ARUP

IAPMO

Energy and Carbon Savings Opportunities

Water Demand Calculator

Reference:

| March 17, 2023

This report takes into account the particular instructions and requirements of our client. It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

Job number 287651

Arup US, Inc.
560 Mission Street, Suite 700
San Francisco, CA 94105
USA
arup.com

Contents

Tables

Figures

Appendices

a. Copper – UPC Chart A 105.1(1)

b. IECC 2018 Insulation Requirements

c. IPC

d. IPC, UPC Appendix C

e. WDC Hot Water Isometrics

    a. Single-Family

    b. 6-Unit

    c. 45 and 48 Unit

f. UPC Hot Water Isometrics

    a. Single-Family

        i. Single-Family – Appendix C

    b. 6-Unit

        i. 6-Unit – Appendix C

    c. 45 and 48 Unit

        i. 45 and 48 Units – Appendix C

g. IPC Hot Water Isometrics

    a. Single-Family

    b. 6-Unit

    c. 45 and 48 Units

h. UPC High Rise Diagram

i. UPC – Appendix C High Rise Diagram

j. IPC High Rise Diagram

k. WDC High Rise Diagram

1. Executive Summary

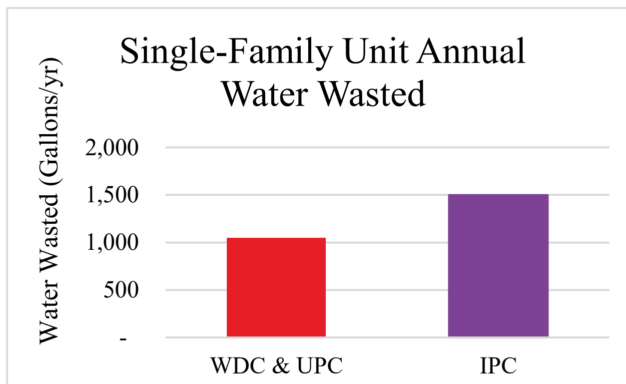
Arup was commissioned by IAPMO to analyze the Water Demand Calculator (WDC) developed by IAPMO to better understand its potential for energy and embodied carbon savings. This energy and embodied carbon savings analysis compared the Water Demand Calculator with the Hunters Curve method included in the International Plumbing Code (IPC) and Uniform Plumbing Code (UPC) for sizing domestic hot water systems in four residential use cases. Currently, the WDC is available for use in UPC Appendix M, WE•Stand, and as a standalone document.

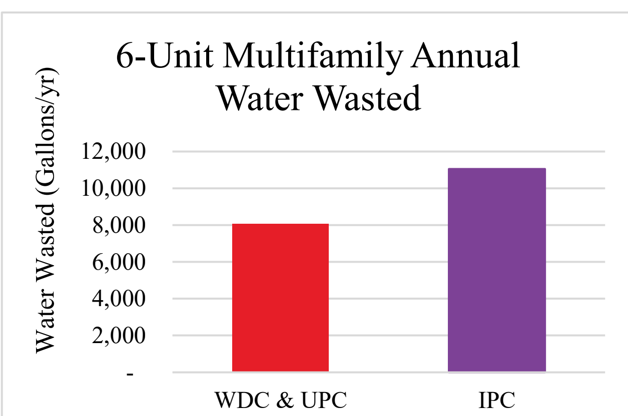
IAPMO developed the Water Demand Calculator in response to the consistent oversizing of potable water distribution systems in the built environment. Oversized domestic water systems result in larger pipes, larger piping appurtenances, and excessive energy and material use. IAPMO contracted Arup to calculate operational energy savings, embodied carbon savings, and water savings using the WDC for four common building types. The analysis included a single-family residence, a 6-unit multifamily residence, a 45-unit residence, and a high-rise residence; these use cases represent a large majority of housing in the country.

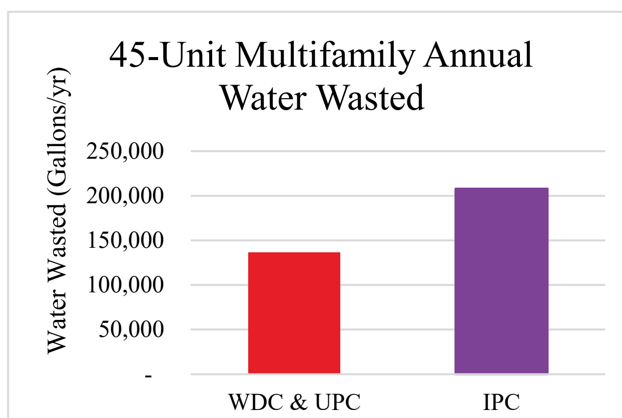
The Water Demand Calculator sizing methodology allows for significant sizing reduction in domestic water systems for residential buildings. The calculator allows for water savings *without affecting how the building occupants use water.* The water, energy, and carbon savings are all embedded within the efficient design of the domestic water system.

The results of this study indicate that when the WDC is used for domestic water design for residential buildings instead of the UPC or IPC Hunter's Curve sizing methods, there are resulting operational energy and embodied carbon savings in all four of the use cases, as well as water savings in the non-circulating units.

Water savings were demonstrated through minimized time-to-tap using the Water Demand Calculator sizing. Water savings range from 450 gallons to 71,000 gallons annually depending on the building size. This represents water savings between single-family, 6-unit, and 45-unit buildings from 27% – 34% oversizing using IPC.



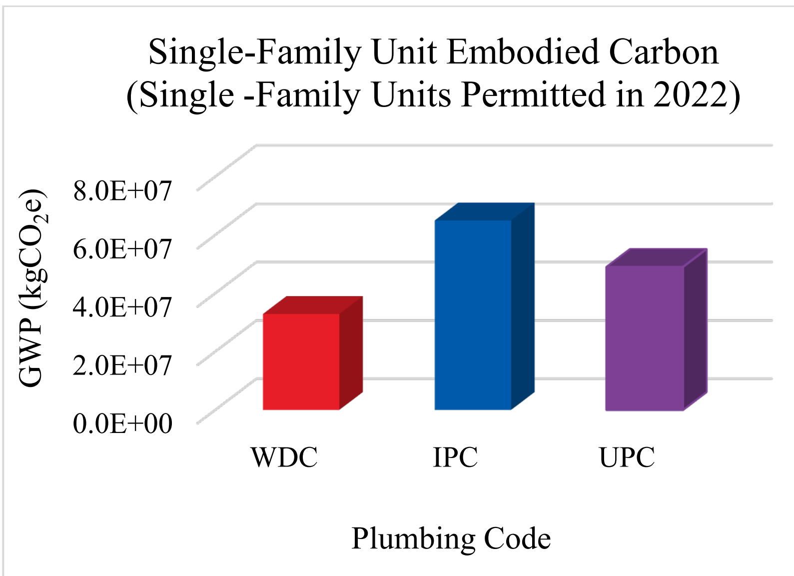




A single-family unit prototype showed annual water savings of 450 gallons. Using U.S. Census Data for single residential permits, this water savings across the 975,584 single-unit residences permitted in 2022 has the potential to save approximately 440 million gallons of water annually when compared to the use of IPC for sizing[1].

High-rise residential buildings show savings in operational carbon between 73 – 84% for booster pumps and embodied carbon savings ranging from 20% to 41%. Using the Water Demand Calculator instead of the UPC or IPC Hunter's method to size domestic water systems in high-rise residential buildings shows savings of operational carbon ranging from 2,000 lbs CO_2 to ~24,000 lbs CO_2 per high-rise residential building, depending on grid emissions at the project site. Additionally, a reduction in pipe sizing allows for reduced heat loss through pipes.

Notably, there are embodied carbon savings associated with interior water mains and branches, and incoming services appurtenances including ball valves, water meters, and backflow preventers. Using the Water Demand Calculator in lieu of the IPC Fixture Units to size domestic water systems in single-family residences can save up to 32.9 kg CO_2e from water service entry appurtenances per single-family home alone.



Arup has vetted the Water Demand Calculator for its completeness, and it is easy to adopt. A code authority needs to only accept Appendix M of the UPC to allow for the Water Demand Calculator to be used for residential plumbing system sizing. The water, energy, and carbon savings shown in this study can be attained by simply adopting the Water Demand Calculator as an acceptable sizing method. Adopting the Water Demand Calculator does not affect how plumbing fixtures operate, or how they are used.

[1] U.S. Census Permits 2022

2. Introduction

2.1 WDC vs. IPC vs. UPC

The International Plumbing Code (IPC) is published by the International Code Council (ICC) on a three-year cycle and is adopted widely across the country. The water distribution sizing method in the IPC uses Hunter's Curve and fixture units for sizing methods. The International Plumbing Code includes "bathroom groups" in fixture sizing that includes a water closet, lavatory, and tub/shower. This combination fixture allows for fewer fixture units than these fixtures counted individually, which accounts for the discrepancy in sizing between IPC and UPC using the same Hunter's Curve methodology. The Uniform Plumbing Code (UPC) was developed by the International Association of Plumbing and Mechanical Officials (IAPMO) to govern the installation and inspection of plumbing systems to promote public health and welfare. The Uniform Plumbing Code includes Hunter's Curve method for water distribution sizing but also includes Appendix M, which details the use of the Water Demand Calculator and was approved by the UPC's technical committee for use in 2018. The Water Demand Calculator can currently be used in UPC jurisdictions, as well as jurisdictions that accept IAPMO's Water Efficiency and Sanitation Standard (WE•Stand). The UPC also has Appendix C, which includes combination fixture groupings also included in this analysis.

The Water Demand Calculator is the first major update in domestic water system sizing since the publishing of Hunter's Curve in 1940. Hunter's Curve was developed well before modern-day water-saving low-flow fixtures. The WDC is a computational model that predicts peak water demand for single-family and multi-family dwellings. It removes the need for assigning fixture units to plumbing fixtures and corresponding to Hunter's probability curve. Instead, it directly calculates peak demand using algorithms depending on the building size[2]:

Table 1: Water Demand Calculator Methods

Methods to estimate peak demands in residential buildings with efficient fixtures.

Region in Figure 4-10	Building Size	Algorithm in Water Demand Calculator	Boundary Criteria	Probability of Peak Period Stagnation, P_0
Green	Small	Exhaustive Enumeration [ExEn]	$n \leq 30$	Very High
Yellow	Medium	Modified Wistort Method [MWM]	$n > 30$ $\mathbf{H} < 5$	Moderate
Red	Large	Wistort Method [WM]	$\mathbf{H} \geq 5$	Very Low

Courtesy of Dr. Steven Buchberger, University of Cincinnati

[2] WDC Flow of Algorithms

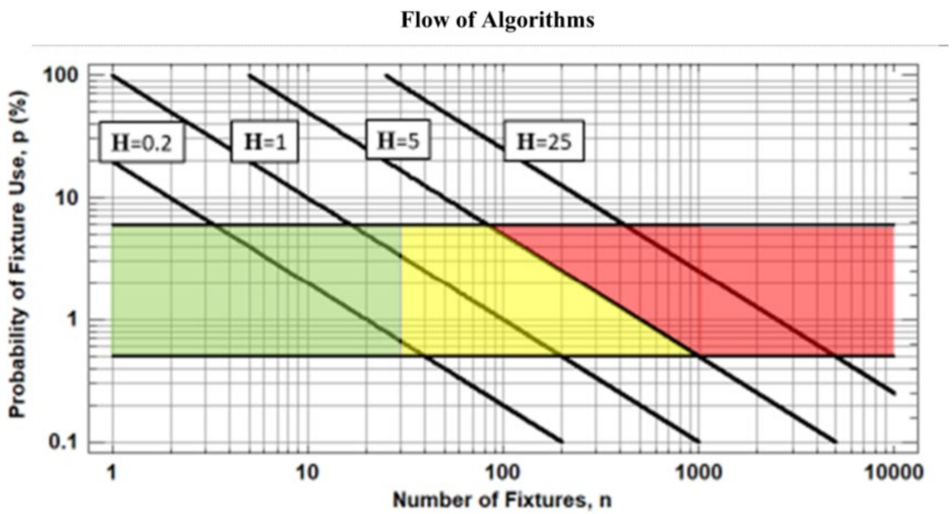
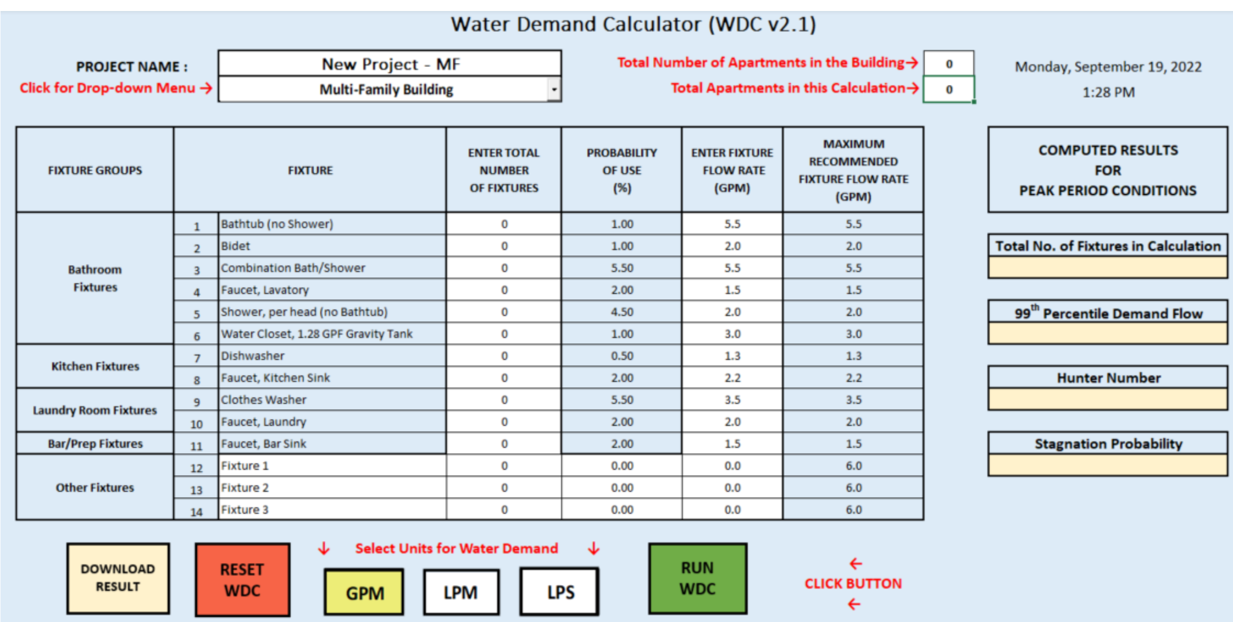


Figure 1: Water Demand Calculator Algorithms

Courtesy of Dr. Steven Buchberger, University of Cincinnati

The water demand calculator is an Excel calculator that calculates the 99th percentile of the instantaneous water demand expected during a peak period of fixture use in a residential building that uses water-conserving fixtures. The application includes features for the user to specify the number of fixtures in the building and their respective flow rates to ultimately calculate the resulting 99th percentile demand flow which can be used to further size the domestic water distribution system. The building-type drop-down offers options for a single-family residence or multi-family residence. If the multi-family residence is selected, the user is prompted to include both the number of apartment units in the calculation and in the entire building. The number of residential units that are included in the calculation is linked to the probability of fixture use, reducing the percentage as the number of residential units in the building increases.



Water Demand Calculator (WDC v2.1)

PROJECT NAME : New Project - MF
Click for Drop-down Menu → Multi-Family Building
Total Number of Apartments in the Building→ 0
Total Apartments in this Calculation→ 0
Monday, September 19, 2022
1:28 PM

FIXTURE GROUPS		FIXTURE	ENTER TOTAL NUMBER OF FIXTURES	PROBABILITY OF USE (%)	ENTER FIXTURE FLOW RATE (GPM)	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

Figure 2: Water Demand Calculator Template

3. Multifamily Home Prototypes

3.1 Single-Family Prototype

These designs included storage-type water heaters within each unit and did not include any domestic hot water circulation. For these units, we assessed changes in pipe size with the three (3) different calculators, and water savings given smaller pipe sizes. For the high-rise building, we assumed the same unit layout as the 8-story 45-unit residence example; however, we assumed an 8-story building with 6 residences per floor, resulting in a total 48-unit high-rise building.

The single-family residence example is approximately 2,380 feet and includes the fixtures displayed in the below floor plan. This prototype is meant to represent an average single-floor home.

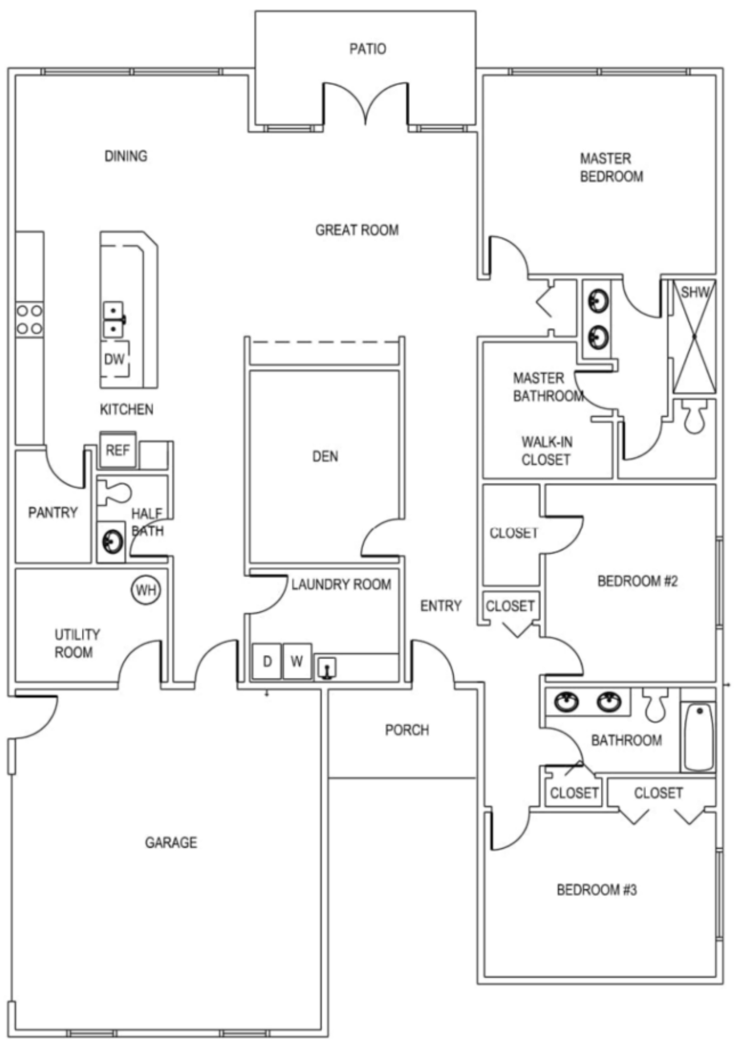


Figure 3: Single-Family Residential Floor Plan

3.2 6-Unit Multifamily Prototype

The 6-unit residence example represents a three-story building with two units on each floor, and each unit is approximately 2,380 feet and includes the fixtures displayed in the below floor plan.

