ANALYSIS OF HUNTER'S METHOD FOR DESIGN OF PUMP SYSTEMS IN MULTIFAMILY BUILDINGS FOR MIDDLE CLASS IN BOGOTA, COLOMBIA.

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Nowadays, dwelling construction is mostly developed in multifamily housing buildings with central pumping systems for water supply, which are oversized in general.[2] It is therefore advisable to develop a methodology that allows the selection of a system that meets the actual conditions of use and consumption habits of the population. An alternative to accomplish this is to put forward an adjustment of the probability *p* having being found *r* fixtures of a total of *n* in use, described in Hunter's method of estimating loads in plumbing systems, applied to multifamily housing buildings of middle class in Bogotá City. For this purpose, measurements of instantaneous maximum flow rate in the discharge of pressure equipment with hydro pneumatic systems of five multifamily housing buildings were carried out by means of an ultrasonic flow meter. From such measurements, the maximum instantaneous and maximum average flow were obtained; from which the *p* value was evaluated to propose a new estimated curve for design purposes where the expected flow rates in relation to *n* fixtures can be found in order to design pumping systems, achieving better sizes of equipment, more efficient systems (at lower costs), with lower energy and water consumption.[6]

Keywords: Pumps systems, Hunter's method, maximum probable flow, plumbing systems.

INTRODUCTION

On Colombia the Code for Plumbing and Hydraulic Installations (NTC 1500 – third update) suggest the modified Hunter method for design of loads in plumbing systems one of the most spread and used methodologies, in which a fixture weigh is assigned to the water consumption of each pumping device in the building.[1] However, recent studies on pumping installations suggest that the methodology generates over sizing in the design of pressure equipment [2], noticeable in the frequent occurrence of pipe breaks and also in the fact that while operating, equipment that is expected to operate on different pumps simultaneously never reach that optimal condition. On the contrary, demand is supplied efficiently by a single pump. This generates cost overrun in the construction, maintenance and system operation among others.[3]

The problems mentioned above mainly occur in multifamily housing buildings where there is a storage tank and a central pumping supply system. From the tank and through the pumping system pressure is applied to supply the system demand so that conditions of efficiency and comfort are achieved in the usage of the plumbing fixtures in the building, evaluating the device with the highest flow and pressure demand in the weakest point of the network.

Based on the aforementioned, this work presents a comparative analysis between the maximum instantaneous flow as a result of the measurement analysis of the discharge of pumbling fixtures on multifamily housing buildings for middle class in Bogotá city with an ultrasonic flowmeter (reference TDS 100H) and the maximum probable flow using Hunter's method for designing hydro pneumatic systems referred in the NTC1500 (third update - Table B. 1.3.3(3). Table for estimated demand) and annex C of it. It was considered for the analysis of the data the distribution of binomial probability exposed on the original Hunter method approximated by a normal distribution to define the probability p of be found m fixtures of a total of n working, analyzing under statistical parameters the correlation between the data taken and the value of the probability of occurrence for the case study.

From the data analysis during the measurements and the probabilistic behavior of Hunter's curve, is presented a method to obtain a p value (probability value) sui to the designing needs for the pressure equipment required by the multifamily housing buildings for social middle class in Bogotá, Colombia.

Hunter’s Method

For the sizing of the water supplying system in buildings, it is important to establish the requirements both for the amount of pressure for the plumbing fixtures work, and the flow that runs through the plumbing sections. Such flow turns out difficult to establish given that opposed to the conventional hydraulics, this one is subject to consumption patterns from the users, environmental and social conditions, variety and way of using sanitary devices; because of this, it is necessary to resort to calculation alternatives based on empirical, semi empirical or probabilistic methods. Among the probabilistic methods the most used is the one developed by Dr. Roy Hunter from the National Standards Office in 1940, who developed a graphic approach to estimate the percentile 99 of water consumption in public facilities, assuming that: "*... the operation of the main sanitary devices that constitute a system might be particularly considered random* "[3]

Hunter determined the frequency of usage of the main sanitary devices that produce wear in hydraulic installations from a housing building, basing his values on the frequency registers, y and the time of a simple operation from each one of them[3], assigning a flow value, according to the type of device.

