Table C.1 – Indicative outdoor ventilation velocities (u_w)

Type of outdoor locations	Unobstructed areas			Obstructed areas		
Elevation from ground level	≤ 2 m	> 2 m up to 5 m	> 5 m	≤ 2 m	> 2 m up to 5 m	> 5 m
Indicative ventilation velocities for estimating the dilution of lighter than air gas/vapour releases	0,5 m/s	1 m/s	2 m/s	0,5 m/s	0,5 m/s	1 m/s
Indicative ventilation velocities for estimating the dilution of heavier than air gas/vapour releases	0,3 m/s	0,6 m/s	1 m/s	0,15 m/s	0,3 m/s	1 m/s
Indicative ventilation velocities for estimating the liquid pool evaporation rate at any elevation	> 0,25 m/s			> 0,1 m/s		
Generally, values in the table may be considered with an availability of ventilation fair (see D.2). For indoor areas, the evaluations should normally be based on an assumed minimum air speed of 0,05 m/s, which will be present virtually everywhere. Different values may be assumed in particular situations (e.g. close to the air inlet/outlet openings). Where ventilation arrangement can be controlled, minimum ventilation velocity may be calculated.						

C.3.5 Assessment of the degree of dilution

The degree of dilution may be assessed by using the chart in Figure C.1:

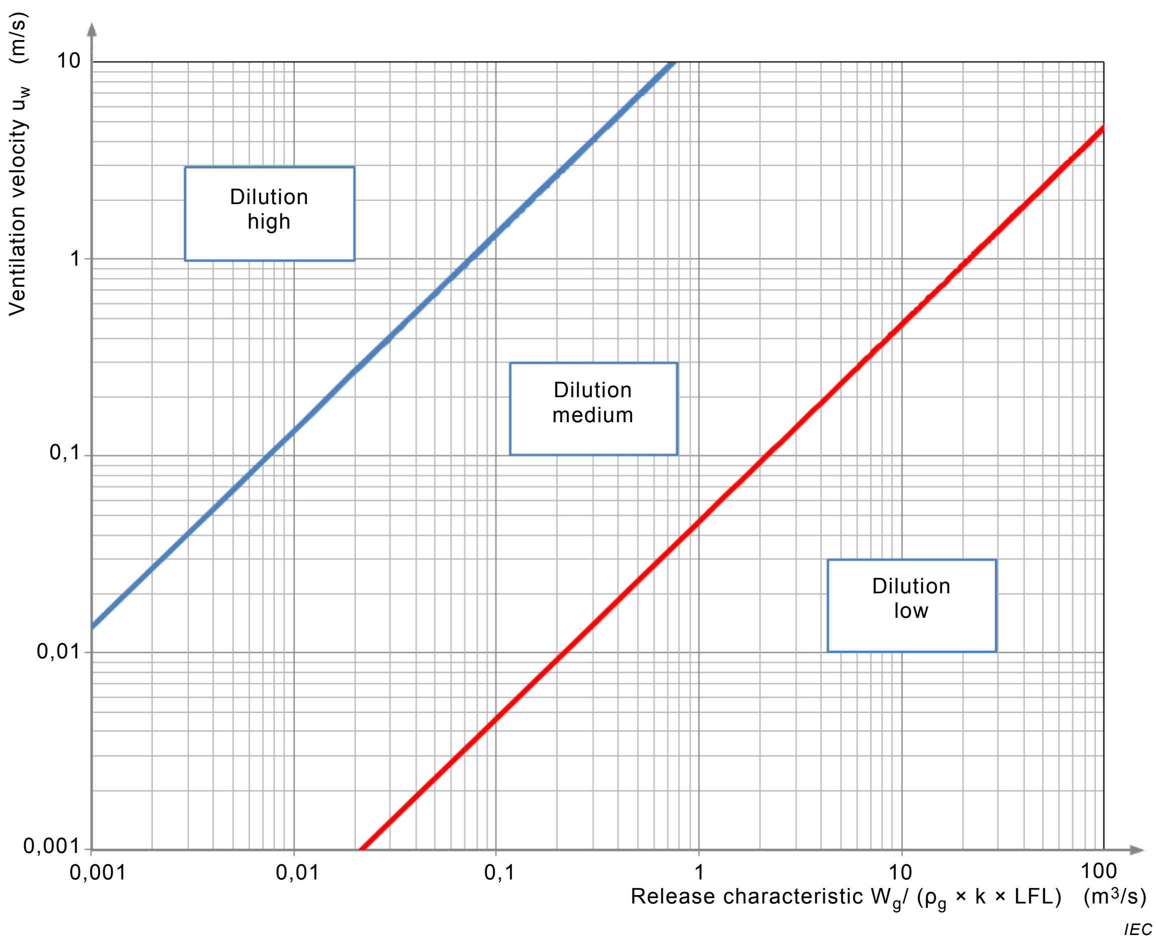


Figure C.1 – Chart for assessing the degree of dilution

Where

$\frac{W_g}{\rho_g \, k \, LFL}$ is a characteristic of release in (m^3/s);

$\rho_g = \frac{p_a M}{R \, T_a}$ is the density of the gas/vapour (kg/m^3);

k is the safety factor attributed to LFL, typically between 0,5 and 1,0.

Figure C.1 is based on an initial zero background concentration.

The degree of dilution is obtained by finding the intersection of respective values displayed on horizontal and vertical axis. The line dividing the chart area between 'dilution high' and 'dilution medium' represents a flammable volume of 0,1 m^3, so any intersection point left to the curve implies an even smaller flammable volume.

In outdoor locations where there are no significant restrictions to air flow, the degree of dilution should be classified as medium if the condition for high dilution is not met. A low degree of dilution will not generally occur in open air situations. Situations where there are restrictions to air flow, for example, in pits, should be considered in the same way as an enclosed area.

For indoor applications users should also assess the background concentration in accordance with C.3.6.2 and if the background concentration exceeds 25 % of the LFL the degree of dilution should generally be considered as low.

C.3.6 Dilution in a room

C.3.6.1 General

Dilution may occur by either the exchange of fresh air that dominates the release of the gas or vapour or by having sufficient volume to allow the gas or vapour to disperse to a low concentration even with minimal fresh air. In this later case the volume available for dilution must be high with respect to the anticipated volume of the release.

For a jet release of gas, dilution may occur even without any local air movement due to entrainment of air in the expanding jet. However if a jet is impeded due to impact on nearby objects then the ability for self dilution is greatly reduced.

The degree of dilution can also be assessed by assessment of the average background concentration of the flammable substance (see C.3.6.2). The higher the ratio of release rate against the ventilation rate the higher will be the background concentration X_b and the lower will be the degree of dilution.

In assessing background concentration the release rate, ventilation rate and efficiency factor must be carefully selected to take into account all relevant factors considering an appropriate safety margin. The ventilation efficiency factor should recognize if there is a possibility of recirculating or impeded air flow in a space which may reduce the efficiency compared to a good air flow pattern.

A zero background concentration should be considered only outdoors or in regions with local extraction ventilation which controls the movement of flammable substance near the source of release. A negligible background concentration, described as $X_b << X_{crit}$, may be considered in highly ventilated rooms or enclosures. X_{crit} is an arbitrary value below LFL, e.g., the value at which a gas detector is set to alarm.

A low background concentration does not mean that the whole room is a non hazardous area. The larger part of the room may be considered non hazardous but the area near the source of the release is still a hazardous area until the release is sufficiently dispersed (similar as for open air situations).

Consideration of background concentration and the extent of possible zones around sources of release also need to be moderated with practical factors considering variations in possible dispersion patterns in an enclosed space. Many enclosed areas contain multiple sources of release and it is not good practice to have multiple small hazardous areas within an enclosed area generally classified as non hazardous. Also, it is not good practice to have a limited hazardous area within a relatively small room and the whole room should be considered for a uniform classification.

