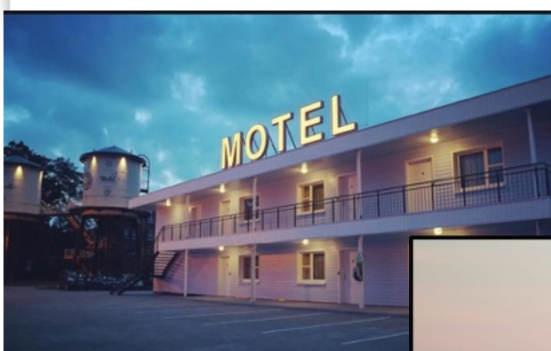
## Types of Nonresidential Buildings?

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# Number of Fixtures to Sample?

$$n = \frac{z^2 p(1-p)}{e^2}$$

| | |
|---|---|
| $n$ | - *Sample size* |
| $p$ | - *Fixture p-value* |
| $z$ | - *Standard normal deviate* |
| $e$ | - *Margin of Error* |

*The average characteristics from the sample size* ***n*** *will be similar to the average characteristics of the entire population* ***N*** *with a % confidence level and within a margin of error.*

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*Reference: Cochran, W. G. (1977). Sampling techniques (3rd ed.). New York: John Wiley & Sons.*

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# Observe Fixture Use

- $N$ = Number of people exiting the restroom
- $T$ = Observation time period (minutes)
- $V$ = Volume of flow per water use event (gallons)
- $q$ = Fixture flow rate (gpm)
- $n$ = Number of fixtures
- $a$ = Percentage of people activating the fixture

$$p = \left(\frac{N}{T}\right)\left(\frac{V}{q}\right)\left(\frac{1}{n}\right)a$$

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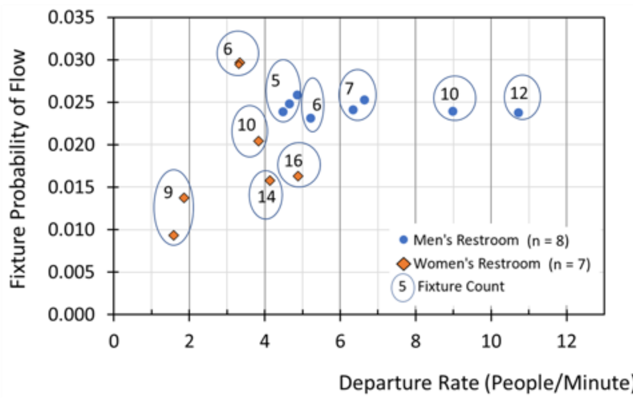
# Probability of Flow at Restrooms From Observing Fixture Use

- 7 college basketball games
- 48 restrooms monitoring events
- 15 to 20-minute window
- 9,500 average attendance per game
- Average p-value for Toilet (flush valve)

Men's Restroom; $p$ = 0.024

Women's Restroom; $p$ = 0.020

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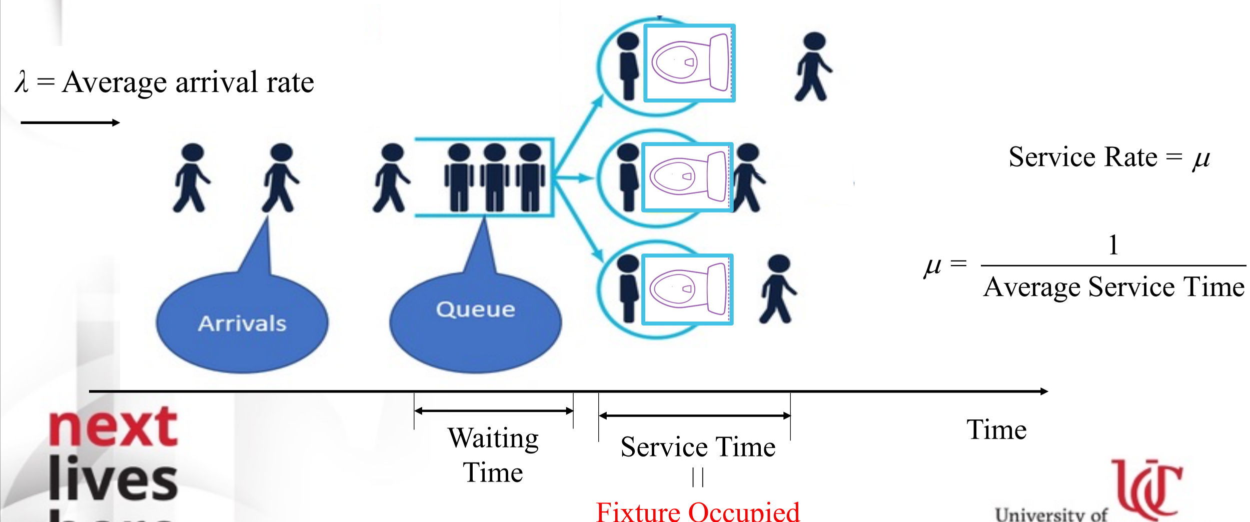
# Queueing Theory

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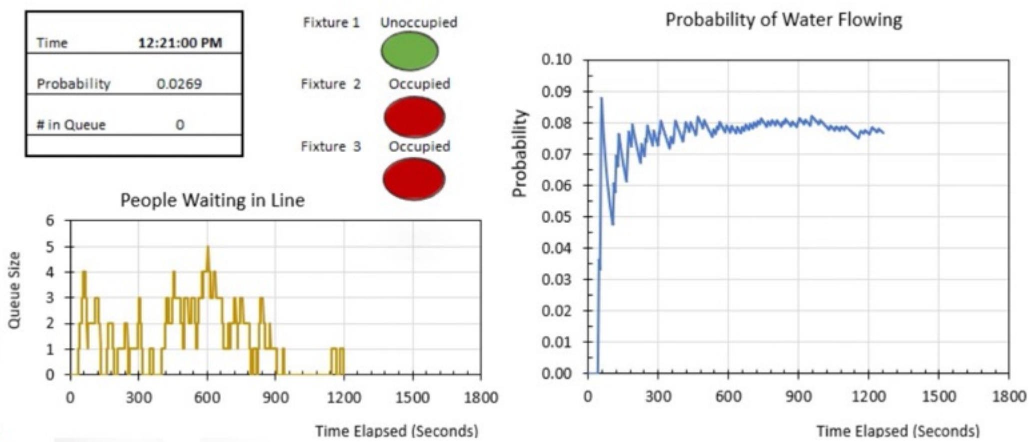
# Simulate Fixture Use

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3 fixtures; Assuming 5-second flush/use
Average Room Arrival Rate, λ = 1 person every 20 seconds;
Fixed Fixture Service Rate, μ = 1 person every 60 seconds

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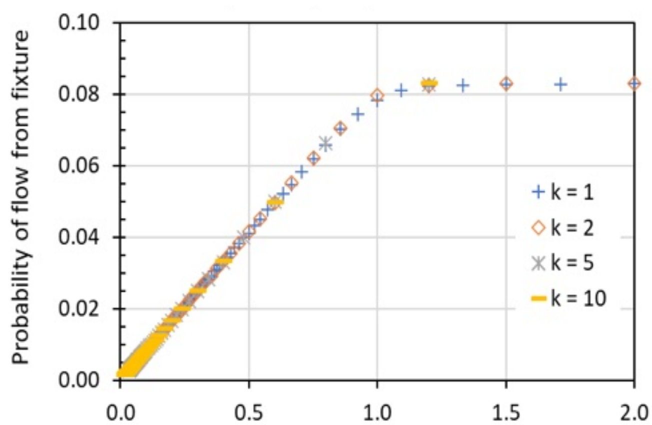
# Simulated Results

Average room arrival rate, λ =
1 every 10 seconds
up to
1 every 600 seconds


*k* is the number of stalls in a restroom

**Assumptions**

- Flush valve toilets
- 5 second per flush
- 60 seconds service time (i.e., fixture occupation time)




Utilization factor, $\rho = \frac{\lambda}{k\mu}$

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# Next Steps - DATA

- Study and understand user behavior per fixture type in different buildings (i.e., arrival rate, occupancy time)
- Create a catalog of possible maximum (congestion) fixture p-values
- Use data to estimate utilization factor for fixture in various types of buildings

next lives here

University of CINCINNATI

11

11

# Comparing Measured Peak Flow Rates to WDC Estimates

Gary Klein
Gary Klein and Associates, Inc.
gary@garykleinassociates.com
916-549-7080



1

1

**Special thanks to:**
Steffi Becking and Elise Wall, 2050 Partners, Inc.
Amy Dryden and Jack Aitchison, Association for Energy Affordability
Kelly Cunningham, Codes and Standards Program Pacific Gas and Electric Company (PG&E)
California Public Utilities Commission

2

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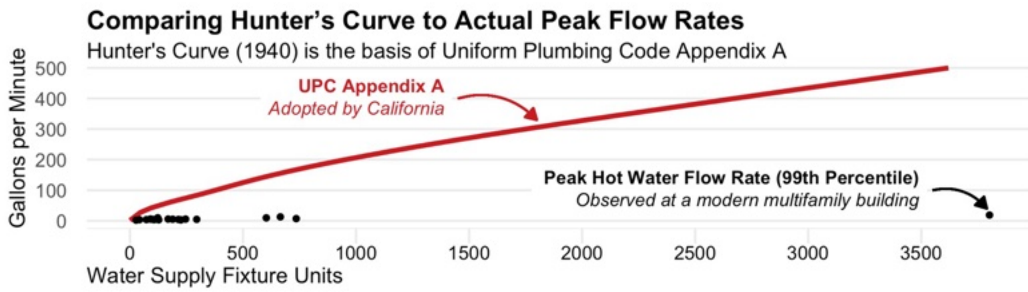
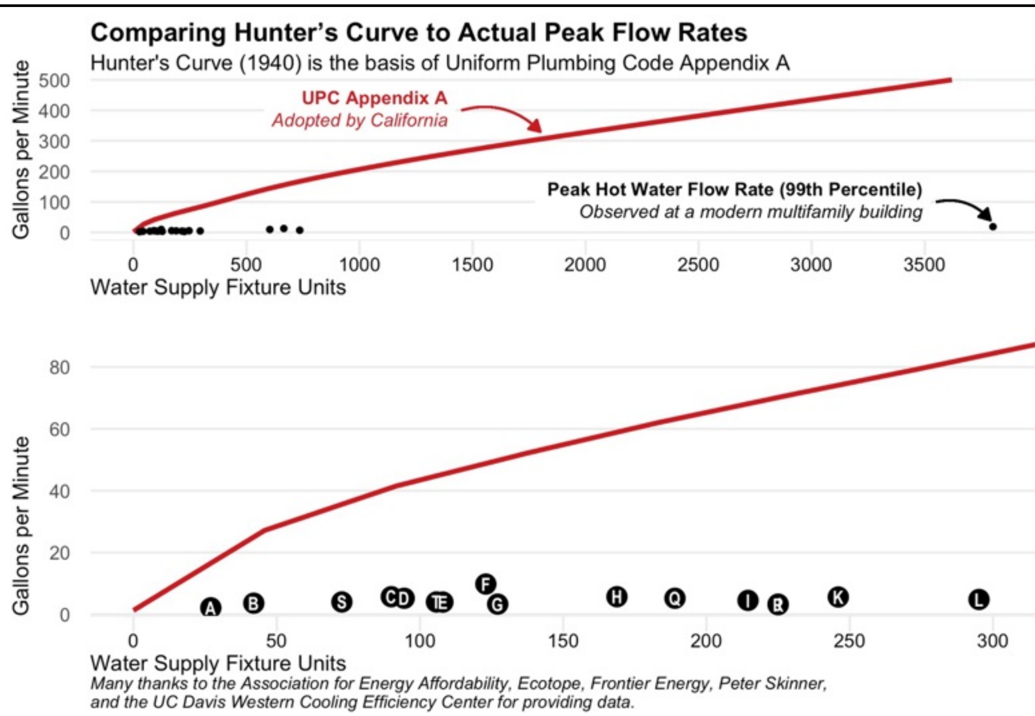

Comparing Hunter's Curve to Actual Peak Flow Rates
Hunter's Curve (1940) is the basis of Uniform Plumbing Code Appendix A
Gallons per Minute
500
400
300
200
100
0
UPC Appendix A
Adopted by California
Peak Hot Water Flow Rate (99th Percentile)
Observed at a modern multifamily building
0
500
1000
1500
2000
2500
3000
3500
Water Supply Fixture Units