- Device flow: corresponds to the flow or discharge in a device in each use. (q)
- Duration of the flow: Average time of the discharge. (t)
- Frequency of use: Average time among successive operations. (T)

By applying the theory of probability, Hunter developed a model that allows to estimate the number of devices that would start operating simultaneously in a period of time *p*. In his original document, Hunter specifies each one of the variables and values, which are selected based on his own judgment, recommending that it is necessary to evaluate and analyze such characteristics for each specific case.

Development of the probability function

The kind of device chosen by Hunter correspond to a flush valve toilet with the following characteristic values:

Table 1. Characteristic values to calculate discharge probability of a device. (Source: Hunter 1940)

Device flow (q)	27 gpm
Flow duration (t)	9 seconds
Frequency of usage (T)	5 minutes (300 seconds)

As previously stated, these values correspond to analysis done by Hunter, in which he identified usage patterns, however, these were done in the decade of the 40's with devices of the time, when customs and usage habits were quite different.[7]

Based on the above, Hunter established that the probability of (1) one of a number of fixture *n* are found working properly in any instant correspond to:

$$p = \frac{t}{T} \quad (1)$$

The same way that the probability of a device not to be working in a determined period of time is:

$$1 - p = 1 - \left(\frac{t}{T}\right) \quad (2)$$

From the product of the two previous probabilities, it is possible to calculate the composite event, in which the number of chances where two independent fixtures may discharge at the same time, and none of the others n-2 fixtures is discharging, thus:

$$p = (1 - p)^{n-2} * p^2 \quad (3)$$

To generalize this point it is necessary to resort to a combinatory, where *r* is defined as the number of objects, from a total of devices *n* that are working at the moment of observation to impose a charge demand in the supply system. The above described is expressed probabilistically this way:

$$C_r^n = \frac{n!}{r!\,(n - r!)} \quad (4)$$

Where C_r^n is the combinatory for *n* objects taking from them a value *r* in a determined period of time.

From the previous expression and replacing the parameters of equation 3 it is possible to obtain the probability of each event. Considering the unit as the value given by the probability to achieve certainty it is carried out the sum of probabilities obtaining the following expression:

$$p_r^n = \sum_{r=0}^{r=n} C_r^n\,(1 - p)^{n-r}\,p^r = 1 \quad (5)$$

Keeping in mind that one of the terms of the equation corresponds to binomial expansion, binomial distribution must be applied in order to solve it. Also, considering the discrete type of the binomial expansion, an approximation through normal function is used so that it generates values of continuous type.

Probable maximum flow estimation

Hunter took on as condition to his model that a service is satisfactory as long as the system is sized to probably only 1% of time *r* devices from a total of *n* are working simultaneously, 1% condition is arbitrary and corresponds to the author's consideration expressed in his original document.[7] With such value it has been demonstrated that satisfactory designs are produced, however, this value could be even higher and not generate any functioning problems.

To define the maximum instantaneous flow rate, it is defined a number of devices *m* that operate, taken from a total of *n* multiplied by the flow of the fixture type.

$$Q = mq \quad (6)$$

From equation 6 it is necessary to precise that *m* is the "designing factor" corresponding to the particular value *r* from a total *n* that will be found working simultaneously in a given instant under certain usage characteristics. The equation 7 reflects the aforementioned criteria:

$$p_{r=m}^{r=n} = \sum_{r=m+1}^{r=n} C_r^n \, (1-p)^{n-r} \, p^r \leq 0.01 \; (7)$$

Expecting that when the sum of probabilities to which the devices number m exceeds the value 0.99 will correspond to the number of devices which discharge will be simultaneous in a given instant.

Moreover, the component q of equation 6, was evaluated considering the advances in taps, bathroom fittings and sanitary devices, as well as the current regulation (See resolution 0549 from The Ministry of Housing, City and Territory, Colombia) regarding the water consumption savings and the own usage habits from the population, to which the average flow is presented in three of the main devices installed in apartment buildings, related in turn to the manufacturer's fact sheets.

