

Water supply in tall buildings: roof tanks vs. pressurised systems



Introduction

The use of roof tanks to ensure adequate water pressure in buildings, and especially tall buildings, is very common.

The alternative to roof tanks is the use of pressurised systems, where a number of booster pumps provide the necessary pressure.

This article analyses a case study with five different systems for water supply in a 250m tall building with a daily water consumption of 295m³. The analysis includes a roof-top system and four different pressurised system configurations. The pros and cons of each system are described and a lifecycle cost calculation over 20 years is offered, with all significant costs taken into account. This article is vital reading for consulting engineers designing domestic water systems in tall buildings.

Roof tank solutions

Roof 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 pressurised 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 roof tanks.

About the authors:



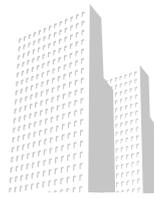
Jens Nørgaard

Jens Nørgaard is an Application Manager for Grundfos Commercial Building Services. He holds a B.Sc. in mechanical engineering. In his capacity as an Application Specialist and Project Manager, he has advised on public health and mechanical services in numerous building projects for consulting engineering companies.



Anders Nielsen

Anders Nielsen is an International Project Sales Manager at Grundfos. He is a technical engineer and has previously worked as an energy advisor in district heating, and as Sales Engineer and Product Manager in Domestic Building Services at Grundfos.



Water at the ready

Roof tanks allow the users to have both water pressure and water supply in situations where there is no electrical power. Roof 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.

Traditions abound

The establishment and usage of roof tanks is often deeply rooted in local traditions. Several cities and geographical areas around the world still employ roof tanks, and will continue to do so for years. An estimated 15,000 roof tanks dot the skyline of New York City, forming an integral part of the city’s water supply system. In Central and South America, as well as the Middle East, roof tanks are very common as well. In Europe, roof tanks are employed much less, where instead pressurised systems are primarily chosen. Numerous types of pressurised system configurations are available, each having its own pros and cons. Common to the different types of pressurised system, is less of a demand for space and lower life cycle cost.

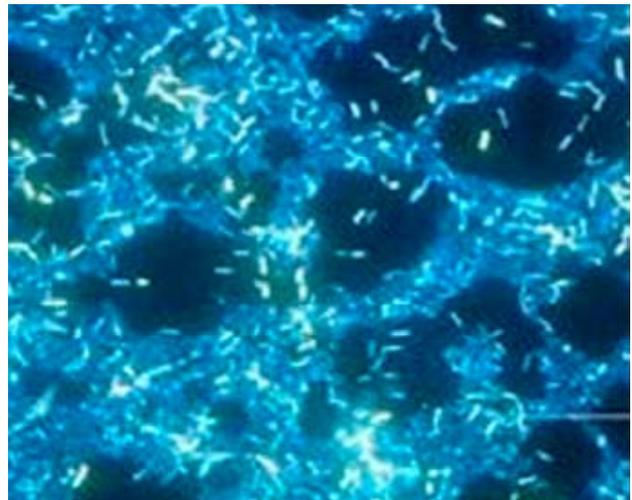
However from a functional point of view, roof tanks of today work adequately in many aspects. The technology is mature, and operation is stable. The user receives the water pressure required.

On the negative side, roof 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 roof tank itself.

Hygienic aspects

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. In order to survive, the habitat for legionella and other micro-organisms 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. If the water tank is made of an organic material such as wood, the tank itself serves as food stock for bacteria during its entire lifetime. Regular cleaning and maintenance of water tanks in many countries is required by law, so the additional costs, including disinfection, should also be taken into consideration.



Legionella in biofilm

Case study

Like buildings, booster systems vary greatly in size and design, making it difficult to determine which is most efficient. In this fictitious case study, we will look at five different system configurations. We will look into their pros and cons allowing you to see which is the most economical choice in this example.

The 20-year life cycle cost calculation (LCC), includes the initial investment in the booster systems, pipes and tanks, as well as energy costs, lost revenue costs, and maintenance costs.

