Appendix 1

Unit conversion tool

Introduction

In order to assess the impact of a combustion appliance on air quality, it is necessary to estimate the emissions from the appliance to atmosphere. Manufacturers and suppliers of combustion appliances provide the information required to estimate the rates of emission in various ways.

Manufacturers may provide information about the capacity of a heating appliance in terms of:

- The rate of fuel use
- Heat input
- Heat output
- Volumetric flowrate of flue gases at specified conditions of temperature, moisture content and oxygen content

They may provide information about the emissions of pollutants in terms of:

- Emission factors based on the quantity of fuel consumed;
- Emission factors based on the heat input;
- Discharge concentrations in the flue gas.

The unit conversion tool is intended to provide a convenient means for calculating rates of emission from the information provided.

Calorific value

In many cases, the relationships between the information provided and the rate of emission depend on the characteristics of the fuel:

- Calorific value;
- Moisture and ash content;
- Ultimate analysis of the dry, ash free fuel in terms of the weight per cent of carbon, hydrogen, oxygen, sulphur and nitrogen.

The calorific value of a fuel is the heat produced by the complete combustion of a unit quantity of fuel in a calorimeter under specified conditions. The result includes the latent heat of vaporization of the water in the combustion products and is called the gross calorific value or high heating value. In most appliances the water in the combustion products is discharged as water vapour and the heat of vaporization is not available. The net calorific value or low heating value is calculated as the gross calorific value less the latent heat of vaporization:

Calorific values may be specified as “As received”, “Dry” and “Dry, ash free”:

- As Received (AR)indicates that the fuel heating value has been measured with all moisture and ash forming minerals present.
- Dry (D) indicates that the fuel heating value has been measured after the fuel has been dried of all inherent moisture but still retaining its ash forming minerals.

- Dry, Ash Free (DAF) indicates that the fuel heating value has been measured in the absence of inherent moisture and ash forming minerals.

The following relationships between the calorific values apply:

$$G_D = G_{DAF}(1-a)$$

$$G_{AR} = G_{DAF}(1-a-m)$$

$$N_{DAF} = G_{DAF} - \frac{h}{2M_H} L_v$$

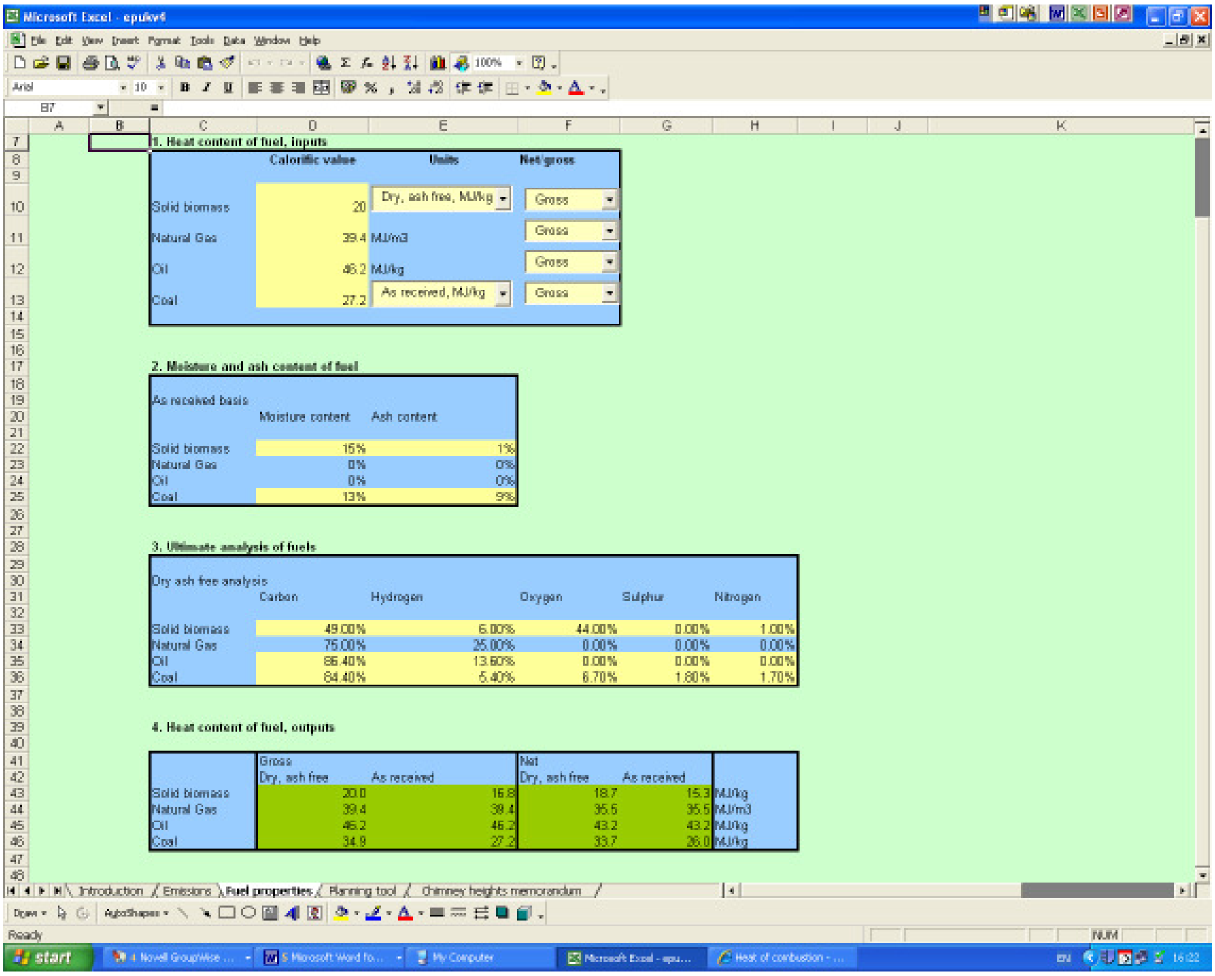
$$N_{AR} = N_{DAF}(1-a-m) - \frac{m}{M_{H_2O}} L_v$$

$$N_D = N_{DAF}(1-a)$$

where G and N are the gross and net heating values, MJ/kg;
a is the fraction of ash by weight in the fuel as received;
m is the fraction of moisture by weight in the fuel as received;
h is the fraction of hydrogen in the fuel by weight on a dry ash free basis;
L_v is the latent heat of vapourization of water, 44 kJ/mole;
M_H is the molar mass of hydrogen, 0.001 kg/mole;
M_{H2O} is the molar mass of water, 0.018 kg/mole.

The spreadsheet “Fuel properties” implements these relationships. Fig. A1 shows a screenshot of the fuel properties spreadsheet with recommended default values. Items in cream may be adjusted by the user. In general, the default values for the ultimate analysis should be satisfactory in most cases.
The gross calorific value of most woods is approximately 20 MJ/kg on a dry, ash free basis: however, the calorific value on an as received basis is often substantially lower where the moisture content is high.

Fig. A1: Screenshot of the fuel properties spreadsheet



1. Heat content of fuel, inputs

	Calorific value	Units	Net/gross
Solid biomass	20	Dry, ash free, MJ/kg	Gross
Natural Gas	39.4	MJ/m3	Gross
Oil	46.2	MJ/kg	Gross
Coal	27.2	As received, MJ/kg	Gross

2. Moisture and ash content of fuel

As received basis

	Moisture content	Ash content
Solid biomass	15%	1%
Natural Gas	0%	0%
Oil	0%	0%
Coal	13%	9%

3. Ultimate analysis of fuels

Dry ash free analysis

	Carbon	Hydrogen	Oxygen	Sulphur	Nitrogen
Solid biomass	49.00%	6.00%	44.00%	0.00%	1.00%
Natural Gas	75.00%	25.00%	0.00%	0.00%	0.00%
Oil	86.40%	13.60%	0.00%	0.00%	0.00%
Coal	84.40%	5.40%	6.70%	1.80%	1.70%