C.3.6.2 Background concentration and releases in a ventilated room

For indoor releases it is necessary to specify the room background concentration, X_b, which embodies the effects of ventilation. Background concentration is the mean concentration of flammable substance within the volume under consideration (room or building) after a period of time during which a steady state has been established between the release and the flow of air induced by ventilation.

Consideration of the background concentration then provides a measure for assessing ventilation in a room which removes gas or vapour compared to dispersion of the gas or vapour. This ratio then influences the consideration of the degree of dilution.

The background (vol/vol) concentration may be assessed as:

$$X_b = \frac{f \times Q_g}{Q_g + Q_1} = \frac{f \times Q_g}{Q_2} (\text{vol/vol}) \quad (C.1)$$

and the air change frequency and ventilation flux are related by:

$$Q_2 = CV_0 \left(\text{m}^3/\text{s}\right)$$

The average background concentration X_b which is ultimately achieved depends on the relative magnitude of source and ventilation fluxes, but the timescale over which this is achieved is inversely proportional to the air change frequency.

The factor f is a measure of the degree to which the air in the enclosure outside of the release zone is well mixed and can be considered as follows:

- $f = 1$; the background concentration is essentially uniform and the outlet is distant from the release itself, so that the concentration at the outlet reflects the mean background concentration.
- $f > 1$; there's a gradient of background concentration in the room due to inefficient *mixing*, and the outlet is distant from the release itself, so that the concentration at the outlet is smaller than the mean background concentration. f may be between 1,5 for mildly inefficient mixing and 5 for very inefficient mixing.

Given the origin of the cases $f = 1$ or $f > 1$, this value may be denoted as a safety factor related to the inefficiency of mixing (as progressively larger values reflect progressively less efficient mixing of air within the room). This factor allows for imperfections of air flow patterns in a real space with obstructions and where ventilation openings may not be ideally positioned for maximum ventilation (see C.5).

NOTE Ventilation alone which describes how air enters the room has little to say about the expected hazardous volume. That depends on how the gas, or vapour and air are distributed within the room, i.e. on dispersion.

C.3.7 Criteria for availability of ventilation

C.3.7.1 General

The availability of ventilation has an influence on the presence or formation of an explosive gas atmosphere. Thus the availability (as well as the degree) of ventilation needs to be taken into consideration when determining the type of zone.

Three levels of availability of the ventilation should be considered (see Table D.1):

- **good:** ventilation is present virtually continuously;
- **fair:** ventilation is expected to be present during normal operation. Discontinuities are permitted provided they occur infrequently and for short periods;
- **poor:** ventilation which does not meet the standard of fair or good, but discontinuities are not expected to occur for long periods.

Ventilation that does not even meet the requirement for poor availability must not be considered to contribute to the ventilation of the area, i.e. low dilution would apply.

Different types of ventilation require different approaches for assessing their availability, e.g. availability of natural ventilation indoors shall never be considered as good because it depends heavily upon ambient conditions, i.e. outdoor temperature and wind (see C.5). As a matter of fact, the availability of natural ventilation depends on how realistic the assessment of indoor or outdoor conditions has been, i.e. whether the worst case scenario has been applied. If yes, then it may be that the level of availability could be fair, but never good. It has to be assumed that the higher the difference between indoor and outdoor temperature applied for calculation, the lower the level of availability in terms of diluting an explosive atmosphere.

On the other hand, artificial ventilation that serves the areas exposed to explosion conditions usually has a good availability because it incorporates technical means to provide for high degree of reliability.

The level of availability should be assessed as realistically as possible taking into account all the relevant factors. For outdoor gas jet releases dilution will occur irrespective of the ambient wind, and so the dispersion must be considered as being equivalent to good availability of ventilation indoors.

C.3.7.2 Criteria for natural ventilation

In case of natural ventilation, the worst case scenario shall be considered to determine the degree of ventilation. Such a scenario will then lead to a higher level of availability. Generally, for any natural ventilation, a lower degree of ventilation leads to a higher level of availability and vice versa. That will compensate for too optimistic assumptions made in the procedure of estimating the degree of ventilation.

