Performance Indicators for Water Supply in Buildings

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Abstract: - Drinking water is a vital resource for the population’s quality of life and health. The satisfaction of their needs is increasingly demanding, essentially associated with the growth of the population's income and the possibility of improvements in terms of comfort, quality, and safety at lower costs. However, despite the accuracy of engineering design, the functional performance of the building's water networks does not always match the expectations because it can be subjected to failures, which can compromise other infrastructures and cause a lot of inconvenience to the residents or users. In this case, we can say that the water supply system is no longer reliable. In the study presented in this article, profiles were developed that make easier the assessment of the reliability of the installation, specifying key aspects involved, which may be called performance indicators. The indicators combined in a balanced way according to their importance make it possible to translate the relevant aspects regarding the operation of the water supply systems in the building and their reliability. In this sense, it is expected to contribute to the improvement and durability of building installations, regarding the water supply's performance, security, and quality.

Key-Words: - building, durability, functional performance, quality, reliability, water supply in buildings, performance indicators, water supply security

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1 Introduction

Currently, there is a growing trend in the standard of living of the population, as a result of the increased markets offer in all areas, competitive edges and consumer demands in which, in many cases, quality is the preferred criterion. The building water supply systems, which seek to respond to the need to ensure the supply of drinking water for human consumption, also follow this trend [1,2].

In the construction of water supply networks in buildings sought comfort and security at the lowest cost. But several factors can influence these purposes, resulting in technical conditions of the installations, conditions of use, and economic and environmental conditions [3-5].

A large number of problems and discomforts detected in buildings are related to the malfunction of the water networks and may, ultimately, compromise the health and welfare of the occupants [6]. Thus, it is considered important to have mechanisms that allow assigning a confidence level to the behavior of the water supply systems, examining whether it can be more or less reliable [7].

This evaluation is not simple, because the design of the system depends on factors that are variable in each case, such as the architectural characteristics of the building and the water pressure available in the public network. Other important aspects that can affect reliability are the materials and equipment used, the sizing of the system components, the construction practices, and the maintenance performed.

To facilitate this assessment is proposed the creation of performance indicators that can quantify levels of security for each variable that can affect the operation of the water supply system. These variables, when properly combined, according to their degree of importance, can provide significant information about the reliability of the system. In summary, it is intended to identify and detail the variables which can affect, with greater or lesser complexity, the behavior of the water supply system in buildings.

The use of performance indicators has already been used in some countries, such as Saudi Arabia or Hong Kong, to evaluate the construction of buildings as a whole in these specific countries [8,9]. Indeed, over the last few years, several authors have sought to establish Key Performance Indicators (KPIs) for general application in buildings, in the construction or use phases, but few of these works have focused on building installations [10-14]. In the bibliography can be found proposals for KPIs applications in the energy field (or HVAC) [15-17], but there are practically no specific references to performance indicators for hydraulic networks in buildings. It should be noted that some authors focus on special buildings, such as hotels, commercial buildings, or industrial buildings, and others propose more complex approaches, such as models based, for example, on an artificial neural network [18-19],

The performance indicators proposed in this article were developed based on Portuguese practice and regulations, but insofar as they follow European directives, they are directly applicable in a broader scope. It is easy to realize that the proposed methodology can be easily adapted to different realities.

In this paper, no formula is proposed to weight these indicators, with a view to a final valuation of the installation, given that the weight to be attributed to each indicator may depend on specific circumstances, such as the priority on the comfort of users, the search for a low maintenance network, the existence of other specific construction control mechanisms, etc.

2 Concept of Reliability

In general, reliability is the degree of trust which is attributed to a system in operation, placed in a particular environment for a while, without failure occurrence. A reliable system is synonymous with a robust system, insofar as it can overcome barriers and in which it can be trusted, being free of errors and with predictable results [7-20,21].

But, there always is a probability of happenings undesirables in the operation of the system, designated as failures. In other words, failure is defined as the consequence of the combined action of several factors random and unpredictable associated with the system, as well as the influence of the environment in which it operates.

It is perceivable that the reliability of a system decreases with the period of operation. However, the operation period is not always measured in units of time. Other units may be considered, such as distance traveled, shifts/operating cycles, or a combination of these two measures.

The reliability theory is not more than a set of ideas, models, or methods intended to estimate the occurrence of problems. The objective is to contribute to obtaining optimization solutions that increase the probability of survival of a system, related to the lifetime of its components and equipment [7-20,21].

The first applications for mathematics models about reliability were observed in the maintenance machines, from the decades 30 and 40, but it should be noted that was essentially in the II Mundial War period that the reliability theory was developed, to respond to the need to improve military technology. However, in the 50s, were developed some other aspects of reliability, for example, life tests performed on electronic equipment, missiles, and aircraft, providing information about the problems associated.

