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Influence of Design Efficiency of Water Supply Network Inside Building on its Optimum Usage: Review

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ABSTRACT

The water supply network inside the building is of high importance due to direct contact with the user that must be optimally designed to meet the water needs of users. This work aims to review previous research and scientific theories that deal with the design of water networks inside buildings, from calculating the amount of consumption and the optimal distribution of the network, as well as ways to rationalize the use of water by the consumer. The process of pumping domestic water starts from water treatment plants to be fed to the public distribution networks, then reaching a distribution network inside the building till it is provided to the user. The design of the water supply network inside the building is mainly affected by the amount of water consumed in the building. On this basis, the pipes' dimensions and the water tank's volume are determined. The operating pressure of the water supply network inside the building is calculated to overcome the height difference and the friction inside the pipes and provide sufficient pressure to operate the most remote fixture. The most important results of the research are that the optimal use of the water distribution network inside the buildings is achieved by the correct design and implementation using skilled labor, materials, and devices of high quality and rationalization of water consumption by the user.

Keywords: Plumbing, Water supply network, Up-feed, Down-feed, Efficiency design.

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تأثير كفائة التصميم لشبكات الماء الصافي على الاستخدام الامثل لها داخل البناية: مراجعة الادبيات

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الخلاصة

تعتبر شبكة تجهيز الماء داخل البناية ذات اهمية عالية كونها بتماس مباشر مع المستخدم فيجب ان تصمم هذه الشبكات بالشكل الامثل لتلبية احتياجات المستخدمين من الماء. الهدف من هذا الدراسة هو استعراض البحوث السابقة و النظريات العلمية التي تتناول تصميم شبكات الماء داخل الابنية من احتساب كمية الاستهلاك والتوزيع الامثل للشبكة وايضاً طرق ترشيد استخدام الماء من قبل المستهلك . تتم عملية ضخ الماء الصافي من محطات تصفية الماء الى شبكات التوزيع العمومية الى ان تصل لشبكة توزيع داخل البناية ثم المستخدم . ان تصميم شبكة توزيع الماء داخل البناية يتاثر بشكل رئيسي بكمية الماء المستهلك للبناية حيث على هذا الاساس يتم تحديد ابعاد الانابيب و حجم خزان الماء . يتم حساب ضغط التشغيل لشبكة إمدادات المياه داخل المبنى للتغلب على الفرق في الارتفاع والاحتكاك داخل الأنابيب وتوفير الضغط الكافي لتشغيل التركيب الصحية الأكثر بعدا. اهم النتائج للبحث ان الاستخدام الامثل لشبكة توزيع الماء داخل الابنية يتحقق بالتصميم الصحيح والتنفيذ باستخدام العمالة الماهرة و المواد و الاجهزة ذات الجودة العالية وترشيد استهلاك الماء من قبل المستخدم.

الكلمات الرئيسية: اكتب سباكة, شبكة تجهيز الماء, تغذية للاعلى, تغذية للاسفل, التصميم الكفوء.

1. INTRODUCTION

Water is the most important natural element for continuing human life and for carrying out various daily activities. In urban areas, water is supplied to citizens through water treatment plants, and then the water is stored and pumped to buildings of all kinds **(Amjad, 2017).** The water supply networks inside the building are very important because they deliver water to the user directly for drinking, cooking, washing, and other uses **(Alaa-Eldin, 2020).** The water network system inside the buildings consists of several parts, pipes, pumps, tanks, valves, pressure reducers, and multi-type fixtures. The water network system inside the buildings is designed to ensure water availability in the worst operating conditions and provide the appropriate pressure to operate the healthiest installations within the network **(Ali and Alaa-Eldin, 2015).** There are several systems for feeding buildings with water. Up-feed system, in which water is pumped to the top of the building by pumps at the bottom. Down-feed system, in which the building is fed from a tank at the top of building **(Mahmoud and Sayed, 2021).** The internal water supply network pipe sizes and storage tanks mainly depend on the water demand of the users inside the building. It is determined by several factors including users' habits, climate, geographical location, water bill cost, and other factors **(Zotov et al., 2022).** So that the effective design of the inside water supply network can be achieved and avoiding the oversizing and under sizing problems by determining the optimal usage of the water demand by users **(Tiago and Orestes, 2020).**

