

**ENVIRONMENT PROTECTION AUTHORITY
of NSW**

**GUIDELINES FOR ESTIMATING CHIMNEY HEIGHTS
FOR SMALL TO MEDIUM SIZE FUEL BURNING EQUIPMENT**

February 1993

Organisations making application to the Environment Protection Authority (EPA) for approval to install fuel-burning equipment at their premises need to demonstrate that the installation will meet recognised air quality goals. The chimney to be used must be of adequate height to sufficiently disperse the pollutants before they reach ground level.

The formulae which follow apply to relatively small installations where the only emissions of concern are sulphur oxides, nitrogen oxides and fluorides. Larger installations, those in sensitive residential areas, industrial processes which produce pollutants other than the three mentioned above and cases requiring simulation of local meteorology would need the application of more complex computer modelling. The chimney heights determined by these formulae are not necessarily final and the EPA may vary the height in individual cases if the circumstances warrant it.

1. FLAT TERRAIN

The uncorrected chimney height h_u (in metres) for an isolated chimney in flat terrain may be calculated by the following formulae:

- a) For sulphur-bearing fuels:

$$h_u = 13 - 4(M_s)^{0.2} + 5(M_s)^{0.4} \quad \dots\dots\dots (1)$$

where M_s is the hourly mass emission rate of sulphur dioxide (kg/h) at full rated capacity. M_s should not exceed 300 kg/h for these formulae to apply.

M_s may be calculated as follows:

Since $S + O_2 = SO_2$
then 32g of S + 32g of $O_2 = 64g$ of SO_2
or 1g sulphur products 2g sulphur dioxide.

$$\text{Then } M_s = 2(S_u)Q \quad \dots\dots\dots (1A)$$

Where S_u is the sulphur content of the fuel (% by weight),
 Q is the fuel consumption rate (kg/h).

b) For natural gas:

$$h_u = 8 - 4 (M_n)^{0.2} + 5(M_n)^{0.4}$$

where $M_n = 0.05(H_{cap})^{1.14}$ or, (2)
 $M_n = 0.22(P_{cap})^{1.14}$

The empirical formulae above are based on source testing where M_n is an estimate of the hourly mass emission rate of nitrogen oxides (kg/h).

M_n should not exceed 100 kg/h for these formulae to apply.

H_{cap} = heat capacity of boiler in gigajoules per hour (GJ/h) or,

P_{cap} = thermal power capacity of boiler in megawatts (MW).

Note: In some cases the capacity of a boiler is not known while the fuel consumption is. Fuel consumption depends on the heating value of the fuel and the thermal efficiency of the boiler. The thermal efficiency is an indication of the amount of energy in the fuel which is converted to useful heat.

In saturated steam boilers the approximate fuel consumption rates required to produce 1 MW (thermal) or 100 boiler HP, assuming typical thermal efficiencies, is as follows:

| | |
|---------------------|--|
| black coal: | 180 kg/h, |
| fuel oil: | 100 kg/h, |
| natural gas: | 91 kg/h or |
| (assuming 80% | 4.5 GJ/h or |
| thermal efficiency) | 120 m ³ /h (at 15° C and 1 atmosphere). |

Approximate heating values of fuels:

| | |
|--------------|---|
| black coal: | 27.9 MJ/kg, |
| fuel oil: | 43.8 MJ/kg, |
| natural gas: | 49.3 MJ/kg or |
| | 37.5 MJ/m ³ (at 15° C and 1 atmosphere). |

c) Hydrogen Fluoride

When the emission of hydrogen fluoride is likely to be a cause for concern, as in the case of brick-making or even coal-fired boilers close to fluoride-sensitive vegetation, special analysis may be required. However, in many cases a simplified chimney height assessment may be made using the following equation:

$$h_u = 28.5 (M_f)^{0.5} \quad \text{..... (3)}$$

where M_f is the hourly mass emission rate of HF (kg/h). M_f should not exceed 7 kg/h for these formulae to apply.

Equations (1), (2) & (3) are shown graphically in Fig. 2; the uncorrected chimney height (h_u) may be estimated directly from this graph. Chimney heights for natural gas are also shown in Fig 3 which has a more expanded ordinate (chimney height axis). In this figure, chimney heights are plotted against kg/h and m^3/h of natural gas flow as well as megawatt thermal power capacity of the boiler.

d) Odorous Emissions

This is dealt with in some detail in the background notes.

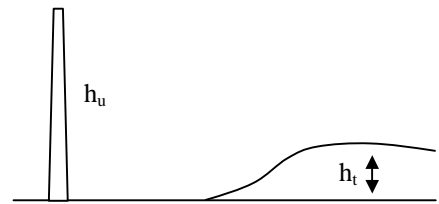
2. HILLY TERRAIN

In the unusual case that the chimney has no buildings around it and is surrounded by flat terrain, h_u is the final height of the chimney. If the chimney is in flat terrain and there are buildings present, go to Section 3.

