Feasibility Study of Implementing an Indoor Air Quality (IAQ) Index in Hong Kong

香港室內空氣質素指數可行性研究

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Ir. Dr. K.W. Mui, Horace
Associate Professor
Department of Building Services Engineering,
The Hong Kong Polytechnic University

PhD, BEng(Hons), MHKIE, MCIBSE, MASHRAE, CEng, RPE
Personal website: https://sites.google.com/site/drmuikwokwai/home

6 June, 2017
Behind the News

Mention pollution and fingers usually point at the border. In the second of a three-part series, Robina Kwong examines what makes up our pollutants and who is responsible.

We're off the air

In the last few months, government officials have been telling Hong Kong's citizens that they were off the air. The "off the air" is a frequent refrain in local news, often heard in the context of air pollution.

The government has been warning citizens about the dangers of air pollution, particularly nitrogen dioxide (NO2) levels. This is due to the increasing number of vehicles on the road and the lack of effective pollution control measures. The government has also been urging citizens to reduce their carbon footprint and adopt more sustainable lifestyles.

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The South China Morning Post, 23 Feb 2006

Newspaper clips on IAQ Issues

"South China Morning Post, 23 Feb 2006"
Why should we concern about IAQ?

- Indoor Air Quality (IAQ):
  - Exposure: People spend >85% time indoor
  - Concerns of health and comfort
    - e.g. Sick leave, low productivity, money loss
  - Impact on energy use

Where do we spend most of our time?

Indoors 89%
In vehicles 7%
Outdoors 4%
Health concerns of IAQ

- 3.8 million premature deaths (WHO, 2014)

**Pathogenic**
- Long term effects (chronic)
- Short term effects (acute)

**Annoyance**
- Odour
- Irritation (eye, nose and throat)

What is acceptable air quality?
- No more than 5% occupants complaint
- No known pollutants exceed existing IAQ standard

Economic concerns of IAQ

Productivity + Sickness absence = Labour and production costs

2% decrease in productivity due to SBS symptoms would cost USD 60 billion annually (Fisk, 2000a; Fisk 2000b)

International Responses ...

- Australia
- China
- Europe
- Japan
- Taiwan
- South Korea
- USA
- HK
- WHO
- ...

Prepared by K.W. Mui (BSE, PolyU)
Various indoor sources

Sampling technique & location

Measurement equipment and required accuracy

Any regional assessment database for typical indoor environments

Level of representation to the overall IAQ acceptance

Balance between assessment efforts and level of IAQ understanding

Interpretation of assessed results
IAQ development in Hong Kong

1990
Pilot study on IAQ in 35 air-conditioned office

1993
Second review of the "1989 White Paper on Pollution in Hong Kong"

1994
Interim IAQ Guidelines

1995
Consultancy study on Indoor Air Pollution in Offices and Public Places in Hong Kong

1998
Indoor Air Quality Management Group (IAQMG)

1999
IAQ Management Programme

since 2000
IAQ Objective

since 2003
IAQ Certification Scheme for Offices and Public Places

Public education and publicity campaign

Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places

IAQ Information Centre

Prepared by K.W MUI (BSE, PolyU)
Parameters in IAQ Scheme

- Carbon Dioxide (CO₂)
- Carbon Monoxide (CO)
- Respirable Suspended Particulates (RSP)
- Nitrogen Dioxide (NO₂)
- Ozone (O₃)
- Formaldehyde (HCHO)
- Total Volatile Organic Compounds (TVOC)
- Radon (Rn)
- Airborne Bacteria
- Room Temperature
- Relative Humidity
- Air Movement
Validity of GN (Guidance Notes)?

Trend of IAQ?

Assessments of IAQ??

4 Assessments

A  B  C  D
Assessment A

1990 Pilot study on IAQ in 35 air-conditioned office

1993 Second review of the "1989 White Paper on Pollution in Hong Kong"

1994 Interim IAQ Guidelines

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1998 Indoor Air Quality Management Group (IAQMG)

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IAQ Information Centre

since 2003

IAQ Certification Scheme for Offices and Public Places

Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places

Prepared by K.W MUI (BSE, PolyU)
• **Assessment A:**
  First extensive IAQ study for Hong Kong carried out by an independent consultant. The sampling protocol based on the US Environmental Protection Agency’s BASE (Building Assessment Survey and Evaluation) study and modified as necessary to cope with the local constraints.