4. Heat content of fuel, outputs

	Gross		Net		
	Dry, ash free	As received	Dry, ash free	As received	
Solid biomass	20.0	16.8	18.7	15.3	MJ/kg
Natural Gas	39.4	39.4	35.5	35.5	MJ/m3
Oil	46.2	46.2	43.2	43.2	MJ/kg
Coal	34.9	27.2	33.7	26.0	MJ/kg

Appliance capacity

The Unit Conversion Tool applies the following relationships to estimate the capacity of the appliance:

$$H_{ig} = G_{AR} F$$

$$H_{ig} = \frac{H_o}{E_g}$$

$$H_{ig} = \frac{H_o}{E_n} \frac{G_{AR}}{N_{AR}}$$

$$H_{ig} = \frac{V(1-m_a)}{F_d} \frac{(0.209-[O_2])}{0.209} \frac{273}{T}$$

$$H_{in} = H_{ig} \frac{N_{AR}}{G_{AR}}$$

where:

H_{ig} is the gross heat input rate;

F is the fuel input rate,
H_o is the heat output rate of the appliance,
E_g is the gross heat efficiency of the appliance,
E_n is the net heat efficiency of the appliance;
V is the volumetric flowrate of the flue gas, with moisture fraction m_a by volume in the flue gas,
$[O_2]$ is the fraction of oxygen in the dry flue gas, by volume;
T is the temperature of the flue gas, K; and
F_d is the stoichiometric volume of dry flue gas at 273 K corresponding to unit gross heat input, m3/MJ;

$$F_d = \frac{\left(\frac{C}{12} + \frac{S}{32} + \frac{N}{28} + \left(\frac{C}{12} - \frac{O}{32} + \frac{H}{4} + \frac{S}{32} \right) \times \frac{79.1}{20.9} \right)}{G_{DAF}} \times 0.0224 \times 1000$$

where C, S, N, O, H are the mass fractions of these elements in the dry, ash free analysis of the fuel.

Fig. A2 shows a screenshot of part of the spreadsheet. The user should select the fuel type from the drop-down box at 1. There are 4 types of input within element 3, the boiler capacity data input: the user should select the most appropriate input type from the drop-down box at 2. Data input is then only required for the selected input type. The user may then input data in the cream boxes: drop down boxes then allow the input of appropriate units. The following conversions are applied:

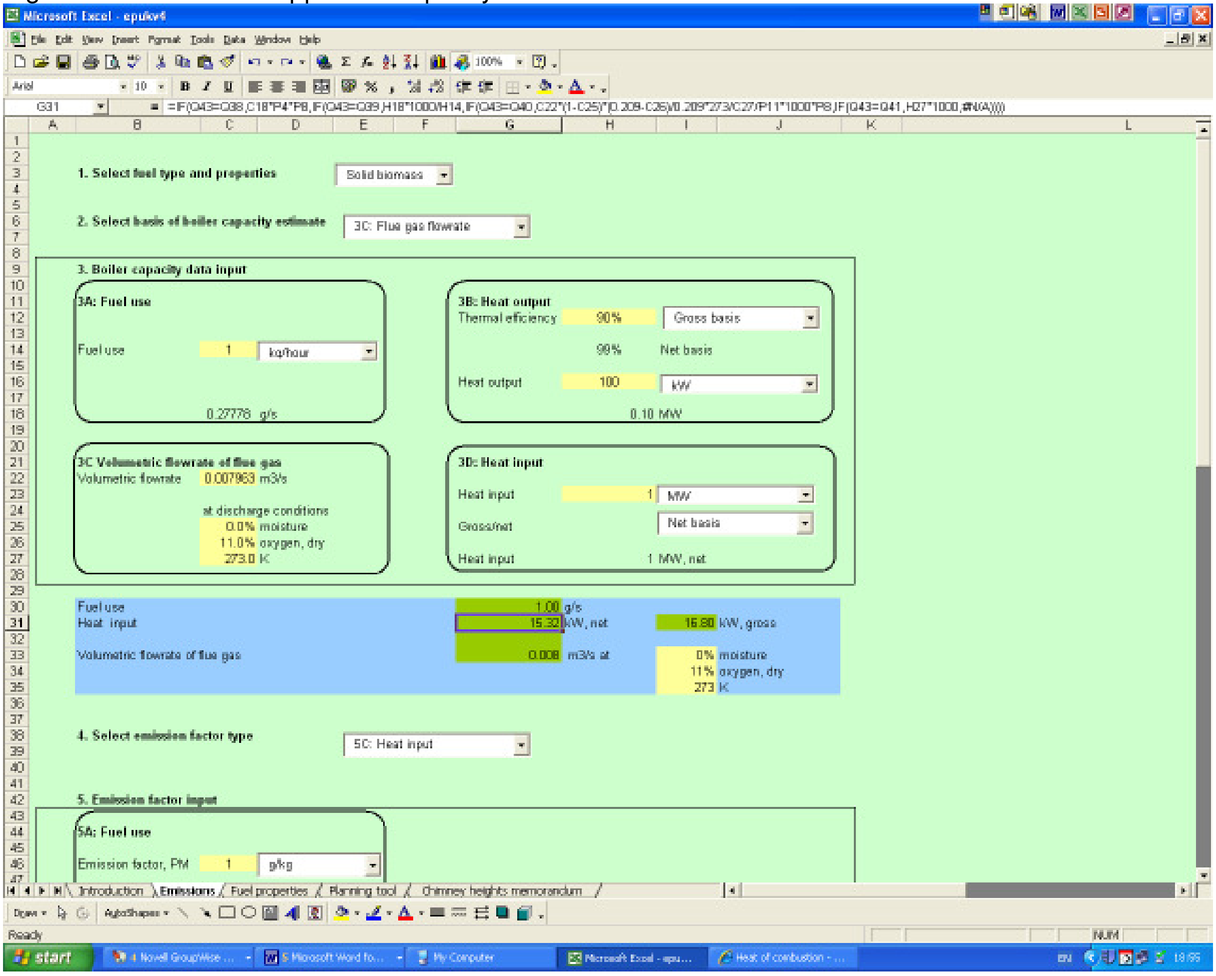
g/s to g/s	1
kg/hour to g/s	0.278
lb/hour to g/s	0.126

litre/s to litre/s	1
m3/h to litre/s	0.278
cubic ft/s to litre/s	28.3

MW to MW	1
kW to MW	0.001
kcal/s to MW	0.00418
Btu/s to MW	0.001055
therms/hour to MW	0.02931

The spreadsheet then estimates the fuel use, heat input and volumetric flowrate of flue gases at specified conditions of moisture, oxygen content and temperature.

Fig. A2: Screenshot of appliance capacity conversion



G31 =IF(Q43=Q38,C18*P4*P8,IF(Q43=Q39,H18*1000/H14,IF(Q43=Q40,C22*(1-C25)*(0.209-C26)/0.209*273/C27/P11*1000*P8,IF(Q43=Q41,H27*1000,#N/A))))

1. Select fuel type and properties Solid biomass

2. Select basis of boiler capacity estimate 3C: Flue gas flowrate

3. Boiler capacity data input

3A: Fuel use
Fuel use 1 kg/hour
0.27778 g/s

3B: Heat output
Thermal efficiency 90% Gross basis
99% Net basis
Heat output 100 kW
0.10 MW

3C Volumetric flowrate of flue gas
Volumetric flowrate 0.007963 m3/s
at discharge conditions
0.0% moisture
11.0% oxygen, dry
273.0 K

3D: Heat input
Heat input 1 MW
Gross/net Net basis
Heat input 1 MW, net

Fuel use 1.00 g/s
Heat input 15.32 kW, net 16.80 kW, gross
Volumetric flowrate of flue gas 0.008 m3/s at 0% moisture
11% oxygen, dry
273 K

