An international review of design requirements for the single stack drainage configuration

J. S. Lansing
john.lansing@pae-engineers.com
PAE, Portland, Oregon

Abstract

The single stack drainage system, also known as the primary ventilated stack, is a piping configuration that utilizes standard drainage fittings and the atmospheric opening at the top of the drainage stack termination as a means of stabilizing transient air pressure differentials throughout the piping system without a separate network of vent piping. Following extensive investigations at the Building Research Station in the 1950-1970s, variations of the single stack system have become widespread globally, resulting in regionally distinctive design and installation criteria. These variations are reflected in regional standards and are discussed in detail here, focusing on widely used configurations and configurations with unique requirements. Contrasting design and installation standards may be useful for developing generalized design and installation guidance for the single stack configuration as well as highlighting inconsistencies between regional characteristics to guide future investigations focusing on performance validation. The single stack drainage system in the following design and installation standards were chosen for review: BS EN 12056-2 (United Kingdom), DIN 1986-100 (Germany), NEN 3215 (Netherlands), DS 432 (Denmark), Byggvägledning 10 (Sweden), SANS 10252-2 (South Africa), GB 50015-2019 (People's Republic of China), SHASE-S 206-2019 (Japan), COPSSW (Singapore), AS/NZS 3500.2 (Australia & New Zealand), NBR 8160:1999 (Brazil), Philadelphia Plumbing Code, IPC and UPC (United States).

Keywords

Single stack drainage system, primary ventilated stack, drainage systems, plumbing codes, drainage standards, international standards

Definitions

Auxiliary vent: a drainage stack with a parallel vent to support greater airflow

Bypass stack: a separate drainage stack connecting upstream and downstream of the connection clearance zones of the main drainage stack the (Figure A1.7)

Bypass vent: vent piping that extends from the fixtures to the drainage stack (Figure A1.6)

Drainage branch: drainage piping carrying the flow from two or more fixture drains

Fixture drain: drainage piping between the trap and the drainage branch or drainage stack

Long sweep bend: a 90° bend with a radius equal to at least twice the drain diameter

Secondary vented stack: a drainage stack with a parallel vent to support greater airflow. Fixture drains and drainage branches may connect into the drainage stack unvented

Short sweep bend: a 90° bend with a radius less than twice the drain diameter

Square branch connection: a horizontal branch connection to the drainage stack with a centerline radius less than the diameter of the drain.

Stack base: where the stack transitions from vertical to horizontal (Figure A1.1)

Stack offset bypass: drainage and vent piping that extends from the lower drainage and the upper drainage stack (Figure A1.8)

Stack vent: extension of the drainage stack above the highest branch connection (Figure A1.1)

S-trap: A trap type similar to a P-trap except featuring a vertical segment immediately downstream of the trap outlet to direct the drainage downwards.

Swept branch connection: a horizontal branch connection to the drainage stack with a centerline radius at least twice the internal drain diameter

Unvented: a drain, whether vertical or horizontal, that is not connected to dedicated vent piping

Wye branch connection: a branch connection forming a 45° angle into the stack

Inspection chamber: point of access junction where two or more horizontal drains converge, located inside or outside (Figure A1.5)

1 Introduction

The water seal in fixture traps separates occupant spaces from foul air and aerosols within sanitary drainage piping in buildings. Traps typically have a water seal height of 50 mm (2 inches) or more, which allows a limited pressure differential within the drainage system without displacing water seals. As fixtures discharge into the drainage piping, air is drawn through the vent terminations to the exterior to stabilize the pressure differentials produced by the drainage flow. The sewer system outside of the building also allows for the stabilization of pressure differentials within the sanitary drainage system inside the building.

Trap seal loss events may be broken down into three categories: induced siphonage, self-siphonage and back pressure. Induced siphonage occurs when a trap seal is removed by negative pressure caused by drainage flow from an adjacent branch or drainage stack.

This form of siphonage is often addressed by providing an auxiliary vent stack with cross connections to the drainage stack to balance pressure differentials. Self-siphonage occurs when there is insufficient airflow downstream of an actively draining trap. Self-siphonage is most likely to occur in long, small diameter drains with flow high enough to fill the cross-sectional area of the drain. This is most often mitigated with an induvial trap vent, also known as an anti-siphon vent, but may also be addressed with a larger diameter drain to avoid hydraulic closure. Back pressure is another cause of water seal loss and occurs when the trap is subjected to positive pressure, in some cases, high enough to eject the water seal into the occupant space. All three trap seal loss scenarios may be addressed without a separate network of vent piping by extending the upper portion of the drainage stack to the exterior. This configuration, known as the single stack or primary ventilated stack, is the basis of many drainage design standards and achieved widespread use following the results of key investigations at the Building Research Station in the 1950s (Figure A1.1). Single stacks are ideally suited for conditions where fixtures are concentrated in close proximity and where stack offsets do not occur. Bathrooms in residential buildings and hotels are common applications for single stacks as well as remotely located fixtures such as kitchen sinks or washing machines.

Due to the complexity of the interactions within the stack, many design recommendations are based on regionally based investigations, trial and error, arbitrary judgements, and traditional practice within a given region. A review of existing design recommendations may provide valuable insight into the methods available for maintaining subjectively acceptable risk of trap seal failure with respect to system complexity and installation cost. The following review will assess recommendations based on peak drainage loads, height limitations, accommodations for fixtures near the stack base, branches and stack connections, and stack offsets while providing regional context. Many of the characteristics discussed in the regional context are not specific to the single stack drainage system but may influence aspects of the performance.

The information provided here is the culmination of reviews of design standards, industry journals, and interviews with subject matter experts, such as designers and standards specialists. Given the nature of this study, the literature review for each regional section is uneven due primarily to varying levels of guidance within the respective standards. Additional contributing factors to uneven discussion include varying availability for publications, challenges accessing information as well as language, social, and regional barriers. Subject matter experts for many of the regions discussed were consulted to increase accuracy and to provide greater context.

The modified single stack, also known as the secondary ventilated stack, is a configuration similar to the single stack system, except a parallel auxiliary vent stack is provided to allow for increased airflow. The auxiliary vent stack connects above the base of the stack and extends to the atmosphere, which may feature cross-connections between the vent and drainage stack and is most often used for stacks in high-rise buildings or stacks with offsets. Like the single stack, fixture branches and sanitary branches may connect to the drainage stack unvented. Branch-to-stack connections are assumed to use standard drainage fittings, such as the swept branch and wye unless noted otherwise.

Systems using special branch connection fittings, namely the Sovent system, which feature branch connection aerators, deaerator, or fittings with vanes to influence the movement of drainage flow within the stack are outside of the scope of this review. Similarly, single stack configurations with mechanical ventilation devices such as air admittance valves (AAV) or positive transient attenuators (PTA) are not considered in this review.

1.1 General comments on regional context

The historical adoption of vent piping to support the attenuation of airflow within sanitary drainage systems is varied. The transition away from individual vent piping in the United Kingdom begin as a result of post-war rebuilding efforts in the 1940s, leading A.F.E Wise of the Building Research Station (BRS) to perform testing of drainage systems with unvented drainage branches [1]. Wise's *One Pipe (Single Stack) Plumbing for Housing* 1952 publications [2] [3] demonstrated that unvented fixtures may discharge into a drainage stack while maintaining pressure differentials, provided that the upper portion of the stack was open to the atmosphere. In 1969, BRS introduced a methodology using the steady flow energy equation to calculate the maximum negative pressure developed within the single stack, taking into account both drainage flow and stack height, among other influencing factors [4]. These efforts were well-received and supported the adoption of the single stack internationally. In regions such as Germany and the Northeast United States however, similar configurations had been utilized prior to efforts at the BRS.

Some published drainage standards serve as a guide whereas others serve as a legal requirement or 'code' that may be legally enforced. Many standards are published as national standards intended to apply to a specific territory or region whereas other standards are intended for multinational usage.

The European Committee for Standardization (CEN) effort led to the publication of the 5 part harmonized drainage standard EN 12056 *Gravity drainage systems inside buildings* in 2000, part 2 of which contains a majority of the design guidance for sanitary drainage systems [5] While many regions of Europe continue to independently issue national design standards, the regional design and installation practices mostly fall within the four design categories described in Part 2 of EN 12056. Each of the design categories, designated as System I, II, III, and IV, feature separate values for calculating drainage loads, branch filling height, maximum drainage branch length, stack connection type, minimum gradient, minimum fixture drain diameter, and other specifications. The design and installation practices of System I reflect those of Germany, Switzerland, and Belgium and are most prevalent in Europe. System II reflects the design and installation practices of the Netherlands and to some extent Scandinavia, System III reflects those of the UK, and System IV reflects those of France [6]. The EN 12056 standard is republished by member nations of CEN as a national standard with a prefix identifying the associated national standards organization. All four System Type categories require a minimum trap seal of 50 mm (2 inches), effectively establishing a uniform minimum pressure performance criterion. EN 12056-2 features an equation for calculating the peak drainage flow (Equation B1.1), using empirical discharge units based on the fixture type and a frequency factor to account for statistical usage criteria. The design loading basis for the single stack in EN 12056 is 1/6th of the cross-sectional area and does not take into consideration stack airflow with respect to height [7].

1.2 General comments on stack height

When drainage flows from a branch into the stack, an annular flow forms around the interior wall, allowing a core of air to pass through the center. The shear force between the drainage and airflow generated by the 'no slip' condition draws air into the top of the stack to balance the developed negative pressure. Taller drainage stacks will generate greater negative pressures as the frictional resistances are greater due to the distance to the atmospheric termination [8]. Contrary to the assumptions that form the basis of many design standards, there is no simple relationship between airflow and drainage flow and many of the computational methods for determining negative pressure are complex and generally not considered suitable for routine design applications [9]. For this reason, many standards prescriptively indicate maximum height limits for single stacks, which are subject to greater pressure differentials due to the reduced airflow capacity compared to systems with dedicated vent piping. The use of DN 100 (4 inch) stacks in the single stack configuration is fairly standard for stacks serving residential bathrooms internationally while DN 150 (6 inch) stacks are sometimes used for taller buildings due to the increased airflow capabilities.

1.3 Stack base

Most standards require a connection clearance zone (Figure A1.2) extending a specified distance above and downstream of the stack base, where no drainage connections are permitted. The connection clearance zones account for the positive pressure waves due to the water curtain formation along the inner radius of the stack base transition from vertical to horizontal. While this requirement is often solely attributed to addressing the pneumatic effects of a hydraulic jump or suds production depending on the design standard, the clearance zone addresses a variety of performance issues to reduce the likelihood of pressure differentials exceeding established thresholds that will result in the failure of trap seals near the stack base. Due to the connection clearance zones at the stack base, the fixtures at the lowest floor are in many cases prohibited from connecting into the stack serving the floors above. Since single stacks do not have an auxiliary vent connecting shortly above the stack base, the single stack drainage system will generate larger pressures differentials, which may impact the water seals in traps unless countermeasures, such as connection clearance zones are implemented. Larger pressure differentials are associated with taller stacks due to the greater airflow needed to overcome the frictional resistance within the drainage stack as well as the style of fittings used for the stack base transition. Stack diameter, style of branch connection fitting to the stack, and vertical to horizontal arrangement at the stack base have a significant influence on the pressure differentials generated in the single stack [8].

2.4 Branches and stack connections

Fixture drains and drainage branches connecting into the single stack are often described as ‘unvented’ as they do not have individual vent piping installed. The design recommendations of the single stack are intended to provide adequate airflow to the unvented drainage branches to protect the water seals in traps, serving the same function as individual vent piping.

Unvented connections with small diameters may produce suction noise when draining at a high flow as well as produce siphonage that may compromise the water seal in the trap. The impact of self-siphonage tends to be greatest when draining a plugged basin[1] with a rounded bottom into an unvented drain or unvented S-trap configuration. In flat bottom fixtures such as a shower, bathtub or kitchen sink, the trailing discharge that occurs as the draining process is nearly complete has the tendency to refill any siphonage that may have occurred [10] [11].

The type of stack connection fitting from drainage branches and fixture drains may influence siphonage in unvented drainage branch. Wye fittings are more likely to create hydraulic closure conditions while swept and square branch fittings allow better airflow.