• **Assessment B:**
  Three government office measurements were also performed in a trial run to verify the validity of the GN (Guidance Notes).

• **Assessment C:**
  Four of the HKEPD listed indoor pollutants, namely CO$_2$, HCHO, RSP and ABC, were measured in 10 typical air-conditioned offices installed with mechanical ventilation systems.

• **Assessment D:**
  A regional cross-sectional measurement of pollutant levels was conducted in 422 air-conditioned offices in Hong Kong.
## Predicted Satisfactory Office Environment in Hong Kong from 1996 to 2003

### (a) At excellent level

<table>
<thead>
<tr>
<th>Parameters</th>
<th>CO$_2$ (ppm)</th>
<th>CO (μg m$^{-3}$)</th>
<th>RSP (μg m$^{-3}$)</th>
<th>NO$_2$ (μg m$^{-3}$)</th>
<th>O$_3$ (μg m$^{-3}$)</th>
<th>HCHO (μg m$^{-3}$)</th>
<th>TVOC (μg m$^{-3}$)</th>
<th>Rn (Bq m$^{-3}$)</th>
<th>ABC (CFU m$^{-3}$)</th>
<th>T (°C)</th>
<th>RH (%)</th>
<th>V (ms$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria for ‘Excellent’</td>
<td>&lt;800</td>
<td>&lt;2,000</td>
<td>&lt;20</td>
<td>&lt;40</td>
<td>&lt;50</td>
<td>&lt;30</td>
<td>&lt;200</td>
<td>&lt;150</td>
<td>&lt;500</td>
<td>20-25.5</td>
<td>40-70</td>
<td>&lt;0.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source of data</th>
<th>Sample size</th>
<th>Predicted satisfactory rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment A</td>
<td>40</td>
<td>28% 99% 34% 97% 73% 16% -- -- 33% 100% 98% 100%</td>
</tr>
<tr>
<td>Assessment B</td>
<td>3</td>
<td>56% 100% 14% 96% 100% 31% 15% 100% 61% 79% 100% 100%</td>
</tr>
<tr>
<td>Assessment C</td>
<td>10</td>
<td>52% -- 53% -- -- 93% -- -- 76% -- -- --</td>
</tr>
<tr>
<td>Assessment D</td>
<td>422</td>
<td>82% 100% 35% 84% 82% 42% 26% 98% 51% 88% 86% 93%</td>
</tr>
</tbody>
</table>

### (b) At good level

<table>
<thead>
<tr>
<th>Parameters</th>
<th>CO$_2$ (ppm)</th>
<th>CO (μg m$^{-3}$)</th>
<th>RSP (μg m$^{-3}$)</th>
<th>NO$_2$ (μg m$^{-3}$)</th>
<th>O$_3$ (μg m$^{-3}$)</th>
<th>HCHO (μg m$^{-3}$)</th>
<th>TVOC (μg m$^{-3}$)</th>
<th>Rn (Bq m$^{-3}$)</th>
<th>ABC (CFU m$^{-3}$)</th>
<th>T (°C)</th>
<th>RH (%)</th>
<th>V (ms$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria for ‘Good’</td>
<td>&lt;1,000</td>
<td>&lt;10,000</td>
<td>&lt;180</td>
<td>&lt;150</td>
<td>&lt;120</td>
<td>&lt;100</td>
<td>&lt;600</td>
<td>&lt;200</td>
<td>&lt;1,000</td>
<td>&lt;25.5</td>
<td>&lt;70</td>
<td>&lt;0.3</td>
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<tr>
<td>Assessment A</td>
<td>40</td>
<td>56% 100% 100% 100% 100% 75% -- -- 69% 100% 98% 100%</td>
</tr>
<tr>
<td>Assessment B</td>
<td>3</td>
<td>88% 100% 100% 100% 100% 98% 22% 100% 100% 100% 100% 100%</td>
</tr>
<tr>
<td>Assessment C</td>
<td>10</td>
<td>61% -- 100% -- -- 100% -- -- 96% -- -- --</td>
</tr>
<tr>
<td>Assessment D</td>
<td>422</td>
<td>97% &gt;99.8 &gt;99.8 &gt;99.8 95% 94% 84% 100% 85% 98% 88% 98%</td>
</tr>
</tbody>
</table>
From 1999 to 2003, with the implementation of the GN:

- Predicted satisfactory rates of CO$_2$, HCHO, TVOC and ABC were enhanced.
- Predicted satisfactory rates for RH and T were decreased.
- It could be explained by the fact that most existing air-conditioned systems had not yet been renovated to cater for the increased fresh air loads.

- Some of the parameters seldom exceeded the recommended criteria, e.g. CO.
- Some contributed to a relatively low unsatisfactory rate, e.g. Rn and V.
Problems and Limitations

- Low participation number: 996 premises (Nov, 2015)
- Certified locations: > 60% in common areas
- Voluntary basis
- Stringent IAQ standards
- High implementation cost and improvement cost
- Lack of flexibility in measurement procedures and subsequent monitoring
- Outdated?

But....

Preamble
Whereas recognition of the inherent dignity and of the equal and inalienable rights of all members of the family is the foundation of freedom, justice and peace in the world.

Whereas disregard and contempt for human rights have resulted in barbarous acts which have outraged

Universal Declaration of Human Rights

The Universal Declaration of Human Rights (UDHR) is a milestone document in the history of human rights. Drafted by representatives with different legal and cultural backgrounds from all regions of the world, the Declaration was proclaimed by the United Nations General Assembly in Paris on 10 December 1948 (General Assembly resolution 217 A) as a common standard of achievements for all peoples and all nations. It sets out, for the first time, fundamental human rights to be universally protected and it has been translated into over 500 languages.

Article 24.
Everyone has the right to rest and leisure, including reasonable limitation of working hours and periodic holidays with pay.

Article 25.
(1) Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing and medical care and necessary social services, and the right to security in the event of unemployment, sickness, disability, widowhood, old age or other lack of livelihood in circumstances beyond his control.
(2) Motherhood and childhood are entitled to special care and assistance. All children, whether born out of wedlock, shall enjoy the same social protection.

Article 26.
(1) Everyone has the right to education. Education shall be free, at least in the elementary and fundamental
Do we need to establish something on indoor air quality?
IAQ Pre-assessment tools

- Two approaches:
  - Health-risk approach
  - Indicator approach

IAQHI

IAQSI
IAQ Health Index (IAQHI)

Based on Air Quality Health Index (AQHI) (Wong et al. 2013):

- Health risk-based air pollution index
- Estimate the short-term risk of respiratory diseases associated with exposure to 4 criteria air pollutants
  - \( \text{SO}_2 \)
  - \( \text{NO}_2 \)
  - \( \text{O}_3 \)
  - \( \text{PM}_{10} \)
Index Calculation

Wong et al., 2013

- Sum of the percentage added health risk (%AR) of daily hospital admissions attributable to the 3-h moving average concentrations of the four air pollutants (SO₂, NO₂, O₃, PM₁₀)

\[
%AR = \sum %AR(c)
\]

- %AR of each pollutant depends on its concentration and a risk factor correlated with local health statistics and air pollution data (Wong et al., 2013)

\[
%AR(c) = \{\exp[\beta(c) \times C(c)] - 1\} \times 100\%
\]

Can we consider to use it in indoor environment?

- Industrial standards are set for healthy adults in the 8 hour-shift work place.
- General population, age, health status vary.
- Exposure-time are different:
  - Intermittent, continuous.
- Effects of long term low level exposure not known.
Proposed Development of IAQHI

- Addition of indoor surrogate parameters into the calculation

- Daily environments may be divided into two distinct groups:
  1. Indoor spaces served by MVAC systems; and
     - CO₂, VOCs (including HCHO) and PM₂.₅
  2. Outdoor spaces (including enclosed places with windows for natural ventilation)
     - VOCs (including HCHO) and PM₂.₅
Difficulties in Developing IAQHI

- At preliminarily stage
- Identification of health risk of individual chemical takes extensive health-based research and collective health assessment study
- Limited knowledge on combined exposure to multiple pollutants
- Individuals respond to chemical exposures in different ways
- age, gender, health status and genetics

Ultimate Goal ??

