II.2 Water systems in high rise residential buildings, guide lines for design and construction

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Abstract

This paper is based on the study and gives a brief summary of the report “Water systems in high rise residential buildings, guidelines for design and construction”. This paper focuses on two of the three aspects: pressure zones with boosting units and hot water production with distribution.

The design of a water system for high rise buildings differs on two important objects from standard installations: the pressure and the hot water distribution. Over the world several solutions are available and described. These solutions depend on the local practices, costs for energy, history and culture.

Keywords

High rise buildings

1. Introduction

In The Netherlands more and more high rise residential buildings are under construction. A building is called a high rise residential building if the height is more than 70 meters and the main function of the building is residential. Up till now
knowledge and experience to design and construct water systems in high rise residential buildings is mainly practical, guidelines or standardization are not readily available. The requirement this knowledge is growing, due to the growth of high rise buildings. The associations TVVL and Uneto-VNI have initiated a study on the specific problems and requirements on potable water systems in high rise residential buildings. The result is a report “Water systems in high rise residential buildings, guideline for design and construction”.

This paper defines the basic design data and conditions water systems in general. Chapter 3 focuses on the design of the hydraulic system; different pressure zones, pressure reduction valves and types of pressure boosting units. Chapter 7 focuses on the hot water production and distribution. Solutions for both local hot water production and central hot water production are also described.

2. Basic design data and conditions

Water systems are constructed in the Netherlands according NEN 1006 “General regulation for water systems”. NEN 1006 describes the requirements for water systems. For a practical translation to design and construct water systems in the Netherlands there are the “Water guidelines”. The main regulations and guidelines for water systems are stated below.

2.1 Pressure

There is no strict regulation on the pressure in water systems in the Netherlands. But, one of the most important aspects to design a well operating water system is the pressure. Different pressures levels are necessary for the various appliances in of the system. The following pressures are mentioned in the various guidelines:

- The pressure delivered by the water company differs per water company. The minimum pressure after the flow meter is 200 kPa. (Water company)
- The minimum design pressure on the taps depends on the application of the tap. Guidelines for the minimum pressure of taps for domestic use are stated in table 1 (according the “Water guidelines”).
- The maximum static pressure on the tap is 500 kPa (according NEN-EN 806-2)
- The maximum pressure on the tap is 600 kPa (according the “Water guidelines”). For high rise buildings it’s not desirable to maintain this pressure.
### Table 1 Minimum pressure on domestic taps

<table>
<thead>
<tr>
<th>Tap</th>
<th>Minimum pressure (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shower, bath, washbasin, kitchen</td>
<td>100</td>
</tr>
<tr>
<td>Fire hose reel</td>
<td>150</td>
</tr>
<tr>
<td>Luxury shower</td>
<td>Specification manufacturer, if unknown 200</td>
</tr>
<tr>
<td>Luxury sanitation</td>
<td>Specification manufacturer</td>
</tr>
</tbody>
</table>

### 2.2 Temperature and availability hot water

Regulation and guidelines with regard to the temperature have as object safety (avoiding scalding and the growth of Legionella) and functionality. The Regulation and guidelines with regard to the temperature are as follows:

- The water company supplies water with a minimum temperature of 4°C and a maximum of 25°C.
- In a house installation without circulation system the temperature at the tap is at least 55°C.
- In a house installation or a collective water system with circulation system the temperature on the tap is at least 60°C.
- In hot water systems with circulation system the temperature at the return is at least 60°C.
- Drinking water is not warmer than 25°C.
- For hot water at the tap the maximum waiting time is 20 + 15 seconds. 20 seconds for the pipe and 15 seconds for the hot water producer.

### 2.3 Noise

Noise is generally described as “unwanted sound”, so the designer of the water system needs to address unwanted noise. Requirements on noise are set up to avoid or reduce noise nuisance. The maximum sound level in houses caused by the sanitary installations is 30 dB(A) according to NEN 5077. This requirements with respect to piping systems are:

- In residential buildings the maximum water velocity in pipes for cold and hot water generally is 1.5 m/s. With an absolute top limit of 2 m/s.
- For the hot water circulation system the maximum water velocity is 0.7 m/s.
3. Hydraulic lay out

Beside the above described guidelines to design a correct hydraulic water system the following issues are also important:

- The height of the building. The fixed height of the taps.
- The friction loss in the distribution pipes

3.1 Friction loss in the distribution pipes

In distribution pipes the friction loss is mainly relevant in very tall buildings. Because of the total length of the distribution pipe, the sum of the friction loss achieves high values. It is possible that on the highest floors a relative big difference occurs between the static pressure and the user pressure. Since the hydraulic design for boosting units is often based on the minimum user pressures, the maximum static pressure is actually less.

