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ADVANCES IN PREMISE PLUMBING MODELING

William Platten[1], Regan Murray[2], Juneseok Lee[3], Robert Janke[4], Terra Haxton[5], Walter Grayman[6], Jonathan Burkhardt[7] and Steven Buchberger[8]

[1,2,4,5,7] U.S. Environmental Protection Agency, Cincinnati, OH, USA 45268
[3]Manhattan College, Riverdale, NY, USA 10471
[6]Walter M. Grayman Consulting Engineers, Oakland, CA, USA 94611
[8]University of Cincinnati, Cincinnati, OH, USA 45221

[8] *Steven.Buchberger@uc.edu*

Abstract

In summer 2019, a new task committee on Premise Plumbing Modeling (PPM) was approved under the auspices of the Water Distribution Systems Analysis Committee of ASCE EWRI. The primary purpose of the PPM task committee is to advance the science of the new field of premise plumbing modeling. In particular, the PPM committee intends to identify areas where methods and models developed over the past several decades to manage municipal water distribution systems can also be applied to solve vexing problems that arise in the premise plumbing systems of contemporary buildings. The ultimate goal of the PPM committee is to identify and develop water systems management tools for use by practicing engineers, as well as the larger water distribution research community, in support of the safe design and operation of indoor water distribution systems. Initially, three general areas were identified where current modeling approaches could be applied to premise plumbing: [1] hydraulic design and performance, [2] building water quality and age, and [3] water safety and security. Using these three core areas as a backdrop, this presentation will describe key accomplishments of the PPM task committee including: creation of a monthly webinar series reaching an international audience, distribution of a quarterly newsletter to the professional community, presentation of technical sessions at annual EWRI national Congress, and publication of a textbook style final report to archive the main topics covered in the PPM webinar series. Finally, this talk will conclude with a glimpse of the challenging problems posed by modern premise plumbing systems and the unique opportunities waiting for researchers working in the field of water distribution network analysis.

Keywords
ASCE Task Committee, premise plumbing, modelling.

1 BACKGROUND

Widespread provision of safe reliable drinking water to the general population ranks as one of the great engineering achievements of the 20th century [1]. A key component of contemporary water supply infrastructure is the "premise plumbing system", representing the final leg of the journey in the delivery of water to the customer. Premise plumbing systems are an integral part of all modern buildings and encompass the complex collection of pipes, meters, heaters, tanks, valves, fittings, fixtures, and other appurtenances used for indoor water supply, heating, and sanitation.

Over the past half century, civil and environmental engineers have advanced the field of water distribution, with a focus mainly on municipal pipe networks. Current water distribution systems analysis generally stops at the curb. Historically, conventional analysis has not ventured into the building. Although some drinking water regulations extend to the point of consumption, there has been relatively little work related to the movement and transformation of water from the curb to the tap. Research is needed to bridge this gap and advance the science of water quality from

source to tap. While similar in function, there are important operational distinctions between municipal water systems and premise plumbing systems (see Table 1).

Table 1. Some Salient Differences Between Water Distribution Systems and Premise Plumbing Systems.

Network Feature	Water Distribution System	Premise Plumbing System
Responsibility	Public water utility	Private building owner
Network topology	Looped pipes with some stubs	Branching pipes with many stubs
Pipe location	Below ground (in the soil)	Above ground (in the walls)
Flow regime	Mainly turbulent (except dead end)	Mixture of lamina and turbulent
Demands	Continuous random stream	Intermittent random pulses
Stagnation	Relatively rare	Very common
Design flow	Fire demand	99^{th} percentile of peak period
Temperature	Ambient conditions	Hot and cold-water systems
Fixtures	Industry standards	Wide assortment of appliances
Modeling software	EPANET or similar	No comparable software

Three areas where established tools and techniques from analysis of municipal pipe networks could be applied to improve our understanding of premise plumbing systems are: (i) water quality within buildings—specifically, formation and delivery of opportunistic premise plumbing pathogens (OPPPs) and corrosion products; (ii) hydraulic design for improved efficiency, cost effectiveness and resource conservation; and (iii) water security.