From 1955 emerged the initial reliability models for the lifetime of equipment and processes in solving maintenance problems. In the decade of 70, the safety of nuclear reactors spurred greater attention to reliability problems and, in the 80s, the attention was put on the security of computer networks. In the 90s, were traced new guidelines for the investigation of reliability, influenced by physics and differential geometry.

In the present century, there are already models for analysis and application in numerous fields, such as mechanical and electronic equipment, but also in systems more complex, such as public electricity networks, and public telecommunication drainage, among others [7-20,21].

3 Factors Affecting the Performance of the Water Supply in Buildings

The water supply to a building can be done by connecting to a public or private source, through a system formed by a set of pipes, fittings, and equipment that enable the distribution of water for each user device called the internal network of the building, which enables the supply of water for each user device. This internal distribution network can become more or less complex, depending on the needs that are intended to be met concerning the available resources. It can include building reservoirs, water treatment, pumping systems, and sanitary hot water production, for example.

Based on the conviction that any water supply network in buildings can fail, there is an interest in assessing its reliability, as the unpredictable failures, internal or external to the building, as well as the time required for its resolution, can significantly affect the health and life quality of users. It is necessary to discover the potential causes and try to minimize faults in the future, to get contribute to better performance.

One good performance of the network is a result of several factors. The continuity of their functions exercise at optimized conditions, depends on the knowledge of information that can help to keep this objective, or, at worst, anticipate and solve problems that eventually may arise and possibly provide your solution timely, avoiding damages.

The existence of failures is the result of how the system was built and causes inconsistencies in its proper functioning, which can be permanent, temporary, or intermittent. The constant repetition of an occurrence provides indications for the development of methods to avoid or make them bearable. In addition, it is known that the durability of the networks is limited and, therefore, it is necessary, as much as possible, to preserve their stability, acting on its maintenance and control [20-22].

In the first stage, it is important to conceive the building network properly and, in a manner, technically correct, through the development of a project that, knowing the architectural characteristics of the building and the availability of pressures in the public network, provided by the water authority, will lead to a more or less complex network. The selection of the right materials and the development of a good design and correct sizing are extremely relevant, subsequently affecting the conditions of comfort, durability, and operation [6].

Moreover, the compatibility of the solutions envisaged in the project with other building services is essential, lest they arouse changes during the construction phase that could interfere with the expected performances. In the construction stage, they need good construction practices, particularly as regards the correct installation or assembly of materials, fittings, equipment, and devices.

With time, the installations will be degraded naturally. As such, inspection routines become necessary, enabling to correct possible deteriorations or detection the impending of failures that, even allowing continued operation of the system, affect the operating conditions (case, for example, of small water leaks). Thus, preventive repair or timely maintenance operations should be carried out, without harming consumers or causing any damage with associated costs. For example, if there are reservoirs in the building, its periodic inspection is extremely important, for reasons of public health.

However, it is observed with a frequency that these building installations exhibit pathologies associated to project errors, construction errors, or lack of control and maintenance, causing discomfort and inconveniences affecting the quality of life of the inhabitants or users, or even their health, often with high repair costs.

4 Performance Indicators. Definition and Characterization

A building's water supply network is a set of pipes, connections, equipment, and devices. Knowing that internal and external factors can affect its performance, the analysis of its reliability is not simple. To facilitate this assessment, it is important to specify factors that identify and characterize the main aspects involved, which can be called performance indicators.

A performance indicator should be understood as a measure of a quantitative assessment of the efficiency or effectiveness of the performance of the various constitutive elements and factors associated with a given system. Efficiency assesses the extent to which available resources are optimally used for system operation.

Effectiveness assesses the extent to which management objectives, specifically and realistically, are met. Each indicator contributes to the quantification of a given parameter in a given context and for a given period. Thus, it makes it possible to simplify the analysis of the fulfillment of a certain objective and to verify its evolution over time. Indicators are usually expressed as relationships between variables and can be dimensionless (expressed in %) or intensive (eg €/m3).

Although the information inherent to each indicator may be relevant when examined individually, they must be considered together, considering the objectives to be achieved and the context in which they are inserted, to obtain more adequate results in the global assessment of the performance of a given system. Together, the indicators combined in a balanced way according to their importance can translate the relevant aspects of the functioning of building water networks and their reliability.

5 Performance Indicators for Water Supply in Buildings

To quantify the functional performance of a water supply network in a building, it is proposed some performance indicators that evaluate individually each of its parts, according to certain criteria. The following criteria are relatively exhaustive but can be reduced or adapted on a case-by-case basis.

