Effective sampling protocol for managing indoor air quality in air-conditioned buildings

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ABSTRACT

The Environmental Protection Department conducted a territory-wide indoor air quality survey in Hong Kong. The report released in 1997 confirmed that one-third of the sampled buildings were classified as sick buildings. Many of the causes could be attributed to unacceptable indoor air quality (IAQ). In response to this, the Indoor Air Quality Management Group distributed a 'Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places' for public consultation. It includes an annual IAQ certification scheme. The scheme is required to sample air at each location for nine IAQ parameters and three thermal comfort parameters. The cost of IAQ sampling per point is estimated averaged at US$500. This requirement adds to the annual budget of a building at around US$15 000. If all air-conditioned buildings are IAQ certified, the total annual budget can be as high as US$75 million. Although this requirement is voluntary, building managers are concerned that it may be regulated. This paper describes a review of IAQ sampling in buildings and the development of a protocol of effective sampling based on statistical sampling principles. To ease the tension of the building industry, this sampling protocol can reduce the sampling requirement by as much as 50% with an equivalent representation.

INDEX TERMS

Indoor air quality; Guidance notes; Certification scheme; Sampling protocol; IAQ management

INTRODUCTION

The problem of indoor air pollution in Hong Kong has been recognized since 1990s. The Hong Kong Government issued 'A Green Challenge for the Community', which was its second review of the 1989 White Paper in December 1993 to stress the need for public awareness and participation to improve the indoor environment. The Indoor Air Quality Management Group has established to achieve the goal on improvement of indoor air quality (IAQ) in Hong Kong buildings. In October 1995, Environmental Protection Department (EPD) commissioned a consultancy study on 'Indoor Air Pollution in Offices and Public Places in Hong Kong'. After a 2-year survey, the consultancy report concluded that one-third of the sampled air-conditioned buildings were 'sick', which were mainly due to the unacceptable IAQ. The draft 'Guidance Notes for the Management of Indoor Air Quality in Offices and Publics' (GN) was then released by the Indoor Air Quality Management Group in November 1999 for public consultation. The GN is designed to establish an effective self-regulatory system for the maintenance of IAQ. An IAQ Certification Programme of GN is also conducted on a voluntary scheme that is intended to classify IAQ in mechanically ventilated buildings by sampling indoor air with definite sampling number for nine IAQ parameters and three thermal comfort parameters (see Table 1). However, the Certification Scheme is a voluntary basis it requires supports from building owners by complying the GN and also the process is required to support by resources in society. There are several scenarios

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that could jeopardize the successful launch of the GN.

Table 1 Recommended IAQ objectives for office buildings and public places in Hong Kong

Parameter	Unit	8-h average (at 25°C and 101.325 kPa)	
		Level 1	Level 2
Carbon dioxide (CO_2)	ppm	<800	<1000
Carbon monoxide (CO)	μg/m^3	<2000	<10 000
Respirable suspended particulates (RSP)	μg/m^3	<20	<180
Nitrogen dioxide (NO_2)	μg/m^3	<40	<150
Ozone (O_3)	μg/m^3	<50	<120
Formaldehyde (HCHO)	μg/m^3	<30	<100
Total volatile organic compounds (TVOC)	μg/m^3	<200	<600
Radon (Rn)	Bq/m^3	<150	<200
Airborne bacteria	cfu/m^3	<500	<1000
Room temperature	°C	20–25.5	<25.5
Relative humidity	%	40–70	<70
Air movement	m/s	<0.2	<0.3

FACTORS AFFECTING SUCCESSFUL LAUNCH OF GN

Cost to Building Owners

The draft GN specifies 12 IAQ parameters to measure at each sampling point for 8-h time average. Each parameter requires a different measuring principle and hence different instrumentation. The GN requires that the number of sampling points is based on the area of the premises (see Table 2). The certification is required to be done once a year. It is therefore a straightforward matter to estimate in monetary terms of the contribution by building owners. Apart from the cost of the measuring instruments, the cost for sampling one point of all 12 IAQ parameters based on the market price is around US$500. With an average of 30 sampling points for one building, the total cost to building owners for IAQ sampling in one typical office building is US$15 000.