1.1 Water quality

The United States has 140 million residential homes and nearly six million commercial buildings [2]. Maintaining a high standard of water quality at building fixtures is critical to the public health and safety of citizens. Water quality within buildings is a complex issue driven by plumbing materials, layout and usage patterns. Opportunistic premise plumbing pathogens that contaminate premise plumbing systems continue to cause outbreaks of waterborne illness such as *Legionnaires* disease, with serious consequences for human health. This is a problem particularly for systems with low-flow or infrequently used fixtures, and/or in-building storage tanks. Corrosion products also impact water quality during use, and reduction of exposure to lead within homes is a global priority. To minimize public health and safety issues, water system operators and managers recommend flushing contaminated water or decontaminating affected systems by installing in-building treatment facilities as reactive measures. However, *as yet there are no comprehensive information guidelines or models to help building managers, plumbing designers and health officials select and implement the optimum proactive and preventative actions in the facilities for which they are responsible.*

1.2 Hydraulic design

Recent efforts to improve water conservation/water efficiency and to comply with the requirements of the Energy Policy Act of 1992 follow recommendations made by the US Green

Building Council and the US EPA Water Sense initiative [3]. As a consequence, there has been a proliferation of low-flow premise plumbing water systems across the nation. While promoting conservation, such programs unintentionally raise the age of the water in the plumbing system, which can represent an emerging human health concern as OPPPs thrive under such low-flow/high water age conditions. Plumbing systems are not "right sized" to deal with this decrease in water demand, so water can dwell in pipes for lengthy periods before it is used with low or no disinfectant residual. To make matters worse, our existing water infrastructure is beginning to show its age and is starting to deteriorate, making it an ideal environment for OPPPs and corrosion to proliferate. It is critical to develop a better understanding of the potential impact of complex emerging situations on public health that will enable us to predict health risks that are likely to accompany continuing mandated efforts to conserve water in our drinking water systems.

1.3 System security

The security of our public water systems has long been a subject of concern. This was magnified in the aftermath of the September 11, 2001 attacks. Water utilities were required to perform vulnerability studies and premise plumbing was widely identified as a potential source for contaminant intrusion to the water supply system. Intrusions confined to a building would affect the customer directly within the particular premise; intrusions that escaped from the building (through pumpage back into the public system) could affect the entire downstream population. Several studies looked at this situation and applied simple standard distribution system models to the premise plumbing. Deficiencies in applying the general software under these situations were identified and included inadequate representation of dispersion, instantaneous demand patterns, pressure dependent demands, and some components (*e.g.,* hot water heaters, etc.). Whether a source of a contaminant is associated with the premise or came from the distribution system, the need to flush a system after contamination is important for the continued use of that building.

Generally, these problems have been approached from the narrow perspective of water chemistry/ microbial aspects in laboratory conditions or field sampling efforts. It is critical to approach these topics holistically because fate and transport of water contaminants are dictated by inherent hydraulics, demand, and systems characteristics within premise plumbing. This is further complicated by the lack of sampling protocols within premise plumbing regarding frequency, location, and timing. A modeling platform dedicated to premise plumbing issues has the potential to

- Improve our understanding of key phenomena that occur within premise plumbing systems,
- Provide a scientific basis for better planning, design, analysis, and operation of premise plumbing systems, and
- Identify new ways to optimize building water systems operations and management strategies.

2 PREMISE PLUMBING MODELING TASK COMMITTEE

To identify and address emerging challenges in the field of building water supply and to provide a forum for interested researchers in which to collaborate, a Premise Plumbing Modeling (PPM) Task Committee was launched during summer 2019 as part of the Water Distribution Systems Analysis (WDSA) committee. WDSA is a committee under the Environmental Water Resources Institute (EWRI) and is affiliated with the American Society of Civil Engineers (ASCE). EWRI has embraced that field through the Water Distribution System Analysis (WDSA) Committee, sponsorship of a track at their annual conferences, and publication of numerous papers in regular and special issues of the ASCE Journals for the past two decades.