- Indicator of Available Resources [IAR]: related to the availability/suitability of service pressure in the public network, provides information about the relationship between the resources available and needed. May condition the greater or lesser complexity of the building network.
- Indicator of Human Resources [IHR]: translates information about the qualifications/training of professionals, interconnected to the main stages that the installation goes through in its life cycle: design, construction, and use (inspection and maintenance).
- Indicator of Infrastructures [II]: represents information on the degree of complexity of the water supply network, regardless of the adequacy of its design to the available resources, as well as its ability to respond to the continuity of supply, even with less performance, in case of failures occurrence.
- Indicator of Maintenance of the Infrastructures [IMI]: reveals information about the way how are implemented the recommendations or good practices of inspection and maintenance of the installation.
- Indicator of Malfunctions [IM]: provides information on the performance of the network components and the location of failures occurrence.
- Indicator of Quality of the Service [IQS]: gives information on the quality of service provided, whether by the efficiency of the repair of malfunctions or by the impact which this cause on the consumption, reflecting the number of supply interruptions during a certain period.
- Indicator of Costs/Investments [ICI]: provides information about the investments made in the installation, regarding the improvement of the systems, as well the maintenance costs, when the networks have more than 5 years in operation.

5.1 Criteria for the Performance Indicators

The water supply network is a complex system. To simplify its performance analysis, the proposed indicators are subdivided into several criteria, properly identified, as shown in Table 1:

Table 1. Performance Indicators and their criteria

Performance indicators and their criteria	Criteria identification
Indicator of Available Resources (IAR)	***1***
Availability/suitable pressures in the public network	C1.1
Indicator of Human Resources (IHR)	***2***
Qualification/training of personnel assigned to the design, construction, control, and maintenance	C2.1
Indicator of Infrastructures (II)	***3***
Water reserve infrastructures	C3.1
Pumping system and complementary infrastructures	C3.2
Water heating infrastructures or equipment	C3.3
Unitary head losses	C3.4
Sectioning of the network	C3.5
Devices density	C3.6
Indicator of Infrastructure Maintenance (IIM)	***4***
Maintenance of the water reserve system	C4.1
Maintenance of pumping system and complementary infrastructures	C4.2
Maintenance of water heating systems	C4.3
Maintenance of building network	C4.4
Indicator of Malfunctions (IM)	***5***
Failures of the water reserve system	C5.1
Failures of the pumping system or complementary infrastructures	C5.2
Failure of the water heating system	C5.3
Failures of the water distribution components	C5.4
Indicator of Quality of the Service (IQS)	***6***
Repair efficiency of the water reserve system	C6.1
Repair efficiency of the pumping system and complementary infrastructures	C6.2
Repair efficiency of the water heating system	C6.3
Repair efficiency in the building distribution network	C6.4
Interruptions of water supply	C6.5
Indicator of Costs and Investments (ICI)	***7***
Relationship between the sum of the costs invested in improvements and maintenance, and the initial cost of the installation	C7.1

5.2 Indicator of Available Resources

The resources that a public network provides are flow rates and pressures and the conception of the building network must be adequate to the conditions of supply of these resources. It is assumed that water distributed through the public network meets the quality requirements established in the applicable legislation, so this factor will not be considered in the present indicator.

Flow and pressure are not independent, since excessive consumption in the public network implies high-pressure losses, reducing the residual pressures available. Thus, in order not to make the analysis too complex, the present indicator will only consider the "pressure" resource for the required flow rate. It should be noted that the possibility of a non-constant supply, with interruptions, will be analyzed within the scope of indicator C3.1 and not in the present indicator.

The pressure available on the local public network is crucial for the design of the water supply system, making it more or less complex. As previously mentioned, for each new request for a connection for water supply, the public network can be affected by the service pressure it can provide, so there must be an assumed responsibility of the water authority, to guarantee satisfactory values over time.

For reasons of comfort and durability of materials, it is generally recommended that the pressures in the devices are between 150 kPa and 300 kPa [23]. However, according to the technical codes of some countries (such as the Portuguese regulation [24]), the pressures could vary between 50 kPa and 600 kPa. The European standard EN 806-3:2006 considers a domain more restricted, between 100 kPa and 500 kPa [25].

The service pressure insufficiency, typically related to architectural conditions (number of floors to supply), may require the placement of reservoirs and pumping systems, which, in case of failures, can compromise building network performance. On another side, if the service pressures are too high (due to the existence of basements in the building, for example), it may be necessary to install pressure-reducing valves or equivalent devices. The solutions for the reduction of pressures can also generate failures and compromise the longevity of the network.

Thus, given the data provided by the operator of the public system, specifically the pressures (maximum and minimum) available in the public network measured at the site, and the pressure needed to supply the building, by the project, the criteria listed in Table 2 are adopted.