If the chimney is in hilly terrain, care must be exercised. This terrain correction procedure is not applicable to complex situations. In such situations wind tunnel studies may be required.

The simple terrain correction is undertaken by adding to the isolated chimney (h_u) half the maximum increase in the height of hills or rising terrain (h_t) within a radius of ten chimney heights from the location of the chimney. This is called the corrected chimney height (h_c).

$$h_c = h_u + \frac{1}{2} h_t \quad \dots\dots\dots (4)$$

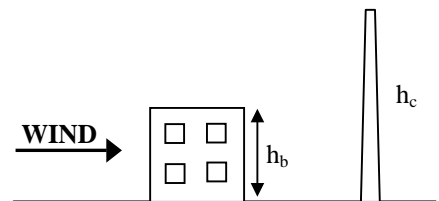


If there are no buildings present, this is the final height of the chimney (h_f).

3. BUILDING EFFECTS

If the chimney has a nearby building, the final height of the chimney required to eliminate the aerodynamic effects of the building may be estimated from the following equation (Dean, 1990).

$$h_f = Ah_c + Bh_b \quad \dots\dots\dots (5)$$



where h_b is the height of building to the roof ridge,
 h_c is the terrain-corrected chimney height,
 ($h_c = h_u$ when there are no terrain effects),
 A and B are selected from the following table:

EFFECTIVE HEIGHT COEFFICIENTS

| BUILDING PLAN DIMENSIONS | ANGLE | A | B |
|---------------------------------|--------------|----------|----------|
| 3x3 | 45° | 0.84 | 1.04 |
| 3x3 | 0° | 0.74 | 1.01 |
| 1x1 | 45° | 0.74 | 1.01 |
| 1x1 | 0° | 0.76 | 0.76 |
| Hemisphere | | 0.76 | 0.76 |
| 1/3x1/3 | 45° | 0.74 | 0.70 |
| 1/3x1/3 | 0° | 0.78 | 0.56 |
| 1/2x1 | 0° | 0.84 | 0.42 |
| 1.5x1 | 0° | 0.76 | 0.83 |
| 2x1 | 0° | 0.76 | 0.91 |
| 3x1 | 0° | 0.76 | 0.94 |
| 5x1 | 0° | 0.76 | 0.97 |
| 8x1 | 0° | 0.76 | 0.97 |
| 14x1 | 0° | 0.76 | 0.97 |

Note: The **BUILDING PLAN DIMENSIONS** referred to above are the width-by-length ratios relative to the building height (assumed to be unity). For a cluster of buildings, the dimensions of the envelope of that cluster should be used.

The **ANGLE** refers to the angle (in plan view) between the wind direction and the longitudinal axis of the building. That is, an angle of 0° denotes a wind direction normal to the building width dimension (W). For Sydney, the prevailing winds are westerlies in the winter and north-easterlies and southerlies in the summer. In most cases 0° should be used and 45° used when sensitive areas lie on the diagonal of the building. These relationships are shown graphically in Figs 4 and 5; h_f may be estimated directly from these figures. Note that the ordinates have no dimensions because the chimney heights have been divided by the building height.

4. AMBIENT AIR QUALITY CRITERION

Estimates of maximum ground level concentration (MGLC) can be made Turner's Work Book (Turner, 1970) or the following equation for SO₂ and NO_x (assuming an average wind speed of 6 m/s). A correction is needed for NO_x because of the different molecular weight – the result should be multiplied by 1.4.

$$MGLC = \frac{380 M}{(h_u + h_p)^2} \text{ pphm} \dots\dots\dots (6)$$

where M is the hourly mass emission rate of pollutant,
 h_u is the uncorrected (or effective) chimney height,
 h_p is the final plume rise (above chimney height).

The uncorrected chimney height (h_u) is used in the equation above rather than the final height (h_f) because the terrain and building effects corrections in Sections 2 and 3 were only sufficient to overcome the downwash caused by the rising terrain and the building. The effective chimney height remains at h_u .

Calculation of h_p depends on a number of assumptions including the type of plume rise formula used. It is recommended that as a first approximation h_p be assumed to be zero. If MGLC is calculated to be greater than the criterion of **16 pphm** then plume rise may need to be assessed.

A simplified formula for plume rise for natural gas, oil and coal is shown below:

$$h_p = \frac{Q^{0.67}}{c} \quad \text{metres} \quad \dots\dots\dots (7)$$

where Q is the fuel consumption rate in kg/h – gas, oil or coal,
 $c = 11.0$ for natural gas and oil,
 $c = 12.5$ for coal

The other assumptions are:
temperature of exhaust gas = 165°C
exhaust gas velocity = 15 m/s,
wind speed = 6 m/s.

Remember these are only approximate estimates. If MGLC is estimated to be close to the criterion, further analysis will be required using computer simulation.