3

3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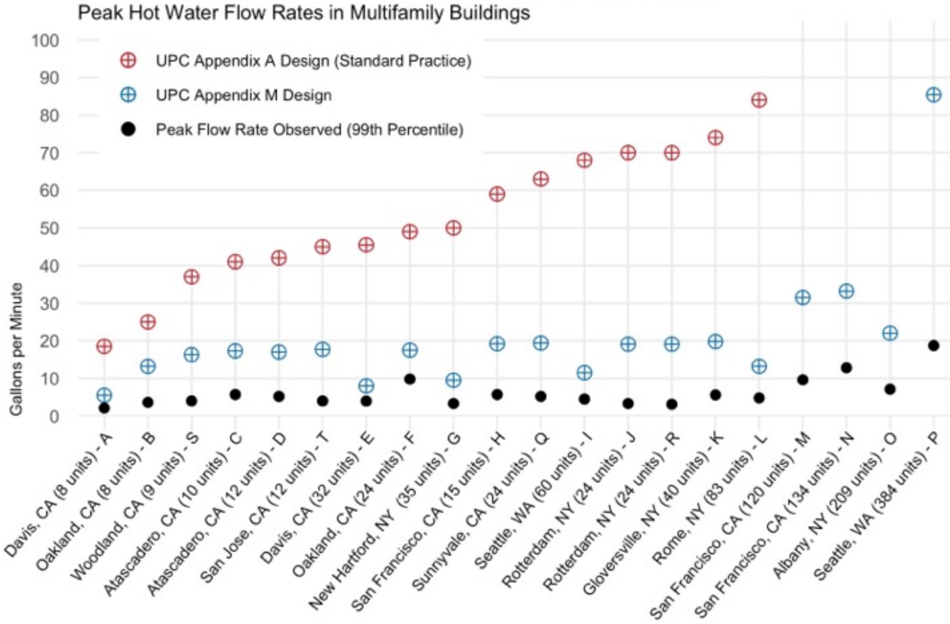
UPC Appendix A
Adopted by California
Peak Hot Water Flow Rate (99th Percentile)
Observed at a modern multifamily building
0
500
1000
1500
2000
2500
3000
3500
Water Supply Fixture Units
Gallons per Minute
80
60
40
20
0
0
50
100
150
200
250
300
Water Supply Fixture Units
Many thanks to the Association for Energy Affordability, Ecotope, Frontier Energy, Peter Skinner, and the UC Davis Western Cooling Efficiency Center for providing data.

4

4

**Comparing Design Predictions to Actual Peak Flow Rates**

Peak Hot Water Flow Rates in Multifamily Buildings




*Many thanks to the Association for Energy Affordability, Ecotope, Frontier Energy, Peter Skinner, and the UC Davis Western Cooling Efficiency Center for providing data.*

5

5

| | | | *Monitoring Data* | | | | *UPC Appendix M* | | *UPC Appendix A* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **City** | **Monitored Apartments** | **Monitoring Period (day)** | **Logging Interval (sec)** | **Time at Zero Flow** | **Study Peak (gpm)** | **Design (gpm)** | **Design Relative to Study Peak** | **WSFU** | **Design (gpm)** | **Design Relative to Study Peak** |
| **A** | Davis, CA | 8 | 304 | 15 | 87% | 2.1 | 6 | 2.6x | 27 | 19 | 8.8x |
| **B** | Oakland, CA | 8 | 10 | 1 | - | 3.6 | 13 | 3.7x | 42 | 25 | 6.9x |
| **C** | Atascadero, CA | 10 | 257 | 60 | - | 5.7 | 17 | 3.0x | 90 | 41 | 7.2x |
| **D** | Atascadero, CA | 12 | 257 | 60 | - | 5.2 | 17 | 3.3x | 95 | 42 | 8.1x |
| **E** | Davis, CA | 32 | 304 | 15 | 56% | 4.0 | 8 | 2.0x | 108 | 46 | 11.5x |
| **F** | Oakland, CA | 24 | 14 | 1 | 48% | 9.8 | 18 | 1.8x | 123 | 49 | 5.0x |
| **G** | New Hartford, NY | 35 | 26 | 60 | 69% | 3.3 | 10 | 2.9x | 127 | 50 | 15.2x |
| **H** | San Francisco, CA | 15 | 9 | 1 | - | 5.7 | 19 | 3.4x | 169 | 59 | 10.4x |
| **I** | Seattle, WA | 60 | 823 | 60 | - | 4.5 | 12 | 2.6x | 215 | 68 | 15.1x |
| **J** | Rotterdam, NY | 24 | 18 | 60 | 38% | 3.3 | 19 | 5.8x | 225 | 70 | 21.2x |
| **K** | Gloversville, NY | 40 | 12 | 60 | - | 5.6 | 20 | 3.5x | 246 | 74 | 13.2x |
| **L** | Rome, NY | 83 | 15 | 60 | 37% | 4.8 | 13 | 2.8x | 295 | 84 | 17.5x |
| **M** | San Francisco, CA | 120 | 12 | 1 | - | 9.6 | 32 | 3.3x | 603 | 143 | 14.9x |
| **N** | San Francisco, CA | 134 | 12 | 1 | 38% | 13 | 33 | 2.6x | 665 | 155 | 12.1x |
| **O** | Albany, NY | 209 | 21 | 60 | - | 7.1 | 22 | 3.1x | 735 | 168 | 23.6x |
| **P** | Seattle, WA | 384 | 609 | 60 | 8% | 19 | 85 | 4.6x | 3802 | 500 | 26.7x |
| **Q** | Sunnyvale, CA | 24 | 272 | 60 | - | 5.4 | 19 | 3.7x | 189 | 63 | 12.1x |
| **R** | Rotterdam, NY | 24 | 22 | 1 | - | 3.1 | 19 | 6.2x | 225 | 70 | 22.6x |
| **S** | Woodland, CA | 9 | 128 | 60 | 84% | 4 | 16 | 4.1x | 73 | 37 | 9.3x |
| **T** | San Jose, CA | 12 | 59 | 60 | 72% | 4 | 18 | 4.4x | 106 | 45 | 11.3x |
| | | | | | | | **Median** | **3.3x** | | | **12.1x** |

**Summary of Detailed Data for the Analyzed Multifamily Buildings**

6

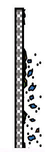
6

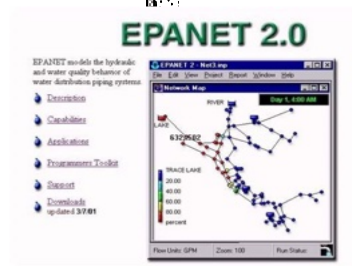
## Enhanced Plumbing System Simulation Tools

Mark Kedzierski
NIST
Engineering Laboratory

**Background:** Existing premise plumbing simulation tools, such as EPANET, which was developed for outdoor water distribution systems, are lacking in two key areas:

- Heat transfer is not well integrated
- Mycobacteria dynamics not understood and poorly modeled (dispersion only in flow direction)




**Technical Approach:**

- Facilitate the incorporation of a TRNSYS Type604 pipe heat transfer model into EPANET
- Develop a reliable model for mycobacteria dynamics in plumbing

1

## Facilitate Axial Temperature Capability in EPANET

NIST

**EPANET models the water flow and quality of distribution pipe systems:**

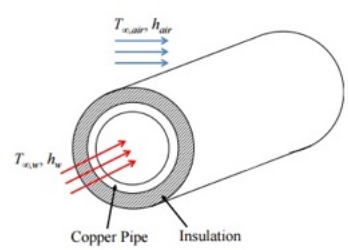
- Local behavior is not modeled

**TRNSYS Type 604 Pipe Heat Transfer Model** ***by Thermal Energy System Specialists*****:**

- The routine models the heat loss from a pipe to the surroundings and the corresponding transient, axial temperature change

**Marriage of Local Pipe Heat Transfer and EPANET:**

- The TRNSYS Pipe Model was converted to a Stand-Alone Fortran Version 4 for the purpose of integration into EPANET
- NIST Purchased Royalty-Fee to allow inclusion into EPANET
- EPA's Water Infrastructure Division plans to incorporate the heat transfer model into EPANET

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## Nontuberculous Mycobacteria Density (NTM)

NIST

**Background:**

- One the four most important OPPPs
- Associated with pulmonary illnesses and inflammatory bowel disease
- Increasing concentration as water moves from treatment plant to points of use.

**Need for Improved Models**

Quantify growth (or inhibition) of mycobacteria for better estimation of the risks association with mycobacteria
in hot and cold-water plumbing

**Complicated 2-D Problem**

**Discharge parameters correlated with or predictive of growth**
Pipe temperature
Pipe disinfectant residual
Pipe pH
Pipe HPC

**Pipe design and operation factors that plays a role in growth**
Pipe diameter
Use frequency/stagnation time

**Feed parameters that determine or predict growth**
Feed temperature
Feed disinfectant residual
Feed pH
Feed HPC



## Nontuberculous Mycobacteria Density (NTM) Measurements

NIST

**Full factorial experimental design**

with duplicate pipes for each set of factors.

- pipe material (PEX, PVC and copper),
- pipe diameter (small [half inch] and large [three quarter inch])
- use (low – once weekly and high – each twelve hours) and
- secondary disinfectant

**Measurements from:**

Tim Bartrand, Executive Director
ESPRI - The Environmental Science Policy and Research Institute
tbartrand@esprinstitute.org

Pipe racks operated for 9 months.

Pipe samples were fed and incubated to produce Mycobacteria Colonies to be counted,

i.e., the NTM

## Nontuberculous Mycobacteria Density (NTM) Model

NIST

**Background:** based on a NIST model that was derived to predict the thickness of the contaminant excess layer on water plumbing surfaces. The original model was developed using in-situ measurements that were obtained from a fluorescence-based measurement technique.

The model is governed by turbulent convection and diffusion of contaminant from the surface.

$$NTM = \frac{4C}{D_\mathrm{i}}\left(27D_\mathrm{i}\left(\frac{D_\mathrm{s}}{D_\mathrm{si}}\right)^{0.8} + \frac{2\nu_\mathrm{d} D_\mathrm{dw}}{K_\mathrm{J} u_*^2 \beta_\mathrm{T}}\right)\left(1 - e^{\frac{-K_\mathrm{J} u_*^2}{2\nu_\mathrm{d}} t_\mathrm{s}}\right)$$

Where $C$ is 1 MPN/ml. NTM was obtained by averaging the repeat measurements.

$NTM$ = NTM Density (MPN/mL)
$D_\mathrm{i}$ = internal tube diameter, m
$t_\mathrm{s}$ = use duration, s
$D_\mathrm{s}$ = disinfectant residual concentration mg/L
$D_\mathrm{si}$ = disinfectant residual concentration in feed mg/L
$K_\mathrm{J}$ = entrainment constant
$D_\mathrm{wd}$ = diffusion coefficient
$B_\mathrm{T}$ = transition depth
$u$ = friction velocity

The modified model captures the rate of NTM colonization in a pipe during a prescribed stagnation period ($t_\mathrm{s}$). The original model was modified by converting the contaminant thickness on the pipe to a rate of the reduction in the contaminant excess layer as the pipe is flushed.