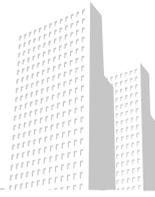
The basis of the calculation:

Building: 250m tall office building

Domestic water required: 295m³/day

The calculation is based on water for domestic purposes only.

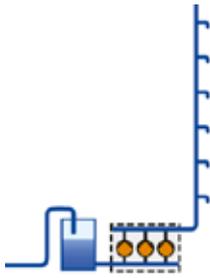
Water for air conditioning is not included.



System configurations

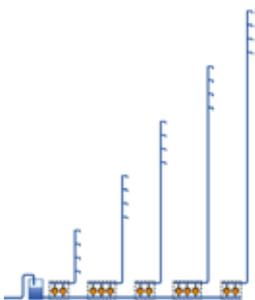
1. Single booster system. A water tank is placed in front of the pump system and filled with water from the mains. This allows the capacity of the mains to be lower than the building's peak demand, ensuring constant pressure even in

peak flow situations. The break tank is filled with water during low consumption periods and ensures a uniform water supply to the booster pumps at all times.

SINGLE BOOSTER SYSTEM	ADVANTAGES	DISADVANTAGES
	<ul style="list-style-type: none"> • <i>No space required for boosters on upper levels</i> • <i>Only one (or a few) riser pipe(s) in the building</i> 	<ul style="list-style-type: none"> • <i>High static pressure booster pump system</i> • <i>Pressure relief valves have to be fitted</i> • <i>High operational costs</i> • <i>High pressure-graded pipes and booster sets</i> • <i>Sensitivity to electricity fall outs</i>

2. Zone-divided system. The supply system is split into several zones supplying a maximum of 12 floors each. This ensures adequate water pressure on all floors without using pressure

relief valves. The minimum pressure on the upper floor in each zone is kept at 1.5 - 2 bar. The maximum pressure on the lowest floor in each zone does not exceed 4 - 4.5 bar.

SINGLE BOOSTER SYSTEM	ADVANTAGES	DISADVANTAGES
	<ul style="list-style-type: none"> • <i>Only the required water pressure is supplied</i> • <i>No space required for boosters on upper levels</i> • <i>Less vulnerable in the event of pump failure</i> • <i>No pressure reduction valves</i> 	<ul style="list-style-type: none"> • <i>More riser pipes in the building</i> • <i>High pressure-graded pipes and booster sets</i> • <i>Sensitive to electricity fall-outs</i>

3. Roof tanks ensure both water pressure and water supply in case of power failure.

In this model the upper six floors require a separate booster system in order to create sufficient pressure. The static pressure there is too low due to the insufficient geometric height to the roof tank.

This solution requires pressure reduction valves on each floor in order to avoid undesired high static pressures at the tap, which creates unacceptable noise while tapping.

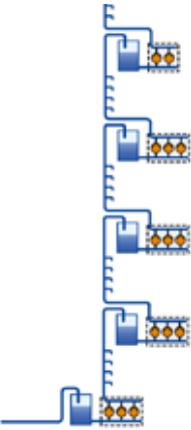


SINGLE BOOSTER SYSTEM	ADVANTAGES	DISADVANTAGES
	<ul style="list-style-type: none"> • <i>Mature technology</i> • <i>Only one discharge from booster set to top</i> • <i>Space saving</i> • <i>Less sensitive to electricity fall-outs</i> 	<ul style="list-style-type: none"> • <i>Water is pumped past where it's required</i> • <i>Insufficient pressure on the uppermost floors</i> • <i>Excessive pressure on the lowest floors</i> • <i>Pressure reduction valves have to be fitted</i> • <i>Need for higher pressure grade of pipe work</i> • <i>Space requirement for tank</i> • <i>Risk of microbiological growth in roof tank</i>

4. Series-connected systems with intermediate break tanks

draw on several other systems, utilising centrally-placed break tanks to supply both the taps in its own boosting zone and all the zones above it. With this system, a building is divided into smaller and more manageable pressure zones of 12 floors each. Every zone is then served by its own booster set.