Table 2. IAR: Criterion C1.1

Indicator of Available Resource - IAR	*Identification*
Availability / Suitability of pressure in the public netwo	C1.1

$$\frac{P_{necessary}}{P_{available}} < 1 \ and \ P_{maximum} \leq 500 \ kPa$$

This Indicates the service pressure in the public network is prope supply the installation needs.

$$\frac{P_{necessary}}{P_{available}} < 1 \ and \ P_{maximum} > 500 \ kPa$$

This indicates the maximum pressure of the public network is h exceeding 500 kPa which involves the need for a pressure-red device.

$$\frac{P_{necessary}}{P_{available}} \geq 1$$

This indicates the service pressure available at the public netw insufficient to satisfy the needs of the installations considering a supply.

It should be noted that to check the minimum pressure the devices must be considered the available service pressure, while, to check the maximum pressure, must be considered the static pressure at the site. The criteria indicated in the next table are adjusted to the European Standards but can be easily adapted to other standards [26].

5.3 Indicators of Human Resources

In countries where there are degrees of professional qualifications (like Portugal), this indicator can be considered, as, in principle, it should be reflected in the quality of the installation. The professional qualifications, somehow, can translate into the adoption of solutions and materials, as well as the implementation of good construction practices, inspection, and maintenance. The training is relevant and requires constant updating, according to new techniques, equipment, systems, and constructive solutions that arise in the market, as well the experience in the working activity, where can be developed knowledge about the "know-how" to tasks run, allowing a continuous quality improvement of the final works.

At the project stage, the adequate choice of the materials and systems for the building network and a correct definition of the hydraulic performance, contribute to the intended operating conditions. In Portugal, the civil engineers registered in the Portuguese Engineers Order can subscribe projects of water building network projects, with the levels of effective members, senior members, and counselor members.

At the construction stage, the good functioning of the installation is associated with a good practice mounting, so special attention must be paid to the quality of the work, through the qualification of installers who perform these tasks, which can be certified or not, as well as their work experience. In Portugal, for example, there is a certification association for plumbers, called ANQIP (National Association for Quality in Building Services).

At the control and maintenance stage, is essential that the network operation and durability are ensured through periodic inspections and maintenance of all its elements. Thus, as in the construction phase, the plumbers' qualifications and experience should be contemplated in this criterion.

Although this indicator must be adjusted to the specific reality of each country, the experience of design engineers and plumbers for each stage of the installation can be defined in a simplified way based on time intervals: [0-5 years], [> 5- 10 years] and [> 10 years]. Table 3 reflects a possible configuration of this indicator for the Portuguese reality.

To validate the criteria, it is suggested the submission of declarations of professional associations, or educational/training certificates, as well as professional curricula.

Table 3. Criterion C2.1 and their sub-criteria

Indicator of Human Resources - IHR	***Identification***
Qualification / Training of personnel assigned to the project, construction, control, and maintenance	C2.1
Design	C2.1.1
Professional Category or Level	C2.1.1.1
Professional Experience	C2.1.1.2
Construction	C2.1.2
Certified Installer	C2.1.2.1
Professional Experience	C2.1.2.2
Control and Maintenance	C2.1.3
Uncertified Installer	C2.1.3.1
Professional Experience	C2.1.3.2

5.4 Indicator of Infrastructures

A system with several alternatives of operation is undoubtedly more complex and prone to failure occur. However, it can respond more efficiently to counteract the occurrence of localized problems without interruption of operation.

a) Water reserve infrastructures

If the existence of a reservoir in the building is imposed, although the system becomes more complex, it can have the advantage of guaranteeing the water supply for a certain period in case of failure in the public network.

In this way, Tank Capacity Reserve [RCT] is defined as the period, measured in days, in which users of the building can use their volume in case of failure of the supply from the public network, corresponding to the relationship between the useful volume of the tank and the average daily consumption expected in the building.

In Europe, taking to account that the uptake is 150 liters of water per day, which can be considered an average value, then to the residential sector is obtained:

$$\text{RCT} = \frac{\text{Useful Volume of Tank}}{150 \cdot \text{Expected Amount of Consumers}} \quad (1)$$

The useful volume is measured in liters. The number of users depends essentially on the characteristics of the building but can vary significantly in similar buildings. In the case of residential buildings, it is proposed to quantify the number of consumers according to the type of building, as shown in Table 4.

Table 4. Conventional Number of occupants according to the type of building unit

Conventional Number of occupants according to the type of building unit					
Typology of the building (according to the number of bedrooms "n")	T0	T1	T2	T3	...Tn
Number of occupants	2	2	3	4	...n+1

In the case of non-residential buildings, there are other known criteria for estimating the number of occupants. Per capita consumption in these buildings must be adequate for the intended use.

If there is a reservoir in the building system, the following criteria and sub-criteria are considered (Table 5):

Table 5. Criterion C3.1 and his sub-criterion

C3.1 – System Water Reserve	***Identification***
Reserve Capacity of tank	C3.1.1
Reserve Capacity of tank ≤ ½ day	
½ day < Reserve Capacity of tank ≤ 1 day	
Reserve Capacity of tank > 1 day.	

