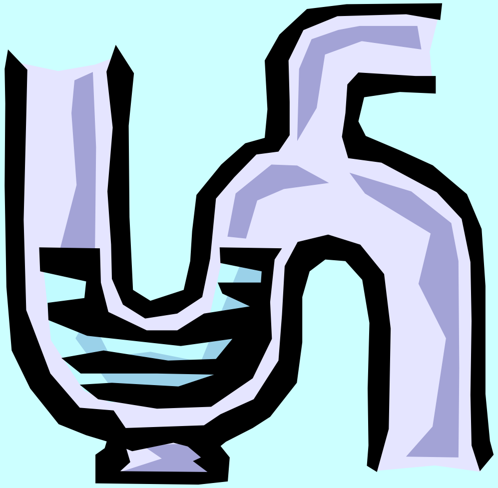
MEBS6000 Utility Services

http://www.hku.hk/mech/msc-courses/MEBS6000/index.html



Sanitary and Stormwater Drainage

Dr. Sam C M Hui

Department of Mechanical Engineering

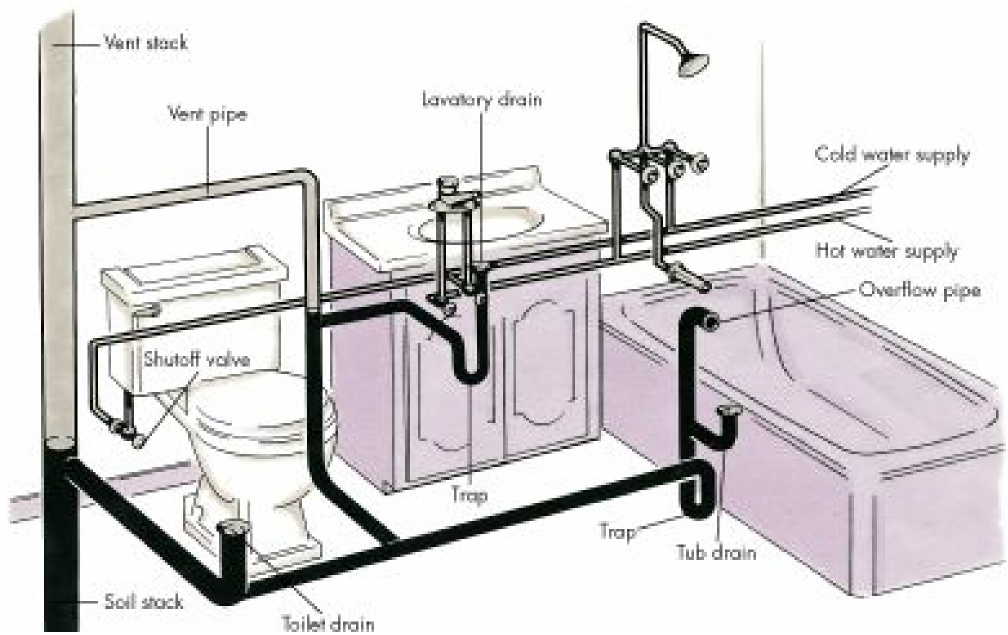
The University of Hong Kong

E-mail: cmhui@hku.hk

Mar 2009

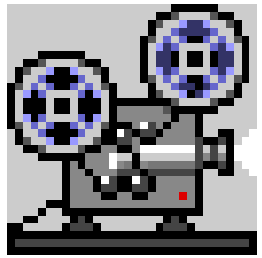
Contents

- Design practices
- Sanitary drainage
- Stormwater drainage



Design practices

- Video presentation: "Drainage" [28 min.]
  - The evolution history in the UK
  - Current practices:
    - Problems of siphonage and the use of traps
    - Two pipe and single stack systems
    - Combined and separate drainage systems
    - Modern pipework and fittings
    - Trenches and pipe protection
    - Inspection chambers
    - Building regulations
  - Modern sewage treatment plant



This gives an overview of the design issues for drainage systems.

Design practices

- Design of drainage systems
  - Sanitary fitments
  - Above ground drainage
  - Below ground drainage (+ sewage disposal)
- Aim: To remove waste, foul & surface water
  - Waste water (廢水) = basins, sinks, baths, showers
  - Soil or foul water (髒水) = from toilets or W.C.
  - Surface water (地面水) = rainwater or stormwater
- Systems will last as long as the building!!

Plumbing system (water supply)

Sanitary fitments

Rainfall, surface water & stormwater

Above ground drainage

Sometimes, sump & pump system is required for disposal e.g. in basement

Below ground drainage

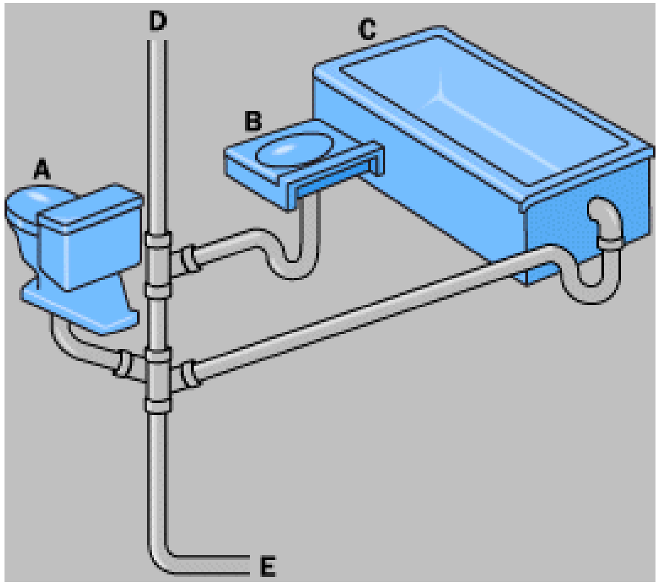
Sewage disposal (and treatment)

Design practices

- Objectives
  - Remove effluent quickly & quietly
  - Free from blockage, durable and economic
- Blockages may occur when
  - It is overloaded with solids
  - It suffers restricted flow at some bends or joints
- Thus, each discharge pipe section must be accessible for inspection & internal cleaning

Design practices

- Sanitary fitments or appliances
  - Common types:
    - Flushing cistern, flushing trough, automatic flushing cistern, flushing valve
    - Water closets (W.C.), urinal, bidets
    - Shower and bath tub
    - Sink, cleaner's sink
    - Drinking fountain
    - Wash basin or washing trough
    - Floor drain



Design practices

- Sanitary fitments or appliances (cont'd)
  - Materials used : (do you know why?)
    - Ceramics, glazed earthenware, glazed fireclay, glazed stoneware, vitreous china, pressed metal, acrylic plastic (Perspex), glass-reinforced polyester, cast iron and terrazzo
  - Practical examples:
    - www.americanstandard-us.com
    - www.thebluebook.co.uk
    - www.totousa.com

Design practices

- Sanitary provisions in HK: refer to Buildings Ordinance (Cap 123) [www.legislation.gov.hk]
  - Building (Standards of Sanitary Fitments, Plumbing, Drainage Works and Latrines) Regulations (Cap 123 i)
    - Residential buildings
    - Offices and other places of work
    - Places of public entertainment
    - Cinemas
    - Restaurants

Example: Standards of sanitary fitments for offices

Type of fitment	No. of male persons employed or likely to be employed and No. of fitments to be provided therefore
Watercloset fitments	Less than 100, 1 such fitment for every 25 such persons, or part thereof. More than 100, 5 such fitments and 1 additional such fitment for every 50 such persons, or part thereof, over 150.
Urinals	10-50 inclusive, 1 such fitment. More than 50, 2 such fitments and 1 additional such fitment for every 50 such persons, or part thereof, over 100.

No. of females employed or likely to be employed	No. of watercloset fitments
1-10 inclusive	1
11-25 inclusive	2
More than 25	3 and 1 additional watercloset fitment for every 25 such persons, or part thereof, over 50.

(Source: Buildings Ordinance, Cap 123)

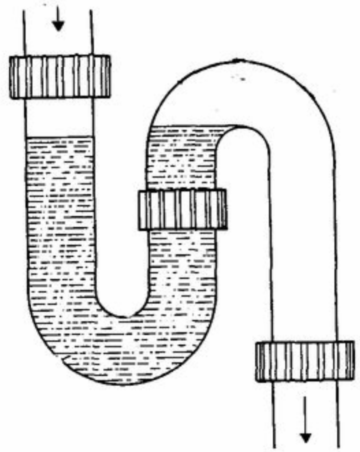
Design practices

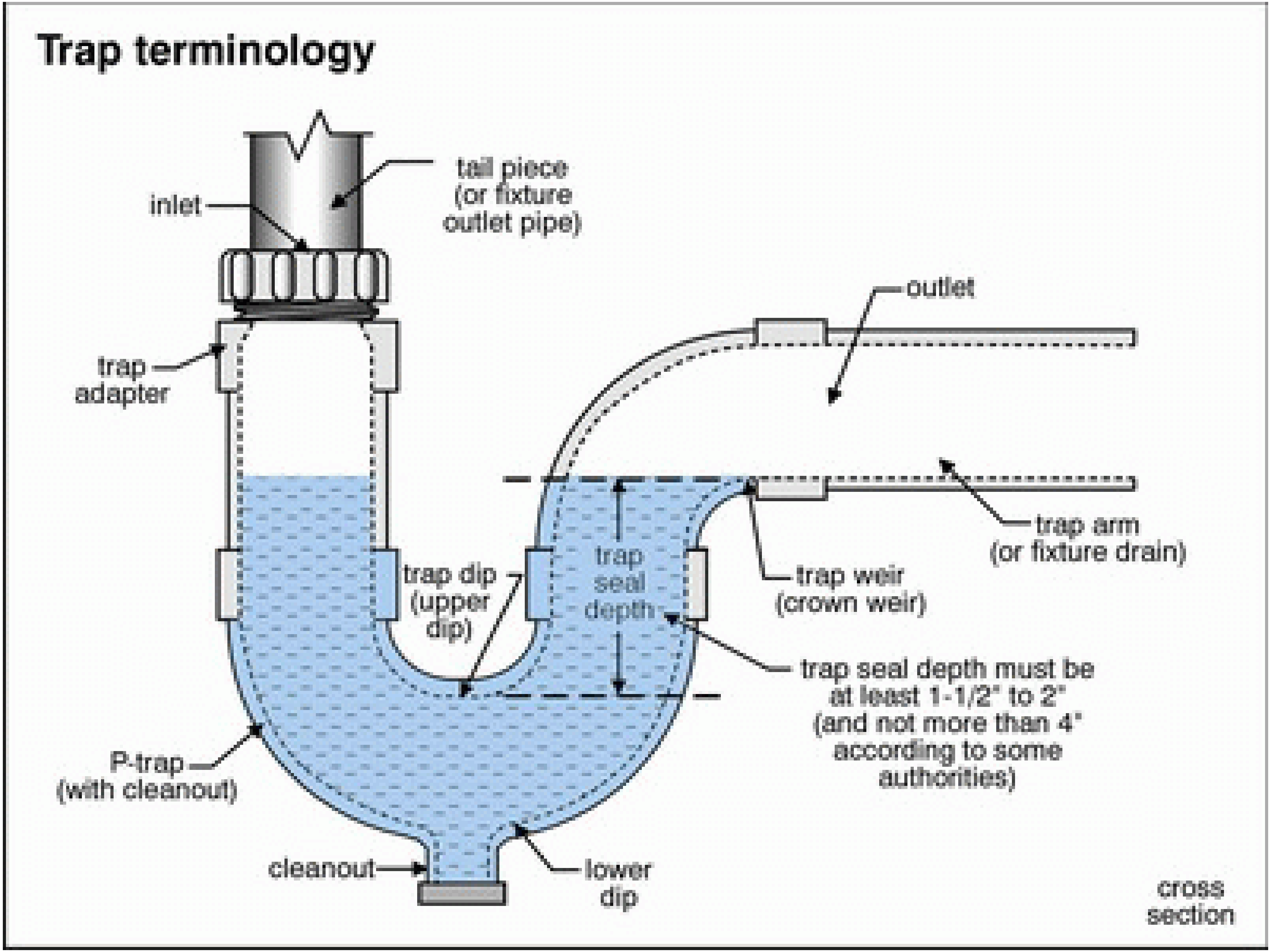
- Sanitary provisions in HK: (Cont'd)
  - Male to female ratio (* see PNAP 297)
    - 1 : 1 for office accommodation
    - 1 : 1.25 for places of public entertainment and cinemas
  - Assessment of population
    - See tables in PNAP 297
  - Provision of sanitary fitments
    - For shopping arcades, department stores, places of public entertainment and cinemas, see tables in PNAP 297; for offices, see Building Regulations Cap 123 i

* PNAP = Practice Note for Authorized Persons and Registered Structural Engineers, from www.bd.gov.hk

Design practices

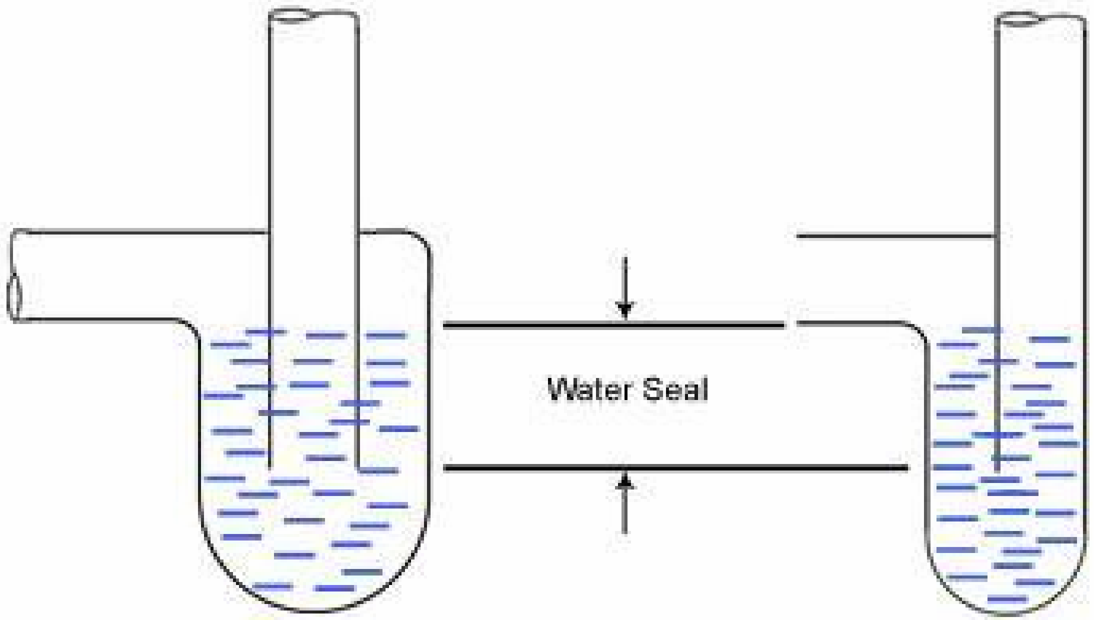
- Types of vertical drainage stacks
  - Waste pipe (WP): e.g. connected to basins & baths
  - Soil pipe (SP): e.g. connected to W.C.
  - Vent pipe (VP)
  - Rainwater pipe (RWP)
  - Air-conditioning condensation drainage pipe
- Use of traps (control foul gas or odour)
  - U-trap: a U-shaped running trap
  - P-trap and S-trap



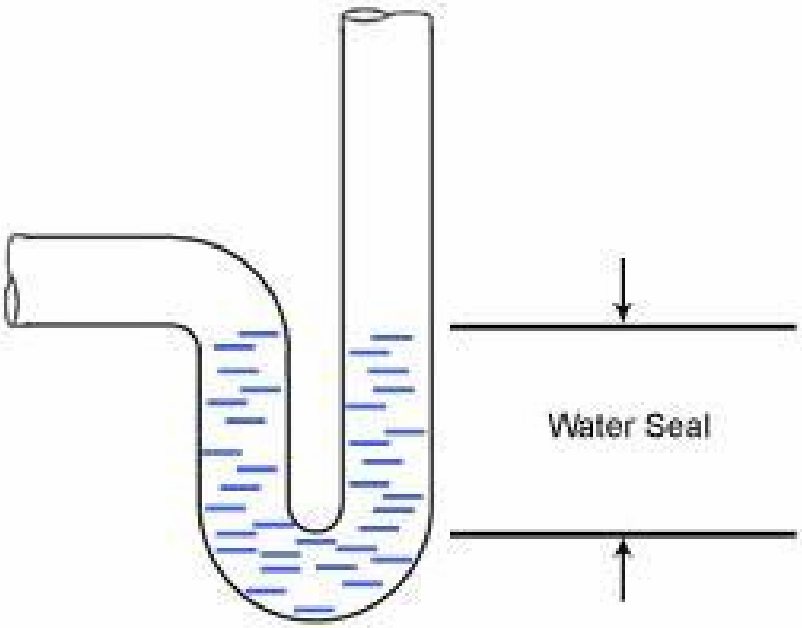


(Source: www.acehomeinspec.com)

Water seal of traps



S-trap

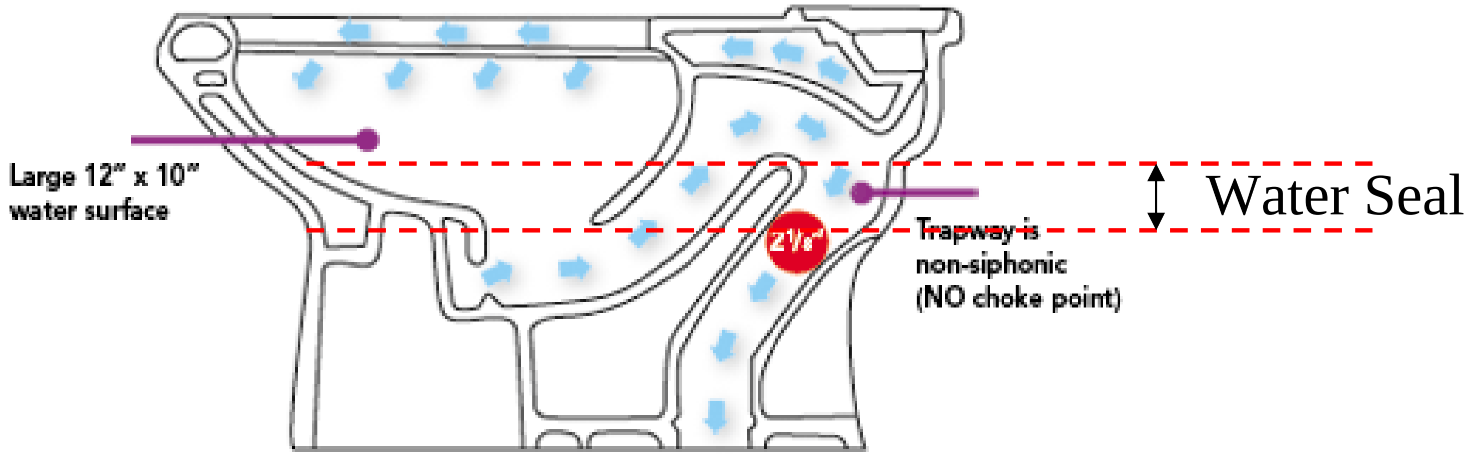


P-trap

Minimum depth of trap seal

Use	**Seal**
Baths & showers which discharge to a stack	50 mm
Baths & showers located at ground floor level which discharge to a gully having a granting	38 mm
Wash basins with spray taps, and no outlet plugs	50 mm
Appliances with an outlet bore of 50 mm or larger	50 mm
All other appliances	75 mm