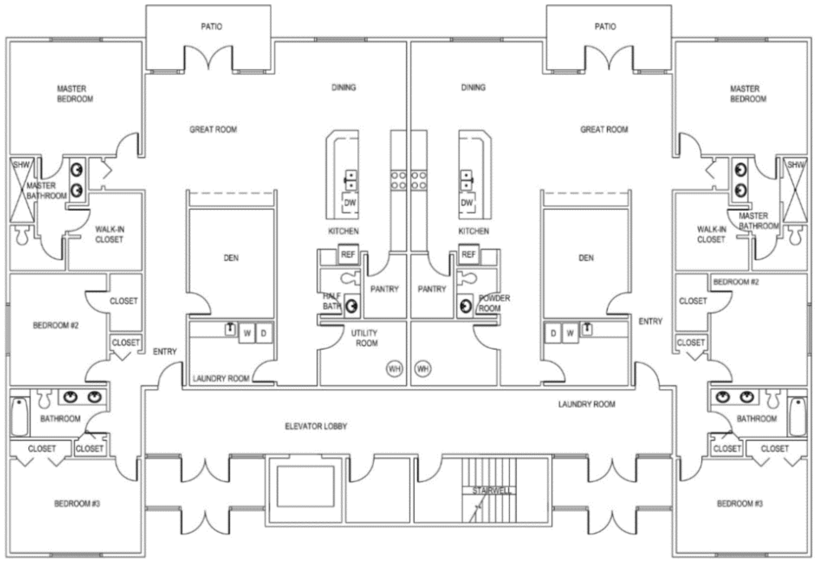


Figure 4: 6-Unit Multifamily Residential Floor Plan

3.3 45-Unit Multifamily Prototype

The 45-unit residence example represents a five-story building with nine units on each floor, and each unit is approximately 1,002 feet and includes the fixtures displayed in the below floor plan.

Figure 5: 45-Unit Multifamily Residential Floor Plan – West Side

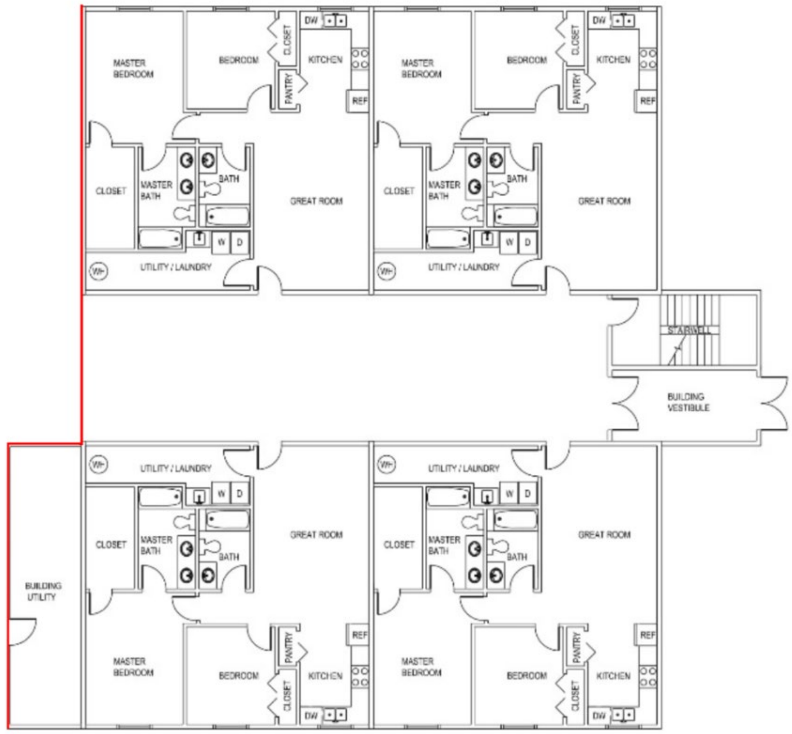


Figure 6: 45-Unit Multifamily Plan - East Side

3.4 48-Unit High-Rise Multifamily Prototype

This high-rise residential example represents an 8-story building with 6 units spread across the floor plan as shown below.

Figure 7: 48-Unit High Rise Residential Floor Plan

4. Plumbing Calculations

4.1 Water Demand Calculator

Cold water pipe sizing was based on a maximum flow rate of 8 ft/s, and hot water pipe sizing was based on a maximum pipe velocity of 5 ft/s. The piping material was assumed to be type L copper. The same pipe configuration was assumed in all of the prototypes. After using the Water Demand Calculator to calculate the 99th Percentile demand flow, the pipe size was found while maintaining a maximum flow rate of 8 ft/s for cold water and 5 ft/s for hot water and type L copper piping. The pipe sizing method uses Appendix M in the UPC.

Table 2: WDC For Single-Family Unit

Water Demand Calculator (WDC v2.1)

PROJECT NAME : Single Unit Residence

Click for Drop-down Menu → Single-Family Residence

Tuesday, October 4, 2022

2:09 PM

FIXTURE GROUPS		FIXTURE	ENTER TOTAL NUMBER OF FIXTURES	PROBABILITY OF USE (%)	ENTER FIXTURE FLOW RATE (GPM)	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	1	5.50	5.5	5.5
	4	Faucet, Lavatory	5	2.00	1.5	1.5
	5	Shower, per head (no Bathtub)	1	4.50	2.0	2.0
	6	Water Closet, 1.28 GPF Gravity Tank	3	1.00	3.0	3.0
Kitchen Fixtures	7	Dishwasher	1	0.50	1.3	1.3
	8	Faucet, Kitchen Sink	1	2.00	2.2	2.2
Laundry Room Fixtures	9	Clothes Washer	1	5.50	3.5	3.5
	10	Faucet, Laundry	1	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	n = 14
99th Percentile Demand Flow	Q = 9.0 GPM
Hunter Number	H(n,p) = 0.33
Stagnation Probability	Pr[Zero Demand] = 71%

DOWNLOAD RESULT | RESET WDC | ↓ Select Units for Water Demand ↓ GPM | LPM | LPS | RUN WDC

The single-family use case building has two hose bibbs, and Appendix M 102.5 requires only 1 hose bibb in the calculation when estimating the building's peak demand for overall water demand calculations. The total flow would be 9.0 gpm + 2.5 gpm for hose bibb = 11.5 gpm. Using a maximum pipe velocity of 8 ft/s, a ¾" water entrance size would be selected. In general, outdoor hose bibbs are used continuously for irrigation purposes while interior hose bibbs such as in a garage are typically used for less continuous uses, such as bucket filling or wash-down. The 2.5 gpm vs. 10 gpm discrepancy between codes applied to the hose bibbs represents a large discrepancy that should be noted.

Table 3: WDC For 6-Unit Multifamily Residential

Water Demand Calculator (WDC v2.1)

PROJECT NAME : 6 Unit Residence

Click for Drop-down Menu → Multi-Family Building

Total Number of Apartments in the Building→ 6

Total Apartments in this Calculation→ 6

Tuesday, October 4, 2022

2:58 PM

FIXTURE GROUPS		FIXTURE	ENTER TOTAL NUMBER OF FIXTURES	PROBABILITY OF USE (%)	ENTER FIXTURE FLOW RATE (GPM)	MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
Bathroom Fixtures	1	Bathtub (no Shower)	0	0.77	5.5	5.5
	2	Bidet	0	0.66	2.0	2.0
	3	Combination Bath/Shower	6	3.06	5.5	5.5
	4	Faucet, Lavatory	30	1.68	1.5	1.5
	5	Shower, per head (no Bathtub)	6	2.16	2.0	2.0
	6	Water Closet, 1.28 GPF Gravity Tank	18	0.66	3.0	3.0
Kitchen Fixtures	7	Dishwasher	6	0.42	1.3	1.3
	8	Faucet, Kitchen Sink	6	1.68	2.2	2.2
Laundry Room Fixtures	9	Clothes Washer	6	3.05	3.5	3.5
	10	Faucet, Laundry	6	1.68	2.0	2.0
Bar/Prep Fixtures	11	Faucet, Bar Sink	0	1.68	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: n = 84
99th Percentile Demand Flow: Q = 13.6 GPM
Hunter Number: H(n,p) = 1.35
Stagnation Probability: Pr[Zero Demand] = 26%

DOWNLOAD RESULT | RESET WDC | ↓ Select Units for Water Demand ↓ GPM | LPM | LPS | RUN WDC

The 6-Unit multifamily building water entrance size using the WDC gives a total flow of 13.6 gpm. Using a maximum flow rate of 8 ft/s, a 1" water entrance size would be selected.

Table 4: WDC for 45-Unit Multifamily Residential

Water Demand Calculator (WDC v2.1)

PROJECT NAME : Test Case WDC - 45 Unit Residence

Click for Drop-down Menu → Multi-Family Building

Total Number of Apartments in the Building→ 45

Total Apartments in this Calculation→ 45

Tuesday, October 4, 2022

2:56 PM

FIXTURE GROUPS		FIXTURE	ENTER TOTAL NUMBER OF FIXTURES	PROBABILITY OF USE (%)	ENTER FIXTURE FLOW RATE (GPM)	MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
Bathroom Fixtures	1	Bathtub (no Shower)	0	0.46	5.5	5.5
	2	Bidet	0	0.57	2.0	2.0
	3	Combination Bath/Shower	45	1.74	5.5	5.5
	4	Faucet, Lavatory	135	1.24	1.5	1.5
	5	Shower, per head (no Bathtub)	45	1.18	2.0	2.0
	6	Water Closet, 1.28 GPF Gravity Tank	90	0.57	3.0	3.0
Kitchen Fixtures	7	Dishwasher	45	0.34	1.3	1.3
	8	Faucet, Kitchen Sink	45	1.24	2.2	2.2
Laundry Room Fixtures	9	Clothes Washer	45	1.67	3.5	3.5
	10	Faucet, Laundry	45	1.24	2.0	2.0
Bar/Prep Fixtures	11	Faucet, Bar Sink	0	1.24	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: n = 495
99th Percentile Demand Flow: Q = 30.7 GPM
Hunter Number: H(n,p) = 5.5
Stagnation Probability: Pr[Zero Demand] = 0%

DOWNLOAD RESULT | RESET WDC | ↓ Select Units for Water Demand ↓ GPM | LPM | LPS | RUN WDC

The 45-Unit multifamily building water entrance size using the WDC gives a total flow of 30.7 gpm. Using a maximum flow rate of 8 ft/s, a 1-1/4" water entrance size would be selected.

Table 5: WDC for 48-Unit High Rise Multifamily Residential

Water Demand Calculator (WDC v2.1)

PROJECT NAME :	Test Case WDC - High Rise Residence	Total Number of Apartments in the Building→	48	Friday, February 10, 2023
Click for Drop-down Menu →	Multi-Family Building	Total Apartments in this Calculation→	48	3:54 PM

FIXTURE GROUPS		FIXTURE	ENTER TOTAL NUMBER OF FIXTURES	PROBABILITY OF USE (%)	ENTER FIXTURE FLOW RATE (GPM)	MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
Bathroom Fixtures	1	Bathtub (no Shower)	0	0.46	5.5	5.5
	2	Bidet	0	0.57	2.0	2.0
	3	Combination Bath/Shower	48	1.71	5.5	5.5
	4	Faucet, Lavatory	144	1.23	1.5	1.5
	5	Shower, per head (no Bathtub)	48	1.16	2.0	2.0
	6	Water Closet, 1.28 GPF Gravity Tank	96	0.57	3.0	3.0
Kitchen Fixtures	7	Dishwasher	48	0.34	1.3	1.3
	8	Faucet, Kitchen Sink	48	1.23	2.2	2.2
Laundry Room Fixtures	9	Clothes Washer	48	1.64	3.5	3.5
	10	Faucet, Laundry	48	1.23	2.0	2.0
Bar/Prep Fixtures	11	Faucet, Bar Sink	0	1.23	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
n = 528
99th Percentile Demand Flow
Q = 31.9 GPM
Hunter Number
H(n,p) = 5.8
Stagnation Probability
Pr[Zero Demand] = 0%

DOWNLOAD RESULT | RESET WDC | ↓ Select Units for Water Demand ↓ | GPM | LPM | LPS | RUN WDC

The 48-Unit multifamily building water entrance size using the WDC gives a total flow of 31.9 gpm. Using a maximum flow rate of 8 ft/s, a 1-1/2" water entrance size would be selected.

4.2 International Plumbing Code

The International Plumbing Code 2021 Appendix E water sizing method was used for all four of the building use cases shown below. The total flow – Hunter's Curve for the system was used to size the incoming line service size. Table E103.3(2) was used to assign fixture units, and Table E103.3(3) was used to convert fixture units to gpm. In the below tables, red cells indicate values referencing this table. White cells indicate user input and bold values are calculated. Note that bathroom groups were used that combine water closets, and a tub/shower into one fixture unit value.

a) Single-Family Residence

Table 6: IPC for Single-Family Residential

Single Family Residence											
Fixture	Note	Occupancy	WSFU								
			Cold	Min Fixture E	Hot	Min Fixtu	Total	Fixture Quantity	Cold	Hot	Total
Bathroom Group	WC, lav, tub/shower	Private	2.7		1.5		3.6	2	5.4	3	7.2
Clothes Washer	8 lb, private	Private	1		1		1.4	1	1	1	1.4
Dishwasher		Private			1.4		1.4	1	0	1.4	1.4
Lavatory		Private	0.5		0.5		0.7	3	1.5	1.5	2.1
Sinks	Kitchen Domestic	Private	1		1		1.4	1	1	1	1.4
	Laundry	Private	1		1		1.4	1	1	1	1.4
Water Closet	Tank	Private	2.2				2.2	1	2.2	0	2.2
Hose Bibb		Private	2.5				2.5	0	0	0	0
Total Fixture Units									**9.9**	**8.9**	**17.1**
Total Flow - Hunter's Curve									**14.6**	**13.7**	**18.4**
Incoming Service	**1-1/4"**										

Adding 10 gpm for the two (2) hose bibbs in multifamily gives a total service flow of 28.4 gpm and a resulting water service entry of 1-1/4".

b) 6-Unit Residence

Table 7: IPC for 6-Unit Multifamily Residential

Single Family Residence											
Fixture	Note	Occupancy	WSFU								
			Cold	Min Fixtu	Hot	Min Fixt	Total	Fixture Quantity	Cold	Hot	Total
Bathroom Group	WC, lav, tub/shower	Private	2.7		1.5		3.6	12	32.4	18	43.2
Clothes Washer	8 lb, private	Private	1		1		1.4	6	6	6	8.4
Dishwasher		Private			1.4		1.4	6	0	8.4	8.4
Lavatory		Private	0.5		0.5		0.7	18	9	9	12.6
Sinks	Kitchen Domestic	Private	1		1		1.4	6	6	6	8.4
	Laundry	Private	1		1		1.4	6	6	6	8.4
Water Closet	Tank	Private	2.2				2.2	6	13.2	0	13.2
Total Fixture Units									**72.6**	**53.4**	**102.6**
Total Flow - Hunter's Curve									**35.8**	**30.1**	**44.1**
Incoming Service	**1-1/2"**										

The 6-unit residence sized with the IPC gives a total flow rate of 44.1 gpm, and a water service entry of 2".

Table 8: IPC for 45-Unit Multifamily Residential

Single Family Residence											
Fixture	Note	Occupancy	WSFU								
			Cold	Min Fixture I	Hot	Min Fixtur	Total	Fixture Quantity	Cold	Hot	Total
Bathroom Group	WC, lav, tub/shower	Private	2.7		1.5		3.6	90	243	135	324
Clothes Washer	8 lb, private	Private	1		1		1.4	45	45	45	63
Dishwasher		Private			1.4		1.4	45	0	63	63
Lavatory		Private	0.5		0.5		0.7	45	22.5	22.5	31.5
Sinks	Kitchen Domestic	Private	1		1		1.4	45	45	45	63
	Laundry	Private	1		1		1.4	45	45	45	63
Water Closet	Tank	Private	2.2				2.2	0	0	0	0
Total Fixture Units									**400.5**	**355.5**	**607.5**
Total Flow - Hunter's Curve									**105**	**96**	**143.8**
Incoming Service	**3"**										

The 45-unit residence sized with the IPC gives a total flow rate of 143.8 gpm, and a water service entry of 3".

Table 9: IPC for 48-Unit High Rise Residential

Single Family Residence											
Fixture	Note	Occupancy	WSFU								
			Cold	Min Fixtu	Hot	Min Fixtu	Total	Fixture Quantity	Cold	Hot	Total
Bathroom Group	WC, lav, tub/shower	Private	2.7		1.5		3.6	96	259.2	144	345.6
Clothes Washer	8 lb, private	Private	1		1		1.4	48	48	48	67.2
Dishwasher		Private			1.4		1.4	48	0	67.2	67.2
Lavatory		Private	0.5		0.5		0.7	48	24	24	33.6
Sinks	Kitchen Domestic	Private	1		1		1.4	48	48	48	67.2
	Laundry	Private	1		1		1.4	48	48	48	67.2
Water Closet	Tank	Private	2.2				2.2	0	0	0	0
Total Fixture Units									**427.2**	**379.2**	**648**
Total Flow - Hunter's Curve									**110.2**	**100.8**	**151.2**
Incoming Service	**3"**										

The 48-unit high-rise residence sized with the IPC gives a total flow rate of 151.2 gpm, and a water service entry of 3".

4.3 Uniform Plumbing Code

The Uniform Plumbing Code 2021 sizing table used for these calculations is A103.1 – for water supply fixture units and minimum fixture branch size. Note that the UPC Appendix A does not have the bathroom group fixture option and has resulting higher calculated flows and pipe sizes than the IPC. Shaded red cells indicate references to the UPC sizing table, white cells indicate user input for the number of fixtures, and numbers in bold are calculated. The Uniform Plumbing Code includes Appendix C which allows for using group combination fixtures, which are included as another iteration of these calculations.