5. IMPINGEMENT

A plume containing SO_2 or NO_x may impinge on a building downwind of the chimney. Calculation of the concentration at the face of the building C_b (in pphm) can be made using the following formula for oil and coal-burning equipment.

$$C_b = \frac{9720 M}{d^{1.75}} \quad \text{pphm} \quad \dots\dots\dots (8)$$

where M is the hourly mass emission rate of pollutant and
 d is the downwind distance from chimney to building.

C_b needs to be multiplied by 1.4 for NO_x concentration from natural gas-fired equipment.

If C_b is greater than **16 pphm**, further analysis will be required. This may include computer simulation of the plume impinging on the building.

6. WORKED EXAMPLE

A new coal-fired boiler designed to use 20,000 kg/h of coal with a sulphur content of 0.5% is housed in a square building 35m high and 35m wide with a rise in terrain of 6m, 300m south of the building.

Use equation (1A) to find M_s , the hourly mass emission rate of SO_2 .

$$\begin{aligned}M_s &= 2(S_u)Q \\ &= 2(.005)20,000 \text{ kg/h} \\ &= 200 \text{ kg/h} - \text{OK (emissions less than 300 kg/h)}\end{aligned}$$

Uncorrected Chimney Height:

From equation (1),

$$\begin{aligned}h_u &= 13 - 4(M_s) + 5(M_s)^{0.4} \\ &= 13 - 4(200)^{0.2} + 5(200)^{0.4} \\ &= 43 \text{ metres}\end{aligned}$$

Terrain Effects:

From equation (4),

$$\begin{aligned}h_c &= h_u + 1/2h_t \\ &= 43 + 1/2(6) \\ &= 46 \text{ metres}\end{aligned}$$

Building Effects:

Use equation (5) and A and B for the cube building at 0° (1x1),

$$\begin{aligned}h_f &= Ah_c + Bh_b \\ &= 0.76(46) + 0.76(35) \\ &= 61.6 \text{ metres}\end{aligned}$$

Ambient Air Quality Criterion:

Estimate MGLC using equation (6),

$$\text{MGLC} = \frac{380M_s}{(h_u + h_p)^2} \quad \text{pphm}$$

In this case, $M_s = 200 \text{ kg/h}$
 $h_u = 43\text{m}$
 $h_p = Q^{0.67}/12.5$ [from (7); $Q = 20,000 \text{ kg/h}$, then $h_p = 60.9\text{m}$]

$$\begin{aligned}\text{MGLC} &= \frac{380(200)}{(43 + 60.9)^2} \quad \text{pphm} \\ &= 7.0 \text{ pphm}\end{aligned}$$

Note: If we had assumed $h_p = 0$ as a first approximation, $\text{MGLC} = 41 \text{ pphm}$, giving a worst case approximation.

A tower building 75m tall is situated 1 km away and we need to check for **impingement** using equation (8).

$$\begin{aligned}C_b &= \frac{9720 M_s}{d^{1.75}} \\&= \frac{9720 (200)}{1000^{1.75}} \\&= 11 \text{ pphm } (< 16 \text{ pphm, therefore OK})\end{aligned}$$

Note: As the plume is likely to be higher than the tower building height, the impinging concentration should be lower than that calculated.

Check for SO₂ odour (see background notes first):

TOC_{50%} for SO₂ is 50 pphm or $1.4 \times 10^{-3} \text{ g/m}^3$

The uncorrected (or effective) chimney height h_u must be greater than

$$\begin{aligned}&(0.1M_o/\text{TOC}_{50\%})^{0.5} \\&> [0.1(200000/3600)/1.4 \times 10^{-3}]^{0.5} \\&> 63\text{m}\end{aligned}$$

As this is above the calculated h_u , further analysis will be required using computer modelling.

BACKGROUND NOTES FOR USE WITH THE GUIDELINES

GUIDELINES APPLICABILITY

The simplified chimney height determination method used by the EPA is based on a regression curve fitted to several empirical and theoretical chimney height curves. This method is not appropriate for mass emissions of sulphur dioxide in excess of 300 kg/h or nitrogen oxides in excess of 100 kg/h. The other assumptions in the regression formulae are a plume rise consistent with an exhaust gas temperature of 165°C and an exhaust gas velocity of 15 m/s with a wind speed at chimney height of 6 m/s (see Fig 1). Rain caps if fitted should be of a type that do not impede the vertical discharge of gases.

Where new fuel burning equipment is to be installed in a premises which already contains sources of air pollutants, the existing air quality should be assessed. As maximum pollutant ground level concentrations are additive, the sum total of all maximum ground level concentrations should not exceed the ambient criteria. In situations where two or more chimneys are to be located in close proximity such that their separation is less than twice the uncorrected heights, they may be regarded as a single source with mass emission rate equal to the sum of the individual sources.