(Source: IOP, 2002. *Plumbing Engineering Services Design Guide*)

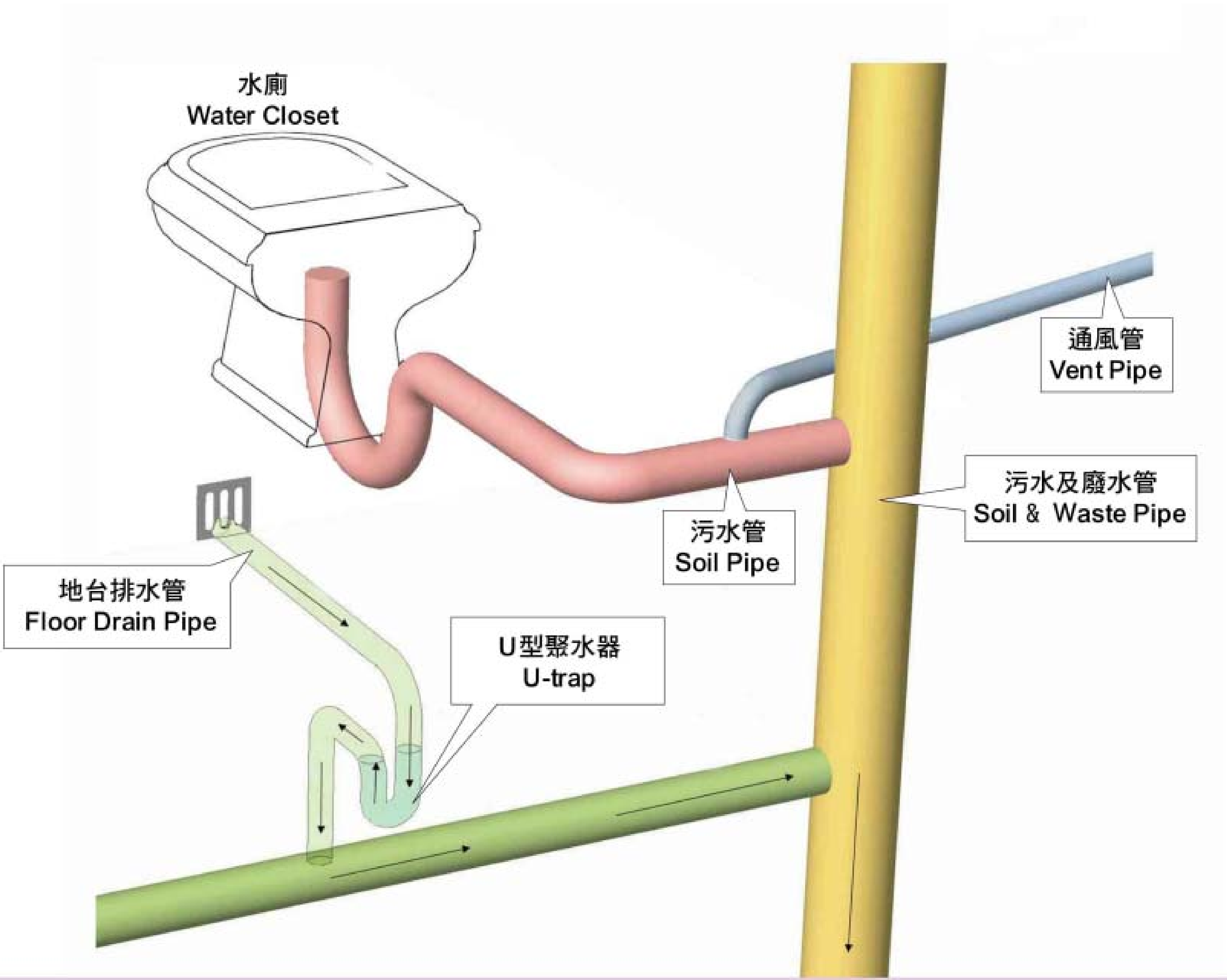


Design practices

- Do you still remember SARS in 2003?
  - SARS disease might have spread because the U-trap of the floor drain dried out at the Amoy Garden (淘大花園)
  - How to prevent this?
    - Anti-siphonage pipes and traps
    - Back-filling arrangement
    - W-trap (proposed by the Housing Authority)
    - Self-refilling function

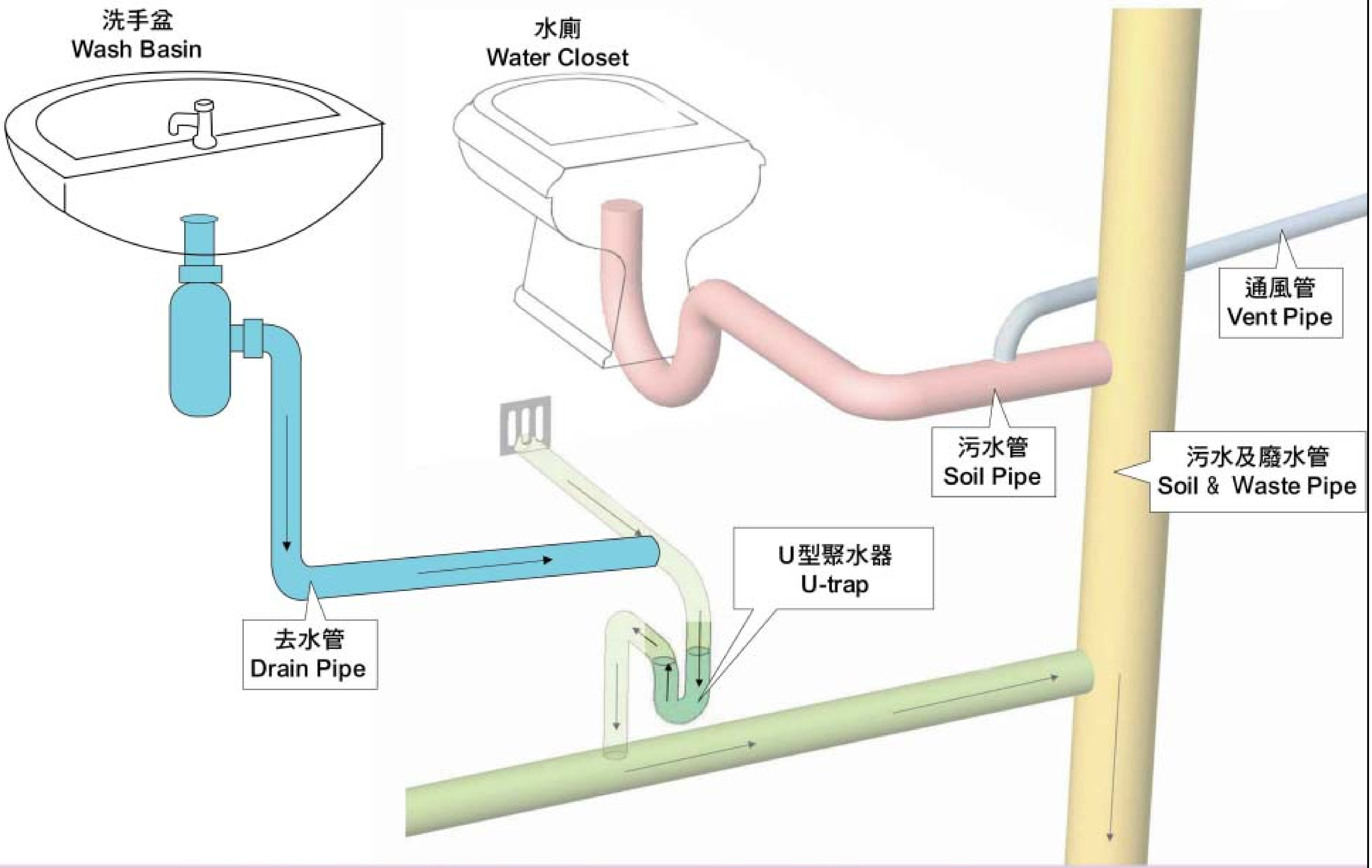
傳播方式	可能性
廁所污水渠系統	病者糞便或唾液經廁所水渠沖下時，病毒經通風管道傳至相連同一座向的其他單位
空氣	美國疾病控制及預防中心不排除此可能
飛沫	醫學界公認最有可能的傳播途徑，附在物件上的病毒至少可生存3小時
信箱	勞永樂醫生指7號和8號單位的信箱在同一直排，若同沾上帶病的口水或鼻涕，居民取信時可能感染
冷氣機滴水	勞永樂指可能性不大
晾衫滴水	勞永樂指可能性不大
食水喉	梁秉中教授指可能性不大

(Source: Apple Daily, 2003)



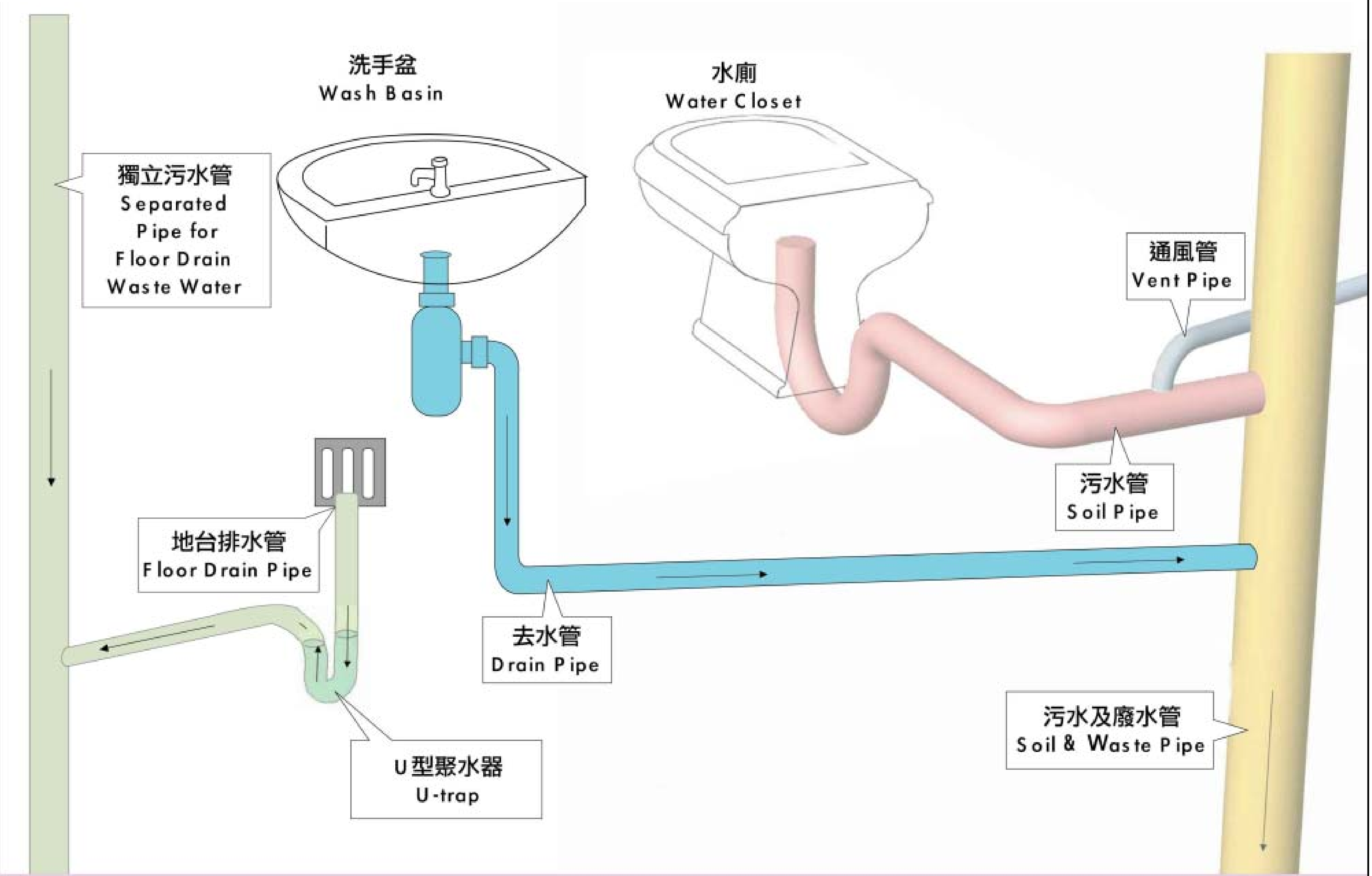
一般地台排水設計 General Pipe Work Design

(Source: Urban Renewal Authority, www.ura.org.hk)



U型聚水設計 U-trap Refilling Design

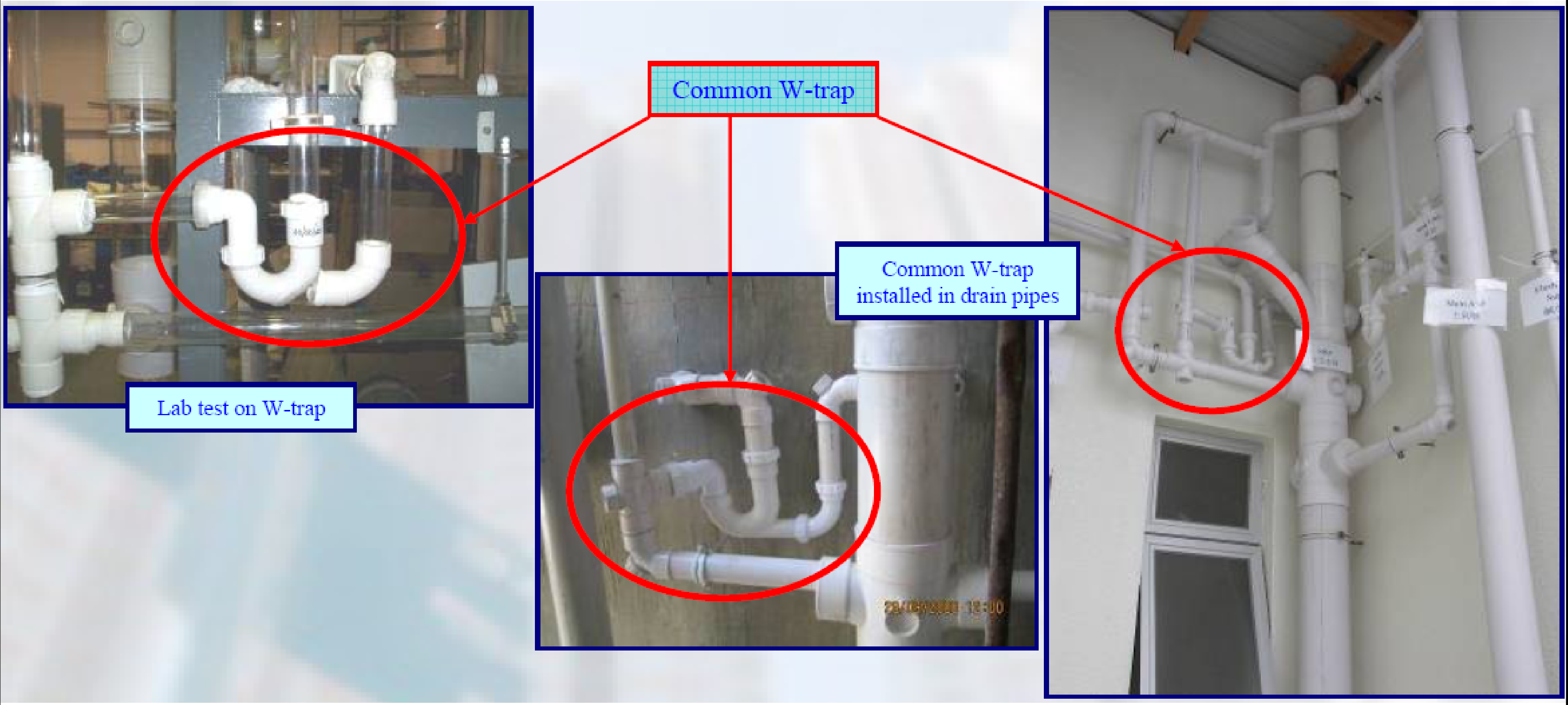
(Source: Urban Renewal Authority, www.ura.org.hk)



分開喉管設計 Pipes Separation Design

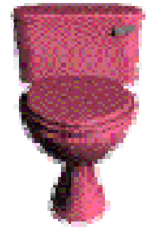
(Source: Urban Renewal Authority, www.ura.org.hk)

W-trap (proposed by the Housing Authority)



(Source: Housing Authority, www.housingauthority.gov.hk)