Table 10: UPC for Single-Family Residential

Single Family Residence											
Fixture	Note	Occupancy	WSFU								
			Cold	Min Fixture Branch Pipe	Hot	Min Fixture Branch Pipe	Total	Fixture Quantity	Cold	Hot	Total
Combination Shower / Bath		Private	3	1/2"	3	1/2"	4	1	3	3	4
Clothes Washer		Private	3	1/2"	3	1/2"	4	1	3	3	4
Dishwasher		Private			1.5	1/2"	1.5	1	0	1.5	1.5
Hose Bibb	First	Private	2.5	1/2"			2.5	1	2.5	0	2.5
	Additional	Private	1	1/2"			1	1	1	0	1
Lavatory		Private	0.75	1/2"	0.75	1/2"	1	5	3.75	3.75	5
Sinks	Kitchen Domestic	Private	1.125	1/2"	1.125	1/2"	1.5	1	1.125	1.125	1.5
	Laundry	Private	1.125	1/2"	1.125	1/2"	1.5	1	1.125	1.125	1.5
Shower Head		Private	1.5	1/2"	1.5	1/2"	2	1	1.5	1.5	2
Water Closet	1.6 GPF Gravity Tank	Private	2.5	1/2"			2.5	3	7.5	0	7.5
Total Fixture Units									**24.5**	**15**	**30.5**
Total Flow - Hunter's Curve									**17**	**11.2**	**20.2**
Incoming service	1"										

The single-family residence sized with the UPC gives a total flow rate of 20.2 gpm, and a water service entry of 1".

Table 11: UPC for 6-Unit Multifamily Residential

6-Unit Residence											
Fixture	Note	Occupancy	WSFU								
			Cold	Min Fixture Branch Pipe	Hot	Min Fixture Branch Pipe	Total	Fixture Quantity	Cold	Hot	Total
Combination Shower / Bath		Private	3	1/2"	3	1/2"	4	6	18	18	24
Clothes Washer		Private	3	1/2"	3	1/2"	4	6	18	18	24
Dishwasher		Private			1.5	1/2"	1.5	6	0	9	9
Hose Bibb	First	Private	2.5	1/2"			2.5	0	0	0	0
	Additional	Private	1	1/2"			1	0	0	0	0
Lavatory		Private	0.75	1/2"	0.75	1/2"	1	30	22.5	22.5	30
Sinks	Kitchen Domestic	Private	1.125	1/2"	1.125	1/2"	1.5	6	6.75	6.75	9
	Laundry	Private	1.125	1/2"	1.125	1/2"	1.5	6	6.75	6.75	9
Shower Head		Private	1.5	1/2"	1.5	1/2"	2	6	9	9	12
Water Closet	1.6 GPF Gravity Tank	Private	2.5	1/2"			2.5	18	45	0	45
Total Fixture Units									**126**	**90**	**162**
Total Flow - Hunter's Curve									**48.6**	**40.5**	**56.7**
Incoming Service	2"										

The 6-unit multifamily residence sized with the UPC gives a total flow rate of 56.7 gpm, and a water service entry of 2".

Table 12: UPC for 45-Unit Residential

45-Unit Residence											
Fixture	Note	Occupancy	WSFU								
			Cold	Min Fixture Branch	Hot	Min Fixture Branc	Total	Fixture Quantity	Cold	Hot	Total
Combination Shower / Bath		Private	3	1/2"	3	1/2"	4	45	135	135	180
Clothes Washer		Private	3	1/2"	3	1/2"	4	45	135	135	180
Dishwasher		Private			1.5	1/2"	1.5	45	0	67.5	67.5
Hose Bibb	First	Private	2.5	1/2"			2.5	0	0	0	0
	Additional	Private	1	1/2"			1	0	0	0	0
Lavatory		Private	0.75	1/2"	0.75	1/2"	1	135	101.25	101.25	135
Sinks	Kitchen Domestic	Private	1.125	1/2"	1.125	1/2"	1.5	45	50.625	50.625	67.5
	Laundry	Private	1.125	1/2"	1.125	1/2"	1.5	45	50.625	50.625	67.5
Shower Head		Private	1.5	1/2"	1.5	1/2"	2	45	67.5	67.5	90
Water Closet	1.6 GPF Gravity Tank	Private	2.5	1/2"			2.5	90	225	0	225
Total Fixture Units									**765**	**607.5**	**1012.5**
Total Flow - Hunter's Curve									**170.2**	**144.2**	**207.2**
Incoming Service	3-1/2"										

The 45-unit residence sized with the UPC gives a total flow rate of 207.2 gpm, and a water service entry of 3-1/2".

Table 13: UPC for 48-Unit High Rise Residential

48-Unit High Rise Residence											
Fixture	Note	Occupancy	WSFU								
			Cold	Min Fixture Branch Pipe	Hot	Min Fixture Branch Pipe	Total	Fixture Quantity	Cold	Hot	Total
Combination Shower / Bath		Private	3	1/2"	3	1/2"	4	96	288	288	384
Clothes Washer		Private	3	1/2"	3	1/2"	4	48	144	144	192
Dishwasher		Private			1.5	1/2"	1.5	48	0	72	72
Hose Bibb	First	Private	2.5	1/2"			2.5		0	0	0
	Additional	Private	1	1/2"			1		0	0	0
Lavatory		Private	0.75	1/2"	0.75	1/2"	1	144	108	108	144
Sinks	Kitchen Domestic	Private	1.125	1/2"	1.125	1/2"	1.5	48	54	54	72
	Laundry	Private	1.125	1/2"	1.125	1/2"	1.5	48	54	54	72
Shower Head		Private	1.5	1/2"	1.5	1/2"	2		0	0	0
Water Closet	1.6 GPF Gravity Tank	Private	2.5	1/2"			2.5	96	240	0	240
Total Fixture Units									**888**	**720**	**1176**
Total Flow - Hunter's Curve									**185**	**160**	**230**
Incoming Service	4"										

The 48-unit high-rise residence sized with the UPC gives a total flow rate of 230 gpm, and a water service entry of 4".

The Uniform Plumbing Code Appendix C includes Table C 303.2, which includes “bathroom groups” defined as a fixture group including one water closet, up to two lavatories, and a bathtub or shower. A half-bath or powder room groups together one water closet and a lavatory. The associated fixture units in the table are in Appendix C of this report.

Table 14: UPC Appendix C for Single-Family

Single Family Residence											
Fixture	**Note**	**Occupancy**	**WSFU**								
			Cold	**Min Fixture Branch Pipe**	**Hot**	**Min Fixture Branch Pipe**	**Total**	**Fixture Quantity**	**Cold**	**Hot**	**Total**
Combination Shower / Bath		Private	3	1/2"	3	1/2"	4	0	0	0	0
Clothes Washer		Private	3	1/2"	3	1/2"	4	0	0	0	0
Dishwasher		Private			1.5	1/2"	1.5	0	0	0	0
Hose Bibb	First	Private	2.5	1/2"			2.5	1	2.5	0	2.5
	Additional	Private	1	1/2"			1	1	1	0	1
Lavatory		Private	0.75	1/2"	0.75	1/2"	1	0	0	0	0
Sinks	Kitchen Domestic	Private	1.125	1/2"	1.125	1/2"	1.5	0	0	0	0
	Laundry	Private	1.125	1/2"	1.125	1/2"	1.5	0	0	0	0
Shower Head		Private	1.5	1/2"	1.5	1/2"	2	0	0	0	0
Water Closet	1.6 GPF Gravity Tank	Private	2.5	1"		1/2"	2.5	0	0	0	0
Half-Bathroom	Lavatory, WC	Private	3.5	1/2"	0.8	1/2"	3.5	1	3.5	0.8	3.5
Bathroom Group	2 lavatories, WC, tub/shower	Private	5	1/2"	2.5	1/2"	5	0	0	0	0
2 Bathroom Groups		Private	7	1/2"	3.5	1/2"	7	1	7	3.5	7
Kitchen Group	Kitchen Sink, Dishwasher	Private	2		2		2	1	2	2	2
Laundry Group	Laundry Sink, Clothes Washer	Private	5		5		5	1	5	5	5
Total Fixture Units									**21**	**11.3**	**21**
Total Flow - Hunter's Curve									**15**	**9**	**15**
Incoming service	1"										

The Single-family unit sized using Appendix C fixture groups gives a total flow rate of 15 gpm and a water service entry of 1".

Table 15: UPC Appendix C for 6-Unit Residence

6-Unit Residence											
Fixture	Note	Occupancy	WSFU								
			Cold	Min Fixt	Hot	Min Fixture Branch Pipe	Total	Fixture Quantity	Cold	Hot	Total
Combination Shower / Bath		Private	3	1/2"	3	1/2"	4	0	0	0	0
Clothes Washer		Private	3	1/2"	3	1/2"	4	0	0	0	0
Dishwasher		Private			1.5	1/2"	1.5	0	0	0	0
Hose Bibb	First	Private	2.5	1/2"			2.5	0	0	0	0
	Additional	Private	1	1/2"			1	0	0	0	0
Lavatory		Private	0.75	1/2"	0.75	1/2"	1	0	0	0	0
Sinks	Kitchen Domestic	Private	1.125	1/2"	1.125	1/2"	1.5	0	0	0	0
	Laundry	Private	1.125	1/2"	1.125	1/2"	1.5	0	0	0	0
Shower Head		Private	1.5	1/2"	1.5	1/2"	2	0	0	0	0
Water Closet	1.6 GPF Gravity Tank	Private	2.5	1"		1/2"	2.5	0	0	0	0
Half-Bathroom	Lavatory, WC	Private	3.5	1/2"	0.8	1/2"	3.5	6	21	4.8	21
Bathroom Group	2 lavatories, WC, tub/shower	Private	5		2.5	1/2"	5	0	0	0	0
2 Bathroom Groups		Private	7		3.5	1/2"	7	6	42	21	42
3 Bathroom Groups		Private	9		4.5		9	0	0	0	0
Kitchen Group	Kitchen Sink, Dishwasher	Private	2		2		2	6	12	12	12
Laundry Group	Laundry Sink, Clothes Washer	Private	5		5		5	6	30	30	30
Total Fixture Units									**105**	**67.8**	**105**
Total Flow - Hunter's Curve									**45**	**36**	**45**
Incoming service	1-1/2"										

The 6-Unit multifamily residential unit sized using Appendix C fixture groups gives a total flow rate of 45 gpm, and a water service entry of 1-1/2".

Table 16: UPC Appendix C for 45-Unit Residence

45-Unit Residence											
Fixture	Note	Occupancy	WSFU								
			Cold	Min Fixture Branc	Hot	Min Fixture Branch Pipe	Total	Fixture Quantity	Cold	Hot	Total
Combination Shower / Bath		Private	3	1/2"	3	1/2"	4	0	0	0	0
Clothes Washer		Private	3	1/2"	3	1/2"	4	0	0	0	0
Dishwasher		Private			1.5	1/2"	1.5	0	0	0	0
Hose Bibb	First	Private	2.5	1/2"			2.5	0	0	0	0
	Additional	Private	1	1/2"			1	0	0	0	0
Lavatory		Private	0.75	1/2"	0.75	1/2"	1	0	0	0	0
Sinks	Kitchen Domestic	Private	1.125	1/2"	1.125	1/2"	1.5	0	0	0	0
	Laundry	Private	1.125	1/2"	1.125	1/2"	1.5	0	0	0	0
Shower Head		Private	1.5	1/2"	1.5	1/2"	2	0	0	0	0
Water Closet	1.6 GPF Gravity Tank	Private	2.5	1"		1/2"	2.5	0	0	0	0
Half-Bathroom	Lavatory, WC	Private	3.5	1/2"	0.8	1/2"	3.5	0	0	0	0
Bathroom Group	2 lavatories, WC, tub/shower	Private	5	1/2"	2.5	1/2"	5	0	0	0	0
2 Bathroom Groups		Private	7	1/2"	3.5	1/2"	7	45	315	157.5	315
Kitchen Group	Kitchen Sink, Dishwasher	Private	2		2		2	45	90	90	90
Laundry Group	Laundry Sink, Clothes Washer	Private	5		5		5	45	225	225	225
Total Fixture Units									**630**	**472.5**	**630**
Total Flow - Hunter's Curve									**150**	**120**	**150**
Incoming service	3"										

The 45-unit multifamily residential unit sized using UPC Appendix C fixture groups gives a total flow rate of 150 gpm, and a water service entry of 3".

Table 17: UPC Appendix C for 48-Unit High-Rise Residential

48-Unit High Rise Residence											
Fixture	Note	Occupancy	WSFU								
			Cold	Min Fixture Branch Pipe	Hot	Min Fixture Branch Pipe	Total	Fixture Quantity	Cold	Hot	Total
Combination Shower / Bath		Private	3	1/2"	3	1/2"	4	0	0	0	0
Clothes Washer		Private	3	1/2"	3	1/2"	4	0	0	0	0
Dishwasher		Private			1.5	1/2"	1.5	0	0	0	0
Hose Bibb	First	Private	2.5	1/2"			2.5	0	0	0	0
	Additional	Private	1	1/2"			1	0	0	0	0
Lavatory		Private	0.75	1/2"	0.75	1/2"	1	0	0	0	0
Sinks	Kitchen Domestic	Private	1.125	1/2"	1.125	1/2"	1.5	0	0	0	0
	Laundry	Private	1.125	1/2"	1.125	1/2"	1.5	0	0	0	0
Shower Head		Private	1.5	1/2"	1.5	1/2"	2	0	0	0	0
Water Closet	1.6 GPF Gravity Tank	Private	2.5	1"		1/2"	2.5	0	0	0	0
Half-Bathroom	Lavatory, WC	Private	3.5	1/2"	0.8	1/2"	3.5	0	0	0	0
Bathroom Group	2 lavatories, WC, tub/shower	Private	5	1/2"	2.5	1/2"	5	0	0	0	0
2 Bathroom Groups		Private	7	1/2"	3.5	1/2"	7	48	336	168	336
Kitchen Group	Kitchen Sink, Dishwasher	Private	2		2		2	48	96	96	96
Laundry Group	Laundry Sink, Clothes Washer	Private	5		5		5	48	240	240	240
Total Fixture Units									**672**	**504**	**672**
Total Flow - Hunter's Curve									**160**	**125**	**160**
Incoming service	3"										

The 48-unit multifamily residential unit sized using UPC Appendix C fixture groups gives a total flow rate of 160 gpm, and a water service entry of 3".

5. Water Savings

Smaller domestic hot water delivery pipe times in non-circulating hot water systems result in shorter hot water delivery times. The time it takes for the furthest fixtures to get hot water allows us to calculate how much water is wasted when waiting for hot water. For the single-family building, 6-unit building, and 45-unit building use cases, the residential units all had storage-type water heaters within the individual units with no circulating pump. In order to calculate the water savings, we sized the hot water distribution system based on the given layouts. We took the longest run of hot water piping and compared the volume of water in the distribution based on sizing with the three calculation methods. Using standard data from type L copper piping volumes, the furthest fixture flowrate and the time to get hot water was calculated. This was done by segmenting the longest run from the water heater in each use case into pipe sections, calculating the volume of water in that segment per Table E202.1 below, and dividing the volume (gallons) in that segment by the demand flow of the fixture to calculate seconds. Each of the segments was ultimately summed to reach the total seconds it would take for the hot water to get to the furthest fixture. For the single-unit building and 6-unit building, the furthest fixtures were showers with an estimated 2.5 gpm, and for the 45-unit building, the furthest fixture was a kitchen faucet with an estimated 2.2 gpm. In order to understand how much water this saves in a typical building; we assumed 2 occupants per unit for all building types. We assumed 1 use/day/occupant for the shower, and 4 uses/day/occupant for the kitchen faucet in the 45-unit building example per ENERGY STAR guidelines[3].

The internal volume calculator for this analysis was pulled from the IPC Table E202.1 Internal Volume of Various Water Distribution Tubing.

Table 18: IPC Table E202.1

TABLE E202.1 INTERNAL VOLUME OF VARIOUS WATER DISTRIBUTION TUBING

	OUNCES OF WATER PER FOOT OF TUBE								
Size Nominal, Inch	Copper Type M	Copper Type L	Copper Type K	CPVC CTS SDR 11	CPVC SCH 40	CPVC SCH 80	PE-RT SDR 9	Composite ASTM F 1281	PEX CTS SDR 9
3/8	1.06	0.97	0.84	N/A	1.17	—	0.64	0.63	0.64
1/2	1.69	1.55	1.45	1.25	1.89	1.46	1.18	1.31	1.18
3/4	3.43	3.22	2.90	2.67	3.38	2.74	2.35	3.39	2.35
1	5.81	5.49	5.17	4.43	5.53	4.57	3.91	5.56	3.91
1 1/4	8.70	8.36	8.09	6.61	9.66	8.24	5.81	8.49	5.81
1 1/2	12.18	11.83	11.45	9.22	13.20	11.38	8.09	13.88	8.09
2	21.08	20.58	20.04	15.79	21.88	19.11	13.86	21.48	13.86

The internal volume for Type L Copper was used for ½", ¾", 1", and 1-1/4". The volume of water per pipe segment was converted to gallons and multiplied by the length of piping for that segment. Ultimately, the below equation was used to calculate the time to tap.

$$Time\ to\ tap\ (seconds) = \sum\{\frac{Volume\ of\ water\ in\ pipe\ segment\ (gallons)}{fixture\ demand\ flow\ (gpm)} * \left(\frac{60\ seconds}{1\ minute}\right)\}$$

[3] ENERGY STAR MF Simulation Guidelines, May 2019

5.1.1 Single-Family Unit

In the Single-Family Units, there was not a difference in pipe sizing for the longest hot water run between the UPC and the Water Demand Calculator; however, there was a difference in sizing between those and the IPC sizing. The hot water distribution paths were kept consistent between the three sizing methodologies.

Table 19: Water Delivery Time – Single-Family

Segment	HW (ft)	WDC	Volume (gallons)	Seconds	UPC	Volume (gallons)	Seconds	IPC	Volume (gallons)	Seconds
A	3.75	1"	0.161	3.860	1"	0.1608	3.86	1-1/4"	0.2449	5.88
B	8	1"	0.343	8.235	1"	0.3431	8.24	1"	0.3431	8.24
C	2	1"	0.086	2.059	3/4"	0.0858	2.06	1"	0.0858	2.06
D	15.75	3/4"	0.396	9.509	3/4"	0.3962	9.51	1"	0.6755	16.21
E	3.75	3/4"	0.094	2.264	3/4"	0.0943	2.26	3/4"	0.0943	2.26
F	2.5	3/4"	0.063	1.509	3/4"	0.0629	1.51	3/4"	0.0629	1.51
G	19.5	1/2"	0.236	5.667	1/2"	0.2361	5.67	3/4"	0.4905	11.77
H	4.5	1/2"	0.054	1.308	1/2"	0.0545	1.31	1/2"	0.0545	1.31
Total (seconds)				34.411			34.41			49.24

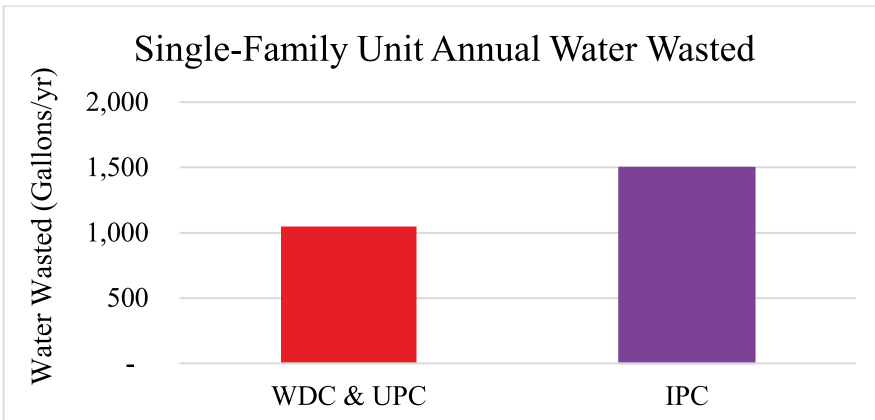


Figure 8: Single-Family Unit Annual Water Wasted

5.1.2 6-Unit Family Residence

Similar to the Single-Family Units, there was no difference in pipe sizing for the longest hot water run between the UPC and the Water Demand Calculator for the 6-unit family residence. However, there was a difference in sizing between UPC/WDC and IPC sizing. The hot water distribution paths were kept consistent between the three sizing methodologies.