2.1 PPM purpose and objectives

The purpose of the PPM task committee is to advance the science of the new field of premise plumbing modeling and to help develop building water systems management tools for use by practicing engineers, as well as the larger water distribution research community, in support of the safe design and operation of water distribution systems. The main objective is to develop and disseminate techniques and tools that can be used to improve planning, design, analysis, and operation of building water supply systems.

2.2 PPM research products

The Premise Plumbing Modeling committee identified several research milestones to achieve and end products to deliver over a three-year period, as highlighted in the list below:

- Sponsor technical sessions on premise plumbing and building water systems analysis at 2020-2022 EWRI Congresses and other venues.
- Organize on-line webinars with international experts to disseminate knowledge on the current state of building water systems modeling, highlight linkages to design, analysis, operational decision-making in practice, and identify gaps in knowledge, data or capabilities.
- Publish a final report, following a textbook format, that highlights the key findings of the international on-line workshops
- Publish a quarterly newsletter to keep the user community informed of latest developments in the PPM field.
- Publish an ASCE journal paper featuring a state-of-the-art review covering what has been done in the area of premise plumbing modeling and outlining what else needs to be done.
- Promote design goals for adoption in premise plumbing modeling software.
- Develop and distribute educational materials suitable for use in a Civil and/or Environmental Engineering curriculum, including a nomograph with public domain spreadsheet on estimating design water demands in premise plumbing systems.
- Promote interaction and collaboration with other professional organizations and agencies (AWWA, ASPE, IAPMO, NIST, USEPA, *etc*.) who work in the premise plumbing arena.

3 PPM COMMITTEE PROGRESS

Since its inception in 2019, the PPM task committee has made significant progress on many of its research milestones and end products, as discussed below:

3.1 Sessions at annual EWRI Congress and other venues

Table 2. Technical sessions on premise plumbing modeling at recent conferences.

Date	Location	Event	Status / Outcome
May 2020	Henderson, NV	ASCE EWRI Congress	Cancelled due to pandemic
June 2021	Milwaukee, WI	ASCE EWRI Congress	Sponsored virtual PPM session
June 2022	Atlanta, GA	ASCE EWRI Congress	Sponsored face-face PPM session
July 2022	Valencia, Spain	CCWI/WDSA Symposium	Presented PPM paper

3.2 International on-line webinars

Starting in April 2020, the PPM Task Committee organized a series of 13 on-line webinars to disseminate information on the current state of building water systems modeling, highlight linkages to design, analysis, operational decision-making in practice, and identify gaps in knowledge, data or capabilities. The schedule and theme of each webinar is listed in Table 3. As shown in Figure 1, 45 speakers participated in the on-line PPM webinars, representing a broad range of international expertise and work experience. All webinars were recorded and uploaded to a dedicated youtube channel accessible at:

(https://www.youtube.com/channel/UCRxdGu3wGpqRwez_VpoezCQ).

Table 3. Webinars hosted by the Premise Plumbing Modeling task committee.

Number	Month and Year	Theme
1	April 2020	Overview and Vision
2	June 2020	Water Age in Buildings
3	July 2020	Estimating Peak Water Demands in Buildings
4	August 2020	Hydraulics of Closed Conduits
5	September 2020	Water Quality and Contaminants
6	October 2020	System Operation
7	December 2020	Instrumentation for Monitoring and Measuring
8	January 2021	Hot Water Systems
9	February 2021	Design Considerations
10	March 2021	Integration Tools (BIM, CFD)
11	April 2021	Looking to the Future
12	October 2021	Committee Report
13	April 2022	Building Water Systems Data Repository