Table 2. Consumption of typical devices installed in multifamily housing

Fixture	**Average flow of the device [l/s]**
Shower (9.5 l/min)	0.16
Sink (8.3 l/min)	0.14
Flush tank (6 l)	0.17

According to the information displayed in Table 2 and keeping in mind the residential character of the monitored buildings a flow of 0.17 l/s (2.69 GPM) is taken as average consumption of the typical current fixture.

Methodology

In order to obtain the maximum instantaneous flow of each building, samples were taken all day for a week in order to find patterns, periods of maximum consumption and maximum flow readings. This sample taking was carried out by means of an ultrasonic flowmeter which has two transducers located in the discharge plumbing of the pressure equipment.

Once identified the vales of maximum instantaneous flow and knowing previously the number and type of plumbing fixture installed in each project, a curve is obtained through Hunter's methodology which relates the number of typical fixtures working simultaneously and the read flow.

With the maximum probable flow and the readings of pressures for on and off to which the pumping equipment is working, obtain the maximum possible powers required by each one of the systems.

Data analysis

The data registration made by the flowmeter to each of the buildings stored values of instantaneous flow for a given instant, based on these the data was grouped by days, then daily consumption curves were defined and the maximum instantaneous flow was identified for each building.

Once identified the maximum values, an analysis of statistics parameters was made. The following charts correspond to a sample of average consumption curves which each of the projects shows. The tables show the maximum values found and the evaluation of statistics parameters.

SENDEROS DE SAN ANTONIO

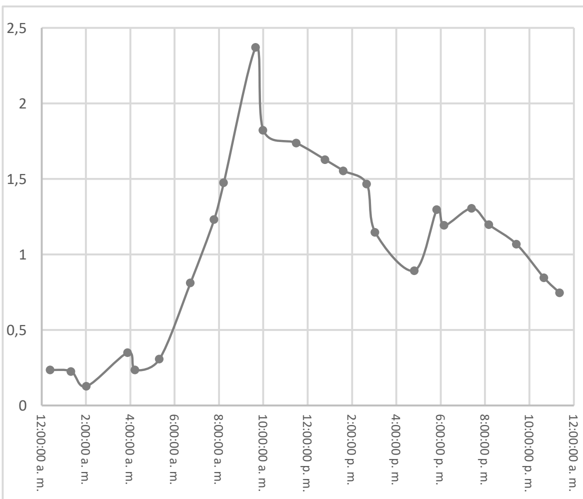

Figure 1. Consumption curve - Senderos de San Antonio (Source: own)

Table 3. Maximum instantaneous flow per day Senderos de San Antonio.

Maximum flow rates - Senderos de San Antonio

Fact	Hour	Flow [l/s]	Day	Observation
1	9:05:00 a. m.	1.735	Monday	Holiday
2	9:40:00 a. m.	2.371	Tuesday	
3	2:53:00 p. m.	1.602	Wednesday	
4	6:27:36 a. m.	1.679	Thursday	
5	6:06:24 a. m.	1.737	Friday	
6	5:52:36 a. m.	1.660	Saturday	
7	11:24:00 a. m.	1.599	Sunday	
8	6:27:36 a. m.	0,570	Monday	Atypico

Table 4. Statistic parameters Senderos de San Antonio

Average	1,769
Standard Deviation	0,271
Lower limit	1,498
Upper limit	2,041
Variance	7%
Asymmetry coefficient	2,42

BOCHICA II

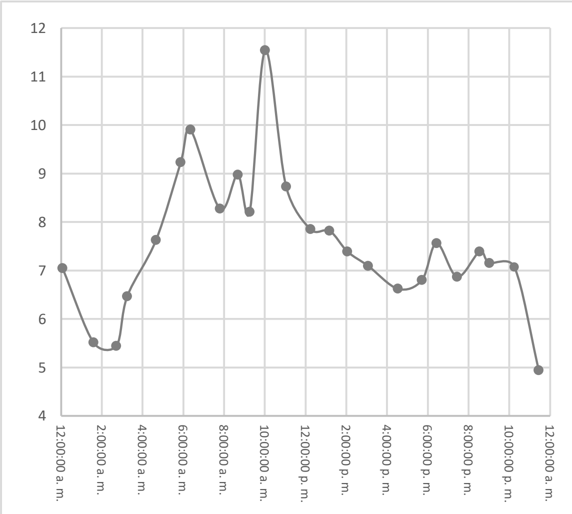

Figure 2. Consumption curve – Bochica II (Source: own)