Table 2 Guidelines for the minimum number of sampling points

Total certified area with the premises (served by MVAC system) (m^2)	Minimum number of sampling points
<3000	1 per 500 m^2
3000 to <5000	8
5000 to <10 000	12
10 000 to <15 000	15
15 000 to <20 000	18
20 000 to <30 000	21
>30 000	1 per 1200 m^2

Resource Support

It is clearly a huge resource requirement for IAQ sampling industry. Such business is very attractive to contractors and suppliers. It seems inevitable that, with the overwhelming workload for all concerned, the quality of survey and assessment will decline. EPD intends to control the quality by tightening up the quality of the ‘authorized samplers’ and laboratories. However, neither EPD nor any government department has any plan to invest in the regulatory process. It leads to concern that the good intentions of the Certification Scheme and GN will not be met, and instead end up with rather worthless certificates bought for millions of dollars.

Rationale for IAQ Levels

The GN benchmarks IAQ into two levels:

Level 1—represents very good IAQ that a high-class and comfortable building should have.
Level 2—represents IAQ that provides protection to the public at large including the very young and the aged.

In general, regulations require a minimum quality in order to safeguard the general public from hazardous conditions, like the Codes of Practice for Minimum Fire Service Installations and Equipment and Inspection, Testing and Maintenance of Installations and Equipment enforced through legislation. A natural response of the building owner would be that they would only spend US$15 000 annually for sampling to get a Level 1 certificate. Unfortunately, he/she may have to spend several times more to mitigate or renovate airside systems to meet the requirement.

DEVELOPMENT OF A PRAGMATIC PROTOCOL

From the previous discussion, it is possible that the GN will not be very successful as a voluntary scheme. However, there is pressure to regulate IAQ, this together with the market forces towards more sustainable buildings means building owners need to optimize their management strategies, to mitigate against liability should the building IAQ be unacceptable, the business incentive to certify the IAQ, and the annual budget to maintain compliance. Therefore, a more pragmatic protocol for managing the IAQ in large buildings is desirable. This protocol should help building owners to optimize expenditure to obtain meaningful certification. Then, the GN becomes more executable and that the public at large is exposed to lower IAQ risks. This revised protocol can also provide hindsight in the management of IAQ. Adopting the parameters in the GN for IAQ sampling the revised protocol is based on several principles:

Principle 1—a rationale of determining the population of measurement points.
Principle 2—a rationale of determining the number of sampling points.
Principle 3—a rationale of reducing the number of sampling parameters in each sampling point.
Principle 4—a rationale of reducing the amount of sampling time for each parameter in each sampling point.
Principle 5—a rationale of acceptance of the measured data.

Principle 1—Determination of Population of Measurement Points

In general, in air-conditioned indoor spaces, concentration of any pollutant is a function of three elements:

- quality of the ventilating air;
- distribution of the air; and
- emission characteristics of significant pollutants.

A sampling zone is then defined as a region of indoor space, whether it is confined by partitions providing a physical barrier to another zones, or a part of an open indoor space within which every physical location (preferably the workstations) has the same quality of ventilating air, the same distribution of the ventilating air and the same emission characteristics of all significant pollutants. Within a zone, the pollutant concentrations of a set of pollutants are expected to be unchanged within any location in the zone, within the accuracy of the measuring instruments used.

The air quality of the ventilating air is considered to be the same when the whole zone is served by the same airside system, including the fresh air supply system. Distribution of ventilating air is considered the same when the layout of the supply and return grilles, diffusers or registers gives a uniform circulation of the air within the zone. Emission characteristic of a pollutant will be the same if the pollutant sources are evenly distributed.

Air sampling zones can be defined by a trained operator doing an initial walkthrough survey of all air-conditioned spaces. The total number of zones forms the population of the representative air quality zones.