Any change in the terrain surrounding the chimney or any nearby building within a radius of ten isolated chimney heights needs careful evaluation. The presence of large obstacles such as hills or buildings near a chimney will normally reduce the effective height of that chimney. When compared to the isolated chimney, maximum pollutant ground level concentrations are higher and appear at distances nearer the source. The greatest effect occurs when the chimney is attached to a building and the aerodynamic influence becomes less significant the further away the building is from the chimney. For equivalent distances, a building causes greater downwash when it is upwind of the chimney. In addition, the taller the chimney in relation to the nearby building, the less significant the building effect. If the chimney height to building height ratio is greater than 3 to 1 the building effect is negligible. The building effect formula in the guidelines represents the worst-case situation where the chimney is attached to the building. Therefore, the application of the formula to all cases will yield conservative results.

Impingement may occur and produce high concentrations on the face of a building or on hills quite some distance down-wind of the chimney, especially under stable conditions. Note that the impingement formula contains the emission rate and separation distance alone and is independent of the height of the building. The assumption is that the centre of the plume impinges on the building. Again, this is the worst-case situation yielding the most conservative result.

The guidelines contain estimations based on recent research, but care needs to be exercised in their application. Complex situations may require wind tunnel studies to resolve them.

AMBIENT AIR QUALITY CRITERIA

The results apply to average conditions and may not prevent detectable concentrations at sensitive receptors in unusual circumstances. The aim has been to prevent concentrations of SO₂ above 16 ppm and NO_x above 15 ppm at ground level, each based on a three minute averaging period.

The criterion for SO₂ was originally arrived at by dividing the threshold limit value (TLV) for SO₂ by 30. The TLV is the maximum concentration that workers inside a factory may be exposed to over an eight hour working day. The rationale behind this procedure can be explained in two stages:

- (1) The TLV was divided by 3 because people living near a factory may be exposed to pollution continuously throughout 24 hours of the day, not just for 8 hours on which the TLVs are based,
- (2) This level was then divided by 10 to allow for the very old, young or ill people in the local community who are more vulnerable to air pollution than healthy adult workers for whom the TLVs are intended.

At the time when the criteria were originally derived, the TLV for SO₂ was 5 ppm and hence TLV/30 is 16 pphm. (Note that the TLV for SO₂ was reduced to 2 ppm in 1986). The rationale stated above could imply that this is a 24 hour average, however it is used as a 3 minute goal in order to be conservative. In the 1960s, the Alkali Inspectorate in the UK also used the figure of 16 pphm maximum ground level concentration (MGLC) for SO₂ to set chimney heights using the method of Sutton & Bosanquet (see Nonhebel, 1964, P 27).

The level of 16 pphm is also arrived at by converting the World Health Organisation (WHO) goal of 50 µg/m³ annual average to a 3-minute average using Turner's method. Although this method is inappropriate for such a conversion, it is interesting to note how much supporting evidence there is for using 16 pphm as a design criterion.

Recently, the WHO issued guidelines for Europe (WHO, 1987) with stringent goals for sulphur dioxide averaged over 10 minutes and over one hour. They are 17.5 pphm and 12 pphm respectively. To comply with the WHO 10-minute goal when other sources of SO₂ are present the MGLC of SO₂ for a complete development should be less than 23pphm averaged over three minutes.

Although the pollutants mentioned are unlikely to be a problem when dispersed to levels below our criteria, soot and flue gas odours may still cause problems under certain conditions.

ODOROUS EMISSIONS

Odorous gases require special consideration and treatment. The human nose is capable of detecting wafts of odorous gases in as little as one or two seconds duration. For such very short periods, the concentration of gases in a dispersing plume may be up to ten times higher than the design values averaged over a three minute period. Dispersion of odorous emissions via a chimney is not recommended unless the emission source is properly quantified by an odour panel test.

The results of an odour panel test need to give the number of dilutions (also called odour units) required to disperse the odorous source to levels below the threshold odour concentration for 50% of the odour panel (abbreviated TOC_{50%}). It is generally not practical to disperse greater than 200 odour units per cubic metre per second of exhaust gas flow without correctly designed chimneys.

Warren Spring Laboratory in the U.K. suggests the following technique to make a first estimate of the uncorrected chimney height h_u .

$$h_u = (0.1DQ)^{0.5}$$

where D is the number of dilutions or odour units required to disperse the emission source to the $TOC_{50\%}$ and Q is the volumetric flow rate in m^3/s at $0^\circ C$ and 760 mm Hg.

An equivalent expression is:

$$h_u = (0.1M_o/TOC_{50\%})^{0.5}$$

where M_o is the mass emission rate of the odorous gas in g/s and the $TOC_{50\%}$ has units of g/m^3 .

There can be considerable variation in the value quoted for $TOC_{50\%}$ in different references so care is needed in the interpretation of TOC values.

