

WATER DISTRIBUTION IN HIGH RISE BUILDINGS

WHITEPAPER

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Introduction:

The desire to build high into the sky has been a part of human existence for thousands of years. Just think of the pyramids in Egypt, the lighthouse of Alexandria in ancient Greece, or the Angkor Wat temple in Cambodia. High rise buildings have been used to represent political power and affluence; to honor statesmen or religious icons.

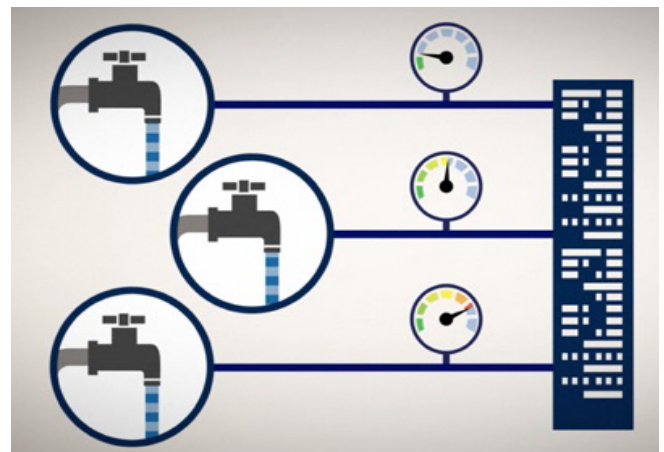
Over the last couple of hundred years, however, a more practical aspect has been built into these high-profile projects. High rise buildings reflected the need to make the best possible usage of a relatively small area of land in densely populated urban spaces across the world.

Further with the increase in density of population in major metro cities across the world, there is an exponential vertical development calling for high rise structures sprawling the city skylines. This poses a huge challenge when it comes to design of efficient water distribution systems in these high-rise structures. And when we talk about design of these distribution systems, it does not stop only with capacity calculation and piping design, but also on the intricacies of booster controls, which also avoids certain operating issues while running a booster system in high rise structures.

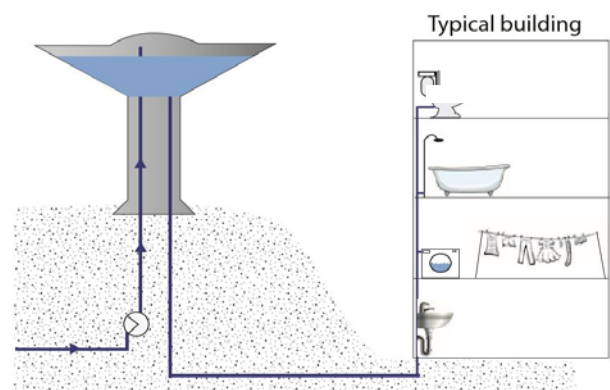
Water Distribution in general:

Pressure boosting can be necessary for one or more reasons as follows:

- Buildings placed on a hilltop where pressure supplied from mains is inadequate.



Water pressure supplied from the mains is not sufficient to cover top floors



The principle of an elevated water tower

- Tall buildings where the height of the building prevents the community water from reaching the top floors. For example, a mains pressure of 3.0 bar should, theoretically, be sufficient for a 30m tall building, but this is not the case. There must be sufficient surplus pressure

to cover resistance in riser pipes, single components such as shower heads, toilets and cooling towers.

- The peak load flow might be greater than what is possible to supply from the mains. In these cases, a break tank is supplied to the building, from where one or more booster sets take the water and boost it to the required pressure level. The normal specifications are that the pressure on each floor does not fall below 1.5 bar and does not exceed 5 bar.

Use of overhead tanks in high rise buildings:

The use of overhead tanks to ensure adequate water pressure in buildings, and especially tall buildings, is very common. The alternative to overhead tanks is the use of pressurized systems, where several booster pumps provide the necessary pressure. Overhead tank solutions were originally created more than a century ago, as buildings grew taller and taller. The required water pressure for both fire-fighting and domestic use increased and mains water was insufficient to supply a whole building.