There are some situations which require particular care. In the case of natural ventilation of enclosed spaces, consideration of unfavorable conditions needs to be accounted for. I.e. frequency and probability of occurrence of such situations. As an example, during hot and windy summer days, two potential scenarios exist. In one scenario the indoor temperature may be slightly above the outdoor temperature so that buoyancy induced ventilation may hardly work and the wind from a certain direction may prevent the flow of air. Therefore in this case there is a combination of poor ventilation and a poor availability which will likely result in a more onerous classification. In another scenario, if only buoyancy is considered, then modest, buoyancy induced ventilation could be present virtually all the time and hence the availability could be estimated as fair if not good.

In open air situations the degree of dilution is generally considered as medium while the availability of ventilation in terms of wind presence may be considered as good unless there is restricted ventilation such as within pits, dykes or areas surrounded by high structures.

C.3.7.3 Criteria for artificial ventilation

In assessing the availability of artificial ventilation, the reliability of the equipment and the availability of, for example, standby blowers should be considered. Good availability will normally require, on failure, automatic start-up of standby blower(s). However, if provision is made for preventing the release of flammable substance when the ventilation has failed (for example, by automatically closing down the process), the classification determined with the ventilation operating need not be modified, i.e. the availability may be assumed to be good.

C.4 Examples of ventilation arrangements and assessments

C.4.1 Introduction

The following examples are intended to illustrate the interaction between the release of flammable substance and ventilation based on the principles outlined in clauses 6 and 7. It is important to understand that dilution is a complex process which takes place either through air entrainment at the boundaries of a release jet, or through mixing with air caused by ventilation flow or atmospheric instabilities. Usually, both mechanisms are considered because a jet eventually becomes a passive plume susceptible to air movement. Mixing with air generally does not happen uniformly throughout the ventilated space and the background concentration as the result of the mixing with air is just a very rough measure of the average contamination of the volume under consideration.

In a real ventilated space the ventilation arrangement may not be adequate to dilute the flammable substance uniformly. In practice the true nature of dispersion and dilution may substantially deviate from the average results obtained by calculation. The ventilation arrangement, i.e. position of the inlet and outlet openings relative to each other and relative to source of the release, may sometimes have greater influence on the atmosphere than the capacity of the ventilation itself.

The examples below illustrate a few possible scenarios which may help in better understanding of the ventilation arrangements that may be suited for a particular situation.

C.4.2 Jet release in a large building

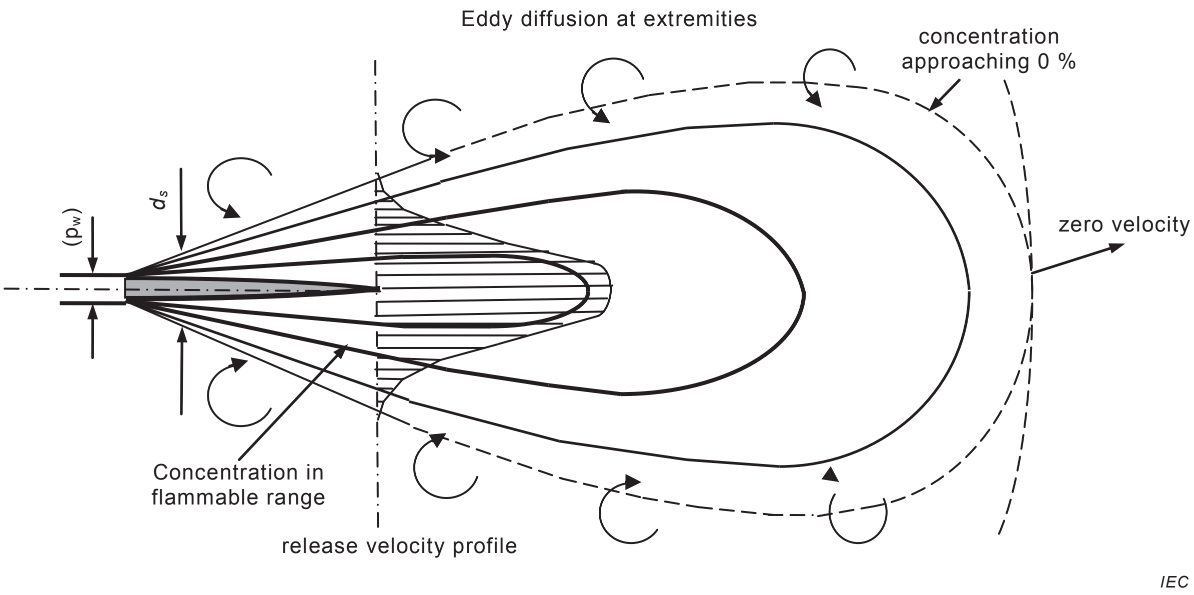
This example (see Figure C.2) illustrates the conditions where there are a limited number of sources of gas release in a large space e.g. gas release from pipe fittings.