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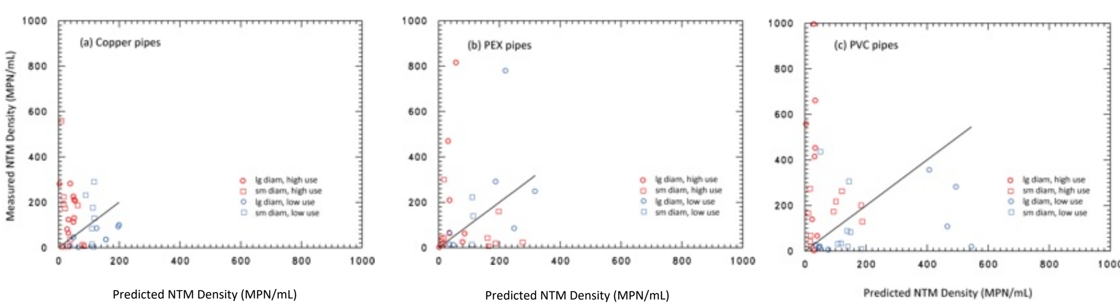
## Nontuberculous Mycobacteria density (NTM) Preliminary Results

NIST

**Plots of measured versus predicted NTM for:**

- Three different pipe materials
- Two different pipe sizes
- Two different use frequencies




Believe it or not, this model is an exciting improvement in prediction because it’s simple and physics based

6

NIST PREMISE PLUMBING RESEARCH WORKSHOP

# Standardized Plumbing System Models

Stephen Zimmerman, Andrew Persily

NOVEMBER 15, 2022

NIST NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY U.S. DEPARTMENT OF COMMERCE

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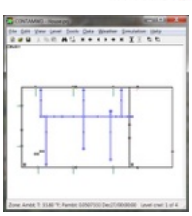
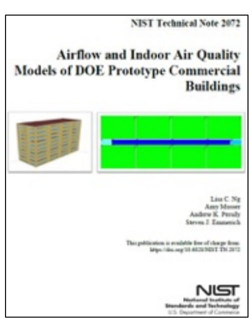
## BACKGROUND

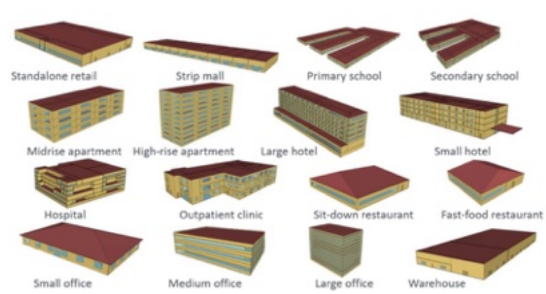
**Background:**

- Assessing plumbing innovations would benefit from standard use cases
- Standard reference building models are key tools in building energy and Indoor Air Quality analyses




NIST Technical Note 2072

Airflow and Indoor Air Quality Models of DOE Prototype Commercial Buildings

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## OBJECTIVE

**Objective:**

To define, develop, and document plumbing systems associated with a subset of prototype buildings for researchers to support consistent analyses of plumbing system performance in residential, commercial and institutional buildings, including studies of the impacts of different/emerging technologies, design approaches and operating strategies.

3

## TECHNICAL APPROACH

**Technical Approach:**

- NIST contract with local A&E firm
- Designed plumbing systems to 2018 International Plumbing Code
- Produced Revit files for all models
- 3 residential & 4 commercial buildings

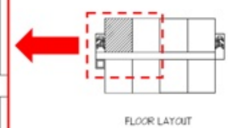
4

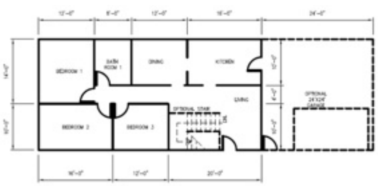
## TECHNICAL APPROACH (continued)

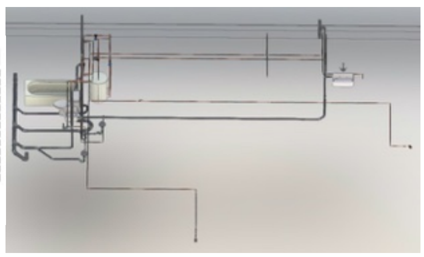
NIST

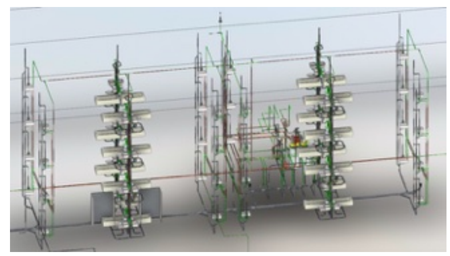
**Technical Approach:**

- 3 residential buildings
  - NIST's Suite of Homes (200+) & DOE's Standard Reference Buildings (16)
    - Single Family, Detached Home (2)
    - Mid-Rise Apartment







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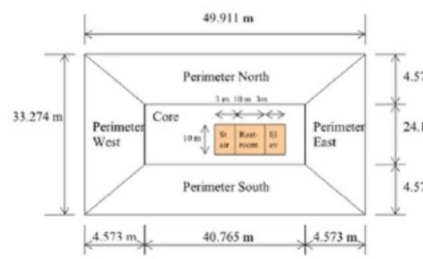
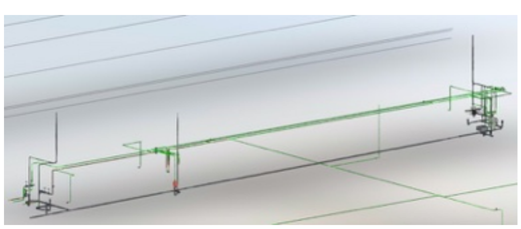
## TECHNICAL APPROACH (continued)

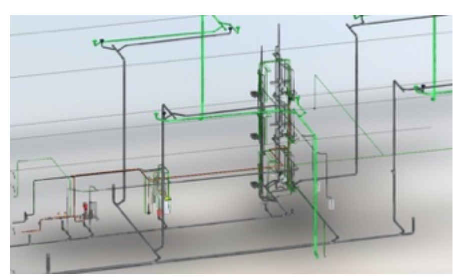
NIST

**Technical Approach:**

- 4 commercial buildings
  - DOE's Standard Reference Buildings
    - Medium Office
    - Stand-Alone Retail
    - Primary School
    - Full-Service Restaurant





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# What's Next?

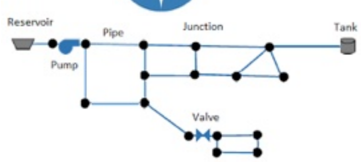
NIST

**Next Steps (FY23):**

- Document models and post for public access.

**Outyears**

- Develop EPANET models.
- Add more building types.





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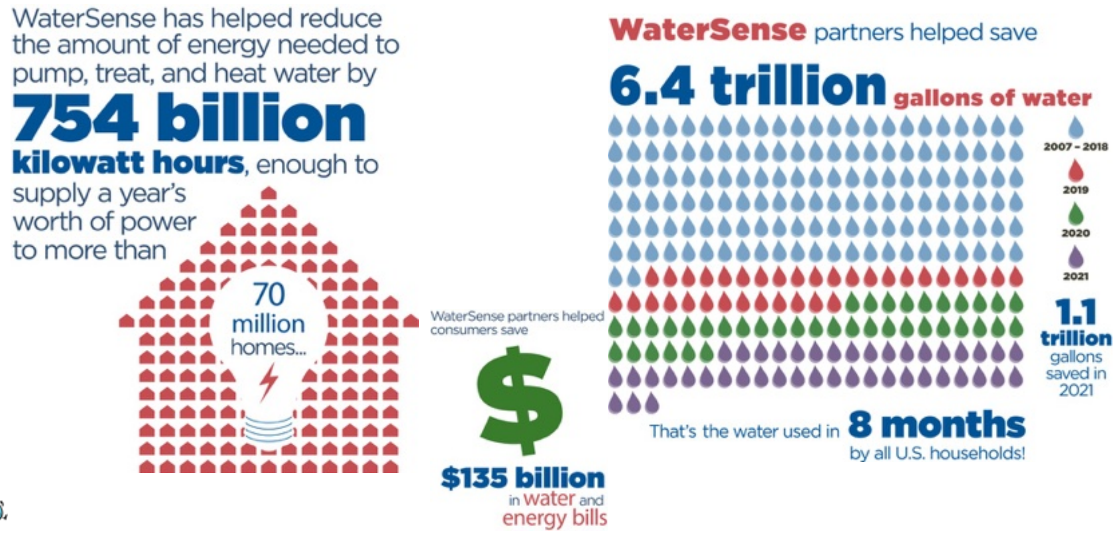
NIST

# Thank you!

8

# How We Use Water Has Changed




# Point-of-Use RO Systems

Can reduce contaminants such as:

- Total dissolved solids (TDS)
- Heavy metals (e.g., lead, arsenic, chromium)
- Nitrite/nitrate
- Volatile organic compounds (VOCs)
- PFAS/PFOA

Potential Savings

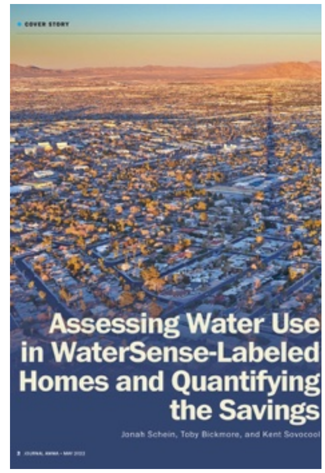
- Estimates around 3,200 gallons per year compared to typical systems

Next Steps

- Notification of Intent (NOI) released in 2022, draft anticipated in 2023
- Expected to incorporate ASSE 1086 and NSF/ANSI 58

# WaterSense Labeled Homes Study

- WaterSense piloted V2 in summer of 2020 in Las Vegas area (following the sunset of SNWA WaterSmart Homes)
  - 568 homes were certified through the pilot project
- Metered water usage was collected from the retail utilities and paired with information gathered during the inspection/certification process
- Median use was 44 kgal/year (based on 160 WaterSense labeled homes) compared to 97 kgal/year in typical new construction in the area
  - At this rate roughly 7.5 homes/year can be supplied with an acre-foot of water compared to 3-4 homes/year typically seen in the West
- Full report available online




# Comparing Data From Other Sources

| Source | Scope | Study period, results, and notes | Average Value (kgal/household/year) |
|---|---|---|---|
| **Residential End Uses of Water Study** | National | Stock housing monitored 2013-2014 | 146 |
| **SNWA** | Greater Las Vegas Area | New homes built 2000-2003 | 129 |
| **SNWA** | Greater Las Vegas Area | New homes built 2008-2009 | 97 |
| **SNWA** | Greater Las Vegas Area | New Water Smart Homes built 2008-2009 | 94 |
| **USGS Daily Withdrawal Data** | Clark County, NV | 2015 domestic withdrawal estimate includes all homes/residential water use in the area | 124* |
| **Real Time Residential Water Use Monitoring** | Greater Las Vegas Area | All Flume water monitoring device users in the area Oct 2020-Sep 2021 | 196 |

*USGS provides estimates in gallons/person/day (gpcd). Value is based on the USGS estimate of 123 gpcd and the Census estimate of 2.76 people/household in Clark County, NV

# Filling Data Gaps

ENERGY STAR & WaterSense work together to reach commercial and multifamily audiences through Portfolio Manager

- Including the EPA Water Score for multifamily properties

What can Portfolio Manager tell us about water use in the U.S.?

- 284,000 properties benchmark in Portfolio Manager (water and/or energy)
- 137,000 properties benchmark water
- Algorithm returns 43,823 properties with a greater than 75% confidence for water use data
- Individual properties types were then evaluated for distribution across age, size, climate, and operators

# How Much Water do Buildings Use?

| Property Type | WUI (gal/ft²) | | | | |
|---|---|---|---|---|---|
| | 5th | 25th | 50th | 75th | 95th |
| College/University | 2.48 | 6.20 | 13.4 | 28.3 | 66.9 |
| K-12 School | 3.02 | 6.69 | 10.5 | 18.0 | 40.6 |
| Hospital (General Medical & Surgical) | 14.3 | 38.3 | 55.7 | 77.4 | 151 |
| Hotel | 23.9 | 40.1 | 52.0 | 69.3 | 120.2 |
| Multifamily | 17.5 | 34.6 | 53.0 | 83.1 | 145 |
| Office | 2.04 | 6.47 | 13.4 | 23.4 | 73.4 |
| Medical Office | 5.18 | 11.4 | 21.2 | 39.8 | 95.2 |
| Fire Station | 4.20 | 13.4 | 26.6 | 51.5 | 158 |
| Retail Store | 1.49 | 3.03 | 7.09 | 21.6 | 55.5 |
| Warehouse/Storage Facility | 1.24 | 2.02 | 3.93 | 7.65 | 17.4 |

*The labeled homes in the previous study had an average use intensity of 25.2 gal/ft$^2$

## EPA Premise Plumbing Research

- Wildfire Research (Levi Haupert and Matthew Magnuson)
  - Study uptake and release of wildfire-associated contaminants (including benzene) from plastic drinking water pipes.
  - Investigate sampling and remediation strategies for drinking water infrastructure affected by wildfires.
  - Working closely with Regions in the west (8, 9, 10) and states like California on scoping the research.
  - Work is primarily bench scale using new and fire damaged pipes.
  - Started with benzene and is now moving on to a mixture of VOCs.