Moreover, reliable and efficient pumps for pressurized systems were not available. The immediate solution was to use standard pumps to lift the water to the tank. From the tank, gravity ensured a natural downwards flow and sufficient pressure. Despite improved and energy-efficient pressure booster technology, many buildings still have overhead tanks.

Overhead tanks allow the users to have both water pressure and water supply in situations where there is no electrical power. Overhead tanks vary greatly in size, but common to them all is that they feature “water at the ready”, storing water for domestic purposes and fire-fighting.

The simple construction basically entails a tank, inlet and discharge piping, a float switch, and a pump. When the water level in the tank drops

below a certain level, the float switch engages the pump, refilling the tank.

Though from a functional point of view, overhead tanks of today work adequately in many aspects, on the flip side, overhead tanks involve elements that are not always desired. Examples include higher capital costs due to the tank set-up and greater structural requirements, high operating costs, a lack of pressure control, and difficulty in maintaining the overhead tank itself.



Water pressure supplied from the mains is not sufficient to cover top floors

In addition to serving as a storage device and creating pressure, roof-top tanks unfortunately can also serve as breeding grounds for bacteria constituting a major health risk. The exceptionally resistant bacteria legionella often appears as an unwelcome guest in water systems. To survive, the habitat for legionella and other microorganisms arises in the biofilm created in the water system. Biofilm is created inside pipes and water tanks, serving as a protective barrier and breeding ground for the bacteria.

System Elements & Layout

System Elements

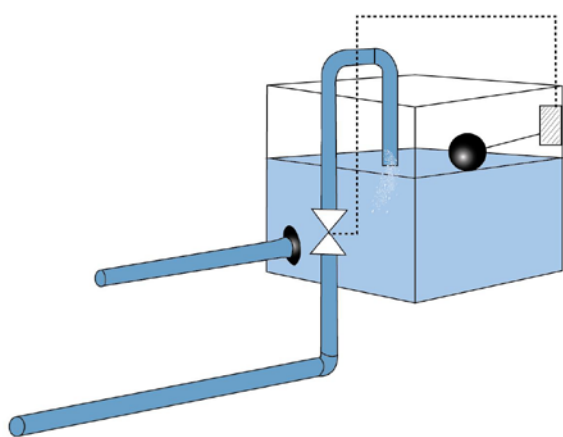
The booster system is based on several basic of hydraulic elements that can be combined in different ways. Below, the most important elements are described briefly about the functionality and role in the booster application in general.

1) Break tanks or Underground tanks

Break tanks are implemented in boosting systems in order to supply the system if the mains supply becomes insufficient during peak demand, or if it is unstable. It is also used to ensure that a surge from starting and stopping pumps does not affect the mains distribution. Tanks are also implemented in series- connected boosting layouts to create

manageable pressure zones. Here, the break tanks supply the taps in the tank's own boosting zone as well as all the zones above it.

A major disadvantage with the break tank is that it is a pressure-neutral tank that absorbs the pressure coming from the public supply, removing any potential inlet pressure. This means that the booster system should supply all the pressure itself, instead of using some of the pressure coming from the inlet. Hygiene is also an issue for break tanks. Because of retention time, the tank should be cleaned regularly and break tanks often feature more than one compartment making it possible to clean the tanks. In some countries, it is not permitted to install booster sets directly on the incoming mains supply. This is primarily to ensure that water cannot be pressed back into the mains supply, thus avoiding the risk of contamination. In those countries, break tanks are a necessity in all booster installations. Normally, the break tank is sized by the consulting engineer and it is generally not regarded as part of the booster set.