It should be noted that limits are established for the maximum volume of tanks in the regulations of some countries, so as not to exceed a maximum retention period, for reasons of water quality.

b) Pumping system and complementary infrastructures

The imposition of the existence of pumping systems in the building is related to the fact that the pressure available in the public network is insufficient for the desired use conditions. To suppress this problem, it is necessary to install pressurization or lifting equipment which, in case of failure, can compromise the water distribution. As such, the redundancy of pumps, though, for example, the doubling of groups, with one generally remaining in reserve, is an advantage, since, in addition to the possibility of having a complementary supply of water at an exceptional peak of consumption, it can ensure continuity of normal water supply in case of service pump failure.

Moreover, the functioning of the pumps depends in general on the electric energy. However, can exist failures of the electricity supply, and without an energy source, the equipment doesn´t work and, consequently, the water distribution is compromised. So, the pump operation can be ensured by the existence of others energy supply alternatives, such as generators.

Then, in case of the existence of a pumping system, it is assumed (Table 6):

Table 6. Criteria C3.2 and their sub-criteria

C3.2 – Pumping system and interconnected systems	***Identification***
Reserve the pumping system	C3.2.1
Pumping system without reserve	
Pumping system with 50% of the reserve	
Pumping system with 100% of the reserve	
Reserve of supply energy	C3.2.2
Existence of an alternative energy supply system	
No existence of an alternative energy supply system	

c) Water heating infrastructures or equipment

The distribution of hot water is generally considered one of the minimum comfort requirements in buildings, especially in the residential sector. To meet this requirement, buildings must have at least one device for producing sanitary hot water (SHW).

However, when there are failures in its operation, the heating of the water is naturally compromised, so it is relevant the existence of other equipment, complementary or not, for the production of SHW (for example, solar panels), to minimize the impact of eventual deficiencies in the operation of the main equipment.

Thus, if sanitary water heating equipment is available, the sub-criterion of the following table (Table 7) can be considered:

Table 7. Criterion C3.3 and his sub-criterion

C3.3 – System water heating	***Identification***
Amount of heating sanitary water equipment	C3.3.1
1 sanitary hot water equipment	
2 sanitary hot water equipment	
> 2 sanitary hot water equipment	

d) Unitary head losses

The length and diameter of the pipes, as well as their accessories, equipment, and valves, lead to more or fewer pressure losses. The water pressure in the most unfavorable use device concerning the entry point may have fewer comfort conditions, with greater variations in pressure heads [27].

In this criterion, the head losses calculated in the design phase can be considered in the installation phase but, in the construction and control, and maintenance phases, the actual head losses can be measured with a pressure gauge. When the analyses are cumulative, the value of the head loss measured on site should be considered, as it is more real.

In this way, the reference values inherent to the criterion are shown in the next table (Table 8):

Table 8. Criterion C3.4

C3.4 – Unit Load Loss
Reference values:
Unitary head loss average < 0.05 m/m
0.05 < Unitary head loss average ≤ 0.1 m/m
Unitary head loss average > 0.1 m/m

e) Sectioning of the network

The building network is made up of branches and as long as the sectioning valves are strategically positioned, it is possible to localize failures (and carry out the respective repairs), without compromising the overall functioning of the network, as long as the failures are local.

This criterion can be defined as a sectioning index of the network [SN]:

$$SN = \frac{\text{Amountofcutvalvesofwatersupplyperbranch/sub-branches}}{\text{Total Amount of branches/sub-branches ofnetwork}} \quad (2)$$

According to the exposed, the criterion considered is shown in the next table (Table 9):

Table 9. Criterion C3.5

C3.5 –Network sectioning
Network Sectioning Index < 1
Network Sectioning Index ≥ 1

f) Devices density

The total number of devices in the building installation can make the system more or less complex (and more or less subject to failures), affecting network performance. Thus, the sub-criterion indicated in Table 10 is assumed:

Table 10. Criterion C3.6 and his sub-criterion

C3.6 – Devices Density	***Identification***
Total Amount of use devices in the building installation of water distribution	C3.6.1
< 10 devices	
11 to 20 devices	
21 a 30 devices	
> 30 devices	

5.5 Indicator of Infrastructures Maintenance

The early detection of possible problems in the network allows for its timely resolution, without higher costs and discomfort to the users. Those problems could translate, besides the supply cuts, situations that can damage other infrastructures.

Therefore, the inspection frequency and maintenance of the infrastructures of the building network is a factor to take into account in this performance indicator. During the network operation, the maintenance/inspection processes that are verified should be registered, for example, the date that the process was made, the operation type and network components involved, identification and professional category involved, etc.

a) Maintenance of Water Reserve System

The inspection, maintenance, and cleaning of the reservoir components are important, as regards their conservation state and the quality of the water consumed. A stationary water reserve for long periods can compromise the water quality for human consumption.