In distribution pipes the friction losses per meter are limited. As a result of the relative high calculated maximum flow, pipes with big diameters are selected which results in lower friction losses. Table 1 shows the friction losses for the basic design.

Table 1 Design friction loss

<table>
<thead>
<tr>
<th>Water velocity in riser (m/s)</th>
<th>Design friction loss (kPa/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.25</td>
</tr>
<tr>
<td>1,5</td>
<td>0.6</td>
</tr>
<tr>
<td>2</td>
<td>1.25</td>
</tr>
</tbody>
</table>

3.2 Maximum pressure in the installation

The height of the building, the minimum user pressure for the index tap and the friction losses in the main determines the maximum static pressure in the pipe system. This maximum static pressure is necessary to select the quality of the pipe material.

The maximum pressure in the pipe system is determined as follows:

1. Determine the maximum height \( h_{\text{max}} \) (m) from the booster pumps to the highest leading tap.
2. Determine the minimum user pressure \( p_{\text{dyn, tap}} \) (kPa) for the index tap.
3. Determine the friction losses in the index pipe work $\Delta p_{\text{dyn}}$ (kPa/m).
4. Calculate the maximum pressure $p_{\text{max}}$ (kPa) with:

$$p_{\text{max}} = p_{\text{dyntap}} + h_{\text{max}} \times (10 + \Delta p_{\text{dyn}}) \quad (1)$$

Example

A high rise residential building, index tap on 150 metres above the boosting pumps. Minimum use pressure index tap on 150 metres 200 kPa, friction losses in the mains at 2 m/s velocity are estimated on 1.25 kPa/m. Maximum pressure:

$$p_{\text{max}} = 200 + 150 \times (10 + 1.25) = 1,889 \text{ kPa}$$

**3.3 Maximum height of a riser**

In paragraph 3.2 the height of the building is a governing factor to determine the maximum pressure in the installation. In this paragraph the maximum pressure of the pipe, limited by the pipe pressure rating, is the basis to determine the theoretical maximum height of the riser.

The maximum height of the riser determined as follows:

1. Determine the maximum pressure in the pipe material. For pipes there are three ratings: 1,000 kPa, 1,600 kPa and 2,500 kPa.
2. Determine the minimum use pressure $p_{\text{dyntap}}$ (kPa) for the index tap.
3. Determine the friction losses in the riser $\Delta p_{\text{dyn}}$ (kPa/m)
4. Calculate the maximum height $h_{\text{max}}$ of the mains with:

$$h_{\text{max}} = \frac{p_{\text{max}} - p_{\text{dyntap}}}{10 + \Delta p_{\text{dyn}}} \quad (2)$$

Table 2 shows for the most common situations for the maximum height $h_{\text{max}}$ of the riser.
Table 2 Maximum height $h_{\text{max}}$ of the riser in relation to the pressure rating

<table>
<thead>
<tr>
<th>Min. use pressure (kPa)</th>
<th>Max. rating 1,000 kPa</th>
<th>Max. rating 1,600 kPa</th>
<th>Max. rating 2,500 kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Friction loss (kPa/m)</td>
<td>Friction loss (kPa/m)</td>
<td>Friction loss (kPa/m)</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>0.6</td>
<td>1.25</td>
</tr>
<tr>
<td>100</td>
<td>88</td>
<td>85</td>
<td>80</td>
</tr>
<tr>
<td>150</td>
<td>83</td>
<td>80</td>
<td>76</td>
</tr>
<tr>
<td>200</td>
<td>78</td>
<td>75</td>
<td>71</td>
</tr>
</tbody>
</table>

As explained in paragraph 3.1 in high rise buildings also the maximum static pressure can lead. This occurs mainly if there is a high friction loss caused by elbows, changes in diameter and devices in the pipes. In case of standard circumstances this is not a problem: The static pressure will not exceed the maximum static pressure on the leading tap. If the average friction loss at the total height of the riser is higher than indicated in table 3 the difference between the user pressure and the static pressure will be too high. In that case pressure reducing valves are necessary or it is necessary to reduce the friction losses. In this case keep also in mind the losses in the hot water producer.