The EPA uses computer modelling to size chimneys for special situations such as odour emissions. More than 30 computer models are available including those in the US EPA "UNAMAP" version 5 package and the AUSPLUME model which has been developed in Australia. These models require detailed meteorological information and specialist assistance in their application.

METHODS OF ODOUR CONTROL

- (A) Dispersion Tall chimney required – moderate capital cost, low running costs. Need to design for 0.1 odour unit. If this is not achievable, source control options need to be explored.
- (B) Wet Scrubbing Absorption – moderate to high costs, three stages often required. Needs careful selection of scrubber liquor and usually trials. Not always successful – requires regular maintenance and daily tests of active agent and pH control in some cases.
- (C) Afterburner
- Direct Temperatures between 600°C and 1000°C with residence time of 0.3 to 1 second. Doubling of residence time may enable afterburner temperature to be reduced 20 to 100°C. Requires careful design to reduce air volume to a minimum. Capital cost high and cost of running is high if air volume large. Needs further control if sulphur or chlorine present in exhaust gases.
- Afterburner
- Catalytic Temperature 500°C. Lower temperature operation than direct method, however the catalyst may be destroyed if not operated and maintained correctly. This is frequently a problem.
- (D) Carbon Adsorption Needs regenerating at regular intervals – can be effective but expensive for large volumes. Small operations are reasonably inexpensive to deal with.
- (E) Mist Filter Mist filter of plastic or metal, self cleaning – inexpensive
- (F) Good Housekeeping Cleanliness, avoiding spills requires human effort but is relatively inexpensive.
- (G) Masking Odour Deodorant disguises the problem – usually not effective but can help in marginal cases or with accidental releases – inexpensive.
- (H) Biological Has been successful overseas for rendering works. Uncle Bens at Raglan was the first to install in NSW.
- (I) Condensers Condensable liquids removed from the exhaust gas stream reduces the amount of odorous gas to be treated

SPECIFIC APPLICATION

| Operation Type | Emissions | Odour Control |
|-----------------------|------------------------------------|----------------------|
| Boiler | SO ₂ | A |
| Acid plant | Acid gases | A, B, E |
| Fertiliser | Fluorides, fertiliser odour | A, B, F |
| Rendering works | Decomposing flesh, amines | A, C, D, G |
| Coffee | Aldehydes, amines | A, C, D |
| Chicken feathers | Amines | B, D |
| Fish meal | Amines, aerosols | B, C, D, E |
| Garbage | Decomposing organics, sulfides | C, G |
| Ammonia | Ammonia | A, B |
| Detergent & soap | Soapy | A, B, I |
| Oil refinery | Hydrocarbons, sulfides (complex) | A, C, G |
| Chemical plant | Various (complex) | A, B, C |
| Rockwool | Burnt oil, aldehydes | A, B, C |
| Varnish & paint | Burnt oil, hydrocarbons, aldehydes | A, C |
| Solvent storage | Various solvents | A, D, G |
| Animal incineration | Amines, aldehydes | A, C, F, I |
| Grease trap waste | Amines | B, D, G, I |
| Fermentation | Yeast, fermenting | A, D, G |
| Non-ferrous foundry | Burnt core odour, aldehydes | A, C |
| Foundry (ferrous) | | A |
| Laminated plastic | Phenols, formaldehyde | A, C |
| Fibreglass | Styrene, acrylates | A, D |