1.4 Stack offsets

Similar to the pressure conditions produced by the water curtain at the stack base, stack offsets create conditions for a second water curtain as the horizontal drain transitions to the vertical position of the lower stack. To protect the water seals in traps, the pressure differentials resulting from the second water curtain must be accounted for in the design and installation of the system with connection clearance zones (Figure A1.2).

1.5 Units of measure

Many standards specify maximum height limits for single stacks in values of ‘floors of fixtures’. Where maximum stack height values are listed in meters or feet, values will be converted to equivalent floors, with 3 m (9.8 ft) being equal to one floor.

Drainage loads are generally determined using either units of flow to represent the peak drainage flow expected to occur or by using dimensionless values such as the drainage fixture unit (DFU). To simplify comparisons between methodologies, ‘residential bathrooms’ will be used as a unit of measurement for loading, since this is both somewhat uniform and translates directly into operating installations. While the typical arrangement of fixtures in a residential bathroom varies widely internationally, the chosen arrangement for the comparisons here consists of a flush tank water closet, a combination bathtub/shower, and a basin.

[1] Also known as a lavatory or handwash basin

2 United Kingdom Primary ventilated stack

2.1 Regional context

With the introduction of BS EN 12056-2 in 2000 as the national drainage design standard, the term 'single stack' replaced with 'primary ventilated stack'. System III of EN 12056 reflects the traditional design and installation practices of the United Kingdom, with additional detail described in the appendices. System III requires unvented fixture drains to connect independently to the stack without grouping together into a common branch except under certain conditions where all fixtures are of the same type (e.g. groups of basins, groups of water closets). Accepted practice is to provide swept branch stack connections or wye branch connections. Design guidance is based on the branches achieving a filling degree of 100%, though this filling height is not reached in most observed installations. A minimum trap seal of 75 mm (3 inches) is required at basins to help mitigate issues with self-siphonage. Bottle traps and P-traps tend to be common at basins and washdown type water closets are prevalent. Drainage branches downstream of stacks may be designed for a filling height up to 75%, though 70% or 60% are also often used as a maximum design filling height. Additional guidance is given in Approved Document H [12] of the Building Regulations and in industry design publications such as *Guide G - Public health and plumbing engineering* [13] published by the Chartered Institution of Building Services Engineers (CIBSE) and *Plumbing Engineering Services Design Guide* [14] published by the Chartered Institute of Plumbing and Heating Engineering (CIPHE).

Under System III, fixture drains generally connect independently to the drainage stack. A typical bathroom, for example, would have three horizontal branch connections, one each for the WC, bathtub, and basin. The practice of joining the fixture drains together from basin and the water closet to make one stack connection has become more common. Swept connection fittings are used for branch connections to stacks. For the vertical to horizontal transition at the base of the stack, two 45° bends are recommended, with a single 90° long sweep fitting being acceptable as an alternative arrangement. Increasing the diameter at the bend is another alternative arrangement listed in Annex ND.

Prior to the introduction of BS EN 12056-2, the now withdrawn BS 5572 [15] standard set a maximum stack pressure differential of ±38 mm (1.5 inches) of water column, equivalent to ±375 Pa. BS 5572 indicates an association between 375 Pa (1.5 inches) and a water seal loss of 25 mm (1 inch) from a typical washdown water closet and 19 mm (0.75 inches) from a P-trap, with either a trap seal depth of 50 mm (2 inches) or 75 mm (3 inches).

2.2 Peak loads and height limitations

A DN 100 (4 inch) stack may flow up to 5.2 L/s (82 gpm), which is equivalent to 38 standard bathrooms or 19 stories with two bathrooms on each floor. While recommendations for height limits are missing from guidance documents, designers often recommend limiting the single stack to somewhere between 15 and 20 levels [16]. DN 150 (6 inch) stacks are used less often for single stacks.

2.3 Stack base

For single stacks greater than 5 stories in height, National Annex ND of BS EN 12056-2 recommends fixtures at the lowest level connect downstream of the stack. This is typically accomplished utilizing the stub stack configuration (Figure A1.3). A stub stack is an unvented DN 100 (4 inch) stack that serves fixtures located on the same floor and is capped at the top rather than vented to the atmosphere. A maximum flow 5.0 L/s (79 gpm) is allowed and is limited to a height of 2.5 m (8.2 ft) between the invert level of the horizontal drain and highest fixture connection (S1 in Figure A1.3). The water closet must not be greater than 1.5 m (4.9 ft) above the invert level of the horizontal drain (S2 in Figure A1.3). The stub stack configuration is also often used for fixtures located on the floor above a stack offset [17]. Guide G recommends a connection clearance zone of at least 2 m (6.6 ft) downstream of the stack base (Figure A1.2) when serving more than 5 floors. BS EN 12056-2 also recommends separating the lowest 2 floors from the main stack when serving more than 20 floors. Given that stub stacks may only serve one level of fixtures, stacks extending more than 15 to 20 floors will typically be provided with an secondary vented stack, which may also serve as the stack vent extension for the stack serving the lower 2 floors. For stacks below 5 stories, a vertical connection clearance of 0.74 m (2.5 ft) is given (V1 in Figure A1.2).

2.4 Branches and stack connections

Swept or 45° wye fitting connections are used in traditional practice for branch connections to the stack to limit the negative pressure produced in the stack during a discharge. Branch connections to the stack that have a comparatively small diameter, such as those from a basin or bathtub, may connect without a swept or 45° wye fitting.

The height, length, and gradient limits for the drainage piping between the fixture trap and the stack are indicated in EN 12056 for different fixture types for System III. Many fixture types have no limits on the length. For basins, only horizontal piping is allowed between the trap and the stack connection whereas all other fixture types allow vertical piping up to 1.5 m (4.9 ft). The maximum length between the trap and stack for basins is 3 m (9.8 ft) at a gradient of 1.8% with a minimum diameter of DN 40 (1.5 inch). Steeper gradients have shorter allowable lengths, as indicated in Figure 2.1. No more than 2 bends are permitted if the 3 m (9.8 ft) limit or 1.8% gradient is utilized.

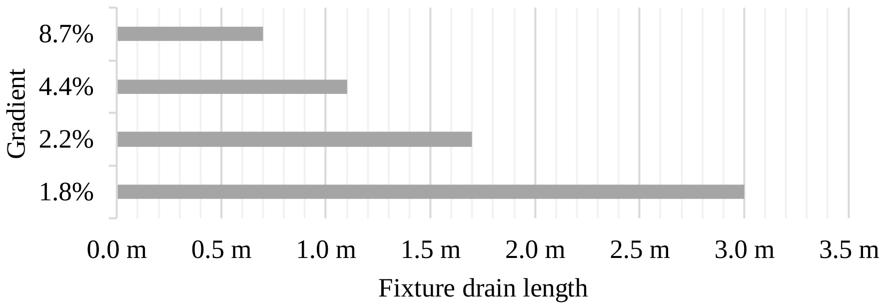

Figure 2.1 – Basin fixture drain length

No limit is indicated for bath/shower drains at DN 40 (1-1/2-inch), though a footnote in EN 12056-2 states that for drains longer than 3 m (9.8 ft), noisy discharges may result with an increased risk for blockages. The same footnote is indicated on kitchen sinks. Similarly, no limit is given for water closets, whether DN 80 (3 inch) or DN 100 (4 inch).

2.5 Stack offsets

A secondary vent stack is usually provided if fixtures connect to a stack below an offset. BS EN 12056-2 states that offsets less than 3 m (9.8 ft) can produce large pressure fluctuations.

3 Germany Hauptlüftung

3.1 Regional context

System I of EN 12056-2 is used in Germany with additional provisions and requirements featured in DIN 1986-100 *Drainage systems on private ground* [18] published by Deutsches Institut für Normung with guidance published in *Gebäude- und Grundstücksentwässerung* [19] published by Beuth Verlag. The single stack is the standard drainage configuration used in Germany. Secondary vent stacks or special aerator fittings are typically only installed in applications where the single stack is not expected to provide acceptable performance. DIN 1986-100 states that pressures within the drainage system must be maintained to limit the maximum water seal loss to 25 mm (1 inch). No specific pressure limits are indicated. As for typical fixture installations, bottle traps are generally installed at basins and washdown type water closets are most common.

The first edition of DIN 1986 was published in 1928 [20]. Unlike many other drainage standards published in the first half of the 20th century, installing a separate network of vent piping for each fixture trap was not required in the DIN 1986 standard. The 1932 edition [21] stated that traps were required to be installed as close as possible to the drainage stack and be protected from siphonage. The 1942 edition [22] featured a graphic showing a drainage stack for the water closet, a drainage stack for the bathtub, and a drainage stack shared between the sink and basin, with the only vent piping being the upper portion of the drainage stack where it terminates to the atmosphere above the roof. The current drainage values in DIN 1986-100 for stack loading match those in EN 12056. These values were informed by investigations at drainage testing facilities in Zürich in the 1980s and the original work of Wyly and Eaton [23] regarding drainage stack capacity [19].

3.2 Peak loads and height limitations

The DIN 1986-100 standard identifies limits on maximum drainage flow without specific reference to maximum stack height. Square branch connections are traditionally used in Germany, though swept branch connections are permitted as well and allow for higher maximum flow rates. The maximum drainage flow permitted for a DN 100 (4 inch) stack is 4.0 L/s (63 gpm), equivalent to 20 floors of residential bathrooms. If swept branch connection fittings are used, the maximum drainage flow is increased to 5.2 L/s (82 gpm) for a DN 100 (4 inch) stack, equivalent to 34 floors of bathrooms or 17 floors with two bathrooms per floor. A DN 150 (6 inch) stack may handle the load of 9.5 L/s (151 gpm), equivalent to 116 standard residential bathrooms. Due to the large negative pressures associated with tall stacks, the single stack is not often used for stacks greater than 100 m (328 ft), equivalent to 34 floors, though there is a lack of consensus and guidance on an appropriate maximum height.

The grouping together stack vents into a single header (Sammelhauptlüftung) is common for limiting the number of atmospheric terminations. The vent header size must have a cross-sectional area equal to at least half the total of the connected stacks. For example, a DN 150 (6 inch) stack has a cross sectional area equal to 167 cm^2 (26 in^2), and may serve as a vent for up to four DN 100 (4 inch) stacks, each having a cross-sectional area of 72 cm^2 (11 in^2).

3.3 Stack base

Fixtures on the lowest floor may connect to the drainage stack provided the stack is less than 10 m (33 ft) in height, equivalent to a stack serving 4 levels of fixtures. The height refers only to the drainage portion of the stack and not the vent extension. For stacks greater than 10 m (33 ft), fixtures at the lowest floor must connect at least 1 m (3.3 ft) downstream of the stack (H1 in Figure A1.2) and 1.5 m (4.9 ft) downstream of the stack for stacks taller than 22 m (72 ft), equivalent to a stack serving 8 floors of fixtures. Fixtures at the lowest floor may be provided with a bypass vent (Figure A1.6) or connect unvented to the horizontal drain downstream of the stack base clearance zone (Figure A1.4). In instances where there are no fixtures at the lowest level and the stack is greater than 22 m (72 ft), a bypass vent must still be provided, connecting between the drainage stack and horizontal drain. The vent connection to the drainage stack must also comply with the vertical clearance zone (V1 in Figure A1.2).

Table 3.1 – Connection clearance zone by stack height

Maximum Stack Height	Equivalent Floors	Minimum Connection Clearance Zone	
		V1	H1
10 m	≤ 4 levels	-	-
22 m	4 to 8 levels	2 m	1 m
≥ 22 m	≥ 9 levels	2 m	1.5 m

See Figure A1.2 for V1 and H1

The stack base transition is made with two 45° bends separated by a minimum of 0.25 m (0.8 ft) of diagonal drainage pipe. If the drainage stack is less than 22 m (72 ft) and the group of fixtures at the lowest floor are provided with a bypass vent, the 0.25 m (0.8 ft) separation between the 45° bends is not required. Stacks less than 10 m (33 ft) in height may use a single 90° bend for the vertical-to-horizontal transition, but this approach is not normally recommended due to lower acoustical and hydraulic performance.