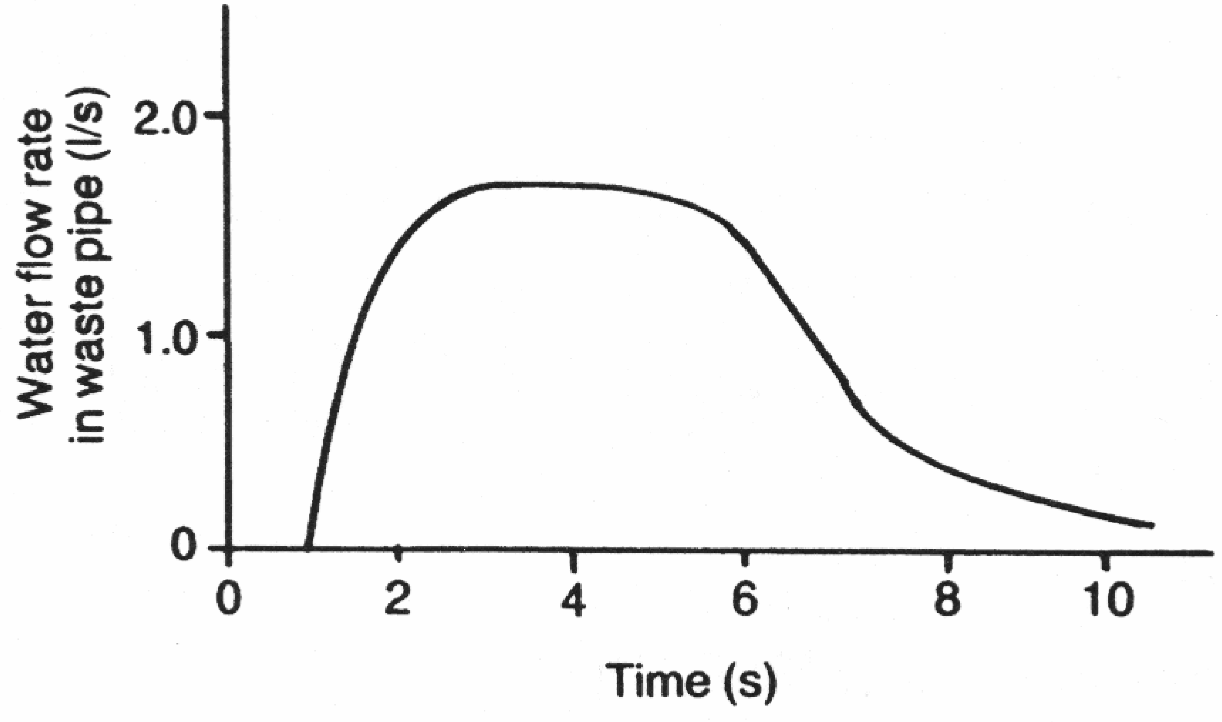
Sanitary drainage



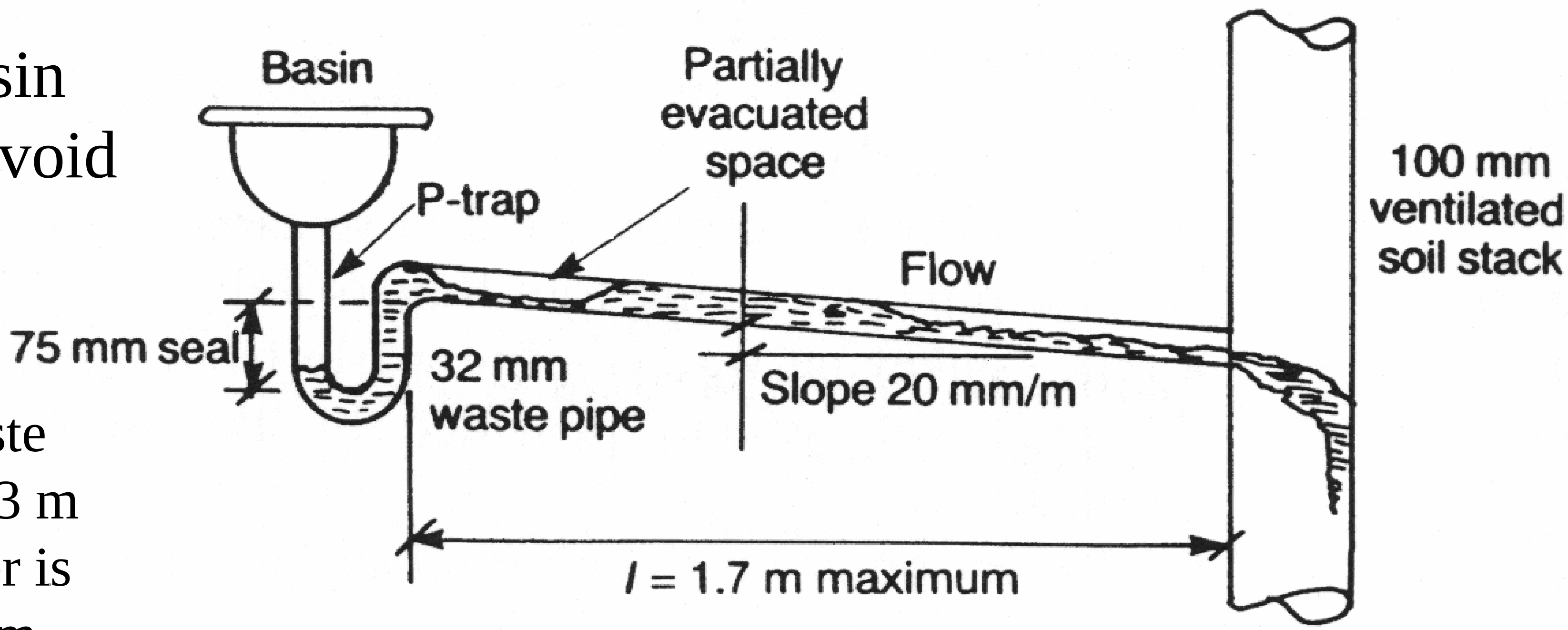
- Principles of fluid flow in waste pipes
  - Waste, soil or drain pipes
    - Discharge: random occurrence
    - Surges and pressure fluctuation
    - Two-phase flow (air + fluid) or 3-phase (air, fluid, solid)
  - Vertical soil and vent stacks
    - Open & ventilated on top, entrains air downwards
    - High air flow rate (10-15 l/s)
    - Friction losses, terminal velocity
    - Suction pressure at branch connection

Principles:
Hydraulics (water)
+ Pneumatic (air)

Discharge of water from a sanitary appliance



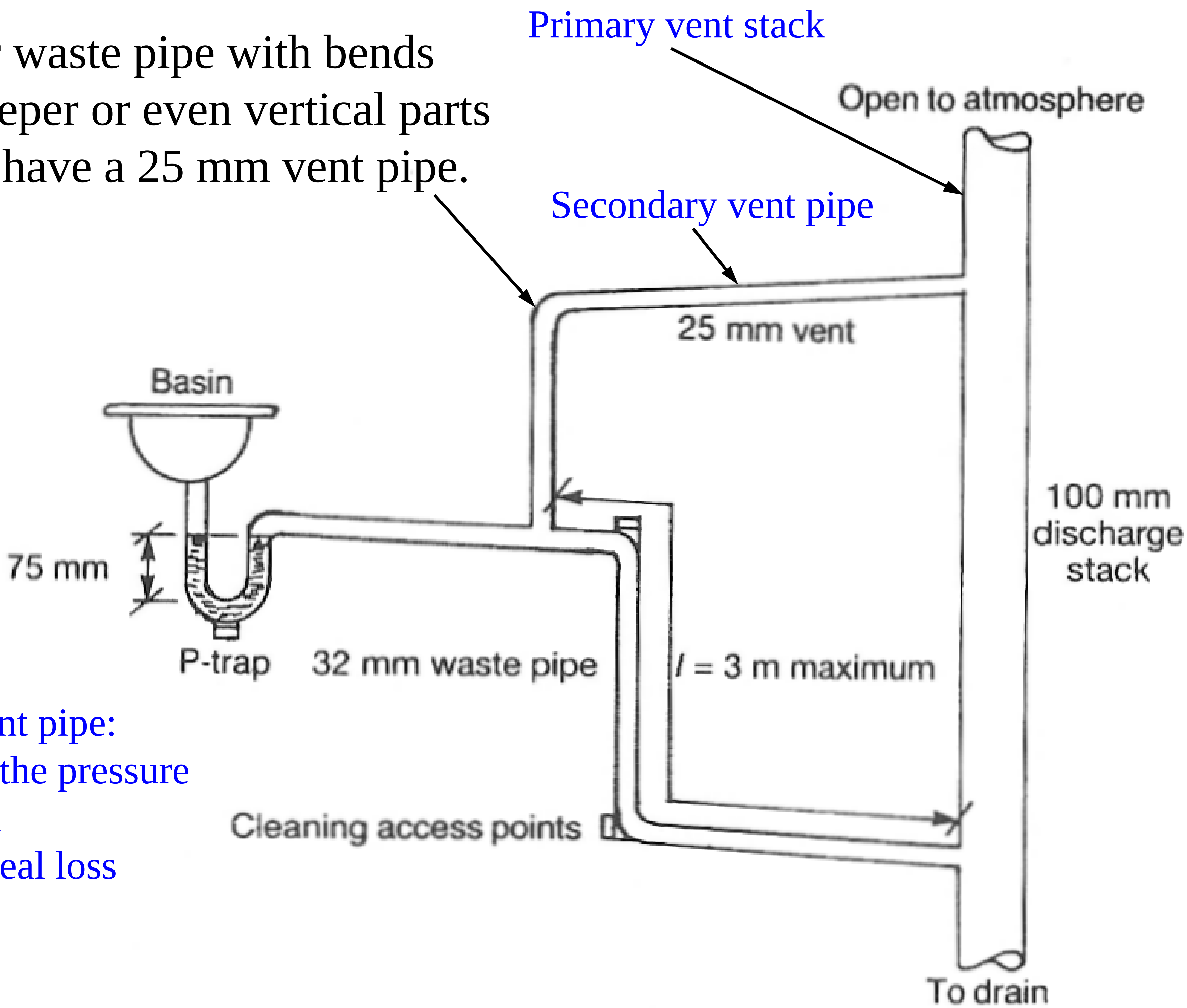
Design of a basin waste pipe to avoid self-siphonage



* The sloping waste pipe can be up to 3 m long if its diameter is increased to 40 mm.

(Source: Chadderton, D. V., 2007. *Building Services Engineering*)

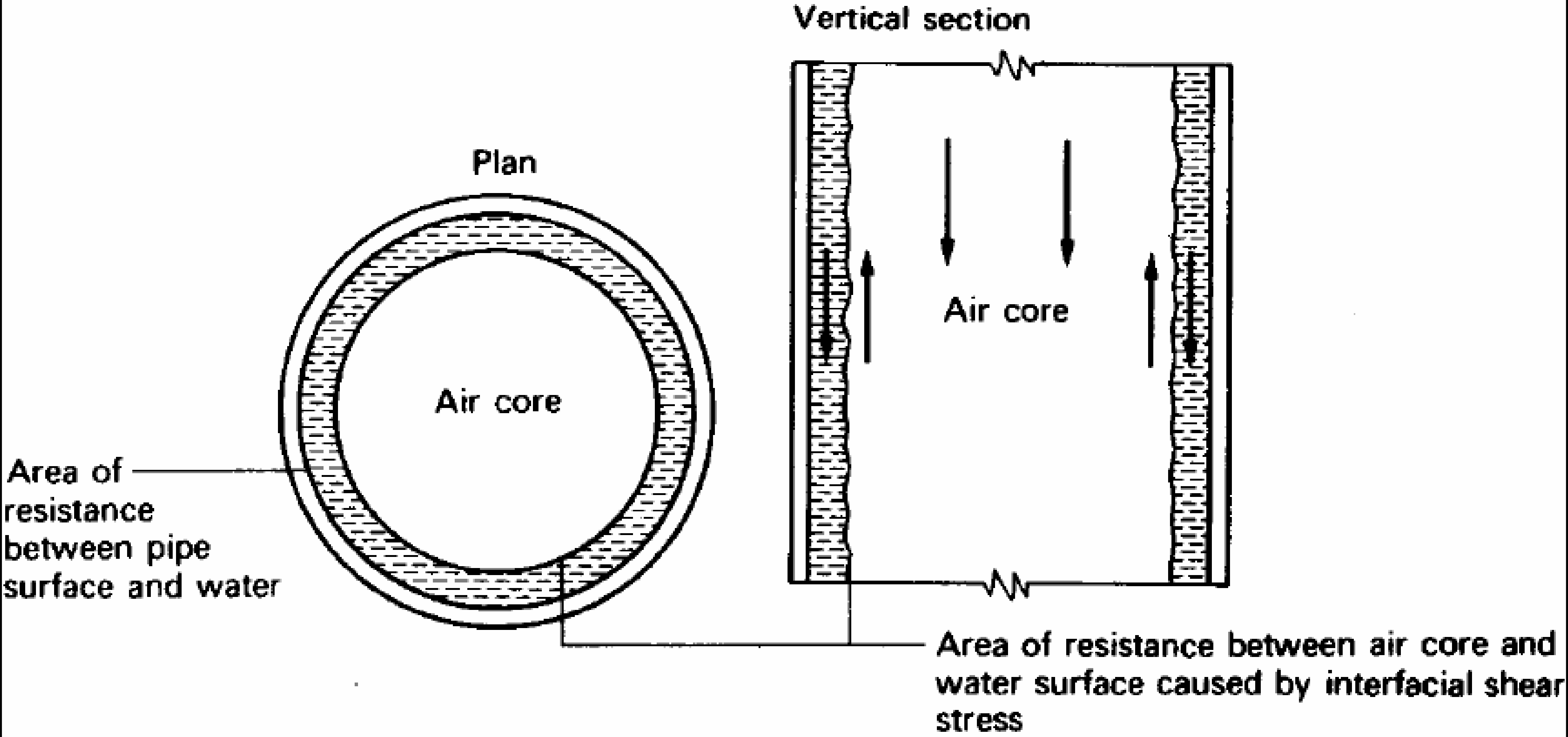
Longer waste pipe with bends and steeper or even vertical parts should have a 25 mm vent pipe.



Uses of vent pipe:

- Equalise the pressure fluctuation
- Prevent seal loss

(Source: Chadderton, D. V., 2007. *Building Services Engineering*)



Terminal Velocity (when friction balances gravitational force)

$V_T = 10.073\ (Q/\mathrm{D})^{0.4}$

$L_T = 0.1706 \times V_T^2$

where V_T is terminal velocity (m/s)

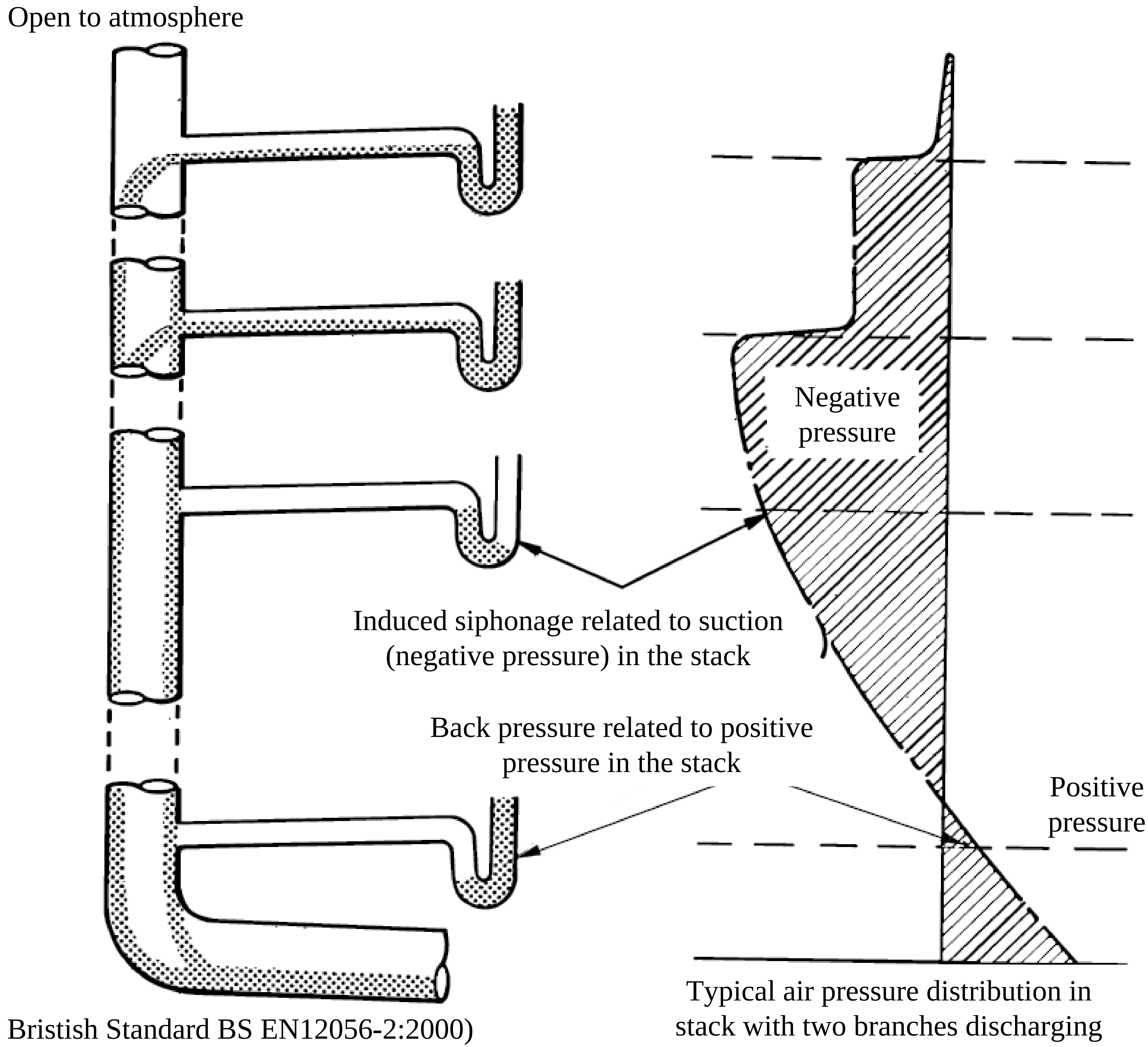
Q is discharge rate (L/s)

D is diameter of stack (mm)

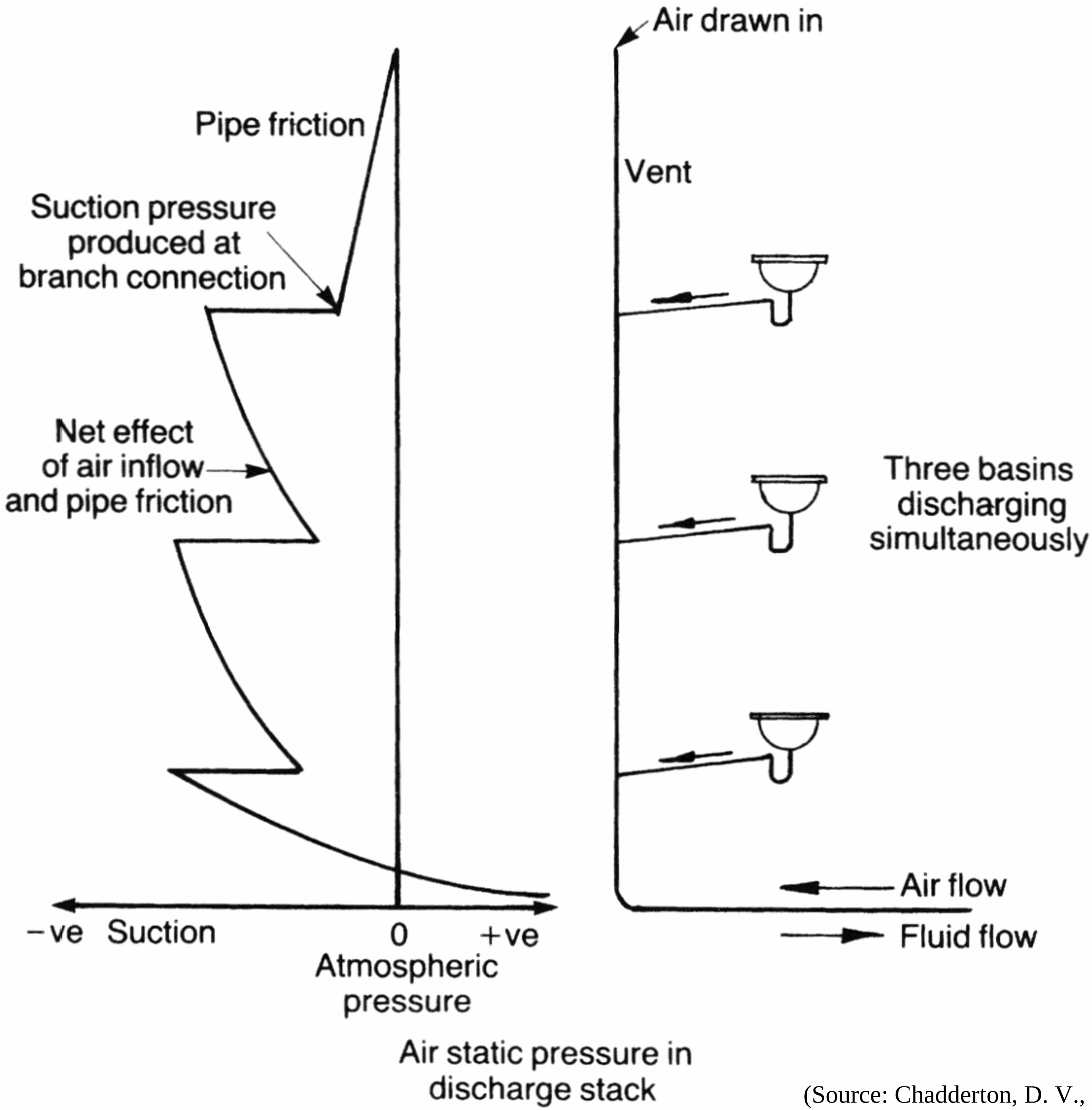
L_T is terminal length below point of entry (m)