Table 20: Water Delivery Time – 6-Unit Residence

Segment	HW (ft)	WDC	Volume (gallons)	Seconds	UPC	Volume (gallons)	Seconds	IPC	Volume (gallons)	Seconds
A	2	1"	0.0858	2.06	1"	0.0858	2.06	1-1/4"	0.1306	3.14
B	12	1"	0.5147	12.35	1"	0.5147	12.35	1-1/4"	0.7838	18.81
C	8	1"	0.3431	8.24	1"	0.3431	8.24	1"	0.3431	3.00
D	2	3/4"	0.0503	1.21	3/4"	0.0503	1.21	1"	0.0858	2.06
E	16.25	3/4"	0.4088	9.81	3/4"	0.4088	9.81	1"	0.6970	16.73
F	3.25	3/4"	0.0818	1.96	3/4"	0.0818	1.96	3/4"	0.0818	1.96
G	1.25	3/4"	0.0314	0.75	3/4"	0.0314	0.75	3/4"	0.0314	0.75
H	20	1/2"	0.2422	5.81	1/2"	0.2422	5.81	3/4"	0.5031	12.08
I	7	1/2"	0.0848	2.03	1/2"	0.0848	2.03	1/2"	0.0848	2.03
Total (seconds)				44.23			44.23			60.56

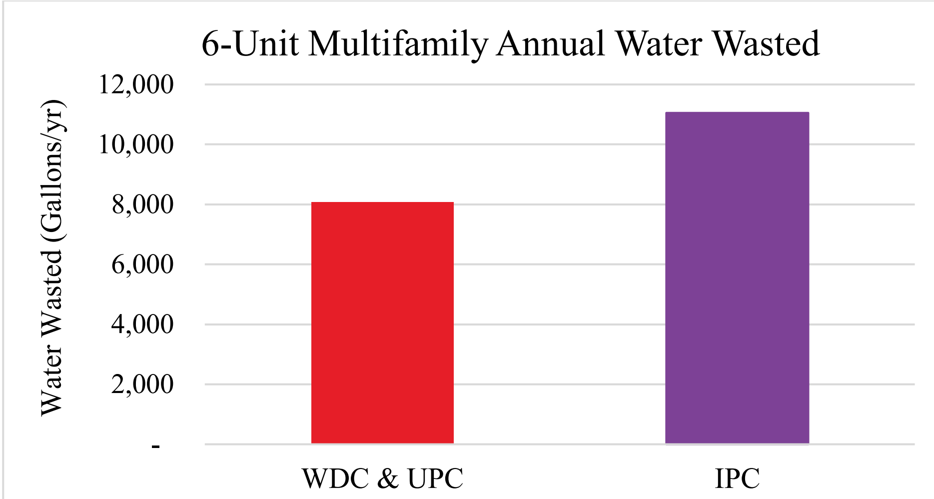


Figure 9: 6-Unit Annual Water Wasted

5.1.3 45-Unit Residence

Like the Single-Family and 6-Units residences, there was no difference in pipe sizing for the longest hot water run between the UPC and the Water Demand Calculator for the 45-unit family residence. However, there was a difference in sizing between UPC/WDC and IPC sizing. The hot water distribution paths were kept consistent between the three sizing methodologies.

Table 21: Water Delivery Time - 45-Unit Residence

45-Unit	HW (ft)	WDC	Volume (gallons)	Seconds	UPC	Volume (gallons)	Seconds	IPC	Volume (gallons)	Seconds
A	9.5	1"	0.4075	11.11	1"	0.4075	11.11	1"	0.4075	11.11
B	3	3/4"	0.0755	1.81	3/4"	0.0755	1.81	1"	0.1287	3.09
C	2	3/4"	0.0503	1.21	3/4"	0.0503	1.21	1"	0.0858	2.06
D	4	3/4"	0.1006	2.42	3/4"	0.1006	2.42	1"	0.1716	4.12
E	2.75	3/4"	0.0692	1.66	3/4"	0.0692	1.66	3/4"	0.0692	1.66
F	35	1/2"	0.4238	10.17	1/2"	0.4238	10.17	3/4"	0.8805	21.13
Total (seconds)				28.38			28.38			43.17

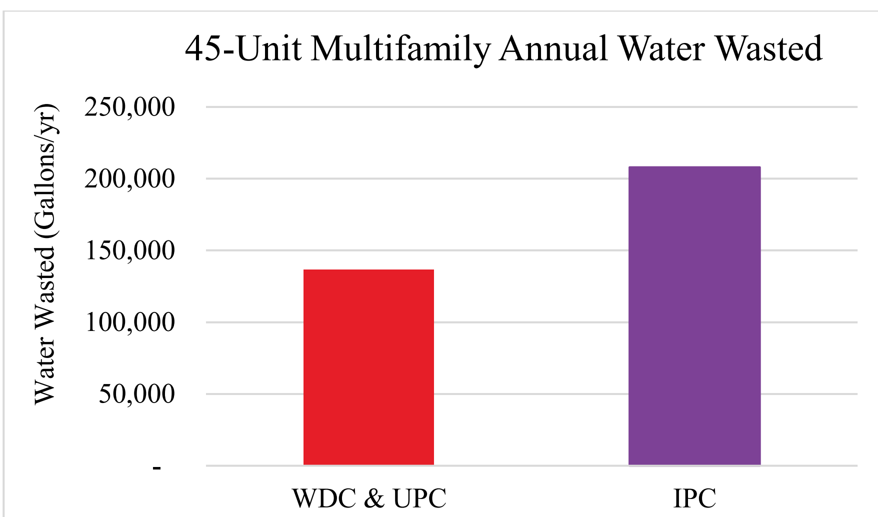


Figure 10: 45-Unit Annual Water Wasted

Table 22: Annual Water Savings for WDC vs. IPC

Building Type	Unit Water Savings per fixture* use (gallons)	Building Water Savings per unit per day (gallons)	Building Water Savings per building per day (gallons)	Annual Building Water Savings (gallons)
Single Unit	0.62	1.24	1.24	451
6-Unit	0.68	1.36	8.16	2,980
45-Unit	0.54	4.34	195	71,258

* Shower for Single and 6-Unit buildings and Kitchen Faucet for the 45-Unit building

The length of run for these use cases did not have a difference in sizing between the WDC and UPC; therefore, the only comparison was identified between WDC and IPC. It is important to note a couple of things in the water savings analysis. Because these prototypes are small, single-floor residential units, there are minimal lengths of hot water distribution piping runs. The longer the runs to the final fixtures, the more water savings can be quantified by waiting for hot water to get to the fixture.

6. Energy Savings

Heat Loss through pipes

The heat loss savings through smaller pipes were analyzed for each building use type between WDC, UPC, and IPC calculators. We assumed the same hot water layout and distribution that was provided to us ahead of this analysis for the single-family home, 6-unit residence, and 45-unit residence. Insulation thickness was chosen in accordance with Table C403.11.3 in the 2018 IECC (International Energy Conservation Code). For service hot water piping within the domestic hot water temperature range (105 – 140 degrees F), pipe sizes smaller than 1.5" nominal diameter were assumed to have 1" thick insulation, and pipe sizes 1.5" and larger were assumed to have 1.5" thick insulation.

There were no significant savings in heat loss across the domestic hot water pipes in the single-family home, 6-unit residence, or 45-unit residence. This is because these residential building examples do not have central domestic hot water systems, rather they all have in-unit storage water heaters, and the hot water pipe sizes do not vary greatly between the different calculator uses. The insulation across the pipes also minimizes the amount of heat loss.

Table 23: Single-Family Residence Piping Counts

Pipe Size	WDC	UPC	IPC
½"	88.5'	88.5'	35'
¾"	22'	24'	59.75'
1"	16.75'	14.75'	25.75'
1-1/4"	0	0	6.75'

The resulting heat loss assuming 1" thick insulation and a 120 degrees F distribution temperature for the single-family residences are:

Table 24: Single-Family Residence Heat Loss

Calculator	Single-Family Residence – Heat Loss in Single Unit (BTU/hour)	Single-Family Residence – Heat Loss in Entire Building (BTU/hour)
WDC	667	667
UPC	665	665
IPC	742	742

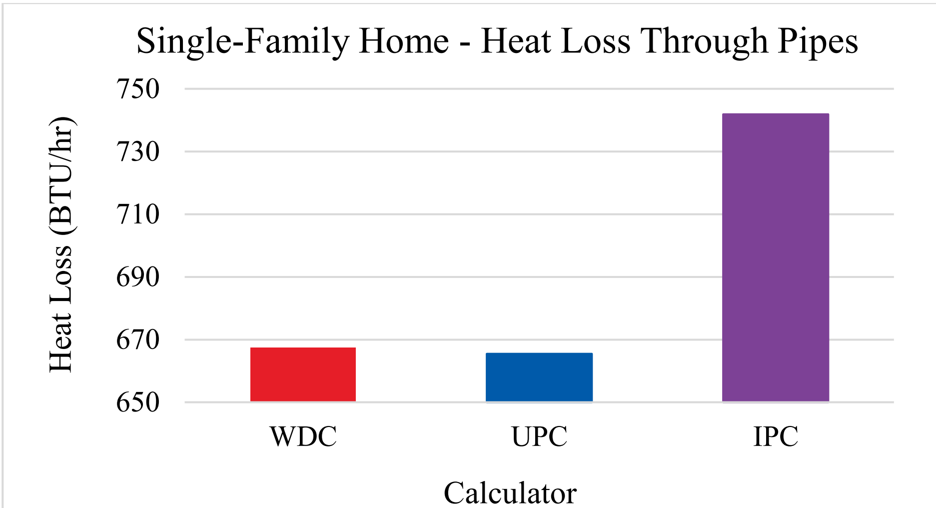


Figure 11: Single-Unit Heat Loss through Pipes

Table 25: 6-Unit Residence Piping Counts

Pipe Size	WDC	UPC	IPC
½"	53.75'	53.75'	4'
¾"	22.75'	22.75'	54.25'
1"	22'	22'	26.25'
1-1/4"			14'

The resulting heat loss assuming insulation thickness equal to pipe diameter and a 120 degrees F distribution temperature for the 6-Unit family residences are:

Table 26: 6-Unit Residence Heat Loss

Calculator	6-Unit Residence – Heat Loss in Single Unit (BTU/hour)	6-Unit Residence – Heat Loss in Entire Building (BTU/hour)
WDC	540	3,240
UPC	540	3,240
IPC	620	3,719

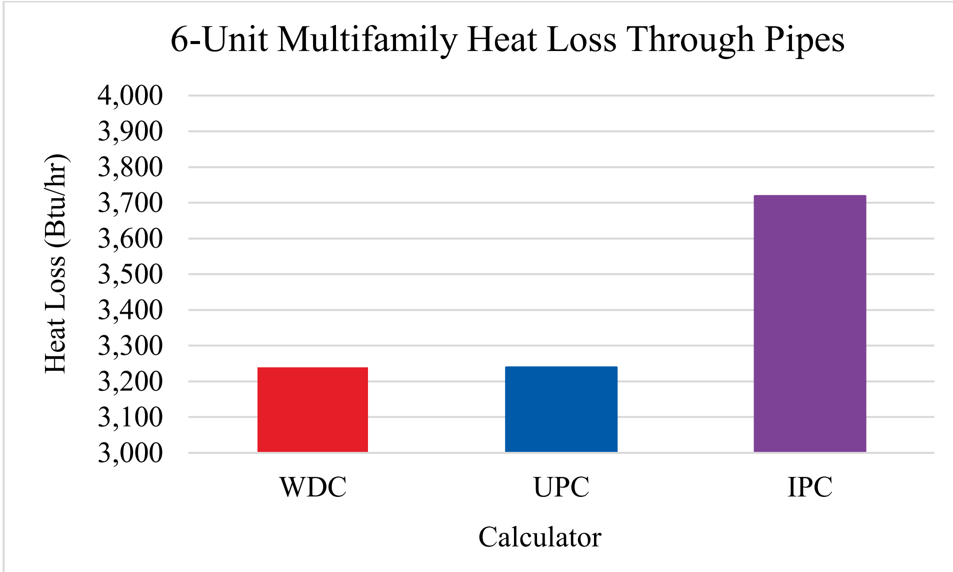


Figure 12: 6-Unit Heat Loss through Pipes

Table 27: 45-Unit Piping Counts

Pipe Size	WDC	UPC	IPC
½"	41'	41'	6'
¾"	15'	15'	41'
1"	9.5'	9.5'	18.5'

The resulting heat loss assuming 1" thick insulation and a 120 degrees F distribution temperature for the 45-Unit family residences are:

Table 28: 45-Unit Residence Heat Loss

Calculator	45-Unit Residence – Heat Loss in Single Unit (BTU/hour)	45-Unit Residence – Heat Loss in Entire Building (BTU/hour)
WDC	349	15,700
UPC	349	15,700
IPC	392	17,652

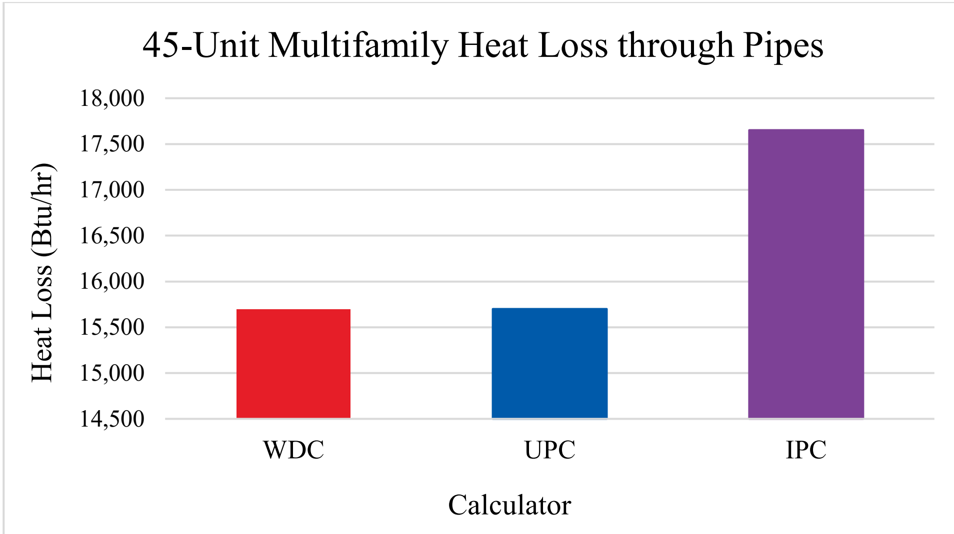


Figure 13: 45-Unit Heat Loss Through Pipes

6.1.1 High-rise Residence

The booster pump savings were calculated for the high-rise residential building with the following assumptions:

- Duplex booster pumps, each sized at 100% demand
- Pump efficiency: 70%
- Height to highest fixture: 80 feet
- Total feet of pipe (3lbs/100 ft): 240 feet
- PSI required at highest fixture: 45 psi
- Pressure loss through incoming water meter: 7.0 psi
- Pressure loss through backflow preventer: 12.5 psi
- Street water main pressure: 74 psi
- Loss in fittings 15% of total feet of pipe: 0.3 psi
- Pumps operate at 50% power for 80% of annual hours; annual operating hours are 7,008 hours

$$Pump\ Power\ (hp) = \frac{(flow\ per\ pump\ (gpm) * pressure\ to\ overcome\ (head))/3960}{pump\ efficiency}$$

Domestic water booster pumps are sized for instantaneous peak flow, not the average hourly flow. Booster pumps will rarely operate at full horsepower at the pump set. To standardize the comparison, we assumed an average annual consumption of the pump's horsepower over every hour of the year. As a result of this, the annual energy consumption should not be considered as typical energy consumption but is used for comparing sizing methodologies.

Table 29: Booster Pump Energy Use

Calculator	Total Duplex Pump Set Power (hp)	Single Pump 50% Power (hp)	Single Pump 50% Power (kW)	Annual Energy (kWh)
WDC	2.4	0.60	0.4476	3,137
IPC	9.0	2.25	1.6785	11,763
UPC	14.8	3.70	2.7602	19,343

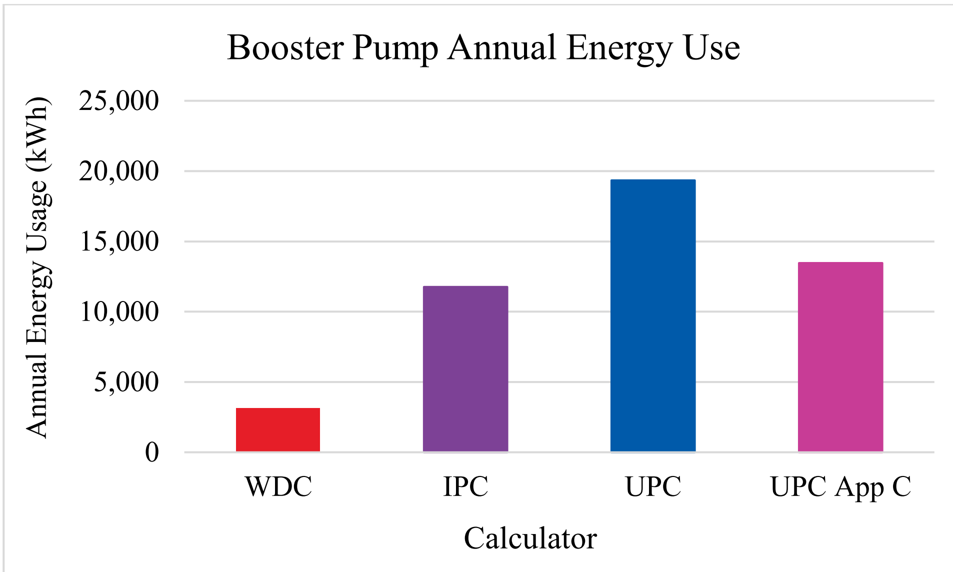


Figure 14: Booster Pump Annual Energy Use

Circulation Pump Sizing – High-Rise Residential

For the heat loss calculations included in circulator pump sizing, we included the following assumptions:

- Pipe sizes less than 1-1/2" have 1" thick insulation.
- Pipe sizes 1-1/2" and larger have 1.5" thick insulation.
- Assume heating hot water to 140 degrees, delivering at 120 degrees, and allowing a 10-degree temperature drop across the circulation system.