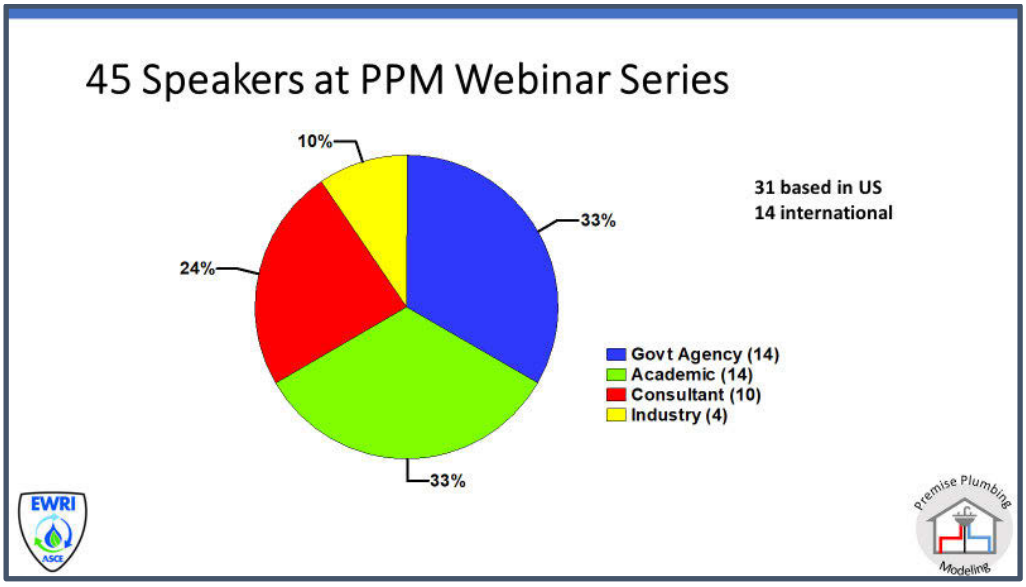

Figure 1. Speakers at the PPM webinar series represented a diverse mix of backgrounds and nationalities.

3.3 Textbook style final report

The essence of the 13 PPM webinars were distilled to eight chapters in a text style book written to capture the current state of the science in premise plumbing modeling. The book covers critical aspects of premise plumbing modeling, including, but not limited to, hydraulics and water quality fundamentals, indoor water demand estimation (especially during peak conditions), current PPM modeling capabilities/limitations, design/code/standards, operations, and instrumentations.

In addition to highlighting current and past work, the objective of this effort is to identify limitations of current modeling, describe opportunities for future modeling, and documents needs related to data gaps or modeling tools for premise plumbing modeling. The book aims to disseminate knowledge regarding building water system modeling and its close connection to design, analysis, and operational decision-making.

The goal of this book is to discuss and examine the various aspects of premise plumbing systems and how they could be or have been modeled for purposes of engineering design and operation. Special emphasis is placed on highlighting weaknesses and limitations in current premise plumbing modeling efforts. Finally, promising opportunities for future premise plumbing modeling research are identified. The theme for each of the eight chapters and one appendix is listed in Table 4.

Table 4. Chapters in the Premise Plumbing Modeling textbook.

Chapter	Theme
1	Introduction and overview; the vital importance of premise plumbing systems in cities of the future.
2	Fundamental steady state conditions and transient hydraulic phenomena in premise plumbing systems.
3	Water quality concerns in premise plumbing; water age, and stagnation; chemical and biological issues.
4	Water demand in buildings: estimating instantaneous peak flows and simulating indoor diurnal water patterns.
5	Computer-based premise plumbing analysis, including tools for simulation and information management support.
6	Design and operation of premise plumbing systems in modern buildings; Management plans for premise plumbing systems.
7	Fundamentals of building hot water systems and interaction with building energy systems.
8	Future of premise plumbing modeling in a digital world; use of BIM models and CFD programs; importance of interagency collaboration and cooperation. Codes and standards.
Appendix A	Data requirements for modeling premise plumbing, with focus on selecting and collecting data using sensors.

The PPM textbook will be published by ASCE with an anticipated release date of summer 2023.

3.4 PPM e-newsletter

A periodic newsletter was distributed to keep the user community informed of latest developments in the PPM field. An example appears in Figure 2.