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3 common IAQ control strategies

- Source
- Distribution (e.g. Air Duct, Water Pipe)
- Dilution
- Emission control
- Removal
- Receptor
IAQ Index with Surrogate Indicators (IAQSI)

- Surrogate indicators (Wong et al., 2006)
  - $\text{CO}_2$: Surrogate indicator for ventilation & occupant load
  - RSP: Dominant outdoor air pollutant; indicator of the filtration performance
  - TVOC: Indicator of indoor air pollutants emitted from building materials, finishes and human activities

IAQ Index with Surrogate Indicators (IAQSI)

- “IAQ index” \( \theta \)

- Average fractional dose \( \phi_j^* \) of the average level \( \phi_j \) to the exposure limit \( \phi_{j,0} \) of Good Class in the Scheme for \( N \) selected surrogate parameters \( j \) (Wong et al., 2007)

\[
\theta = \frac{1}{N} \sum_{j=1}^{N} \phi_j^* \quad \quad \quad \phi_j^* = \frac{\phi_j}{\phi_{j,0}}
\]

Existing standards used as a reference

<table>
<thead>
<tr>
<th>No.</th>
<th>Air pollutant</th>
<th>HKEPD recommended maximum level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CO (ppm)</td>
<td>1000</td>
</tr>
<tr>
<td>2</td>
<td>CO (( \mu )g ( m^3 ))</td>
<td>10000</td>
</tr>
<tr>
<td>3</td>
<td>RSP (( \mu )g ( m^3 ))</td>
<td>180</td>
</tr>
<tr>
<td>4</td>
<td>NO(_2) (( \mu )g ( m^3 ))</td>
<td>150</td>
</tr>
<tr>
<td>5</td>
<td>O(_3) (( \mu )g ( m^3 ))</td>
<td>120</td>
</tr>
<tr>
<td>6</td>
<td>HCHO (( \mu )g ( m^3 ))</td>
<td>100</td>
</tr>
<tr>
<td>7</td>
<td>TVOC (( \mu )g ( m^3 ))</td>
<td>600</td>
</tr>
<tr>
<td>8</td>
<td>Rn (Bq ( m^3 ))</td>
<td>200</td>
</tr>
<tr>
<td>9</td>
<td>ABC (CFU ( m^3 ))</td>
<td>1000</td>
</tr>
</tbody>
</table>

IAQ Index with Surrogate Indicators (IAQSI)

Based on the feasibility study conducted by Mui et al. (2011), effect of using different combinations of surrogate IAQ parameters in IAQ index “θ” for predicting unsatisfactory IAQ in office is investigated by Wong et al. (2016).

Combination (Wong et al., 2016)

1. IAQ index $\theta_1$ - CO$_2$
2. IAQ index $\theta_2$ - CO$_2$ and RSP
3. IAQ index $\theta_3$ - CO$_2$, RSP and TVOC

Proposed Step-wise Screening Protocol

Wong et al. 2016

- For decision making in practical IAQ management
- Testing threshold and test-treatment threshold are set according to facility management strategies
- Balance between resources and effectiveness

How Likely the Test is Telling the Truth?

Further to that, likelihood ratio $L_r$ is used to provide information about the reliance of the test result

i.e. how likely a positive result in a test is indicating a true problematic case.

Based on the testing thresholds, three indices were categorized into five screening levels

i.e., multilevel likelihood ratios with an order of magnitude $L_r = 10$ or $0.1$ used in a medical test for diagnosing a disease.

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How to Use?