Break tank with level switch

Boosting with break tank

Advantages
Water always in stock
Break tanks used on different floors in high rise buildings, makes sizing easier compared to single boosting from basement
Disadvantages
Pressure in mains is not utilized
Space is a scarce resource in modern high rise buildings, making it difficult to have the needed space allocated for break tanks
Break tanks must be kept clean and appropriately cleaning should be a scheduled activity

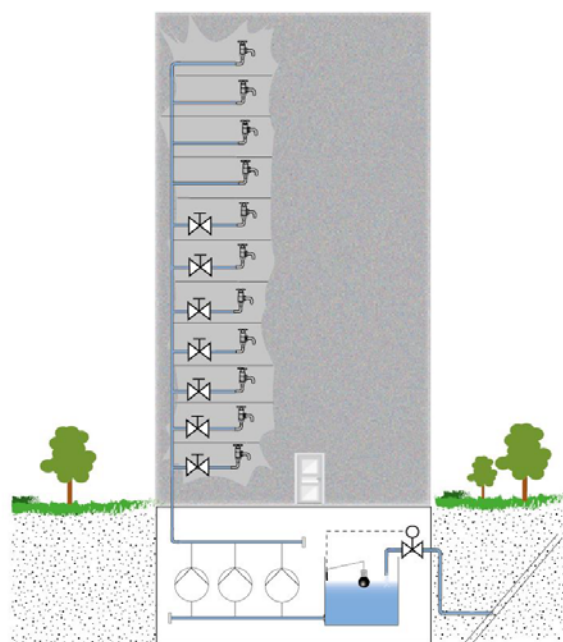
A water tank is placed before the pump system and filled with water from the mains. This allows the capacity of the mains to be lower than the building's peak demand, ensuring constant pressure even in peak flow situations. The break tank is filled with water during low-consumption periods, always ensuring even water supply to the booster pumps.

2) Booster Pumps:

Water distribution to buildings is vital for several reasons. People who live in multi-story buildings always need sufficient water and so does industrial processes. Therefore, high-quality pumps are crucial in booster systems.

What counts for all though, is the way the core of the pump is designed. Multi-stage pumps for boosters are all in-line multi-stage pumps. That means water pressure is gradually built up when the water passes through the different stages. When the final pressure level is met, the water exits the pump at the same level it entered. This is the in-line principle.

3) Risers and branches:



Building with one branch per floor

Building supply system is normally divided into risers and branches. In the risers, the geodetic height has been overcome, and the water is distributed to the different floors. The branches distribute water to each tap point. When using pressure reduction valves (PRV), the branches are often joined into main branches, creating a zone

for each PRV to reduce the required number of PRVs. If the buildings are identical and with only one riser, PRVs will be needed at each floor. In the example shown to the right, we need to add PRVs on each branch on the building.

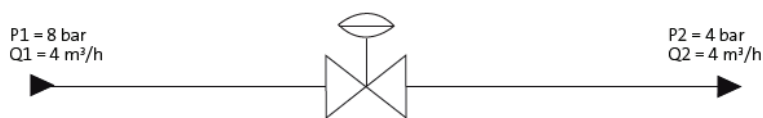
- The PRVs also need maintenance and therefore they need to be placed at an accessible place.
- Each PRV represents a loss, because of the energy consumed by creating higher pressure is wasted.

4) Pressure reduction valves (PRV)

Example: Energy wasted in the pressure relief valve

The presence of PRVs will cause a waste of built-up pressure and thus energy. This is illustrated by a simple example.

A high-rise building needs pressure boosting from the basement floor. In the example, a maximum water tap pressure of 4 bar is allowed. However, due to the system layout, excessive pressure is present in the lower part of the system. This is dealt with by installing PRVs in main branches before the taps. Below it is illustrated how an excess pressure of 8 bar is reduced to the allowed 4 bar. The pipe will supply a water flow of 4 m³/h.