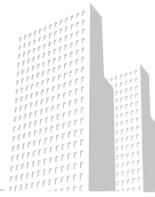
No pressure reduction valves are required and in case of electrical breakdown the tanks will be able to supply pressure and water for up to 12 hours. However, the tanks take up valuable space within the building, reducing the room available for revenue generation.

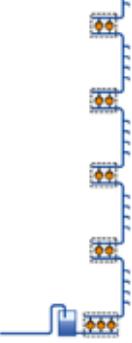
SINGLE BOOSTER SYSTEM	ADVANTAGES	DISADVANTAGES
	<ul style="list-style-type: none"> • <i>Low cost operation</i> • <i>Low pressure in each zone</i> • <i>Manageable pressure zones</i> • <i>High system resilience</i> • <i>Low power consumption of pumps and reduced load on power grid</i> • <i>Less sensitive to electrical fall outs</i> • <i>Low pressure-graded pipes</i> 	<ul style="list-style-type: none"> • <i>High initial investment</i> • <i>Booster sets and tanks require space on service floors</i> • <i>Loss of potential revenue-generating space</i> • <i>Risk of microbacterial growth in break tanks</i>

5. A series-connected system operates on the same principles as the previous system, but without the intermediate break tanks.

This enables an effective usage of power because the water is only pumped to 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 deliver the water from the bottom of the building.



SINGLE BOOSTER SYSTEM	ADVANTAGES	DISADVANTAGES
	<ul style="list-style-type: none"> • <i>Low cost operation</i> • <i>No space is required for tanks</i> • <i>Low pressure in each zone</i> • <i>Manageable pressure zones</i> • <i>Low power consumption of pumps and reduced load on power grid</i> • <i>Low pressure-graded pipes</i> 	<ul style="list-style-type: none"> • <i>Vulnerable in case of pump failure</i> • <i>Sensitive to electrical fall outs</i>

Look at the real picture

The Life Cycle Cost (LCC) analysis is a tool that can help minimise waste and maximise energy efficiency for many types of systems, including water boosting systems.

What makes the calculation a usable tool is that it creates a standard frame of reference which makes it possible to compare different types of booster solutions and different suppliers of booster technology.

Life Cycle Cost

Life cycle cost calculations for pumping systems are normally conducted with only three parameters taken into account.

These observable costs are:

- Initial cost of booster sets
- Maintenance costs
- Energy costs

In this case study, hidden costs are included in order to provide a more realistic system evaluation.

$$LCC = C_{ib} + C_{ip} + C_m + C_e + C_r$$

LCC = Life cycle cost

C_{ib} = Initial cost for booster sets

C_{ip} = Initial costs for piping, pressure reduction valves and tanks

C_m = Maintenance costs

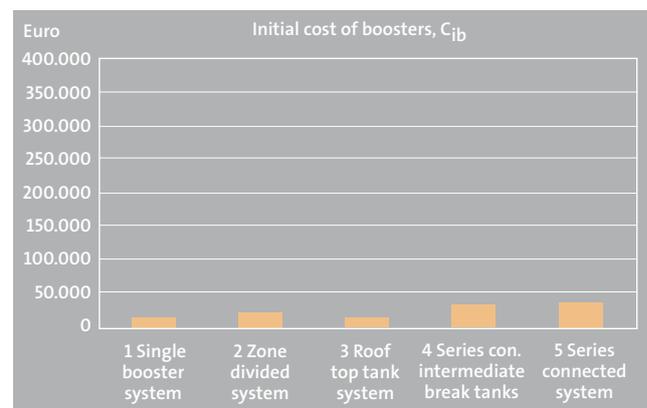
C_e = Energy costs

C_r = Lost revenue costs

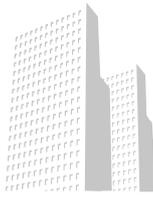
Initial cost for booster sets, C_{ib}

This includes a booster set or pumps and all the equipment and accessories needed to operate the booster sets:

- Pumps
- Frequency converters
- Control panels
- Pressure sensors
- Diaphragm tanks



Comparison of initial costs for boosters, C_{ib}



Initial costs for tanks and pipes, C_{ip}

In tall buildings, capital costs for piping, valves and tanks often exceed the costs for boosters many times over. This case study is no exception.

