Indoor air quality of air-conditioned offices of Hong Kong: An IAQ policy influence


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SUMMARY
In Hong Kong, the existing indoor air quality (IAQ) policy was in the form of guidance which audited 3 thermal comfort and 9 IAQ parameters. However, the influence of such policy on fungi exposure in offices was not extensively evaluated. This study aims to investigate the probable influences of existing IAQ policy and unsatisfactory rate with respect to some target exposure levels of airborne fungi count (AFC) in an air-conditioned office of Hong Kong. It was found that the dilution strategy was adopted in many offices and probably some outdoor air pollutants would be introduced to indoor environment for improperly designed systems. Enhancement of ventilation was observed by the decrease in unsatisfactory rate of CO₂. Moreover, enhancement of mean AFC in offices was reported. This study concludes the positive influence of the IAQ policy in promoting healthy workplace with IAQ improved in the past decade in Hong Kong.

KEYWORDS
Indoor air quality, Policy influence, Organic, Inorganic, Air-conditioned office

INTRODUCTION
Standards and guidelines on achieving good Indoor Air Quality (IAQ) have been developed for many developed cities in order to specify IAQ (WHO 2005). In Hong Kong, an IAQ certification scheme was implemented in 2003 and the IAQ performance would be labeled as ‘Excellent’ or ‘Good’ by assessing the exposure levels of 12 parameters in the indoor environment. These parameters included 3 for thermal comfort parameters, 8 for common indoor air pollutants and 1 for bioaerosols; they were air velocity (V), room air temperature (T) and relative humidity (RH); and carbon dioxide (CO₂), carbon monoxide (CO), formaldehyde (HCHO), nitrogen dioxide (NO₂), ozone (O₃), radon (Rn), respirable suspended particulates (RSP) and total volatile organic compounds (TVOC); and airborne bacteria count (ABC) respectively (HKEPD 2003).

The development of the current IAQ policy would be traced back to early 1990’s. In 1993, the Hong Kong Government recognized the IAQ issue in the second review of the ‘1989 White Paper on Pollution’ and a study on Indoor Air Pollution in Offices and Public Places was initiated in 1995 (HKEPD 1997), and the IAQ Management Group was set up to coordinate the development and implementation of IAQ policy in Hong Kong. In 1999, the Management Group proposed an ‘IAQ Management Programme’ for public consultation (IAQMG 1999). It resulted the implementation of a voluntary IAQ certification scheme which adopted a set of IAQ objectives for air pollutants as a performance indicator for office IAQ in 2003 (HKEPD 2003). The IAQ labels ‘Good’ and ‘Excellent’ evaluated by the exposure limits of the listed 12 parameters were shown in Table 1. It was addressed the strategies for better management of IAQ in offices in the form of Guidance Notes (GN) (IAQMG 2003).
Another bioaerosols – airborne fungi transported from the source of contamination through an Heating, ventilating and air-conditioning (HVAC) system was reported in some offices and would raise health and comfort concerns (Law et al. 2001). Indeed, exposure to indoor airborne fungi would cause allergic, respiratory symptoms and disease and sick-building symptoms (Hardin et al. 2003). Until now, an acceptable airborne fungi count (AFC) for offices of Hong Kong has not been defined. Indeed, it would be difficult in establishing uniform standards for AFC, probable due to insufficient scientific evidence between the AFC and threat to human health for setup AFC action levels. Simple airborne fungi counts would give some indication but the compositions of airborne fungi in the samples would be more important (Chow et al. 2005). Evaluation of the exposure risk of airborne fungi in offices could not be ignored. Fungi counts measured in some offices of Hong Kong were reported (HKEPD 1997, Law et al. 2001, Chow et. al. 2005, Mui et al. 2007). However, the influence of the current IAQ policy on the fungi exposure in offices was not extensively evaluated systematically.