This work aims to review previous work dealing with the designs of water supply networks inside buildings and the optimum usage of this network to reduce water consumption**.**

2. WATER SUPPLY NETWORK DESIGN INSIDE THE BUILDING

The design of pipes for water supply networks inside buildings depends on the amount of water sufficient to supply the fixtures within the network and to provide the appropriate pressure to operate these fixtures. For this reason, the amount of water consumed is determined by the assumption of operating the largest possible number of fixtures simultaneously, as well as calculating the required pressure within the network, which overcomes the difference in the elevation and the friction within the pipes network to provide the proper operating pressure for each fixture **(Mangalekar and Gumaste, 2021).** The water distribution network is in the system that ensures the delivery of the appropriate water flow with sufficient pressure in any place and at any time inside the building. There are several systems for the water distribution network inside the buildings. The system can be chosen depending on several factors, the most important of which are the height of the building and the use of the building to determine the appropriate storage of water **(Alan, 2002).**

2.1 Up-Feed Systems

A water distribution system is supplied and fed upward through a vertical pipe to the highest point within the building using the pressure available in the system. In low-rise buildings, the water pressure in the public water pipes is sufficient to supply water to the farthest hydraulic point. In medium-rise and high-rise buildings, the pressure in the public water pipes is insufficient to supply the heights parts of the building with water. In this case, the building is divided into two parts: the lower part is fed with water from the public water pipe, and the upper part of the building by a system of pumps to provide the appropriate pressure to operate sanitary installations **(Cyril, 1998).**

2.2 Down-Feed Systems

The water distribution system has a tank on top of the water distribution network. That is fed with water utilizing a vertical pipe (risers), and then the water is distributed down to the lowest point in the network. The water network is distributed by gravity flow, as it provides the appropriate pressure inside the network by the level difference between the tank and the rest of the network. The level difference in the floors near the tank is small and unsuitable for operation. The booster pump is connected to provide the appropriate pressure **(Cyril, 1998**). In high-rise buildings, the building is divided into several parts. At the top of each part, a water tank feeds the lower part with water. **(Yang et al., 2019).** A comparison can be made between the two systems, as given in **Table 1**. **Figs. 1 and 2** show the types of water supply systems**.** Both systems can be used in the same building where the lower parts of the building are fed directly from the public water pipe (Up-feed System). The rest of the building is fed by a gravity tank at the top of each part (Down-feed System), called the Combination Up-feed/Down-feed System **(Cyril, 1998).**

Table 1. Comparison between the up and down feed systems **(Alan, 2002).**

Up-Feed Systems	Down-Feed Systems
It does not provide water storage in the event of water supply or power failure.	It provides water storage in the event of water supply or power failure.
It needs more complex control equipment.	It requires only very simple control equipment.
It requires more maintenance.	It requires only a minimum of maintenance.
It consumes more energy.	It consumes less overall energy.
No need to strengthen the building structure.	The building structure must be strengthened to carry this additional load from The combined weight of the tank and water.
Less pipe size.	Large pipe size due to limited available head.
Higher delivery pressures.	Lower delivery pressures.
More noise due to higher flow speed.	Less noise due to lower flow speed.

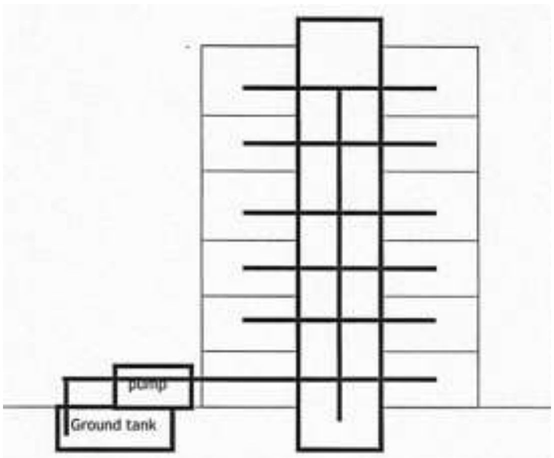


Figure 1. Up-Feed Systems.