4. Select emission factor type 5C: Heat input

5. Emission factor input

5A: Fuel use
Emission factor, PM 1 g/kg

Emission factors

The Unit Conversion Tool applies the following relationships between

- The emission factor based on gross heat input, g/GJ gross, f_g;
- The emission factor based on net heat input, g/GJ net, f_n;
- The emission factor based on the mass of fuel consumed, g/kg, f_m;
- The concentration in the flue gas, c, mg/m^3, at specified conditions of moisture content, m_a, oxygen content, [O_2} and temperature T ^{o}K

$$f_g = \frac{f_m}{G_{AR}} 1000$$

$$f_g = \frac{cF_d}{(1-m_a)} \frac{0.209}{(0.209-[O_2])} \frac{T}{273}$$

$$f_n = f_g \frac{G_{AR}}{N_{AR}}$$

Fig. A3 shows a screenshot of part of the spreadsheet. There are 3 types of input within element 5, the emission factor data input: the user should select the most appropriate input type from the drop-down box at 4. Data input in 5 is then only required for the selected input type. The user may then input data in the cream boxes: drop down boxes then allow the input of appropriate units. The following conversions are applied:

g/kg to g/kg	1
kg/kg to g/kg	1000
kg/tonne to g/kg	1
ktonne/Mt to g/kg	1

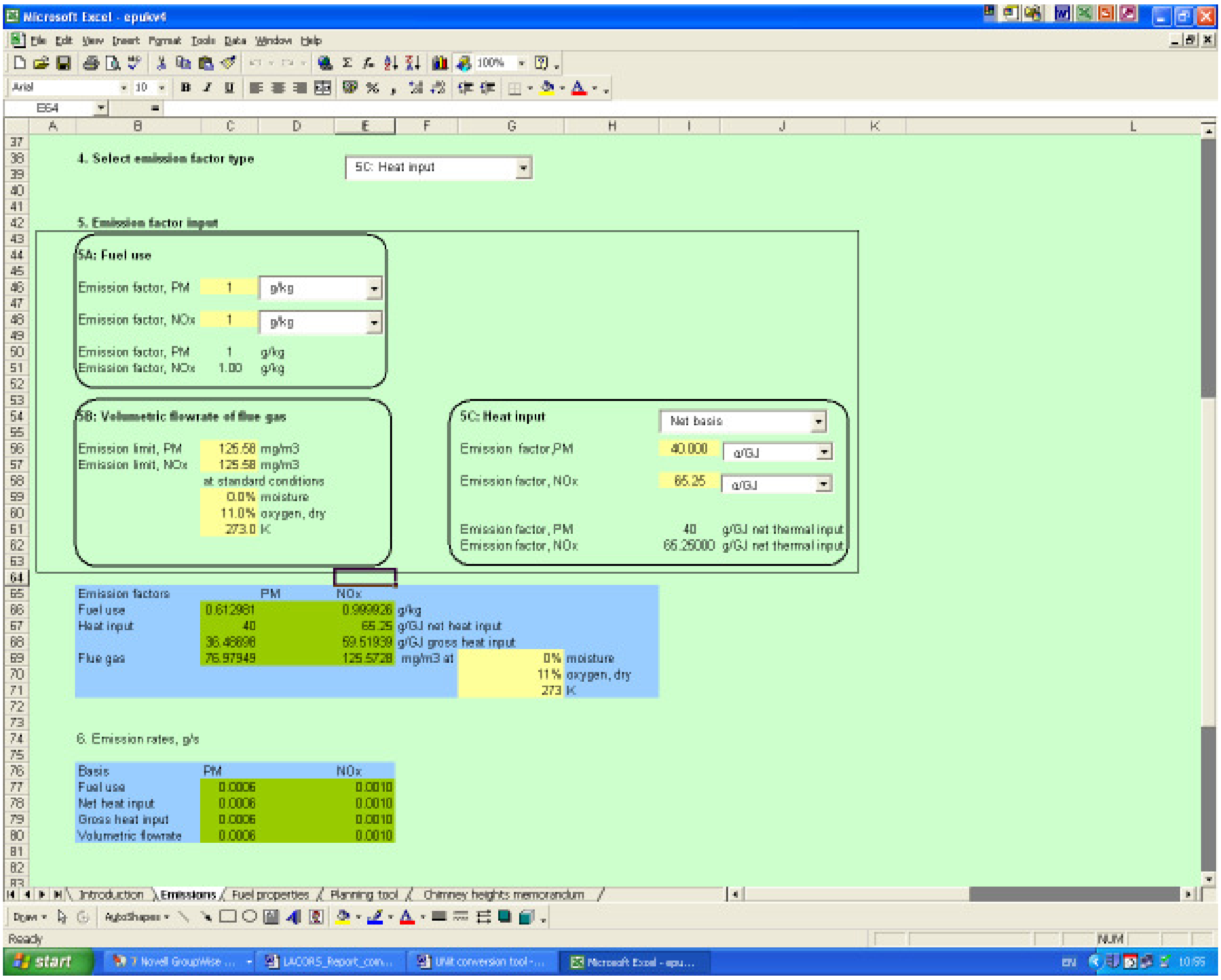
g/GJ to g/GJ	1
kg/TJ to g/GJ	1
tonne/PJ to g/GJ	1
kg/therm to g/GJ	9478.672986
ktonne/Mtherm to g/GJ	9478.672986