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Pressure effects and seal losses due to water flow in a discharge stack



(Source: Bristish Standard BS EN12056-2:2000)



1. water discharged into the stack entrains air downwards

2. air static pressure is reduced by friction losses

3. water falls down as a helical layer attached to the pipe surface

4. restricted air passage at junctions further lowers the air static pressure

5. net effect of air inflow & pipe friction

6. at the stack base, air flow into the low pressure region

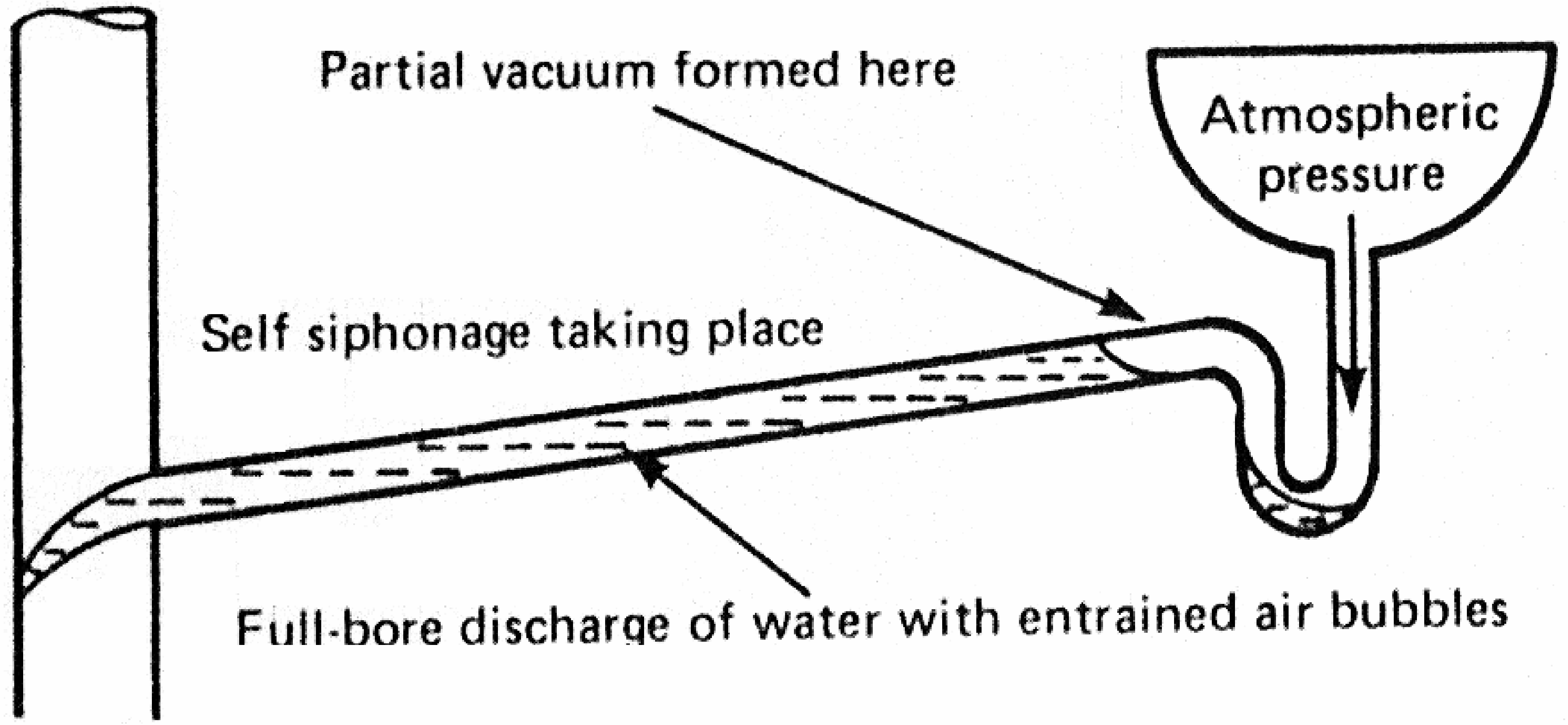
7. fluid fills the pipe near the base & positive air static pressure can be generated

(Source: Chadderton, D. V., 2007. *Building Services Engineering*)

Sanitary drainage

- Loss of water seal can occur through:
  - Self-siphonage
  - Induced siphonage
  - Compression or back pressure
  - Capillary action
  - Wavering out
  - Other causes:
    - Evaporation, cross-flow, bends and offsets, surcharging, intercepting traps, leakage

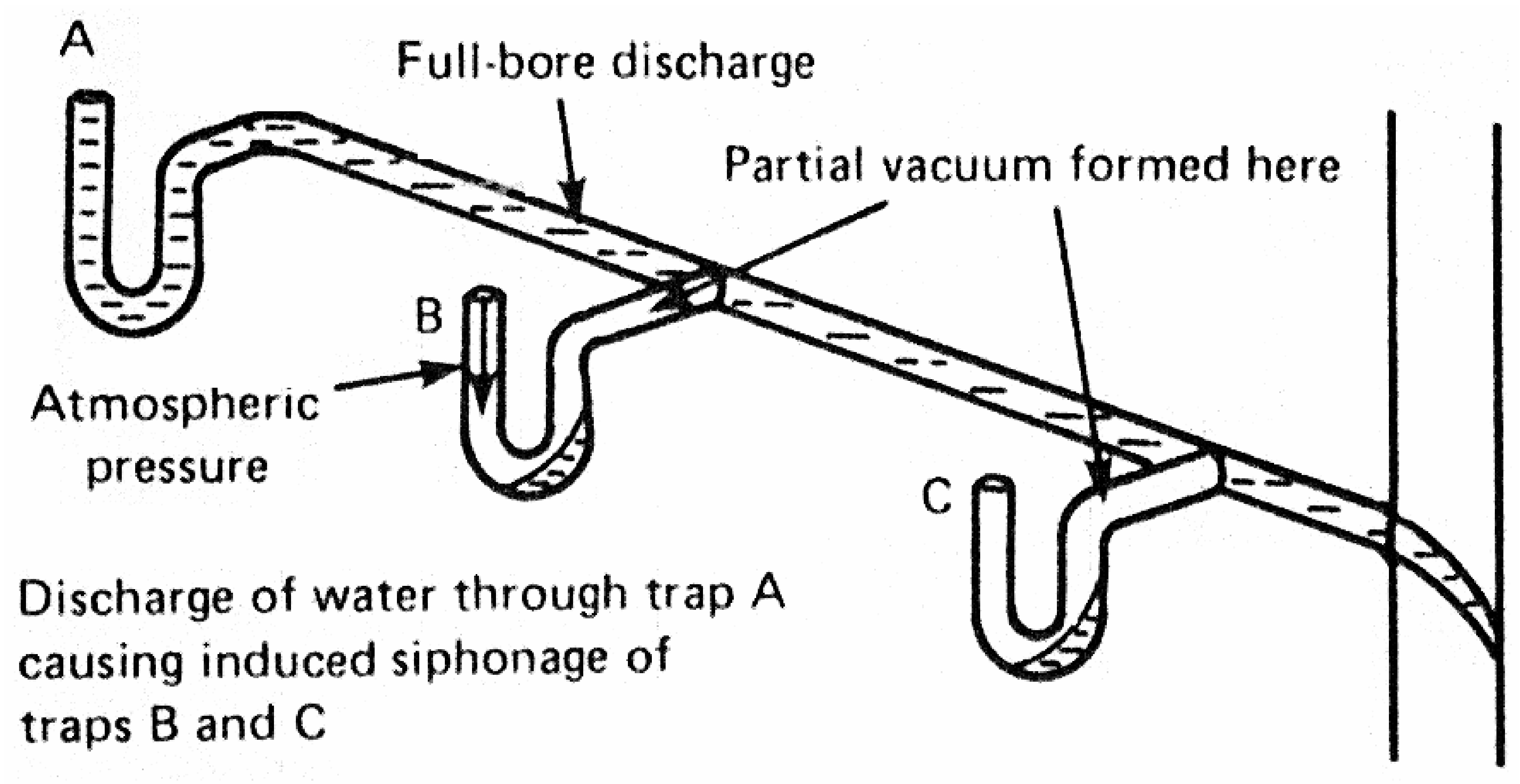
Self siphonage



- Caused by: a moving plug of water in the waste pipe
- Avoided by: placing restrictions on lengths and gradients and venting long or steep gradients

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

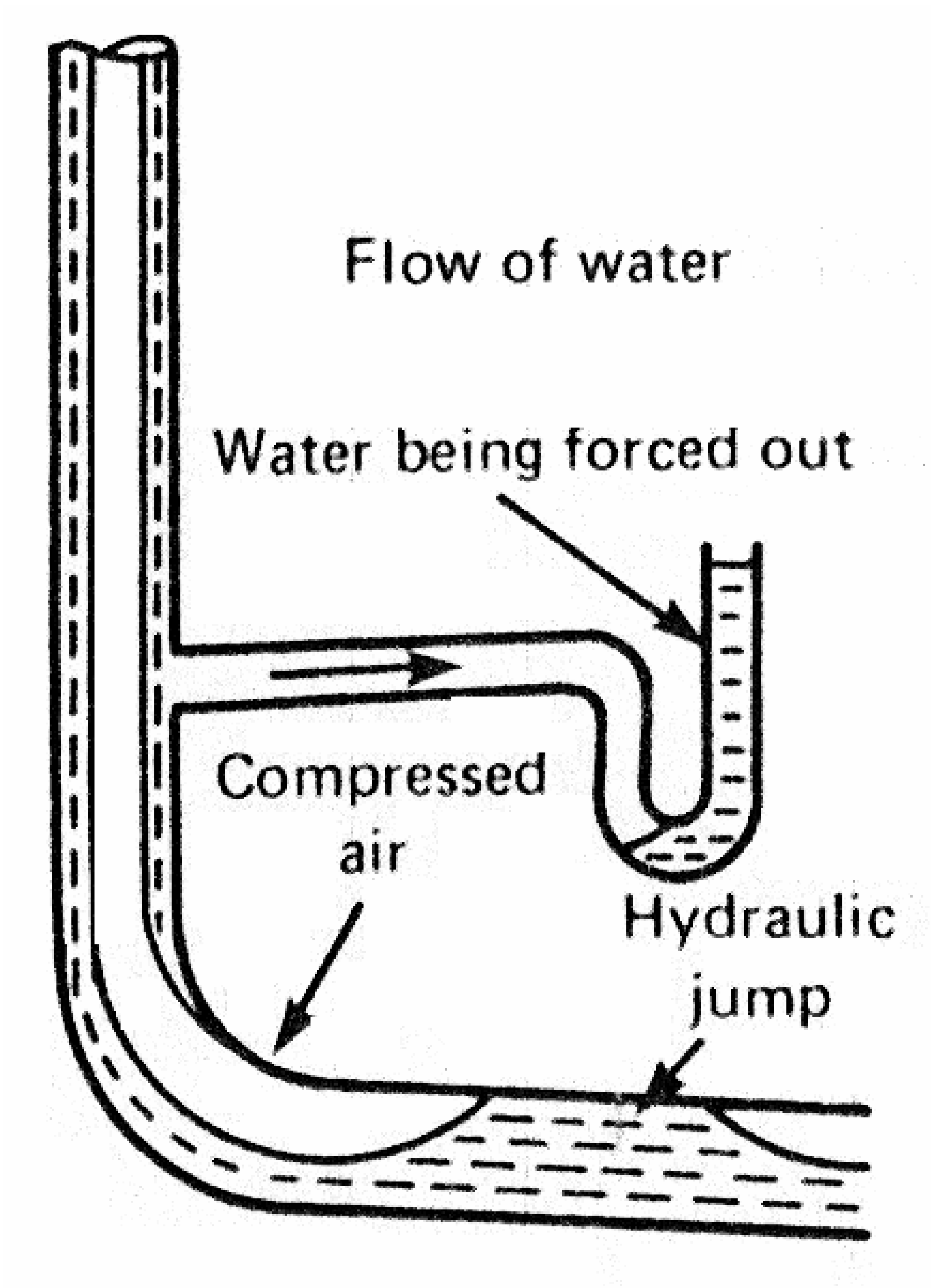
Induced siphonage



• Caused by: discharge from one trap
• Overcame by: design of the pipe diameters, junction layouts and venting arrangements

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Compression or back pressure

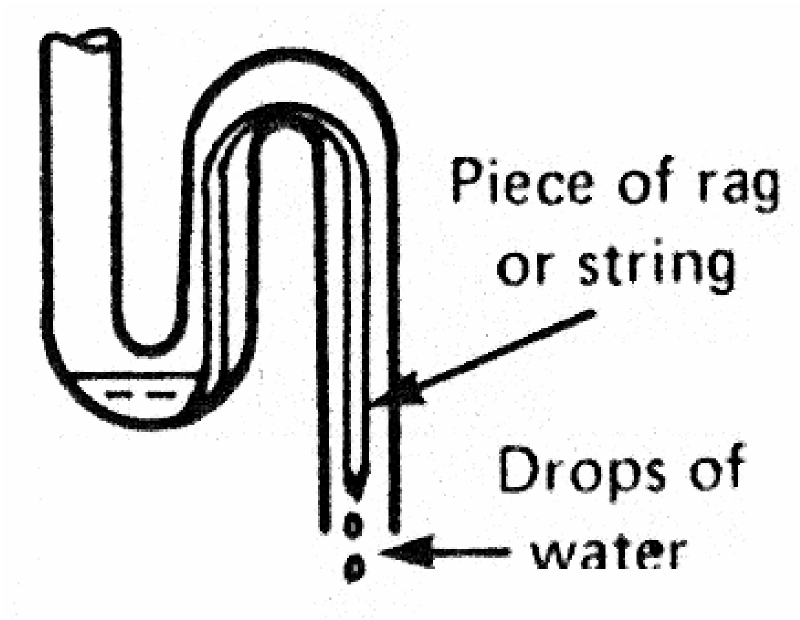


• Water flowing → compresses air in pipe → forces out the trap water seal

• Prevention: waste pipes not connected to the lower 450 mm of vertical stacks (measured from the bottom of the horizontal drain); waste discharges at the lower floors must be connected separately to drain

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

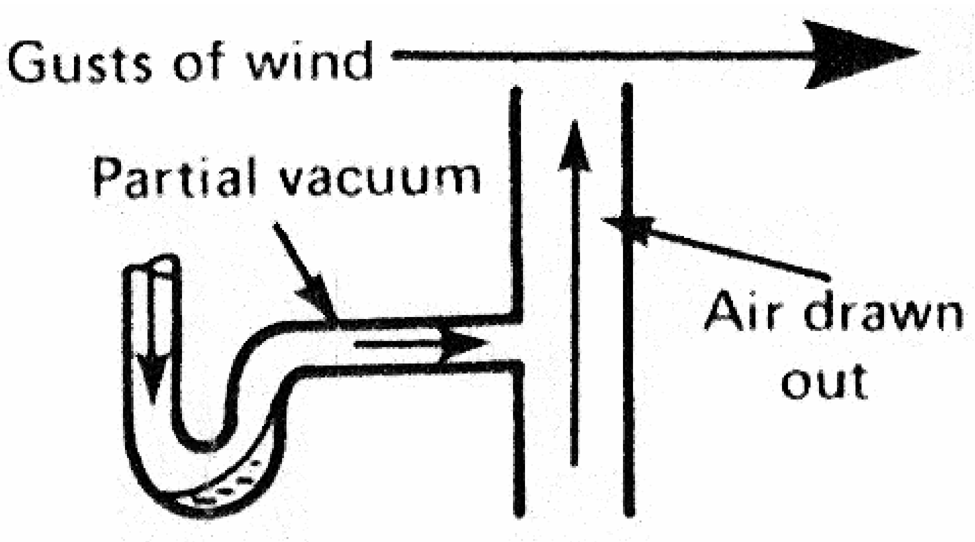
Capillary action



• A piece of rag or string caught on the outlet of the trap

• Additional maintenance should be carried out in high-risk locations

Wavering out



• Gusts of wind blowing across the top of a stack

• Site the vent terminal away from areas with troublesome effects

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Sanitary drainage

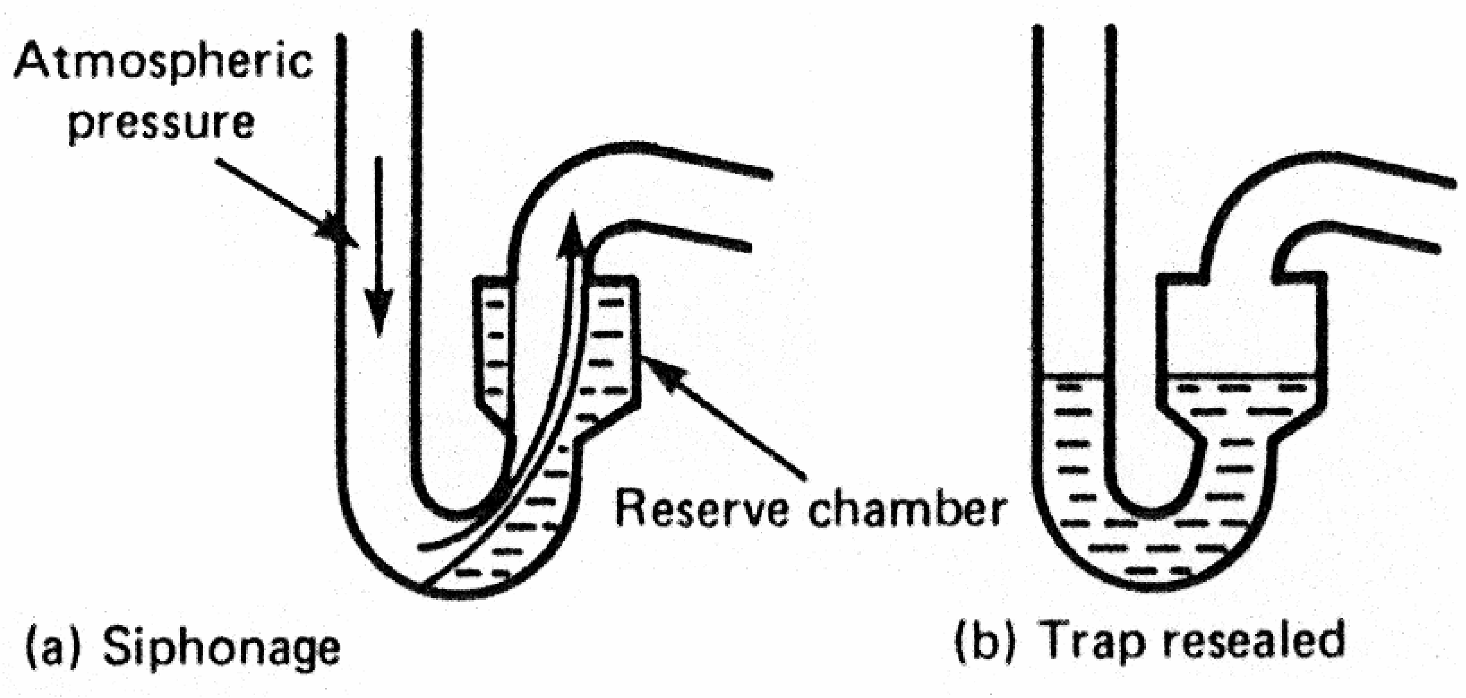
- Loss of water seal (cont'd)
  - Evaporation:
    - About 2.5 mm of seal loss per week while appliances are unused
  - Bends and offsets:
    - Sharp bends in a stack → partial or complete filling of the pipe → large pressure fluctuations
    - Foaming of detergents through highly turbulent fluid flow increases pressure fluctuations
    - A bend of minimum radius 200 mm at the base of a soil stack