3.4 Branches and stack connections

Unvented fixture drains and drainage branches DN 80 (3 inches) and larger must connect to the stack within 10 m (33 ft) of the furthest fixture. Unvented drainage branches less than DN 80 (3 inches) must connect to the stack within 4 m (13 ft) or to a drainage branch DN 80 (3 inches) or larger. The distance limitation accounts for both the horizontal distance and the vertical distance to the fixture (H and V in Figure A1.9). The vertical distance between the trap outlet and horizontal drainage branch must not exceed 1 m (3.2 ft). If the vertical distance is greater, the trap must be vented or provided with an AAV. DN 80 (3 inch) branches may be used to carry the drainage from both the WC, bathtub, and basin. The minimum slope for unvented branches is 1%.

3.5 Stack offsets

A connection clearance zone of 1 m (3.3 ft) must be maintained upstream and downstream of the horizontal-to-vertical transition of the stack offset (H2 and V2 in Figure A1.2). The horizontal-to-vertical transition must be made with two 45° bends. For stack offsets with a horizontal length less than 2 m (6.6 ft), fixtures must connect into a stack offset bypass (Figure A1.8) and connect at a minimum distance of 1 m (3.3 ft) below the horizontal-to-vertical transition. For stacks above 22 m (72 ft), a bypass vent is required regardless of whether fixtures are present at the lowest level.

4 Netherlands Primaire ontspanningsleiding

4.1 Regional context

NEN 3215 *Drainage system inside and outside buildings within the property boundaries* [24] is the national building drainage standard published by Netherlands Standardization Institute (NEN). NTR 3216 *Sewerage inside buildings* [25] provides additional guidance and commentary on the application of NEN 3215. The single stack drainage system (primaire ontspanningsleiding) is the typical drainage configuration used the Netherlands. Where the conditions for a single stack are determined to be insufficient, a secondary vent stack (secundaire ontspannings leiding) is required. Horizontal drains are designed to a maximum filling height of 70%. Comparatively shallow gradients are utilized on horizontal branches, with a gradient between 0.5% and 2% being allowed for a DN 100 (4 inch) drain within a bathroom or downstream of a stack. The requirements outlined in NEN 3215 are based on a maximum pressure differential of 300 Pa (1.2 inches of water column) and a trap seal depth of 50 mm (2 inches). Water closets flushing with less than 6 L (1.6 gal) are not permitted due to reduced carrying capacity in the drainage piping.

4.2 Peak loads and height limitations

NTR 3216 indicates a maximum flow of 4.0 L/s (63 gpm) for DN 100 (4 inch) stacks and 9.0 L/s (143 gpm) for DN 150 (6 inch) stacks with a height between 10 m (33 ft) and 50 m (164 ft), equivalent to the drainage of 19 and 99 residential bathrooms respectively. NTR 3216 provides additional guidance on the drainage loads with respect to the stack height with the standard flow values above being based on stack heights between 10 m (33 ft) and 50 m (164 ft). Adjustment factors are provided in Table 4.1 to reduce the maximum recommended allowable drainage loading for stacks greater than 50 m (164 ft) up to 200 m (656 ft), equivalent to 19 to 67 levels respectively. No adjustment factors are needed below 50 m (164 ft), though an allowance of 40% additional drainage flow is given for stacks less than 10 m (33 ft) in height.

A DN 100 (4 inch) stack may carry the loading of up to 19 bathrooms, effectively limiting the stack to serving 21 floors of residential bathrooms, with the lower two floors being separated from the stack (see section 4.3 regarding connection clearance zones). A DN 150 (6 inch) stack may receive the drainage of up to 38 floors of residential bathrooms, taking into account the stack height adjustment factor. Interpolating the values shown in Table 4.1 produces an adjustment factor for a 113 m (371 ft) stack of 0.63, reducing the maximum recommended drainage load a DN 150 from 9.0 L/s (143 gpm) down to 5.67 L/s (90 gpm), approximately equal to 38 residential bathrooms.

Table 4.1 Maximum drainage flow for single stack drains in high-rise buildings

Stack Height	Equivalent Floors	Adjustment Factor	
		DN 100 (4 inch)	DN 150 (6 inch)
55 m (180 ft)	18	1.00	1.00
60 m (197 ft)	20	1.00	1.00
70 m (230 ft)	23	0.96	1.00
80 m (262 ft)	26	0.82	0.93
90 m (295 ft)	30	0.72	0.81
100 m (328 ft)	33	0.66	0.72
110 m (361 ft)	36	0.57	0.65
120 m (394 ft)	40	0.51	0.59
130 m (426 ft)	43	0.47	0.53
140 m (459 ft)	46	0.43	0.49
150 m (492 ft)	50	0.39	0.45
160 m (525 ft)	53	0.36	0.42
180 m (590 ft)	60	0.32	0.36
200 m (656 ft)	66	0.28	0.32

Stack height as defined in NTR 3216 extends from the stack base to atmospheric termination of the vent. Stack vent extensions may be combined together into a vent header (gecombineerde ontspanningsleiding) to limit the number of atmospheric terminations, provided the total length and height is taken into account. Depending on the airflow resistance imposed by the length of piping and fittings, vent header segments may be 1 or 2 nominal diameters larger than the horizontal drain receiving the drainage from the stack [26]. Formulas are provided in NTR 3216 for determining airflow losses in the vent piping.

4.3 Stack base

The connection clearance zones near the stack base are dependent on the stack height. Table 4.2 shows clearances zones ranging from 1 m (3.3 ft) to 9 m (30 ft). Fixtures at the lowest level may connect downstream of the stack base clearance zone unvented (Figure A1.4). For stacks less than 50 m (164 ft), a height equivalent to 16 levels, unvented fixtures at the lowest level may connect 3 m (9.8 ft) downstream of the stack base. For example, a DN 150 (6 inch) stack in a 38 floor building will separate the lower 3 floors from the stack using a bypass stack configuration (Figure A1.7). The vent from the top of the bypass stack may terminate into the drainage stack using a wye branch fitting and must connect at least 9 m (30 ft) above the stack base, as required for stacks greater than 80 m (262 ft).

Table 4.2 – Stack Base Clearance Zone

Maximum Stack Height[2]	Equivalent Floors	Connection Clearance Zone at Stack Base
10 m (33 ft)	3	1 m (3.3 ft)
20 m (66 ft)	6	2 m (6.6 ft)
50 m (164 ft)	16	3 m (10 ft)
80 m (262 ft)	26	6 m (20 ft)
≥80 m (262 ft)	26	9 m (30 ft)

Note: Connection clearance zone at stack base refers to V1 and H1 (Figure A1.2)

4.4 Branches and stack connections

The maximum allowable distance of fixture drain (toestelleiding), measured between the trap and drainage branch (verzamelleiding) or stack, is 3.5 m (11.5 ft), including any vertical offsets (Figure A1.9). The vertical drop between the fixture trap and the stack (V in Figure A1.9) may be not more than 1.5 m (4.9 ft), otherwise vent piping or an AAV is required. Wye fittings are not permitted for unvented stack connections from branches, due to the tendency to create hydraulic closure conditions within the branch and potentially compromise trap seals.

4.5 Stack offsets

The stack base transition must be made with two 45° bends separated by 0.25 m (0.8 ft) of diagonal piping. Long or short sweep 90° bends are prohibited. Fixture drains and drainage branches at the offset level may connect into the horizontal segment between the upper and lower stack using a bypass vent configuration (Figure A1.6), provided that the connection is made outside of the connection clearance zones (aansluitvrije zone) between H1 and H2 (Figure A1.2). In cases where the combined H1 and H2 clearance zones are greater than the horizontal segment between the upper and lower stacks, fixture drains and drainage branches may connect into a stack offset bypass (Figure A1.8). The stack offset bypass must be equal to or greater than 0.8 times the diameter of the stack and connect at least 1 m (3.2 ft) below the horizontal-to-vertical transition of the lower stack and above the stack base of upper stack, in accordance with the connection clearance zones shown in Table 4.2 (H1 and V2 in Figure A1.2). Where a stack offset occurs, a stack offset bypass or bypass vent must be provided for the fixtures at the offset level. Fixture drains and drainage branches on levels below the stack offset may also connect unvented into the lower stack if a bypass vent is provided between the upper and lower stack and no drainage connections are made into the bypass vent. For stack offsets equal

[2] Stack height with respect to connection clearance zones refers to the distance between the stack base and highest drainage branch connection

to or less than 45° and not greater than 1.5 m (4.9 ft) in length, a clearance zone equal to 0.5 m (1.6 ft) must be maintained above the offset and 1 m (3.3 ft) below the offset.

5 Nordic region

5.1 Regional context

Harmonization efforts of the Nordic Committee for Building Regulations in the 1960s led to Sweden, Denmark, Finland, Norway and Iceland sharing a similar drainage design methodology, which are now independently issued as national standards with some regionally specific requirements. The single stack is the predominant drainage configuration used throughout the Nordic region. Many of the traditional design practices are reflected System II of EN 12056 though additional appendices are not provided for regional context on the Nordic approach. The EN 12056-2 standard is not widely used in Nordic region, instead utilizing regionally developed design standards. DS 432 [27] is used in Denmark and Byggvägledning 10 [28] is used in Sweden, both of which are the most predominantly used drainage standards in the Nordic region. When drafting EN 12056-2, Technical Committee CEN/165 Working Group 21 did not reflect the 50% branch filling height used in the Nordic region, instead indicating the 70% filling height used in the Netherlands, but managed to unify other criteria, such as many of the loading values for fixtures, branches and maximum branch length, under System II. A maximum pressure differential of ±400 Pa (1.6 inches of water column) is indicated in DS 432. Because the single stack system is assumed for design and installations, no name is given to differentiate the single stack from the secondary ventilated stack in either DS 432 or Byggvägledning 10. Air admittance valves (AAV) are common and bottle traps, P-traps, and S-traps are often used. Normflöde and summerade normflöden (standard flow and sum of standard flows) are used to determine peak drainage loads in units of flow using graphical charts. The equation and values for System II provided in EN 12056-2 achieve similar values. Basin drains often discharge into a common trap that also serves as a floor drain. Most water closets are dual flush, with the larger flush using 4 L (1.1 gal) and the smaller flush using 2 L (0.5 gal). A drainage branch gradient of 2% is typically used.

5.2 Peak loads and height limitations

DS 432 specifies a maximum stack loading equal to a cross-sectional area of 1/5th. This diverges from the 1/6th filling area that loosely formed the basis[3] for the values shown in EN 12056. DS 432 provides the Wyly Eaton stack formula along with roughness values to calculate the drainage capacity of the stack. In the case of the loading values for the DN 100 (4 inch) stack, this results in a loading of 4.2 L/s (67 gpm) if using cast-iron

[3] While 1/6th was agreed to serve as the basis for the values indicated in drainage loading Table 11 in EN 12056-2 for primary ventilated stack, the values arbitrarily diverge from the 1/6th in many instances to satisfy the recommendations of CEN Technical Committee 165 Working Group 21.

piping and 4.6 L/s (7.3 gpm) if using plastic or stainless-steel piping. From a drainage loading standpoint, a DN 100 (4 inch) stack receiving the drainage from residential bathrooms may serve up to 27 floors for cast-iron and 34 floors for plastic or stainless steel. The drainage allowance for a DN 150 (6 inch) stack is much higher than any realistic installation for a single stack, equivalent to the drainage of 300 residential bathrooms for cast-iron and over 600 residential bathrooms for plastic or stainless steel. No consideration is given to the effect of stack height with respect to maximum allowable drainage flow in DS 432 or Byggvägledning 10.

5.3 Stack base

DS 432 requires clearance zones upstream and downstream of the stack base of 1 m (3.3 ft) if one or more water closets is located more than 10 m (33 ft) above the stack base (V1 and H1 in Figure A1.2). The stack base transition is accomplished with two 45° bends or a long sweep 90° bend while a short sweep 90° bend may be used if the following specified conditions are met: If the stack does not contain more than 3 water closets, does not exceed 10 m (33 ft), and the V1 connection clearance zone (Figure A1.2) can be maintained for at least 2 m (6.6 ft), a short sweep 90° bend may be used for the stack base transition. Stacks with a height greater than 8 levels are provided with two 45° bends separated by a 0.3 m (1 ft) diagonal segment of piping at the stack base transition.