Principle 2—Determination of the Number of Sampling Points

If the zones within a building are viewed as the total population, once this is defined, the number of sampling points can be computed using classic statistical sampling theory. Determination of the number of sampling points is done using two procedures. The first procedure involves in grouping of similar zones into ‘categories’. When zones have the same three factors as defined in Principle 1, they will be grouped together to form ‘category’. In a given category, zones are expected to have similar pollutant profiles. For example, zones within a building where the activities are the same, such as typical offices with sedentary and non-smoking workers, served with typical air conditioning systems, and with the same pollutant inventories within the zones, can be grouped together to form a category.

The second procedure follows the definition of all the categories. The classic statistical sampling comes into effect the number of sampling points can be reduced to provide a more economical and viable monitoring schedule. Typically, the number of sampling points (N) in a category can be computed by Eqn (1):

$$N = \frac{t^2 S^2}{d^2} \qquad (1)$$

where

t = number of standard deviations that account for the confidence level;
S = standard deviation for the variable to be estimated; and
d = the margin of error (e.g. 10% of the mean value).

Principle 3—Reduction of the Number of Sampled Pollutants

A problem with extensive air sampling is the potentially high cost of measurements. In most cases, the indoor pollutants defined in the draft GN (Table 1) only exist in traces. To be confident in the air sampling, the lowest detectable limit should be one order below the prescribed level. Each pollutant has to be measured using a different technology, making comprehensive indoor air sampling very expensive. Therefore, it is possible to consider reducing the number of sampled pollutants. There are two ways by which the number of sampled pollutants can be reduced.

1. If the pollutant comes from outdoor sources only, and if its concentration at the intake point is below the prescribed criteria at all times, this pollutant can be discounted.

Vehicular borne pollutants, such as carbon monoxide and nitrogen oxides, are good examples.

2. If the pollutant is known to have a constant emission rate, and if its profile relative to the ventilation rate is known and is under control at all times, this pollutant can be discounted. Radon gas, which is ubiquitous in Hong Kong buildings, is a good example.

Principle 4—Reduction of Sampling Time for Each Pollutant in Each Sampling Zone
Most air quality sampling is done 8 h continuously. The resources required for such measurements are significant burdens on IAQ management. The reduction of sampling time is based on the assumption that when a building enters into its routine operation that including the activities of the occupancy and the operation of ventilation system, the function of the zone or the pollutant inventory are ever changing, it is reasonable to assume that the pollution profiles of the target pollutants would remain similar with small changes of magnitude. When the pollutant profile has always known, a snapshot of measurement at any time can be used to determine the equivalent 8-h exposure, and to check if any abnormal build-up of the pollutant has occurred. This is particularly useful when availability of instrumentation is a problem.

Principle 5—Choice of Alternative Instrumentation
Even with a limited set of target pollutants for monitoring purposes, the demand for instrumentation can remain high. Since most pollutants in most zones will normally prevail in traces, the requirements in respect of precision and accuracy of instrumentation are particularly demanding.

If the simpler measuring instrument used in the sampling is different from the requirement mentioned in GN for some reasons, the calibration of this measuring instrument against the standard should be undertaken in order to prove that the measuring instrument is available for the sampling. Therefore, the cost of the resource for sampling can be reduced if the building management company already has the instrument which is not specified by GN for sampling.

DISCUSSION
In order to check for its effectiveness, the sampling protocol was conducted in a Grade A office building. The total floor area of this building is 40 960 m^2. The minimum sampling points required by GN are therefore 35. However, when Principles 1 and 2 were applied for determining the number of sampling point, only 17 points were required to complete the sampling. By comparing the results, this protocol can reduce the sampling requirement by as much as 50% with an equivalent representation. Also, when applying the other principles, the cost of IAQ sampling can effectively reduce in terms of manpower, time and sampling resources.

CONCLUSION
The objective of the GN is to safeguard the occupant inside the office premises and public places and provide a sufficient quality of indoor air for the occupants. However, the resource of managing IAQ used in sampling would be too uneconomical, which may make the building manager feel that the costs are too prohibitive to get possibly meaningless values of IAQ parameters. By using these five principles of sampling protocols, the quality of indoor air can also be sustained and these economical and effective approaches not only concern the sampling, but also consider the rationale of the IAQ situation inside the building and the IAQ management.

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