# IAQ at two vocational institutes in Hong Kong

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**ABSTRACT**
Since the initiative by the government in 1999, indoor air quality (IAQ) has received attention from the community at large in Hong Kong and the education sector has also been actively monitoring IAQ in line with the proposed objectives. This paper reports the finding of an IAQ study conducted in 2002 at two vocational education institutes. It begins with a brief review of IAQ development in the education sector. An outline of the site inspection, the IAQ objectives and the equipment used in the study then follows. The overall results, based on 8-h average data, show that most of the locations monitored meet the level I classification, indicating a comfortable environment. In the discussion, an example of $CO_2$ and occupancy rate time-history is given and examined, which highlighted dynamic effects. In the learning environment, $CO_2$ level might have a bearing on academic performance and would be further investigated.

**INDEX TERMS**
Classroom; IAQ assessment; Carbon dioxide; Occupant rate

**INTRODUCTION**
The Hong Kong Special Administrative Region Government (HKSARG) launched a public consultation on the proposed Indoor Air Quality (IAQ) Management Programme in 1999. This has provided a great impetus to develop local IAQ standards. The initiative, in essence, aims at protecting public health in the indoor environment and raising public awareness of the importance of IAQ. Although it was primarily for office buildings and public places with totally enclosed areas provided with mechanical ventilation and air-conditioning, the education sector has also taken an interest in IAQ.

At the tertiary level, a number of institutions with technical expertise have already examined IAQ for their campus. The initial drive could be traced back to around 1995, when one university started to conduct air sampling survey at selected campus sites. It was found that ‘more energy is not always needed for good IAQ’. Another university undertook a 15-month IAQ study, which was completed around December 2000. In short, universities with expertise in building services engineering were quick to deploy resources into addressing IAQ in the campus environment.

At the secondary and primary school level, the authority has already started to conduct IAQ survey of schools, with a view to incorporate energy efficiency at the same time. In this, the Architecture Services Department of HKSARG has taken a lead in applying the 2-level IAQ objectives to new school design. For government buildings, the Electrical and Mechanical Services Department of HKSARG has also undertaken IAQ survey at education related premises. In the US experience, there has been far greater participation and involvement from school stakeholders. Valuable experience can be gained from the various papers at the Indoor Air 2002 conference. Also, the Environmental Protection Agency of the US government has been providing a wealth of information through its web-site, which encourages self-help initiatives and start-ups.

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In the local vocational sector, the Vocational Training Council is the major education and training service provider, with nine campuses for further education and seventeen centres for skill-based training. Some in-house work has been carried out over the past few years in a number of campuses and corporate owned buildings. No major adverse results have been reported from these ad hoc projects. In due course, attention should be directed at the training centres too. With their diverse range of industrial focus, covering from welding to banking services, each site would require a different set-up for monitoring IAQ.

Recently, building IAQ and ventilation has been evaluated using indoor $CO_2$ (Persily, 1997). In various researches (Vaculik and Plett, 1993; Levine *et al.*, 1993; Ke and Mumma, 1997; Mohsin *et al.*, 2002), $CO_2$ was suggested as a control parameter for ventilation system and the $CO_2$ based demand controlled ventilation were studied. In this study, the air quality inside two campuses was measured and the correlation of IAQ objective, occupancy rate and concentration $CO_2$ was discussed.

## METHODS

The study began with an examination of existing facilities, which was followed by site inspection. Excluding staff rooms, lecture theatres, lecture rooms, computer rooms, libraries, canteens and workshops, totalling over 20 locations, were selected for this study. The selection was based on the feedback received by the estate management, the functions and locations characteristics. Details of the location are listed in Table 1.