DS 432 features an unvented stack configuration (stående ikke-udluftede ledninger), similar to the stub stack, which is not often utilized since connection clearance zones are not required. A DN 100 (4 inch) unvented stack is limited to a height of 6 m (20 ft).

5.4 Branches and stack connections

While System II in EN 12056-2 allows for a filling height of 70%, DS 432 specifies that this is only applicable under circumstances where both sanitary drainage and storm drainage utilize the same piping. Under circumstances where only sanitary drainage loading is applied, a maximum filling height of 50% permitted. According to Byggvägledning 10, horizontal branch drains may be up to 10 m (33 ft) in length before connecting into the stack. In DS 432, maximum length limitations only apply for branches with a water closet with a flush volume less than 6 L (1.6 gal), in an effort to limit blockages (H in Figure A1.9). For WCs flushing with less than 6 L (1.6 gal), a maximum length of 10 m (33 ft) is allowed for branches (koblingsledninger) with a minimum gradient of 4% whereas branches with a minimum gradient of 2% are limited to a maximum distance of 3 m (9.8 ft). This requirement is unique in comparison to other design standards in that the steeper gradient is associated with a greater maximum length allowance rather than a shorter maximum length. In DS 432, DN 50 (2 inch) drains normally have a vertical drop allowance (V in Figure A1.9) of 2 m (6.6 ft) whereas DN 100 (4 inch) drains have a vertical drop allowance of 6 m (19.7 ft). In Byggvägledning 10, a maximum vertical drop of 2 m (6.6 ft) is allowed between the fixture and stack for DN 50 (2 inch) drains whereas 4 m (13 ft) is allowed for both DN 80 (3 inch) and DN

100 (4 inch) drains (V in Figure A1.9). DN 80 (3 inches) is the minimum diameter for a branch carrying the drainage of a water closet in DS 432 while Byggvägledning 10 requires a minimum of DN 100 (4 inches).

5.5 Stack offsets

For stacks with a height greater than 10 m (33 ft) in DS 432, equivalent to 3 levels, a 1 m (3.3 ft) connection clearance zone must be maintained for V1 and V2 (Figure A1.2). Two 45° bends are also required for the horizontal-to-vertical transition. No clearances are required for H2 or V2, unless a 90° short sweep bend is used, which may not contain more than one water closet and must maintain a clearance for H2 and V2 of 1 m (3.2 ft). Unvented fixtures and branches may connect below the horizontal-to-vertical transition as well as the horizontal section upstream, provided the connection clearance zones are observed.

6 South Africa Single stack

6.1 Regional context

SANS 10252-2 *Drainage installations for buildings* [29] is the code of practice for sanitary drainage systems in South Africa and features commentary and guidance for design and installation. The single stack is common in residential applications in South Africa. SANS 10252-2 limits the maximum pressure differential is 38 mm (1.5 inches) water gauge, equal to 372 Pa (1.5 inches of water column). A water seal of 75 mm (3 inches) is required at all fixtures except for water closets, which may have a minimum seal have 50 mm (2 inches). Fixture units are used to represent the maximum allowable loading for sanitary drainage piping. SANS 10252-2 also features an empirical equation and chart for converting fixture units into units of flow (L/min), though units of flow are not featured in any of the drainage sizing tables.

6.2 Peak loads and height limitations

The single stack design is prescriptive in SANS 10252-2 and provides a table indicating the maximum number of floors that may be served by a DN 100 (4 inch) and DN 150 (6 inch) single stack. A DN 100 (4 inch) stack may serve up to 10 floors of fixtures in residential applications. The maximum stack height, specified by the number of floors, is the limiting factor whereas the allowable loading for a DN 100 (4 inch) stack would otherwise be suitable for 61 floors of residential bathrooms. Increasing the diameter of the stack to DN 150 (6 inch) allows the stack to serve up to 30 floors.

6.3 Stack base

A horizontal connection clearance zone of 2.5 m (8.2 ft) must be maintained downstream of the stack base (H1 in Figure A1.2). The vertical connection clearance zone (V1 in

Figure A1.2) for a single stack extending up to 5 levels must be a minimum of 0.75 m (2.5 ft). For a single stack serving more than 5 stories in height, the fixtures on the lowest floor are required to discharge separately from the stack. It is recommended that stacks serving more than 20 floors maintain a clearance zone equal to two floors.

Two 45° bends are recommended at the vertical-to-horizontal transition of the stack base. In the case where a long sweep bend is used, the drain size must be a minimum of DN 150 (6 inches) to comply with a 0.3 m (1 ft) minimum radius requirement. In instances where the drainage load allows for a DN 100 (4 inch) stack but is increased to a DN 150 (6 inch) drain at the base to comply with the 0.3 m radius requirement, the horizontal drain may transition back to a DN 100 (4 inch) drain using an eccentric transition at a distance of 2.5 m (8.2 ft) downstream of the stack base (Figure A1.10).

The stub stack configuration (Figure A1.3) is typically used at the lowest floor. The South African stub stack is similar to the British stub stack with a few key differences. SANS 10252-2 allows up to two floors to discharge into a stub stack. A minimum of 0.45 m (1.5 ft) vertical distance between the WC and invert elevation of the horizontal portion of the drain is required in SANS 10252-2 (S2 in Figure A1.3). The fixture drain from a basin draining into a stub stack must not have a gradient greater than 4.4%, be longer than 3 m (9.8 ft), or have more than 2 bends with a radius of 75 mm (3 inches).

6.4 Branches and stack connections

Fixture drains connect independently to the stack unless they are of the same fixture type. Basin drains must be at least DN 40 (1.5 inch), though the trap may be DN 32 (1.25 inch). Horizontal drains from WCs must have a minimum gradient of 2.5% and a maximum of gradient of 25% whereas other fixture drain gradients must be a minimum of 2.2% and a maximum of 8.7%.

6.5 Stack offsets

SANS 10252-2 recommends avoiding offsets wherever possible. Where the horizontal-to-vertical transition occurs in a stack offset, a connection clearance must be maintained 0.45 m (1.5 ft) upstream on the horizontal drain (H2 in Figure A1.2) and 0.6 m (2 ft) below on the vertical stack (V2 in Figure A1.2). Fixtures may connect unvented into the horizontal drain between the clearance zones and below the V2 connection clearance zone.

7 People's Republic of China 伸顶通气

7.1 Regional context

The design and installation standards in the People's Republic of China are featured in GB 50015-2019 *Building Water Supply and Drainage Design Standard* [30], also known as the Jiànshuǐ (建水). Additional guidance and commentary are featured in the *Design Manual for Building Water Supply and Drainage* (设计手册建筑给水排水) [31] published by the China Architectural Design and Research Institute.

The single stack, known as extension ventilation (伸顶通气), is frequently utilized in China and is typical in residential buildings. The drainage stack capacity was originally based on flowing at 15% full, or 50% less than that of a stack flowing at 7/24th full, using the Wyly-Eaton Formula. Early investigations in 1973 in the Qiansanmen district in Beijing found pressures in the stack were occurring as high as 500 Pa (2 inches of water column), prompting the development of new methodologies for design [32]. Recommendations on single stack drainage design are continually updated in GB 50015 to reflect current research and testing. Current drainage load recommendations are informed by experimental test towers constructed to simulate transient airflow in drainage stacks, including an Shangxi Xuanshi Tower at over 60 m (197 ft) and the Vanke Tower at over 122 m (400 ft). The testing procedures for the drainage stacks are outlined in CJJ/T 245-2016 *Standard for capacity test of vertical pipe of the domestic residential drainage system* [33]. The test includes two procedures, one reflecting an instantaneous or 'burst flow' into the stack and the other reflecting a constant or steady flow. Washdown type and siphon type water closets were tested and the recommended standards were based on the siphon type water closet, due to having a greater instantaneous drainage flow during flushing. The constant flow method tests drainage flows with characteristics similar to the drainage from a shower, draining bathtub, or a basin. CJJ/T245-2016 states that the test results show that a negative pressure of 318 Pa (1.3 inches of water column) will result in a trap seal loss of 25 mm (1 inch) when using the instantaneous method.

Discharging multiple stacks to a single horizontal drain is uncommon in residential buildings. The horizontal drainage piping downstream of the stack and the drainage piping serving the lowest floor fixtures often discharge independently into an outdoor inspection chamber (Figure A1.5) before draining into DN 300 (12 inch) drainage piping around the perimeter of the building [34].

Vent covers are common at the atmospheric termination of the stack and provide protection against wind interference. One unique alternative to terminating the vent through the roof is the self-circulating stack configuration. This configuration returns the stack vent down to the horizontal drain downstream of the stack base. This is however not a typical approach and is only used in unusual circumstances. Air admittance valves are also generally not used.

7.2 Peak loads and height limitations

GB 50015 indicates the maximum drainage flow for each stack diameter. While the maximum drainage flow values were informed by tall testing towers, maximum stack heights are not specified. The drainage loading is calculated using an empirical square root equation (Equation B1.2). A DN 100 (4 inch) stack has a maximum drainage loading of 4.0 L/s (63 gpm), allowing a DN 100 (4 inch) stack to serve 23 levels of residential bathrooms. For bathrooms with a shower instead of a bathtub, this limit is equal to 33 levels of residential bathrooms. A DN 150 (6 inch) stack has a maximum drainage capacity of 6.4 L/s (101 gpm), allowing a loading equal to 97 residential bathrooms. DN 150 (6 inch) stacks are not often used due to the space requirements of the larger diameter piping. In the prior edition of GB 50015, the single stack was not recommended for residential buildings 10 stories or more in height. Updated values were introduced in the 2019 edition after testing [35] [36].

7.3 Stack base

The lowest floor fixtures may be installed without vent piping. Drainage connections may not be made within 1.5 m (5 ft) downstream of the stack base. The length between the furthest unvented fixture and the horizontal drain connection may not be greater than 12 m (40 ft). Additional limitations are given on the quantity of unvented fixtures in non-residential buildings that can be connected into the horizontal drain and must not exceed more than 5 water closets.

The connection clearance zone at the base of the stack is dependent on the number of floors served by the stack. Table 7.1 indicates the stack base clearance zones for various stack heights. Fixtures at the lowest floor may not connect to the stack if serving more than 13 levels. For stacks with a height between 7 and 12 floors, a connection clearance of 1.2 m (3.9 ft) must be maintained above the stack base. Stacks less than 4 floors in height must maintain a connection clearance zone of 0.45 m (1.5 ft). GB 50015 also provides clearance zone requirements for stacks with secondary ventilation, which are much less than those provided for the single stack. If the clearances cannot be met or if there is a 90° bend within 1.5 m (4.9 ft) measured horizontally from the stack base, the lowest level is required to discharge separately to an inspection chamber. The *Design Manual for Building Water Supply and Drainage* recommends using two 45° bends at the stack base or using a single 90° long sweep bend as an alternative.

Table 7.1 – Minimum vertical clearance between the stack base and lowest branch into the stack

Floors served by stack	Vertical connection clearance zone
	Extension ventilation
≤ 4	0.45 m (1.5 ft)
5 - 6	0.75 (2.5 ft)
7 – 12	1.20 (3.9 ft)
13 – 19	Lowest floor separate from drainage stack
>20	

Note: Refer to V1 in Figure A1.2

Another configuration for fixtures at the lowest floor is the bypass vent (Figure A1.6) for the group of fixtures at the lowest floor. The connects into the drainage stack with a wye branch fitting at least 2 m (6.6 ft) above the stack base (V1 in Figure A1.2). This bypass vent configuration is limited to use in residential buildings at the lowest floor.

7.4 Branches and stack connections

A swept branch connection to the stack is recommended over a wye branch connection. S-trap configurations from basins are acceptable. The minimum diameter of the drain from the WC is DN 100 (4 inches). DN 100 (4 inch) drainage branches have a minimum gradient of 1% but are typically installed at gradients equal to or greater than 2%. The intended peak filling height for drainage branches is 50%. There are no maximum length recommendations for drainage branches between the furthest fixture and the stack.