Table 5.Maximum instantaneous flow per day Bochica II

Maximum flow rates - Bochica II

Fact	Hour	Flow [l/s]	Day	Observation
1	7:09:36 p. m.	5.433	Sunday	Atypico
2	9:27:12 a. m.	8.547	Monday	Holiday
3	9:06:00 p. m.	6.352	Tuesday	Atypico
4	6:14:24 a. m.	8.284	Wednesday	
5	10:01:00 a. m.	11.538	Thursday	Atypico
6	6:20:48 a. m.	9.899	Friday	
7	10:24:18 a. m.	10.135	Saturday	
8	10:57:36 a. m.	10.669	Sunday	
9	6:07:36 a. m.	9.363	Monday	

Table 6. Statistic parameters Bochica II

Average	9,483
Standard Deviation	0,931
Lower limit	8,552
Upper limit	10,414
Variance	87%
Asymmetry coefficient	-0,20

AV. 68 – High Pressure

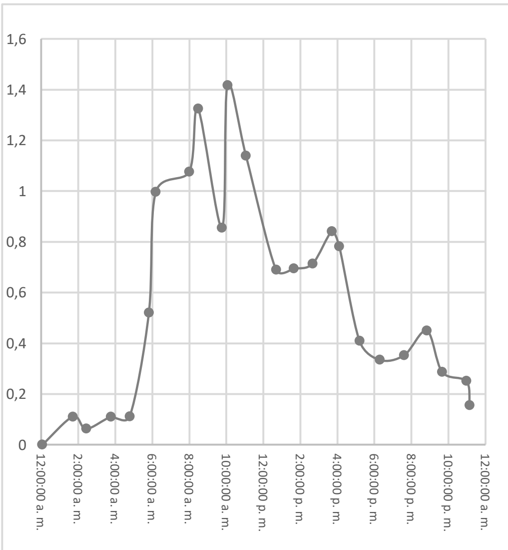

Figure 3. Consumption curve – Av. 68 (Source: own)

Table 7. Maximum instantaneous flow per day AV 68

Maximum flow rates - 68 Avenida

Fact	Hour	Flow [l/s]	Day	Observation
1	7:36:48 a. m.	0.922	Tuesday	
2	7:24:36 a. m.	1.347	Wednesday	
3	7:13:00 a. m.	1.160	Thursday	
4	8:28:06 a. m.	1.324	Friday	
5	10:03:18 a. m.	1.418	Saturday	
6	9:20:24 a. m.	0.874	Sunday	

Table 8. Statistic parameters AV 68

Average	1,174
Standard Deviation	0,231
Lower limit	0,944
Upper limit	1,405
Variance	5%
Asymmetry coefficient	-0,49

Tierra Grata

Table 9. Maximum instantaneous flow per day Tierra Grata

Maximum flow rates - Tierra Grata

Fact	Hour	Flow [l/s]	Day	Observation
1	9:56:12 a. m.	3.279	Saturday	pipe break
2	8:30:24 p. m.	1.820	Sunday	Atypico
3	11:37:48 a. m.	2.601	Monday	
4	5:45:00 a. m.	2.982	Tuesday	
5	5:23:54 a. m.	3.079	Wednesday	
6	5:43:48 a. m.	3.011	Thursday	
7	5:24:54 a. m.	3.534	Friday	
8	8:40:52 a. m.	2.775	Saturday	

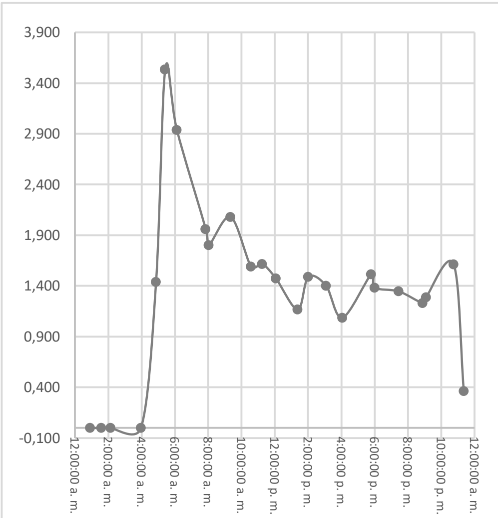

Figure 4. Consumption curve – Tierra Grata (Source: own)