A small leak in a pipe fitting would be expected to create a jet release with a high velocity if the pressure is high. The jet would self dilute and disperse even without much other apparent air movement in the building.

For a space with normal ventilation, (e.g. good sized door and wall openings and/or roof ventilation or other designated ventilation provisions), the volume of the space and natural air movement would suggest the degree of dilution is medium and the availability of ventilation is fair.

For a space with poor ventilation, (e.g. an unventilated basement), a jet release may initially self dilute and disperse into the space but the lack of air movement may also lead to a longer term build up of gas in the space. In this situation the diluted gas from the release will be re-entrained in the continuing jet release resulting in a build-up of the background gas concentration.

Unless the ventilation provisions are adequate to control the background concentration in the space the degree of dilution is considered low. However it may still be practical to provide for different zone classifications throughout the space.



NOTE d_s is pseudo source radius, i.e. the radius of the jet at the downstream cross section at which it becomes isobaric (reduced to atmospheric pressure).

Figure C.2 – Self diffusion of an unimpeded high velocity jet release

C.4.3 Jet release in a small naturally ventilated building

This example illustrates conditions where there may be sources of gas release in a small room or building.

Dispersion and dilution factors are the same as described in 6.5.4.

Where the building includes provision for ventilation to ensure adequate removal of any gas from a release then the interior of the building may be considered to have a medium degree of dilution.

Where there are a limited number of sources of release (or locations for the sources of release) it may be practical to classify hazardous areas that are limited to regions around the sources of release. Where there are large numbers of possible sources of release then it is common practice to classify the entire space with a single zone classification. This reflects the consideration of the self dilution volume from a jet from many possible positions and the possible variants in gas or vapour dispersion from various locations.

Where the degree of dilution is low then it is normal practice to provide a single zone classification for the enclosed space irrespective of the number of sources of release.

C.4.4 Jet release in a small artificially ventilated building

This example (see Figure C.3) might apply to a situation such as a gas compressor room.

Irrespective of the rate of ventilation or arrangement of a ventilation system a jet release is not likely to be diluted to below the *LFL* immediately at the source of release unless the pressure is very low. Therefore the degree of dilution at the source of release can rarely be described as high.

The degree of dilution for the remainder of the space is largely dependent on the arrangement and rate of artificial ventilation. The degree of dilution may also be highly sensitive to both these factors as illustrated by Figure C.3 and Figure C.4.

