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Physical controls in the simulation of hydraulic networks in buildings using Epanet 2.0 software

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Abstract. Water supply and distribution are an important design criterion in building construction. For this it is necessary to make an analysis of hydraulic networks, which is generally done through conventional methods based on iterative processes in spreadsheets. However, the Epanet 2.0 software can serve as an analysis method through simulation that is not currently considered for these applications, while such software is not a conventional method, it holds the possibility of being a model which through physical controls can serve as a simulator for hydraulic networks with the hypothesis that it can optimize costs and solution times. Therefore, the research has as purpose the application of physical controls for the analysis of the hydraulic networks in buildings by means of the software. For this reason, a design of the hydraulic network calculated by the modified Hunter model was executed and compared with the simulation in the software. The results obtained from the study demonstrated effectiveness of the software with a minimum percentage of error (0.24% to 1.06%) from one method to another, achieving to optimize calculation times and the economy of designs.

1. Introduction

The supply of drinking water is a prerequisite for life and progress of humanity, so water is one of the most important needs for human life and other living beings [1]. It requires safe and reliable storage systems [2]. According to the layout of the sanitary equipment and its operating conditions, an open network is to be built, one that satisfies in the points where the flow and pressure are located, for the comfort required in its use. Nowadays, at national and international level, conventional methods are used such as the simultaneity factor method, the method of presumption of expenditure, the Hunter method and the modified Hunter method [3,4] for the analysis of hydraulic networks in buildings. These methods are based on numerical processes carried out in spreadsheets, seeking through iterative processes to determine the ideal conditions of the hydraulic network in order to comply with the pressures in the sanitary devices.

The Epanet 2.0 software is a public domain computer program, developed by the United States Environmental Protection Agency, which allows the hydraulic analysis of pipeline networks from the physical characteristics of the pipelines and the dynamics of the nodes to obtain the pressure and the flows in nodes and pipes respectively. This software allows improving and optimizing the water supply network and has the advantage of fast operation speed and good simulation effect [2]. Among the elements that the program can simulate are mainly pipes, nodes, tanks and reservoirs and more complex elements such as pumps and valves [5].

Currently there are different calculation procedures, however, most are limited to the calculation of flow rates and energy losses in the sections of hydraulic networks, as well as the determination of piezometric dimensions and pressures available in the nodes by means of iterative processes. The current trend is to use programs that allow optimizing the cost of hydraulic networks and solution times. This project aims to make the technical feasibility for the analysis of hydraulic networks in buildings through software 2.0 using the third update of the "Norma Técnica Colombiana (NTC)" for plumbing (NTC 1500) [6]. As mentioned by Cheung P B and collaborators, simulation models are a tool to see the physical behavior of water distribution systems, since they are based on pressure-driven models [7]. Thus, this work aims to apply physical controls for the analysis of hydraulic networks in buildings through software 2.0 using the third update of the NTC 1500 [6].

2. Materials and methods

2.1. Data collection instruments
The evaluation of the networks using the Epanet 2.0 software considers as analysis parameters the length, diameter and flows demanded by sanitary devices. Data were taken from a three-store building, consisting of a parking lot on the second floor and two apartments per floor on the following levels.

2.2. Data analysis and processing techniques
For the hydraulic analysis, a layout of the building's network is established, which transports water from the storage tank to the sanitary devices. The determination of the flows demanded by each sanitary device is made to estimate the diameters of the pipe applying the modified Hunter method, so that the required pressures according to the NTC 1500 [6] are met. To establish the physical controls in the software, the two types of hydraulic operation are considered, which consists of a section of pipe in series and a section of branched pipe. The physical controls are based on the inclusion of a new node in the simulation, which allows adding or subtracting flows to match the results of the modified Hunter model. In this way, the flows that are overestimated by the software are adjusted. The formulas that were used for the analysis of the data that is part of the modified Hunter model [8] are as Equation (1), Equation (2), Equation (3) and Equation (4).

$$Q = vA, \tag{1}$$

$$D = \left(\frac{4Q}{\pi v}\right)^{1/2}, \tag{2}$$

$$h_v = \frac{v^2}{2g}, \tag{3}$$

$$NR = \frac{vD}{\nu}, \tag{4}$$

where Q is the flow or volumetric flow to be transported through the pipe, v is the average velocity of the fluid, A is the cross-sectional area of the pipe, D is the diameter of the pipe section, h_v is the head of velocity which means the movement of the fluid (kinetic energy), g is gravity, ν represents the kinematic viscosity of the fluid. For the development of the formula of turbulent flow f (Equation (5)) of Swame Jain [9].