Table 3: Maximum average friction loss per meter riser.

<table>
<thead>
<tr>
<th>Height riser (m)</th>
<th>Minimum pressure index tap (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
</tr>
<tr>
<td>75</td>
<td>4.0</td>
</tr>
<tr>
<td>100</td>
<td>3.0</td>
</tr>
<tr>
<td>125</td>
<td>2.4</td>
</tr>
<tr>
<td>150</td>
<td>2.0</td>
</tr>
<tr>
<td>175</td>
<td>1.7</td>
</tr>
<tr>
<td>200</td>
<td>1.5</td>
</tr>
<tr>
<td>225</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Remark: Maximum pressure on index tap 400 kPa
Figure 1 indicates the consequences if the friction loss in the riser is too high. With a height of the riser of 150 metres, an average friction loss of 2.5 kPa/m and, on the index tap a minimum user pressure of 150 kPa, the static pressure on this index tap will be 525 kPa. As shown in table 3 the average friction loss is limited at 1.7 kPa.

![Diagram](image.png)

**Figure 2** With an average friction loss of 2.5 kPa/m in high risers the difference between static pressure and user pressure becomes too high

Remark on figure 1: On the total height of the riser the maximum flow differs from the design maximum flow, therefore the relation between the user pressure and the height is not proportional

### 4. Pressure boosting principles

The following paragraphs describe the various pressure boosting principles and how to determine the pressure zones.

1. Pressure zones without pressure reducing valves
2. Pressure zones with single pressure reducing valves
3. Pressure zones with serial pressure reducing valves
4. Pressure zones with break units with atmospheric pressure

#### 4.1 Pressure zones without pressure reducing valves

The principle of pressure zones without pressure reducing valves is shown in figure 2. A boosting unit is necessary for each different pressure zone. The pressure realised by the
water company is generally sufficient to feed the lower floors. The minimum and the maximum user pressure for the index taps determines the height of a pressure zone.

![Diagram of pressure zones without pressure reducing valves]

**Figure 2 Pressure zones without pressure reducing valves**

### 4.2 Pressure zones with single pressure reducing valves

The application of pressure reducing valves (PRVs) offers flexibility for the design. It is possible to realize higher pressure zones and the number of boosting units consequently decreases, its sometimes possible to use only one boosting unit. In addition of the booster pumps the equipment, piping, valves, fittings must be designed and rated to accommodate the high water pressures particular at the base of the water piping system.

Safety measurements are necessary to avoid that the pressure becomes too high in the installation in the residential accommodations. These are as follows:

- A maximum pressure of 600 kPa at the inlet of the pressure reducing valve by creating more pressure zones. See figure 3. This solution leads to high energy losses.
- More pressure reducing valves in serie.
- A safety valve in the apartments. This safety valve requires a drainage. See figure 4.

The diagram printed in figure 4 b results in hundreds of PRVs for every building. Access must be provided to service these valves. The costs of the valves and the additional costs for providing access is a deciding disadvantage. This method is not very popular. The diagram printed in figure 4 b eliminates some of the PRVs by making branches and serve several floors with one PRV.
4.3 Pressure zones with serial pressure reducing valves

Downstream arrangement of PRVs offers also more flexibility for the design of the distribution system. When more PRVs are used less boosting systems are necessary. The initial investment costs are lower but the energy costs increases. Figure 5 shows a up-feed system with serial connected PRVs.
4.4 Pressure zones with break units and top tank

It’s also possible to create pressure zones with atmospheric tanks. Several tanks are installed on different heights in the building. See figure 6. The lowest pump serves the fixtures in the lowest pressure zone and the upper tank. The capacity of the basement pumps is sized for the total building demand. This normally used is regular if the pressure will be too high for the pipe rating. The application of an atmospheric tank has risks, the water is in contact with the ambient air (by a filter), so bacterial contamination is a threat. If the water temperature in the tank increases there is a risk for growing legionella. In the Netherlands it’s not common to use gravity tank systems with atmospheric storage tanks.
5. Height of the pressure zones

A pressure zone is defined as a pipe system where at the connected taps the required minimum user pressure and maximum user pressure or maximum static pressure are maintained. There are two principles: Without PRVs and with PRVs.