In that way, in the case of the existence of tanks, are assumed the Table 11 criteria and sub-criteria:

Table 11. Criterion C4.1 and their sub-criteria

C4.1 – Maintenance of water reserve system	***Identification***
Maintenance/Cleaning of the system components of the tank:	C4.1.1
Cleaning frequency of filters	C4.1.1.1
No one time per semester	
1 time per semester	
2 times per semester	
> 2 times per semester	
Cleaning frequency and sanitation of the tank	C4.1.1.2
No one time per year	
1 time per year	
> 1 time per year	
Maintenance Frequency of control unit of the tank levels	C4.1.1.3
No one time per year	
1 time per year	
2 times per year	
> 2 times per year	
Inspection of system components of the tank:	C4.1.2
Inspection frequency of the filters	C4.1.2.1
No one time per semester	
1 time per semester	
2 times per semester	
> 2 times per semester	
Inspection frequency of the tank	C4.1.2.2
No one time per year	
1 time per year	
2 times per year	
> 2 times per year	
Inspection frequency of control unit of the tank levels	C4.1.2.3
No one time per semester	
1 time per semester	
2 times per semester	
> 2 times per semester	
Equipment of treatment and disinfection / Monitoring of water quality of reservoirs:	C4.1.3
Inspection frequency of treatments equipment of water	C4.1.3.1
No one time per month	
1 time per month	
> 1 time per month	
Maintenance frequency of treatments equipment	C4.1.3.2
No one time per month	
1 time per month	
> 1 time per month	

All the sub-criteria presented inherent to the water reserve system, depending on the frequency that is executed by the competent professionals. This frequency should be correctly registered during the operation of the network.

b) Maintenance of pumping system and complementary infrastructures

In the case of the existence of pumping equipment, as well as other complementary infrastructures, is considered good practice its periodic inspection and maintenance, to evaluate the conservation state and functional performance, that way to detect timely possible damages that can occur and repair them, without major impacts on the building network performance (Table 12).

Table 12. Criterion C4.2 and their sub-criteria

C4.2 – Maintenance of pumping system and complementary infrastructures	*Identification*
Inspection frequency of pumping system	C4.2.1
No one time per year	
1 time per year	
> 1 time per year	
Calibration frequency of pressure switches	C4.2.2
No one time per year	
1 time per year	
2 times per year	
3 times per year	
> 3 times per year	
Inspection frequency of normal system of electric energy supply	C4.2.3
No one time per year	
1 time per year	
> 1 time per year	
Inspection frequency of alternative system of energy supply	C4.2.4
No one time per year	
1 time per year	
> 1 time per year	

c) Maintenance of water heating systems

The good functional performance of the domestic hot water heating system implies frequent inspection and maintenance, according to the manufacturer's recommendations, to increase the probability of continuing an efficient hot water supply.

Thus, is established the criterion shown in the next table (Table 13). It assumes that the inspection frequency should be registered:

Table 13. Criterion C4.3

C4.3 – Maintenance of system water heating	*Identification*
Inspection frequency of SHW system	C4.3.1
No one time per year	
1 time per year	
> 1 time per year	

d) Maintenance of the building network

The periodic inspection of the building network can check the conservation and cleaning state of the components system (pipes, accessories, devices, etc.), alerting to failures eventually at the occur eminency. The criterion and sub-criterion are shown in Table 14.

Table 14. Criterion C4.4 and his sub-criterion

C4.4 – Maintenance of network building distribution of water	*Identification*
Inspection frequency of pipes, accessories, and devices	C4.4.1
No one time per year	
1 time per year	
> 1 time per year	

The frequency and the components involved should be registered.

5.6 Indicator of Malfunctions

In case of failures, the occurrence should be registered, with detection date, failure type, and cause. When analyzing the individual criteria of this indicator, it's possible to evaluate which elements can compromise the system and, if it is justified, proceed to its preventive substitution, to improve the reliability of the system.

Moreover, the complete stop of water distribution in the system implies a repair as quickly as possible, knowing that the discovery of the problem source is not always immediate. Therefore, based on the malfunction's history, is possible to establish a priority order of checks, investigate their provenance and minimize the repair time.