This study reviews regional office IAQ measurements before and after the implementation of the current IAQ policy in 2003. Probable improvements of IAQ between the 2 periods are highlighted. In particular, the airborne fungi counts of these assessments are reviewed thus to investigate the probable influences of the IAQ policy on the fungi exposure levels in air-conditioned offices of Hong Kong. The implications of probably unsatisfactory rate with respect to some target exposure levels of AFC are also discussed.

**IAQ IN HONG KONG OFFICES**

Regional IAQ assessments in air-conditioned offices were conducted before implementation of the IAQ certification scheme (HKEPD 1997, Chao et al. 2001, Lee et al. 2002, Wong et al. 2006). The first extensive IAQ assessment in Hong Kong was conducted in 1996 that 40 offices was assessed by the measurements of the 12 listed parameters and airborne fungi (HKEPD 1997). The examined offices included both smoking and non-smoking areas in private and governmental office buildings. The second regional assessment referred in this study was conducted from 1998 to 2003 that the IAQ was evaluated by the 12 listed parameters in 422 randomly picked air-conditioned offices (Wong et al. 2006). A total of 462 office samples (denoted as “Assessment A”) were used to approximate the office IAQ before the implementation of the IAQ certification scheme as shown in Table 1.

With the implementation of IAQ certification scheme after 2003, an IAQ study was conducted in 82 offices ready for IAQ certification in Hong Kong (denoted as “Assessment B”) with the 12 listed IAQ parameters measured and AFC were also measured. The offices were mechanically ventilated and air-conditioned, and being maintained to target for excellent IAQ. It was reported that the offices were served by an HVAC system with fresh (outdoor) air supplied from a centralized primary air handling plant, and the system was undergoing schedule maintenance that replaced air filters and cleaning the cooling coil of the air handling every 3 months. The details of measurement equipment, sample protocols were reported elsewhere and would not be repeated in this paper (Mui and Wong 2004, Wong et al. 2006, Hui et al. 2007).

**RESULTS AND DISCUSSIONS**

Table 1 summarized the IAQ assessment results of air-conditioned offices before the year 2003 (denoted as ‘Assessment A’) and after the implementation of IAQ certification scheme of year 2003 (denoted as “Assessment B”). In this study, the IAQ assessments were evaluated in 3 aspects: thermal comfort, organic and inorganic pollutants, and bioaerosols. It was
reported that the 3 thermal comfort parameters, i.e. T, RH and V, were normally distributed (p>0.05) and the other assessment parameters were geometrically distributed (p>0.05) (Wong et al. 2006, Mui et al. 2007). The corresponding means and standard deviations (SD) of the assessment parameters were presented in Table 1 The unsatisfactory rates of the offices f_i regarding the exposure limits of IAQ labels ‘Good’ and ‘Excellent’ were determined by the Equation (1), where G is the distribution functions of the assessment parameter approximated by a distribution function with a mean and a standard deviation, Φ^* is the set criterion of unsatisfactory environment having Φ_i > Φ^* (HKEPD 2003, Mui et al. 2007),

\[
f_i = 1 - \int_{-\infty}^{\Phi^*_i} G(\Phi_i) \, d\Phi_i
\]  

Compared the unsatisfactory rates of the listed 12 parameters between assessments A and B, it was not surprising that the IAQ of air-conditioned offices were ‘improved’ in general, except for CO and NO_2. And the unsatisfactory rate of CO and NO_2 increased in ‘Excellent’ level, however, the mean levels as well as the unsatisfactory rate in ‘Good’ level were decreased. These improvements might probably due to the effects of mitigation strategies suggested for the IAQ certification scheme (HKEPD 2003). These mitigation strategies included four areas: source control, ventilation, air cleaning and administration measures. The pollutant source can be controlled by total elimination, substituting, sealing, blocking or relocating the source. And it is observed that the practical strategies of IAQ improvement adopted for many existing buildings were related to the operation and maintenance of the existing HVAC system, such as diluting indoor air pollutants with outdoor fresh air and improvement of air filtration performance etc.