The high-rise residential building's domestic water design included a central circulator pump and two separate zones with re-circ pumps. Circulator pumps are sized based on the flow rate required and the head on the pump.

Although the water demand calculator has significantly reduced pipe distribution sizing across the high-rise building, the piping insulation reduces heat loss across all pipes. So, while the nominal pipe sizes are reduced when sizing systems using the Water Demand Calculator, insulation works to reduce heat loss. Recirculation flow rates are dictated by the hot water supply piping heat loss to the farthest fixture at a given change in temperature. The required flow to compensate for the heat loss of insulated copper piping is typically a low flow rate. In this analysis, the flow rate was slightly lower using the water demand calculator compared to the hunter's curve sizing methods. There is not a reduction in flow or friction of sufficient magnitude to account for a smaller pump selection. Therefore, we did not further consider savings in circulator pumps from using the water demand calculator.

Table 30: Circulation Pump Flow Rates

	Flow Rate (GPM) - WDC	Flow Rate (GPM) - IPC	Flow Rate (GPM) - UPC	Flow Rate (GPM) - UPC App C
CP-1	0.791	0.822	0.889	0.877
CP-2	0.498	0.525	0.565	0.552
CP-3	0.293	0.296	0.325	0.324

Table 31: BTU/Hr*Ft Heat Loss in Pipes Smaller than 1.5”

BTU PER HOUR HEAT LOSS IN BTU / HOUR*FOOT FOR VARIOUS PIPE SIZES AND TEMPERATURES WITH 1" THICK INSULATION									
PIPE SIZE	ACTUAL OUTSIDE DIAMETER	ln (D_o/D_i)	100	110	120	130	140	150	160
1/4"	0.375	1.846	2.38	3.06	3.74	4.43	5.11	5.79	6.47
1/2"	0.625	1.435	3.06	3.94	4.82	5.69	6.57	7.44	8.32
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
8"	7.725	0.230	19.10	24.56	30.02	35.48	40.93	46.39	51.85

Table 32: BTU/Hr*Ft Heat Loss in Pipes 1.5" & Larger

BTU PER HOUR HEAT LOSS IN BTU / HOUR*FOOT FOR VARIOUS PIPE SIZES AND TEMPERATURES WITH 1.5" THICK INSULATION									
PIPE SIZE	OUTSIDE DIAMETER	ln (D_o/D_i)	100	110	120	130	140	150	160
1/4"	0.375	2.197	2.00	2.57	3.15	3.72	4.29	4.86	5.43
1/2"	0.625	1.758	2.50	3.22	3.93	4.65	5.36	6.08	6.79
3/4"	0.875	1.488	2.96	3.80	4.64	5.49	6.33	7.18	8.02
1"	1.125	1.299	3.39	4.35	5.32	6.29	7.25	8.22	9.19
1-1/4"	1.375	1.157	3.80	4.89	5.97	7.06	8.14	9.23	10.31
1-1/2"	1.625	1.046	4.20	5.41	6.61	7.81	9.01	10.21	11.41
2"	2.125	0.880	5.00	6.42	7.85	9.28	10.71	12.13	13.56
2-1/2"	2.625	0.762	5.77	7.42	9.07	10.72	12.37	14.02	15.66
3"	3.125	0.673	6.54	8.40	10.27	12.14	14.01	15.87	17.74
4"	4.125	0.547	8.05	10.35	12.65	14.95	17.24	19.54	21.84
6"	6.125	0.399	11.03	14.19	17.34	20.49	23.64	26.79	29.95
8"	7.725	0.328	13.40	17.23	21.06	24.89	28.72	32.55	36.38

7. Energy Savings Across the Country

To better understand the energy savings associated with the Water Demand Calculator across the country, the savings were converted into CO_2e emissions in three states in the country that have varying emissions factors due to the make-up of their electricity generation. The eGRID regions selected were SERC Midwest on the high end of emissions, NPCC Upstate NY on the low end of emissions, and WECC Southwest near the middle.

eGRID data was used to quantify these emissions; eGRID is a comprehensive data source on the environmental characteristics and emissions on electric power generated in the United States. This data is from the Environmental Protection Agency[4] eGRID subregions, last updated in January 2022.

Table 33: Emissions for three eGRID Regions

eGRID	Grid	Avg. CO_2e (lbs/MWh)
NYUP	NPCC Upstate NY	233.50
AZNM	WECC Southwest	846.60
SRMW	SERC Midwest	1,480.70

Booster pump energy analysis was converted into these emissions factors to understand the carbon emissions in the three different grid conditions:

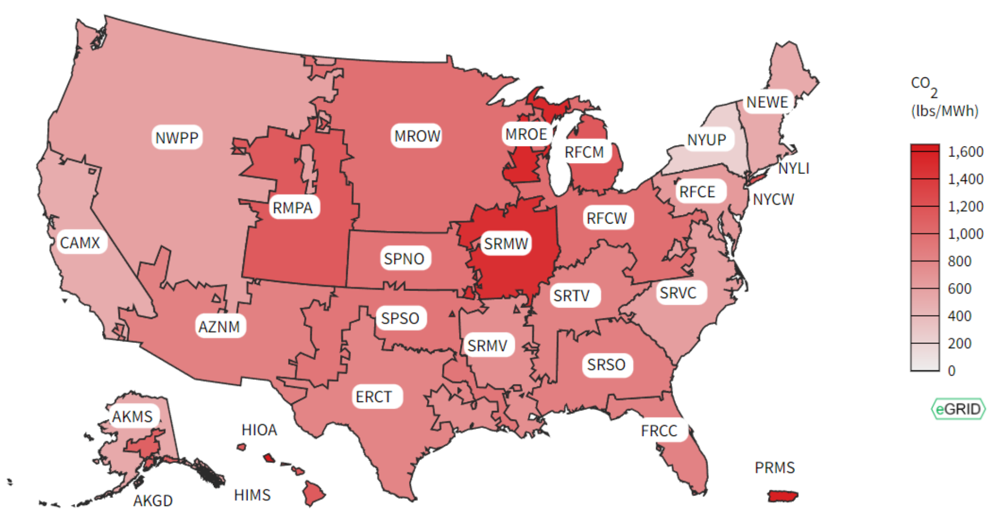


Figure 15: CO_2 Emissions for eGRID Regions

[4] EPA eGRID Power Profile

Table 34: Booster Pump Energy Use and Carbon Emissions in Three EPA eGRID Regions

High Rise Residential			CO_2 (lbs)*			
Code	**Annual Energy use (kWh)**	**Annual Energy use (MWh)**	**Code**	**NYUP**	**AZNM**	**SRMW**
WDC	3,136.78	3.14	WDC	732.44	2,655.60	4,644.63
IPC	11,762.93	11.76	IPC	2,746.64	9,958.49	17,417.37
UPC	19,343.48	19.34	UPC	4,516.70	16,376.19	28,641.89

*Annual energy use (MWh) multiplied by average CO_2e (lbs/MWh) from Table 33

Compared to UPC Hunter's method for sizing domestic water systems in high-rise residential buildings, the Water Demand Calculator shows savings of operational carbon ranging from 2,000 lbs CO_2 to ~24,000 lbs CO_2 per high-rise residential building, depending on grid emissions at the project site.

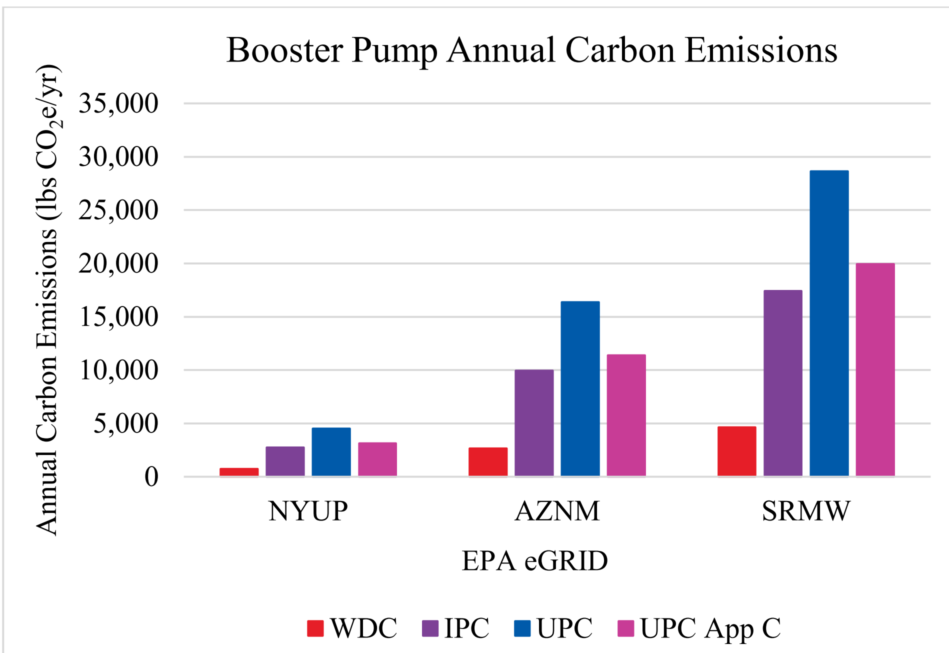


Figure 16: Booster Pump Annual Carbon Emissions

Additionally, the heat loss through pipes can be scaled up across the country. To take a closer look at energy savings of heat loss through pipes in different parts of the country, we can use single-family home permits granted in areas that may correspond with the EPA eGRID emissions. The individual grid emissions used for this analysis may not directly correspond with the homes granted the permits in that state as tracked by the U.S. Census; however, we are using them as an estimate. While energy savings associated with heat loss through pipes is relatively minor, scaling up the heat loss per home by the number of permits with a grid associated with higher emissions demonstrates how a switch to the Water Demand Calculator can be a minor change with major energy savings.

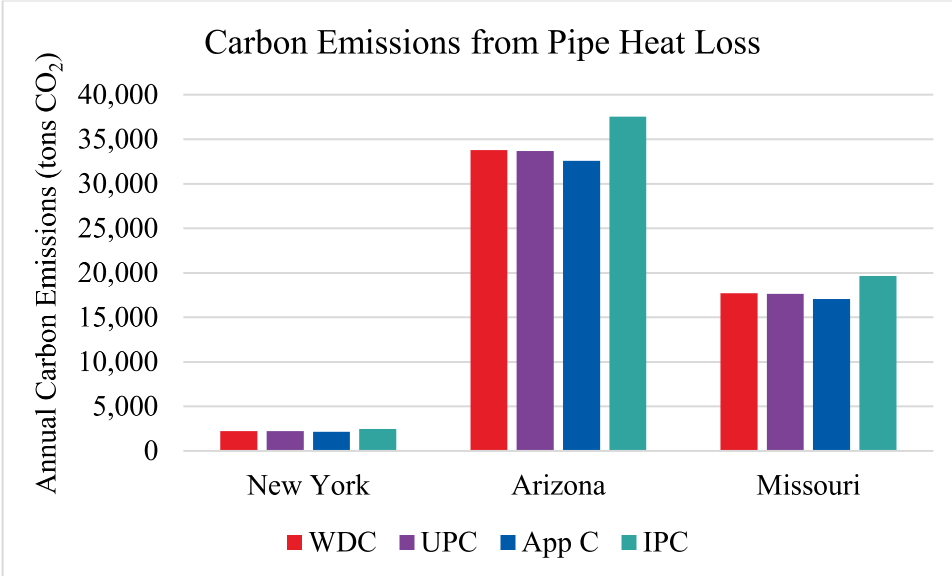


Figure 17: Carbon Emissions from Pipe Heat Loss

To calculate this, we took the BTU/hr heat loss from the hot water distribution and multiplied it by 8,760 hours annually. Then we converted annual BTUs to annual MWh and multiplied by the number of single-family unit permits issued per state. The eGRID emissions associated with the state were used to calculate the annual tons of CO_2 emitted to generate the annual MWh. To show this, comparing the difference in carbon emissions between using the Water Demand Calculator and the International Plumbing Code for pipe sizing, tons of CO_2 may be saved.

Table 35: State-Level Carbon Emissions from Pipe Heat Loss Between WDC & IPC

State	2021 Single-Unit Permits	EPA eGRID emissions factor CO_2 (lb/MWh)	Difference in tons CO_2 between WDC & IPC
New York	11,099	233.5	248
Arizona	46,561	846.6	3,769
Missouri	13,941	1480.7	1,974

8. Embodied Carbon Analysis

Embodied Carbon (a.k.a. "carbon footprint") of a material refers to the lifecycle of greenhouse gas emissions. It evaluates how much carbon is emitted through the supply of materials. To calculate embodied carbon of materials used in a building project, this would include the carbon cost of the initial material and manufacturing process, transportation to a project site, maintenance and replacement of failed products, and end-of-life carbon emissions.

This study takes a closer look at the embodied carbon of varying materials including Type L copper tubes, water meters, backflow preventers, and shut-off valves. Because the Water Demand Calculator leads to smaller size water distribution systems, these pumps and appurtenances will require less material. This study quantifies these embodied carbon savings.

For the purposes of this study, we only looked at known values of Global Warming Potential (GWP) for materials for their product life (lifecycle stages A1-A3). We did not include an analysis of embodied carbon for the transportation, maintenance, and replacement, or end-of-life carbon costs. In order to calculate these, we took the net shipping weight of the components as provided on their cut sheets and estimated the percentage by weight for the varying material components. We then multiplied by the impact factors for each material from publicly available sources to calculate the overall embodied carbon associated with each component. There is an assumed percent error in these calculations because Environmental Product Declarations (EPDs) are not available for these products.

8.1 High-Rise Copper Piping Savings

Copper piping embodied carbon savings were calculated across the high-rise building for all three calculators. Domestic cold water, hot water, and hot water return piping were sized across the high-rise building. The nominal pipe sizes were multiplied by their respective weights/ft. The lengths of piping per nominal size were multiplied by the GWP for copper piping in order to calculate the total embodied carbon for the high rise. This comparison shows a savings of 20% embodied carbon between the WDC and IPC, and 41% between WDC and UPC.

Table 36: High-Rise Copper Piping Counts

Pipe Size	Weight (lb/ft)	WDC	IPC	UPC
½"	0.285	356	356	156
¾"	0.455	592	372	260
1"	0.655	200	540	452
1-¼"	0.884	480	240	280
1-½"	1.14	300	80	320
2"	1.75		240	280
2-1/2"	2.48		80	80
3"	3.33		20	80
4"	5.38			20

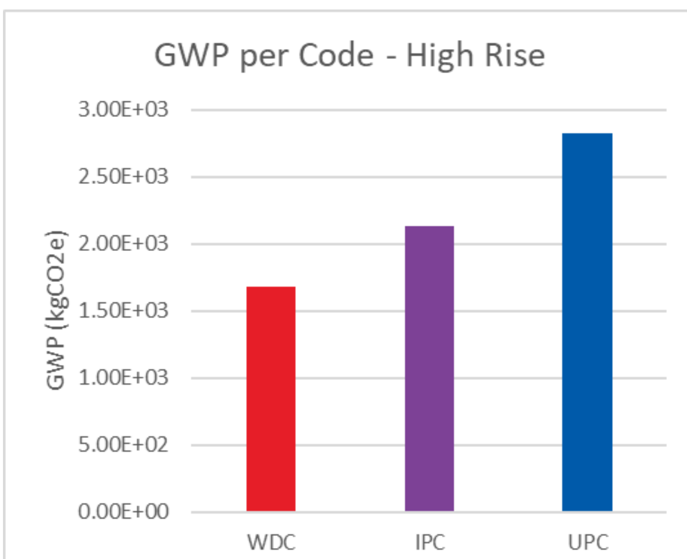


Figure 18: High Rise Copper Piping Embodied Carbon

8.2 Backflow Preventer Savings

The Watts Series LF909 Reduced Pressure Zone Assembly was assumed for this application for backflow preventers 2.5" and larger, and the Watts Series ES-009 for backflow preventers 2" and smaller. For this analysis, pressure drop across the backflow preventer was kept between the recommended range for each incoming service size. This is relevant because each backflow preventer is not necessarily the same size as the incoming water service line size; they are selected based on the total flow rate and the resulting pressure drop across the backflow preventer. The assumed pressure drop across the backflow preventers was kept consistent for each calculator type. The Watts Series LF909 has epoxy-coated cast iron for the check valve bodies, stainless steel seats and trim, and copper silicon alloy relief valve body. The Watts Series 009 has a bronze body construction with silicone rubber in the check and relief valves. GWP values were found through publicly available sources and proprietary sources for materials included. These values were calculated with Watts models, but similar savings with Wilkins, Ames, and other manufacturers are expected.

Using these impact factors to measure the global warming potential of the embodied carbon in the backflow preventers, the difference in GWP could be measured using the water demand calculator to size the system versus the hunter's curve methods with the IPC and UPC.

Table 37: GWP For Backflow Preventers

	Global Warming Potential (GWP) for each Backflow Preventer							
Code	**Single-Family**		**6-Unit**		**45-Unit**		**High-Rise**	
Calculator	**BFP Size**	**GWP ($kgCO_2eq$)**	**BFP Size**	**GWP ($kgCO_2eq$)**	**BFP Size**	**GWP ($kgCO_2eq$)**	**BFP Size**	**GWP ($kgCO_2eq$)**
WDC	¾"	12.8	1"	21.4	1"	21.4	1"	21.4
UPC	1"	21.4	1.5"	29.9	3"	352	3"	352
IPC	1-1/4"	25.6	1.5"	29.9	3"	352	3"	352
UPC App C	1"	21.4	1.5"	29.9	3"	352	3"	352

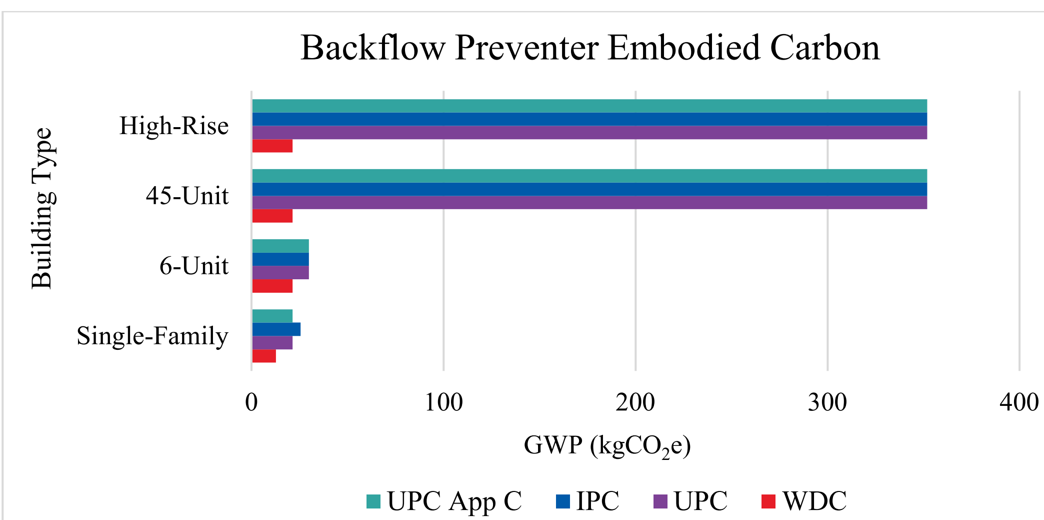


Figure 19: Backflow Preventer Embodied Carbon Comparison

It should be noted that the 3" backflow preventer in the UPC – Hunter's Curve 45-unit use case and high-rise building use case are significantly larger than the ¾" – 1-1/2" series counterparts, and therefore have much larger embodied carbon values.