References

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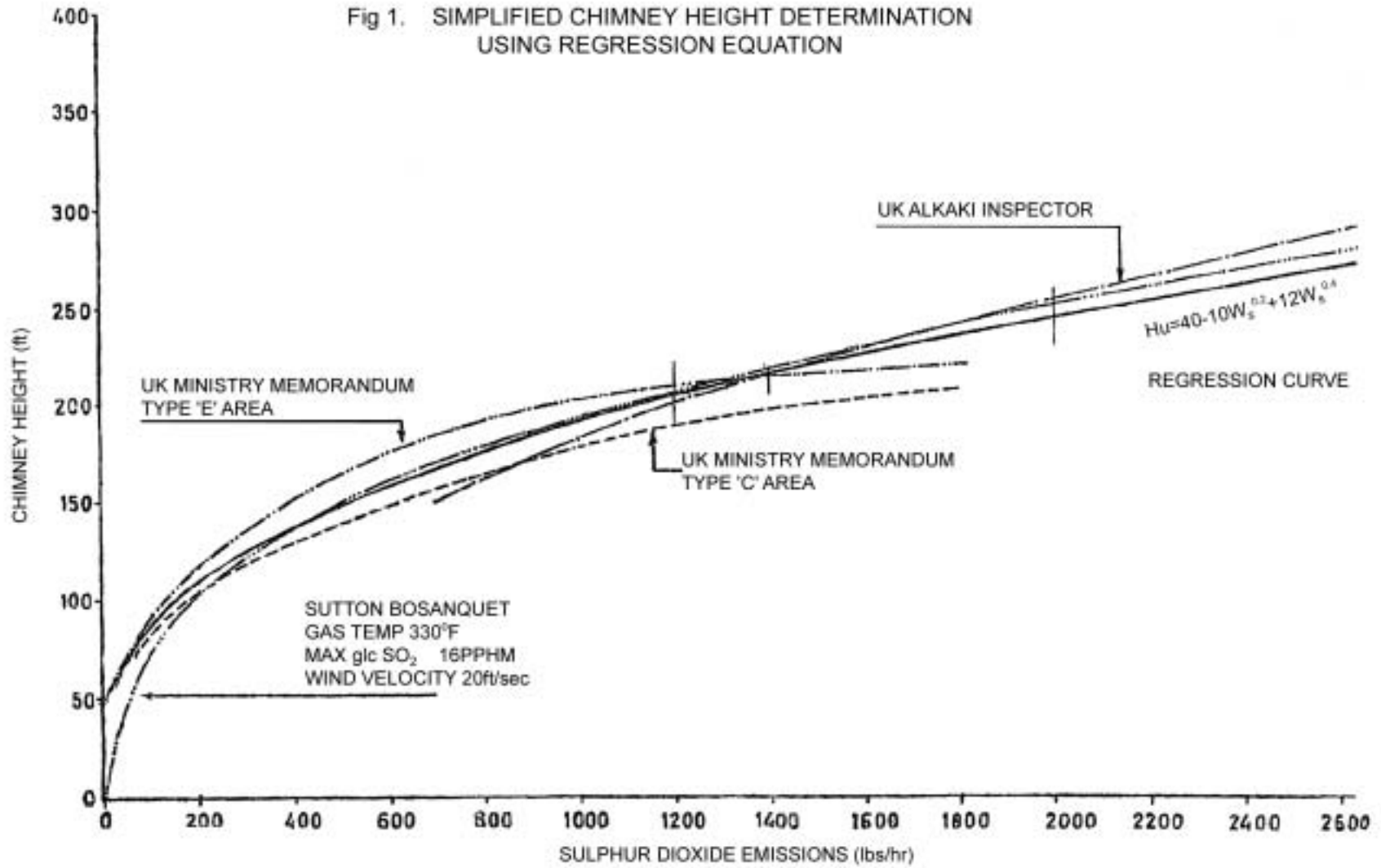