5.1 Without pressure reducing valves

Without the use of PRVs the minimum and maximum user pressure determine the height of the pressure zone. The height of the pressure zone is determined by the lowest value of the following two formulas:

Based on the minimum and maximum user pressure:

\[
 h = \frac{p_{\text{dyn,tap}\text{;}\text{max}} - p_{\text{dyn,tap}\text{;}\text{min}}}{10 + \Delta p_{\text{dyn}}} \tag{3}
\]

And based on the minimum user pressure and maximum static pressure:

\[
 h = \frac{p_{\text{stat,tap}\text{;}\text{max}} - p_{\text{dyn,tap}\text{;}\text{min}} - h_1 \times \Delta p_{\text{dyn}}}{10 + \Delta p_{\text{dyn}}} \tag{4}
\]

- \( h \) Maximum height of the pressure zone (m)
- \( h_1 \) Height of the start of the pressure zone (m)
- \( p_{\text{dyn,tap}\text{;}\text{max}} \) Maximum user pressure
- \( p_{\text{dyn,tap}\text{;}\text{min}} \) Minimum user pressure
- \( \Delta p_{\text{dyn}} \) Average friction loss per meter
For the most situations formula 3 determines the maximum height. Table 4 shows the maximum height of a pressure zone for the most common situations.

**Table 4: Maximum height in metres of a pressure zone without pressure reducing valves, based on a minimum user pressure and an maximum user pressure (300 kPa).**

<table>
<thead>
<tr>
<th>Minimum user pressure</th>
<th>Friction loss (kPa/m)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.25</td>
<td>0.6</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>100 kPa</td>
<td>20</td>
<td>19</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>150 kPa</td>
<td>15</td>
<td>14</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>200 kPa</td>
<td>10</td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7 shows an example with a minimum user pressure of 100 kPa, a maximum user pressure of 300 kPa and a maximum static pressure of 400 kPa. The minimum and maximum user pressures determine the height of the pressure zone. See also figure 8, with the same design data, but the friction losses are higher. In figure 8 the minimum user pressure and the maximum static pressure determine the height of the pressure zone.
Figure 7: The minimum user pressure and the maximum user pressure determine the height of the pressure zone

Figure 8: The minimum user pressure and the maximum static pressure determine the height of the pressure zone

5.2 With pressure reducing valves

Item 4 describes that if PRV’s are used there is a primary pressure zone and a secondary pressure zone. See figure 9. The height of the secondary pressure zone is determined by the minimum and maximum user pressure, as explained in item 5.1 (formula 3). To adjust the pressure on the outlet of the PRV account must be taken for the pressure loss in case of flow (pressure loss piping and PRV).
6. Comparison of the energy consumption

Application of PRV’s result in energy loss. The energy needed for a water flow is proportional with the multiplication of the flow (l/s) and the difference in pressure. Assume a high rise building with apartments with a equal water demand, the energy consumption is then proportional to the difference in pressure and the amount of apartments or floors. Figure 10 shows two schemes where the energy consumption is calculated. Table 5 shows a overview of the two calculated pressure zones. For this comparison it’s assumed that the two boosting concepts have the same pump technology.

To compare the energy consumption for both concepts the pressure difference for each boosting system is multiplied by the amount of floors that’s served by the boosting system. Result for the concept with two boosting systems:

Zone 1: $850 \times 11 = 9,250$

Zone 2: $520 \times 11 = 5,720$

Zone 3: 0 (Water company)

Total 15,070

Result for the concept with one boosting system:

Zone 1: $850 \times 22 = 18,700$

Zone 2: 0 (Water company)
The theoretical energy consumption of both concepts are in proportion of 15,070 to 18,700. That is 1 : 1.24. Concept 2 consumes theoretically approximately around a quarter more energy.