Sanitary drainage

- Loss of water seal (cont'd)
  - Surcharging:
    - An underground drain that is allowed to run full causes large pressure fluctuations
    - Solution: additional stack ventilation
  - Intercepting traps:
    - Where a single-stack system is connected into a drain with an interceptor trap nearby, fluid flow is restricted
    - Additional stack ventilated is used
  - Leakage:
    - Can occur through mechanical failure of joints or the use of a material not suited to the water conditions

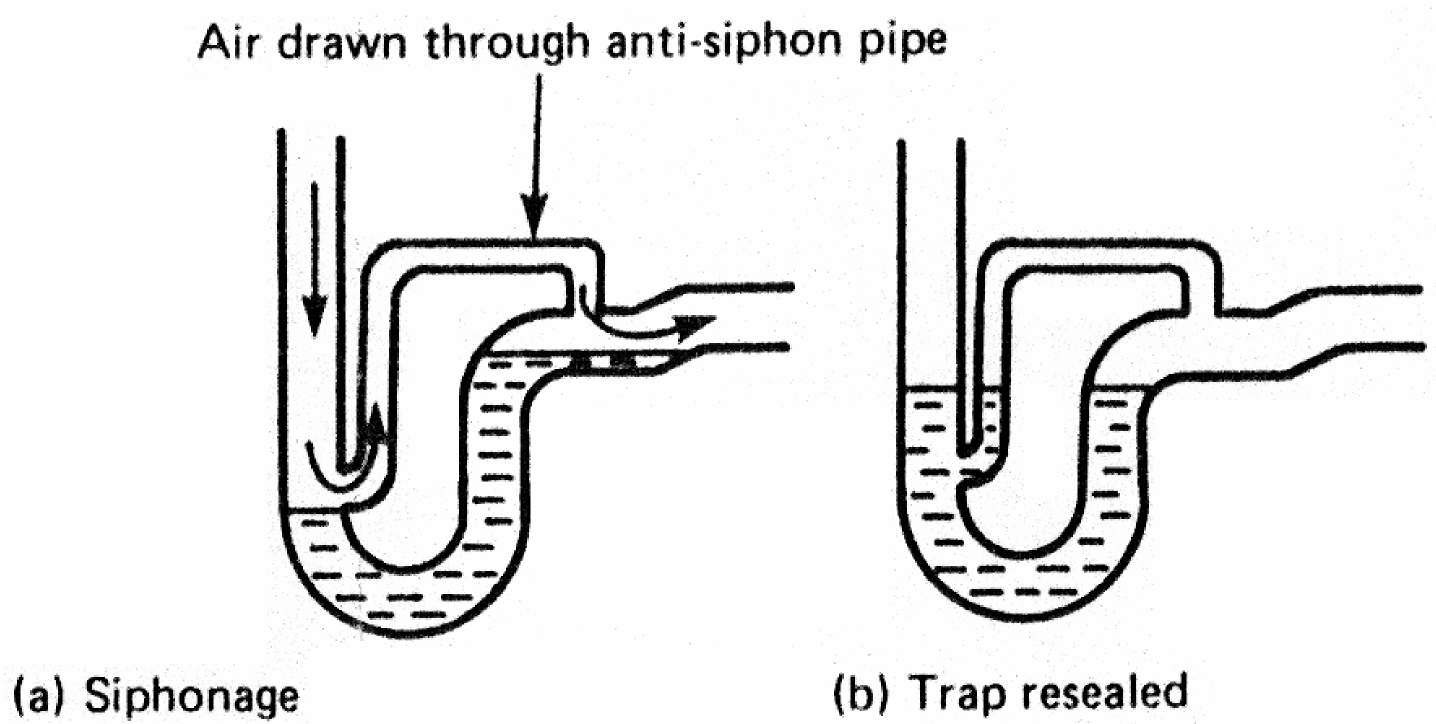
Sanitary drainage

- Maintain trap water seals by using resealing or anti-siphon (反虹吸) traps, such as
  - McAlpine trap
  - Grevak trap
  - Econa trap
  - Anti-siphon trap
- However, they may require more maintenance & are liable to be noisy



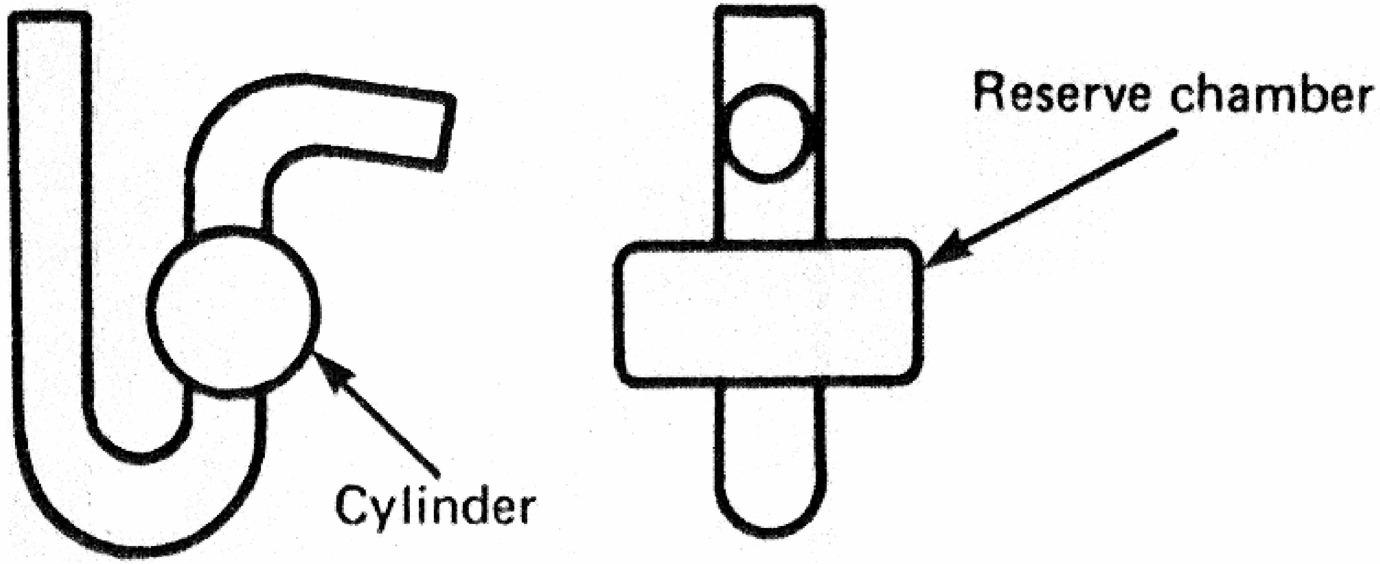
McAlpine resealing trap

Grevak resealing trap

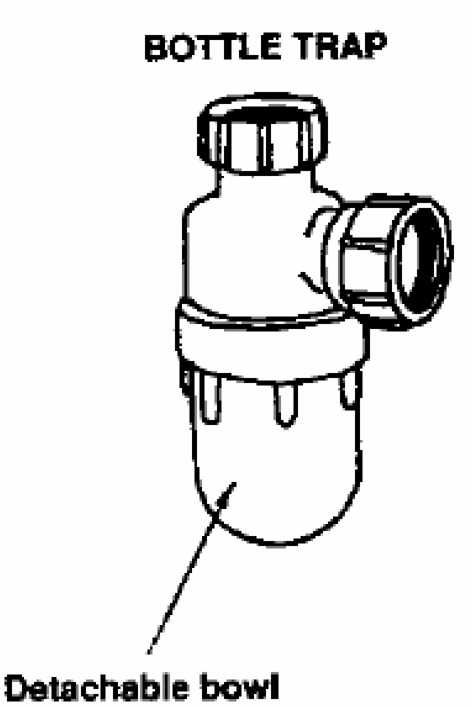


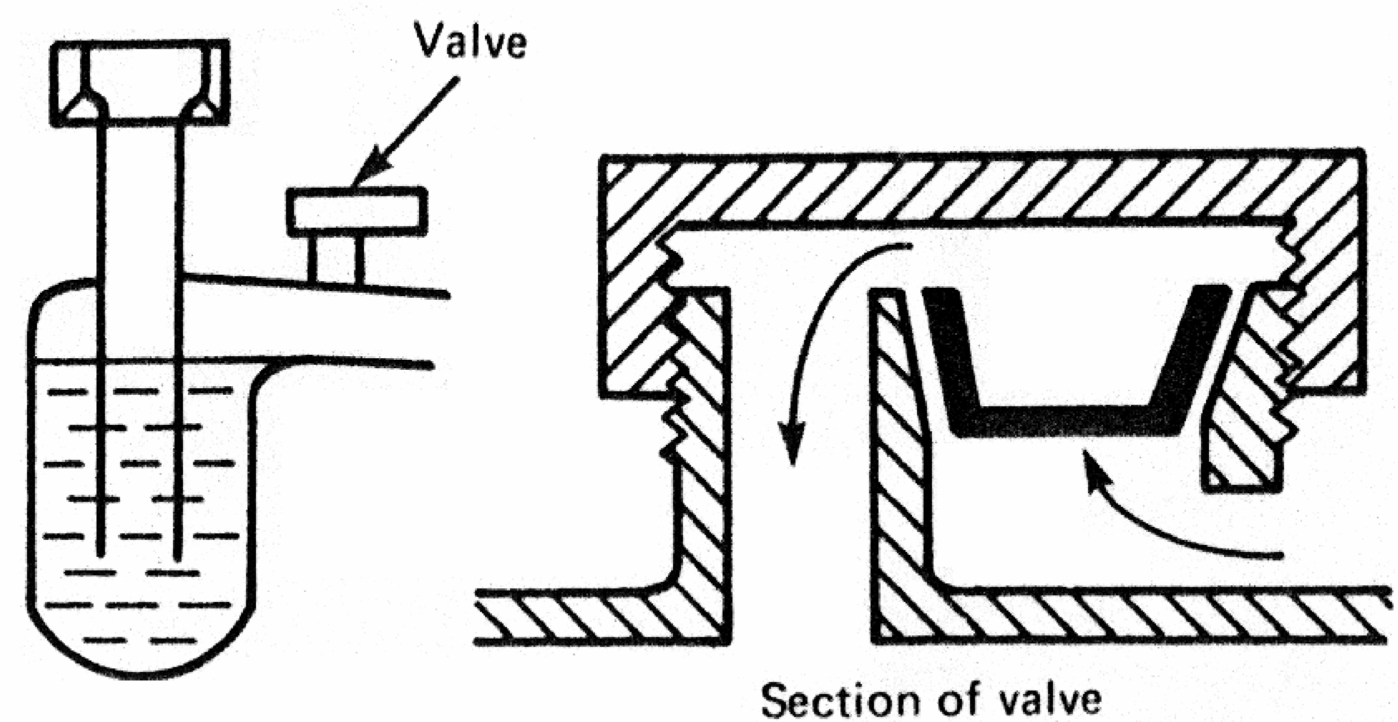
(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Econa resealing trap



Anti-siphon trap





(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Sanitary drainage

- Capacities of stacks
  - Maximum stack capacity is normally limited to about one quarter (1/4) full bore
    - To allow space for a core of air in centre of the stack
    - The air keeps pressure fluctuations to a minimum
  - [New] Discharge unit (DU) method (see tables)
    - Add up all the DUs (l/s) applicable to a discharge stack
    - Not all fitments will be in simultaneous use
    - The peak design flow is assessed by applying a frequency of use K factor to the sum of DUs
    - Must also add any other continuous or fixed flow

Discharge unit (DU) for common appliances & K factor

Appliance	DU (l/s)*
Wash basin or bidet	0.3
Shower without plug	0.4
Shower with plug	1.3
Single urinal with cistern	0.4
Slab urinal (per person)	0.2
Bath	1.3
Kitchen sink	1.3
Dishwasher (household)	0.2
Washing machine (6 kg)	0.6
Washing machine (12 kg)	1.2
WC with 6 litre cistern	1.2 – 1.7
WC with 7.5 litre cistern	1.4 – 1.8
WC with 9 litre cistern	1.6 – 2.0

* For a single stack system with full bore branch discharge pipes

Usage of appliance	K
Intermittent use, e.g. dwelling, guesthouse, office	0.5
Frequent use, e.g. hotel, restaurant, school, hospital	0.7
Congested use, e.g. toilets and/or showers open to the public	1.0
Special use, e.g. laboratory	1.2

$Qww = K \sqrt{\sum DU}$

where

Qww = wastewater flow rate (l/s)

K = frequency of use

$\sum$ DU = sum of DUs

Qtot = Qww + Qc + Qp

Qtot: total flowrate (l/s)

Qc: continuous flowrate (l/s)

Qp: pumped flowrate (l/s)

(Source: IOP, 2002. *Plumbing Engineering Services Design Guide*)

Maximum capacity of primary ventilated discharge stacks

Min. stack & vent internal diameter	**litre/sec**
75 mm*	2.6
100 mm	5.2
150 mm	12.4

Maximum capacity of secondary ventilated discharge stacks

Usage of appliance		**litre/sec**
Stack & vent	**Vent**	
75 mm*	50 mm	3.4
100 mm	50 mm	7.3
150 mm	50 mm	18.3

* No WC's allowed on 75 mm stacks.

Once the Qtot value has been obtained, a decision about the stack size, and ventilation principle can be made by referring to the above Tables.

(Source: IOP, 2002. *Plumbing Engineering Services Design Guide*)

Example 1: Determine total design flowrate and stack requirements for an 11-storey block of apartments. The stack will serve one apartment per floor, comprising of bathroom, en-suite shower room and fully fitted kitchen.

Answer:-

DU per flat:

2 WC's x 1.7	= 3.4
2 wash basins x 0.3	= 0.6
1 bath	= 1.3
1 shower	= 0.4
1 kitchen sink	= 1.3
1 washing machine	= 0.6
1 dishwater	= 0.2

Total DUs	= **7.8**

Assume a primary ventilated stack is adequate, thus the bottom storey must connect separately to drain.

For 10 storeys, $\sum$DU: 7.8 x 10 = 78

K = 0.5, so Qww = $0.5\sqrt{78}$ = 4.42 l/s

Qc & Qp = zero, so Qtot = **4.42 l/s**

From table, a **100 mm** primary ventilated stack has a limit of 5.2 l/s, so this size is adequate. Secondary ventilation is not required.

(Source: IOP, 2002. *Plumbing Engineering Services Design Guide*)

Example 2: Determine total design flowrate and stack requirements for an 11-storey hotel. The stack will serve two en-suite bathrooms on each floor; there will be air conditioning units on the roof with a peak discharge of 0.2 l/s, and laundry equipment on the 5th floor with a peak discharge of 0.5 l/s.

Answer:-

DU per typical floor:

2 WC's x 1.7	= 3.4
2 wash basins x 0.3	= 0.6
2 baths x 1.3	= 2.6

Total DUs	= **6.6**

Assume a primary ventilated stack is adequate, thus the bottom storey must connect separately to drain.

For 10 storeys, $\sum$ DU: 6.6 x 10 = 66

K = 0.7, so Qww = $0.7\sqrt{66}$ = 5.7 l/s

Qtot = 5.7 + 0.2 + 0.5 = **6.4 l/s**

There are two options: a 150 mm primary ventilated stack, or a 100 mm secondary ventilated stack and 50 mm secondary vent. Practical considerations would dictate the best choice, for example, a proprietary fitting such as the collar boss is only available in the 100 mm size.

(Source: IOP, 2002. *Plumbing Engineering Services Design Guide*)

Sanitary drainage

- Normal practice for branch pipes
  - Soil & vent stack or branch with at least one WC: at least 100 mm diameter
  - Outlets from wash basins: a 32 mm minimum diameter
  - Sinks and baths discharge pipes: a 40 mm minimum diameter

Materials for sanitary pipework

Material	Application	Jointing
Cast iron	50 mm and above vent and discharge stacks	50 mm and above vent and discharge stacks
Galvanised steel	Waste pipe	Screwed
Copper	Waste pipes and traps	Compression, capillary, silver solder, bronze weld or push-fit rings seal
Lead	Waste pipes and discharge stacks	Soldered or lead welded
ABS (acrylonitrile butadiene styrene)	Up to 50 mm waste and vent pipes	Solvent cement and push-fit ring seal
High-density polyethylene	Up to 50 mm waste and ventilating pipes and traps	Push-fit ring seal and compression fittings
Polypropylene	Up to 50 mm waste and ventilating pipes and traps	Push-fit ring seal and compression couplings
Modified PVC	Up to 50 mm waste and vent pipes	Solvent cement and push-fit ring seal
Unplasticized PVC	Over 50 mm soil and vent stacks; vent pipes under 50 mm	Solvent cement and push-fit ring seal
Pitch fibre	Over 50 mm discharge and vent stacks	Driven taper or polypropylene fitting with a push-fit ring seal

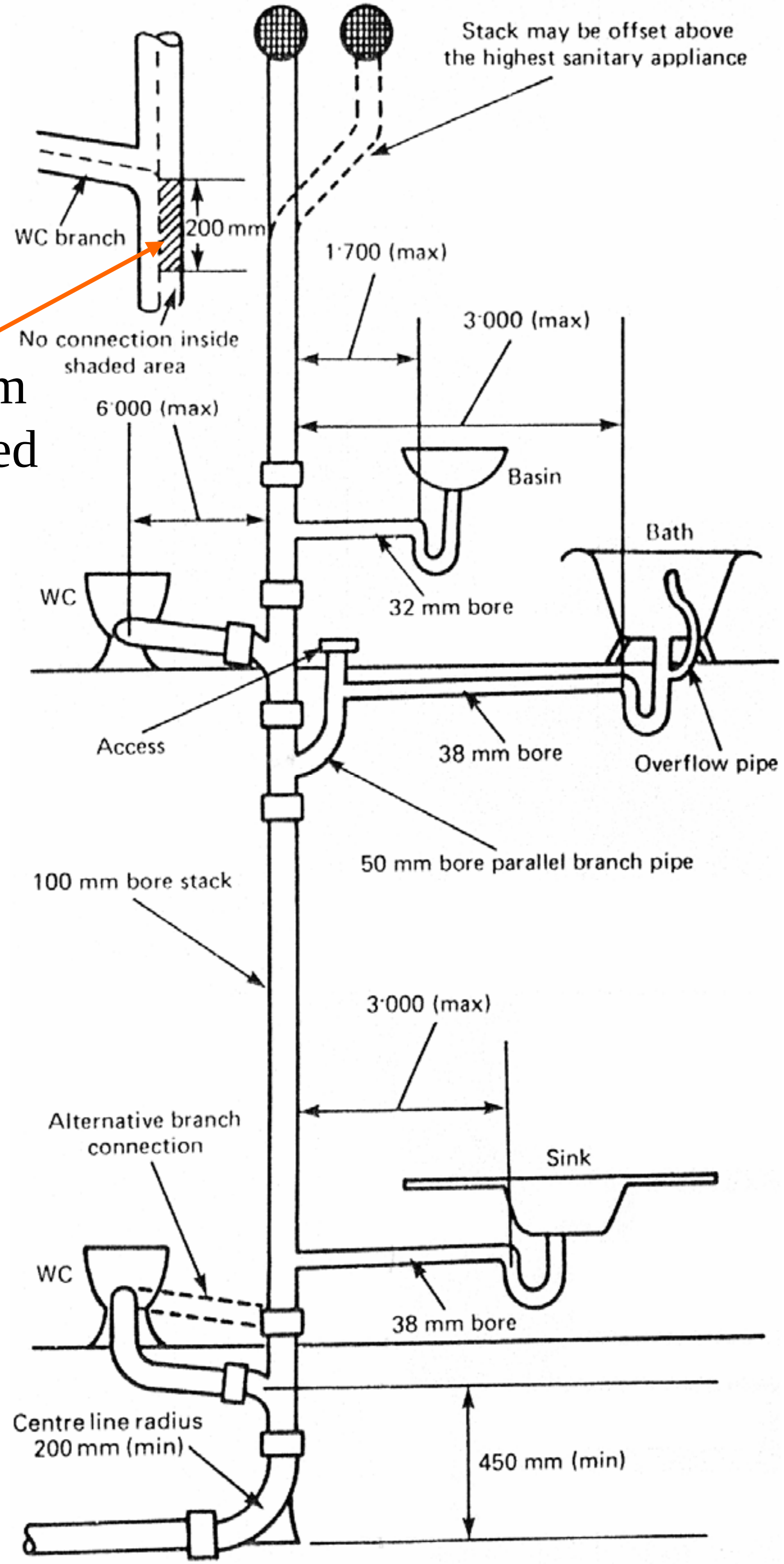
(Source: Drainage Services Department, www.dsd.gov.hk)