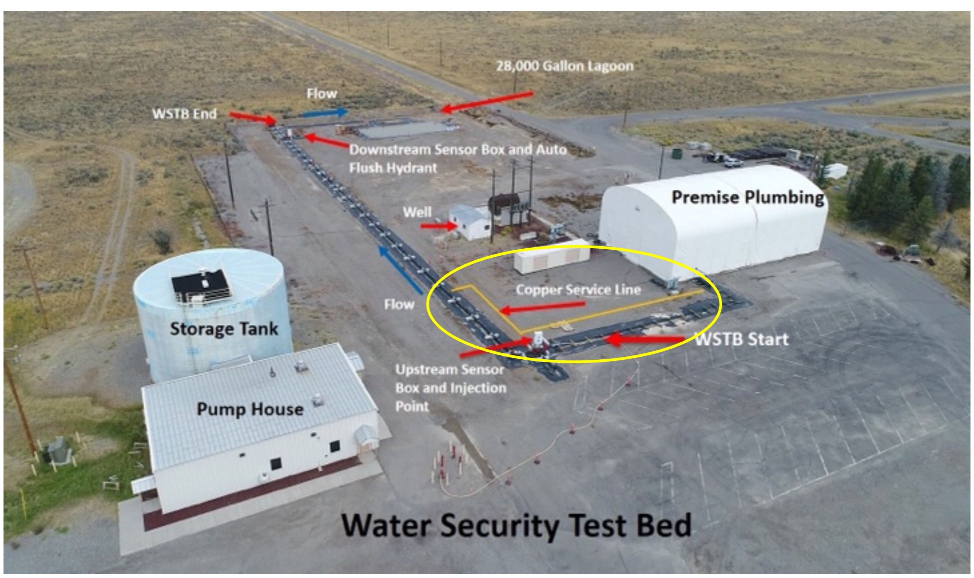
## EPA Premise Plumbing Research

- Homeland Security Full Scale Premise Plumbing Research (Helen Buse and Jeff Szabo)
  - Monitoring of chemical and microbiological water quality parameters while the newly constructed PPS reaches a steady water usage and operational state
  - Evaluation of various disinfectants (e.g., HOCl, NH2Cl, etc.), operational practices(e.g., frequent flushing, increased HWH temperatures), and decontamination technologies (e.g., POE, POU tech) to remediate chemical and microbiological contaminants in both the bulk and biofilm phases
  - Aerosolization of contaminants from showers and toilets

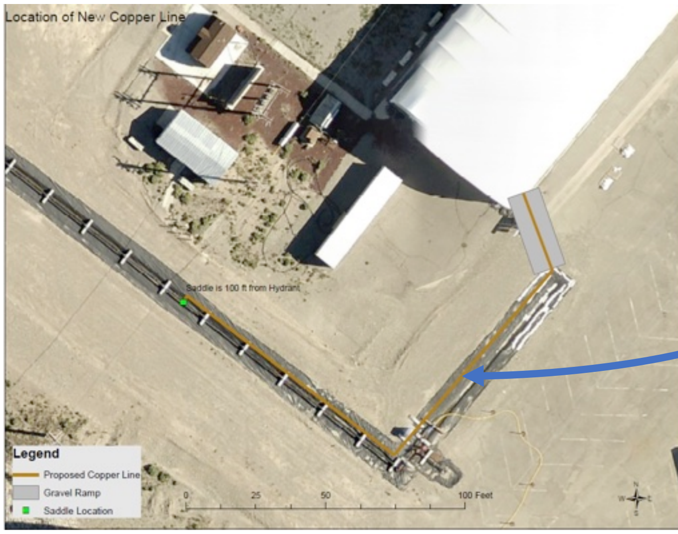
# EPA Premise Plumbing Research

- Water Infrastructure Division Research (Jon Burkhardt)
  - Started to support research into Lead exposure in premise plumbing systems
  - Developing open-source Python tool (PPMtools) as a modeling framework for this work
  - Single family home experimental rig built
    - Instrumented with pressure, flow and conductivity sensors
  - Utilizing EPA hydraulic modeling tools: EPANET, EPANET-MSX, WNTR
  - Identified data needs and limitations associated with modeling
    - Lack of fixture level pressure data, dispersion modeling for relevant flow rates/pipe sizes, lack of understanding into inter-use stagnation
  - Future work focused on effects of flushing, dispersion modeling validation, lead exposure modeling, modeling capabilities for using EPANET-MSX in PPMtools

# Water Security Test Bed

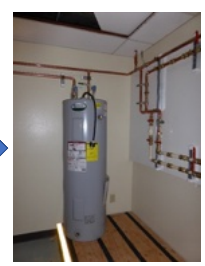


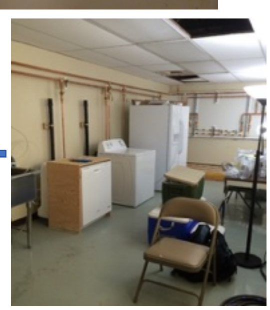
# WSTB Premise Plumbing



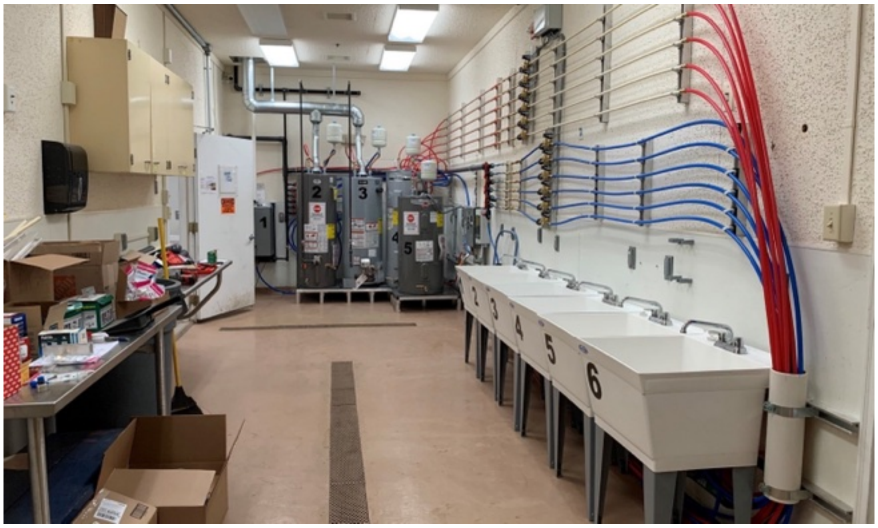

**1" Copper Service Line to Indoor Plumbing (~ 200')**

# WSTB Premise Plumbing



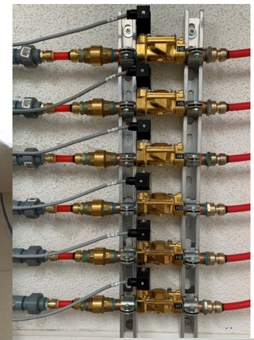


# Full Scale Premise Plumbing – T&E Facility

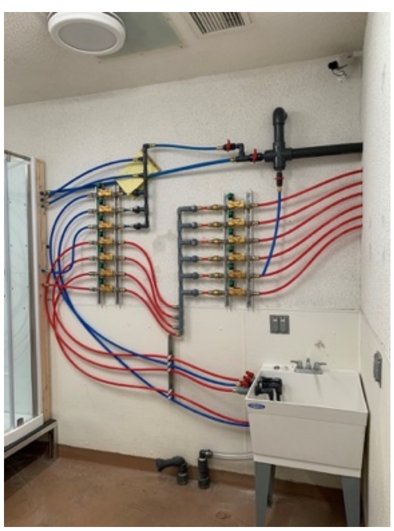


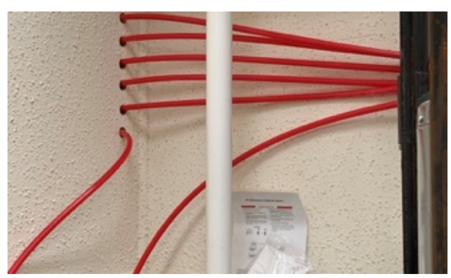

# Hot Water Heaters

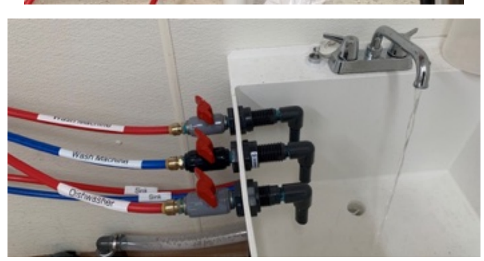

# Piping, Sinks and Control Valves




# Inlet, Shower and Toilet Connections

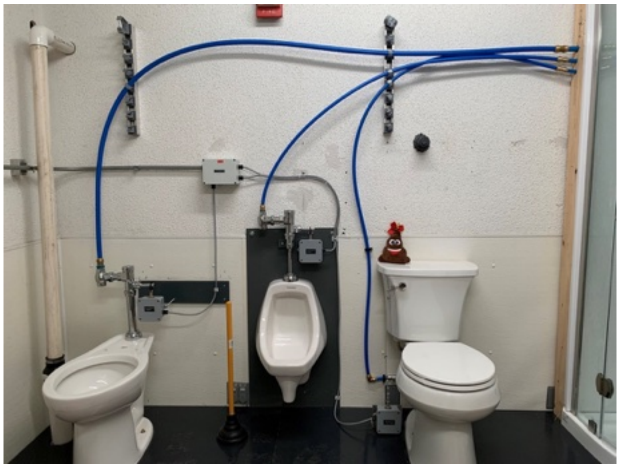






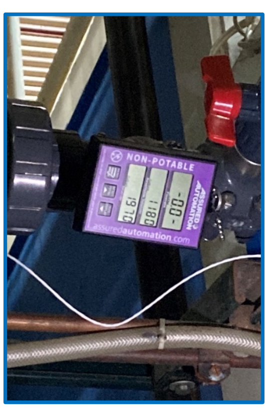
EPA United States Environmental Protection Agency

# Shower and Toilets

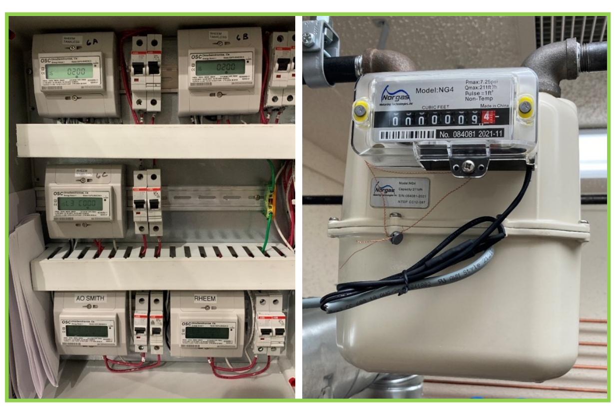


EPA United States Environmental Protection Agency

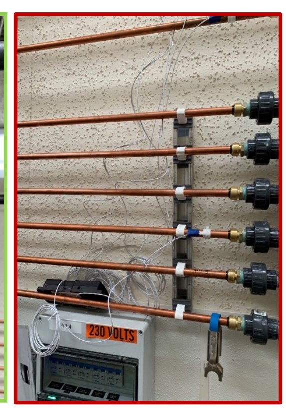
# Online Monitoring



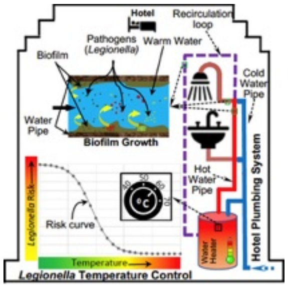

Water Usage

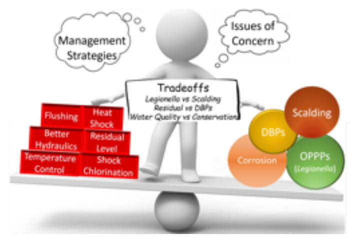



Energy Usage




Pipe Temperature




# Water Quality in Buildings

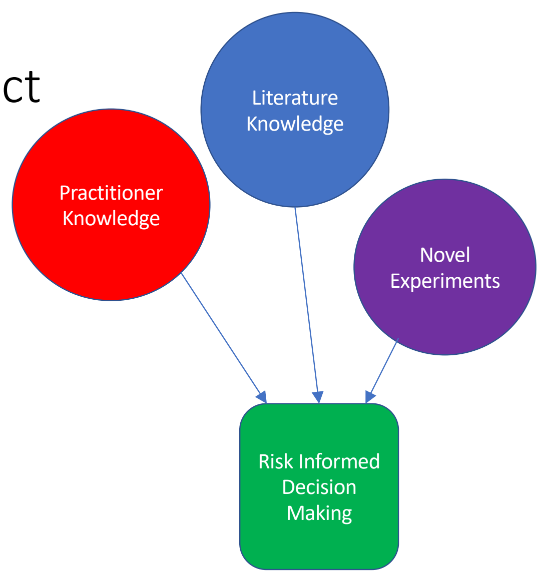
Results of EPA sponsored study conducted by