Table 38: Backflow Preventer Weights

Backflow Preventer	Weight (kgs)
Watts ES-009 ¾"	3 (assumed bronze is 90%wt, silicone 10%wt)
Watts ES-009 1"	5 (assumed bronze is 90%wt, silicone 10%wt)
Watts ES-009 1-1/2"	7 (assumed bronze is 90%wt, silicone 10%wt)
Watts LF-909 3"	104 (assumed cast iron 80%wt, ss 10%wt, bronze 10%wt)

8.3 Water Meter Savings

Badger disc-type water meters were used as the basis for this analysis. The Disc Meters (3/4" and 1") and the Compound water meter were used depending on the calculator demand flow. Similar savings for other manufacturers are anticipated. For the purposes of this study, we assumed weight percentages of the components of the meters as the weights of the meter components are not publicly available. The meters selected include lead-free bronze alloy meter housing, polymer measuring chambers and discs, ceramic magnets, and stainless-steel trim. The smaller disc meters also included cast iron housing bottom plates. These materials were used in embodied carbon analysis with known GWP coefficients:

Table 39: Water Meter Weights

Water Meter	Weight (kgs)
Badger Model 25 ¾"	2 (assumed bronze 40%wt, cast iron 40%wt, polymer 5%wt, ceramic 5%wt, stainless steel 10%wt)
Badger Model 35 ¾"	2.5 (assumed bronze 40%wt, cast iron 40%wt, polymer 5%wt, ceramic 5%wt, stainless steel 10%wt)
Badger Model 70 1"	5.2 (assumed bronze 40%wt, cast iron 40%wt, polymer 5%wt, ceramic 5%wt, stainless steel 10%wt)
Badger Model 55 1"	3.9 (assumed bronze 40%wt, cast iron 40%wt, polymer 5%wt, ceramic 5%wt, stainless steel 10%wt)
Badger Model Recordall 3"	23 (assumed bronze 40%wt, cast iron 40%wt, polymer 5%wt, ceramic 5%wt, stainless steel 10%wt)

Water meters were sized for the overall flow from each of the sizing methods for each building type. They were selected to maintain a reasonable pressure drop across the meters, and pressure drops were kept constant across the sizing methods for each building type. The resulting GWP are shown here:

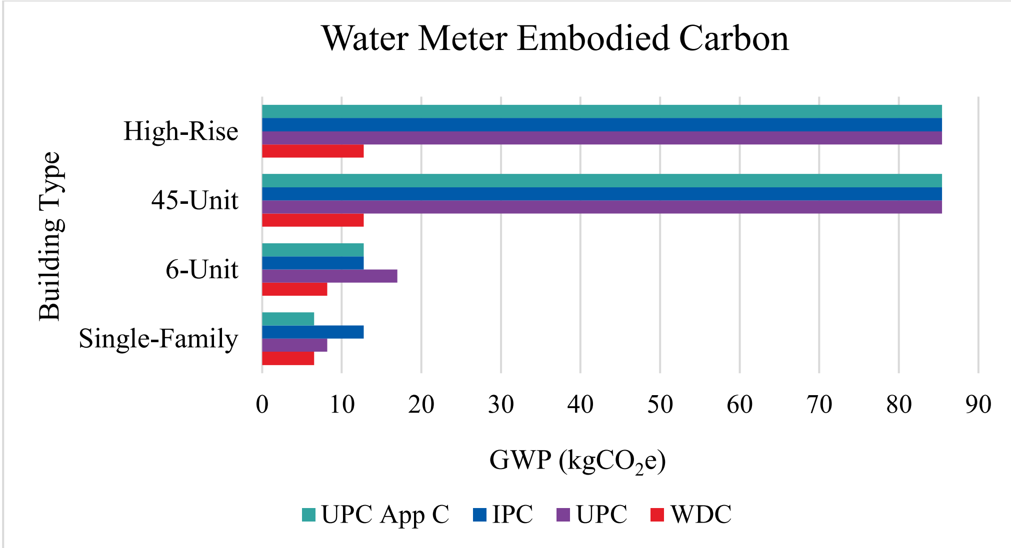


Figure 20: Water Meter Embodied Carbon Comparison

8.4 Shut-off Valve Savings

Apollo full port solder end brass ball valves were selected for this analysis. These valves were considered as the shut-off valves at the water service entrance to each of the building types. It is understood that due to smaller pipe sizes across the buildings, it is likely that there would be further embodied carbon savings than only the shut-off valves at the water service entrance. The 77FLF-200 Series ball valves were used across all calculators and building types. We considered the entire ball valve to be brass for this analysis as the majority of the weight of the valves is the brass ball and body.

Table 40: Ball Valve Weights

Ball Valve	Weight (kgs)
Apollo 77FLF-200 Series – ¾"	0.41
Apollo 77FLF-200 Series – 1"	0.59
Apollo 77FLF-200 Series – 1-1/4"	0.91
Apollo 77FLF-200 Series – 1-1/2"	1.5
Apollo 77FLF-200 Series – 2"	2.54
Apollo 77FLF-200 Series – 3-1/2"	8.75
Apollo 77FLF-200 Series – 4"	11.61

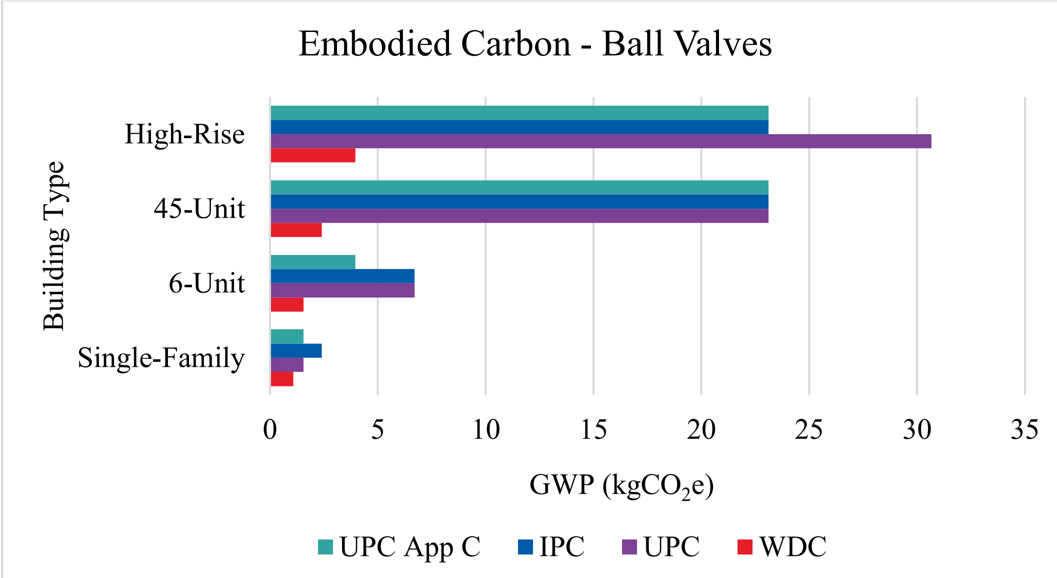


Figure 21: Ball Valve Embodied Carbon Comparison

8.5 Single-Unit Dwelling Savings

In order to quantify the potential savings from the use of the water demand calculator in a tangible way, the savings in embodied carbon in a typical water service entry for a single residence was scaled up for building permits in the United States in 2022. Data for residential building permits is publicly available for every state across the country[5]. It should be noted that the UPC does not require shut-off valves in multifamily units, which furthers embodied carbon savings. Using this data along with the embodied carbon savings calculated for a typical water service entrance: 10' water service entrance-sized copper piping, backflow preventer, water meter, and shut-off valve, the savings for the single-family unit dwelling can be scaled up across the country:

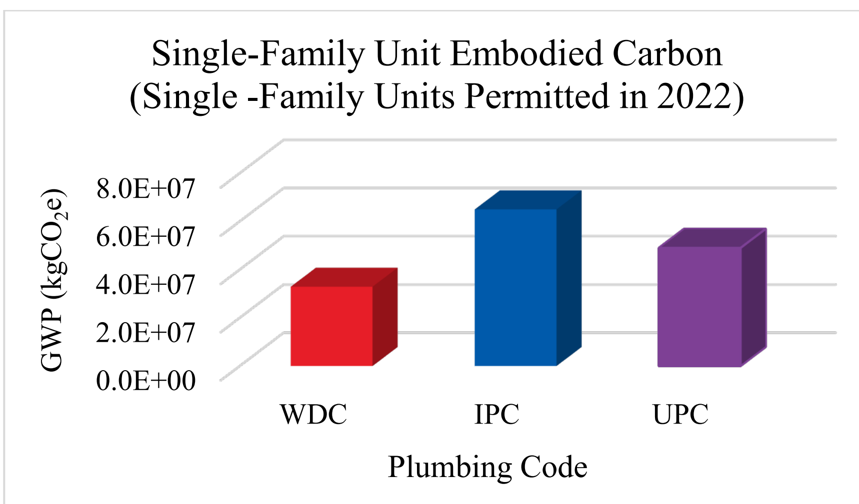


Figure 22: Single-Family Water Service Embodied Carbon Comparison

[5] US Census Permit Data

Notably, there was a 49% savings in embodied carbon between the Water Demand Calculator and the IPC Hunter's Curve and a 33% savings in embodied carbon between the Water Demand Calculator and the UPC Hunter's Curve. There is a savings of 32.9 kg CO_2 through using the WDC rather than the IPC for sizing the water service entry in a single-family home.

9. Conclusion

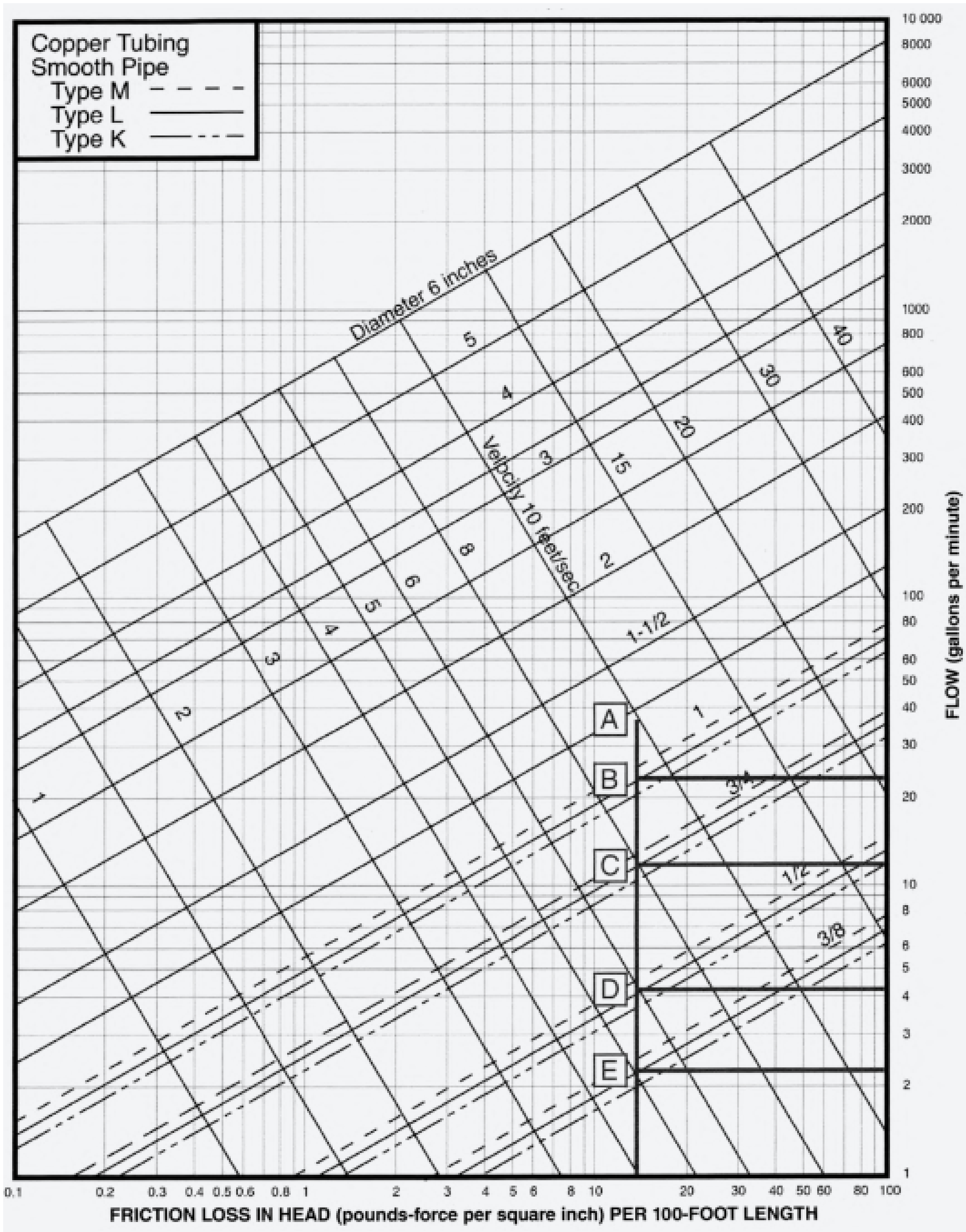
This analysis has shown there are energy savings, carbon savings, and water savings available through adopting the Water Demand Calculator as an alternative to traditional Hunter's Curve sizing methods in both the International Plumbing Code and the Uniform Plumbing Code. The crucial purpose of this study aims to demonstrate how these savings are available with no change to how residents use plumbing fixtures in their homes every day. With a more efficient domestic water distribution design that can be achieved by using the Water Demand Calculator, residential homes and buildings can see immediate savings. There is no change in the user experience in their homes; however, quantifiable energy, carbon, and water savings can be reached through the adoption of the Water Demand Calculator in state jurisdictions.

Booster pump savings in the high-rise apartment example shows operational carbon savings between 73% and 84% by using the Water Demand Calculator rather than Hunter's Curve sizing methods for the IPC and UPC, respectively. Smaller pipe sizes, backflow preventers, water meters, and ball valves show results in embodied carbon savings between 33% and 49% in single-family unit entrances alone. The use of the Water Demand Calculator to size domestic water systems results in savings of carbon, both operational and embodied. Depending on the hot water distribution design, smaller pipes can grant substantial savings of thousands of gallons of water annually.

Ultimately, the Water Demand Calculator as a tool to size domestic water distribution presents a solution to the decades of oversized plumbing distribution systems. Plumbing fixtures' flow rates have changed dramatically since the development of Hunter's Curve, and distribution systems should follow suit.

Appendix A: References

a. Copper – UPC Chart A 105.1(1)



b. IECC 2018 Insulation Requirements

TABLE C403.11.3 MINIMUM PIPE INSULATION THICKNESS (in inches)[a, c]

FLUID OPERATING TEMPERATURE RANGE AND USAGE (°F)	INSULATION CONDUCTIVITY		NOMINAL PIPE OR TUBE SIZE (inches)				
	Conductivity Btu • in./(h • ft² • °F)[b]	Mean Rating Temperature, °F	< 1	1 to < 1 1/2	1 1/2 to < 4	4 to < 8	≥ 8
> 350	0.32 – 0.34	250	4.5	5.0	5.0	5.0	5.0
251 – 350	0.29 – 0.32	200	3.0	4.0	4.5	4.5	4.5
201 – 250	0.27 – 0.30	150	2.5	2.5	2.5	3.0	3.0
141 – 200	0.25 – 0.29	125	1.5	1.5	2.0	2.0	2.0
105 – 140	0.21 – 0.28	100	1.0	1.0	1.5	1.5	1.5
40 – 60	0.21 – 0.27	75	0.5	0.5	1.0	1.0	1.0
< 40	0.20 – 0.26	50	0.5	1.0	1.0	1.0	1.5

For SI: 1 inch = 25.4 mm, °C = [(°F) - 32]/1.8.

a. For piping smaller than 1 1/2 inches and located in partitions within conditioned spaces, reduction of these thicknesses by 1 inch shall be permitted (before thickness adjustment required in footnote b) but not to a thickness less than 1 inch.

b. For insulation outside the stated conductivity range, the minimum thickness (T) shall be determined as follows:

$$T = r\,[(1 + t/r)^{K/k} - 1]$$

where:

T = minimum insulation thickness,
r = actual outside radius of pipe,
t = insulation thickness listed in the table for applicable fluid temperature and pipe size,
K = conductivity of alternate material at mean rating temperature indicated for the applicable fluid temperature (Btu • in/h • ft² • °F) and
k = the upper value of the conductivity range listed in the table for the applicable fluid temperature.

c. For direct-buried heating and hot water system piping, reduction of these thicknesses by 1 1/2 inches (38 mm) shall be permitted (before thickness adjustment required in footnote b but not to thicknesses less than 1 inch.

c. IPC

TABLE E103.3(2) LOAD VALUES ASSIGNED TO FIXTURES[a]

FIXTURE	OCCUPANCY	TYPE OF SUPPLY CONTROL	LOAD VALUES, IN WATER SUPPLY FIXTURE UNITS (wsfu)		
			Cold	Hot	Total
Bathroom group	Private	Flush tank	2.7	1.5	3.6
Bathroom group	Private	Flushometer valve	6.0	3.0	8.0
Bathtub	Private	Faucet	1.0	1.0	1.4
Bathtub	Public	Faucet	3.0	3.0	4.0
Bidet	Private	Faucet	1.5	1.5	2.0
Combination fixture	Private	Faucet	2.25	2.25	3.0
Dishwashing machine	Private	Automatic	—	1.4	1.4
Drinking fountain	Offices, etc.	3/8" valve	0.25	—	0.25
Kitchen sink	Private	Faucet	1.0	1.0	1.4
Kitchen sink	Hotel, restaurant	Faucet	3.0	3.0	4.0
Laundry trays (1 to 3)	Private	Faucet	1.0	1.0	1.4
Lavatory	Private	Faucet	0.5	0.5	0.7
Lavatory	Public	Faucet	1.5	1.5	2.0
Service sink	Offices, etc.	Faucet	2.25	2.25	3.0
Shower head	Public	Mixing valve	3.0	3.0	4.0
Shower head	Private	Mixing valve	1.0	1.0	1.4
Urinal	Public	1" flushometer valve	10.0	—	10.0
Urinal	Public	3/4" flushometer valve	5.0	—	5.0
Urinal	Public	Flush tank	3.0	—	3.0
Washing machine (8 lb)	Private	Automatic	1.0	1.0	1.4
Washing machine (8 lb)	Public	Automatic	2.25	2.25	3.0
Washing machine (15 lb)	Public	Automatic	3.0	3.0	4.0
Water closet	Private	Flushometer valve	6.0	—	6.0
Water closet	Private	Flush tank	2.2	—	2.2
Water closet	Public	Flushometer valve	10.0	—	10.0
Water closet	Public	Flush tank	5.0	—	5.0
Water closet	Public or private	Flushometer tank	2.0	—	2.0