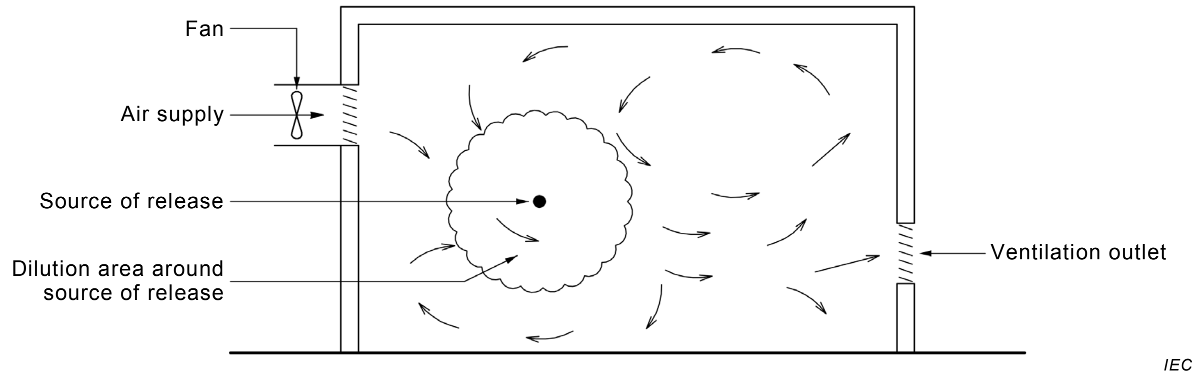


Figure C.3 – Supply only ventilation

In this case an enclosed space is supplied with fresh air with an equal volume discharging through a vent.

Despite an apparently high number of air changes per hour the ventilation arrangement can create a circulatory air movement within the enclosure resulting in an elevated background concentration. An alternative way of looking at this is that the re-entrained gas increases the dilution volume from the sources of release. Where this happens the degree of dilution should be treated as low.

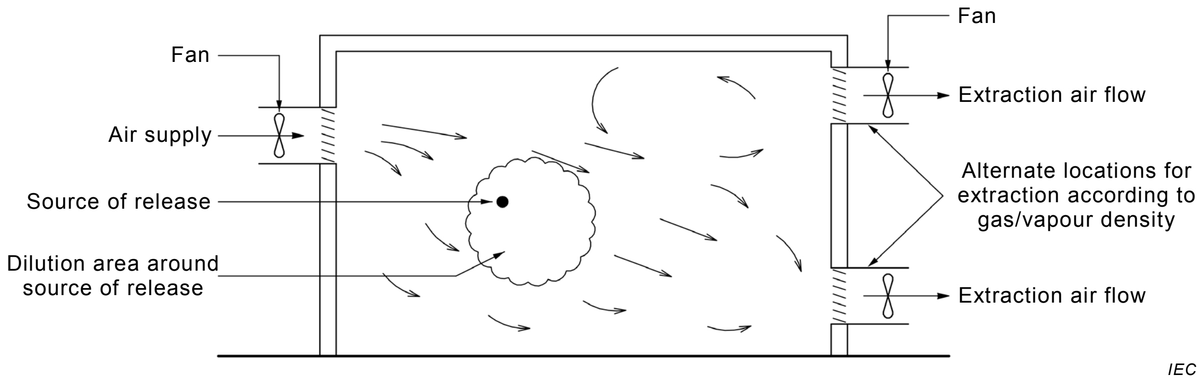


Figure C.4 – Supply and extraction ventilation

In this case the enclosed space is provided with both supply and extraction ventilation. As with the case for supply only there is a possibility that the ventilation arrangement will create recirculating air movement and result in re-entrainment of the diluted gas into a jet release thereby increasing the background gas concentration.

With careful consideration of the ventilation arrangements and positioning of the extraction points it is possible to minimize any re-circulatory air patterns. In this case a degree of dilution of medium or even high may be achieved.

NOTE Ventilation is commonly applied as an extraction system only which may be either general or local (for local extraction ventilation see 6.5.3.3).

C.4.5 Release with low velocity

Releases at low velocity are common in many industrial processes and include applications such as evaporation of flammable liquids from vents, baths, drains or printing and painting.

A jet release may also be considered a low velocity release if the jet impinges on a surface. Velocity of the jet can be reduced with the jet turning into a passive plume.

For releases at low velocity dispersion and dilution are influenced largely by air movement in the space and the buoyancy of the gas or vapour.

As for jet releases the degree of dilution will be dependent on the size of the building or room, rate of release and ability to control any background concentration by general ventilation.