Drexel, ESPRI, University of Colorado

2016-2021

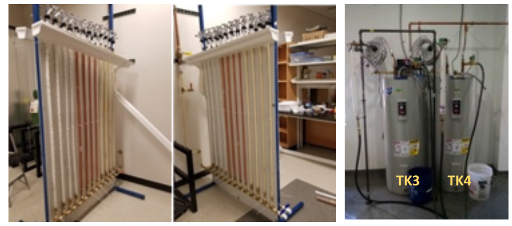
## Overview of Project

- Knowledge synthesis



# Laboratory research and risk assessment

- Nitrifiers and nontuberculous mycobacteria are pervasive in chloramine system
  - Even with flushing twice a day
- DALY framework for health impact of microbial and chemical contaminants
  - Disinfection byproducts risk > mycobacteria risk




ORIGINAL RESEARCH — AWWA WATER SCIENCE

**Full factorial study of pipe characteristics, stagnation times, and water quality**

Dienye L. Tolofari[1] | Sheldon V. Masters[2] | Tim Bartrand[2] | Kerry A. Hamilton[3,4] | Charles N. Haas[1] | Mira Olson[1] | R. Scott Summers[5] | Md Rasheduzzaman[1] | Audrey Young[5] | Rajveer Singh[1] | Patrick L. Gurian[1]

ACS ES&T Water
pubs.acs.org/estwater — Article

**Disability-Adjusted Life Year Frameworks for Comparing Health Impacts Associated with *Mycobacterium avium*, Trihalomethanes, and Haloacetic Acids in a Building Plumbing System**

Dienye L. Tolofari,* Tim Bartrand, Charles N. Haas, Mira S. Olson, and Patrick L. Gurian

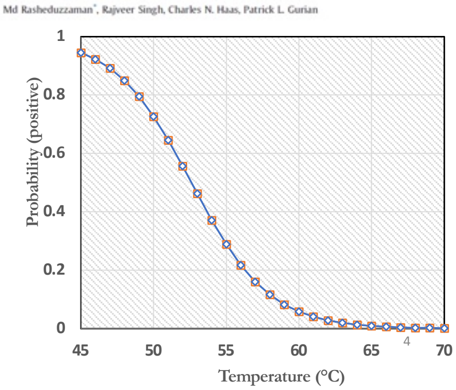
# Learning from existing studies: Meta-analysis of temperature and *Legionella* occurrence in hotels

- Logistic regression fit to data from different studies of hotels
- Temperature above 65°C at the hot water tap is required to reduce the probability of detectable *Legionella* to **<1%**
- If a tolerable concentration of *Legionella* was defined as ~1000 CFU/L (Hamilton et al., 2019), then substantially lower hot water temperatures such as 50°C might suffice

Contents lists available at ScienceDirect
Water Research
journal homepage: www.elsevier.com/locate/watres

Required water temperature in hotel plumbing to control *Legionella* growth

Md Rasheduzzaman*, Rajveer Singh, Charles N. Haas, Patrick L. Gurian



# Research needs

water MDPI

Article

**Managing Water Quality in Premise Plumbing: Subject Matter Experts' Perspectives and a Systematic Review of Guidance Documents**

Rajveer Singh [1,*,†], Kerry A. Hamilton [2,3,†], Md Rasheduzzaman [1,†], Zhao Yang [1,4,†], Saurajyoti Kar [1], Angelita Fasnacht [1], Sheldon V. Masters [5] and Patrick L. Gurian [1]

| Concern Areas | Significant Knowledge Gap Issues | Basis for Knowledge Gap Identification |
|---|---|---|
| Flushing (Operational) | 1. Determine optimum flushing frequency considering the tradeoff between residual replenishment and OPPPs nutrient feeding. | Disagreement among SMEs and GDs |
| Residual levels (Operational) | 2. Determine optimum numerical values for residual concentrations under different conditions with consideration of OPPPs control and tradeoffs with DBP formation. | Disagreement among SMEs and GDs |
| Thermostatic mixing valves (Design) | 3. Investigate TMVs as problematic elements for OPPPs growth and if just alternative designs or proper maintenance can resolve issues. | Disagreement among SMEs |
| Chloramine vs. chlorine (Operational) | 4. Investigate tradeoffs between disinfectants and if chloramines are effective for mycobacteria control. | Disagreement among SMEs and GDs |
| Temperature control strategy (Design and operational) | 5. Despite a consensus understanding of temperate effects on *Legionella*, there is a lack of consensus on the emphasis on temperature, hydraulics, and the role of mixing valves for OPPPs control. Very roughly one might describe the approaches as: (1) use high temperature (60 °C heater setpoint) and (2) use more moderate temperature (49–55 °C heater setpoint) but require short flow times and limited temperature drops in pipes. | Disagreement among SMEs |
| Water heater type (Design) | 6. Compare water quality of on-demand tankless heaters with tanked heaters. | Consensus that gap exists among SMEs |
| Pipe materials (Design) | 7. Investigate suitable pipe materials or anti-microbial coating for OPPPs growth.<br>8. Investigate impacts of copper as pipe material with respect to *Legionella* and other OPPPs, leaching properties, and compatibility with hot water. | Consensus that gap exists among SMEs |
| Control strategy (Operational) | 9. Does temperature control work for mycobacteria and other OPPPs too? How do microbial communities adapt/shift in composition in response to temperature changes? | Consensus that gap exists among SMEs |
| OPPPs Characterization | 10. *Legionella* (and other OPPPs) growth characterization with respect to temperature, time, residuals, nutrients, and other conditions.<br>11. Standardize OPPPs characterization techniques (staining, etc.) and identify factors associated with OPPPs (concentration, etc.) and health risk | Consensus that gap exists among SMEs |

Complex and varied information needs

Gaps in knowledge

Differences in how to interpret available knowledge

Follow up Delphi study with more specific points of consensus/disagreement

# Build plumbing systems are commonly operated in ways ***known*** to provide favorable growth conditions for opportunistic pathogens

water MDPI

Article

**Practitioners' Perspective on the Prevalent Water Quality Management Practices for *Legionella* Control in Large Buildings in the United States**

Rajveer Singh [1,*], Deepika Chauhan [2,†], Alanna Fogarty [2,†], Md Rasheduzzaman [1,3,†] and Patrick L. Gurian [1]

How do we act on the ***knowledge we already have***?

Building water systems are generally operated at temperatures that protect against scalding but are favorable for growth of opportunistic pathogens

# Temperature Summary in Building Surveys

| Parameters | Interview Response °F (°C) | | Buildings in Compliance Total (Low Vuln., High Vuln.) | Guidance Compliance Recommendation °F (°C) | References |
|---|---|---|---|---|---|
| Water Heater Set Point Temp | N | 35 | 37% (33%, 43%) | ≥ 140 (≥60) | OSHA, 1996<br>CDC, 2003<br>WHO, 2007<br>EGWG, 2017<br>NASEM, 2020 |
| | Median | 130 (54) | | | |
| | Range | 105-192 (41-89) | | | |
| | St. Dev. | 21 (12) | | | |
| Point of Use Temperature | N | 36 | 47% (52%, 40%) | < 110 (<43) | WHO, 2011<br>IPC, 2015 |
| | Median | 110 (43) | | | |
| | Range | 90-128 (32-53) | 94% (90%, 100%) | 122-124 (50-51) | DVA, 2014<br>EGWG, 2017 |
| | St. Dev. | 11 (6) | | | |
| Recirculation Loop Temperature | N | 24 | 25% (27%, 22%) | ≥ 122 (≥50) | WHO 2007<br>EGWG 2017 |
| | Median | 110 (43) | | | |
| | Range | 90-179 (32-82) | | | |
| | St. Dev. | 20 (11) | | | |
| Maximum Temperature loss in plumbing (Set Point – Recirculation Loop) | N | 22 | 26% (39%, 15%) | < 9 (<5) | ASPE, 2008 |
| | Median | 13 (7) | | | |
| | St. Dev. | 12 (7) | | | |
| Hot Water Temperature Time to Tap | 0 - 30 sec | 18 (49%) | 73% (73%, 73%) | 10-30 secs | ASPE, 2003 |
| | 31- 60 sec | 9 (24%) | | 122-131 (50-55) at POU within 60 Sec | EGWG, 2017 |
| | > 60 sec | 10 (27%) | | ≥ 131 (≥55) at distal point within 60 Sec | NASEM, 2020 |

7

# Plumbing Information and Performance Evaluation Tool (PIPE): Guidance is available but it's complicated

➢ Potential Risks

**Microbial Risk**

| Hot Water °C | Hot Water °F | Compliance with 8 Guidance Documents |
|---|---|---|
| < 43 | < 110 | ✘✘✘✘✘✘✘✘(0/8) |
| 43 - 48 | 110 – 118 | ✘✘✘✘✘✘✘✘(0/8) |
| 49 - 50 | 119 – 122 | ✔✔✔✔✘✘✘✘(4/8) |
| 51 - 54 | 123 – 130 | ✔✔✔✔✔✔✘✘(6/8) |
| 55 - 59 | 131 – 139 | ✔✔✔✔✔✔✔✔(8/8) |
| >= 60 | >= 140 | ✔✔✔✔✔✔✔✔(8/8) |

Annotation
✘ Not hot enough to comply
✔ Hot enough – complies with guidance

**Scald Risk**

| Point of use °C | Point of use °F | Compliance with 4 Guidance Documents |
|---|---|---|
| < 43 | < 110 | ✔✔✔✔(4/4) |
| 43 - 48 | 110 – 118 | ✔✔✘✘(2/4) |
| 49 - 50 | 119 – 122 | ✔✔✘✘(2/4) |
| 51 - 54 | 123 – 130 | ✘✘✘✘(0/4) |
| 55 - 59 | 131 – 139 | ✘✘✘✘(0/4) |
| >= 60 | >= 140 | ✘✘✘✘(0/4) |

Annotation
✘ Too hot to comply with guidance
✔ Cool enough – complies with guidance

Website to help practitioners identify appropriate sources of guidance
Many guidance documents – almost every topic is covered somewhere
Tradeoff between microbial risk and scald risk leads to conflicting guidance
Get the knowledge we already have to the people who need it

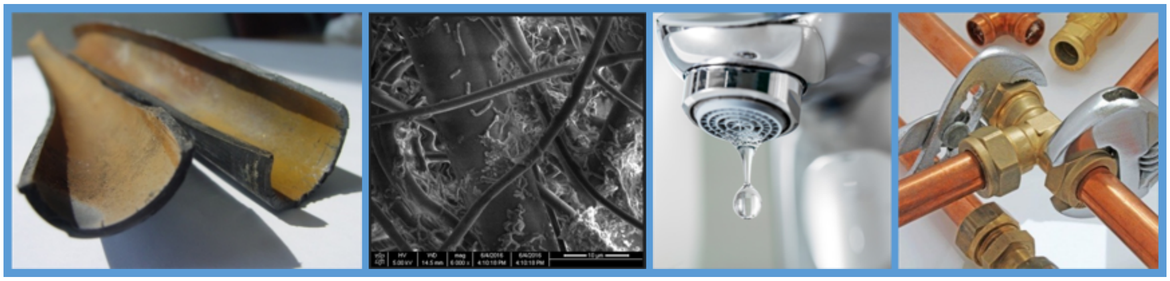
# Contact information

- Patrick Gurian, Civil, Arch., and Env. Engineering, Drexel Univ.
  - pgurian@drexel.edu
- ResearchGate
  - https://www.researchgate.net/project/Building-Water-Quality
- Plumbing Information and Performance Evaluation (PIPE) tool
  - https://research.coe.drexel.edu/caee/pipe/
  - Still getting some bugs out

University of Colorado Boulder

DREXEL UNIVERSITY College of Engineering

# Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health



Completed: 2016-2022

Andrew Whelton, Jade Mitchell, Joan Rose, Juneseok Lee, Pouyan Nejadhashemi, Erin Dreelin, Tiong Gim Aw, Amisha Shah, Maryam Salehi

*NIST Premise Plumbing Research Workshop*
*November 15, 2022*

*Final Report:* Now available at www.PlumbingSafety.org

PURDUE UNIVERSITY | MICHIGAN STATE UNIVERSITY | SJSU SAN JOSÉ STATE UNIVERSITY | MANHATTAN COLLEGE | Tulane University | THE UNIVERSITY OF MEMPHIS

System Basics

## Building water system public health **risks**

*Exposure Routes of Concern: Ingestion, Dermal, Inhalation*

### Routine Operations

**Disinfectant residual** may not be replenished

**Heavy metals** can leach (Cu, Mn, Ni, Pb, Zn..)

**Organics** can leach/form (VOCs, SVOCs, DBPs)

**Scale** can destabilize and suspend

**Harmful organisms** can grow (e.g., *L. pneumophila, MAC, P. aeruginosa* …)

### Accident and Post-Disasters

Pressure loss, backflow, chemical spill, hurricane, flooding, wildfire, intentional attack, and more