Afterwards, the total loss is calculated with Darcy's equation [10], which is the addition of friction loss and minor losses. Then the pressures of each section are determined, for which initially takes an available hydraulic load of 15 meters (minimum hydraulic load required for new pressure requirements according to the update of the NTC 1500 [6]), it is adjusted to obtain as a result the available pressure of each section studied.

$$f = \frac{0.25}{\left[log\left(\frac{1}{3.7*\left(\frac{D}{E}\right)}+\frac{5.74}{NR*0.9}\right)\right]^2}. \tag{5}$$

3. Results

3.1. Equipment and consumption

The total daily consumption of the building was evaluated with the consumptions as stipulated in NTC 1500 [6] as shown in Table 1. Following the calculation process according to the Colombian standard, the form of water storage is established to provide the fluid to the building. In this sense, the design specifications are considered for the second floor, and in the provision for washing floors, it is taken as a reference that in level 2 and 3 there are 2 apartments with three rooms per apartment and two people per room, and in level 1 the parking lot. The results of the design are presented in Table 2.

The daily consumption will be stored for one day, taking as a hypothesis that there is no reasoning and it is stored in a subway tank with a capacity of 70% of the total daily consumption. To define the area that corresponds to the capacity for the fluid endowment, a depth of 1.50 meters is taken. As for the geometry, the side of the tank that forms the square of the tank is determined. The approximation to a constructive measure is established as 2.20 meters. While the elevated tank corresponds to the remaining fluid, *i.e.* 30% of total daily consumption, the result of which suggests placing two $2\,m^3$ plastic tanks for construction. Hydraulic analysis is performed by gravity from the elevated tank using the modified Hunter method and Epanet 2.0 software.

Table 1. Equipment according to NTC 1500 [6].

Use	Consumption	Unit
Housing	200	L/person/day
Floor washing	1	L/m^2

Table 2. Building storage design.

Calculation	Result	Unit
Daily Consumption	10.22	m^2
Daily consumption (70%)	7.15	m^2
Storage area (subway tank)	4.77	m^2
Length (subway tank)	2.18	m
Storage volume (raised tank)	3.07	m^3

3.2. Hydraulic analysis using the modified Hunter method

The following is an example of the hydraulic calculation of a section to verify the minimum pressure in the critical sanitary apparatus at the third level, it is shown that the dishwasher is the most removed sanitary apparatus (Figure 1). Figure 1 is the layout of the hydraulic network of sanitary equipment, where in the section 4A there is an appliance (dishwasher) with a consumption unit of 2, its flow is according to the consumption units calculated to find the turbulent flow to recognize the value of losses and adjust the pressure in each section, the results are presented in Table 3. Consequently, with the flow estimate for section 4A, the diameter measured in inches and for commercial pipe acquisition purposes its approximate diameter in millimeters is 16.60. For the losses, the hydraulic accessories are numbered, and the minor losses are calculated, in this first section with 1 90° elbow.

Table 3. Calculations for the estimation of the pressure per stretch 4A.

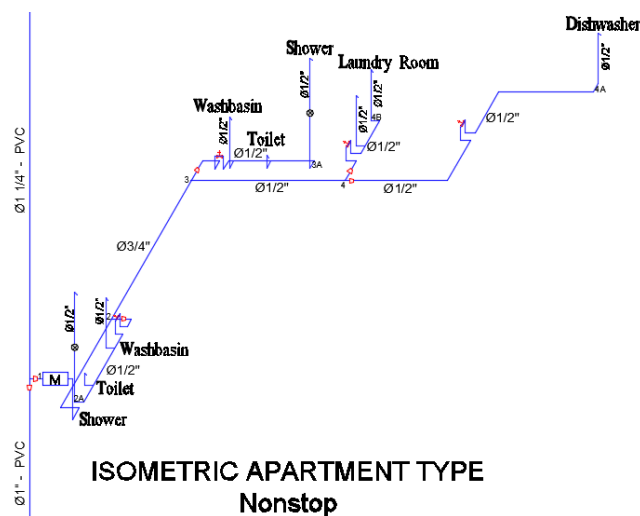| Calculation	Result	Unit
Flow	10.22	L/s
Pipe diameter	8.605	mm
Volume	0.5374	m/s
Speed head	0.5374	m/s
Reynolds number	8.109*103	
Turbulent flow	0.0330	
Total losses	0.019	m
Stretch pressure	18.724	mWC

Figure 1. Isometrics of the type apartment.