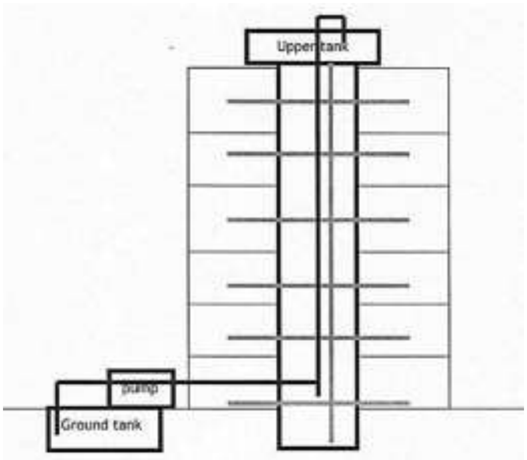


Figure 2. Down-feed system**.**

3. STANDARD DESIGN REQUIREMENTS ACCORDING TO CODES

A water supply network inside the buildings is designed based on local codes according to each country or international codes, the most famous codes **(Kaustav et al., 2021).**

- National Standard Plumbing Code.
- International Building Code (IBC).
- International Plumbing Code (IPC).
- The American Society of Plumbing
- Engineers (ASPE).
- Uniform Plumbing Code.

Most of them depend on estimating the design load for each building in determining the sizes of the pipes by calculating the fixtures that each pipe feeds. Each fixture is given a different value, as shown in **Table 2.** this value depends on the probability of operating the fixture, water flow consumption during operation, method, and operating time. These values are called Fixture Units **(Toritseju et al., 2020; Rohit and Krishnakedar, 2022).** Using the

Hunter curve, shown in **Fig. 3**, relates the flow inside the pipe to the number of fixture units fed to this pipe. The flow amount inside a pipe is taken by applying this value within the appropriate design schemes based on the type of pipe inside the code. The suitable design diameter for each pipe is calculated based on fixing the speed limits (1.2 to 2.4 m/s) and the value of Pressure losses, as shown in **Fig. 4 (Christopher et al., 2019).**