PURDUE UNIVERSITY

# Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health, 2017-2022

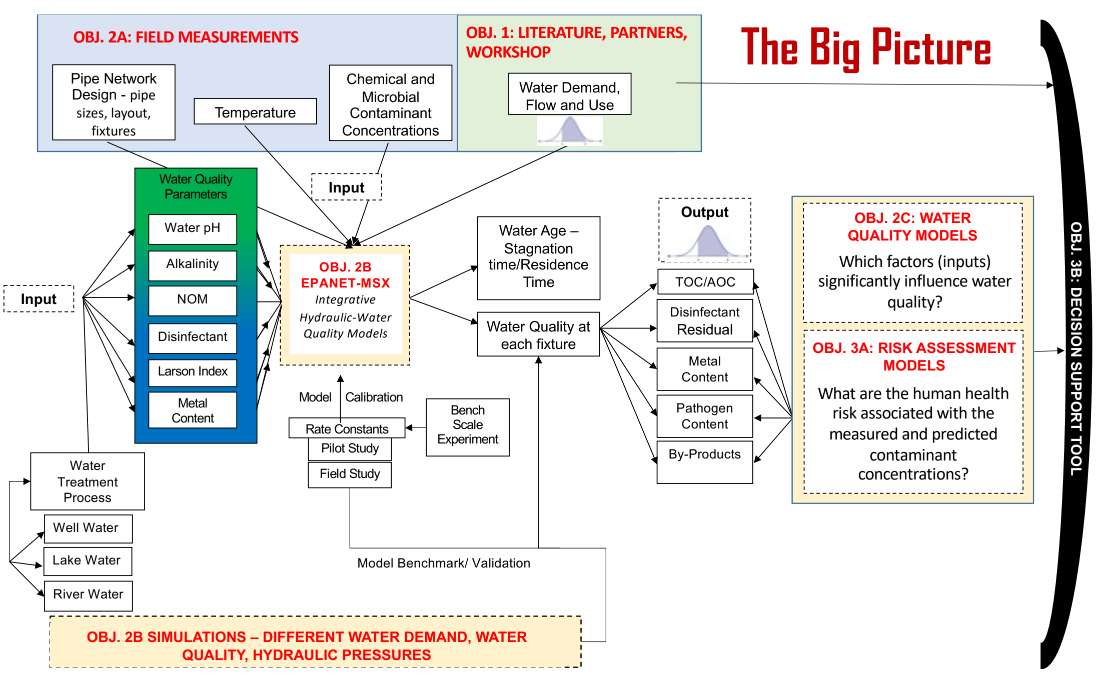
*To better understand and predict water quality and health risks posed by declining water usage and low flows*

1. **Improve the public's understanding of decreased flow** and establish a range of theoretical premise plumbing flow demands from the scientific literature and expert elicitation with our strategic partners
2. **Elucidate the factors and their interactions that affect drinking water quality** through fate and transport simulation models for residential and commercial buildings
3. **Create a risk-based decision support tool** to help guide decision makers through the identification of premise plumbing characteristics, operations and maintenance practices that minimize health risks to building inhabitants.

Andrew Whelton, Jade Mitchell, Joan Rose, Juneseok Lee, Pouyan Nejadhashemi, Erin Dreelin, Tiong Gim Aw, Amisha Shah, Maryam Salehi

FINAL REPORT: To posted at www.PlumbingSafety.org
December 2022

Purdue University | Michigan State University | SJSU San José State University | Manhattan College | Tulane University | The University of Memphis



**OBJECTIVE 1. Improve the understanding of decreased flow and establish a range of theoretical plumbing flow demands from the scientific literature and expert elicitation with our partners (Ind., Gov.)**

The www.PlumbingSafety.org website had 10,000s page views. Educational YouTube videos as well as lists of resources, and FAQs were created.

70+ presentations for multiple sectors (public health, water utility, manufacturer, building design) in the U.S., Canada, the U.K., and also an international water association webinar.

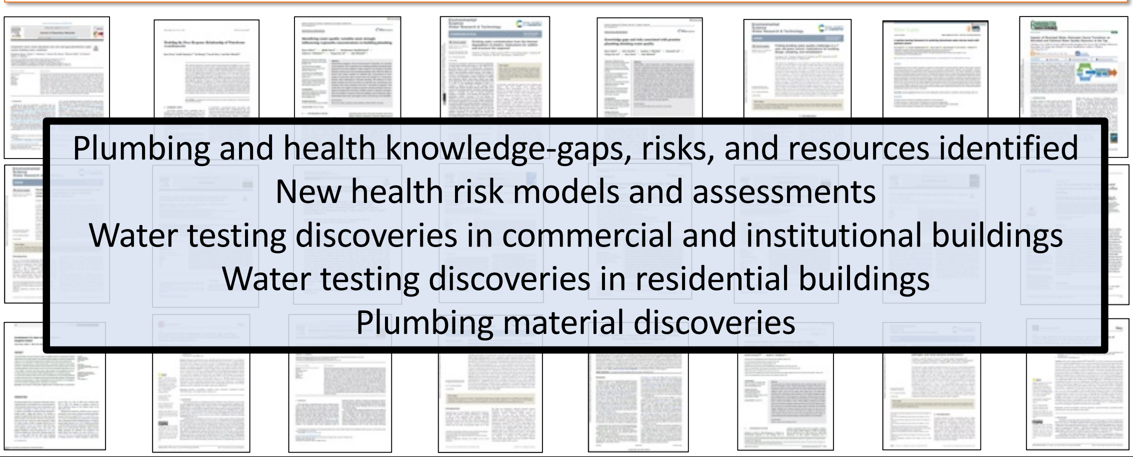
Supported homeowners about water testing, materials, and also wildfires.

Helped develop the AWWA COVID-19 building water system guidance.

Established a range of theoretical plumbing flow demands in the peer-review literature.

PURDUE UNIVERSITY | MICHIGAN STATE UNIVERSITY | SJSU SAN JOSÉ STATE UNIVERSITY | MANHATTAN COLLEGE | Tulane University | THE UNIVERSITY OF MEMPHIS

**OBJECTIVE 2. Elucidate the factors and their interactions that affect drinking water quality through fate and transport simulation models for residential and commercial buildings (25+ peer-reviewed publications)**

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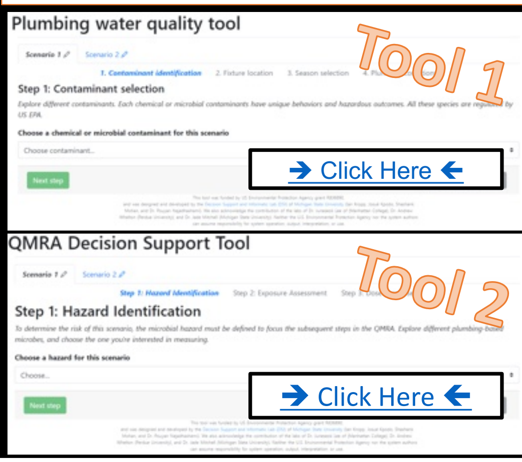
**OBJECTIVE 3. Create a risk-based decision support tool to help guide decisions through the identification of plumbing characteristics, operations and maintenance practices that minimize health risks to building inhabitants.**




## Online and FREE Building Water Quality Tools Now Available

**Usefulness**

Examine plumbing design impacts
*(pipe length, cold vs. hot, conservation)*

Evaluate water use impacts
*(fixture type, seasons)*

Compare exposure scenarios
*(Legionella spp., MAC, HPC, $Cl_2$, Cu, Fe, Pb, $NO_3^-$, TTHM)*

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## *Thank you. Final report now on PlumbingSafety.org*

Andrew Whelton, Ph.D. awhelton@purdue.edu @TheWheltonGroup

www.PlumbingSafety.org

- ✓ Online short-course
- ✓ Plumbing education videos
- ✓ Flushing plans
- ✓ Plumbing explainers
- ✓ List of projects
- ✓ Scientific opinions
- ✓ Resources → presentations
- ✓ Scientific reports
- ✓ External plumbing docs
- ✓ YouTube Channel

**10 hr, 1 CEU, Self-paced, Online**
**Building Water Essentials Short-Course:**
https://engineering.purdue.edu/online/certifications/building-water-essentials

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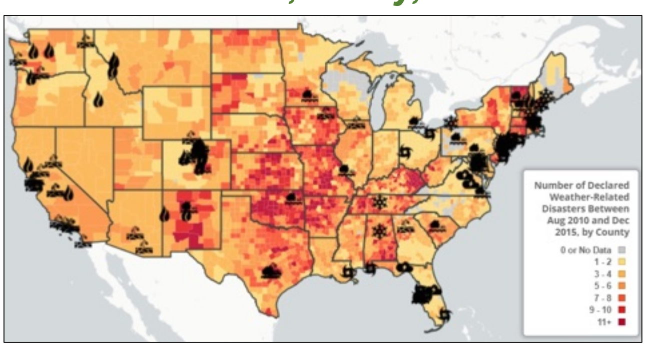
# Disaster Impacts on Plumbing

NIST Premise Plumbing Workshop
November 2022

*Andrew J. Whelton, Ph.D.*
*Purdue University*

***Safe drinking water and infrastructure are critical to the health, safety, and economic security***

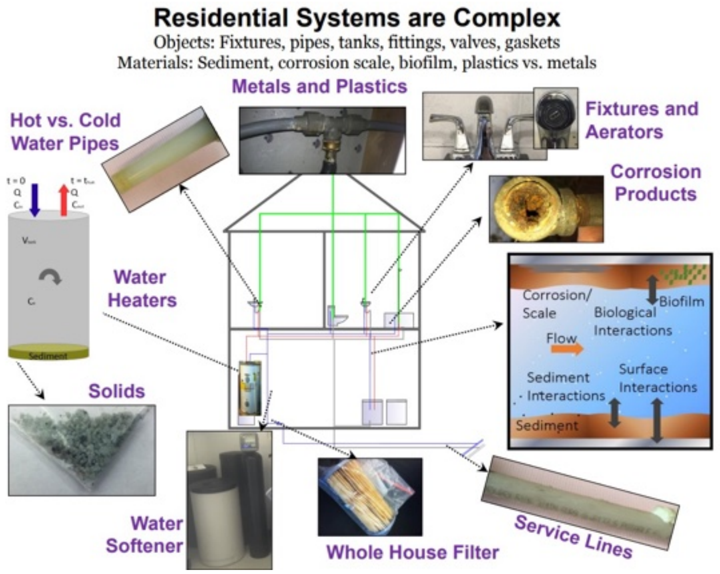



Floods, Hurricanes
Tropical Storms,
Tornadoes, Snow, Ice,
And Wildfires

1,000s of communities each year are affected prompting drinking water safety risks

**Wildland Urban Interface (WUI)**
Human development intermingles with vegetative and wildland fuels
Fastest growing land use
46M+ residences in 70,000 communities