**Table 1** Summary of the selected locations

| Room No. | Description | Area, $m^2$ | Occupancy capacity | Ventilation system |
|---|---|---|---|---|
| **Campus A** | | | | |
| A1 | Library (Study area) | 1055 | 258 | AHU |
| A2 | Library (photocopy area) | | | AHU |
| A3 | Hall | 780 | Recreational | AHU |
| A4 | Lecture Room | 60 | 40 | PAU + FCU |
| A5 | Lecture Room | 68 | 40 | PAU + FCU |
| A6 | Lecture Theatre | 117 | 112 | PAU + FCU |
| A7 | Lecture Theatre | 179 | 200 | AHU |
| A8 | Canteen staff | 445 | 400 | PAU + FCU |
| A9 | Canteen student | 770 | 760 | AHU + FCU |
| A10 | Language Laboratory | 216 | 80 | PAU + FCU |
| A11 | Laboratory | 380 | 40 | VF |
| A12 | Laboratory | 283 | 40 | PAU + FCU |
| A13 | Workshop | 220 | 40 | PAU + AHU |
| **Campus B** | | | | |
| B1 | Library | 336 | 27 | AHU |
| B2 | Library (study area) | 275 | 106 | AHU |
| B3 | Lecture Room | 120 | 80 | AC |
| B4 | Lecture Room | 60 | 40 | AC |
| B5 | Lecture Theatre | 125 | 121 | AHU |
| B6 | Computer Room | 178 | 56 | AHU |
| B7 | Laboratory | 175 | 48 | VF |
| B8 | Laboratory | 176 | 33 | AHU |
| B9 | Workshop | 226 | 17 | VF |
| B10 | Workshop | 92 | 22 | VF |

AHU = Air handling unit; PAU = Primary Air Unit; FCU = Fan coil unit; VF = Ventilation fan; AC = Air conditioner

The Indoor Air Quality Certification Scheme, in which there is a proposal of 2-level Indoor Quality Objectives, provides a benchmark for evaluating and assessing IAQ of government building and public places. An example of the recommended levels, based on an 8-h average, for a number of parameters are given in Table 2.

**Table 2** Examples of IAQ objectives

| Parameter | Unit | Level One | Level Two |
|---|---|---|---|
| Carbon Dioxide | ppm | < 800 | < 1,000 |
| Relative Humidity | % | 40 - 70 | < 70 |
| Room Temperature | °C | 20-25.5 | < 25.5 |
| Air movement | m/s | < 0.2 | < 0.3 |

The measurements were conducted according to the HKIAQMG 1999. Temperature, relative humidity, air velocity and $CO_2$ were measured at most of the selected locations, whilst TVOC and formaldehyde were measured according to the characteristics of the location and the constraint of the availability of the equipment. Although not stipulated in the guidelines, in all measurements, ambient conditions as well as occupancy rate were also recorded to gauge their likely impact on IAQ. Each measurement was conducted continuously for 8 h. The averaged and simultaneous results at selected locations are shown in the following section. The equipment and the measurement methodology are summarized in Table 3.

**Table 3** Equipment and measurement techniques

| **Measurement** | **Equipment** | **Sampling** |
|---|---|---|
| Carbon dioxide | Testo (model 400 and 445) | 2 channel infrared absorption |
| Temperature | | NTC Thermistor |
| Relative humidity | | Polymer capacitor |
| Air movement | | Hot-bulb anemometer |
| Total volatile organic compound TVOC | ppbRAE (model PGM-7240) | Photo-ionization detector (PID) |
| Formaldehyde (HCHO) | PPM (model Formaldehyde 400) | Electrochemical formaldehyde sensor |

## RESULTS AND DISCUSSION

The results of 8-h continuous sampling are summarized in Table 4. The measurement was conducted between January and April 2002, which is winter/spring in Hong Kong. Based on the IAQ objectives, the study has shown good overall IAQ for most of the selected locations serving different activities as shown in Table 4. In general, most of the locations at both institutes were at Level One, which represented a high-class and comfortable environment, and some were at Level Two, which still met general health standards. In the workshop, at locations A13, B10 and B13, a high level of pollutant was recorded, which are discussed and examined further. Some locations would need attention after renovation work, such as location A1, A2, A6 and B5. Procedures should be set out for monitoring the condition.