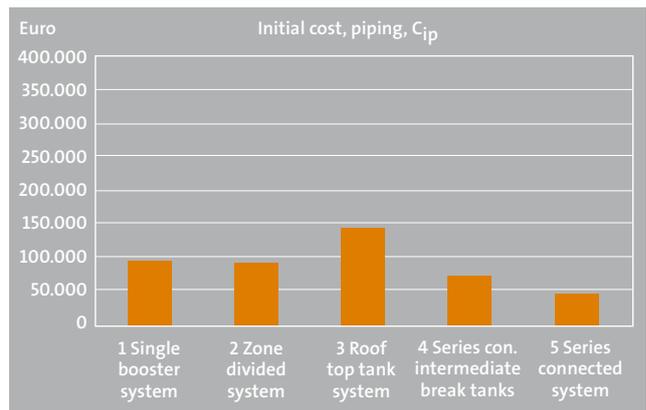
The calculation of costs includes:

- Vertical riser pipes including pipe insulation, pipe bearings and mounting
All pipes calculated are stainless steel pipes according to DIN 2463. Prices range from 50 €/m for 35mm (1¼") to 150 €/m for 108mm (4")
- Tanks. Costs of tanks 200 €/m³.
In case of electrical breakdowns tank volumes are sized so they will be able to supply water for up to 12 hrs.
- Pressure Reduction Valves (PRVs). Price 450 €/piece including mounting.

PRVs are included in the calculation where the pipe layout imposes static pressure at the taps to exceed approximately 5 bar.

The systems 1. Single booster system and 3. Roof-top tank are provided with PRVs.

Note: Costs for horizontal water distribution pipes over suspended ceilings, pipes in office floors and water fixtures are not included. Costs for these are the same regardless which boosting configuration is chosen.



Comparison of initial cost for piping etc, C_{ip}

Maintenance costs, C_m

Maintenance over a 20-year period:

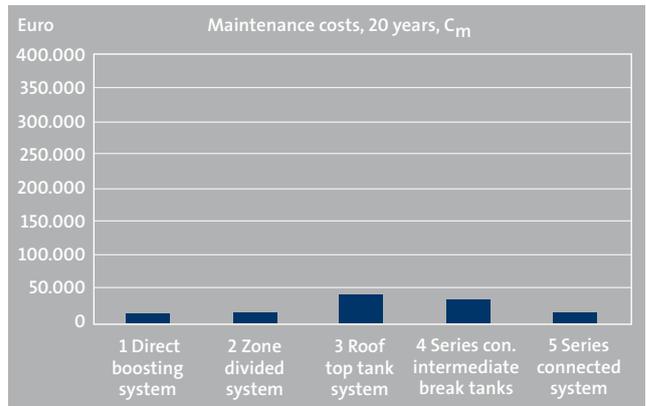
Maintenance of booster sets is estimated to constitute 50% of the booster's initial purchase price.

- Pipes and PRVs: 5% of the initial investment
- Roof and break tanks: 20% of the tank's initial cost

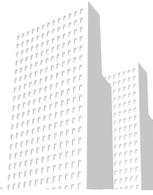
Both roof top tanks and break tanks must be emptied and cleansed every year according to local regulations. Booster systems that operate with tanks are disadvantaged in comparison with pressurised systems.