So, during the network operation, the malfunctions which occur and their frequency should be registered. This register should include detection, malfunction type, affected elements in the network, identification, and professional category involved, among others.

a) Failures of the Water Reserve System

In case of the existence of a water reserve cistern, when detected the occurrence of its failures should naturally be registered. The criterion adopted is shown in the next table (Table 15):

Table 15. Criterion C5.1 and his sub-criterion

C5.1 – Failures of the water reserve system	*Identification*
Occurrence frequency of failures in the water reserve system	C5.1.1
No one malfunctions per year	
1 or 2 malfunctions per year	
3 or 5 malfunctions per year	
>5 malfunctions per year	

b) Failures of the pumping system or complementary infrastructures

In case of the existence of a pumping system and complementary infrastructures (such as expansion tanks, pressure gauges, etc.), the occurrence of failures should also be registered. In the fowling table it is assumed (Table 16):

Table 16. Criterion C5.2 and their sub-criteria

C5.2 – Failures of the pumping system or complementary infrastructures	***Identification***
Occurrence frequency of failures in the pumping system	C5.2.1
No one malfunctions per year	
1 or 2 malfunctions per year	
3 or 5 malfunctions per year	
>5 malfunctions per year	
Occurrence frequency of failures in complementary infrastructures of the pumping system	C5.2.2
No one malfunctions per year	
1 or 2 malfunctions per year	
3 or 5 malfunctions per year	
>5 malfunctions per year	
Occurrence frequency of failures in the normal supply of energy	C5.2.3
No one malfunctions per year	
1 or 2 malfunctions per year	
3 or 5 malfunctions per year	
>5 malfunctions per year	
Occurrence frequency of failures in the alternative supply of energy to the pumping system	C5.2.4
No one malfunctions per year	
1 or 2 malfunctions per year	
3 or 5 malfunctions per year	
>5 malfunctions per year	

c) Failures of the water heating system

In the case of the existence of system water heating, is also indispensable to consider the register of the failures detected. Thus, it is proposed the criterion indicated in the table (Table 17):

Table 17. Criterion C5.3 and their sub-criteria

C5.3 – Failures of the system water heating	***Identification***
Occurrence frequency of failures in the systems heating water	C5.3.1
No one malfunctions per year	
1 or 2 malfunctions per year	
3 or 5 malfunctions per year	
>5 malfunctions per year	

d) Failures in the water distribution components

The failures occurrence of the water distribution components, correctly registered, is related to the sub-criterion indicated in Table 18:

Table 18. Criterion C5.4 and his sub-criterion

C5.4 – Failures of network building distribution of water	***Identification***
Occurrence frequency of failures in the pipes, accessories, and devices	C5.4.1
No one malfunctions per year	
1 or 2 malfunctions per year	
3 or 5 malfunctions per year	
>5 malfunctions per year	

5.7 Indicator of Quality Service

Sometimes, the repairs of equipment failures (pumps, heating water equipment, pipes, devices, etc.) are inconclusive, so the malfunctions quickly reappear by the same motive.

In this way, it is important to verify the quality of the services provided, evaluating, for example, the frequency of water interruptions that can be attributed to failures or inaccuracies in the provision of these repair services.

a) Repair Efficiency of the Water Reserve System

In the case of tank existence in the building network, this criterion is related to repeated faults frequency in the reserve system (Table 19):

Table 19. Criterion C6.1 and his sub-criterion

C6.1 – Repair efficiency of the water reserve system	***Identification***
Occurrence Frequency of repeated faults in the water reserve system	C6.1.1
No one repeated malfunction per year	
1 repeated malfunction per year	
2 repeated malfunctions per year	
>2 repeated malfunctions per year	

b) Repair efficiency of the pumping system and complementary infrastructures

This criterion is subdivided as shown in the next table (Table 20):

Table 20. Criteria 6.2 and his sub-criteria

C6.2 – Repair Efficiency of the pumping system and complementary parts	***Identification***
Occurrence frequency of repeated faults in the pumping system	C6.2.1
No one repeated malfunction per year	
1 repeated malfunction per year	

2 repeated malfunctions per year	
>2 repeated malfunctions per year	
Occurrence frequency of repeated faults in complementary infrastructures of the pumping system	C6.2.2
No one repeated malfunction per year	
1 repeated malfunction per year	
2 repeated malfunctions per year	
>2 repeated malfunctions per year	
Occurrence frequency of repeated faults in the normal supply of energy	C6.2.3
No one repeated malfunction per year	
1 repeated malfunction per year	
2 repeated malfunctions per year	
>2 repeated malfunctions per year	
Occurrence frequency of repeated faults in the alternative supply energy to the pumping system	C6.2.4
No one repeated malfunction per year	
1 repeated malfunction per year	
2 repeated malfunctions per year	
>2 repeated malfunctions per year	

c) Repair efficiency of the water heating system

In the case of a sanitary water heating system, the next table (Table 21) is applied:

Table 21. Criterion C6.3 and his sub-criterion

C6.3 – Repair efficiency of the system sanitary water heating	***Identification***
Occurrence Frequency of repeated faults in the system sanitary water heating	C6.3.1
No one repeated malfunction per year	
1 repeated malfunction per year	
2 repeated malfunctions per year	
>2 repeated malfunctions per year	

d) Repair efficiency in the building distribution network

To check the repair efficiency in the building distribution network of the building is adopted the next criterion (Table 22):

Table 22. Criterion C6.4 and his sub-criterion

C6.4 – Repair efficiency in the building distribution network	***Identification***
Occurrence Frequency of repeated faults in the pipes, accessories, and devices	C6.4.1
No one repeated malfunction per year	
1 repeated malfunction per year	
2 repeated malfunctions per year	
>2 repeated malfunctions per year	

e) Interruptions of water supply

The interruptions of water supply can have more or less impact on the consumption, according to the period in which occur the fault water.