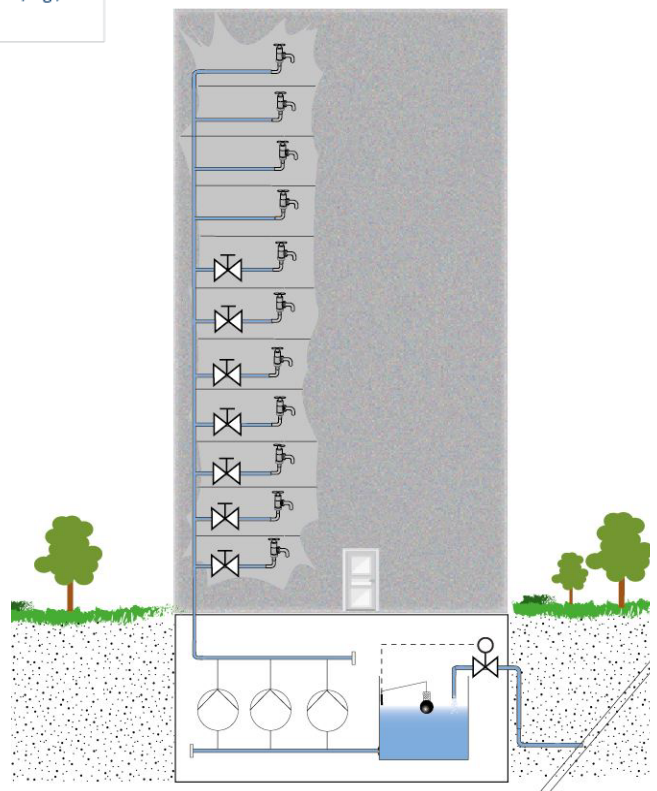
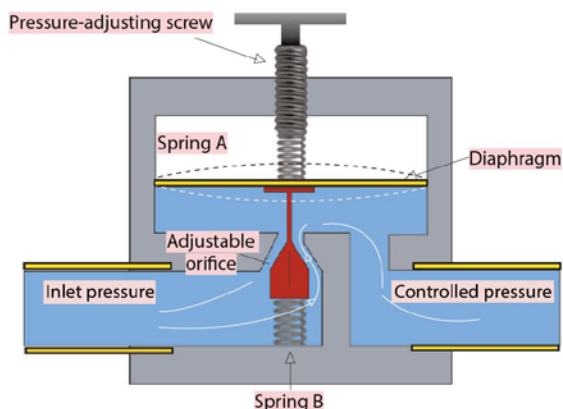
Available hydraulic power before the PRV:

$$P1 = q1/3,600 \times p1 \times 10^3$$

$$P1 = 4 \text{ m}^3/\text{h} / 3,600 \text{ s/h} \times 8 \text{ bar} \times 102 \text{ kPa/bar} = 0.91 \text{ kW}$$

After the PRV, the pressure is halved from 8 bar to 4 bar, resulting in only half the hydraulic power, P2 = 0.45 kW. As such, the PRV represents a power loss of 0.45 kW. Depending on the number of operating hours, this necessary excess pressure will potentially consume a lot of energy. For, e.g., 4,000 hours of operation per year, this PRV alone will 'consume' 1,800 kWh/year.

To equalize pressure on all floors, PRVs are often used in multi-story buildings. The pressure is mechanically reduced directly by the spring, making it possible to adjust the pressure precisely for each floor. The PRV can either be used individually with one on each floor or in a branch of a riser supplying 2-3 floors. The PRV is a rather simple way of controlling the pressure throughout a tall building. However, there are some disadvantages when using PRVs:



Single Booster system with one branch per floor

- For each PRV needed in the building layout, the initial cost increases.

Below, the advantages and disadvantages of some the most used system layouts are described.