7.5 Stack offsets

Where a stack offset occurs, unvented drainage connections may be made below the horizontal-to-vertical transition provided a clearance zone of at least 0.6 m (2 ft) is maintained (V2 in Figure A1.2). No clearance zone is indicated for the horizontal-to-vertical transition (H2 in Figure A1.2).

8 Japan 伸頂通気

8.1 Regional context

SHASE-S 206-2019 *Plumbing Code* [37] is the plumbing standard used in Japan and published by The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan. Additional design specifications for the single stack, known as extension ventilation（伸頂通気）, are included in SHASE-S 218-2021 [38]. SHASE-S 206 was originally published as HASS 206-1967, which used a translation of the 1955 *American Standard National Plumbing Code* ASA-A40.8 [39] as a foundation. Subsequent editions included updates based on national research and testing efforts to improve the standard. Single stack method was first published in the 1982 edition of HASS 206.

Special drainage stack branch fittings（特殊継手）are common for stacks in tall buildings that would otherwise not be suitable as a single stack using standard drainage fittings. A minimum water seal of 50 mm (2 inches) is required for traps along with a maximum pressure differential of ±400 Pa (1.6 inches of water column). SHASE-S 218-2021 indicates a correlation of -410 Pa (1.65 inches of water column) with a water seal loss of 25 mm (1 inch), equal to the maximum allowable water seal loss. Vent covers are common at the atmospheric termination, which add additional airflow resistance but limit the influence of wind on the trap seals. DN 80 (3 inch) stacks with an auxiliary vent stack are historically common for stacks serving restrooms in residential buildings up to 14 floors [40]. Single stack drainage flow is based on a cross-sectional filling area of 18%. Guidance is provided in SHASE standards to ensure that pressures do not exceed ±250 Pa (1 inch of water column) for stack discharges and ±100 Pa (0.4 inches if water column) for drainage branch discharges. A maximum filling height of 50% is recommended for the horizontal drainage piping downstream the stack base where the single stack configuration is used to ensure adequate airflow.

8.2 Peak loads and height limitations

The 1991 edition of SHASE-S 206 limited the maximum height of the single stack to 30 m (98 ft). Investigations revealed that taller stacks could still provide adequate performance and this restriction was removed in the 2000 edition provided that the design could be proved by testing [37]. SHASE-S218-2021 provides direction validated by testing for stacks with more than 10 levels. Empirical equations are provided based on the branch connection type indicating the reduction factor to be applied to the standard maximum drainage flows to account for the increased airflow in stacks. Drainage flow reduction factors are only required for stacks with a height above 10 floors.

Equation 8.1

$$y = 3.18x^{-0.52}$$

Equation 8.2

$$Q_{pm} = yQ_p$$

y = increase/decrease rate value

x = story number, one story approximately 3 m (9.8 ft)

Q_p = Allowable design flow rate value (L/s)

Q_{pm} = Allowable design flow rate value in consideration of increase/decrease rate (L/s)

For example, a DN 100 (4 inch) single stack is given a maximum drainage flow of 3.88 L/s (61 gpm). Using the equation for a swept branch connection (Equations 8.1 and 8.2), a stack serving 19 floors will require a reduction factor of y =0.69, reducing the maximum drainage flow to 2.67 L/s (42 gpm), a flow with the drainage capacity for 19 residential bathrooms. A DN 150 (6 inch) single stack has a maximum flow of 11.4 L/s (181 gpm), allowing for 43 floors of residential units after applying the 0.521 reduction factor.

8.3 Stack base

The lowest floor fixtures are prohibited from connecting to the stack except where testing can prove the system will not result in the blowout of traps due to positive pressure. Fixtures may connect downstream of the stack base provided a connection clearance zone of 3 m (9.8 ft) is maintained (H1 in Figure A1.2). The horizontal drainage piping downstream of the stack base must continue straight for 3 m (9.8 ft) without bends to minimize hydraulic closure. Additional commentary is provided in SHASE-S 206 recommending a clearance zone of at least 10 m (33 ft) based on testing but acknowledges the impracticality of the additional horizontal piping required for compliance, deferring back to the 3 m (9.8 ft) clearance zone with a reasonable level of safety from water seal blowout from positive pressure.

8.4 Branches and stack connections

SHASE-S 206 suggests that the single stack configuration is best suited to applications where fixtures are in close proximity to the stack. Both swept branch fittings and wye branch fittings and are used for stack connections.

8.5 Stack offsets

Offsets are generally not permitted for single stacks unless vent piping is provided for the offset section or if there is minimal flow in the stack.

9 Singapore Single stack

9.1 Regional Context

Code of Practice on Sewerage and Sanitary Works (COPSSW) [41] is the national drainage standard in Singapore and is published by the National Water Agency (PUB). Most fixtures are required to discharge to a common trap from a floor drain (floor trap). These drainage connections occur in the vertical segment between the floor drain and the trap. The common trap has a minimum diameter of DN 100 (4 inches) with a minimum water seal of 50 mm (2 inches). Basins, showers, bathtubs, washing machines, and dishwashers discharge to common traps whereas kitchen sinks, urinals, and WC discharge to drainage piping connecting to the stack. A trap is still required at basins despite discharging into a common trap.

9.2 Peak loads and height limitations

The design approach for the single stack in COPSSW is comparatively prescriptive and limited in height by the number of floors served. DN 100 (4 inch) diameter stacks may be used only up to 4 floors, with the lowest floor connecting downstream of the stack base. DN 150 (6 inch) single stacks may serve up to 6 levels of residential bathrooms. Additional vent piping must be provided where installations cannot meet these requirements. Drainage flow is determined using the methodology outlined in EN 12056-2.

9.3 Stack base

Fixtures at the lowest floor are prohibited from connecting to the drainage stack. Both the horizontal drain downstream of the stack base and the drains from lowest floor fixtures discharge separately into an inspection chamber (Figure A1.5). The inspection chamber is provided with DN 100 (4 inch) vent piping and is vented to the atmosphere. The stack base transition is made using two 45° bends, separated by a diagonal segment with a length equal to 2 times the diameter of the stack e.g. 0.2 m (0.7 ft) for a DN 100 (4 inches).

9.4 Branches and stack connections

The maximum distance measured horizontally from the drainage stack is 2.5 m (8.2 ft). Swept branches or wye branches are suitable fittings for drainage stack connections. S-trap configurations are acceptable.

9.5 Vertical stack offsets

Vertical stack offsets are prohibited for single-stack configurations.

10 Australia & New Zealand Single stack

10.1 Regional context

AS/NZS 3500.2 *Plumbing and drainage Part 2: Sanitary plumbing and drainage* [42] is the standard used in Australia and New Zealand for the design and installation of sanitary drainage systems. Single stack configurations are not often used in residential applications in Australia and New Zealand though the configuration is available as an option within AS/NZS 3500.2. Sanitary drainage systems are designed to maintain a pressure differential within 375 Pa (1.5 inches of water column) of atmospheric pressure. Both P-traps and S-traps are common trap types at basins and washdown type water closets are used. The fixture unit methodology is used for estimating drainage load and determining drain diameter selections.

10.2 Peak loads and height limitations

A prescriptive approach is taken to the design of single stacks in AS/NZS 3500.2 and limitations are specified on the stack height, based on the number of floors served. For residential applications, DN 100 (4 inch) stacks are limited to 10 floors and DN 150 (6 inch) stacks are limited to 30 floors. The drainage loading allows for the equivalent of 43 residential bathrooms on a DN 100 (4 inch) stack and 130 residential bathrooms on a DN 150 (6 inch) stack.

10.3 Stack base

A connection clearance zone must be maintained at a minimum height of 0.6 m (2 ft) above the stack base (V1 in Figure A1.2). For stacks extending more than 5 floors in height, the clearance zone must be a minimum of 1 m (3.3 ft). For any stack where there is risk of excessive foaming of soap discharges from fixtures, the connection clearance zone must be a minimum of 2.5 m (8.2 ft). For stacks with 3 levels or more of fixtures, a 2.5 m (8.2 ft) clearance must be maintained downstream of the stack base (H1 in Figure A1.2). Stacks extending two stories or less must maintain a clearance zone of 0.5 m (1.6 ft) downstream of the stack base. Fixtures at the lowest floor may connect unvented into the horizontal drain downstream of the stack base, provided the connection clearance zones are observed.

The vertical to horizontal transition at the stack base is made with two 45° bends and a diagonal segment between the bends equal to twice the diameter of the horizontal drain in length (e.g. 200 mm (8 inches) for a DN 100 (4 inch) drain. A single 90° long sweep bend may be used alternatively provided the radius is at least 0.225 m (0.73 ft) for a DN 100 (4 inch) stack or smaller and at least 0.3 m (1 ft) for stacks larger than DN 100 (4 inches).

10.4 Branches and stack connections

Fixture drains connect either directly to the stack or through the common trap (4 way riser) of a floor drain (floor waste gully) without combining into a drainage branch. A shower or bathtub may omit a fixture trap if draining to a common trap within a length of 1.2 m (3.9 ft) from the fixture. A fixture trap is required at basins whether connecting into the drainage stack or a common trap. The length of drainage piping between a fixture trap and a common trap or stack must not exceed 2.5 m (8.2 ft) (H in Figure A1.9). Water closets may be installed up to 6 m (19.7 ft) from the stack if a DN 100 (4 inch) fixture drain is used, whereas water closets with a DN 80 (3 inch) fixture drain must be within the 2.5 m (8.2 ft) length requirement. The fixture drain from water closets must be installed at a gradient between 1.65% and 5% whereas the fixture drain from other fixtures must be installed at a gradient at least 2.5% to 5%. The maximum vertical drop from the fixture outlet must be within 1.5 m (4.9 ft) for basins and 2.5 m (8.2 ft) for other fixtures (V in Figure A1.9).

10.5 Stack offsets

Stack offsets must be separated by at least 2 m (6.6 ft) measured horizontally. A 0.9 m (3 ft) connection clearance zone is required above the stack base (V1 in Figure A1.2) or 2.5 m (8.2 ft) where foaming from soap is likely to occur and a 2.5 m (8.2 ft) connection clearance zone is required downstream of the stack base. For stacks with an offset, the total stack height may not exceed 10 levels and a maximum of 5 levels may be located above the stack offset. Only one offset may occur in the stack. The connection clearance zones for the horizontal-to-vertical transition are 0.45 m (1.5 ft) upstream (H2 in Figure A1.2) and 0.6 m (2 ft) downstream (V2 in Figure A1.2). Diagonal stack offsets at an angle of 45° or steeper require 0.6 m (2 ft) connection clearance zones above and below the offset for stacks up to 10 floors while stacks 5 floors or less may reduce the upper clearance zone to 0.45 m (1.5 ft).

11 Brazil Ventilação Primária

11.1 Regional context

The single stack (ventilação primária) is not often utilized in Brazil, instead favoring drainage stacks with an auxiliary vent stack and at least one fixture trap being vented in group of fixtures. NBR 8160 *Building sanitary sewage systems -design and installation* [43] is the national design standard used in Brazil and features two methodologies for calculating drainage flow. The drainage fixture unit methodology is utilized with many of the loading values republished from the 1955 *American Standard National Plumbing Code ASA A40.8*. The Hydraulic Method (Método Hidráulico) is featured in NBR 8160 as an alternate approach which allows the time interval between use of fixtures and drainage duration to be independently selected for predicting peak drainage loads with binomial distribution tables. The design loading criteria for the single stack design methodology is based on the Hydraulic Method and is distinct from the prescriptive approaches used by many other design standards in that the approach is performance based. Limited guidance is provided in NBR 8160 on appropriate statistical values to use. The values used for comparison here are based on values in the 2016 study [44] at the Federal University of Rio Grande do Sul comparing the Unidades de Hunter approach with Método Hidráulico[4].