C.4.6 Fugitive emissions

Fugitive emissions are small releases of gases or vapours from pressurized equipment due to leaks (generally in an order of magnitude between 10^{-7} kg/s and 10^{-9} kg/s). Though small, these releases can still accumulate in enclosures that are not ventilated.

Such fugitive emissions may accumulate in the course of time thus giving rise to an explosion hazard. Therefore, care must be taken when designing particular facilities or equipment such as analyzer houses and sealed enclosures e.g. instrument panels or instrument weather protection enclosures, thermally insulated heated enclosures or enclosed spaces between pipe installations and the envelope of thermal insulation or similar items with higher pressure gas lines. Such items should be provided with some ventilation or provision for gas dispersion even if only for critical periods of time. Where that is not possible or, practicable, effort should be made to keep major potential sources of release out of enclosures, e.g. pipe connections should normally be kept out of insulation enclosures as well as any other equipment that may be considered a potential source of release.

Where tightly closed enclosures are used the effectiveness and availability of ventilation in such enclosures with natural ventilation may need consideration as low and poor respectively.

C.4.7 Local ventilation-extraction

Local artificial ventilation is recommended wherever practical (see Figure C.5).

Local artificial ventilation can improve the degree of dilution near to the source of release. More importantly local artificial ventilation should control the movement of the gas or vapour to limit gas or vapour beyond the intended area of influence of the local ventilation system. Where this is achieved the degree of dilution around the source of release can be considered as medium.

Generally local artificial ventilation should be located close to the source of release to be effective. Local artificial ventilation can be very effective where the source of release is characterized by a very low release velocity. As local artificial ventilation needs to overcome the release velocity of the gas or vapour to control the movement of that release, the applicability of local artificial ventilation for jet releases is greatly reduced over other forms of release.

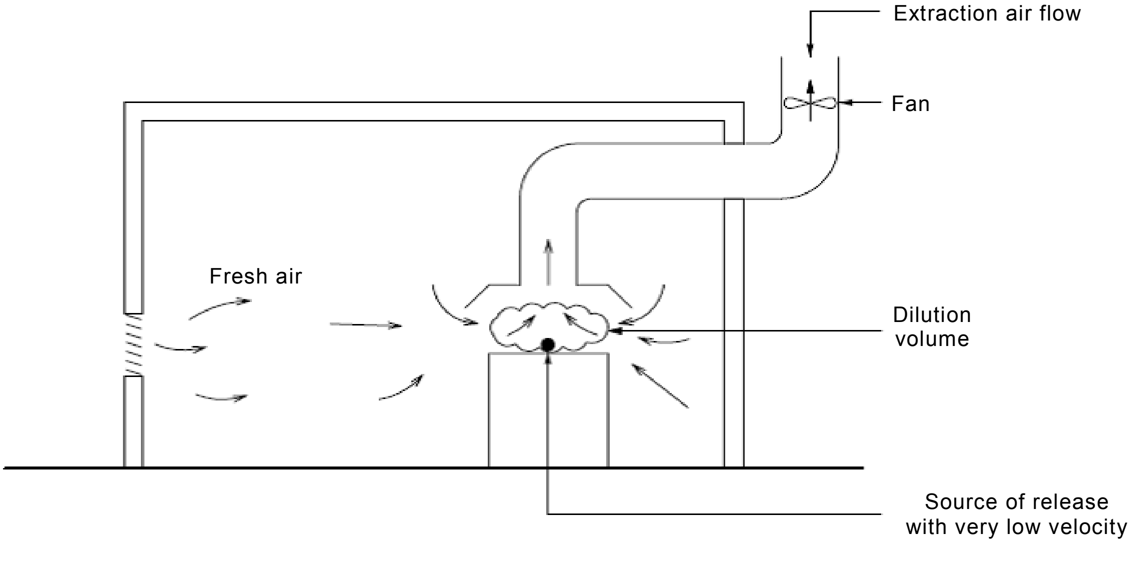


Figure C.5 – Local extraction ventilation

C.5 Natural Ventilation in buildings

C.5.1 General

The clauses below provide a means for assessing the natural ventilation in buildings.