It is suggested the analysis by periods, assuming periods of higher consumption, normal consumption, and lower consumption during the day. (Table 23).

Table 23. Criterion C6.5 and their sub-criteria

C6.5 – Interruptions of water supply	***Identification***
Occurrence frequency of water interruptions during established periods:	C6.5.1
07h00 – 9h00: Higher Consumption period	C6.5.1.1
0 interruption per year	
1 to 2 interruptions per year	
2 to 5 interruptions per year	
> 5 interruptions per year	
09h00 – 11h00: Normal Consumption period	C6.5.1.2
0 interruption per year	
1 to 2 interruptions per year	
2 to 5 interruptions per year	
> 5 interruptions per year	
11h00 – 14h00: Higher Consumption period	C6.5.1.3
0 interruption per year	
1 to 2 interruptions per year	
2 to 5 interruptions per year	
> 5 interruptions per year	
14h00 – 18h00: Normal Consumption period	C6.5.1.4
0 interruption per year	
1 to 2 interruptions per year	
2 to 5 interruptions per year	
> 5 interruptions per year	
18h00 – 23h00: Higher Consumption period	C6.5.1.5
0 interruption per year	
1 to 2 interruptions per year	
2 to 5 interruptions per year	
> 5 interruptions per year	
23h00 – 7h00: Lower Consumption period	C6.5.1.6
0 interruption per year	
1 to 2 interruptions per year	
2 to 5 interruptions per year	
> 5 interruptions per year	

In this context, it is assumed that the interruptions of water supply should be registered according to the schedule established, as well as the date of occurrence.

5.8 Indicator of Costs/ Investments

The investments are related to the initial cost of the building water supply system.

In this context, the following investments are accounted for:

- investments in improvements in the system water reserve
- investments in improvements in the pumping system and complementary infrastructures
- investments in improvements in the water heating system
- investments in improvements of pipes, accessories, and devices
- investments in the maintenance contracts for the installations

Thus, attending to the initial cost of building installation can be defined as the criterion, as shown in the next formula:

$$ICI = \frac{\sum costs\ of\ improvements\ e\ maintenance}{\begin{array}{c} initial\ cost\ of\ the\ installation \\ building\ water\ distribution \end{array}} = coeficient \quad (3)$$

6 Conclusion

Building water networks are one of the most important building infrastructures, in terms of the comfort and health of their users or occupants. Thus, consumers have the best expectations regarding their operational behavior.

However, when the systems are not meeting the requested requirements, they can cause interruptions or damage to the building and the constraint provided can be severe, either by cuts in the water supply or by repair costs. In this sense, it is important to contribute to the improvement and durability of building installations, concerning the performance and guarantee of the quality of the water supply, through a methodology for assessing the reliability of the network.

But, is not possible to establish one simple evaluation, since the system is constituted of a set of elements which, depending on architectural conditions of edifications and the water service pressure available at the public network, can become a complex system. In addition, other aspects can be conditioners, such as the applied materials, the design of the network, the correct dimensions, the good construction practices, and the maintenance.

Therefore, to simplify this objective, it is proposed, similar to what already exists in some countries in relation, for example, to public networks, the creation of performance indices that can quantify the efficiency or effectiveness and the security levels of each of the variables necessary for the functioning of building networks.

These variables, when examined individually, may reflect only a partial aspect and not a view of the entire building water system, about its performance. However, when combined using a mathematical model, weighted according to their specific degrees of importance, the variables can reveal important information for the reliability of the global system.

After the performance indicators have been characterized, a model can be developed that allows, in a certain way, to quantify the performance of the networks and classify their reliability, capable of contributing to predicting, monitoring, and improving the operability of the networks.

Although there are already many references regarding the application of KPIs in different building services or different types of buildings, there is no previous research in the scope of the development of specific performance factors for the water supply in buildings. Given the growing importance of efficient water management in all sectors, for reasons of sustainability or scarcity of the resource, it is considered that this article can contribute to the promotion and development of future studies in this area, such as, for example, the development of mathematical models to weight the performance factors according to the degree of importance attributed to each one. The development of performance factors for drainage in buildings is also a proposal for future research in this context.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

-Mary Lourenço developed the conceptualization of the text and wrote the original draft.

-Armando Silva-Afonso was responsible for defining the methodology of research and supervising and validating the final text.

-Carla Pimentel-Rodrigues collaborated in the research and validation and was responsible for writing (reviewing and editing) the final text.