The spreadsheet then estimates equivalent emission factors in terms of mass of pollutant per mass of fuel, mass of pollutant per unit of heat input (gross or net) and the mass of pollutant per unit of flue gas volume at specified conditions.

Emissions

The spreadsheet calculates the emission rate as the product of the calculated heat input, fuel use and flue gas flowrate and the appropriate emission factor. There are four outputs for each pollutant: these should be identical and are included as a crosscheck between the methods.

Fig. A3: Screenshot of emission factor conversion



4. Select emission factor type: 5C: Heat input

5. Emission factor input

5A: Fuel use

Emission factor, PM: 1 g/kg
Emission factor, NOx: 1 g/kg

Emission factor, PM 1 g/kg
Emission factor, NOx 1.00 g/kg

5B: Volumetric flowrate of flue gas

Emission limit, PM 125.58 mg/m3
Emission limit, NOx 125.58 mg/m3
at standard conditions
0.0% moisture
11.0% oxygen, dry
273.0 K

5C: Heat input Net basis

Emission factor,PM: 40.000 g/GJ
Emission factor, NOx: 65.25 g/GJ

Emission factor, PM 40 g/GJ net thermal input
Emission factor, NOx 65.25000 g/GJ net thermal input

Emission factors	PM	NOx			
Fuel use	0.612981	0.999926	g/kg		
Heat input	40	65.25	g/GJ net heat input		
	36.48898	59.51939	g/GJ gross heat input		
Flue gas	76.97949	125.5728	mg/m3 at	0%	moisture
				11%	oxygen, dry
				273	K

6. Emission rates, g/s

Basis	PM	NOx
Fuel use	0.0006	0.0010
Net heat input	0.0006	0.0010
Gross heat input	0.0006	0.0010
Volumetric flowrate	0.0006	0.0010

Appendix 2

Stack height screening tool

The stack height screening tool has been adapted from:

- **Industrial nomographs** provided in Technical Guidance for Local Authority Review and Assessment LAQM.TG(03) for the assessment of NOx and PM10 emissions against the Air Quality Strategy objectives.

- **Biomass nomographs** were developed for inclusion in Technical Guidance for Local Authority Review and Assessment LAQM.TG(08). The nomographs were developed using results from systematic application of the ADMS4 model for a range discharge situations appropriate for biomass combustion installations. The development of the nomographs is described in http://www.airquality.co.uk/archive/reports/cat18/0806261519_methods.pdf.