Table 2. Fixture units for each type of fixture **(IPC, 2018).**

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

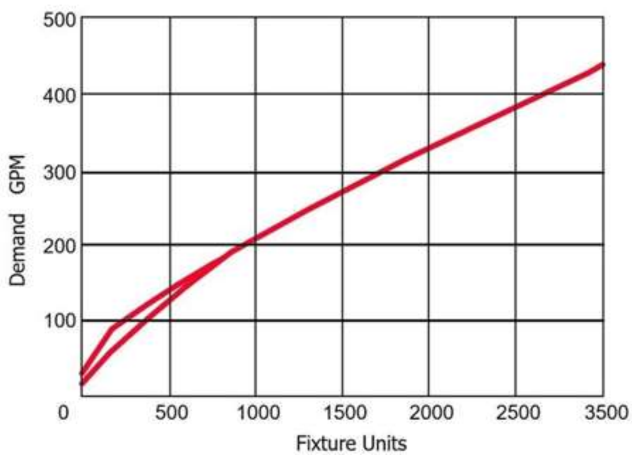


Figure 3. Hunter estimate curve for demand load **(ASPE, 2000)**

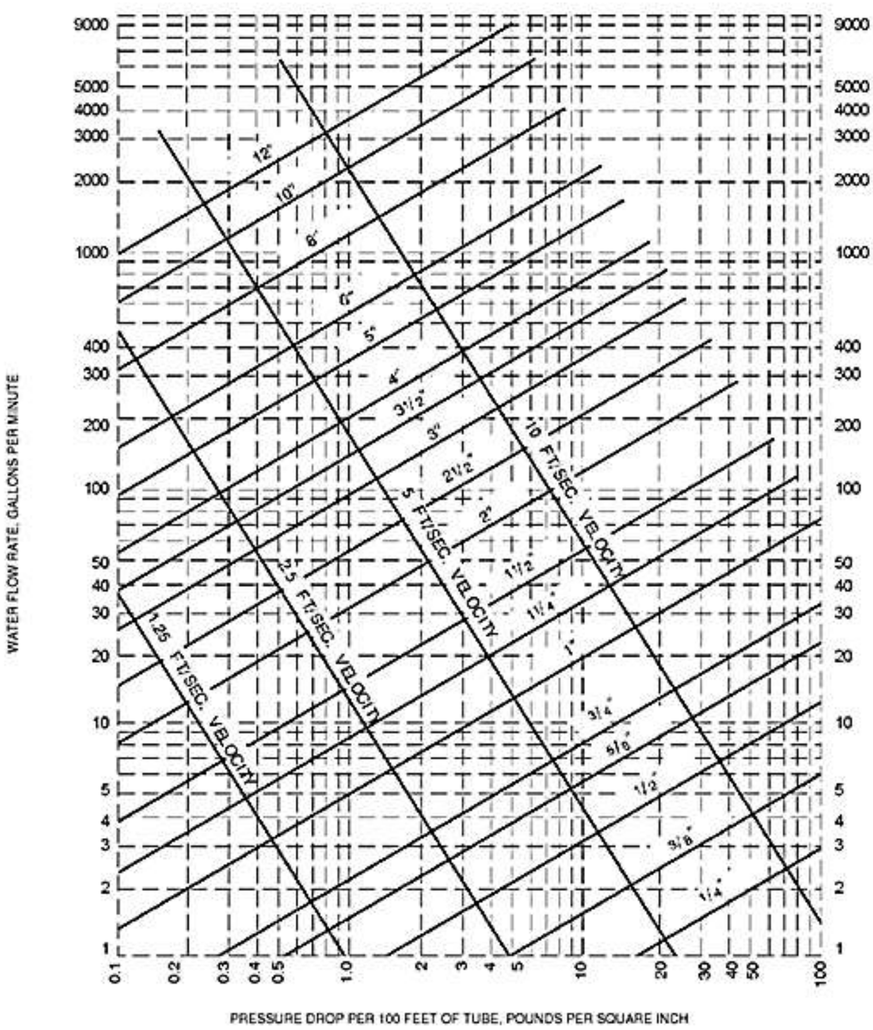


Figure 4. Friction losses in smooth pipes **(IPC, 2018)**

4. OPTIMUM USAGE OF WATER SUPPLY NETWORK INSIDE THE BUILDING (DESIGN–IMPLEMENTATION–USE)

Because there are many methods and research to calculate the real consumption of water inside buildings, the difference in codes from one country to another makes calculating the expected amount of water consumption challenging in various buildings **(Mangalekar and Gumaste, 2021).** Therefore, the quantities of water consumed for buildings must be calculated in an accurate and realistic form to represent the real need of the building. Thus, the appropriate tank and pipe sizes can be determined to meet the user's needs in all circumstances and make the water supply network inside the building work with high efficiency and flexibility **(Suxian et al., 2018).** The improper design of the water supply network inside the buildings leads to ineffective use, increased failures, and the inability to provide the user with the appropriate need for water in various conditions **(Mangalekar and Gumaste, 2021).**