Water boosting set



Comparison of 20-year maintenance costs, C_m



Consumption profile

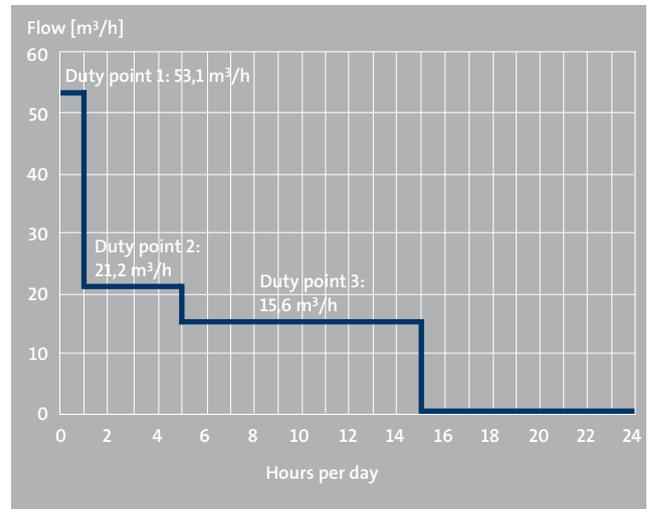
To perform an energy calculation a load profile is needed. The consumption profile shows the changes that occur in flow during a typical 24-hour period. In an office building, as well as in most commercial buildings, water consumption varies greatly depending on the time of day.

In the morning, the largest flow occurs with the start of service activities such as cleaning, coffee making, cooking, and washing. The demand fluctuates for the rest of the day, but does not reach the high morning level. As the building hosts only office space, there is virtually no consumption in late evening and overnight. The load profile is based on the duration curve.

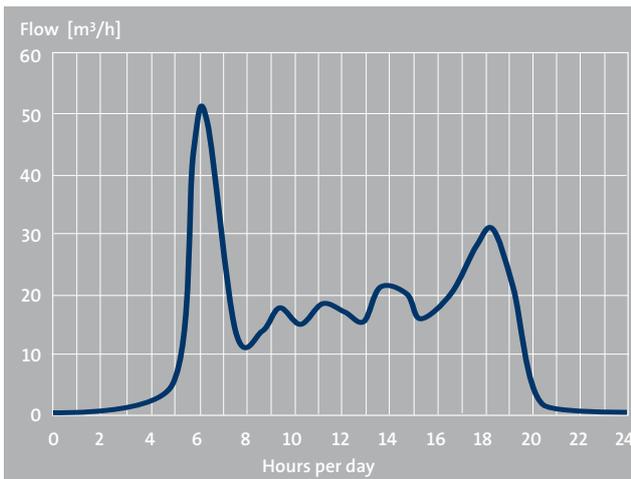
The total drinking water consumption per day is estimated at 295m³ with an estimated annual usage of 250 days.

The energy calculations are performed at three different duty points which are regarded as representative for the consumption profile.

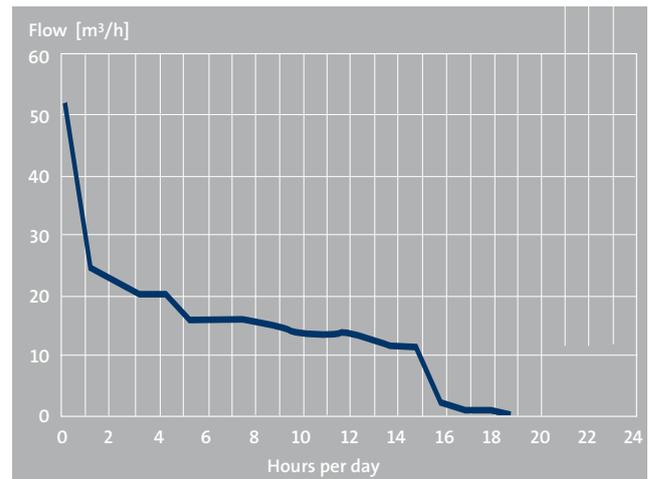
- Duty point 1 is liable for only one hour per day at the peak flow of 53,1m³/h.
- Duty point 2 is liable for four hours per day at a flow of 21,2m³/h
- Duty point 3 is liable 10 hours per day at a flow of 15,6m³/h
- The remaining nine hours are estimated as having no consumption