Single booster system

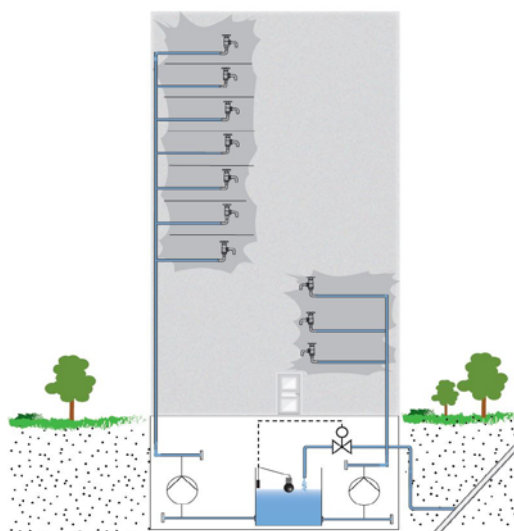
Single Booster System	
Advantages	
Only one riser needed (simple design)	
No space required on upper floors	
Disadvantages	
Excess pressure on lower floors in buildings exceed ten floors (PRVs and high pressure graded pipes needed)	

A single booster system is perhaps the simplest booster system available. It relies on a single set of pumps supplying pressure boosting from the basement to the point farthest away from the booster system. Basically, such systems may be configured with or without initial break tanks.

Zone-divided booster systems

The building is divided into pressure zones of ten floors or less with a booster supplying each zone from the basement through dedicated risers.

Advantages	
Manageable pressure zones	
Increased flexibility and security due to zoning	
No space required on upper floors	
Low-cost operation due to no residual pressure	
Disadvantages	
Higher initial cost than single-zone systems	
Higher static pressure in upper zones (high pressure graded pipes)	

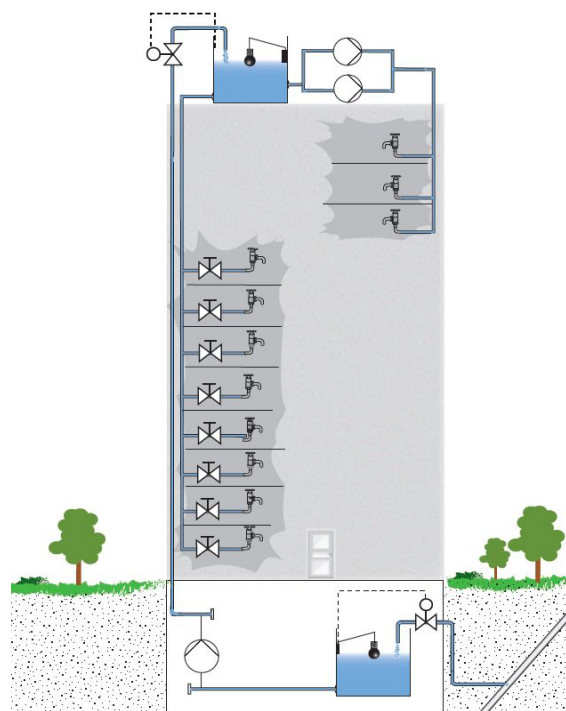


Zone-Divided System

Overhead tanks with terrace booster system

Overhead tank systems use a transfer pump in the basement to fill the overhead tank by a level switch-operated control. The solution requires pressure reduction valves on each floor if the building exceeds approximately 15 stories, to avoid unwanted high static pressure at the taps in the lower floors. It also requires a terrace booster to provide the top floors with the required pressure, as static pressure there will be too low due to insufficient geodetic height at the overhead tank.