The single stack design methodology is outlined in Annex C of NBR 8160 and features a series of formulas which are used to assess the sufficiency of the drainage stack to balance pressure differentials. This methodology was first introduced by Moacyr Graça at Polytechnic School of the University of São Paulo in 1985. Graça's method introduces empirical formulas and coefficients generalized for design purposes. This methodology accounts for stack height, peak drainage flow, wind speed, outdoor air temperature, thermal drawing of air into the stack, water seal evaporation, type of branch connections,

[4]Assuming a drainage duration of 10 seconds for a WC, 30 seconds for a basin, and 500 seconds for a bathtub with 60 minutes between uses and a failure rate of 1%

trap types, airflow pressure losses in the stack, stack length, vent length and various other factors. The minimum allowable trap seal depth in NBR 8160 is 50 mm (2 inches).

11.2 Peak loads and height limitations

To ensure no more than 25 mm (1 inch) of water seal is lost due to negative stack pressure, equations in Annex C indicate that negative pressure must be kept below 485 Pa (1.9 inches of water column) and positive pressure be kept below 970 Pa (3.9 inches of water column). Taking these considerations into account, a DN 100 (4 inch) may carry the drainage of 14 residential bathrooms, equal to a drainage flow of 5.61 L/s (89 gpm), resulting in an airflow of 40 L/s (102 cfm). A DN 150 (6 inch) may carry the drainage of 25 levels of residential restrooms, equal to a drainage flow of 8.46 L/s (134 gpm) resulting in an airflow of 97 L/s (247 cfm).

11.3 Stack base

For installations where foaming from soap may occur, a connection clearance zone (Zonas de sobrepressão) must be maintained within 40 diameters above the stack base and 10 diameters downstream. For a DN 100 stack (4 inches), this is equivalent to a length of 4 m (13.3 ft) upstream of the stack base (V1 in Figure A1.2) and 1 m (3.3 ft) downstream (H1 in Figure A1.2).

11.4 Branches and stack connections

No limits are specified for the length of drainage branches between the fixtures and the stacks. Fixtures within the bathroom, with the exception of the WC, typically discharge directly into a common trap (caixa sifonada) rather than having independent traps at each fixture. The common trap usually features a grate at the top and also serves as a floor drain. Connections to the stack are often made with non-orthogonally placed horizontal piping to limit the amount of bends.

11.5 Stack offsets

No guidance is given with respect to stack offsets in Annex C.

12 United States Single stack vent, Philadelphia single stack

12.1 Regional Context

Architect J. Pickering Putnam introduced the concept of a drainage stack with unvented fixture drains and branches at the AIA Convention in San Francisco in 1911 [45]. This configuration is installed in many buildings throughout Boston and Philadelphia built in the early 20th century and remains a common method used in Philadelphia today. Detailed sizing guidance was introduced for the single stack in the 1961 Philadelphia Plumbing Code (PPC) [46], specifying height and drainage loading limits using the Drainage Fixture Unit method developed by Roy B. Hunter of the National Bureau of Standards. Design guidance remains substantially similar in the 2018 edition [47]. A variation of the Philadelphia single stack is also featured in the International Plumbing Code (IPC) [48] and the Uniform Plumbing Code (UPC) as the single stack vent system [49]. Fixture traps must be protected from pressure differentials exceeding 25 mm (1 inch) water column, equal to 250 Pa in the IPC, UPC and PPC. Siphonic type water closets represent a majority of water closet installations in the US and P-traps are the most common trap type at fixtures. S-traps are generally prohibited except in single stack installations.

Building traps are typically required in the PPC, effectively isolating pressure systems of the building drainage system from the sewer system. A vent is required at the upstream side of the trap for buildings 22 m (75 ft) in height or greater. The vent for the building trap must be at least DN 100 (4 inches). The UPC lists the single stack in the Appendix C, subjecting usage to discretionary approval in regions that have adopted UPC as the plumbing code.

12.2 Peak loads and height limitations

The single stack described in US plumbing codes indicate maximum drainage loads, measured in drainage fixture units (DFU), and stack height. Maximum DFU for various stack diameters and stack heights are indicated in a table featured in all three codes. Due loading limitations for DN 100 (4 inch) stacks above 23 m (75 ft), the single stack is effectively limited to serving 7 floors of residential bathrooms. DN 150 (6 inch) stacks greater than 23 m (75 ft) are practically limited only by the maximum DFU value indicated in a sizing table, allowing a stack to serve up to 45 floors of residential bathrooms. For stacks over 30 stories in height, velocity breakers, consisting of four 45° bends, are required along the drainage stack. Velocity breakers must be installed at intervals of 10 floors.

There is a general requirement to provide an auxiliary vent stack for stacks above 5 stories in the IPC and for stacks above 10 stories in the UPC, with no exception noted when utilizing the single stack drainage system, despite noting an exception for another drainage stack configuration in the IPC[5]. This may have been an unintentional omission in the IPC and UPC codes given the single stack in the PPC only requires a vent stack in instances where separate fixture venting is already required, and the stack is greater than 5 stories[6]. There is however disagreement on the verbiage regarding auxiliary vent stack requirements in the PPC leading some to interpret the requirement to apply to all stacks above 5 stories and not limited to stacks with fixtures that already have vent piping.

[5] Section 904.2, 2021 International Plumbing Code
[6] Section P-919.3.4, 2018 Philadelphia Plumbing Code

12.3 Stack base

A vertical clearance zone (V1 in Figure A1.2) at the stack base is not required for the single stack in the PPC and the lowest floor is typically connected to the drainage stack. In the IPC and UPC, stacks serving 3 or more floors must separate the lower two floors from the stack and connect at least 10 diameters downstream of the stack base (e.g. 1 m (3.3 ft) for a DN 100 (4 inch) stack). This requirement effectively limits the single stack to serving 2 floors, since the lower stack will require a stack vent which must have an atmospheric termination to the exterior, usually at the roof level. This requirement is revised in the 2024 UPC and allows a bypass vent for the lowest floor fixtures. Also included in the revision was the allowance of fixtures on the second level above the stack base to connect into the drainage stack, provided the stack is not greater than 22 m (75 ft) in height.

A single 90° long sweep bend is typically installed at the stack base while short sweep bends are also sometimes used. Two 45° bends are also used but are less common and not required. Records from City of Philadelphia indicate that two 45° bend-fittings were recommended at the stack base, however, this requirement was not explicitly stated in the historic or current PPC.

12.4 Branches and stack connections

Custom manifold branch fittings, known as Merion fittings and feature multiple inlets in one branch fitting, have traditionally been used with single stack installations in Philadelphia, though standard swept branch fittings and wye branch fittings are most common in current installations. Water closets must be installed within a horizontal length of 2.4 m (8 ft) from the drainage stack while other fixtures may be up to 3.7 m (12 ft) from the drainage stack. The S-trap is permitted in the Philadelphia single stack while the IPC and UPC version requires S-trap fixture drains with diameters less than DN 50 (2 inches) to increase in size at the vertical segment (V in Figure A1.9) to a minimum of DN 50 (2 inches), in an effort to reduce siphonage.

12.5 Stack offsets

Unvented fixtures may not connect downstream or below stack offsets for single stacks serving more than 3 floors.

13 Review

13.1 Peak loads and height limitations

DN 100 (4 inch) single stacks are not often recommended for buildings receiving the drainage from more than 20 stories. The maximum recommended height ranges from 4 floors in COPSSW (Singapore) to 21 floors in NTR 3216 (Netherlands) with most other standards recommending limits between this range or featuring little guidance on the subject of stack height. The methods NTR 3216 and SHASE-S 218 (Japan) allow a DN 150 (6 inch) stack to serve 38 and 43 stories of residential bathrooms respectively while SANS 10252-2 and AS/NZS 3500.2 establish a prescriptive limit of 30 stories. Many other design standards and guides recommend either much shorter heights or recommend drainage loadings well beyond what would typically be considered acceptable if applied to a tall residential building serving one bathroom per floor.

Maximum allowable pressure differentials tend to fall between 250 Pa (1 inch of water column) to 400 Pa (1.6 inches of water column). A majority of the standards and recommendations reviewed here specify a water seal loss not to exceed 25 mm (1 inch) as a basis for performance of siphonage protection. There is disagreement between the reviewed standards on the pressure differentials associated with the loss of various trap seal heights. The precision of these specified values may not carry significance given that pressure differential testing is rarely conducted at the completion of new drainage installations in buildings and the actual failure rates are not well established.

13.2 Stack base

A variety of methods are used to protect the fixtures at the lowest floor from the pressure conditions near the stack base. An unvented stack may serve the lowest floor or lowest two floors of fixtures while a bypass vent connecting into the drainage stack from the group of fixtures is also a suitable configuration. Other methods consist of connecting unvented drains downstream of the stack base connection clearance zone. Providing a separate network of drainage piping serving only the lowest floor is also a strategy used. Some standards such as the Philadelphia Plumbing Code and DS 432 and Byggvägledning 10 allow connections near the base of the stack.

The characteristics of the stack base transition account for significant pressure differentials and are addressed with special restrictions in various standards. Some standards limit the allowable stack height when a single long sweep bend is used instead of two 45° bends separated with a short distance of piping. A majority of standards reviewed here recommend two 45° bends over a single 90° bend, with the US codes being an exception.

13.3 Branches and stack connections

Some standards such as BS EN 12056-2, AS/NZS 3500.2 and SANS 10252-2 generally recommend fixture drains connect independently to the drainage stack whereas other standards allow fixture drains to discharge into a drainage branch connecting into the drainage stack. A majority of standards allow the S-trap configuration from the basin while some such as BS EN 12056-2 require the fixture drain to connect horizontally to the stack without any vertical segments downstream of the trap. Many standards indicate a maximum horizontal or vertical distance between the fixtures and stacks whereas others do not. Preferred stack connection fitting type vary depending on region.

13.4 Stack offsets

Many methods prohibit unvented connections at or below stack offsets or do not provide clear direction on accommodating pressure conditions, while some such as DIN 1986-100, NEN 3215, and SANS 10252-2 provide extensive detail on the subject of stack offsets.

13.5 Summary

While the recommendations provided in design standards do not provide conclusive insight into the complex interactions of airflow and drainage flow in single stack configurations, a review of various recommendations may stimulate discussion regarding existing guidance and support further research and testing procedures. Applying the principles of fluid mechanics to single stack design guidance remains a challenging undertaking but significant opportunities remain for optimization and improved performance.

Acknowledgements

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References

[1] M. Gormley, "Myths and Legends: Developments towards modern sanitary engineering," in *CIB W062 International Symposium for Water Supply and Drainage for Buildings*, Brno, Czech Republic, 2007.

[2] A. F. E. Wise, "One-Pipe (Single Stack) Plumbing for Housing: (Part I)," Building Research Station Digest, London, 1952.

[3] A. F. E. Wise, "One-Pipe (Single Stack) Plumbing for Housing: Part II - Principles of Design," Building Research Station Digest, London, 1952.

[4] M. S. T. Lillywhite and A. F. E. Wise, "Towards a general method for the design of drainage systems in large buildings," *Journal of the Institution of Public Health Engineers,* vol. Volume 68, no. no. 4, pp. 239-270, 1969.

[5] BS EN 12056-2 - Gravity Drainage systems inside buildings, British Standards Institute, 2000.

[6] R. Hanslin, "Toward a European harmonised code of practice for drainage installations inside buildings," in *CIB W062 International Symposium for Water Supply and Drainage for Buildings*, Brussels, 1991.

[7] K. De Cuyper, "Toward a standardised code of practice for the drainage systems inside European buildings," in *CIB W062 International Symposium for Water Supply and Drainage for Buildings*, Porto, 1993.

[8] J. Swaffield, Transient Airflow in Building Drainage Systems, London: Spon Press, 2010.

[9] P. White, "Filling the gap in guidance on drainage in residential high-rise," 7 July 2008. [Online]. Available: https://www.building.co.uk/filling-the-gap-in-guidance-on-drainage-in-residential-high-rise/.

[10] J. French and H. Eaton, "Self-siphonage of Fixture Traps," National Bureau of Standards, Washington, D.C., 1951.

[11] J. A. Swaffield and A. F. E. Wise, Water, Sanitary and Waste Services for Buildings, 5th Edition, London: Routledge, 2002.

[12] Approved Document H - Drainage and waste disposal, London: The Building Regulations, 2010.

[13] Guide G - Public Health and Plumbing Engineering, London: The Chartered Institution of Building Services Engineers, 2014.