Calculation profile

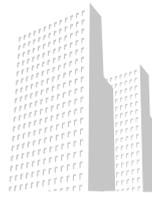


Water consumption profile during a 24-hour period



Duration curve showing hours per day operating above the indicated flow

GRUNDFOS WATER BOOSTING



Energy costs, C_e

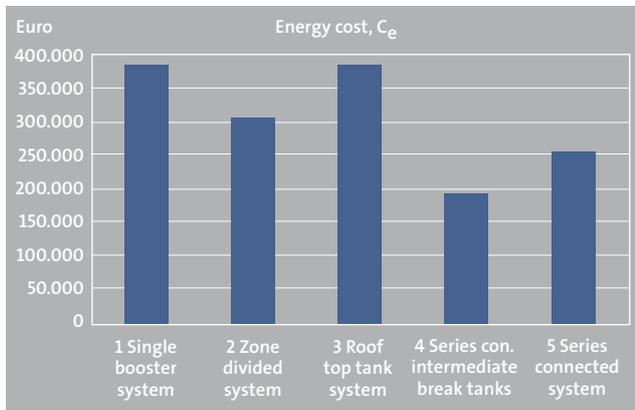
The energy calculations are performed according to the formula shown below.

$$E1 \text{ [kWh]} = \frac{Q \text{ [m}^3\text{/s]} * H \text{ [kPa]} * h \text{ [h]}}{\eta \text{ [-]}}$$

The table on the right shows the principle of all energy calculations. The annual energy consumption is calculated on three duty points. Efficiencies are based on actual Grundfos booster sets or pumps. Energy price used: € 0,20 per kWh.

Duty point	Flow	Head	Service hours per year	Hydraulic power	Efficiency		Annual power consumption
	Q	H	h	P4	η	E4	E1
	m ³ /s	kPa	h	kW	-	kWh	kWh
1	0,015	2871	250	42,5	0,61	10.621	17.411
2	0,006	2728	1000	16,1	0,58	16.145	27.837
3	0,004	2697	2500	11,6	0,59	29.004	49.159
							94.407

System 1 Single booster system. Calculation of one year energy consumption.



Comparison of 20 year energy consumption, C_e



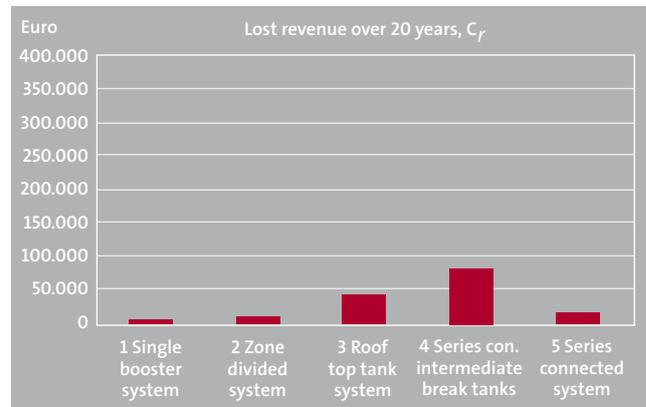
Wooden New York roof top tanks

Lost revenue, C_r

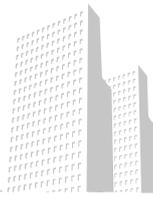
As real estate becomes more valuable, the amount of saleable area gets more and more important. In many instances it is profitable to extend the height of a building. Another and more effective way to increase the saleable area is to reduce "wasted" space for building services.

In this calculation, the value of the space that boosters and break tanks take up is taken into account. The figure used is €5 per m² per month. For basements and roof-tops €2,5 per m² per month is used.

Revenue costs may vary according to individual market conditions.