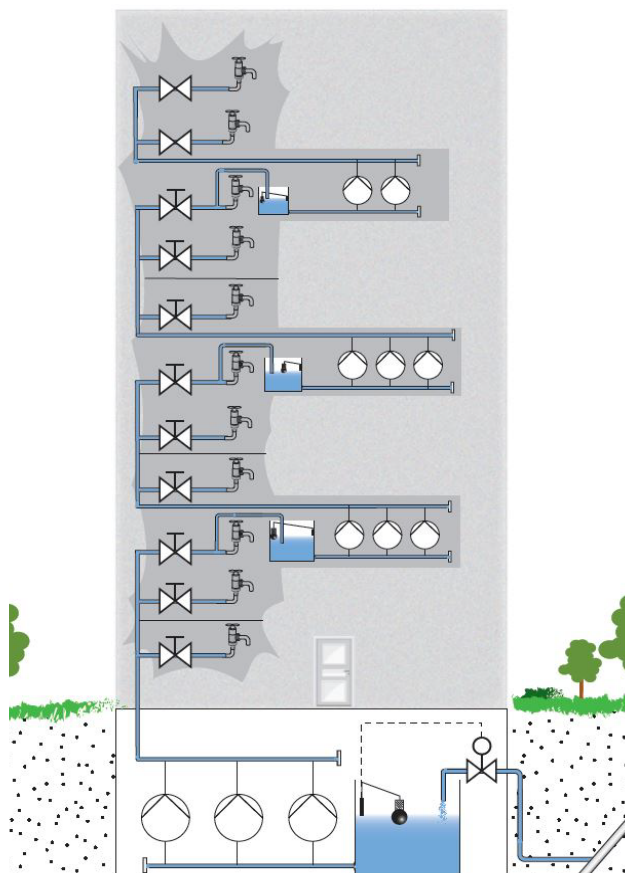
Advantages	
Mature technology	
Small booster power due to roof tank working as buffer	
Reserve capacity in roof tank	
Disadvantages	
Higher initial cost than single-zone systems	
High static pressure in upper zones (high-pressure graded pipes)	



Series-connected systems with intermediate break tanks

Series-connected systems with intermediate break tanks draw on several other systems, utilizing centrally-placed break tanks to supply both the taps,

the tank's own boosting zone and all the zones above it. With this system, a building is divided into smaller and more manageable pressure zones. Every zone is then served by its own booster set.

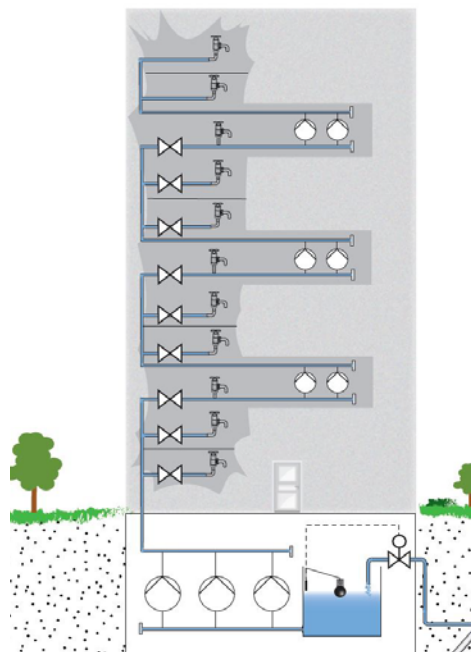


Series-connected systems with intermediate break tanks. In this example, we have three boost zones.

Advantages
Low pressure in each zone (no PRVs and less pressure-graded pipes needed)
Manageable pressure zones
Easy to size because each zone has its own supply tank
Disadvantages
Higher initial cost than single-zone systems
Space required for booster sets and tank on service floors
Risk of microbiological growth in tanks

Series-connected systems without intermediate break tanks

A series-connected system operates on the same principles as the previously mentioned system, but without the intermediate break tanks. This enables an effective usage of power as the water is only pumped to the part of the zone where it is used and not past it. However, complete control is very important. When a consumer draws water on the upper floors, the booster systems must be able to deliver the water from the bottom of the building.