Table 10 Statistic parameters Tierra Grata

Average	3,037
Standard Deviation	0,308
Lower limit	2,729
Upper limit	3,346
Variance	9%
Asymmetry coefficient	0,28

Balcones de Cedro Golf

Table 11. Maximum instantaneous flow per day Balcones de Cedro Golf

Maximum flow rates - Balcones del Cedro Golf

Fact	Hour	Flow [l/s]	Day	Observation
1	2:16:00 p. m.	1.712	Sunday	
2	6:44:36 a. m.	1.599	Monday	
3	10:10:36 a. m.	1.484	Tuesday	
4	7:14:36 a. m.	1.603	Wednesday	
5	7:32:48 a. m.	1.461	Thursday	
6	6:50:48 a. m.	1.463	Friday	
7	10:31:24 a. m.	1.501	Saturday	
8	10:21:48 a. m.	1.305	Sunday	Atypico

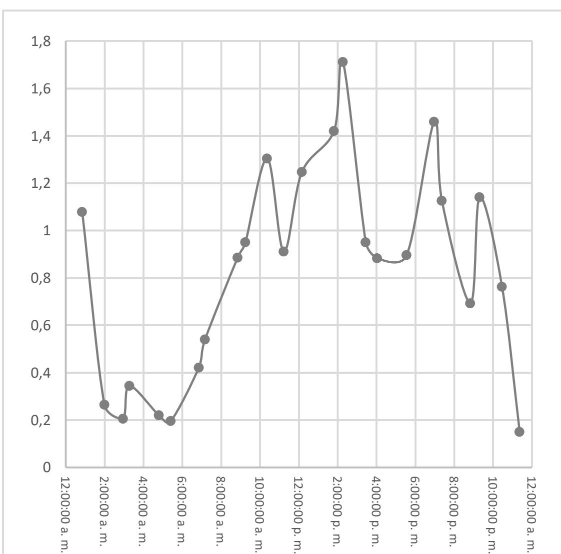

Figure 5. Consumption curve – Balcones de Cedro Golf (Source: own)

Table 12. Statistic parameters Balcones de Cedro Golf

Average	1,516
Standard Deviation	0,122
Lower limit	1,394
Upper limit	1,638
Variance	1%
Asymmetry coefficient	1,14

For data analysis, it was carried out the revision of two operational conditions of the pressure equipment, both for the maximum instantaneous flow measured and the maximum average flow measured. Based on these, the value of probability of finding a number *m* of devices from a total of *n* in full operation was evaluated with the binomial approximation by normal distribution.

Conducive to the establishment of the data correlation, statistic parameters as standard deviation, deviation coefficient were evaluated finding that under the conditions, the standard deviation was located between 0.00396 and 0.00613: and the standard deviation coefficient was not higher than 9%.

Proposed curve of design

The proposed curve of design is presented for the calculation of the maximum probable flow in housing buildings for sanitary unit between 500 and 8000, a typical device flow corresponding to 0.17 Lps (2.69 GPM), and a load assignment to the typical device of 10.

For the construction of the curve the average value of the calculated probabilities was evaluated independently for the instantaneous maximum flow and maximum average, defining this way a unique probability value that adjusts the measured data which would determine the pumping equipment operation of the multifamily housing unit.