PREMISE PLUMBING MODELING E-Newsletter #10

July 2021

Dear Premise Plumbing Modeling (PPM) Community:

We hope this email finds you and your loved ones well! In this tenth edition E-Newsletter, we have three items to share with you:

1. PPM Quarterly Webinar Series.

The PPM Webinar Preference Survey results strongly suggested continuing our PPM Webinar Series. So, we decided to continue our webinar series in a quarterly basis. ***Our next webinar will be in the week of September 20.*** If you're interested in giving a talk, please do not hesitate to contact us (juneseok.lee@manhattan.edu).

2. USEPA's ORISE Position.

Dr. Feng Shang (shang.feng@epa.gov) is looking for postdoctoral fellow in dispersion modeling, which will support EPA's PPM efforts. Please feel free to forward to those who might be interested!
https://www.zintellect.com/Opportunity/Details/EPA-ORD-CESER-WID-2021-05

3. Upcoming Conferences.

Below is a list of upcoming conferences that PPM Community may find interesting!

1. Building Water SLAM – This virtual conference will take place July 7-9, 2021.

https://purdue.ca1.qualtrics.com/jfe/form/SV_39Ki2nvHCX9diNo

2. ASPE Tech Symposium – This conference will take place September 22-26,2021 in San Diego.

https://www.aspe.org/2021-tech-symposium/

3. 46th International Symposium of the commission CIB W062 'Water Supply and Drainage for Buildings' – October 26-27, 2021 (URL not available yet).

4. 2021 IAPMO's Water Demand Calculator Summit – November 4, 2021

More information will be available on IAPMO's website soon.

5. 2021 ASHRAE Building Performance Analysis Conference – November 10-12, 2021

https://www.ashrae.org/conferences/topical-conferences/2021-ashrae-building-performance-analysis-conference

6. PMI21 Manufacturing Success Conference – November 15, 2021–November 18th, 2021

https://www.safeplumbing.org/events/calendar/event/id-pmi21

If you have any questions on Premise Plumbing Modeling Committee, please contact committee chair, Juneseok Lee (juneseok.lee@manhattan.edu) for more information. Thank you very much. We look forward to seeing you during fall 2021!

Sincerely,

The Premise Plumbing Modeling Committee

Figure 2. Sample PPM e-newsletter.

3.5 Other PPM activities and products

Work continues on other PPM research products including preparation of a peer-reviewed manuscript for the ASCE *Journal of Water Resources Planning and Management.* The paper will present a state-of-the-art review of premise plumbing modeling with emphasis on identifying emerging PPM issues that can be investigated using tools already in the arsenal of engineers working in the field of water distribution systems analysis. In addition, the PPM task committee continues to facilitate and promote sustained productive collaboration among other professional organizations and agencies (AWWA, ASPE, IAPMO, NIST, USEPA, *etc*.) who work in the premise plumbing arena.

4 CONCLUSIONS

Premise plumbing systems deliver finished water from the municipal distribution network to individual consumers in a building. Premise plumbing is an integral part of every contemporary facility. The sophistication and complexity of premise plumbing systems have grown dramatically in recent decades. This has led to new operational challenges in achieving acceptable hydraulic performance and maintaining safe water quality in many buildings, large and small. These premise plumbing challenges will increase as the planet adds three billion people in the next three decades.

Many engineers working in the field of outdoor public water supply (especially water distribution systems) have expertise with tools and techniques that can be used to identify, analyze and solve the new problems emerging from indoor premise plumbing systems. The field is ripe for bold innovative modeling. Advanced building water systems modeling can create new knowledge that will lead to safer designs for low-flow premise water systems. This, in turn, will provide helpful "bi-directional feedback" to improve design, operation and maintenance strategies for conventional urban water distribution and supply systems.

Under the auspices of the EWRI WDSA committee, the PPM task committee has worked productively for three years to advance the state of practice of water resources and environmental engineering by providing membership with tools for use in the optimal design and safe operation of building water systems for public wellbeing. These initial efforts are the first steps in what promises to be a long and challenging but worthwhile journey for civil engineers into the field of premise plumbing modeling.

5 REFERENCES

[1] National Academy of Science, "Greatest Engineering Achievements of the Twentieth Century (greatachievements.org) June 2022.

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[3] US Environmental Protection Agency, WaterSense | US EPA, June 2022.