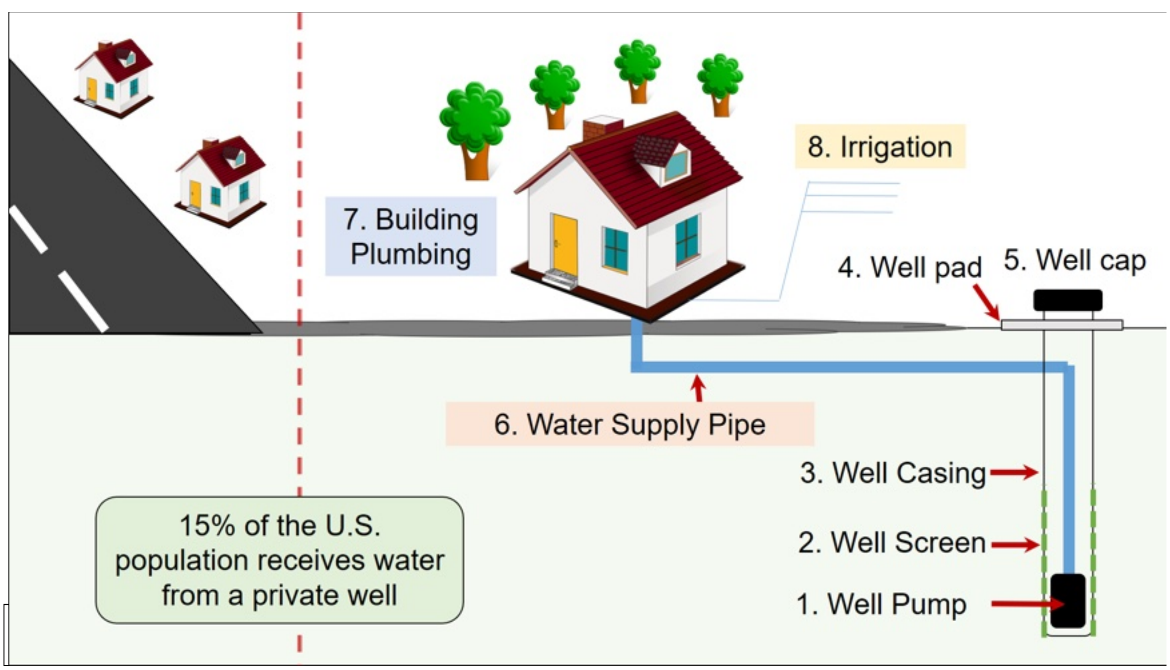
*EnvironmentAmerica.org*

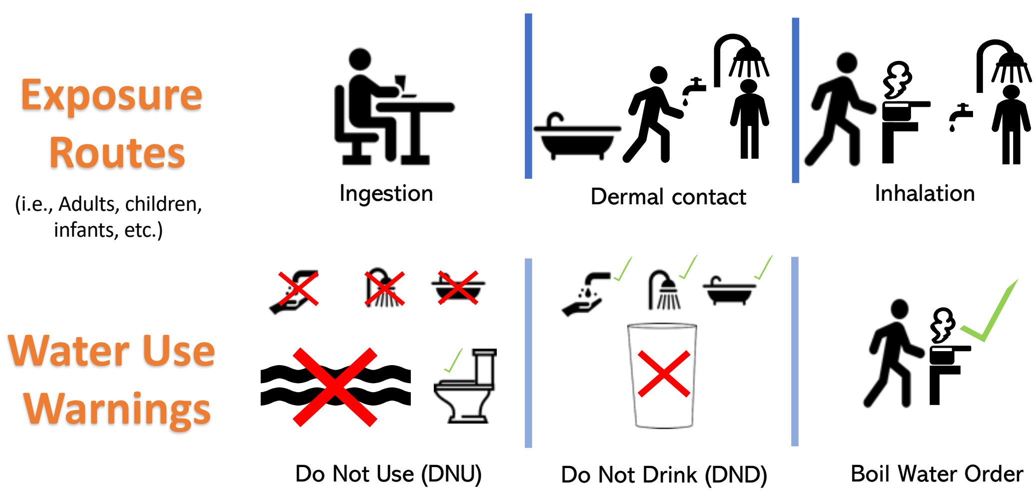



**Assets**
Water source
Distribution
Fittings, Fixtures
Treatment Equipment

**Damage**
Loss of water pressure
Water contamination
Plumbing contam.








*If you do not know the range of contamination, it is not advisable to use in-home water treatment devices. Those are NOT rated to make acutely contaminated water safe.*

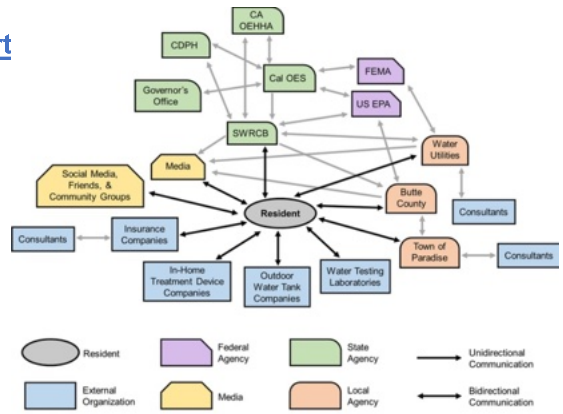
## Water safety attitudes, risk perception, experiences, and education for households impacted by the 2018 Camp Fire

*Natural Hazards, Published May 2021* https://doi.org/10.1007/s11069-021-04714-9

### Household Public Health Support Not (yet) Based on Science

1) Water use restrictions
2) Plumbing sampling and testing
3) Plumbing decon and validation
4) Water tank selection and maintenance
5) In-home treatment device selection and maintenance

*Rural communities are especially impacted*






## *What are the threats?*

Organic chemicals
Inorganic chemicals
Radionuclides
Microorganisms

**A Few (of many) Examples**

2021 (Marshall Fire) Boulder Co., CO, Pop: 40,000

2021 (Petroleum spill) Pearl Harbor, HI, Pop: 93,000

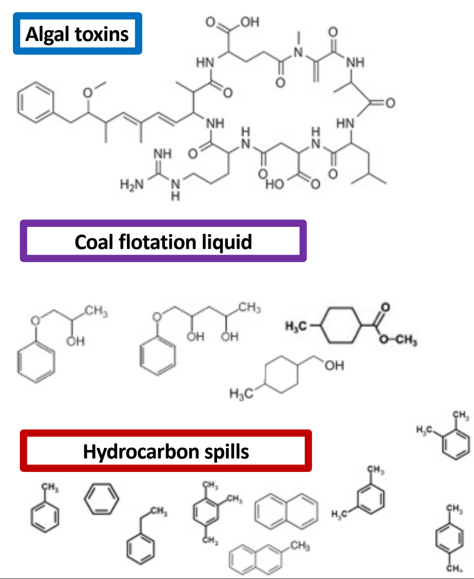
2021 (Petroleum backflow) San Angelo, TX, Pop: 101,000

2020 (*Naegleria fowleri*), Lake Jackson, TX, Pop: 172,000

2018 (Microcystins) Salem, OR, Pop: 199,000

2017 (*E. Coli*), Puerto Rico, Pop: 100,000

2013 (*Naegleria fowleri*) St. Bernard, LA, Pop: 44,000



| Max. Benzene | Wildfire Event / Location | Pop. Affected | System Name | Year |
|---|---|---|---|---|
| 221 | Marshall Fire/ Colorado | 20,319 | City of Louisville | 2021 |
| 5.1 | Marshall Fire/ Colorado | 300 | East Boulder County Water District | 2021 |
| 5.5 | Echo Mountain Fire/ Oregon | 120 | Whispering Pines Mobile Home Park | 2020 |
| 11.3 | Echo Mountain Fire/ Oregon | 362 | Hiland WC - Echo Mountain | 2020 |
| 1.1 | Echo Mountain Fire/ Oregon | 760 | Panther Creek Water District | 2020 |
| 76.4 | Almeda Fire/ Oregon | 6,850 | City of Talent | 2020 |
| 44.9 | Lionshead Fire/ Oregon | 205 | Detroit Water System | 2020 |
| 1.8 | CZU Lightning Complex Fire/ California | 1,650 | Big Basin Water Company | 2020 |
| 42 | CZU Lightning Complex Fire/ California | 21,145 | San Lorenzo Water District | 2020 |
| >2,217 | Camp Fire/ California | 26,032 | Paradise Irrigation District | 2018 |
| 38.3 | Camp Fire/ California | 924 | Del Oro Water Co. - Magalia | 2018 |
| 8.1 | Camp Fire/ California | 1,106 | Del Oro Water Co. - Lime Saddle | 2018 |
| 530 | Camp Fire/ California | 11,324 | Del Oro Water Co. - Paradise Pines | 2018 |
| 40,000 | Tubbs Fire/ California | 175,000 | City of Santa Rosa | 2017 |

| Location | Year | Cause | Contaminant | Plumbing system decon method | Population affected | Health impacts | Duration, days |
|---|---|---|---|---|---|---|---|
| Nibley City, UT[45] | 15 | Truck spill | Diesel fuel | Flushing | 5000 | nr | 1 |
| Glendive, MT[46] | 15 | Pipe rupture, spill | Crude oil | Flushing | 6000 | Yes | 5 |
| Longueuil, QC, CN | 15 | Tank rupture, spill | Diesel fuel | None | 230 000 | No | 2 |
| Washington, D.C.[47] | 14 | Unknown | Petroleum product | Flushing | Est. 370 | nr | 3 |
| Toledo, OH[48] | 14 | Algal bloom | Microcystins[c] | Flushing | 500 000 | No | 2 |
| Charleston, WV[1] | 14 | Tank rupture, spill | Coal chemical | Flushing | 300 000 | Yes | 9[b] |
| Jackson, WI[49] | 12 | Pipe rupture, spill | Petroleum product | nr | 50 | nr | 30 |
| Safed, Israel[38] | 10 | DS backflow | Diesel fuel | Flushing; surfactant | 3000 | nr | 3 |
| Boise, ID[50] | 05 | Unknown | TCE | Flushing | 117 | nr | nr |
| Stratford, ON, CN[51] | 05 | DS backflow | 2-Butoxyethanol | Flushing | 32 000 | Yes | Up to 7 |
| Northeast Italy[52] | 02 | New pipe install | Cutting oil | Flushing | 4 bldgs | nr | Months |
| Guelph, CN[53] | 97 | DS backflow | Petroleum product | nr | 48 000 | nr | 3 |
| Charlotte, NC[36] | 97 | DS backflow | Fire suppressant (AFFF)[d] | Flushing | 29 bldgs | No | nr |
| Tucumcari, NM[32,54] | 95 | DS backflow | Toluene, phenol, *etc.*[a] | Flushing | nr | Yes | nr |
| Uintah Highlands, UT[32] | 91 | DS backflow | TriMec; 2,4-D; dicamba | nr | 2000 homes | Yes | nr |
| Hawthorne, NJ[36] | 87 | DS backflow | Heptachlor | $Cl_2$ flush; replacement | 63 | No | nr |
| Gridley, KS[54] | 87 | DS backflow | Lexon DF | nr | 10 homes, 1 business | nr | nr |
| Hope Mills, NC[36] | 86 | DS backflow | Heptachlor, chlordane | Flushing | 23 homes | No | 3 |
| Pittsburgh, PA[54] | 81 | DS backflow | Heptachlor, chlordane | Flushing; replacement | 300 (23 bldgs) | No | 27 |
| Lindale, Georgia[55] | 80 | DS construction | Phenolic compounds | Super-chlorination | Hospital | Yes | nr |
| Montgomery Cnty, PA[35] | 79 | Tank rupture, spill | TCE | nr | 500 | Yes | nr |

Casteloes et al. 2015. Decontaminating chemically contaminated residential premise plumbing systems by flushing. https://doi.org/10.1039/C5EW00118H.

## A few (of many) examples…

**Statement by Environmental Activist (2014, WV):**
"…the amount of chemical likely destroyed your home water treatment system."

"…if you had an RO system, the chemical likely ate the membrane."

"…your[plumbing] pipe material will not be impacted."

**Statement by Scientist (2014, WV):**
"It's a hydrophobic molecule like oil. You can't just flush it out… a substance like that. It sticks to surfaces, and you have to use soap and water."

**Statement by Homeowner (2015, MT):**
"I ran it for about ten minutes and had to open up the door for five minutes to get the smell out," she said. "My God, did I end up getting a headache."

