



### IN THIS ISSUE

Determination of ETS  
Page 3

Readers Speak Out  
Reply  
Page 6

Rooftop Packages  
Page 7

ASHRAE Releases  
62R for Public Review  
Page 8

New Guidance on *Legionella*  
Page 8

Standardizing Kitchens  
and Saving Money  
Page 11

Reducing Formaldehyde Exposure  
Page 14

## Common Mistakes in Indoor Air Quality Calculations

by Ian Shapiro  
Director  
Taitem Engineering

The field of indoor air quality is growing rapidly. With this growth comes a need for careful and accurate engineering analysis. It is a critical period of time, because, as analytical tools such as spreadsheets and more complex computer programs are developed, there is a risk of mistakes being "codified" into these tools. A survey of commonly used indoor air quality calculations and constants shows many common mistakes, some resulting in large errors, and illustrates the extent of the risk of such mistakes being spread and perpetuated. A set of precautionary measures is offered, to prevent repetition of these mistakes.

### *Common Problems*

The following mistakes were found in a brief, random review of handbooks and other reference sources relating to indoor air quality. The survey was intended to be neither exhaustive nor inclusive. The four general classes of errors are illustrated with examples, and corrections are in italics.

1. *Incorrect Conversion Factors.* Converting between metric units and the foot-pound system used in the US often leads to mistakes, some resulting in large errors.

[cont. on page 4]

## IAQ Calculations Mistakes

[cont. from page 1]

A handbook for mechanical engineers equates the following:

"1 ppm [by weight] = 2 mg/m<sup>3</sup>." *Should be 1.2 mg/m<sup>3</sup>. Also note that the term "ppm" should preferably not be used for mass-based analysis.*

A book on indoor air pollution states:

"1 CFM/ft<sup>2</sup> = 0.05 (l/s)/m<sup>2</sup>" where CFM = cubic foot per minute. *Should be 5.08(l/s)m<sup>2</sup>.*

A chapter on clean rooms in an engineering handbook contains the following errors:

- "10 particles/ft<sup>3</sup> = 0.28 particles/m<sup>3</sup>." *Should be 353 particles/m<sup>3</sup>.*
- "5,000,000 particles/ft<sup>3</sup> = 180 particles/l." *Should be 176,573 particles/l.*
- "100,000 particles per ft<sup>3</sup> = 3.5 particles/l." *Should be 3,531 particles/l.*
- "5,000 particles/ft<sup>3</sup> = 35,000 particles/m<sup>3</sup>." *Should be 176,573 particles/m<sup>3</sup>.*

A standard governing testing of a contaminant-producing appliance provides several incorrect conversions, including:

- "1 CFM = 21.19 liter/second." *Should be 0.47 liter/second.*
- "1 CFM = 2.119 x 10<sup>-3</sup> meter<sup>3</sup>/second." *Should be 4.72 x 10<sup>-4</sup> m<sup>3</sup>/sec.*

A fire protection handbook shows:

"1 cfm = 0.283 m<sup>3</sup>/min." *0.0283 m<sup>3</sup>/min is the correct value.*

A standard on indoor air quality states:

- "mppcf x 6 (approximately) = mg/m<sup>3</sup>."
- "particles per cc x 210 (approximately) = mg/m<sup>3</sup>."

(Note: "mppcf" = millions of particles per cubic foot.)

These two conversions are inconsistent. The standard correctly states that particles per cc (cubic centimeter) is equal to millions of particles per cubic meter. But 1 million particles per cubic foot is equal to approximately 35 million particles per cubic meter. The first equation would imply that this particle density would weigh 6 mg/m<sup>3</sup>, but the second would result in 35 x 210 = 7,350 mg/m<sup>3</sup>.

Incorrect unit nomenclature can also give rise to problems, as engineers perform unit balances in computation. For example, a standard

on indoor air quality states:

"l/s/m<sup>2</sup>." *The units should be l/s/m<sup>2</sup>.*

"1.5 cfm/ft<sup>2</sup> (7.5 l/s/ft<sup>2</sup>)." *The units should be 7.5 l/s/m<sup>2</sup>.*

Respirable particulate concentration given as "mg/m" should be given as mg/m<sup>3</sup>, and asbestos fiber density as "10<sup>3</sup> fiber/m" should be "10<sup>3</sup> fiber/m<sup>3</sup>."

2. *Equations or measurements are given without clearly stating their limitations.* These are then used erroneously for analysis outside their restricted field of applicability.

Contaminant concentrations are commonly provided without differentiating between mass-based and volumetric values. This is particularly the case with the use of "ppm", "ppb," and "per cent." The difference can be significant. For example, 1,000 ppm by volume of CO<sub>2</sub> is equal to almost 1,500 ppm by mass. It is also common to provide conversions between volumetric and mass-based quantities which are implicitly limited to a particular contaminant. As stated earlier in the article, the term "ppm" should not be used for mass-based analysis.

The same is true of conversions between contaminant "count"-based concentrations (such as particles/m<sup>3</sup> for particulates, or fibers/m<sup>3</sup> for asbestos) and mass-based concentra-

tions, which are limited not only to a specific contaminant, but to an aggregate contaminant "count-to-mass" relationship. If one uses conversion factors between, for example, particulates per cubic meter (i.e., "count based") and milligrams per cubic meter (i.e., "mass based"), such conversions are necessarily approximate. Someone who has measured airborne particle concentrations using a counter which measures particles per cubic meter could "convert" this reading to milligrams per cubic meter and be in error.