The screening tool takes account of the effect of the height of nearby buildings using the approach adopted for the Chimney Heights Memorandum.

The screening tool uses the nomograph algorithms to estimate the maximum contribution from the stack to annual mean ground level concentrations of oxides of nitrogen or particulate matter. The method is limited to

The biomass nomographs were developed for:

- biomass combustion installations in the range 50 kW to 20 MW thermal input;

- installations with stack diameters in the range 0.1-1 m;

- a limited range of effective stack heights, dependent on the stack diameter as shown in Table 1;

- discharge velocities shown in Table B1- the methods should not be used for discharge velocities less than those shown in Table B1 and will be conservative for higher discharge velocities;

- discharge temperatures of 100°C - the methods should not be used for lower discharge temperatures and will be conservative for higher discharge temperatures;

- flat terrain.

Table B1: Applicable range of effective stack heights and stack discharge velocities

Stack diameter, m	Stack height range, m	Discharge velocities, m s^{-1}
0.1	1-40	1.3
0.2	1-40	1.9
0.5	2-40	3
1	5-40	4.2

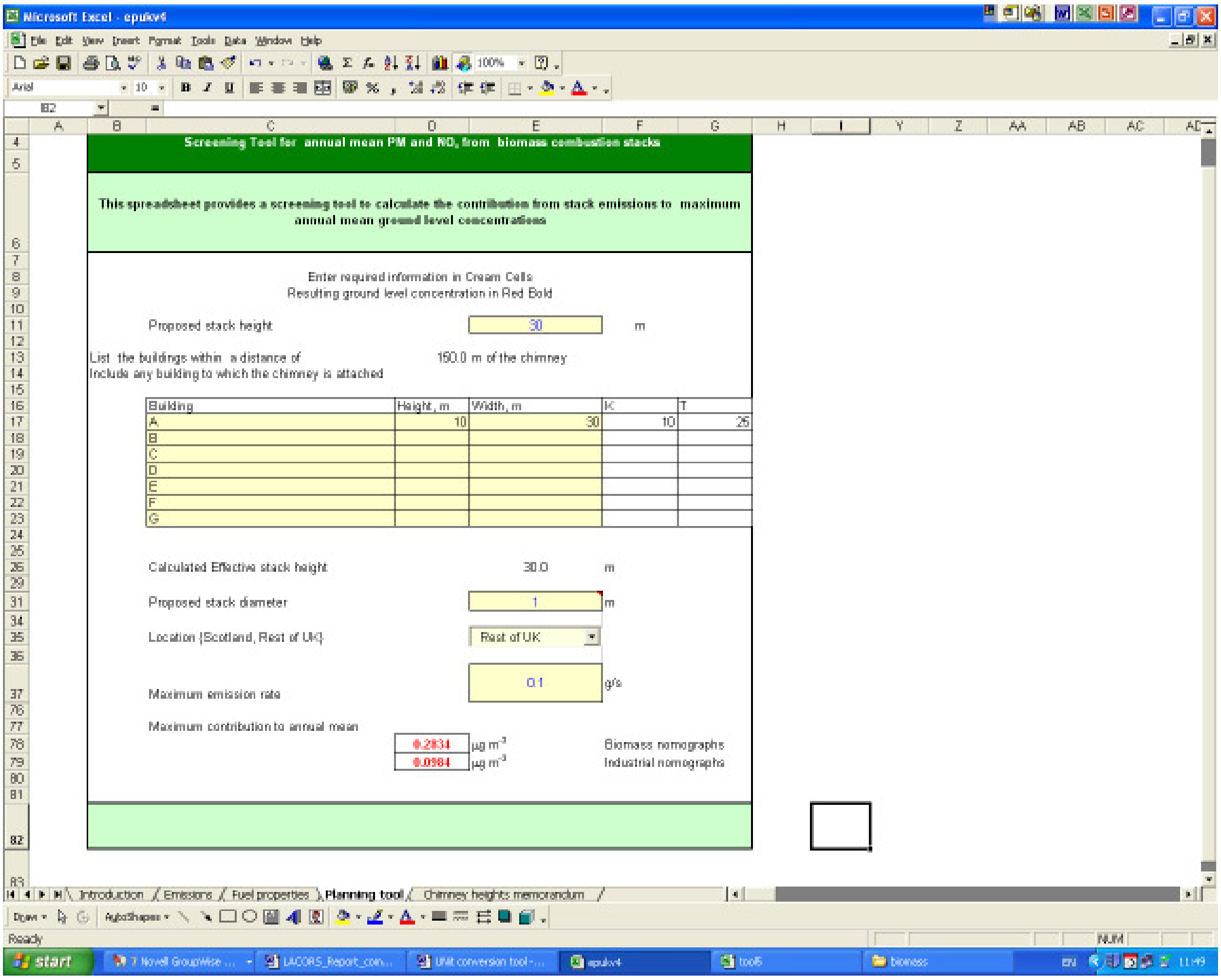
The Industrial nomographs were developed for:

- installations with stack diameters in the range 0.1-1 m;
- effective stack heights in the range 10-200 m;
- discharge velocities greater than approximately 10 m/s
- discharge temperatures of 100°C - the methods should not be used for lower discharge temperatures and will be conservative for higher discharge temperatures;
- flat terrain.

The biomass nomographs are more appropriate for smaller installations with natural draught or fan-assisted air supply. The industrial nomographs are more appropriate for larger installations with induced draught fans.

Fig. B1 shows a screenshot of the screening tool.

Fig. B1 Snapshot of the screening tool



Screening Tool for annual mean PM and NO_x from biomass combustion stacks

This spreadsheet provides a screening tool to calculate the contribution from stack emissions to maximum annual mean ground level concentrations

Enter required information in Cream Cells
Resulting ground level concentration in Red Bold

Proposed stack height: 30 m

List the buildings within a distance of 150.0 m of the chimney
Include any building to which the chimney is attached

Building	Height, m	Width, m	K	T
A	10	30	10	25
B				
C				
D				
E				
F				
G				

Calculated Effective stack height: 30.0 m

Proposed stack diameter: 1 m

Location (Scotland, Rest of UK): Rest of UK

Maximum emission rate: 0.1 g/s

Maximum contribution to annual mean:
0.2834 μg m^{-3} Biomass nomographs
0.0984 μg m^{-3} Industrial nomographs

The user provides details of the proposed stack height and the height and width of buildings within 5 stack heights of the stack. The Chimney Height Memorandum provides further details relating to the specification of the building dimensions.

The user should then supply information relating to the proposed stack diameter, the location (Scotland or the rest of the UK) and the maximum emission rate of the pollutant from the appliance operating at maximum capacity.

The screening tool then provides estimates of the maximum contribution from the discharge to annual mean ground level concentrations. The biomass nomograph method usually provides higher ground level concentrations, reflecting the lower assumed discharge velocities. The user should select the most appropriate estimate based on the discharge velocity from the stack in this case. However, there may be some occasions when the industrial nomograph provides the higher estimate, reflecting the different interpolation methods and meteorological data used in the derivation of the two nomographs: the user should then use the lower value provided by the biomass nomographs.

The screening tool will provide estimates of the maximum contribution to oxides of nitrogen concentrations. It is recommended that it is assumed that all the oxides of nitrogen emitted from the appliance are present as nitrogen dioxide.

The screening tool provides estimates of the maximum contribution to annual mean PM_{10} concentrations. It is recommended that the number of exceedences of the daily mean objective of 50 µg m^{-3} is estimated by

- adding the biomass contribution to annual mean PM_{10} concentrations to estimated “background” concentrations at relevant receptor locations; and

- applying the relationship between annual mean concentrations, x µg m^{-3} and the number of exceedences, y given in Technical Guidance:

$$y = -18.5 + .00145x^3 + \frac{206}{x}$$

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