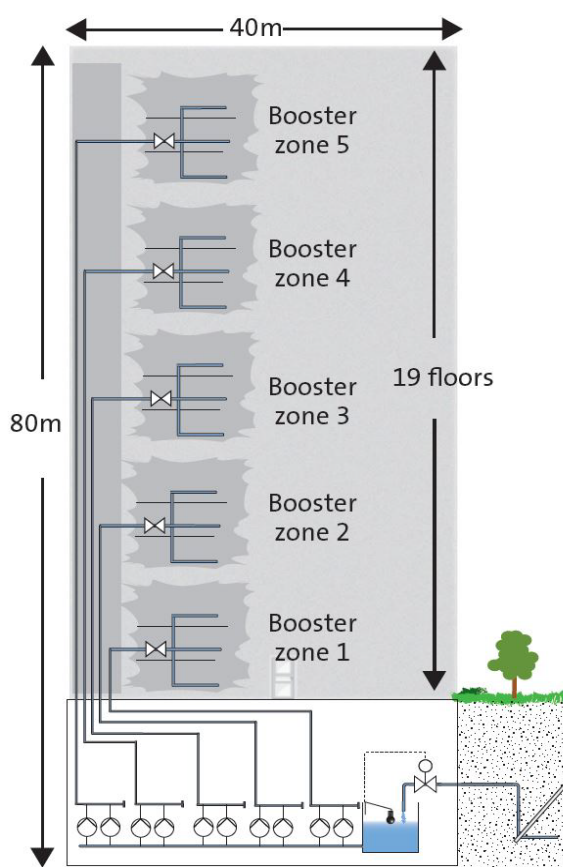


Series-connected systems without intermediate break tanks

Advantages
Low pressure in each zone (no PRVs and less pressure-graded pipes needed)
Manageable pressure zones
No space required for tanks
Less excess boosting (low operation costs)
Disadvantages
Higher initial cost than single-zone systems
Space required for booster sets and tank on service floors
Complex control

Illustration

An example is given to illustrate the differences between the previously mentioned system layouts in terms of necessary hydraulic power (P_4) and energy consumption (E_4) for water transport in a high-rise building.



The Building footprint is 1,600 m² (40m x 40m)

Building case

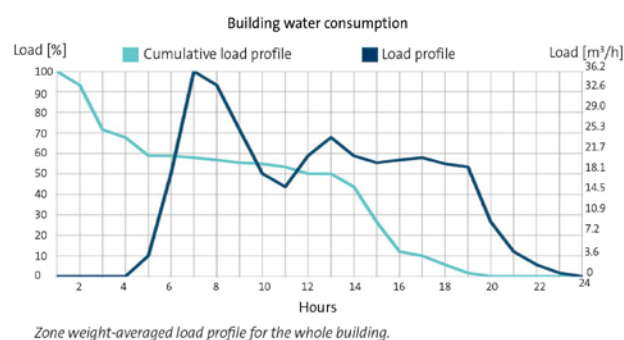
The imaginary building case is 80 meters tall, comprising 19 floors and 5 different hydraulic zones as illustrated on the building to the left. The building footprint is 1,600 m² (40 m x 40 m).

Each of the five hydraulic zones has different users and thereby different consumption profiles,

operating hours, peak flow requirements, etc. These conditions are listed below.

The zone weight-averaged load profile is shown in the graph below. The graph represents the combined water consumption pattern during a typical day (dark blue curve) for the whole building. Arranged as a cumulative load profile (light blue), the number of hours at different duty points are easily interpreted.

The total building peak flow demand is 46.8 m³/h. However, taking the load profile into consideration the peak flow is simultaneity corrected to 36.2 m³/h.



Evaluated booster layouts

- A: Single-booster system.
- B: Zone-divided single booster system.
- C: Single-booster system with roof top tank.
- D: Series-connected booster system with intermediate break tanks in zones.
- E: Series-connected booster system without break tanks.

In this example, layouts with tanks (C and D) are designed so that the tank capacity equals 4 hours of peak load. This corresponds to approximately 60% of the daily water consumption.