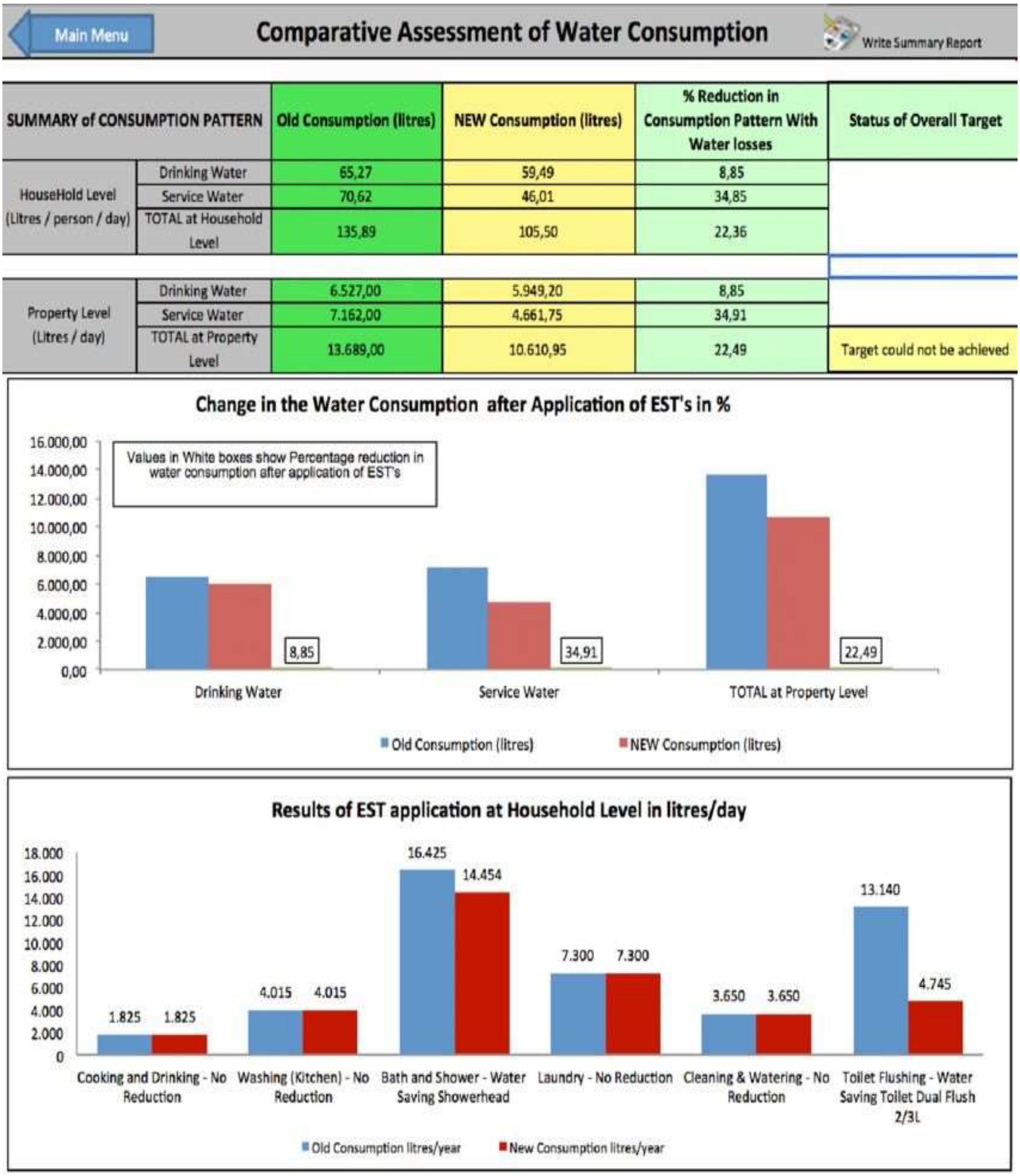
During the implementation of the water supply networks inside the building, highly skilled and experienced implementers are hired, and clear engineering schemes are used to avoid operational errors and facilitate the completion process **(Tianyun et al., 2017).** Also, the use of highly efficient materials and equipment such as pumps, pipes, locks, and other materials of the water supply network inside the buildings ensures the efficiency of the network in various conditions and works to reduce faults and maintenance in the future **(Li et al., 2020).** Changing the habits and culture of the community and educating it about rationalizing water consumption is a major factor in reducing water consumption **(Cristina et al., 2011).** Also, using water-saving devices or replacing old plumbing devices with these-saving devices saves 33% of water consumption, and these changes are a major factor in reaching the optimum usage of the water supply network inside the buildings **(Wahyudi and Eka, 2019).**

5. RATIONALIZATION OF WATER CONSUMPTION

The increase in population and water demand with the decline in water resources led to the rationalization of water consumption being necessary to preserve these resources. Work must be done to activate a plan to reduce consumption **(Martin et al., 2017).** One of the steps to reduce water consumption is to improve the work of water meters by replacing mechanical meters with electronic ones. This reduces water consumption by 10 to 30% **(Harrison et al., 2011).** Also, one of the factors affecting the accuracy of the work of the meters, that is the aging effect, he meter accuracy in calculating the water consumption is reduced with time. **Table 3.** shows the increase in losses in water consumption with the increase in the age of the meter **(Criminisi et al., 2009).** Also, to reduce water consumption, some technologies that provide this principle can be used, including environmentally sound technologies (ESTs), which depend on adding water-saving devices and alternative water sources such as rain and wastewater recycling. **Fig. 5** shows the difference in consumption before and after applying environmentally sound technologies (**Thorsten and Vicente, 2013; Raed and Inaam, 2018).**