The enhancement of the ventilation of the poor ventilated offices was observed as the unsatisfactory rate for CO_2 decreased from 0.055 to 0.008 and 0.232 to 0.132 regarding the exposure limits for ‘Good’ and ‘Excellent’ classes respectively. CO_2 concentration was a surrogate indicator for assessing the IAQ and was correlated with the occupants’ comfort in the environment and the installed ventilation systems’ performance (Persily 1997, CEN 1999, ASHRAE 2004). Moreover, some IAQ improvements due to the use of air cleaners were also believed.

It was reported that adjusting and rebalancing the air-conditioning system would provide improvement of thermal comfort. The mean air speed decreased from 0.09 to 0.08 ms\(^{-1}\); and the corresponding unsatisfactory rates decreased from 0.002 to <0.001 for ‘Good’ level and from 0.065 to 0.015 for ‘Excellent’ level. The mean air temperature T increased from 22.0 to 22.6°C and the unsatisfactory rate decreased from 0.032 to 0.007 for the ‘Good’ level and from 0.183 to 0.020 and ‘Excellent’ level respectively. The enhancement of the dehumidification of the system in the offices of Assessment B resulted a lower mean level of RH (51%) when compared those offices in Assessment A (60%). The unsatisfactory rate of RH deceased from 0.114 to 0.001 and 0.127 to 0.029 for ‘Good’ and ‘Excellent’ levels respectively. With the implementation of the IAQ certification scheme, the unsatisfactory rates of HCHO, O_3, Rn, RSP, TVOC and ABC would be improved as shown in Table 1.
Table 1 IAQ assessment and predicted unsatisfactory rate of air-conditioned offices in Hong Kong before and after 2003.

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<tr>
<td></td>
<td>Good level</td>
<td>Excellent level</td>
<td>Mean (SD)</td>
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<td><strong>Thermal comfort parameters</strong></td>
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<tr>
<td>V (m s(^{-1}))</td>
<td>&lt;0.3</td>
<td>&lt;0.2</td>
<td>0.09 (0.08)(^b)</td>
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<tr>
<td>T (°C)</td>
<td>&lt;25.5</td>
<td>20.0-25.5</td>
<td>22.0 (1.9)(^b)</td>
</tr>
<tr>
<td>RH (%)</td>
<td>&lt;70</td>
<td>40-70</td>
<td>59.5 (8.7)(^b)</td>
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<td><strong>Indoor air pollutant parameters</strong></td>
<td></td>
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<tr>
<td>CO(_2) (ppm)</td>
<td>&lt;1000</td>
<td>&lt;800</td>
<td>662.3 (1.29)(^c)</td>
</tr>
<tr>
<td>CO (ug m(^{-3}))</td>
<td>&lt;1000</td>
<td>0</td>
<td>954.7 (1.46)(^c)</td>
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<tr>
<td>HCHO (ug m(^{-3}))</td>
<td>&lt;100</td>
<td>&lt;30</td>
<td>34.4 (2.72)(^c)</td>
</tr>
<tr>
<td>NO(_2) (ug m(^{-3}))</td>
<td>&lt;150</td>
<td>&lt;40</td>
<td>24.0 (1.74)(^c)</td>
</tr>
<tr>
<td>O3 (ug m(^{-3}))</td>
<td>&lt;120</td>
<td>&lt;50</td>
<td>36.2 (2.17)(^c)</td>
</tr>
<tr>
<td>Rn (Bq m(^{-3}))</td>
<td>&lt;200</td>
<td>&lt;150</td>
<td>40.2 (1.22)(^c)</td>
</tr>
<tr>
<td>RSP (ug m(^{-3}))</td>
<td>&lt;180</td>
<td>&lt;20</td>
<td>27.0 (1.93)(^c)</td>
</tr>
<tr>
<td>TVOC (ug m(^{-3}))</td>
<td>&lt;600</td>
<td>&lt;200</td>
<td>293.2 (2.34)(^c)</td>
</tr>
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</table>