Caution needs to be applied as without evidence and specific building features to promote natural ventilation, the size and shape of the building may not be conductive to promoting natural ventilation and in such cases the degree of the natural ventilation efficiency should be considered as low.

C.5.2 Wind induced ventilation

The degree of air movement in the interior of a building will depend on the size and position of the openings relative to wind direction, as well as on the shape of the building. Ventilation flows may be induced by infiltration through non-airtight doors and windows or cracks and gaps in parts of the structure even if there are no 'architectural' openings in the walls and/or roof, or if those are closed. The equations used here assume flow through openings designed for ventilation, rather than infiltration. This philosophy is also appropriate to adopt for the classification of hazardous areas.

Ventilation implies both ingress and egress of air and some openings will act primarily as inlet openings and others as outlet openings. Windward (upwind) openings will normally act as the inlet openings and leeward (downwind) and roof openings as the outlet openings. This implies that wind induced ventilation could be estimated only with a good knowledge of the wind rose diagram for a particular location.

The driving force of wind induced ventilation is the pressure differential between the windward and leeward sides of a building.

The air flow due to wind can be expressed as:

$$Q_a = C_d A_e u_w \sqrt{\frac{\Delta C_p}{2}} \left(m^3/s\right) \quad (C.2)$$

$$A_e = \sqrt{\frac{2A_1^2 A_2^2}{A_1^2 + A_2^2}} \left(m^2\right) \quad \text{(C.3)}$$

Values for C_d should be derived from ventilation or building codes.

The values for A_1 and A_2 refer to effective areas of the upwind and the downwind openings respectively.

CFD modelling or wind tunnel testing may also be used to provide a more reliable assessment of the pressure coefficient for a building.

Wind strength and direction are variable and not generally predictable. Guidance on wind speed is provided in Table C.1. Wind should be considered in conjunction with other types of ventilation to verify whether it complements or opposes other ventilation. Wind may have a positive effect if the inlet and outlet openings for purely wind-induced ventilation are the same as they would have been for other sources of ventilation, but an impairing effect if they are opposed. e.g. wind of any direction will have a positive effect if there is a ventilation opening on the roof top, but will have an impairing effect if the outlet ventilation openings happen to be upwind.

C.5.3 Buoyancy induced ventilation

Buoyancy induced 'Stack Effect' ventilation is accomplished by the movement of air due to the difference between indoor and outdoor temperatures. The driving force is the difference in air density due to the different temperatures. The vertical pressure gradient depends on the density of air and will therefore not be the same indoors and outdoors, leading to a pressure difference.

If the average indoor temperature is higher than the outdoor temperature the indoor air will have a lower density. If an enclosed space has openings at different heights air will enter through the lower openings and leave through the upper level openings. The flow rate will increase as the magnitude of the temperature difference grows larger. Therefore buoyancy induced ventilation will be more effective at lower ambient outdoor temperatures. At higher ambient outdoor temperatures buoyancy induced ventilation will become less effective and if the ambient outdoor temperature rises above the indoor temperature the flow would reverse.

The indoor temperature may be higher due to natural causes, deliberate heating or process heat. Thermal currents may also be induced indoors varying the effect of average indoor temperature. Assuming that the inside of the building is fully mixed, constant temperatures can be used both inside and outside.

For a temperature gradient, assuming the inside temperature at the lower opening is the same as the outside temperature, T_{out}, and the inside temperature at the upper opening is T_{in}, the volume flow rate of air can be calculated from the following equation:

$$Q_a = C_d A_e \sqrt{\frac{\Delta T}{\left(T_{in} + T_{out}\right)} g H} \left(m^3/s\right) \quad \text{(C.4)}$$

$$A_e = \sqrt{\frac{2A_1^2 A_2^2}{A_1^2 + A_2^2}} \left(m^2\right) \quad \text{(C.5)}$$

The values for A_1 and A_2 refer to effective areas of the lower and the upper openings respectively.