Comparison of lost revenue over 20 years, C_r



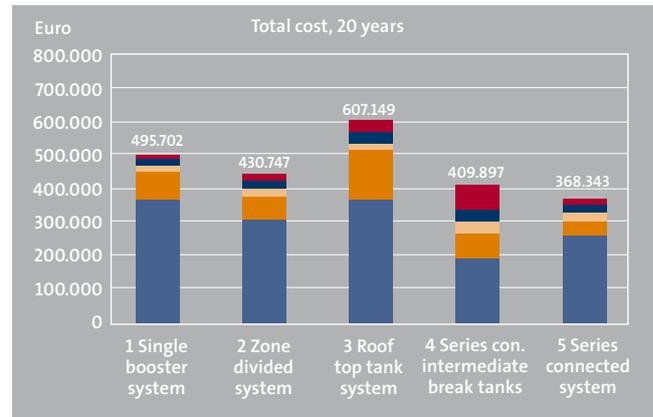
Pressurised system superiority

This article documented a brief history and background for roof tanks and pressurised systems. Five different systems for pressure boosting in tall buildings have been presented, with calculations using them in the same fictitious building created. Comparisons regarding the different parameters in them can be drawn easily. As the analysis shows, the pressurised and zone divided systems are superior to the roof-top tank solutions - both when it comes to initial investment, maintenance and energy efficient operation.

Here's why

1. Creating flow in the water system consumes power and so does creating pressure even when there is little or no flow. Therefore, booster configurations with several booster sets and low pressure levels are preferable as the power consumption will reduce significantly as the provided pressure reduces. The systems (2, 4 and 5) are divided into pressure zones of a maximum of 12 floors. The maximum geometric height is limited to 50m or 5 bar in each zone. Since the required pressure is low compared to the single booster system (1) and the roof-tank system (3) the power consumption is lower. In system 1 the total amount of water (295m³/day) is pressurised to 29 bar which makes the use of pressure reduction valves necessary. The pressure of the zone divided systems (4 and 5) are as low as 6 bar and hence no PRVs are necessary. The roof-top tank system turns out overall, to be the least profitable system and its power consumption to be the highest of all systems. This is surprising as the booster set is allowed to operate at a constant flow of 15m³/h for 20 hours a day. However, in this system all of the water (295m³/day) is pumped past consumers at a high pressure (29 bar) and then allowed to gravitate back to where it is supposed to be used. Again, pressure reduction valves have to be applied in order to remove surplus pressure.

2. The consumption profile shows that water demand changes during the day. Constantly adapting to the flow requires booster sets and a pipe system sized for the peak flow whenever it occurs. Establishing break tanks makes it possible to use water on stock in order to adapt to peak flow situations. In this case boosters and pipes can be downsized dramatically. For example: the booster set at the bottom zone has to supply the four booster sets above it. In the series-connected system without intermediate break tanks (5), it has to be sized for the



- Energy costs, 20 years. €
- Initial cost, tanks and piping. €
- Initial cost, boosters. €
- Maintenance costs, 20 years. €
- Lost revenue, 20 years. €

full flow of 53.1m³/h which results in a booster set with three 16 kW pumps.

Inserting intermediate break tanks (system 4) reduces the required flow to 23.2 m³/h which results in three pumps of 3 kW each and the overall energy consumption is reduced by 24%. In tall buildings, zone divided water boosting systems should always be considered the preferred water supply. The result is significantly lower power consumption because the boosters are running at lower pressure levels. A zone divided system will even make pressure reduction valves obsolete as the static pressure is kept at a low and acceptable level. This ensures increased end-user comfort.

Energy savings is crucial

Traditionally, there has been great focus on initial cost both when choosing booster sets and when settling for a system configuration of boosting systems. The calculation shows that doing so is unwise. However, it is a fact that zone divided systems call for increased investment in booster sets, but this study shows that investment in boosters is of minor importance in the longer term. Focus should be given to the entire boosting configuration as energy consumption is the most important element to consider: energy consumption turns out to account for more than all the remaining costs added together.