[14] Plumbing Engineering Design Services Design Guide, Hornchurch: Chartered Institute of Plumbing and Heating Engineering, 2002.

[15] BS 5572 - Code of practice for sanitary pipework, London: BSI, 1994.

[16] J. Daureeawo, "Performance Testing of Drainage Systems & Components," Vortex, London, 2020.

[17] J. Lansing, "A Comparison of British and American Plumbing Engineering Standards and Practices," World Plumbing Council, Zurich, 2020.

[18] DIN 1986-100 Entwässerungsanlagen für Gebäude und Grundstücke - Part 100: Provisions in conjunction with DIN EN 752 and DIN EN 12056, Berlin: Beuth Verlag, 2016.

[19] Gebäude- und Grundstücksentwässerung, Berlin: Beuth Verlag, 2016.

[20] DIN 1986 - Bau und Betrieb von Grundstücksentwässerungsanlagen, Berlin: Beuth-Verlag, 1928.

[21] Technische Vorschriften für den Bau und Betrieb von Grundstücksentwässerungsanlagen, Berlin: Beuth-Verlag, 1932.

[22] Technische Vorschriften für den Bau und Betrieb von Grundstücksentwässerungsanlagen, Berlin: Beuth-Vertrieb, 1942.

[23] R. S. Wyly and H. N. Eaton, "Capacity of stacks in sanitary drainage systems for buildings, Monograph 31," National Bureau of Standards, Washington, D.C., 1961.

[24] NEN 3215 - Drainage system inside and outside buildings, Delft: Nederlands Normalisatie Instituut, 2018.

[25] NTR 3216 Riolering van bouwwerken, Rotterdam: ISSO, 2019.

[26] N. Post, "Wijzigingen in NEN 3215 en NTR 3216," *TVVL Magazine,* pp. 30-33, 2019.

[27] "DS 432:2020 Wastewater Installations," Dansk Standard, Nordhavn, Denmark, 2020.

[28] Byggvägledning 10, Vatten och avlopp, Stockholm, Sweden: Svensk Byggtjänst, 2018.

[29] SANS 10252-2 Water supply and drainage for buildings Part 2: Drainage installations for buildings, Pretoria: The South African Bureau of Standards, 1993.

[30] GB 50015-2019 Standard for design of building water supply and drainage, Beijing: China Planning Press, 2019.

[31] Design Manual for Building Water Supply and Drainage, Beijing: China Architecture Design & Building Press, 2019.

[32] Z. Shiming, "Factors influencing stack capacities in single stack system," CIB W062 International Symposium for Water Supply and Drainage for Buildings, Yokohama, 1997.

[33] CJJ/T245-2016, Beijing: China Building Industry Press, 2016.

[34] H. Xiè, "Study on the American Building Water Supply and Drainage Design," *Building Water and Wastewater Engineering,* vol. 10, no. 4, pp. 41-47, 2022.

[35] J. Zhang, "建筑给水排水设计标准热点问题研讨," *Water Field,* vol. 6, no. 156, pp. 36-44, 2020.

[36] J. Zou and Q. Xie, "About the standard for design of building water supply and drainage(version 2019) - Discussion on the design of drainage system," *Building Water and Wastewater Engineering,* vol. 8, no. 4, pp. 87-91, 2019.

[37] SHASE-S 206-2019 Plumbing Code, Tokyo: The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, 2019.

[38] SHASE-S 218-2021 Testing Methods of Flow Capacity for Drainage Stack System, Tokyo, Japan: The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, 2021.

[39] ASA A40.8-1955 American Standard National Plumbing Code, New York City: American Society of, 1955.

[40] T. Abe, M. Otsuka, M. Itabashi and N. Ono, "Proposal of Drainage Performance Upgrading Method for Domestic Wastewater Drainage Stack Systems for High-Rise Apartment Housing Stocks," in *CIB W062 International Symposium for Water Supply and Drainage for Buildings,* Taichung, 2022.

[41] Code of Practice on Sewerage and Sanitary Works, Singapore: PUB, 2019.

[42] AS/NZS 3500.2:2021 Plumbing and drainage Part 2: sanitary plumbing and drainage, Standards New Zealand, Standards Australia, 2021.

[43] NBR 8160, Rio de Janeiro: Associação Brasileira de Normas Técnicas, Sistemas prediais de esgoto sanitário - Projeto e execução.

[44] D. S. Feloniuk, "Sistemas prediais de esgoto sanitário: estudo comparativo de dimensionamento pelos métodos hidráulico e das unidades de hunter de contribuição," Departamento de Engenharia Civil da Escola de Engenharia da Universidade Federal do Rio Grande do Sul, Porto Alegre, 2016.

[45] J. P. Putnam, Plumbing and household sanitation, Garden City: Doubleday, Page &, 1911.

[46] Rules and Regulations Relative to the Construction of Plumbing or House Drainage in the City of Philadelphia, Philadelphia: City of Philadelphia, 1961.

[47] Philadelphia Plumbing Code 2018, Country Club Hills: International Code Council, 2018.

[48] 2021 International Plumbing Code, Country Club Hills: International Code Council, 2020.

[49] 2021 Uniform Plumbing Code, Ontario: International Association of Plumbing and Mechanical Officials, 2020.