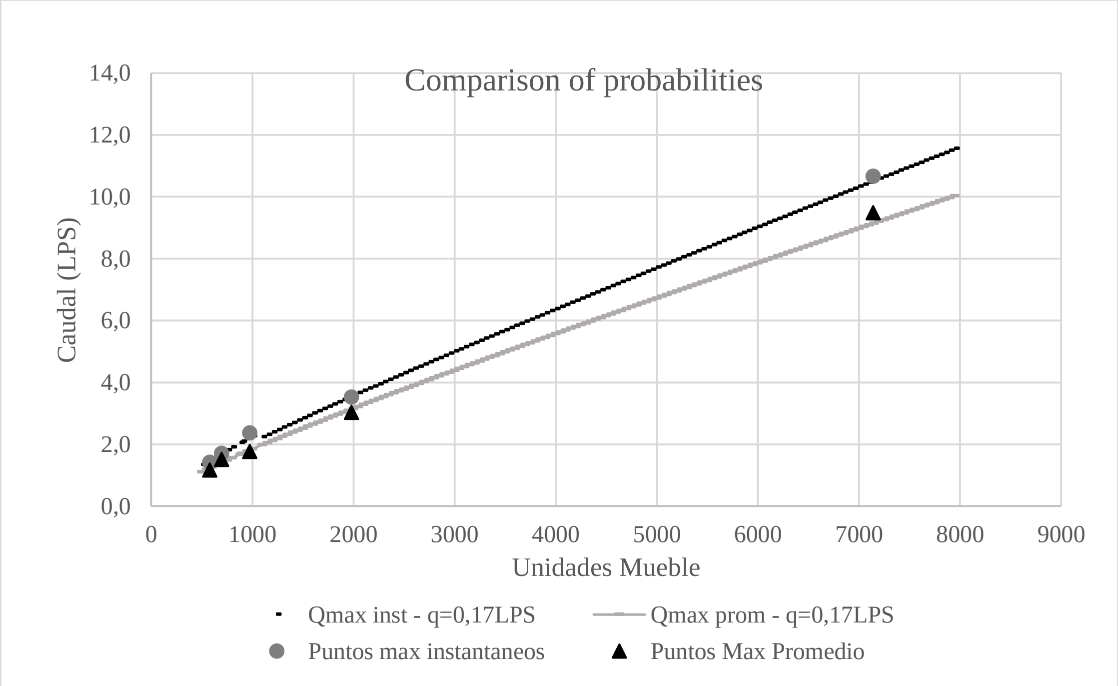

Figure 6. Curves of usage probability to q=0,17l/s /500<n<8000. Source: Own

Is this way that considering mainly the optimal performance of the system, is implemented a probability of simultaneous use of sanitary devices of 0,070, for a housing building in the city of Bogota, for middle class, with sanitary units between 500 and 8000. This value is obtained out of the maximum instantaneous flow monitored per building.

Figure 7 is made from the aforementioned probability.