- **Likelihood ratio** (概似比) of an IAQ index in diagnosing unsatisfactory IAQ can be determined:
  - **TP**: fail counts (of the scheme) against the screening test parameters \( \theta < \theta_a^* \) and \( \theta > \theta_b^* \)
  - **TN**: pass counts (of the scheme) against the screening test parameters \( \theta < \theta_a^* \) and \( \theta > \theta_b^* \)
  - \( n_{TP} \): total fail counts
  - \( n_{TN} \): total pass counts

\[
L_r = \frac{TN \ n_{TP}}{TP \ n_{TN}}
\]

It summarizes the screening results and their corresponding likelihood ratios for IAQ indices \( \theta_1 \), \( \theta_2 \) and \( \theta_3 \)

<table>
<thead>
<tr>
<th>( k )</th>
<th>Screening Level for ( \theta_1, \theta_2, \theta_3 )</th>
<th>Likelihood Ratio, ( L_r )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>( \theta_1 )</td>
</tr>
<tr>
<td>1</td>
<td>(&lt; 0.32 )</td>
<td>/</td>
</tr>
<tr>
<td>2</td>
<td>( 0.32 \text{ – } 0.42 )</td>
<td>0.2</td>
</tr>
<tr>
<td>3</td>
<td>( 0.43 \text{ – } 0.53 )</td>
<td>0.7</td>
</tr>
<tr>
<td>4</td>
<td>( 0.54 \text{ – } 0.64 )</td>
<td>0.9</td>
</tr>
<tr>
<td>5</td>
<td>( \geq 0.65 )</td>
<td>1.3</td>
</tr>
</tbody>
</table>

For example, if we measure CO\(_2\) and RSP; the IAQ index is 0.7
Probability of Having Poor IAQ

- Pre-test probability $P_d$ and $L_r$ are required for calculating the post-test probability $P'_d$ of having poor IAQ.

- Prevalence of unsatisfactory IAQ (i.e. $P_d$) in HK can be acquired from collective IAQ assessment of similar buildings.
  - $P_d$: pre-assessment probability
  - $O_d$: pre-assessment odds
  - $O'_d$: post-assessment odds
  - $P'_d$: post-assessment probability
  - $N_d$: the number of unsatisfactory IAQ samples in N regional IAQ samples

$$\begin{align*}
P_d &= \frac{N_d}{N} \quad O_d = \frac{P_d}{1 - P_d} \quad P'_d = \frac{O'_d}{1 + O'_d} \quad O'_d = O_d \times L_r
\end{align*}$$

IAQ index $\theta_1$
- Low resolution
- Can identify lower risk group

IAQ index $\theta_2$ and IAQ index $\theta_3$
- High resolution
- Can identify lower risk and higher risk group

If 0.5 of $P_d$ (from global), ↑ to 0.8
Probable to Very probable
Advantages of IAQSI

- Reduce cost and the investment of massive resource
- Can be applied to general indoor environments
- Suitable for territory-wide IAQ screening
- Suitable for real-time IAQ monitoring
Suggestions on IAQ Policy Development in Hong Kong

Short term ...

- Improving IAQ objective
  - Should be consistent and expanded to cover all indoor environments.
  - All reference standards should be relevant and up to date.
  - Evaluation of the standards should be conducted to give a set of air pollutant limits that is attainable, while protecting people’s health and the environment.

- To preliminarily identify places having potential IAQ problems, a territory-wide IAQ screening programme should be conducted for a variety of indoor environments.
  - Using IAQSI together with step-wise screening protocol.
Suggestions on IAQ Policy Development in Hong Kong

Long term …

- Establish a comprehensive framework that provides new knowledge towards an integrated approach to assessing health risks from indoor air pollution, focusing on both existing and new buildings.
- Raising public awareness.
- Conducting educational seminars and exhibition on the importance of good IAQ.

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Public Dissemination: IAQ benchmarks

- Overall IAQ situation in Hong Kong can be monitored and improved, a territory-wide IAQ database should be maintained.
- An IAQ profile exclusively for Hong Kong can be generated through extensive IAQ assessments in major local buildings.
- Based on the data collected, a 5-star IAQ benchmarking system can be established.
- For regular updating of the profile, the HKSAR Government may consider annual IAQ data collection.
Acknowledgement

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Thank you very much!