Then, using Darcy's equation [10], the total loss is calculated by adding the friction loss and the minor losses. To determine the pressure in the section studied begins with an available hydraulic load of 15 meters (minimum hydraulic load required for new pressure requirements according to the update of the NTC 1500 [6]), this load is subtracted from the total loss of their respective section, (Tank-1) and the final level is added to the static height of this point, this results in the available pressure of 18,724 mWC in point 1. This way, the available pressures for each section are determined as shown in Table 4.

Table 4. Available pressure for each point of the typical apartment.

Section	Point	Available pressure (mWC)
Tank-1	1	18.724
1-2	2	18.153
2- 2A	2A	17.068
2A-Shower	Shower	15.005
2-3	3	18.006
3-3A	3A	16.971
3A-Shower	Shower	14.887
3-4	4	17.726
4-4B	4B	17.265
4B-Laundry room	Laundry room	16.173
4-4A	4A	17.464
4A	Final	16.445

3.3. Hydraulic analysis using Epanet 2.0 software
Epanet 2.0 software calculates friction losses using Hazen-Williams or Chezy-Manning expressions; it includes minor losses in elements such as elbows, couplings, among others [11]. The layout is based on the isometry of the hydraulic network, which incorporates the lengths, diameters and base flows demanded by each device according to the method used. The data to the pipe is entered in the section Tank-1 with the property values to be used for the hydraulic calculation. Then the procedure is done with all sections, the model is run, as detailed in Figure 2 and Figure 3. Because the software uses the principle of conservation of mass [12] accumulating the flow demand, producing a higher flow than that projected by the methods of Hunter modified and simultaneity, would affect the actual design condition and will not be economic.

Therefore, different options were tested so that the flow rates of the pipes would obtain values similar to those calculated by the Modified Hunter method, resulting in the affectation of the nodes that do not demand flow with sanitary devices with a negative flow that corrects the overestimation produced by the software. To introduce the base demands to the nodes in the network, the flow rates by sections must be estimated according to the conventional method to be used [13]. The series section is about if a section is composed of several sanitary devices, each subsequent node must be subtracted from the flow demanded, so that when software accumulates the flow is projected by the method of Hunter modified. Example: evaluating the section 3A - third floor shower, modified Hunter's method, the shower of that node demands a flow rate of 0.1163 L/s and the node after a flow rate of 0.3016 L/s, so you should subtract the 0.3036l / s flow rate of 0.1163 L/s, to incorporate the node a flow rate of 0.1853 L/s, for when the software adds flows demanded by each node is the value projected by this method.

On the other hand, the branched section constitutes the sum of the flows coming from each pipe will give more than the flow calculated by the modified Hunter method, it is corrected by a negative flow incorporated to the next node. Example: the section 2-3 provides a flow rate of 0.4432 L/s and section 2-2A provides a flow rate of 0.3016 L/s, so the sum of the two would be 0.7448 L/s on the section 1-2, but according to the method the flow rate would be 0.7448 L/s, so the error would be the subtraction between the flow rate of the method to use less the flow rate that would add the software, *i.e.* 0.6047 L/s is subtracted 0.7448 L/s resulting in an error flow of -0.1401 L/s. Figure 2 and Figure 3 represent the two hydraulic systems (serial and branched section) in which the physical models are applied to run the simulation by means of Epanet 2.0 and to be able to compare it with the conventional method (modified Hunter model).
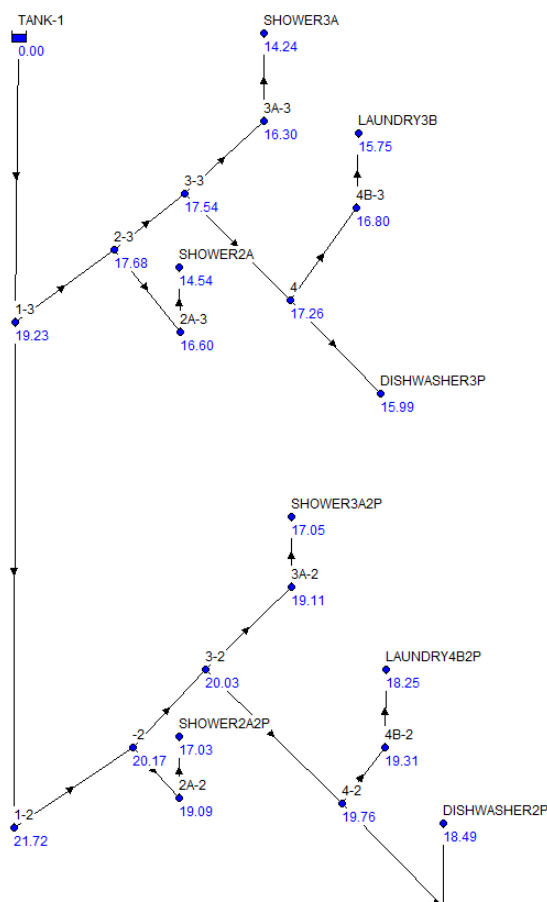