Table 3. Water loss by the increase in the age of the meter **(Criminisi et al., 2009).**

Flow meter age	Measured volume (m^3)	Water consumption (m^3)	Apparent losses (%)
Class C—new	12.645	13.699	-7.8
0-5	12.702	13.699	-7.3
5-10	12.623	13.699	-7.9
10-15	12.482	13.699	-8.9
15-20	12.207	13.699	-10.9
20-25	12.112	13.699	-11.6
25-30	12.518	13.699	-8.6
30-35	11.645	13.699	-15.0
35-40	11.427	13.699	-16.6
40-45	6.447	13.699	-52.9



Main Menu

Comparative Assessment of Water Consumption

Write Summary Report

SUMMARY of CONSUMPTION PATTERN		Old Consumption (litres)	NEW Consumption (litres)	% Reduction in Consumption Pattern With Water losses	Status of Overall Target
HouseHold Level (Litres / person / day)	Drinking Water	65,27	59,49	8,85	
	Service Water	70,62	46,01	34,85	
	TOTAL at Household Level	135,89	105,50	22,36	
Property Level (Litres / day)	Drinking Water	6.527,00	5.949,20	8,85	
	Service Water	7.162,00	4.661,75	34,91	
	TOTAL at Property Level	13.689,00	10.610,95	22,49	Target could not be achieved

Figure 4. Water consumption changes after the ESTs, and the results of EST applications **(Thorsten and Vicente, 2013).**

6. CONCLUSION

The most important points that were deduced from the study of previous studies in the design of pure water networks inside buildings are

1) The process of calculating water consumption must be accurate because it is the main factor in calculating pipe sizes and tank dimensions within the water supply networks inside the building.
2) The design of the method of distributing the water supply network inside the building depends on several determinants, including the height of the building, the building's function, and the pressure in the public water network.
3) The use of skilled workers and high-quality materials is a major reason for the success of the water supply network inside the building and to reduce future failures.
4) Adopting technologies that save water increases the efficiency of the building's water supply networks, reduces the consumption of natural resources, and preserves the environment.
5) The water supply network inside the buildings that uses rainwater and wastewater recycling in irrigation and external washing contributes significantly to environmental sustainability.

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REFERENCES

Alaa-Eldin M., Abd-Elaal, 2020. The influence of simultaneous operation of plumbing appliances on water consumption and conservation inside residential buildings. *Ain Shams Engineering Journal,* 12(3), pp. 2443-2452. doi:10.1016/j.asej.2020.11.018

Alan M., 2002. *Plumbing Engineering Services Design Guide*, pp. 4-5 .

Albadry, A.M., 2017. The Effect of The Utilitarian Need For the High Water Tanks Towers to Sustain Life in the City, *Journal of Engineering,* 23 (2), pp. 21.

Ali A., Gada, M., Alaa-Eldin M., Abd-Elaalb, 2016. Practical guidelines for a reliability-based design of building water supply systems, *Urban Water Journal,* 13(2), pp. 94-107. doi:10.1080/1573062X.2014.993995

Al-Talebi, R., Al-Bazzaz, I., 2018. Similarity and Difference between Sustainable and Green Architecture (a Comparative study). *Journal of Engineering,* 24(12), pp. 21-42. (In Arabic) doi:10.31026/j.eng.2018.12.10

Criminisi, A., Fontanazza, C., Freni G., Loggia, G., 2009. Evaluation of the apparent losses caused by water meter under-registration in intermittent water supply. *IWA Publishing, Water Sci. Technol.* 60(9), pp. 2374–2381. doi:10.2166/wst.2009.423

Douglas, C., Buchberger, S., Mayer, P., 2019. Systematic oversizing of service lines and water meters, *AWWA Wat. Sci.,* 1(6), pp. 1-2. doi:10.1002/aws2.1165

Ferreira T., Goncalves, O., 2019. Stochastic simulation model of water demand in residential buildings. *Building services engineering research and technology*, 41(5), pp. 1-17. doi:10.1177/0143624419896248

Harris, C., 1998. *Practical Plumbing Engineering*, pp. 1-30, McGraw-Hill.

International Plumbing Code (IPC), 2018. Appendix E pp. 147-150.