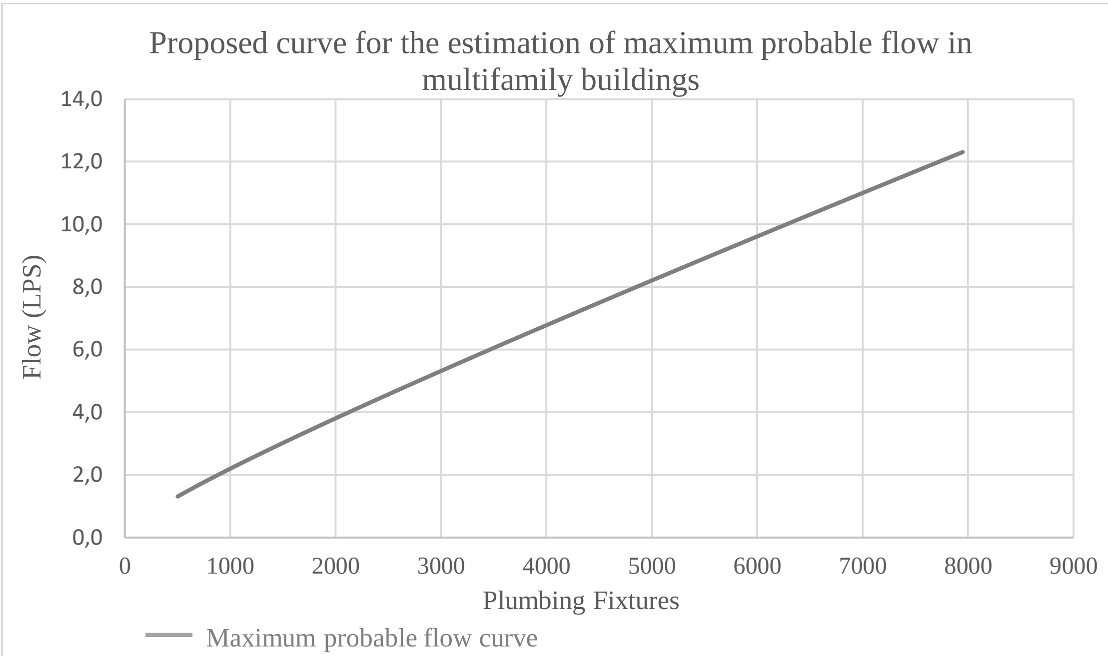

Figure 7. Proposed curve of design. Source: Own.

CALCULATION OF PRESSURE EQUIPMENT

From the proposed curve is presented the comparative calculation of pressure equipment required for the monitored buildings.

Pump load

In the totality of the monitored spots hydro pneumatic equipment was available, which operation was conditioned by the pressure range with which the hydro pneumatic turns on and off the pump, establishing that the turn off pressure of the pump id defined as Total Dynamic Load which is calculated plus a ΔP (Delta Pressure). Readings of pressure were taken with manometers while the turning on and off of the pump with the purpose of defining the load under each one of the systems is operating.

Next, the readings for each one of the buildings, delta pressure and the average are presented:

Table 13. Readings of turn on and off pressure, turn on delta and average pressure for each building.

Building	**Pressure**							
	Turn on		**Turn off**		**Delta**		**Average**	
	[PSI]	**[m.c.a]**	**[PSI]**	**[m.c.a]**	**[PSI]**	**[m.c.a]**	**[PSI]**	**[m.c.a]**
Senderos de San Antonio	53,00	37,29	73,00	51,36	20,00	14,07	63	44,32
Bochica 2 Etapa 3 y4	40,00	28,14	60,00	42,21	20,00	14,07	50	35,18
68 Avenida	130,00	91,46	165,00	116,09	35,00	24,62	147,5	103,77
Tierra Grata	45,00	31,66	75,00	52,77	30,00	21,11	60	42,21
Balcones del Cedro Golf	50,00	35,18	72,00	50,66	22,00	15,48	61	42,92

Flow

Summary of the flow rate for each building.

Table 14. Summary of peak flow average

Building	**Flow**		
	Measured [l/s]	**Theoretical* [l/s]**	**Measured [l/s]**
Senderos de San Antonio	2,37	14,90	2,16
Bochica 2 Etapa 3 y4	10,67	34,30	11,21
68 Avenida	1,42	11,00	1,45
Tierra Grata	3,53	24,00	3,78
Balcones del Cedro Golf	1,71	12,20	1,67

* Theoretical flow corresponds to the calculation with Hunter's conventional method and the adjusted flow to the one obtained with the proposed probability curve of 0.07.

Power

For the calculation of power the average values of pressure and adjusted flow were applied according to the probability found.

Table 15. Calculation of power required by the system.

Building	**Calculation required equipment**		
	Flow [l/s]	**Pressure [m.c.a]**	**Flow [l/s]**
Senderos de San Antonio	2,16	44,32	1,93
Bochica 2 Etapa 3 y4	11,21	35,18	7,98
68 Avenida	1,45	103,77	3,05
Tierra Grata	3,78	42,21	3,23
Balcones del Cedro Golf	1,67	42,92	1,45
γ_{Water} [N/m³]	9800		
η_{Pump}	65%		

Analysis.
Keeping in mind that during monitoring it was only possible to observe the operation of one of the pumps per equipment, a comparison was made between the installed power, power per pump, theoretical power and requested power using the proposed curve.

Table 16. Compared power for equipment.

Building	Power			
	Installed [HP]	**Per Pump [HP]**	**Installed [HP]**	**Required [HP]**
Senderos de San Antonio	27.00	9.00	13.35	1.59
Bochica 2 Etapa 3 y4	36.00	12.00	24.40	6.95
Tierra Grata	12.00	6.00	20.48	2.59
68 Avenida**				
Balcones del Cedro Golf	15.00	5.00	10.59	1.32

** Having in mind that flow measurement was only done for the high column, it was not applied a comparison for this building.