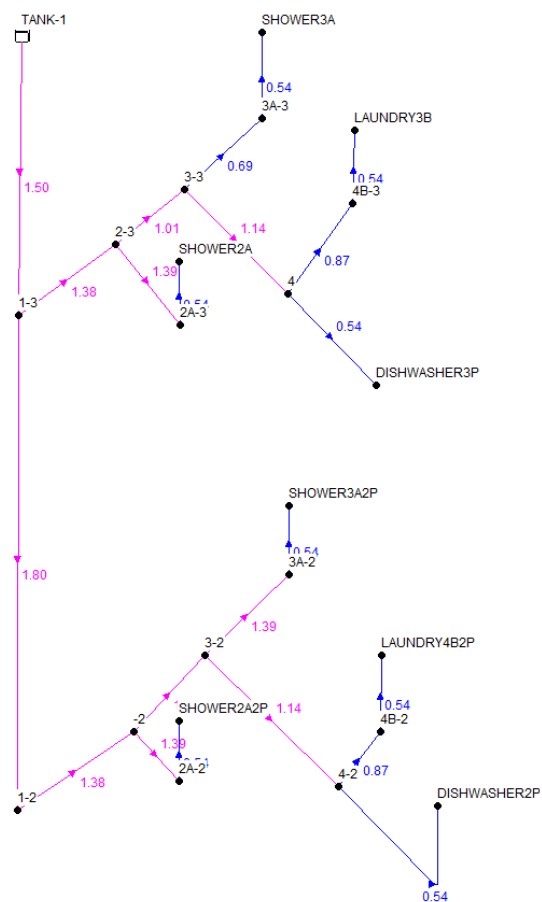**Figure 2.** Pressures in Epanet nodes - modified Hunter.

Figure 3. Velocities in Epanet pipelines - modified Hunter.

3.4. Comparative analysis between the modified Hunter method and the Epanet 2.0 software
Table 5 shows the comparison of the pressures of the modified Hunter method with those of the Epanet 2.0 software. As shown in Table 5, the results obtained from the Epanet 2.0 software do not differ much from those calculated by the modified Hunter method, so that calculation times can be optimized, and different diameter alternatives can be evaluated in order to achieve a more economical design. When comparing these results with other investigations, it is corroborated that there is indeed a strong relationship between the simulation and the data with a correlation value in the range of 0.8-1.

Table 5. Pressure comparison.

Device evaluated	Method used		Error
	Modified Hunter (mWC)	Software Epanet (mWC)	
Dishwasher (3rd floor)	15.94	15.99	0.28%
Laundry room (3rd floor)	15.67	15.75	0.49%
Shower 1 (3rd floor)	14.39	14.24	1.02%
Shower 2 (3rd floor)	14.51	14.54	0.24%
Dishwasher (2nd floor)	18.43	18.49	0.34%
Laundry room (2nd floor)	18.16	18.25	0.52%
Shower 1 (2nd floor)	16.87	17.05	1.06%
Shower 2 (2nd floor)	16.99	17.03	0.24%

4. Conclusions
The physical controls were applied in the Epanet 2.0 software, allowing the hydraulic analysis in buildings, since the software uses the principle of mass conservation, accumulating the flow demanded by each node, producing a higher flow than the one projected by the modified Hunter method. The hydraulic analysis with the software in question proved to comply with the results of pressure and speed established in the Colombian technical standard of plumbing NTC 1500, managing to improve times in the evaluation and accuracy of its results, however it requires a higher pressure in the apparatus and a lower demand for flow, which is achieved by reducing the diameters so that it is more economical, having as disadvantage the need for a higher inlet pressure to comply with the established minimum pressures, which limits the design to gravity by having to place the tank raised to a minimum height of 15 meters from the level of the sanitary apparatus, or it becomes necessary for the service provider to ensure a pressure greater than 15 mWC at the entrance of the building to guarantee the hydraulic operation of each one of the sanitary apparatuses with the pressures established in the Colombian regulations in force. Therefore, it is technically feasible to use in the Epanet 2.0 model, if the proposed simulation methodology is used through the physical controls for the analysis of hydraulic networks in buildings.

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