### *The Response: Answers*

Decontaminating chemically contaminated residential premise plumbing systems by flushing. https://doi.org/10.1039/C5EW00118H

Casteloes et al. 2016. Crude oil contamination of plastic & copper drinking water pipes. https://doi.org/10.1016/j.jhazmat.2017.06.015

Huang et al. 2017. The interaction of surfactants with plastic & copper plumbing materials during decontamination. https://doi.org/10.1016/j.jhazmat.2016.11.067

Hawes et al. 2016. Predicting contaminated water removal from residential water heaters under various flushing scenarios. https://doi.org/10.5942/jawwa.2017.109.0085

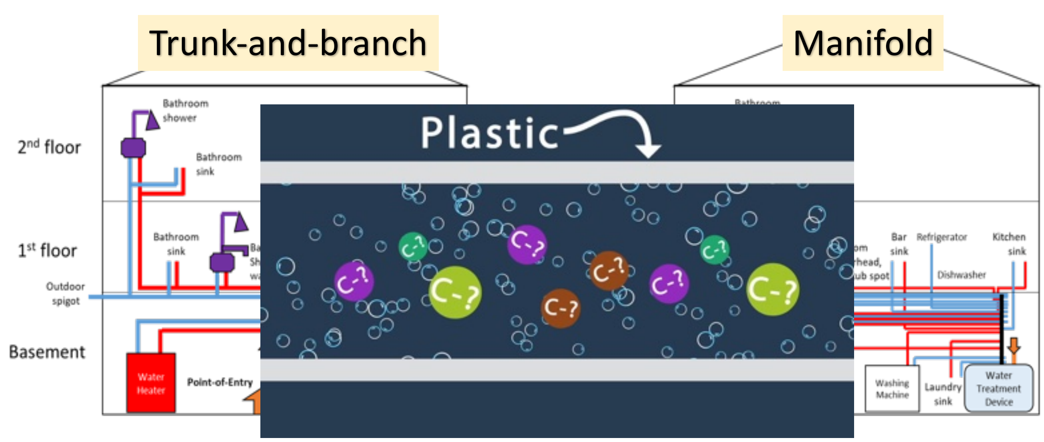
Akalp et al. 2016. Tap water & indoor air contamination due to an unintentional chemical spill in source water. https://10.14455/ISEC.res.2016.9

Sain et al. 2015. Assessing human exposure & odor detection during showering with crude 4-MCHM contaminated drinking water. https://doi.org/10.1016/j.scitotenv.2015.08.050

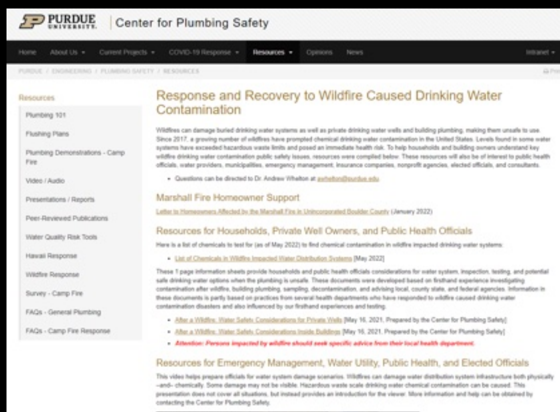
And more…

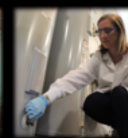


## Sampling buildings and decontamination activities needs to take into considerations the plumbing



Andrew Whelton, Ph.D.
awhelton@purdue.edu



- ✓ Post-fire chemicals to test for
- ✓ Brief videos for emergency managers and health officials
- ✓ Guidance for private well owners
- ✓ Guidance for building owners
- ✓ Federal and state government agency resources
- ✓ FEMA mitigation guidance
- ✓ Other training resources

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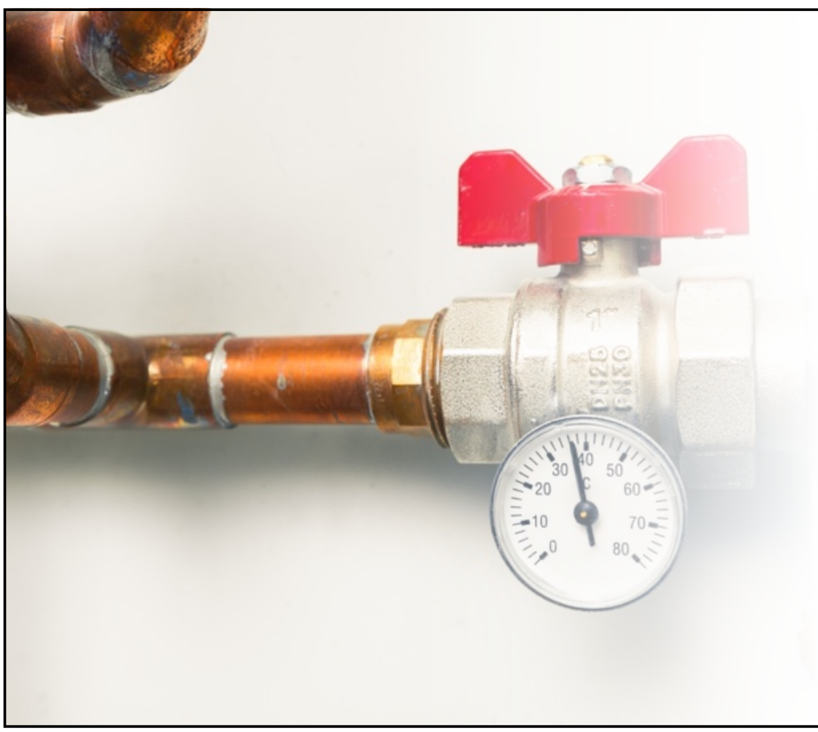
More Lessons Coming at www.PlumbingSafety.org


# 21st Century Water Needs

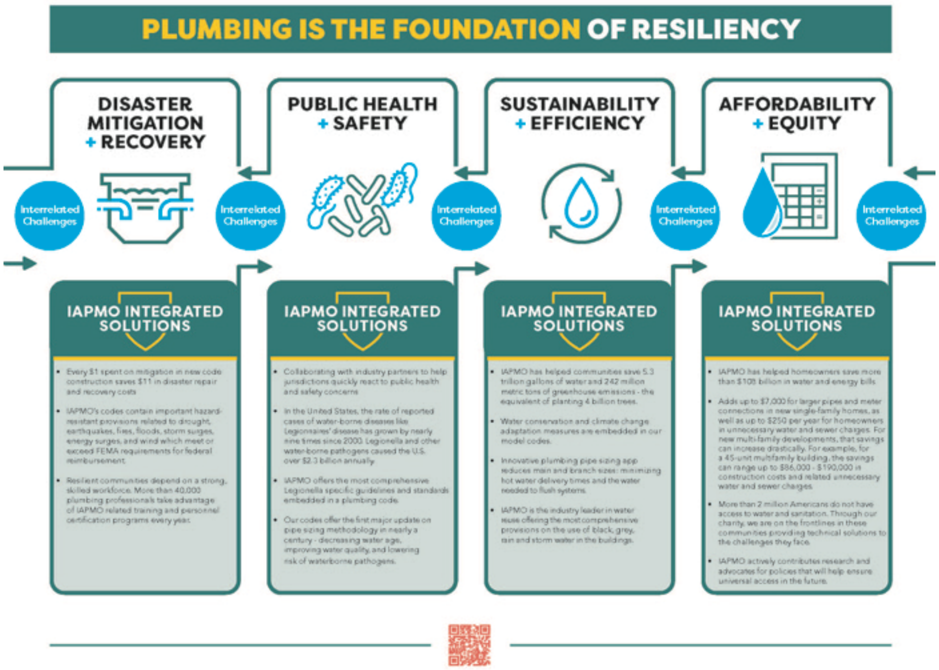
1



"People think that water/plumbing are simple, but they are highly complicated."

-Christoph Lohr, VP Strategic Initiatives, IAPMO
-David LaFrance, CEO,
American Water Works Association

2

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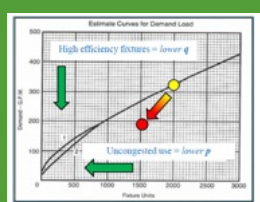
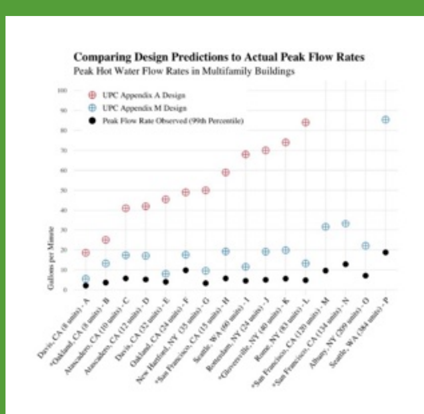
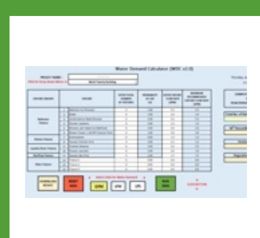


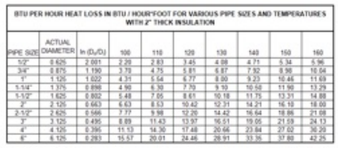




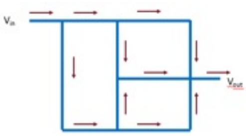
# Right-Sizing Plumbing Systems

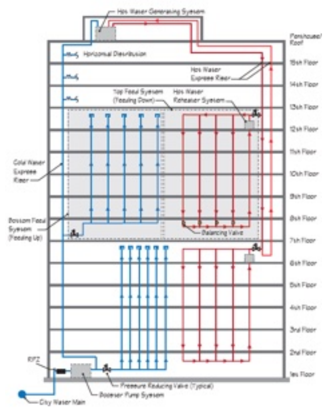
4



| BTU PER HOUR HEAT LOSS IN BTU / HOUR*FOOT FOR VARIOUS PIPE SIZES AND TEMPERATURES WITH 2" THICK INSULATION | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| PIPE SIZE | ACTUAL DIAMETER | $\ln(D_o/D_i)$ | 100 | 110 | 120 | 130 | 140 | 150 | 160 |
| 1/2" | 0.625 | 2.001 | 2.29 | 2.83 | 3.45 | 4.08 | 4.71 | 5.34 | 5.96 |
| 3/4" | 0.875 | 1.190 | 3.70 | 4.75 | 5.81 | 6.87 | 7.92 | 8.98 | 10.04 |
| 1" | 1.125 | 1.022 | 4.31 | 5.54 | 6.77 | 8.00 | 9.23 | 10.46 | 11.69 |
| 1-1/4" | 1.375 | 0.898 | 4.90 | 6.30 | 7.70 | 9.10 | 10.50 | 11.90 | 13.29 |
| 1-1/2" | 1.625 | 0.802 | 5.48 | 7.05 | 8.61 | 10.18 | 11.75 | 13.31 | 14.88 |
| 2" | 2.125 | 0.663 | 6.63 | 8.53 | 10.42 | 12.31 | 14.21 | 16.10 | 18.00 |
| 2-1/2" | 2.625 | 0.566 | 7.77 | 9.98 | 12.20 | 14.42 | 16.64 | 18.86 | 21.08 |
| 3" | 3.125 | 0.495 | 8.89 | 11.43 | 13.97 | 16.51 | 19.05 | 21.59 | 24.13 |
| 4" | 4.125 | 0.395 | 11.13 | 14.30 | 17.48 | 20.66 | 23.84 | 27.02 | 30.20 |
| 6" | 6.125 | 0.283 | 15.57 | 20.01 | 24.46 | 28.91 | 33.35 | 37.80 | 42.25 |

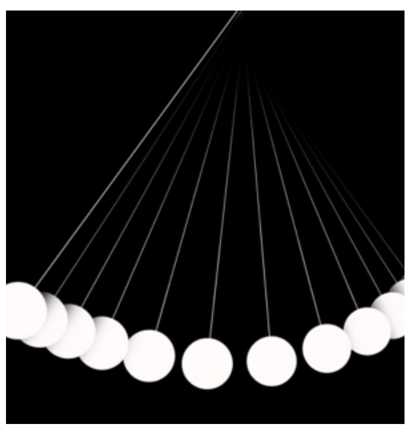
$$h = \frac{(0.2083)(100/c)^{1.852}(V^{1.852})}{d_i^{4.8655}}$$

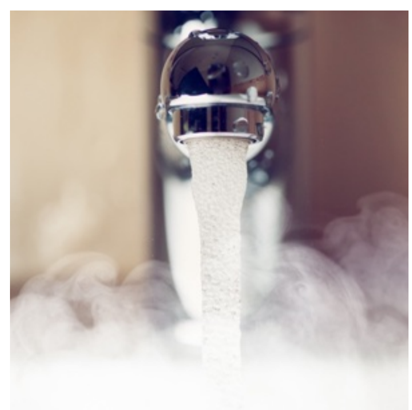



# Pressure Loss Calculations

5





## Balancing Competing Needs: Water & Energy Conservation vs. Public Health/Safety

6

## Why Plumbing-Focused Organizations and Plumbing Specialization Matter for Innovation.

"In a knowledge-based economy (that is an economy which is directly based on production, distribution and use of knowledge and information) requires knowledge-based workers… and that knowledge work is effective if only it is highly specialized (e.g., what makes a brain surgeon effective is that he is highly specialized in brain surgery, but by the same token couldn't repair a damaged knee and would probably be helpless if confronted with a tropical parasite in the blood). This is true for all knowledge work. Generalists… are of limited use in a knowledge economy. In fact, they are productive only they themselves become specialists in managing knowledge and knowledge workers. The knowledge needed in any activity has become highly specialized. It is therefore increasingly expensive and difficult to maintain enough critical mass for every major task in an enterprise. **And because knowledge rapidly deteriorates unless it is used constantly, maintaining within an organization an activity that is used only intermittently guarantees incompetence."** - *Peter Drucker,* On Management, 1974

7

## Plumbing Research Needs: Brainstorming

- **Sustainability (Water and energy efficiency)**
- **Public health (OPPP)**
- **Infrastructure**
- **Resilience**
- **Decarbonization, e.g.**
  - **More focus on energy efficiency and fuel type**
  - **More heat pump water heaters**
- **Climate change – more focus on resilience**

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