Fig 2. SIMPLIFIED CHIMNEY HEIGHT DETERMINATION

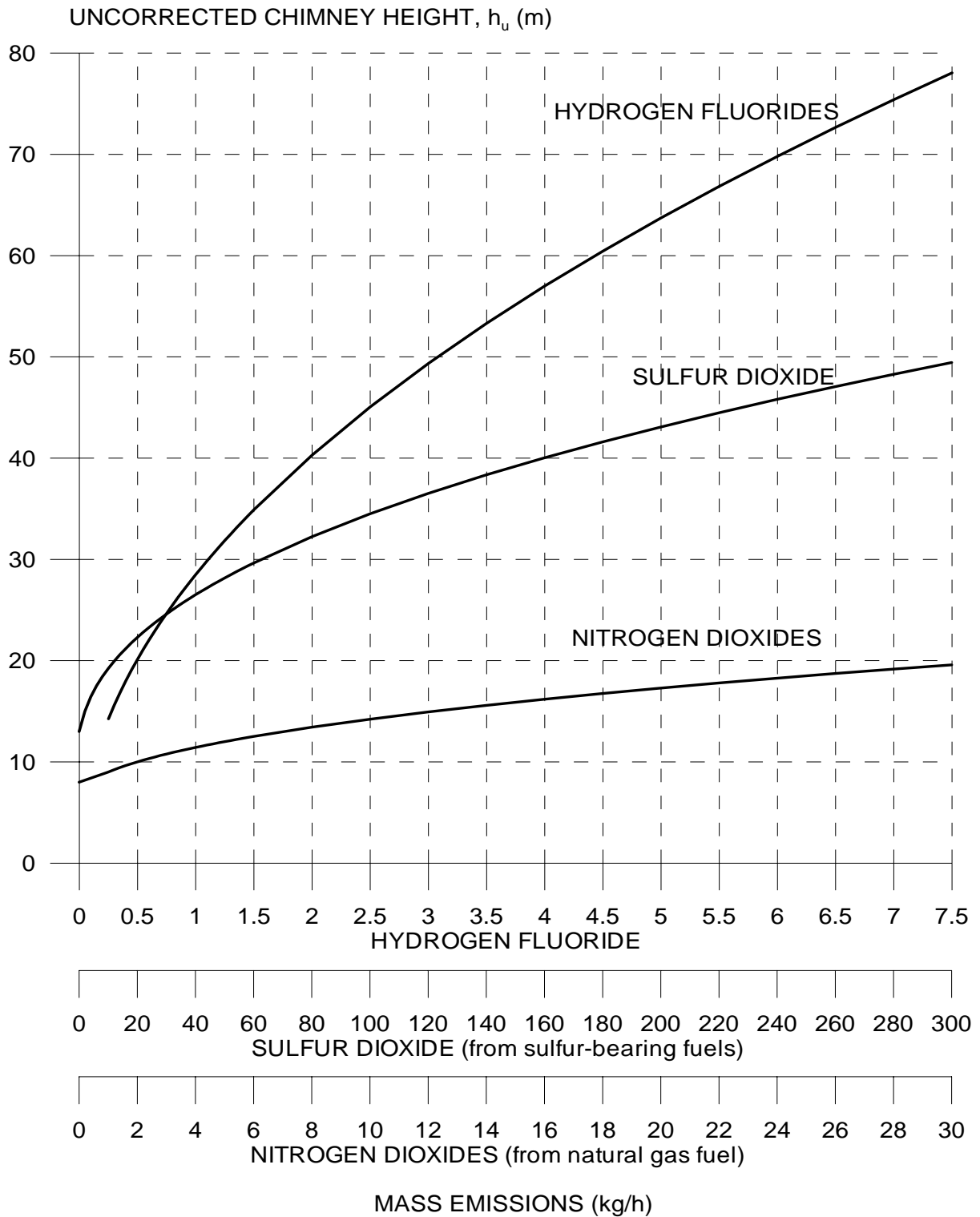


Fig 3. CHIMNEY HEIGHT FOR
NATURAL GAS FUEL

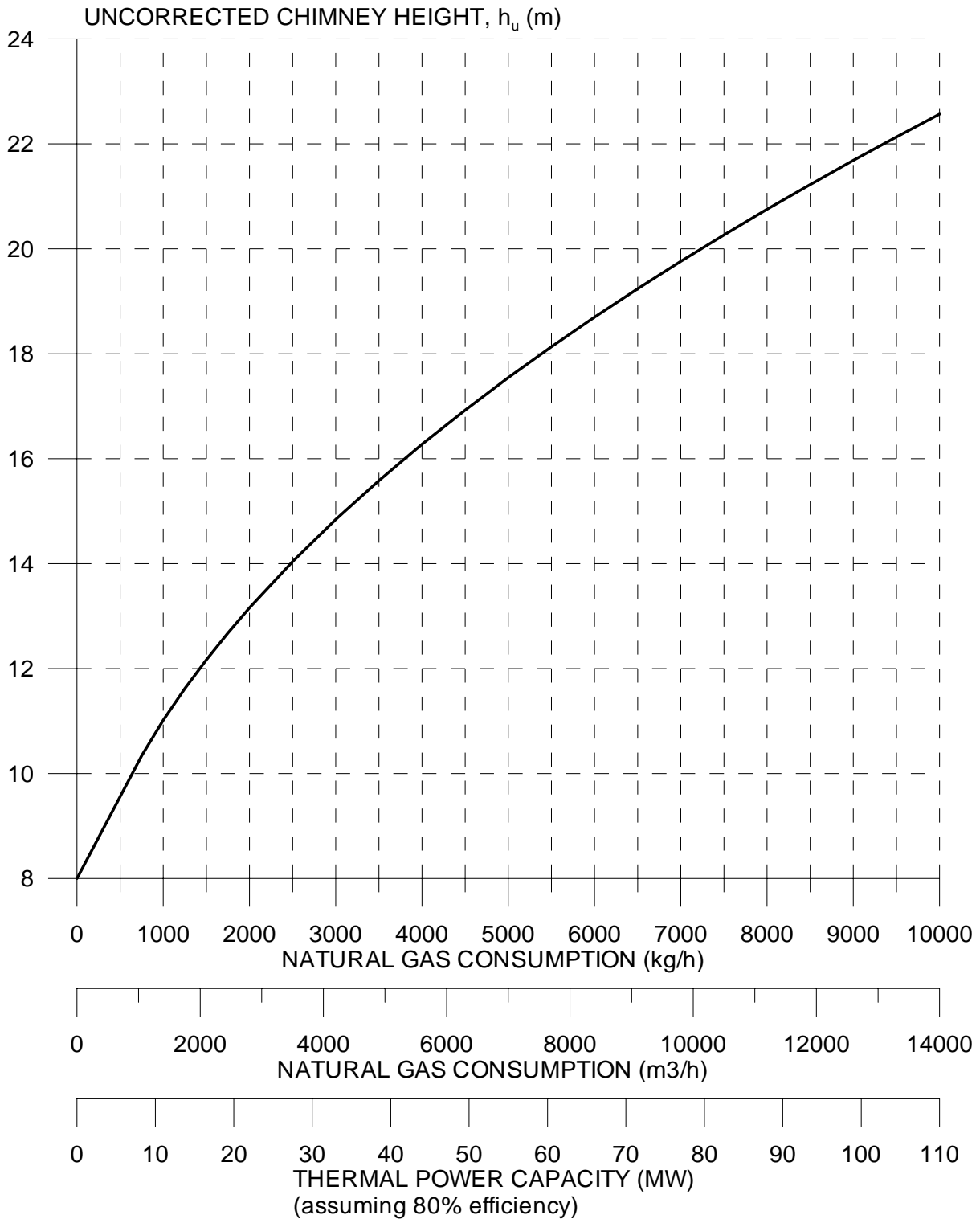
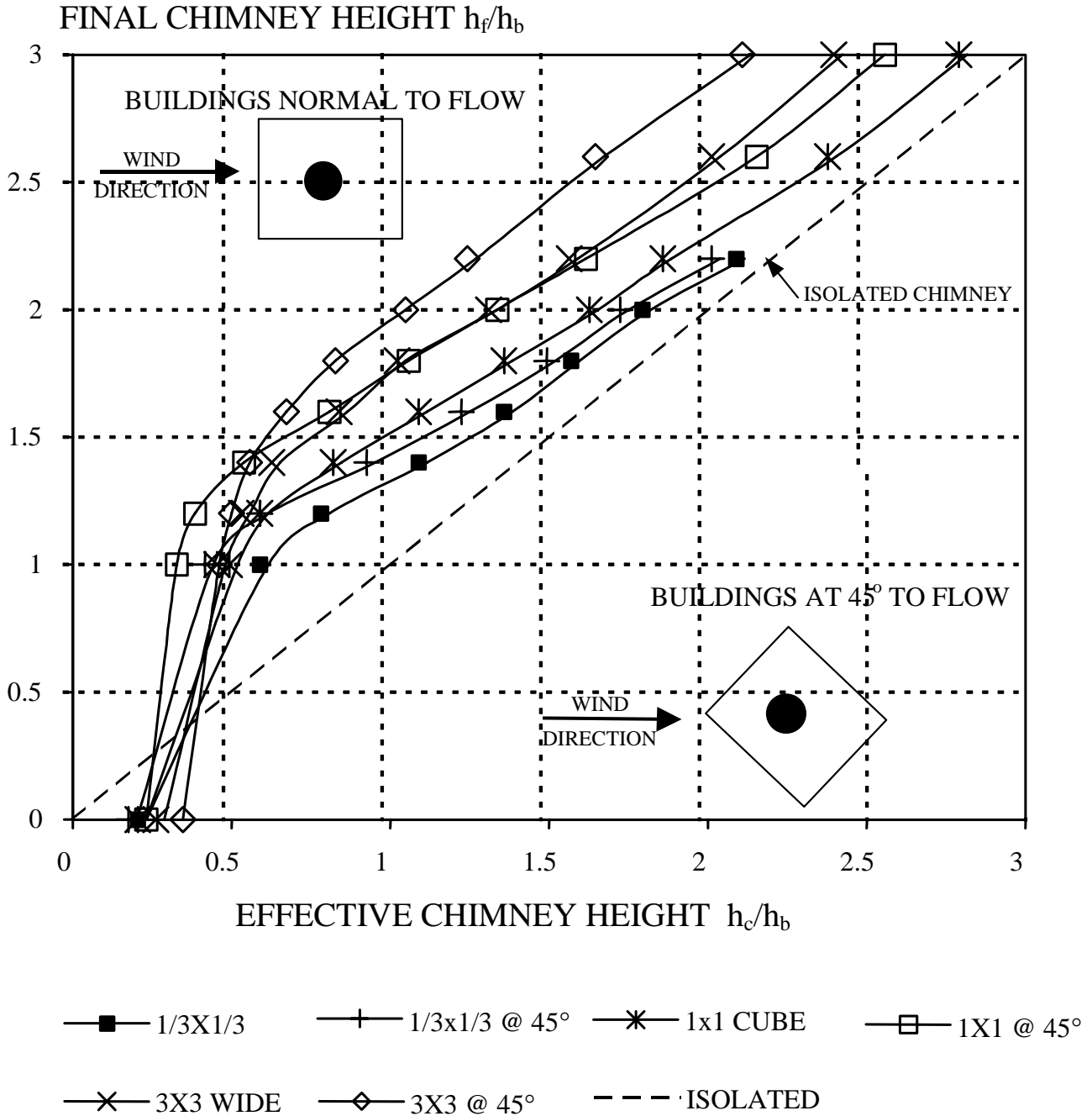


Fig 4 EFFECTIVE CHIMNEY HEIGHT
IN THE VICINITY OF SQUARE
PLAN-FORM BUILDINGS



**Fig 5. EFFECTIVE CHIMNEY HEIGHT
IN THE VICINITY OF RECTANGULAR
PLAN-FORM BUILDINGS NORMAL TO FLOW**