For SI: 1 inch = 25.4 mm, 1 pound = 0.454 kg.

a. For fixtures not listed, loads should be assumed by comparing the fixture to one listed using water in similar quantities and at similar rates. The assigned loads for fixtures with both hot and cold water supplies are given for separate hot and cold water loads and for total load. The separate hot and cold water loads being three-fourths of the total load for the fixture in each case.

d. UPC, UPC Appendix C

TABLE A103.1
WATER SUPPLY FIXTURE UNITS (WSFU) AND MINIMUM FIXTURE BRANCH PIPE SIZES[3]

APPLIANCES, APPURTENANCES, OR FIXTURES[2]	MINIMUM FIXTURE BRANCH PIPE SIZE[1,4] (inches)	Private	Public	ASSEMBLY[6]
Bathtub or Combination Bath/Shower (fill)	1/2	4.0	4.0	-
3/4 inch Bathtub Fill Valve	3/4	10.0	10.0	-
Bidet	1/2	1.0	-	-
Clothes Washer	1/2	4.0	4.0	-
Dental Unit, cuspidor	1/2	-	1.0	-
Dishwasher, domestic	1/2	1.5	1.5	-
Drinking Fountain or Water Cooler	1/2	0.5	0.5	0.75
Hose Bibb	1/2	2.5	2.5	-
Hose Bibb, each additional[7]	1/2	1.0	1.0	-
Lavatory	1/2	1.0	1.0	1.0
Lawn Sprinkler, each head[5]	-	1.0	1.0	-
Mobile Home, each (minimum)	-	12.0	-	-
Sinks	-	-	-	-
Bar	1/2	1.0	2.0	-
Clinical Faucet	1/2	-	3.0	-
Clinical Flushometer Valve with or without faucet	1	-	8.0	-
Kitchen, domestic	1/2	1.5	1.5	-
Laundry	1/2	1.5	1.5	-
Service or Mop Basin	1/2	1.5	3.0	-
Washup, each set of faucets	1/2	-	2.0	-
Shower per head	1/2	2.0	2.0	-
Urinal, 1.0 GPF Flushometer Valve	3/4	3.0	4.0	5.0
Urinal, greater than 1.0 GPF Flushometer Valve	3/4	4.0	5.0	6.0
Urinal, flush tank	1/2	2.0	2.0	3.0
Wash Fountain, circular spray	3/4	-	4.0	-
Water Closet, 1.6 GPF Gravity Tank	1/2	2.5	2.5	3.5
Water Closet, 1.6 GPF Flushometer Tank	1/2	2.5	2.5	3.5
Water Closet, 1.6 GPF Flushometer Valve	1	5.0	5.0	8.0
Water Closet, greater than 1.6 GPF Gravity Tank	1/2	3.0	5.5	7.0
Water Closet, greater than 1.6 GPF Flushometer Valve	1	7.0	8.0	10.0

For SI units: 1 inch = 25 mm

TABLE C 303.2
WATER SUPPLY FIXTURE UNIT (WSFU) FOR BATHROOM GROUPS[1, 2]

	PRIVATE USE BATHROOM GROUP		SERVING 3 OR MORE PRIVATE USE BATHROOM GROUPS	
	COLD	HOT[3]	COLD	HOT
Bathroom Groups Having up to 1.6 GPF Gravity-Tank Water Closets				
Half-Bath or Powder Room	3.5	0.8	2.5	0.5
1 Bathroom Group	5.0	2.5	3.5	1.8
1 1/2 Bathrooms	6.0	2.5	—	—
2 Bathrooms	7.0	3.5	—	—
2 1/2 Bathrooms	8.0	3.6	—	—
3 Bathrooms	9.0	4.5	—	—
Each Additional 1/2 Bath	0.5	0.1	—	—
Each Additional Bathroom Group	1.0	0.5	—	—
Bathroom Groups Having up to 1.6 GPF Pressure-Tank Water Closets				
Half-Bath or Powder Room	3.5	0.8	2.5	0.5
1 Bathroom Group	5.0	2.5	3.5	1.8
1 1/2 Bathrooms	6.0	2.5	—	—
2 Bathrooms	7.0	3.5	—	—
2 1/2 Bathrooms	8.0	3.6	—	—
3 Bathrooms	9.0	4.5	—	—
Each Additional 1/2 Bath	0.5	0.1	—	—
Each Additional Bathroom Group	1.0	0.5	—	—
Bathroom Group (1.6 GPF Flushometer Value)	6.0	2.5	4.0	1.7
Kitchen Group (Sink and Dishwasher)	2.0	2.0	1.5	1.5
Laundry Group (Sink and Clothes Washer)	5.0	5.0	3.0	3.0

Notes:

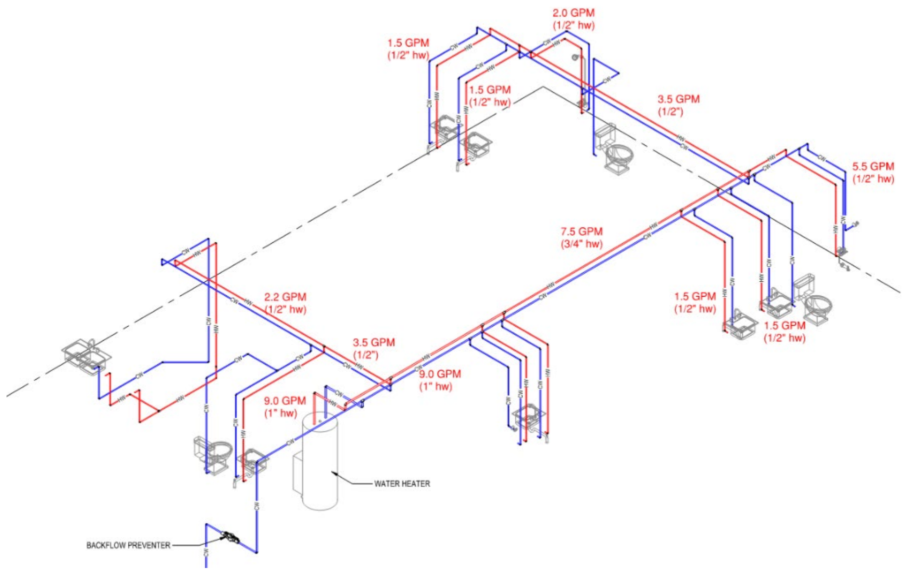
1 A bathroom group, for this table, consists of one water closet, up to two lavatories, and either one bathtub or one shower.

2 A half-bath or powder room, for this table, consists of one water closet and one lavatory.

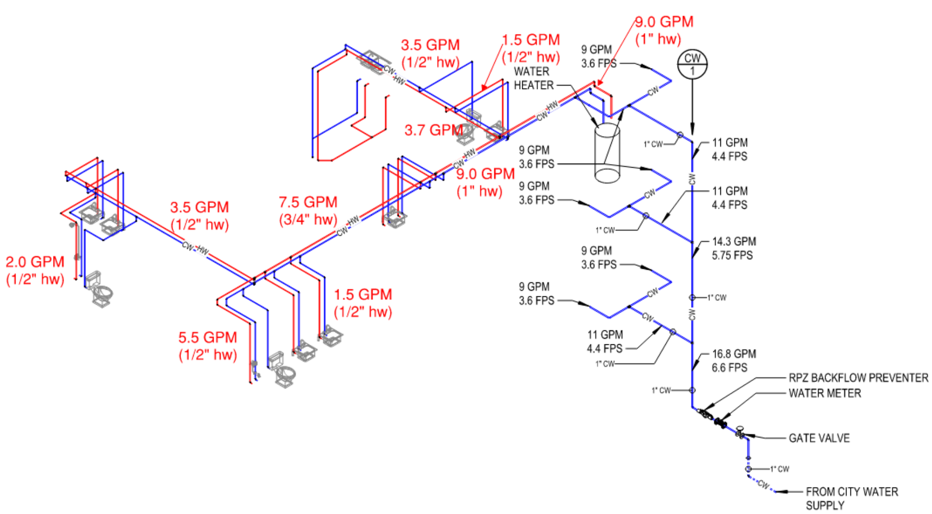
3 Multi-unit dwellings with individual water heaters use the same WSFU as for individual dwellings.

e. WDC Hot Water Isometrics

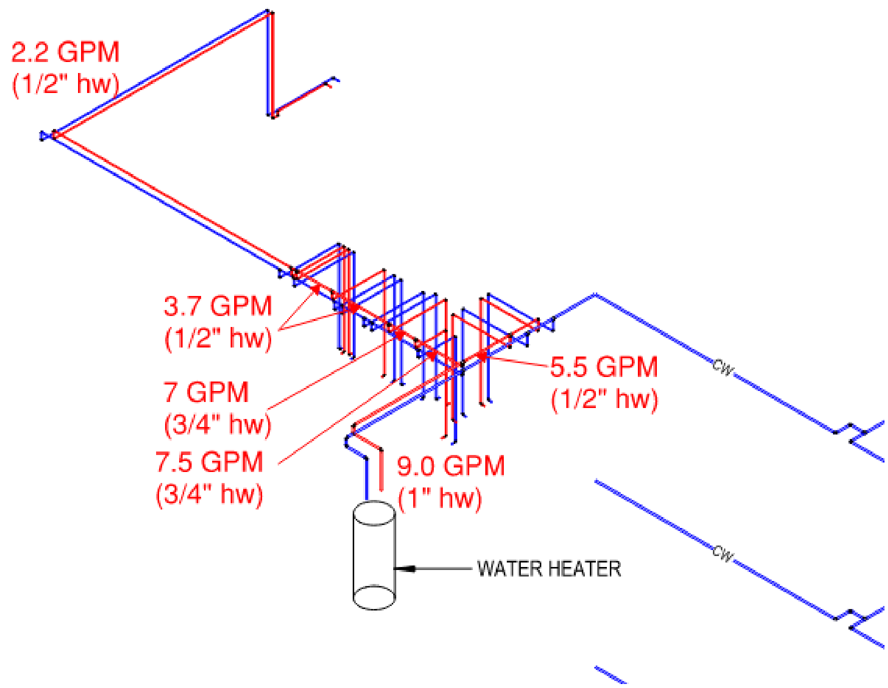
i. Single-Family



ii. 6-Unit

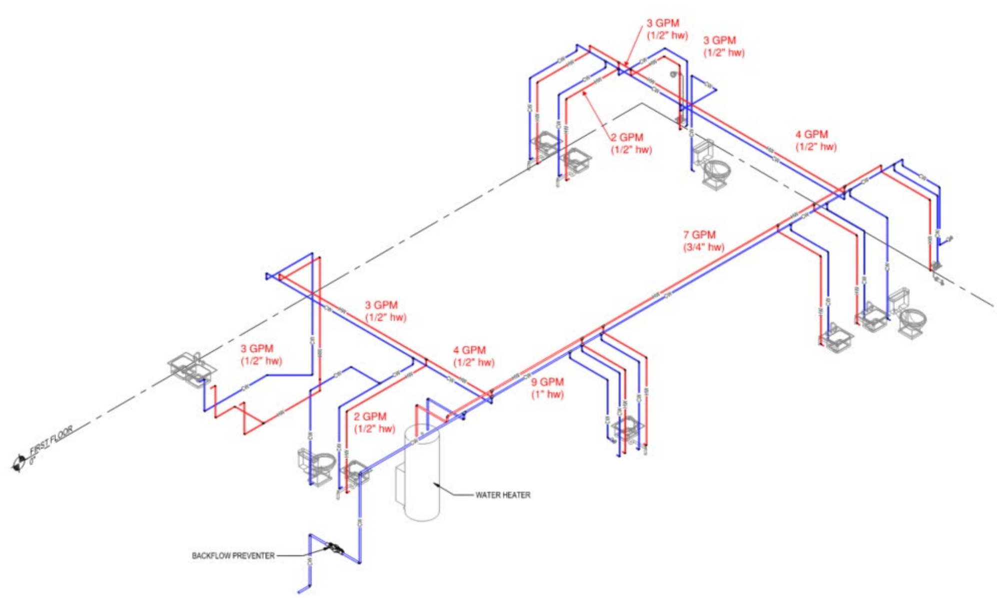


iii. 45 and 48 Unit

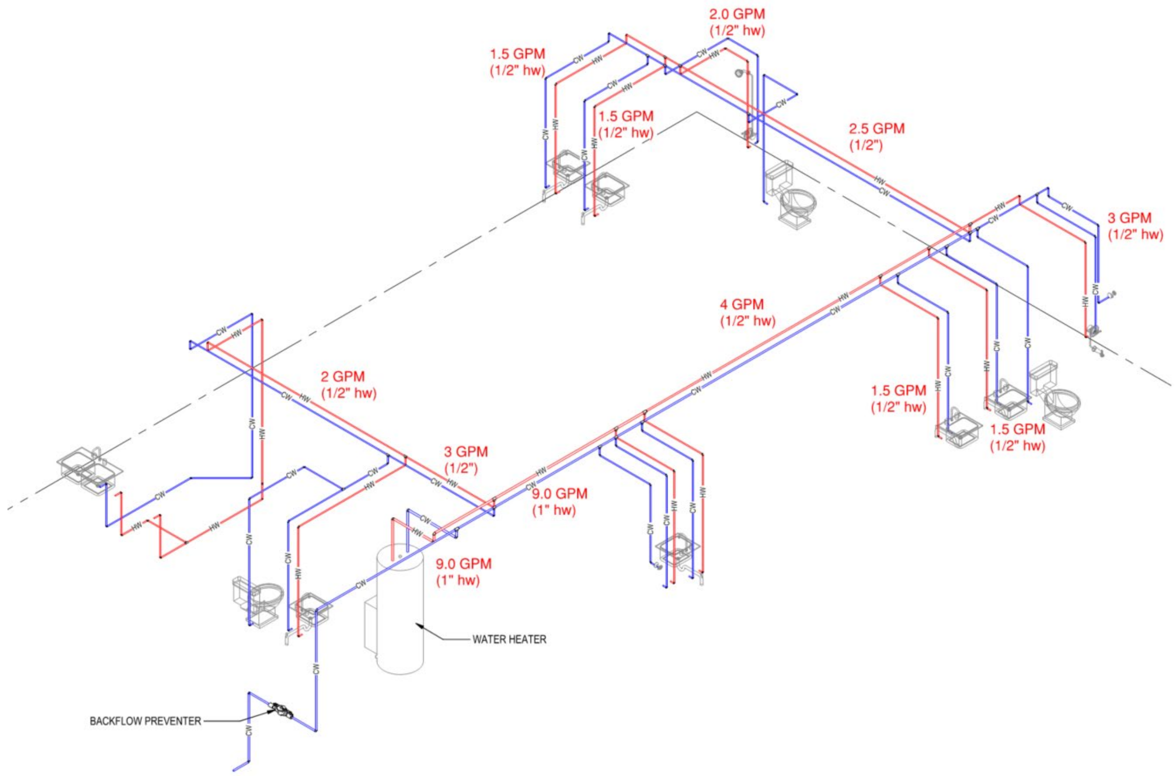


f. UPC Hot water isometrics

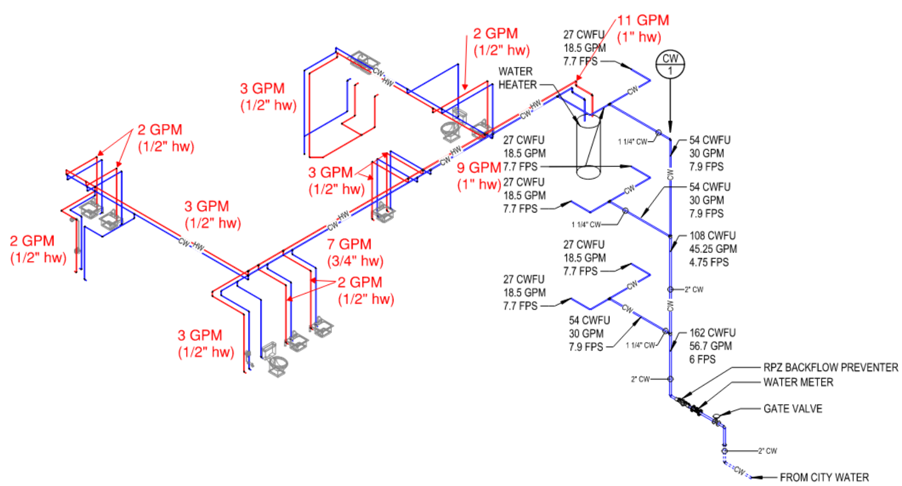
i. Single-Family



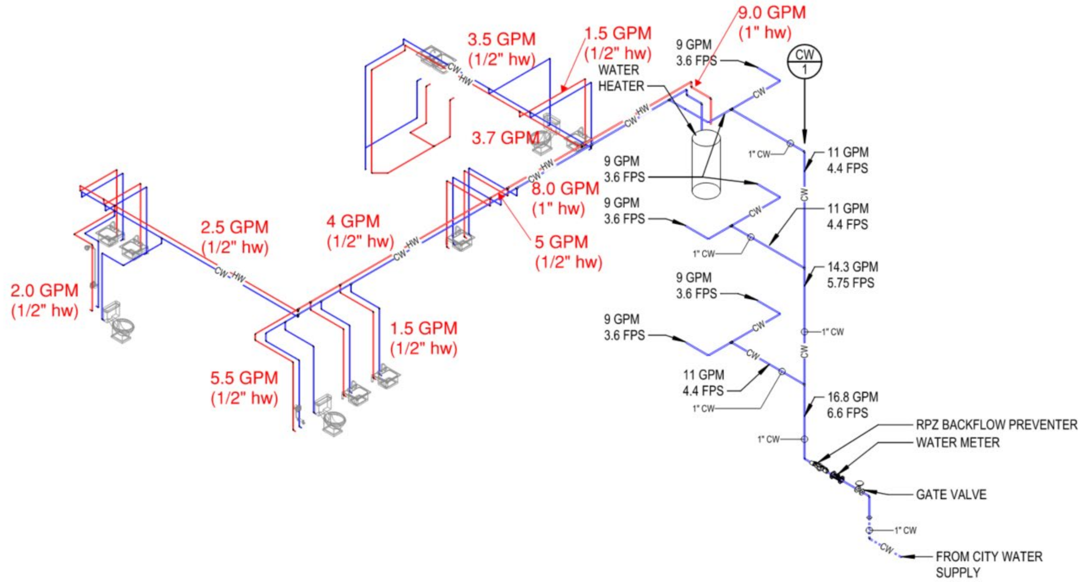
ii. Single-Family – Appendix C



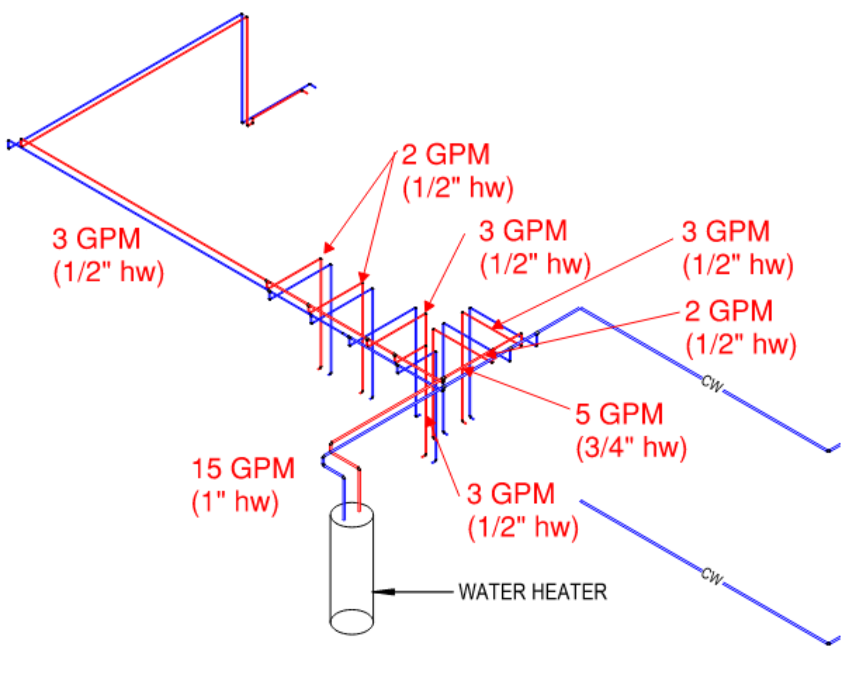
iii. 6-Unit



iv. 6 – Unit – Appendix C:

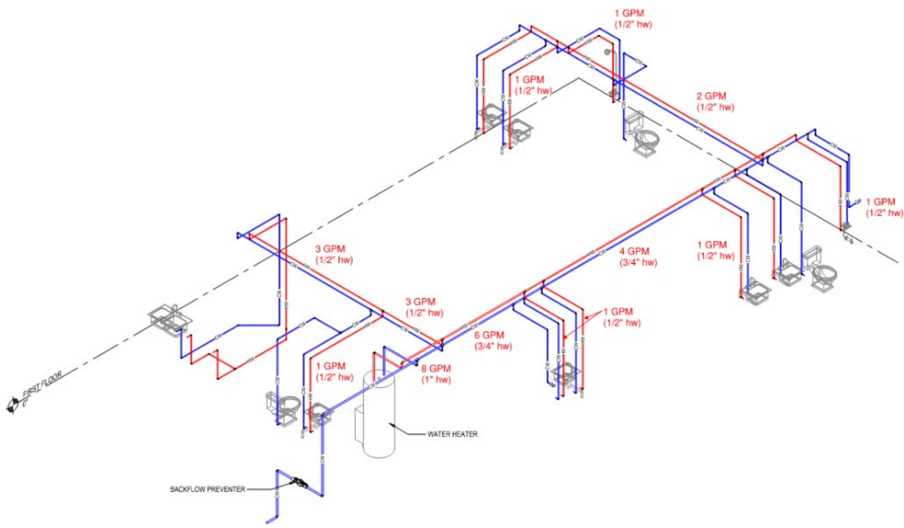


v. 45 and 48 Unit, UPC & Appendix C

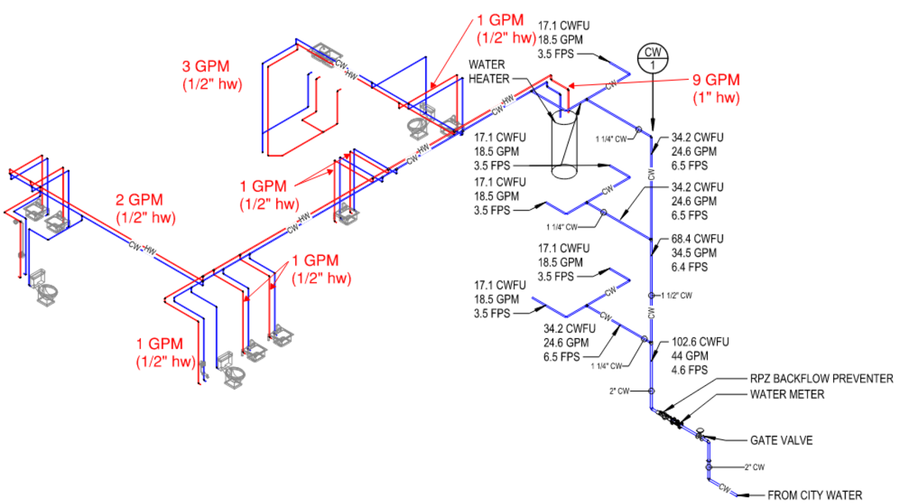


g. IPC Hot water isometrics

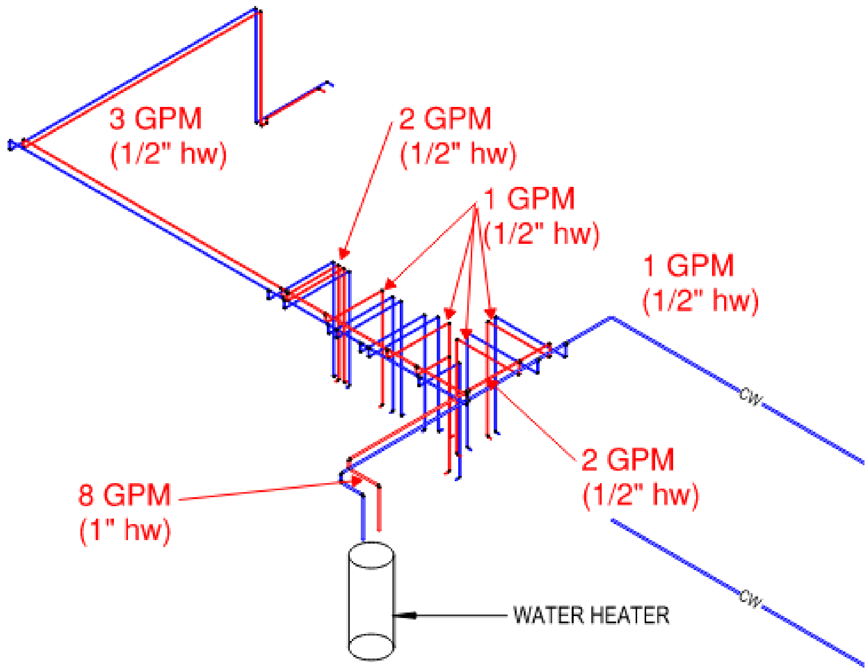
i. Single-Family Unit



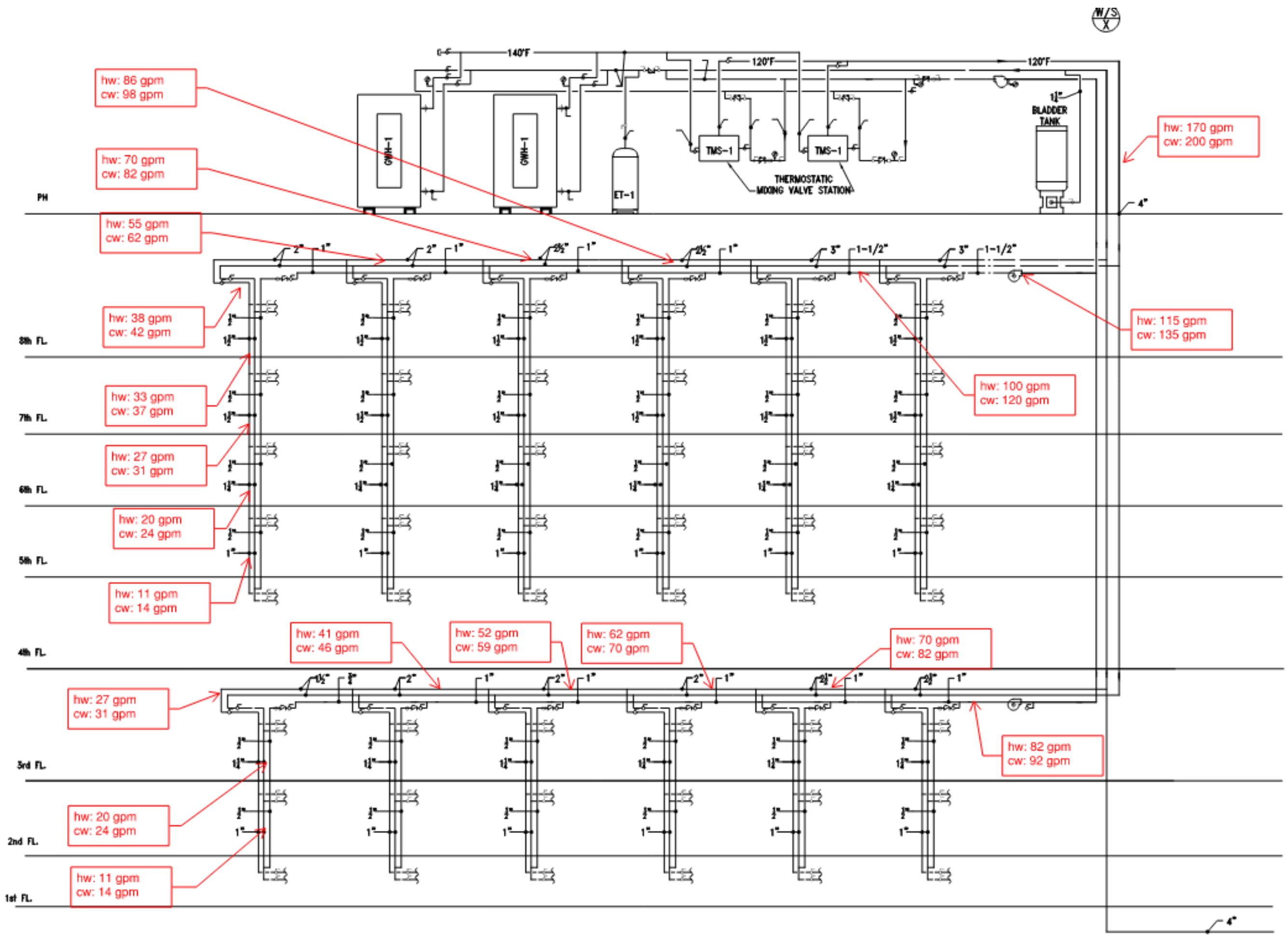
ii. 6-Unit



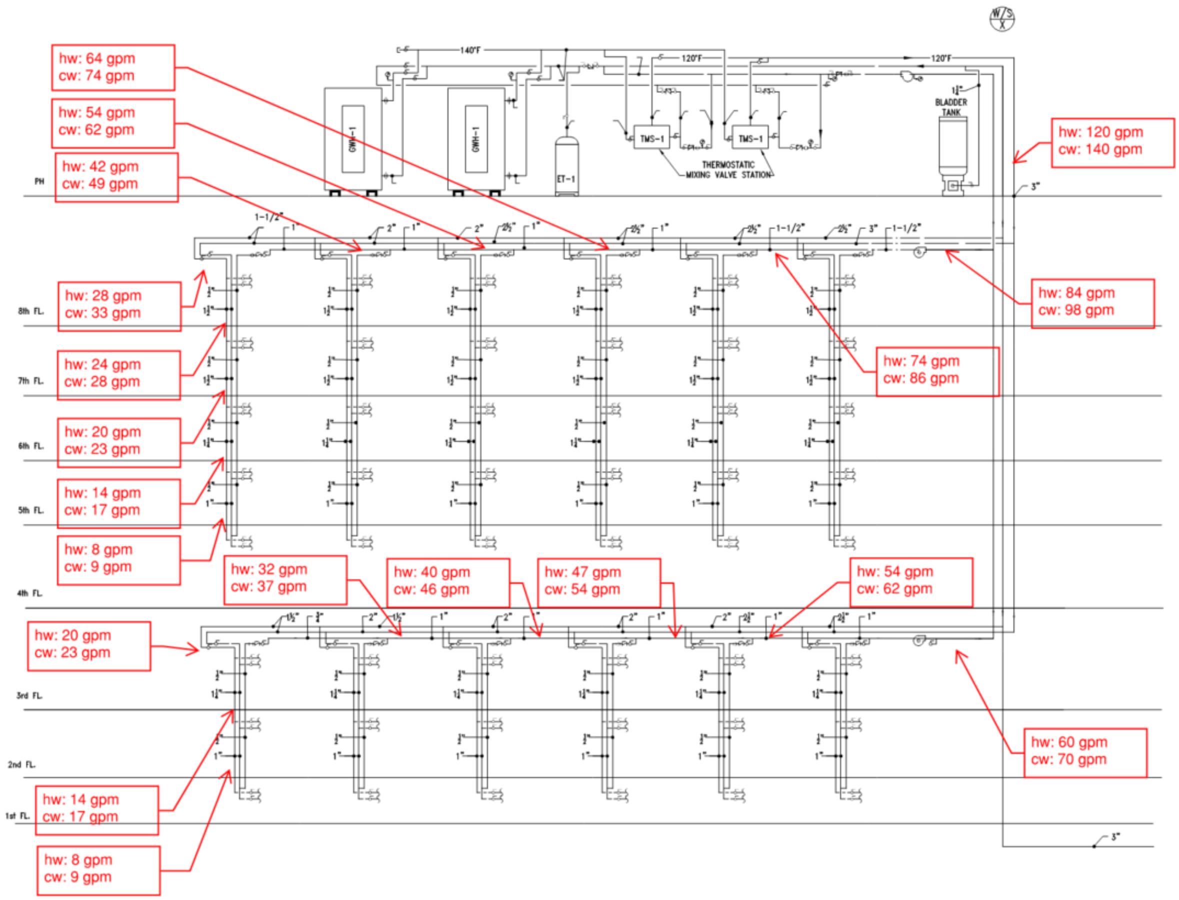
iii. 45 and 48 Unit



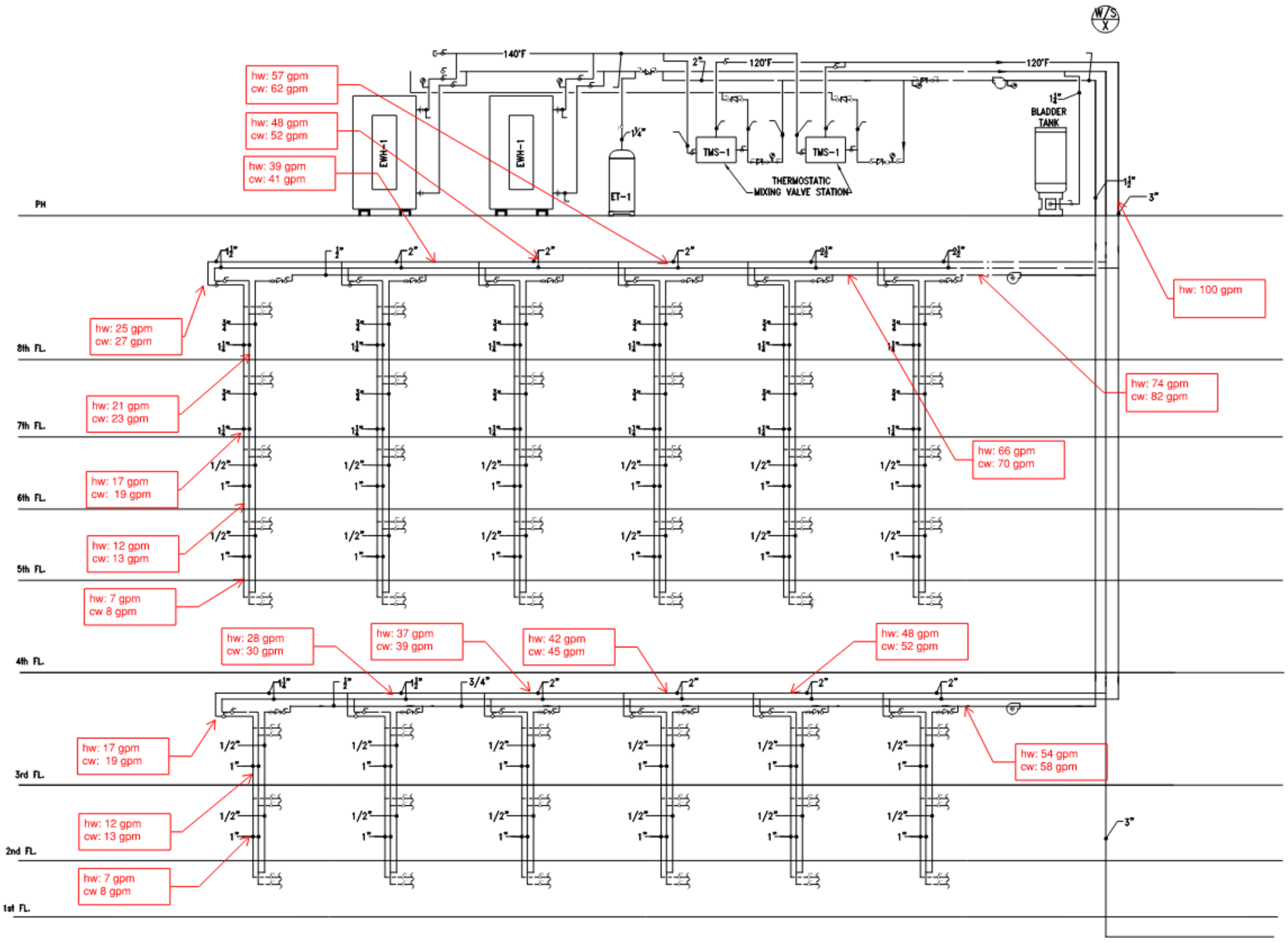
h. UPC High Rise Riser Diagram



i. UPC – App C High Rise Riser Diagram



j. IPC High Rise Riser Diagram



k. WDC High Rise Riser Diagram