Sanitary drainage

- Types of sanitary drainage systems
  - Single stack system
  - Collar boss system
  - Modified single stack system
  - Fully ventilated one-pipe system
  - Two-pipe system
- Selection depends on situations, costs & local design practices
- Design considerations: e.g. pipe size, distance

Single stack system

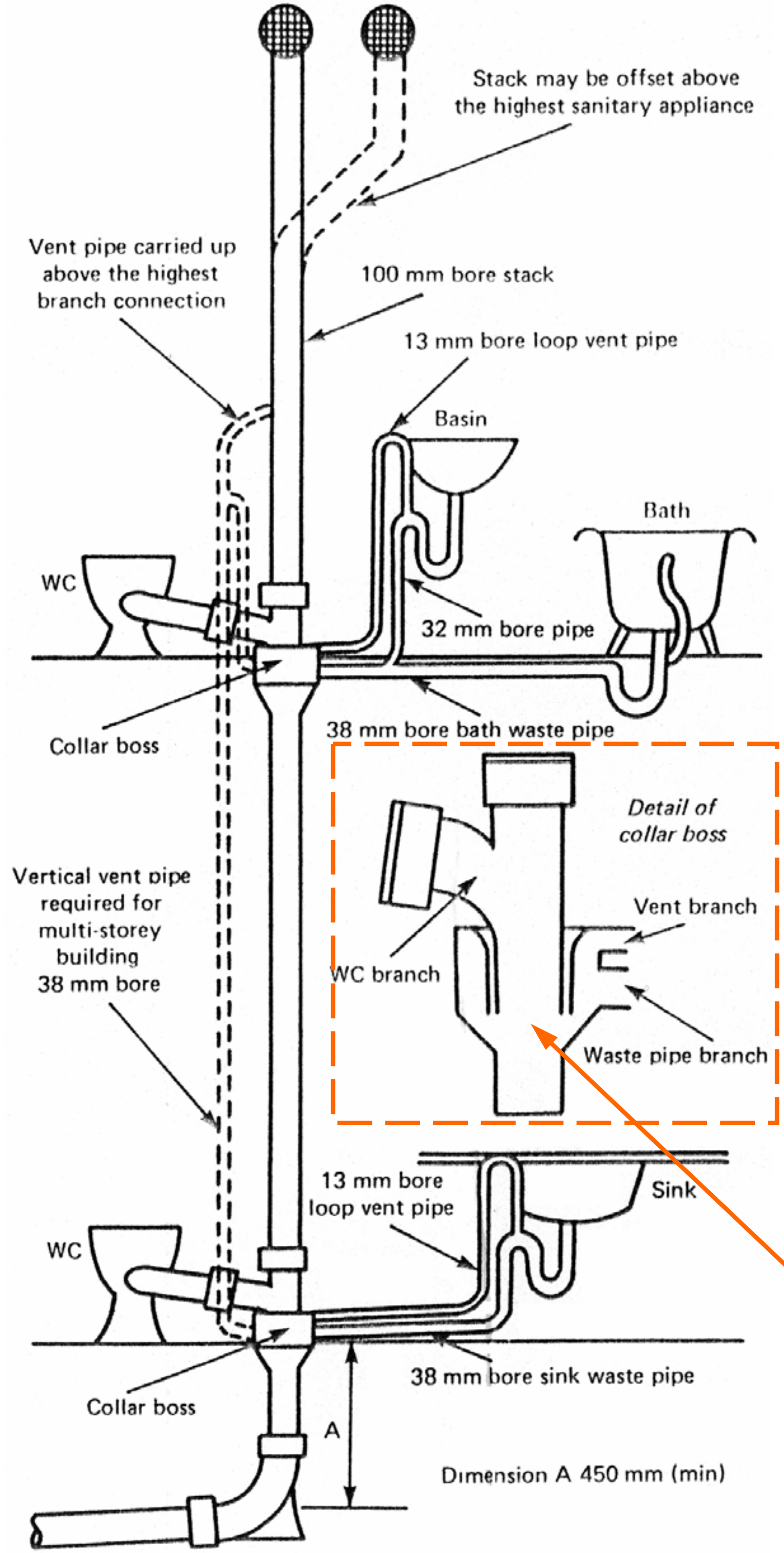
200 mm restricted zone



- Reduces the cost of soil and waste systems
- Branch vent pipes are not required
- But many restrictions in the design
- To prevent loss of trap water seals:-
  - The trap water seals on the waste traps must be 76 mm deep
  - The slopes of the branch pipes are: sink and bath, 18 to 19 mm/m; basin 20-120 mm/m; WC 18 mm/m (min.)
  - Vertical stack at 200 mm below the centre of the WC branch connection

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

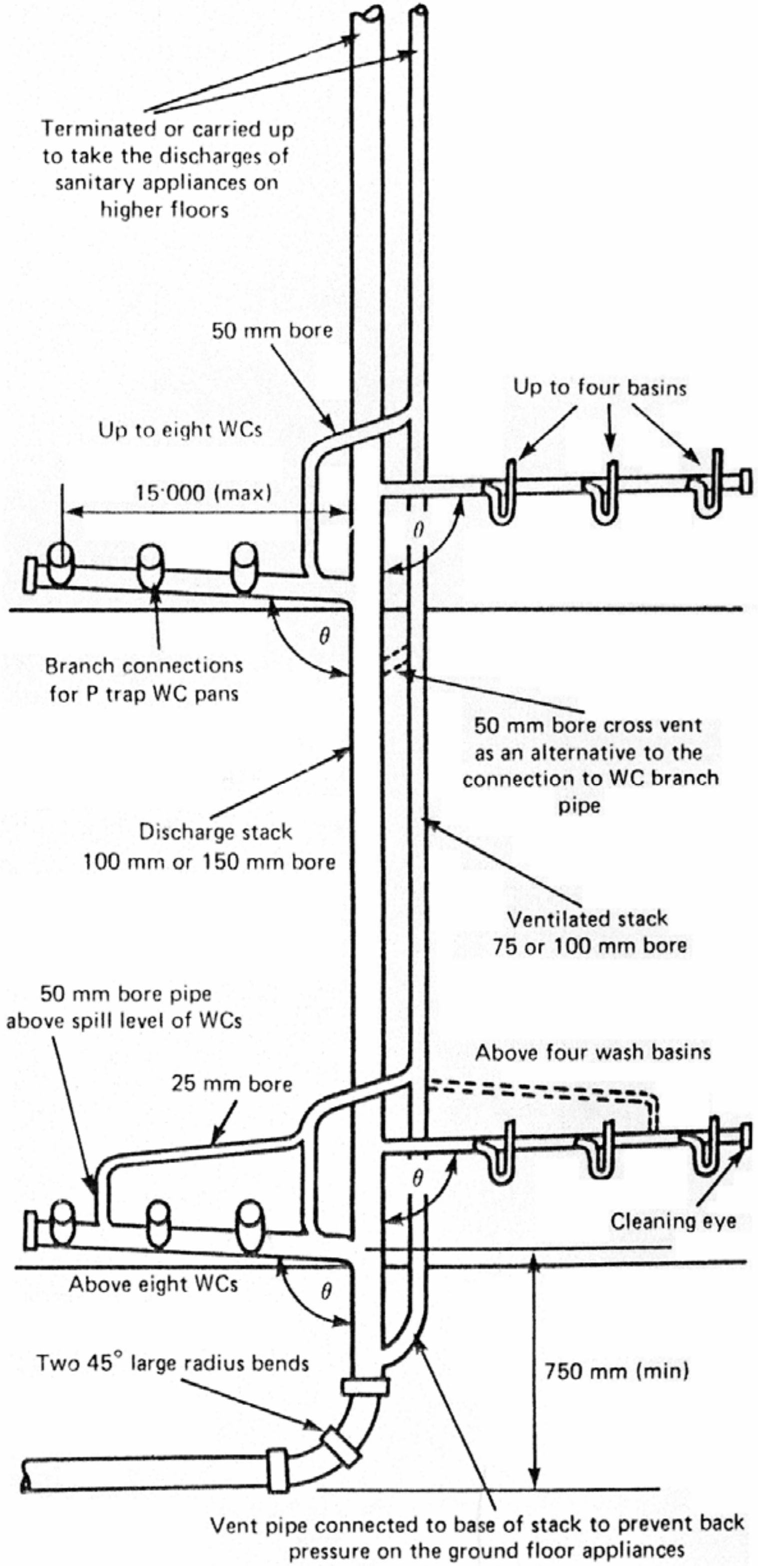
Collar boss single stack system



- Eliminates the restrictions imposed between bath waste pipe and stack
- Bath waste connect to the stack at a higher point (no risk of WC discharge backing up into bath waste pipe)
- Loop vent pipes to the basin/sink traps and connecting these to the collar boss, the waste pipes from these appliances drop vertically before running horizontally to stack
- Loop vent pipe on the basin trap prevent its siphonage when the bath is discharged

Annular chamber protects the small diameter connections from the WC discharge

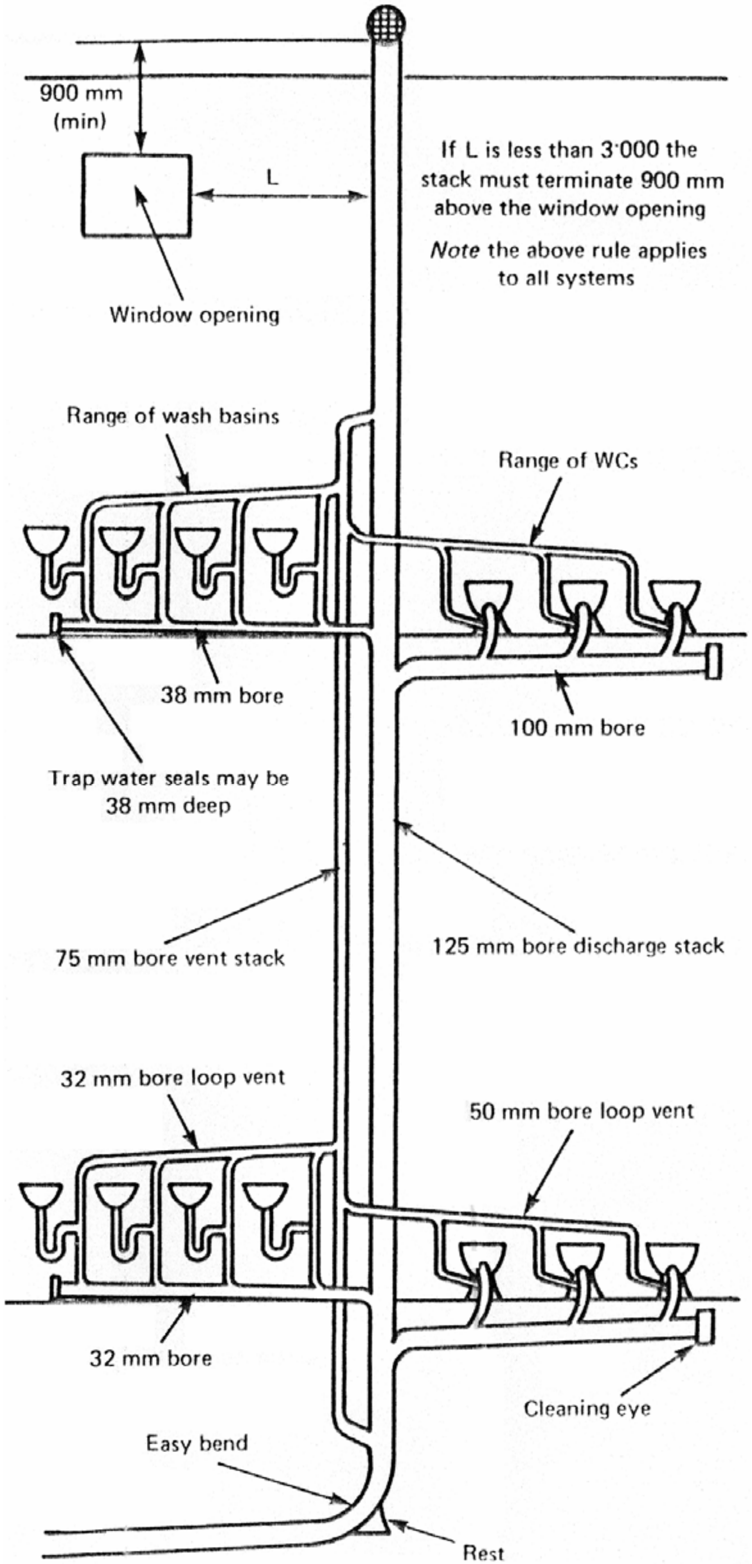
(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)



Modified single stack system

- Close grouping of sanitary appliances → install branch waste and soil pipes without the need for individual branch ventilating pipes
- To prevent the loss of trap water seals → WC branch pipe min. 100 mm bore & angle $\theta = 90.5^{\circ} - 95^{\circ}$
- To prevent the loss of trap water seals → basin main waste pipe min. 50 mm bore & angle $\theta = 91^{\circ} - 92.5^{\circ}$
- Five basins or more / length of the main waste pipe exceeds 4.5 m → a 25 mm bore vent pipe connected to main waste pipe at a point between the two basins farthest from the stack

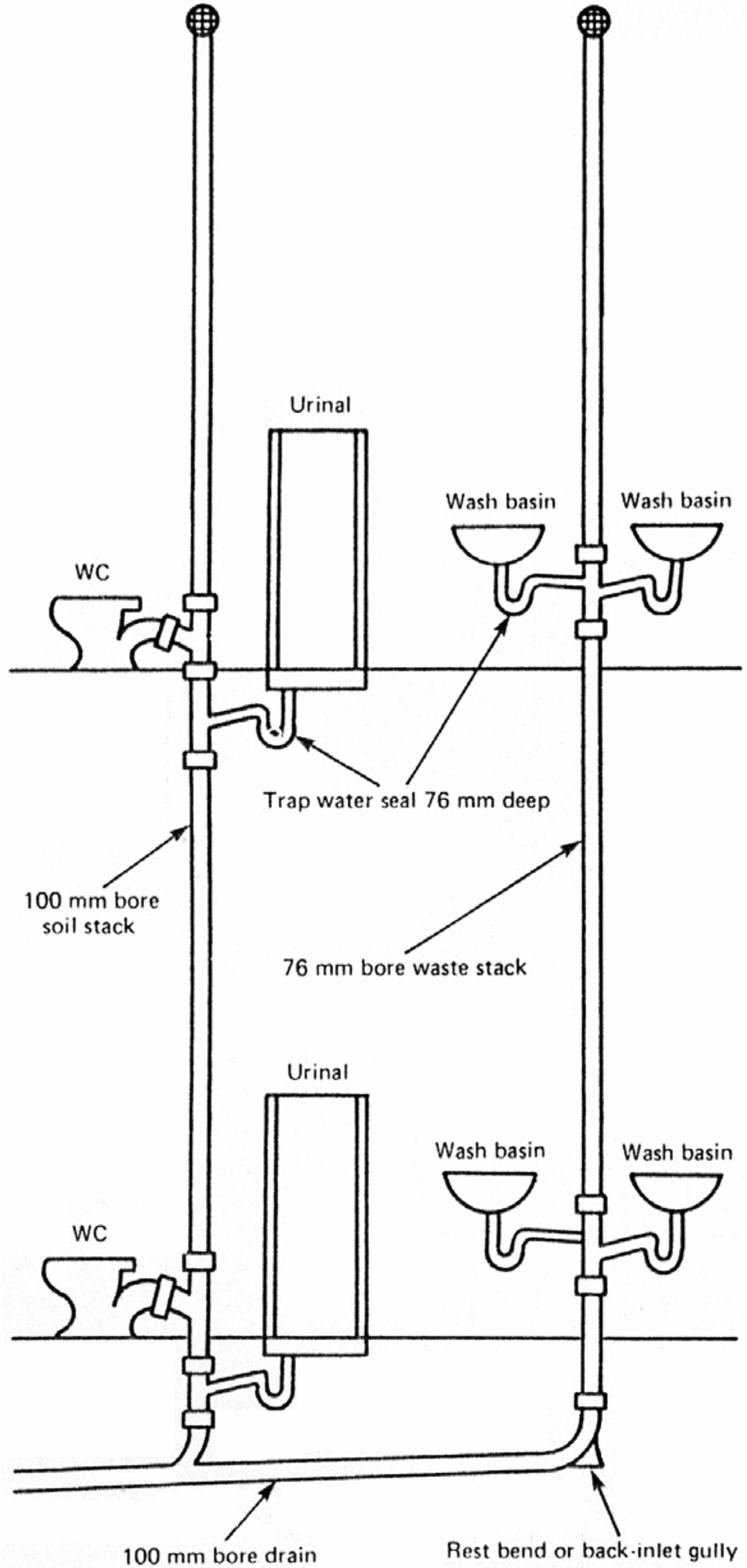
(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)



Fully ventilated one-pipe system

- A large number of sanitary appliances in ranges
- Each trap with an anti-siphon or vent pipe connected to the discharge pipe in direction of the flow of water at a point between 75 - 450 mm from trap crown
- Vent stack connected to the discharge stack near to the bend to remove compressed air at this point

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)



Two-pipe system

- The most expensive and in case with widely spaced sanitary appliances
- Wash basins or sinks in rooms far away from main soil stack → to connect these appliances to a separate waste stack
- The waste stack connected to the horizontal drain either via a rest bend

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

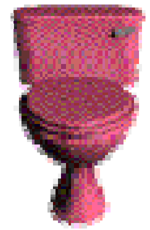
Sanitary drainage

- Drainage for basement
  - The manhole discharging to outside locates at G/F
  - Water from basement floors (some at even basement 3, about 10 meters below ground floor). How to discharge it?
    - By a sump pit and pumps installed at the lowest floor
  - Note the need of standby pump
  - Pump on/off control by level switch

