An Indoor/Outdoor Air Pollution Tool for Cook Stove Developers

Introduction

Many people involved in reducing indoor air pollution for people in developing countries are pushing for cleaner and cleaner cook stoves. The WHO recently released interim indoor air PM2.5 guidelines of 35 ug/m3 (same as EPA outdoor), and said for a stove to achieve the standard it can only emit 1.75mg/min of PM2.5 (WHO 2014). A handful of stoves have been shown to meet that guideline in the lab under controlled conditions, but no stove exists that produces so little PM during real world operation. As new stoves are being developed it will be especially difficult to achieve the standard at the needed firepower and price. The tool shows how current and near term technology affects the pollution in the room and in the environment outside, and is more accessible than currently available tools from the EPA.

Theory

The tool uses a single zone box model for both indoor and outdoor modeling. The indoor model can be expressed mathematically as,

$$C(t+1) = C(t) + \frac{G(t)f}{V} + \alpha\left(C_0 - C(t)\right)$$

where $C(t+1)$ is the concentration at time $t+1$, $C(t)$ is the concentration at time t, $G(t)$ is the emissions rate [mg/min] at time t, f is the chimney removal efficiency (1 being no removal, 0 being total removal), V is the mixing volume [m^3], α is the air exchange rate [1/hr], and C_0 is the concentration outside the mixing volume. The concentrations are in units of [ug/m^3], and time is in [min]. Constants appear in the Excel spreadsheet to satisfy the units.

The outdoor model can be expressed mathematically as,

$$C(t+1) = C(t) + \frac{G(t)}{h(t)A} + \frac{u(t)}{L}\left(C_0 - C(t)\right)$$

where $h(t)$ is the mixing height [m] at time t, A is the area of the mixing volume [km^2], and L is the length of the mixing volume [km], and u is the wind speed [m/s] at time t. Constants appear in the Excel spreadsheet to satisfy the units.

Validation

The indoor model was validated by giving it the same inputs as were used in the 2014 WHO Indoor Air Guidelines and seeing that the average predicted concentration was the same. The predicted real-time concentrations were compared to those shown in Michael Johnson's 2011 paper (Johnson et al. 2011) and were found to be within the same range.

The outdoor model was validated by comparing its performance to the EPA PM2.5 attainment reports from the two small Oregon cities of Oakridge (Hough et al. 2012) and Klamath Falls (Calkins 2012). The validation process considered the area of the city, the average wind speed, the mixing height, and the measured concentrations.

Assumptions and Use

It is expected that the inputs for the indoor tool will be well known. Users may need guidance on α and may wish to choose from common values such as 5 – 60 (Johnson et al. 2011). It may also be difficult to obtain knowledge on *f*, so recommended values are 0.05, 0.1, 0.25, 0.5, and 1.

For the outdoor model it is difficult to estimate an input value for the mixing height. Since high concentrations from wood smoke occur primarily during temperature inversions when the mixing height is low (Calkins 2013) it is recommended that the tool only be used to predict the locale's worse case scenario, and that the default mixing height be used when no other guidance is available.

A cosine function is used to loosely approximate the diurnal variation of the mixing height and of the wind speed (Simpson et al. 2007). The function is used as such,

$$h(t) = -A\cos(t + t_s) + B$$

where $A+B$ is the max, and $B-A$ is the min. The variable t_s [rad] is used to shift the function output to the appropriate time of day. It is recommended that the default value of t_s be used.

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