Having in mind that the multifamily building on 68 avenue has a high pressure water supply line from floors 7 to 14, and a low pressure one from floors 1 to 7 from which floors 1 and 2 have retail spaces, it was chosen the option for using only the measured flows of high pressure given that they did not have any fluctuations produced by commercial area consumption. Therefore, there is no comparison presented between the installed equipment and the required one.

Based on the above is possible to assert that the calculated power with the proposed probability belongs to the range of 14% to 16% from the calculated power according to the NTC (third update) with the exception of Bochica building where considering just the bathroom sets the power is about 33% of the theoretical.

Considering the fact that, during the monitoring it was identified that the demand is supplied by the operation of a single pump, it was also found after the comparison between the calculated power and the proposed probability that the required power lays between 21% to 66% from the power of the installed pumps. This means that if the total power installed in the pumping equipment is analyzed, it will become apparent that it is oversized from 73% to 93%.

CONCLUSIONES Y RECOMENDACIONES

The maximum instantaneous flow for Senderos de San Antonio was 2.37 l/s and the maximum probable flow obtained by the proposed adjustment was 2.17 l/s, for Bochica II was 10.67 l/s versus 11.21 l/s, AV 68 is 1.42 l/s versus 1.45 l/s, Tierra Grata 3.53 l/s versus 3.78 l/s, and Balcones del Cedro Golf 1.71 l/s versus 1.67 l/s.

According to the result obtained along the development of the present study, for multifamily housing buildings located in the city of Bogota from social middle class, between 77 and 1190 housing units, for an entry flow to the typical device of 0.17 l/s (2.69 GPM) and an assigned load of 10 units.

The average probability of usage p from a sanitary device with Hunter's method is 0.07, with a standard deviation of 0.006 and a deviation coefficient of 6% concluding that there is a good correlation between consumption habits of the population and the number of typical sanitary devices and such behavior is open to analysis based on the probabilistic distribution considered. Accordingly, it is plausible to assume that under normal conditions of use and for housing buildings with similar characteristics to the ones studied, same values could be considered, for which it is applicable its use regarding the design of pressure equipment.

$$p_{r=m}^{r=n} = \sum_{r=m+1}^{r=n} C_r^n \, (1-0.07)^{n-r} \, 0.07^r \leq 0.01$$

Applying the approximation it is obtained:

$$p(r,n,p) = C_r 0.07^r q^{n-r} \cong 0.07 \left(Z = \frac{r - n(0.07)}{\sqrt{n(0.07)q}} \right)$$

The adjusted flows with the probability value proposed are, on average, 15% of the ones calculated by Hunter's method, however, for bigger housing complexes this value reaches around 33%.

When evaluating the power of pressure equipment it becomes evident that oversizing is present in the theoretical potencies calculated through the conventional and real method installed, with respect to the calculated power proposed in this study. It is noticeable that, on average, if the theoretical power of the equipment is calculated, these are oversized by approximately 81% with respect to the real required by the system for its operation. Yet, if the power per installed pump is considered, this one turns out to be currently around 57% above the power required by the system, according to the result obtained.

Value of *p* obtained in this study turns out to be not enough to propose a change in the method probability, however, it is possible to infer that an adjustment in the consumption curve is due, in order to obtain real flow values, updated and adjusted to the type of use, geographical location and characteristics of the population.

The value of *p* obtained in this study does not turned out to be enough to propose a change for the method probability, nevertheless, it is possible to infer that an adjustment in the consumption curve must be presented so that it allows to obtain real flow values, updated and adjusted to the type of use, geographic location and population characteristics, so it is convenient to evaluate a higher number of housing buildings in order to grasp new points in the curve and obtain a better correlation among them.

In general, by analyzing the consumption curves of the monitored systems it is noticeable that the time interval in which the highest consumptions are presented, corresponds to the period between 4:30 am and 9:30 am, and in turn, the lowest consumption interval corresponds to the period between 11:00 pm and 4:30 am.

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