**Bioaerosol parameters**

| ABC (CFU m\(^{-3}\)) | <1000 | <500 | 451 (2.20)\(^f\) | 0.156 | 0.448 | 185 (1.61)\(^e\) | 0 | 0.018 |
| AFC (CFU m\(^{-3}\)) | <200 | - | 223 (2.60)\(^f\) | 0.546 | - | 20 (2.82)\(^e\) | 0.013 | - |

\(^a\) ACGIH (1989)
\(^b\) The readings were normally distributed and arithmetic mean and arithmetic standard derivation are presented.
\(^c\) The readings were geometric distributed and the geometric mean and geometric standard derivation are presented.
\(^f\) – no information

Regarding the exposure limits for ‘Good’ offices, the unsatisfactory rate of TVOC was the highest, followed by ABC, HCHO and RSP. It was noted that TVOC was closely related to the emission from building materials, furnishings and other building contents and HCHO would be emitted from new furniture or materials used in renovations. Exposure to these organic compounds would associate with sick building symptoms, acute and chronic health effects (WHO 1989). Cleaning the air-conditioning system would lead to an improvement of ABC levels. Maintenance of air filtration system would improve the filtration performance and reduce the RSP levels. It was reported that the TVOC decreased from 293 to 158 µg m\(^{-3}\), ABC decreased from 451 to 185 CFU m\(^{-3}\), HCHO decreased from 34.4 to 14.9 µg m\(^{-3}\) and RSP decreased from 27.0 to 15.9 µg m\(^{-3}\); correspondingly, the unsatisfactory rates against the ‘Good’ and ‘Excellent’ levels were decreased from 0.200 to 0.038 and 0.673 to 0.377 for TVOC, 0.156 to 0 and 0.448 to 0.018 for ABC, 0.144 to 0.022 and 0.555 to 0.230 for HCHO and 0.002 to 0 and 0.677 to 0.230 for RSP, respectively.
An improvement of mean AFC in offices was found due to the implementation of the IAQ certification scheme. The mean AFC of “Assessment A” was 223 CFU m\(^{-3}\). Taking 200 CFU m\(^{-3}\) as a reference exposure limit (ACGIH 1989), the unsatisfactory rate of offices in “Assessment A” was 0.546, which was the highest rate as compared with the assessments regarding the other 12 assessments parameters. The expected high unsatisfactory rate in office environment of Hong Kong was confirmed with a study that the expected unsatisfactory rate was 19%, which was one of the top ranked contributors of unsatisfactory IAQ in air-conditioned offices of Hong Kong (Mui et al. 2007). Assessments in offices with the implementation of the IAQ certification scheme (Assessment B), the mean AFC significantly decreased to 20 CFU m\(^{-3}\) which corresponding to an unsatisfactory rate of to 0.013. These improvements might be due to the better control of the indoor thermal conditions (i.e. T and RH) and cleaning the air supply system (IAQMG 2003). It was noted that RH and T would be explanatory parameters to the survival of germination, growth and development of the indoor bioaerosols (Chow et al. 2005). It was recommended to maintain an RH between 30% and 60% in order to minimize the growth of allergic or pathogenic microorganism (ASHRAE 2004).

CONCLUSIONS
This study aims to investigate the probable influences of an IAQ policy and unsatisfactory rate with respect to some target exposure levels of airborne fungi count (AFC) in air-conditioned offices of Hong Kong before and after the implementation of the IAQ policy in 2003. It is revealed that, except for predicted unsatisfactory rate of CO and NO\(_2\), the predicted unsatisfactory rates for all thermal comfort, indoor air quality and bioaerosols parameters were decreased. In addition, the level of an important bioaerosols parameter – airborne fungi count (AFC) was decreased as well as the predicted unsatisfactory rate. This study concludes the positive influence of the IAQ policy in promoting a healthy workplace with IAQ improved in the past decade in Hong Kong.

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