Sanitary drainage

- Drainage for grease/oil generating area, such as carparks and kitchens
- Grease and oil cause problems to the sewer by accumulating on the inside of sewer pipes
  - Reduce capacity of sewer pipes and cause sewage overflows, offensive odour and an unhealthy environment
  - The cleaning of grease deposits from sewers is difficult and can be dangerous and costly

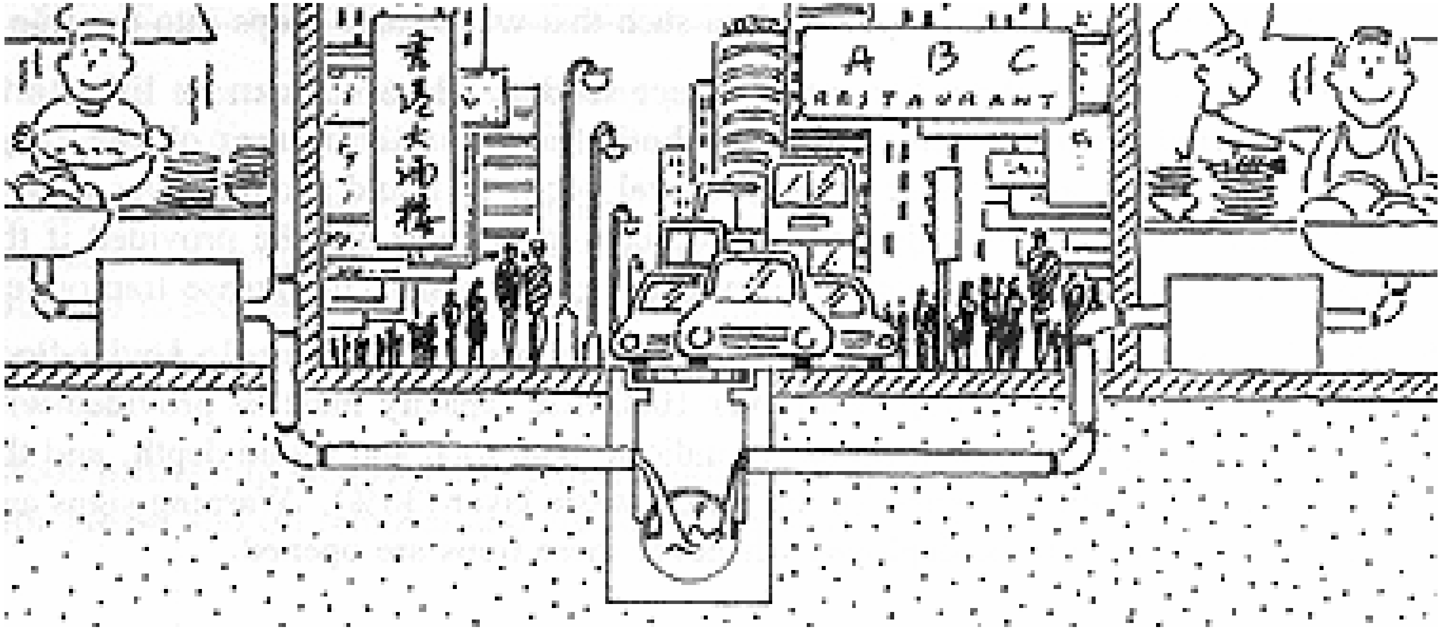
Sanitary drainage



- A petrol interceptor & grease trap are devices used for removing oil and grease from wastewaters
- Petrol interceptor
  - Water from carpark may contain oil (petrol)
  - Water from carpark could not be directly discharged to public sewer
  - Water must pass a petrol interceptor before discharging out

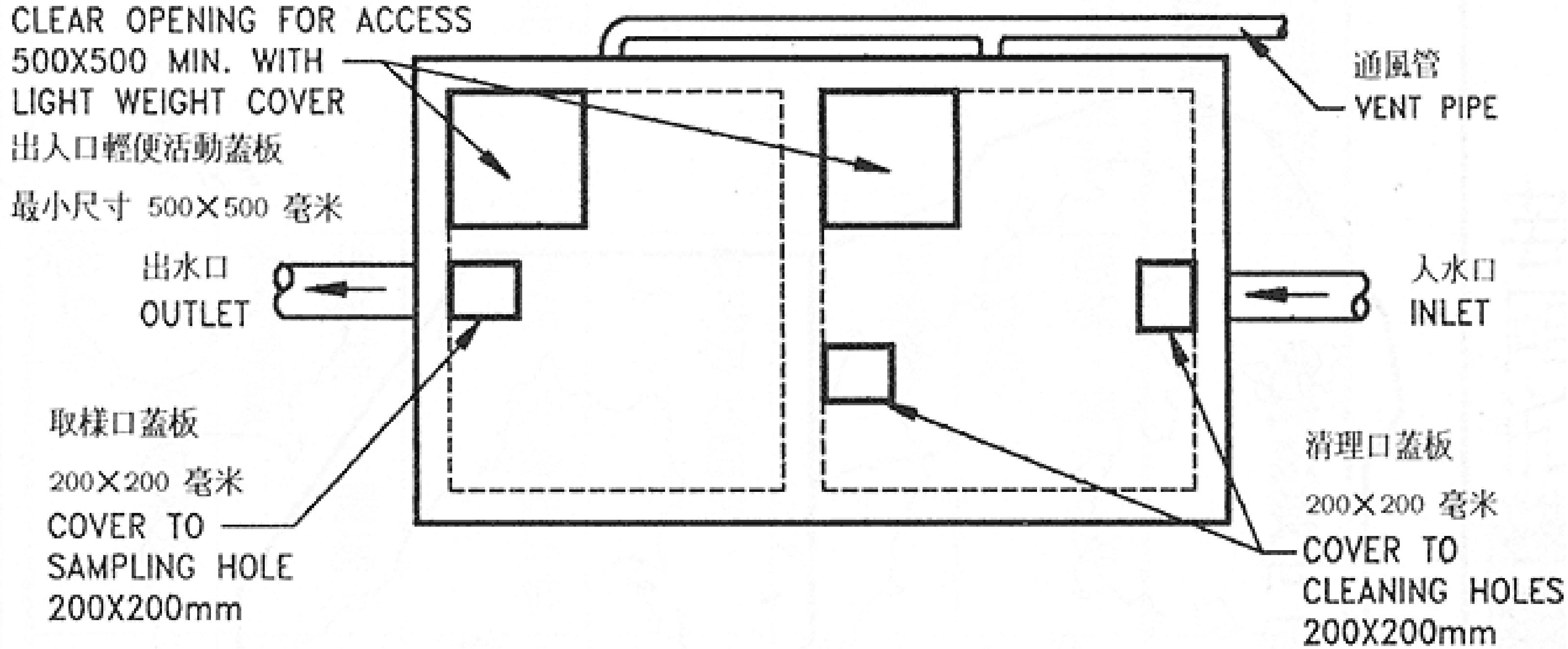
Sanitary drainage

- Grease trap
  - Kitchen from food courts and restaurants contains large quantity of grease that is not permitted to be discharged out to the public sewer
  - Water must pass through a grease trap before discharging out
  - Food license needed before food court and restaurant starting business
  - Provision of grease trap is a licensing requirement



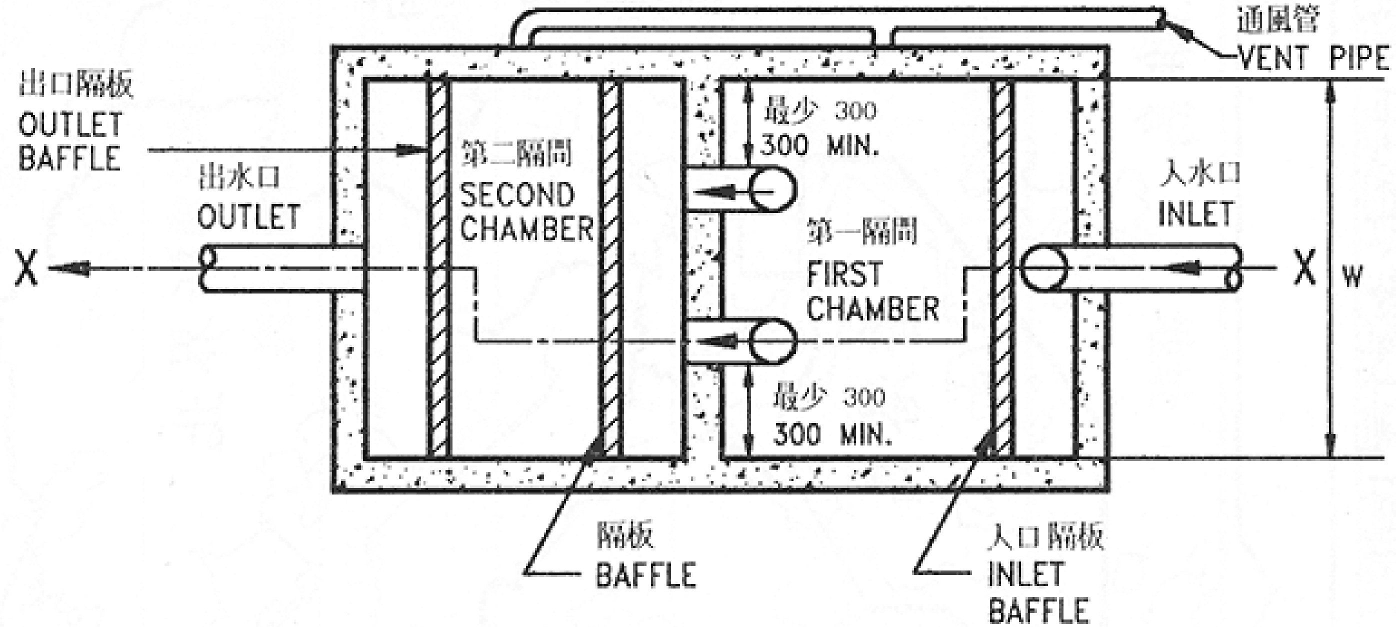
隔油池頂部外視圖(尺寸均以毫米為單位)

EXTERNAL TOP VIEW OF GREASE TRAP (all dimensions in mm)

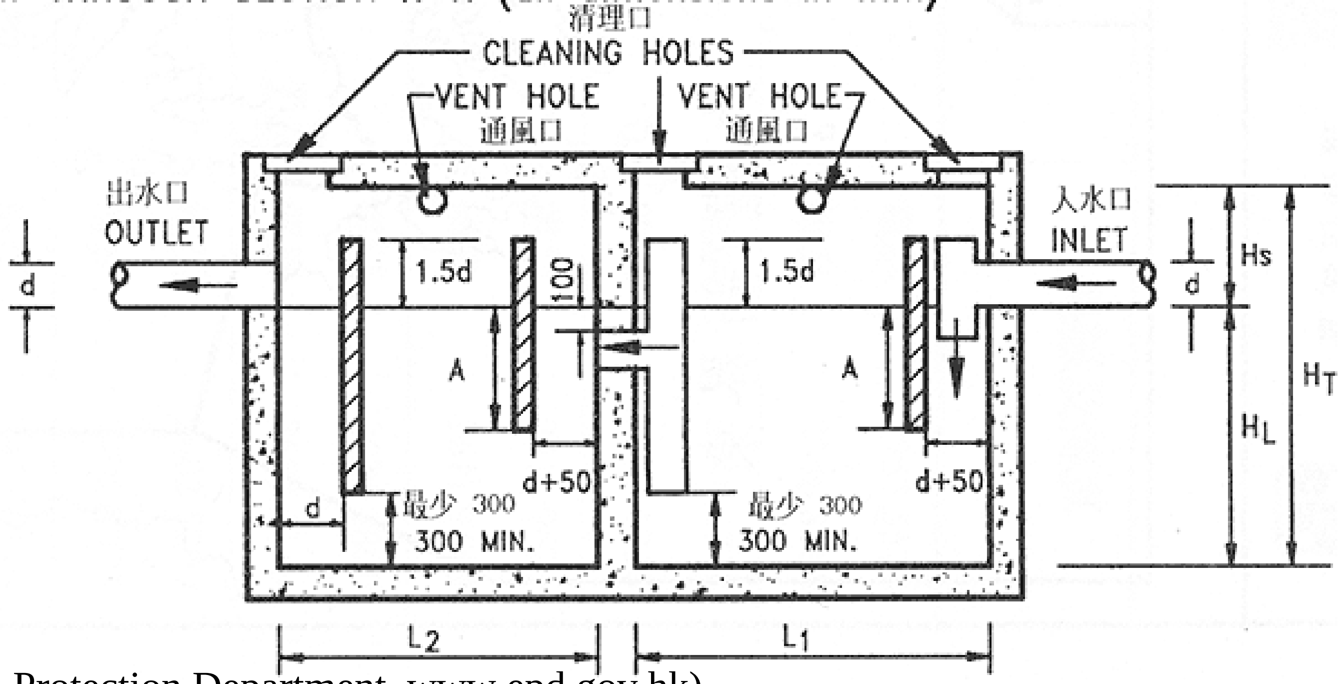


(Source: Environmental Protection Department, www.epd.gov.hk)

混凝土隔油池頂視圖[無蓋](尺寸均以毫米為單位)
TOP VIEW WITHOUT COVER, CONCRETE GREASE TRAP (all dimensions in mm)



橫切面 X - X 側視圖 (尺寸均以毫米為單位)
SIDE VIEW THROUGH SECTION X-X (all dimensions in mm)



(Source: Environmental Protection Department, www.epd.gov.hk)

Grease trap capacity requirements in HK

Average hourly water use (litres)	Kitchen floor area (sq.m)	Minimum grease trap capacity (litres)	Example internal dimensions * (mm)		
			Length	Width	Total depth
0-125	---	250	1200	525	600
250	8	490	1450	700	725
500	16	790	1700	825	850
750	24	1,050	1800	875	1000
1000	32	1,220	1950	950	1000

* The length and width dimensions do not include wall and cover thickness for concrete grease traps (typically 150 mm). For steel traps, wall thicknesses can be ignored.

(Source: Environmental Protection Department, www.epd.gov.hk)

Stormwater drainage

- Stormwater or rainwater drainage systems
  - Design for roofs, walls and ground drainage
    - Include rain water outlets, gutters, rain water stacks and occasional require sum and pump system for disposal
    - Require integration with architect
- Rain water flow rate, *Q* (l/s)
  - $Q = C \times A \times I / 3600$
    - C : impermeability factor or run-off coefficient
    - A : drainage or catchment area (m^2)
    - I : rainfall intensity (mm/hr)

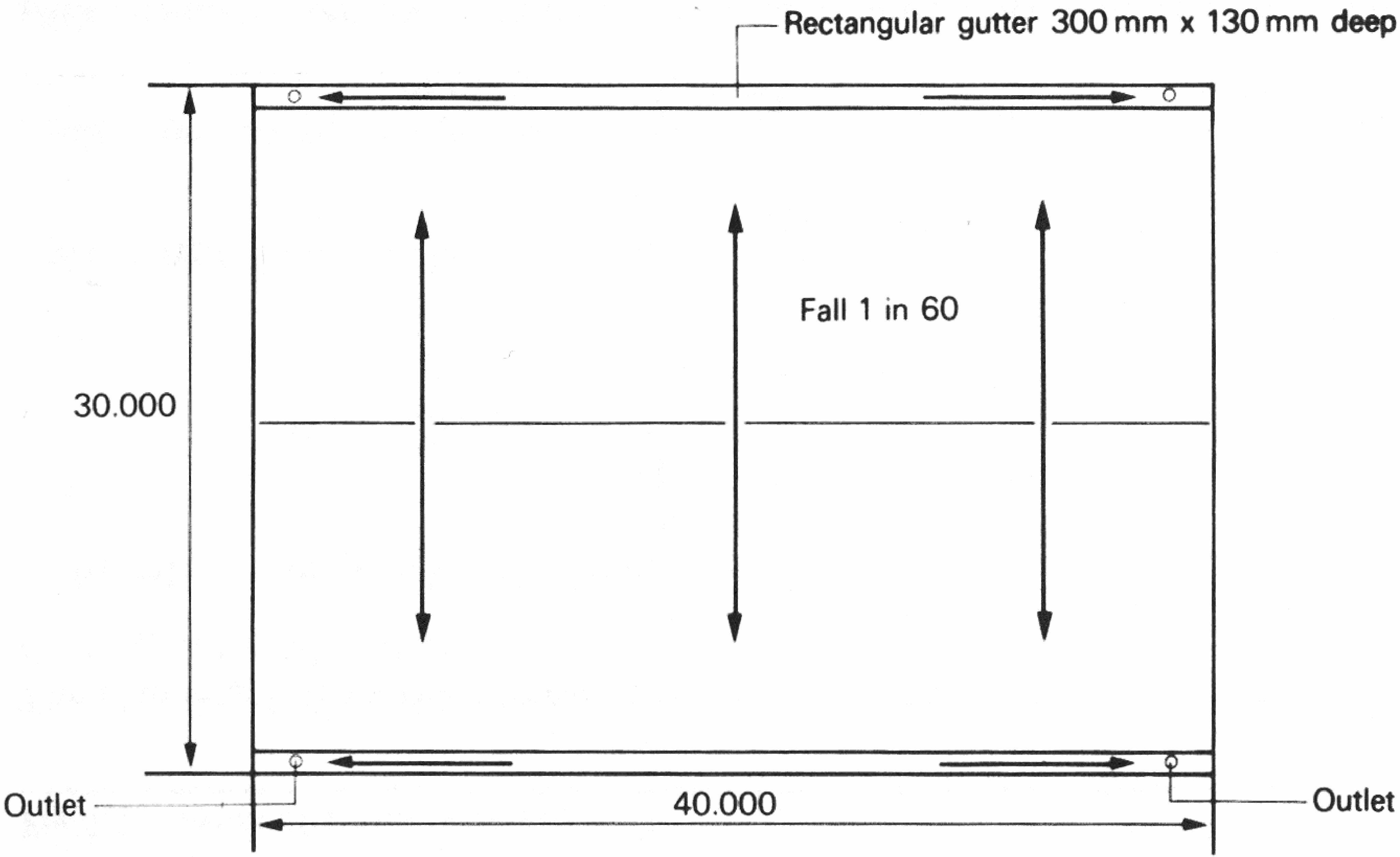
Ground impermeability factor

Nature of surface	Impermeability factor
Road or pavement	0.90
Roof	0.95
Path	0.75
Parks or gardens	0.25
Woodland	0.20

(Source: Chadderton, D. V., 2007. *Building Services Engineering*)

Stormwater drainage

- Drainage or catchment area, A (m^2)
  - It is the area that surface water will be collected and discharge to the drainage outlet
  - For catchment area with vertical wall exists, it shall include 50% of the vertical wall area:
    - $A = A_f + 0.5\ A_w$
    - where A_f is the catchment floor area, A_w is the area of vertical wall
  - The surface area shall be laid in fall to the point of drain outlet of not less than 1:100 to facilitate effective water collection



Example of flat-roof drainage

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Stormwater drainage

- Rainfall: Time of concentration, t_c (min)
  - The maximum time taken by surface water to travel from the catchment boundary to the point of drainage outlet. It can be estimated by:

$$t_c = 0.14465 \times \left(\frac{L}{H^{0.2} A^{0.1}} \right)$$

    - *H* is average fall (m per 100m) from the summit of catchment to the point of drainage outlet
    - *L* is the largest distance from catchment boundary to the point of drainage outlet (m)