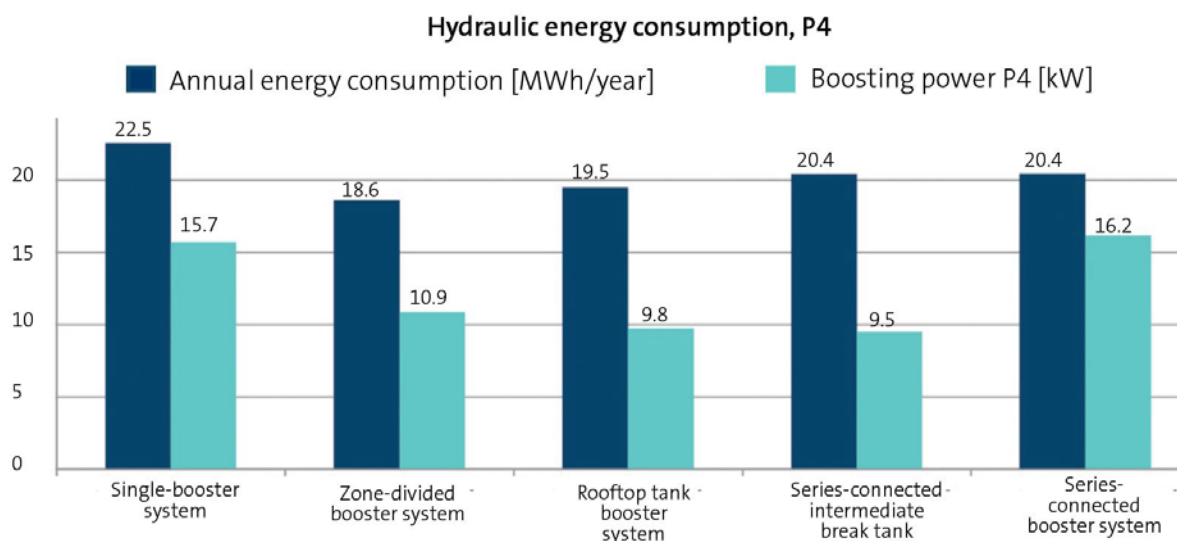
Booster zone	No. of floors	Zone height	Usage	Persons	Min. tap pressure	Peak flow
Zone 5	1 floor	4 m	Penthouse apartments	16 residents	200 kPa	0.3 m ³ /h
Zone 4	1 floor	4 m	Restaurant	160 seats	200 kPa	6.0 m ³ /h
Zone 3	7 floors	30m	Apartments	450 residents	150 kPa	8.3 m ³ /h
Zone 2	6 floors	25 m	Landscaped offices	640 employees	150 kPa	27.6 m ³ /h
Zone 1	4 floors	17 m	Shopping centres	100 employees	150 kPa	4.6 m ³ /h

Hydraulic booster size and energy consumption

The necessary hydraulic booster power (P4) and energy consumption linked to the building case varies per booster system configuration in question.

Also, equally important are the booster system controller's capabilities to address to certain practical issues in high rise buildings, such as:

1. Avoiding surge in vertical pipe lines/shafts through Soft fill functionality.



Energy consumption and required hydraulic booster power using different system layouts.

The result of a rough sizing is shown in the diagram above.

In this example, series-connected pressure boosting systems with break tanks require the smallest boosting power closely followed by the roof tank solution.

However, choosing a zone-divided system, where each zone is supplied by its own booster system will reduce the annual energy consumption by approximately 10% and only require approximately 15% larger booster capacity. Additional benefits like eliminating the need of intermediate break tank, separation of system in hydraulic zones etc. could easily make such systems favorable.

2. Proportional Pressure functionality to reduce higher pressures on pipes and fitting during low flow system conditions.
3. Low flow stop functionality to avoid churning of pumps during low consumption periods.

Generally, major operating issues occur in high rise structures since these factors are not taken into consideration while designing the booster systems controls.

To conclude, a properly sized, zone divided booster system would be more efficient for the operating life of a high rise building when compared to other systems discussed in this article.



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