*3. Rounding errors.* For example, many air quality reference books commonly equate 1 CFM to 0.5 liters/second. This may be acceptable for the very roughest calculations, but is actually in error by approximately 6%.

*4. Ambiguities in unit nomenclature and other definitions.* For example, "grains" (abbreviated as "gr", in contaminant concentrations provided as gr/ft<sup>3</sup>) are often confused with "grams" (abbreviated as "g").

An industrial ventilation handbook lists the units for contaminant concentrations as "Mg/M<sup>3</sup>." The correct nomenclature is "mg/m<sup>3</sup>." Capital "M" stands for "mega", which means 1 million. Lower case "m" stands for "milli", or one-thousandth. The concentrations listed were supposed to represent milligrams per cubic meter.

Finally, gaseous contaminants and air often need to be evaluated at standard temperature and pressure conditions, but the definition of "standard temperature" is not consistent, alternately given as 0°C, 20°C, and 25°C in various sources.

### *Precautionary Measures*

The following general measures can act as a safety net to catch many of the common mistakes in indoor air quality analysis.

- Work from first principles as much as possible. In indoor air quality, the very first of the first principles is the conservation of mass: The rate at which a contaminant is transported into a building plus its internal rate of generation must equal the sum of its rate of removal and its rate of internal concentration change, assuming it does not degrade or decompose.
- Try to identify all limitations and assumptions that apply to equations and constants, and explicitly list these every time they are used, for example when writing reports. Include a list of these limitations and assumptions as a standard part of computer program output reports.
- When deriving equations by hand, write the units out below the equations. Make sure units balance on both sides of every equation. It can be helpful to explicitly state not only the unit, but also if it is referring to the contaminant or to air.

For example:  $\text{lb}_{\text{contaminant}}/\text{lb}_{\text{air}}$ , or  $\text{mg}_{\text{contaminant}}/\text{m}^3_{\text{air}}$ .

- Obtain as much confidence as possible in contaminant property values, such as gas density and molecular weight. Consult at least two reference texts if possible. Use the ideal gas law when applicable.
- Check whether concentrations provided as "ppm", "ppb," and "percent" are volumetric or mass-based. Explicitly state this when writing these units; for example, write "ppm (volume)." Avoid use of mass-based ppm, ppb, or percent altogether.
- Check whether equations are limited to air at standard temperature, pressure, and humidity. Check which "standard temperature" is used: 0°C, 20°C, or 25°C.
- Use standard unit nomenclature practice for common contaminant related prefixes and unit quantities, such as "m" for milli and "μ" for micro.

For computer spreadsheets or other computer source code, the following steps are also recommended:

1. Check constants, such as contaminant properties.
2. Check rounding routines. Keep rounding as accurate as possible during calculations, and then round off as necessary for program output. Keep rounding as consistent as possible. A final result is only as accurate as its least accurate cal-



ulation.

3. Check results against printed conversion tables.
4. Check results against hand calculations.
5. Give results a "reality" check. For example, when a contaminant generation rate is increased, the indoor concentration should increase.
6. Check results against other computer programs.

### Conclusions

Indoor air quality professionals have an important role to play in solving indoor air quality problems. This role derives primarily from the analysis used to back up measurements and recommendations. But when this analysis is itself based on mistaken calculations, there is a risk of contributing very little at all. In this critical developmental period of indoor air quality analysis, a little computational care may go a long way to making analytical contributions both correct and useful.

### References

CRC's *Handbook of Chemistry and Physics*, 54th edition, 1973-1974.

## Readers Speak Out

Last month we asked our readers to discuss in our pages the following question:

Proposed revisions to ASHRAE Standard 62-1989 would eliminate requirements that outdoor air be treated to a minimum quality at least equal to that established in the USEPA National Ambient Air Quality Standards (NAAQS) in order to achieve acceptable indoor air quality. In your experience is this an important feature of ASHRAE Standard 62-1989, and will the change weaken or strengthen the proposed revisions to the standard?

The response we received:

Your "Readers Speak Out" column was somewhat misleading. Standard 62-1989 does NOT require that outdoor air be treated prior to use as ventilation air if it does not meet the NAAQS. It merely suggests that it be done (the word "should" is used, not "shall"). The revised Standard essentially does the same thing: it does not require cleaning but suggests that if cleaning is not done, then acceptable IAQ may not be achieved with respect to the contaminant(s) in violation of the NAAQS.

Steve Taylor, Chair SSPC 62

For your convenience, we have reprinted the relevant section from each standard (the ANSI/ASHRAE Standard 62-1989 and the June draft of the proposed standard, ASHRAE 62-1989R). We still encourage participation from other readers.

#### ANSI/ASHRAE Standard 62-1989

6.1.2 Outdoor Air Treatment. If the outdoor air contaminant levels exceed the values given in 6.1.1 (Table 1), the air should be treated to control the offending contaminants. Air-cleaning systems suitable for the particle size encountered should be used. For removal of gases and vapors, appropriate air-cleaning systems should be used. Where the best available, demonstrated, and proven technology does not allow for the removal of contaminants, the amount of outdoor air may be reduced during periods of high contaminant levels, such as those generated by rush-hour traffic. The need to control offending contaminants may depend on local regulations that require specific control measures.

#### ASHRAE Proposed Draft Standard 62-1989R

5.2.2 Outdoor Air Treatment. This standard requires that the quality of ambient outdoor air be assessed per Section 5.2.1, but it does not require that outdoor air be treated before its use as a source of ventilation for indoor spaces even if outdoor air quality is found to be poor. However, if outdoor air is known to be unacceptable as determined in Section 5.2.1, ventilation without filtration may or may not result in acceptable indoor air quality.