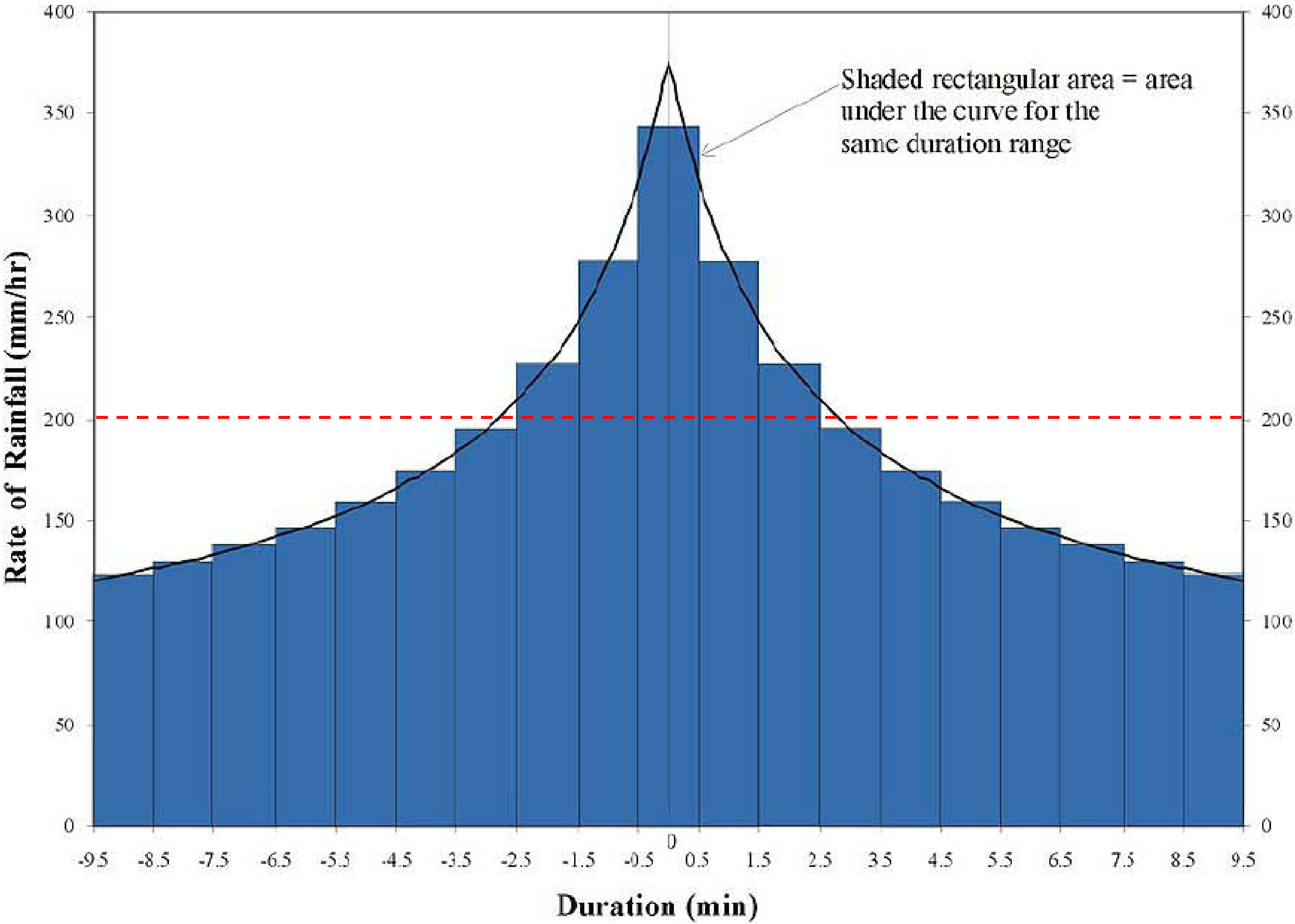
Stormwater drainage

- Select a suitable rainfall intensity based on:
  - Degree of acceptable risk to life and property
    - Use a larger value if overflow cannot be tolerated
  - Statutory requirements
  - Assessment of economic viability
- Average rainfall intensity
  - Determined by using the historical rainfall data of certain return period and duration
  - "Return period" = the period that the rainfall intensity will occur again (e.g. once every 20 years)

Stormwater drainage

- Rainfall intensity, I (mm/hr) can be estimated by the following equation that is reasonable for a 20-years return period:
  - $I = 682 / (t_c + 4.5)^{0.44}$
- It is recommended to take minimum rainfall intensity as 200 mm/hr for design
  - See also rainfall data at Hong Kong Observatory's website (www.hko.gov.hk/)

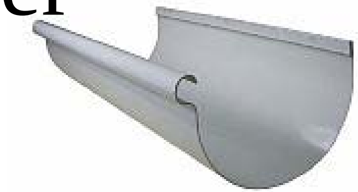
Design storm profile statistics for HK



(Source: Hong Kong Observartory, www.hko.gov.hk)

Stormwater drainage

- Flow capacity of a level half-round gutter
  - $Q = 2.67 \times 10^{-5} \times A_g^{1.25}$ l/s
  - where A_g is cross-sectional area of the gutter (mm^2)



- For level gutters other than half-round,

$$Q = \frac{9.67}{10^5} \times \sqrt{\frac{A_0^3}{W}}$$

  - where A_o is the area of flow at the outlet (mm^2); W is the width of the water surface (mm)

Stormwater drainage

- Other influencing factors
  - Fall or slope of the roof
    - A fall of 1 in 600 increases flow capacity by 40%
  - Frictional resistance of a sloping gutter
    - May reduce water flow by 10%
    - Each bend can reduce this further by 25%
  - Water flow in downpipes
    - Much faster than in the gutter
    - Will never flow full!
    - Their diameter is usually taken as 66% of gutter width

Typical flow capacities of a PVC half-round gutter at a 1 in 600 fall

Nominal gutter width (mm)	***Q* (l/s)**	
	End outlet	**Centre outlet**
75	0.46	0.76
100	1.07	2.10
125	1.58	2.95
150	3.32	6.64

(Source: Chadderton, D. V., 2007. *Building Services Engineering*)

Stormwater drainage

- Sizing vertical stacks
  - In HK, under Building Ordinance (Cap. 123), every 700 mm^2 of pipe cross-section area shall be provided for 10 m^2 of horizontal roof area
  - Also, diameter of rainwater pipe shall be 65 mm minimum
- Hydraulic design may be used to size the vertical and horizontal pipes
  - The static head should cater for the velocity head and pipe friction

Stormwater drainage

- Examples of drainage formula
  - Chezy formula: $V = C\sqrt{m \times i}$
  - Crimp and Bruges formula: $V = 84 \times m^{2/3} \times i^{1/2}$
  - Vertical stack at quarter full: $q = K \times d^{8/3}$
- More complicated one
  - Colebrook-White equation:

$$V = -2 \times \sqrt{2g \times i \times D} \times \log\left[\frac{K}{3.7D} + \frac{2.51\nu}{D \times \sqrt{2g \times i \times D}}\right]$$

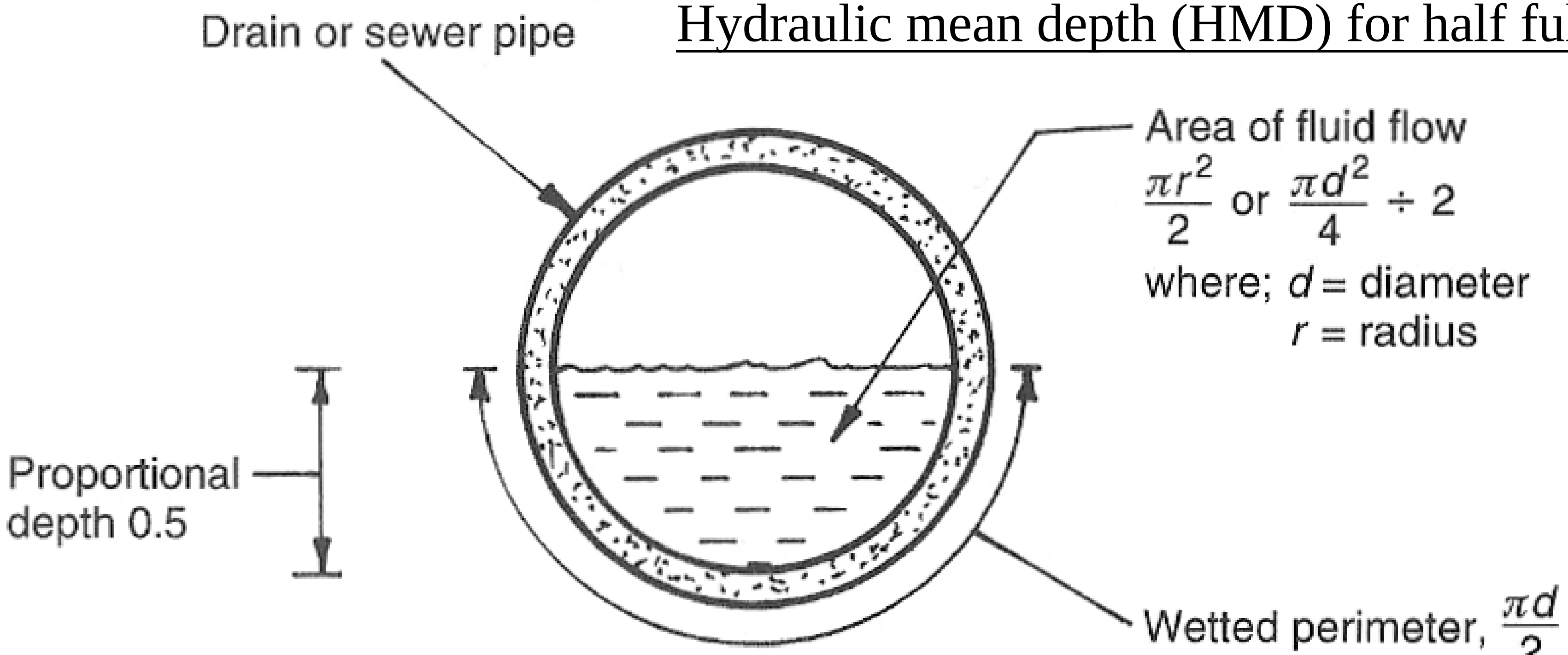
Stormwater drainage

- Velocities of flow
  - Normally, 0.75 m/s is the accepted minimum to achieve self-cleansing
  - An upper limit is required to prevent separation of liquid from solids
    - Such as 1.8 m/s for both surface & foul water drainage
    - Figures up to 3 m/s can be used if grit is present
  - The flow velocity will have a direct impact on drain gradient

Stormwater drainage

- Hydraulic mean depth (HMD)
  - Also known as hydraulic radius, represents the proportion or depth of flow in a drain
  - Calculated by dividing the area of water flowing in a drain by the contact or wetted perimeter
  - Drains are usually at maximum 0.75 full bore
  - Half full bore (0.5) is a more conservative design, allowing ample space for future connection & extension to the system

Hydraulic mean depth (HMD) for half full bore



$$HMD = \frac{\pi r^2}{2} \div \frac{\pi d}{2}$$

Depth of flow	HMD
0.25	Pipe dia. (m) / 6.67
0.33	Pipe dia. (m) / 5.26
0.50	Pipe dia. (m) / 4.00
0.66	Pipe dia. (m) / 3.45
0.75	Pipe dia. (m) / 3.33
Full	Pipe dia. (m) / 4.00

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Drainage design formulae:-

Chezy's formula: $$V = C\sqrt{m \times i}$$

where V = velocity of flow (min. 0.75 m/s)

C = Chezy coefficient

m = hydraulic mean depth (HMD)

i = inclination or gradient as 1/X

Manning's formula: $$C = \frac{m^{1/6}}{n}$$

where C = Chezy coefficient

n = coefficient of pipe roughness (0.010 for uPVC and clay drainware; 0.015 for cast concrete)

m = hydraulic mean depth (HMD)

Example:- A 300 mm (0.3 m) nominal bore drain pipe flowing 0.5 proportional depth (half full bore). The Chezy coefficient can be calculated from Manning's formula:

HMD = 0.3 / 4 = 0.0.75

$C = (0.075)^{1/6} / (0.010) = 65$

Using a velocity of flow of 1.4 m/s, the minimum gradient can be calculated from Chezy's formula:

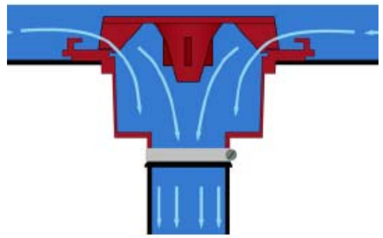
$$V = C\sqrt{m \times i}$$

$1.4 = 65 \text{ x } \sqrt{(0.075 \text{ x } i)}$

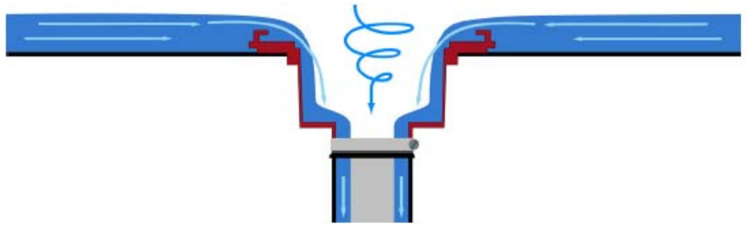
Thus, $i = (1.4/65)^2 / 0.075 = 0.00617$ **or 1 in 162**

Stormwater drainage

- Siphonic roof drainage system
  - First developed in Finland and Sweden in 1960’s
  - “Full-bore” flow (completely fill the pipe)

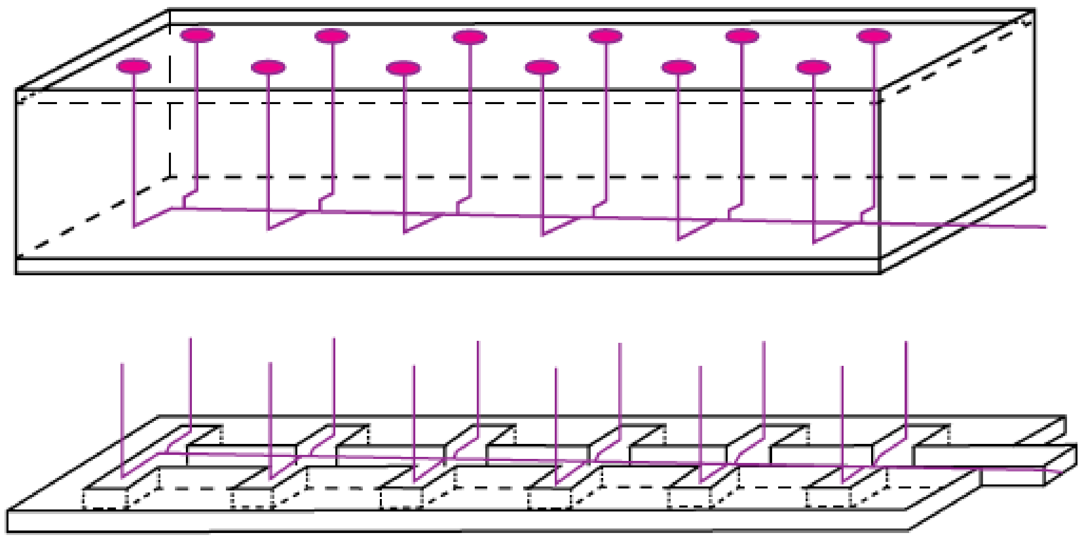


  - Syphonic outlets
    - Designed to reduce the entry of air into the system & stop vortices forming



  - Vertical stack pipe
    - Create siphonic action (negative pressure) to drain water along a horizontal collector pipe

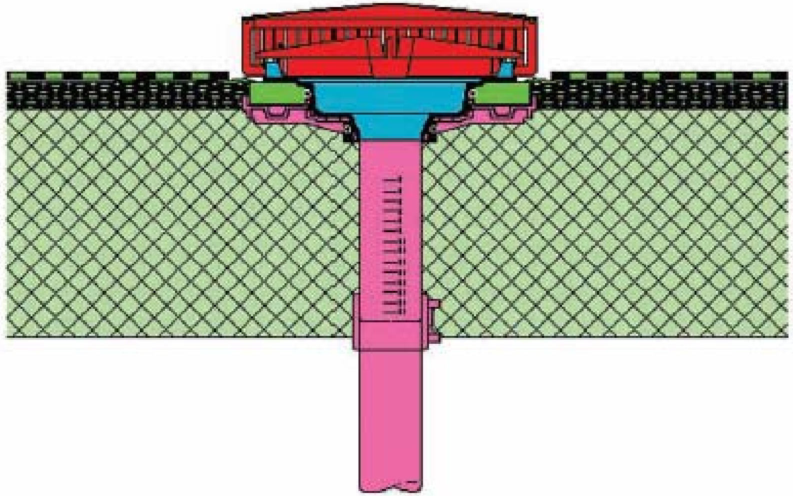
Conventional roof drainage system



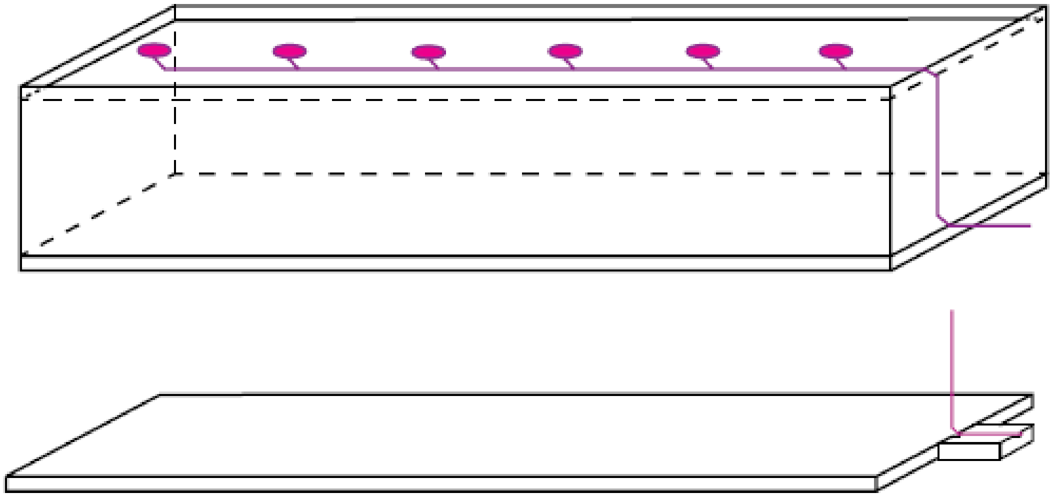
- sloped collecting lines
- numerous stack lines
- extensive groundwork

Siphonic outlet

Siphonic outlet



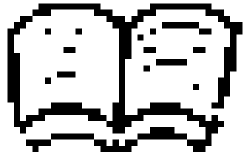
Siphonic roof drainage system



- horizontal collecting lines
- few stack lines
- minimal groundwork

(Source: www.siphonic.com.au)

Further reading



- BSE notes (www.bsenotes.com): Drainage
  - Introduction
  - Design Points
  - Typical Schemes
  - Gradients, Invert Levels & Manholes
  - Basic Sizing
  - Testing