Appendix A – Supporting Figures

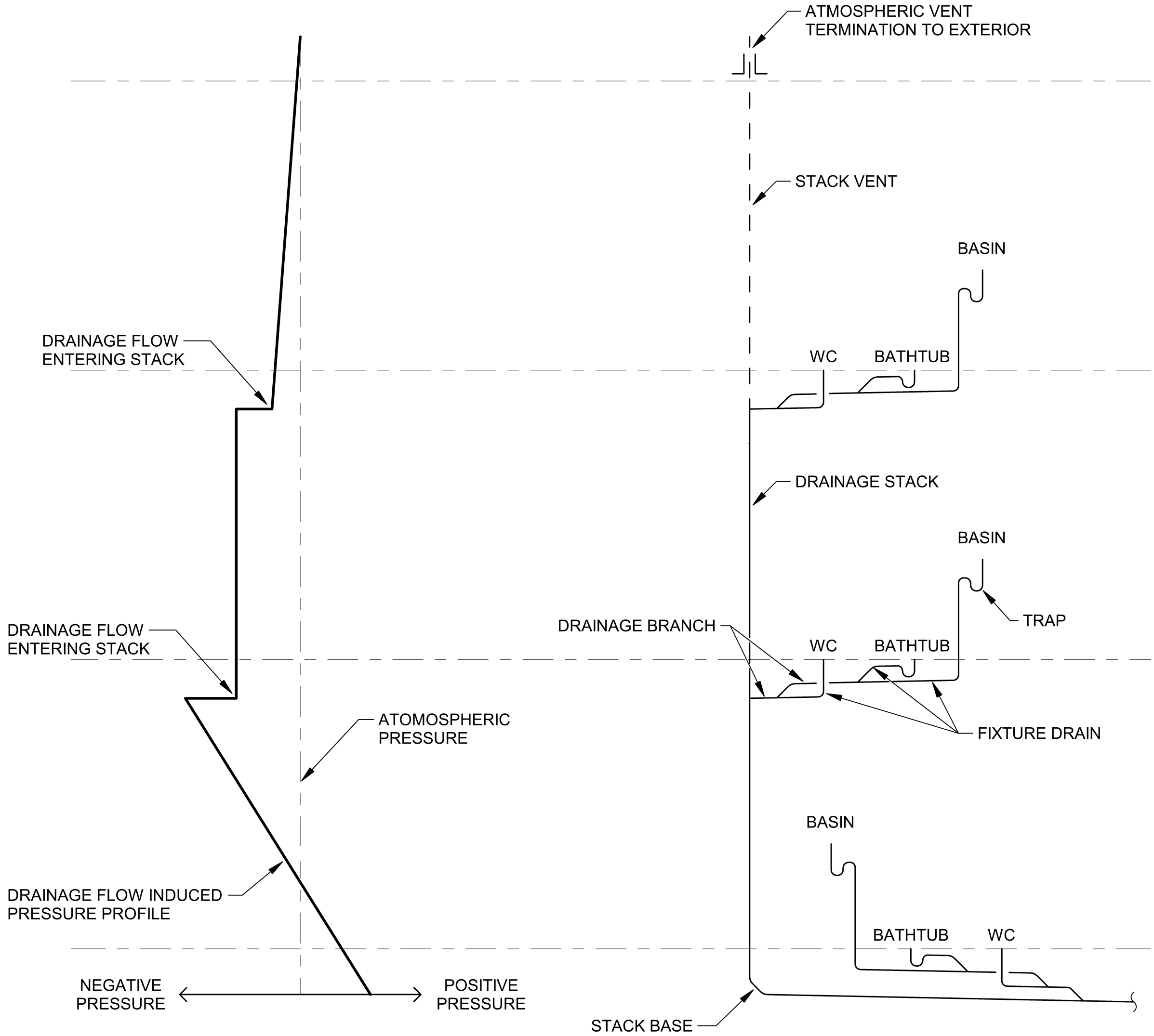

Figure A1.1 – Example of a single stack configuration and pressure profile

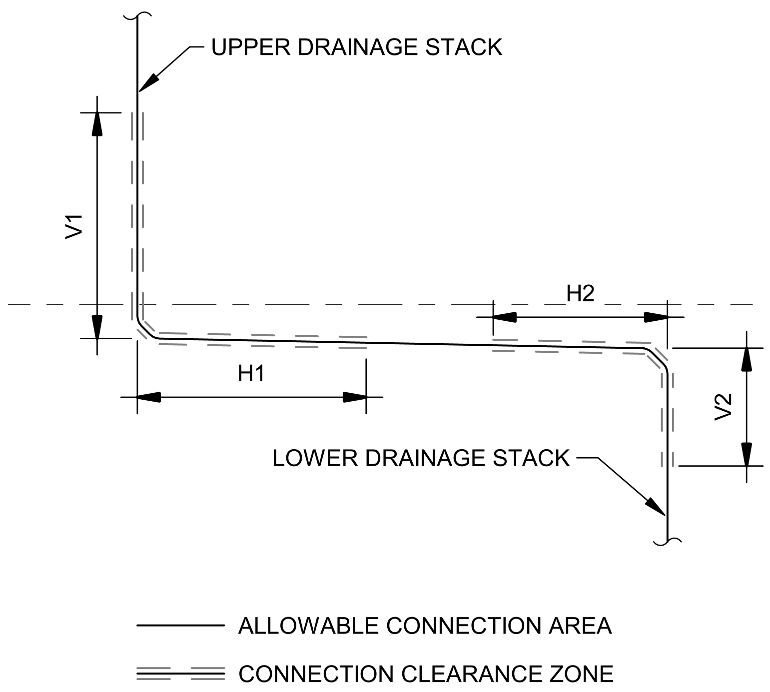

Figure A1.2 – Drainage stack connection clearance zones

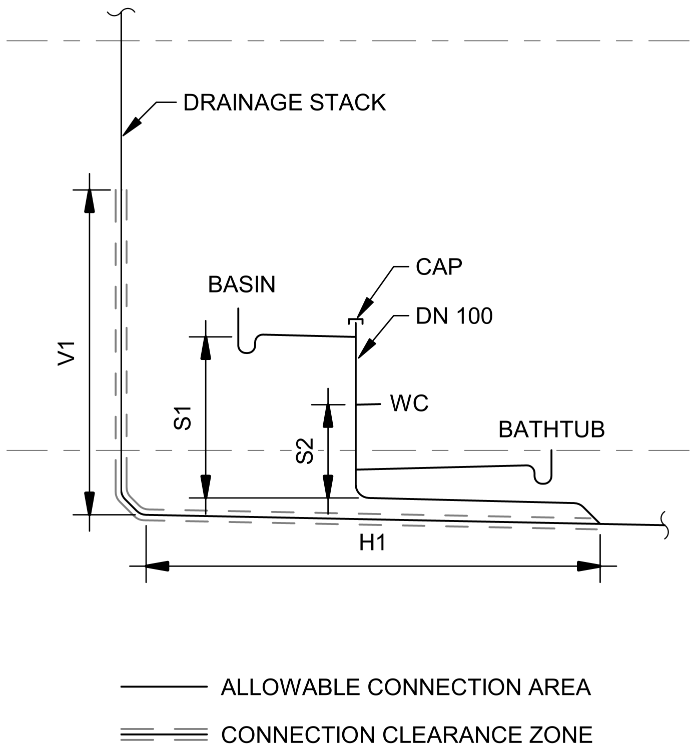

Figure A1.3 – Stub stack

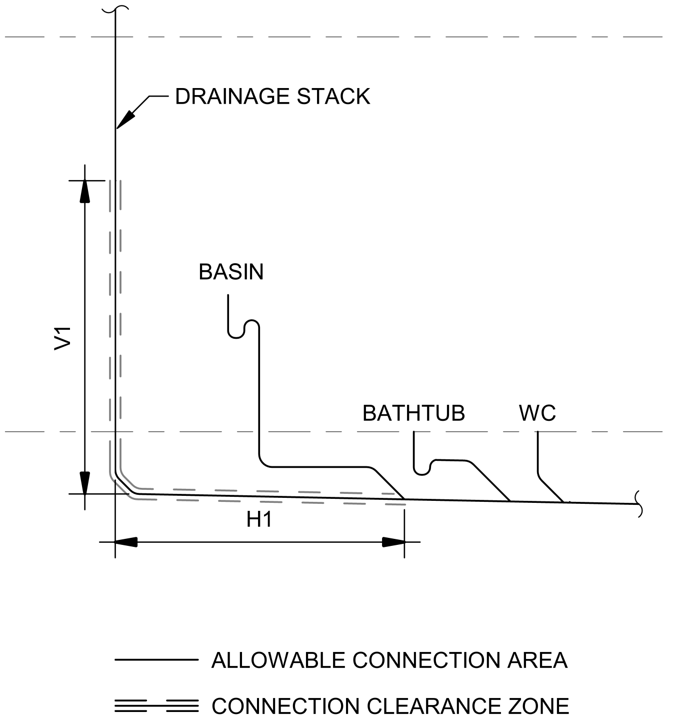

Figure A1.4 – Unvented fixtures at lowest floor

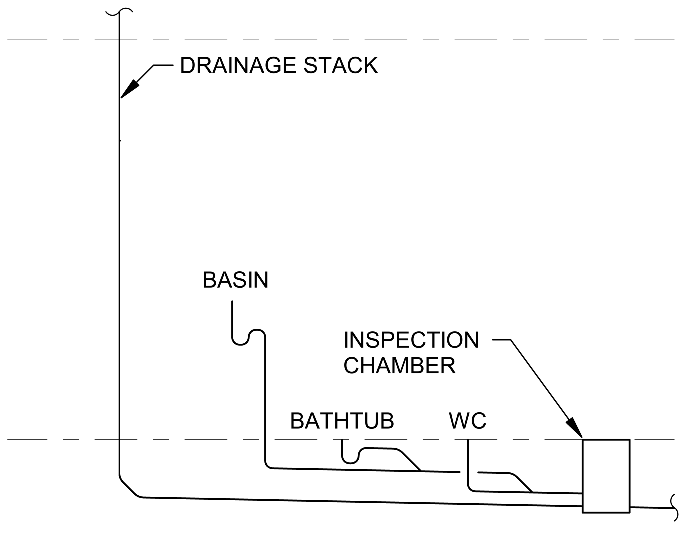

Figure A1.5 – Inspection chamber for lowest floor fixtures

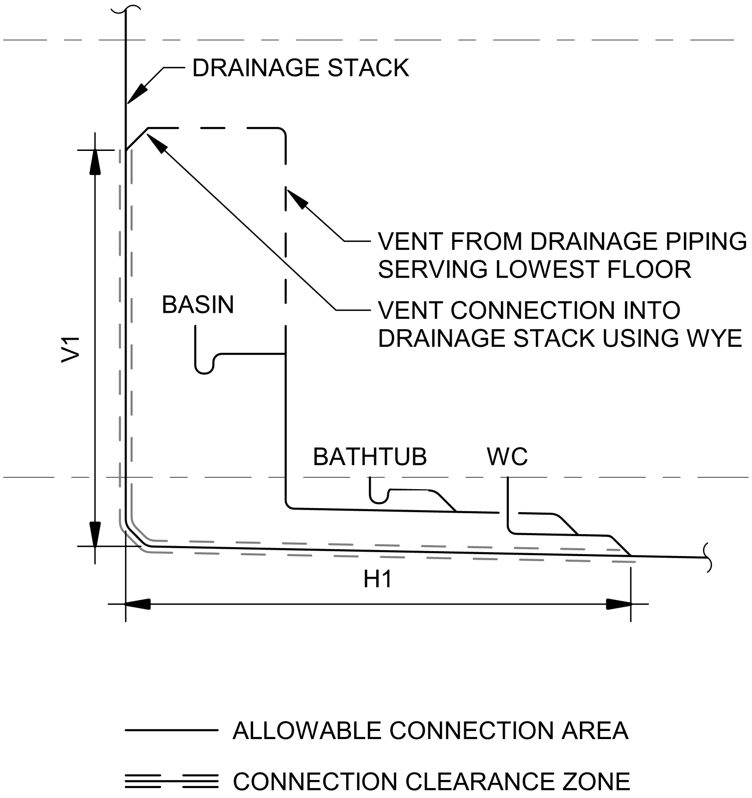

Figure A1.6 – Bypass vent

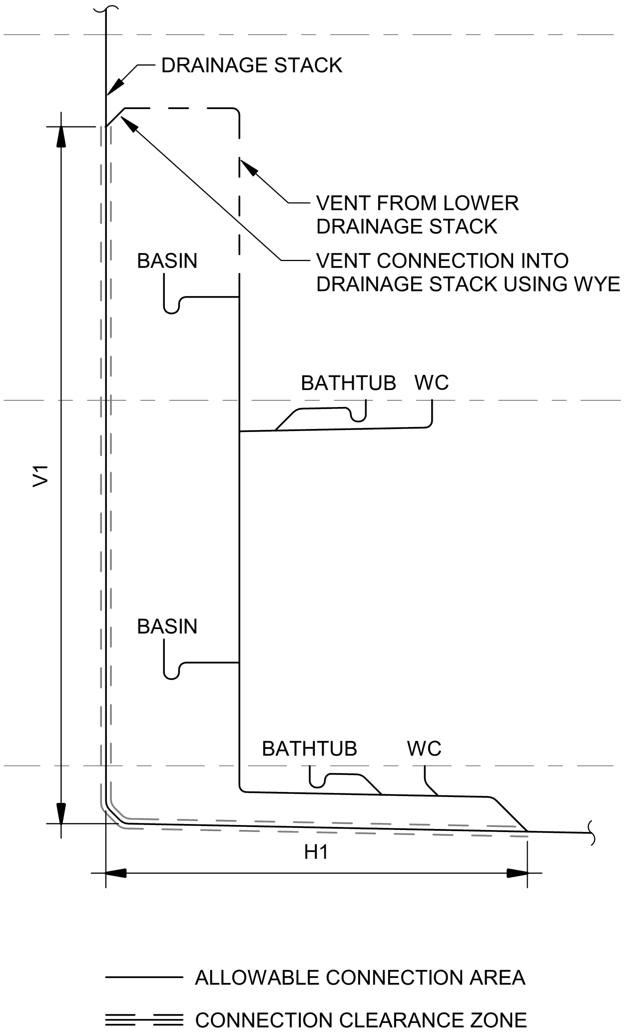

Figure A1.7 – Bypass stack

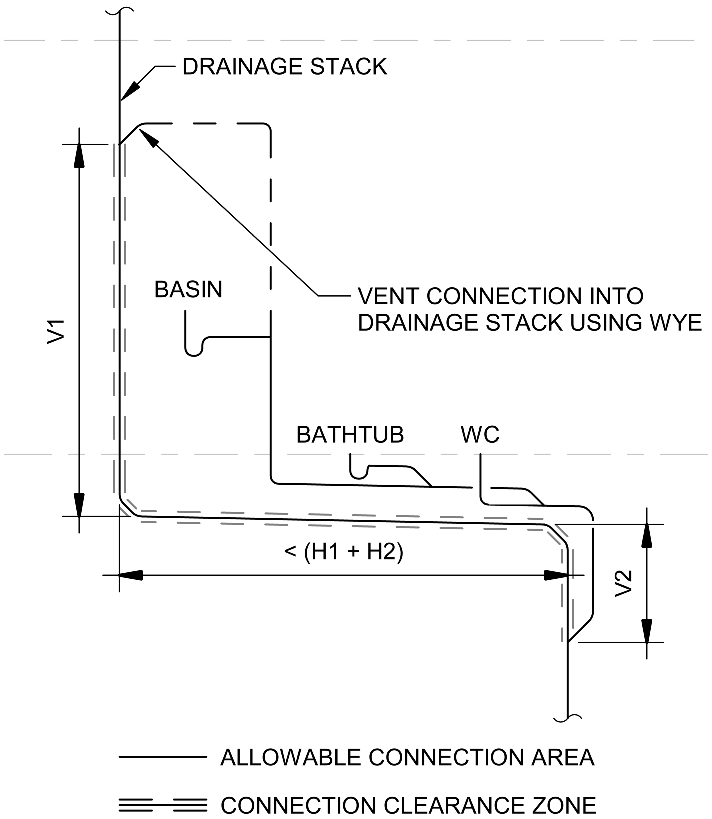

Figure A1.8 – Stack offset bypass

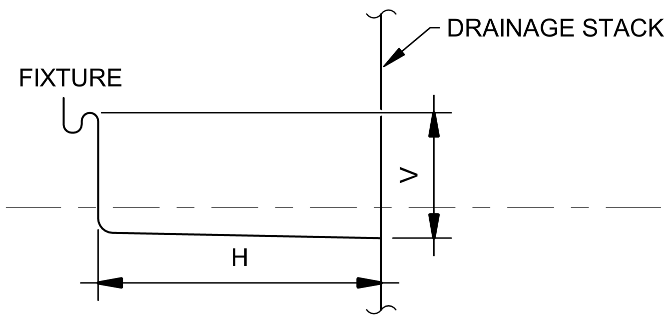

Figure A1.9 – Branch length and height limitations

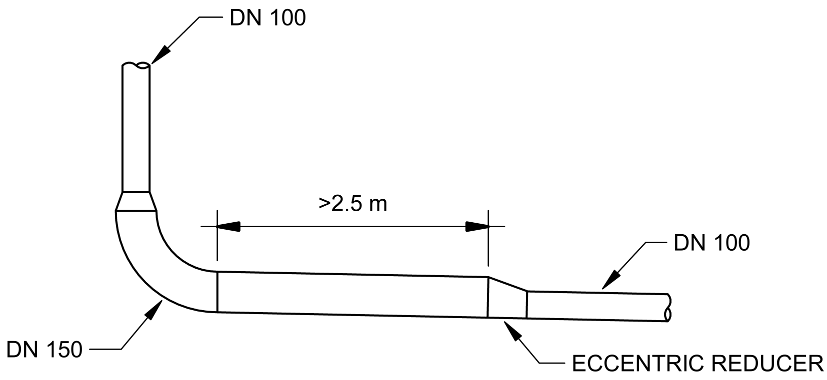

Figure A1.10 – Stack base long sweep configuration

Appendix B – Supporting Equations

Equation B1.1 – Loading calculation in EN 12056

$$Q_{ww} = K\sqrt{\Sigma DU}$$

Q_{ww} = waste water flowrate (L/s)

K = Frequency factor

ΣDU = Sum of discharge Units

Equation B1.2 – Loading calculation in GB 50015

$$q_p = 0.12a\sqrt{N_p} + q_{max}$$

q_p = Drainage design flowrate (L/s)

N_p = Sanitary appliance drainage equivalent value

a = Building type coefficient

Presentation of Author

John Lansing is a lead plumbing designer at PAE in Portland, Oregon. John specializes in applying sustainable solutions to plumbing systems and research on international engineering design guidance. He also serves on the technical committees for the IAPMO Water Efficiency and Sanitation Standard (WEStand) and the ICC 815 Standard for Sizing Water Distribution Sanitary Drainage and Vent Piping Systems.