Mandal, K., Das, S., Mazumdar, A., 2021. Standardization of Fixture Units for Modern Flush Valves by Optimizing Water Demand Using Modified Hunter's Curve. *Journal of pipeline systems engineering and practic*, 12(3), Art. No. 04021022. doi:10.1061/ (ASCE) PS.1949-1204.0000558

Mangalekar, R., Gumaste, K., 2021. Residential water demand modelling and hydraulicreliability in design of building water supply systems: a review. *Water Supply*, 21(4), *pp.* 1385–1397. doi.org/10.2166/ws.2021.021

Mangalekar, R., Gumaste, K., 2022. User-based fuzzy end-use modeling of indoor urban residential water demand. *Building services engineering research and technology,* 43(4). doi:10.1177/01436244221085916

Mutikanga, H., Sharma S., Vairavamoorthy, K., 2011. Investigating water meter performance in developing countries: A case study of Kampala, Uganda*, African Journals Online*, 37(4), pp. 567-574. doi:10.4314/wsa.v37i4.18

Omaghomi, T., Buchberger, S., Hewitt, D., Wolfe, T., 2020. Probability of Water Fixture Use during PeakHour in Residential Buildings, *Journal of Water Resources Planning and Management*, 146(5). doi:10.1061/ (ASCE) WR.1943-5452.0001207

Schuetze, T., Santiago-Fandiño, V., 2013. Quantitative Assessment of Water Use Efficiency in Urban and Domestic Building. *Water,* 5(3), pp. 1173-1193. doi:10.3390/w5031172

Stavenhagen, M., Buurman, J., and Tortajada, C., 2017. Saving water in cities: Assessing policies for residential water demand management in four cities in Europe. *Cities,* 79, pp. 187-195. doi:10.1016/j.cities.2018.03.008

Santos, C., Taveira-Pinto, F., Cheng, C., and Leite, D., 2011. Optimizing water consumption in buildings. A study on the alternatives to potable water supply, *Symposium CIB W062 Aveiro Portugal,* pp. 34.

Taha A., and Nagy, S., 2021. Development of Drainage and water supply systems to reduce water consumption in Residential Buildings in Egypt. *Engineering Research Journal*, 170, pp. 47-62. doi:10.21608/ERJ.2021.176035

The American Society of Plumbing Engineers (ASPE), 2000. 2, pp. 120.

Wahyudi, and Wardhani, E., 2019. The Use of Plumbing Tools Saving Water With Efforts to Save Clean Water With Application of Green Building Concept at Menara Cibinong Apartment. *Journal of Architectural Research and Education*, 1(2), pp. 157-167. doi: 10.17509/jare.v1i2.22307

Wei, T., Chen, G., and Wang, J., 2017. Application of BIM Technology in Building Water Supply and Drainage Design. *IOP Conference Series: Earth and Environmental Science, Volume 100, 1st*

International Global on Renewable Energy and Development (IGRED 2017) 22–25 December 2017, Singapore, pp. 1-5. doi:10.1088/1755-1315/100/1/012117

Ye, S., Li1, J., Yuan, J., Hu, Y., and Han, X., 2018. Design and Analysis of Water Supply and Drainage Engineering for a Residential Building. 3rd International Conference on Advances in Energy and Environment Research (ICAEER 2018), 53(E3S Web Conf.), Art. No. 03044, pp. 1-3. doi: 10.1051/e3sconf/20185303044

Zotov, Y., Strelkov, A., Mikhailova, I., 2022. Water Supply Systems in Multi-Apartment Buildings and their Design Characteristics, *IOP Conf. Ser.: Earth Environ, 988(052019).* doi:10.1088/1755-1315/988/5/052019

Zhou, Y., Lee, E., Wong L., Mui, K., 2019. Modeling Study of Design Flow Rates for Cascade Water Supply Systems in Residential Skyscrapers, *Water,* 11(12), 2580, pp. 1-14. doi:10.3390/w11122580

Zhao, L., Li, Y., Zhang, M., Qin, F., 2020. Discussion on water saving technology of building water supply and drainage, 2nd Int. Conference on Air Pollution and Environmental Engineering *. IOP Conf. Ser.: Earth Environ. Sci.,* 450(012029), pp. 1-5. doi:10.1109/ICDMA.2010.315