![Concept 1](image1.png) ![Concept 2](image2.png)

**Figure 10:** Boosting concepts to compare the energy consumption.

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Two boosting units</th>
<th>One boosting unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>zone 1</td>
<td>zone 2</td>
</tr>
<tr>
<td>75</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>72</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>69</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>66</td>
<td>190</td>
<td></td>
</tr>
<tr>
<td>63</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>57</td>
<td>280</td>
<td></td>
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<tr>
<td>54</td>
<td>310</td>
<td></td>
</tr>
<tr>
<td>51</td>
<td>340</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>370</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>430</td>
<td>100</td>
</tr>
</tbody>
</table>
The dynamic friction losses are negligible

Table 5 Comparison the energy consumption of pressure boosting concepts

To reduce the energy consumption of the booster pumps it is recommended to use a variable-speed drive for each pressure zone. A variable-speed drive eliminates energy-loss and avoid pressure fluctuations in the distribution system.

7. Hot water production

To produce hot water there are several principles:

- Hot water production in the apartments
  - With individual heaters, a gas-fired boiler or electric heater
  - A heat exchanger connected to a central heating system or district heating
- Central hot water production with circulation system
7.1 Hot water production per apartment

This is hot water production with individual gas-fired boilers, electrical heaters or heat pumps in combination with exhaust air. In case of a gas-fired boiler account must be taken for the requirements for the flue gas discharge. For hot water storage tanks keep in mind the extra weight of the storage tank in each apartment.

7.2 Individual heat exchangers

Large city's such as Amsterdam and Rotterdam have a district heating distribution system operated by a private utility company. This district heating distribution system supplies the heat for the heating in the apartment using a heat exchanger. To produce hot drinking water there are double-wall heat exchangers to guaranty the water quality. Both heat exchangers can be combined to one device.

The big advantage of this system is the simple lay out of the water supply system and the individual metering. The water heaters are located close to the fixtures so there is a minimum on heat losses in the hot drinking water system. A disadvantage is that by maintaining a permanent high temperature of the district heating mains a heat loss occurs in the shaft which warms the cold water pipes in the same shaft. One of the regulations is to keep the cold water temperature lower as 25°C, so it is recommended to separate the cold water distribution in “cold” pipe shafts.

To avoid high pressures in the central heating distribution system the systems is seperated by several exchangers. See figure 11.
7.3 Central hot water production

If a central hot water production is used, the hot water is distributed from the central hot water tank to the apartments with a hot water pipe and a hot water circulation pipe. The general principals as follows are applicable:

- Avoid installing the circulation pipe in the apartments, use only supply pipes for the users.
- The maximum pressure in the distribution system is 600 kPa.
- The user pressure for each apartment has a minimum of 200 kPa.
- The maximum pressure for the hot water storage tank is 1000 kPa.

Each pressure zone needs a separate hot water system. See figure 12. It’s not possible to locate the hot water storage tanks in the basement because of the high static pressure. This hot water concept provides space on the floors near the apartments.
In a high rise building where the water distribution system is zoned vertically to maintain pressures within the maximum criteria established, it is imperative that certain precautions be observed in the design of the hot and circulation water system. Each zone must be considered as a complete system with no interconnection with any other zone. Each zone must have its own water heater, distribution piping, circulation hot water piping and circulation pumps. It is always desirable to locate the heater at the top of the system. The pressure on the heater and circulation pump are subjected to are much less than at the base of the system.

Also for this system it is recommended to separate the pipes in a hot and cold shafts.

8. Conclusion

Many parameters must be considered during the engineering of domestic water systems for high rise buildings, and many possible solutions exist. The engineer must consider building height, available municipal water pressure, pressure requirements not only on the upper floor but also throughout the building, flow demand, booster pump capacity and control, pipe and valve materials, riser locations for hot and cold, PRVs and space requirements in the building.

Also are important the economics, energy efficiency and acoustics.

The engineer has to realize that the occupants for this type of apartments in high rise buildings will be people paying top dollar and expect a high quality plumbing system.
At the start of the design the plumping engineer has to determine carefully the pressure zones to maintain the minimum and maximum pressures within the recommended limits. The pressure on the fixtures and the demand flow determine to a significant amount the comfort for the residents and the designer take this in account.

9. References

1. Water systems in high rise domestic buildings, 2008, TVVL Leusden, the Netherlands
2. NEN 1006, General requirements for water supply installations, 2002, NEN, Delft, the Netherlands

10. Presentation of Author

Walter van der Schee is a member of the Dutch Technical Association for Building Installations (TVVL). He is a member of the board of the department Sanitary Technologies (ST). The objective of the association is to promote research and technology in the field of building services. This is done by networking; giving courses; lectures; organising symposia; research and co-financing university-chairs.

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