For the engineering aspect, the IAQ performance and the occupancy rate were studied. The occupancy rate was defined by the ratio of the number of occupants and the designed room capacity. For the time averaged occupancy rate classified as 'HIGH', the value was above 0.7; for 'MEDIUM' the value was between 0.4 and 0.7 and for 'LOW' the value was below 0.4. In most areas, the performance of the ventilation system was good and the air quality achieved Level One. For those locations with Level Two air quality but the occupancy rate was only MEDIUM and LOW, further examination will be conducted.

Other than the normal operational survey, the correlation of the occupancy rate and the level of $CO_2$ was examined. The result of 8-h continuous sampling of a selected room A4 is shown in Figure 1. The concentration of the indoor and outdoor $CO_2$ were normalised by the upper limit of the value of Level One. Hence, the value above 1 represents $CO_2$ level is over the upper limit of Level One; while the value less than 1 shows the concentration of $CO_2$ satisfies Level One requirement. The normalized value 1.25 is the upper limit of Level Two.

The 8-h average of $CO_2$ was 672 ppm and was classified at Level One accordingly to the IAQ objective as shown in Figure 1. In the distribution, the $CO_2$ concentration increased and decreased with respect to the number of occupants. Although the averaged concentration was below 800 ppm, at certain time interval, the concentration was close to or above the limit. Hence, the average value may not reflect the problematic situation when the critical situation was averaged out by certain time interval with low occupancy rate and low concentration. Therefore, using 30-min sampling strategy suggested by Chao (2002) could be inaccurate when the occupancy rate is changing.

**Table 4** Summary of 8 h continuous sampling at different locations (I, Level One; II, Level Two)

| mm/yy | Room No. | Temperature | Relative humidity | Velocity | $CO_2$ | TVOC | Formaldehyde | Occupancy rate |
|---|---|---|---|---|---|---|---|---|
| **Campus A** | | | | | | | | |
| Jan/2002 | A1 | I | > 70% | I | II | - | II | HIGH |
| Mar/2002 | A2 | I | I | II | II | - | II | LOW |
| Mar/2002 | A3 | I | I | I | I | - | I | LOW |
| Feb/2002 | A4 | I | I | I | I | I | I | HIGH |
| Mar/2002 | A5 | < 20°C | > 70% | I | II | I | - | MEDIUM |
| Feb/2002 | A6 | < 20°C | > 70% | I | I | - | II | MEDIUM |
| Mar/2002 | A7 | I | > 70% | I | I | - | I | HIGH |
| Mar/2002 | A8 | I | I | I | I | - | I | LOW |
| Mar/2002 | A9 | I | I | I | I | - | I | HIGH |
| Feb/2002 | A10 | I | I | I | I | - | I | LOW |
| Feb/2002 | A11 | I | I | I | I | - | I | LOW |
| Mar/2002 | A12 | < 20°C | I | I | I | - | I | LOW |
| Mar/2002 | A13 | I | I | I | I | > 600 | II | LOW |
| **Campus B** | | | | | | | | |
| Mar/2002 | B1 | I | I | I | I | - | I | MEDIUM |
| Mar/2002 | B2 | < 20°C | I | I | I | - | I | LOW |
| Mar/2002 | B3 | I | I | I | I | - | I | HIGH |
| Mar/2002 | B4 | I | I | I | I | - | - | NA |
| Mar/2002 | B5 | I | I | I | I | - | II | LOW |
| Feb/2002 | B6 | I | I | I | I | - | I | MEDIUM |
| Apr/2002 | B7 | > 25.5°C | > 70% | I | I | - | I | MEDIUM |
| Feb/2002 | B8 | < 20°C | > 70% | I | I | - | II | MEDIUM |
| Feb/2002 | B9 | I | I | I | I | I | II | LOW |
| Mar/2002 | B10 | I | I | II | I | I | I | MEDIUM |

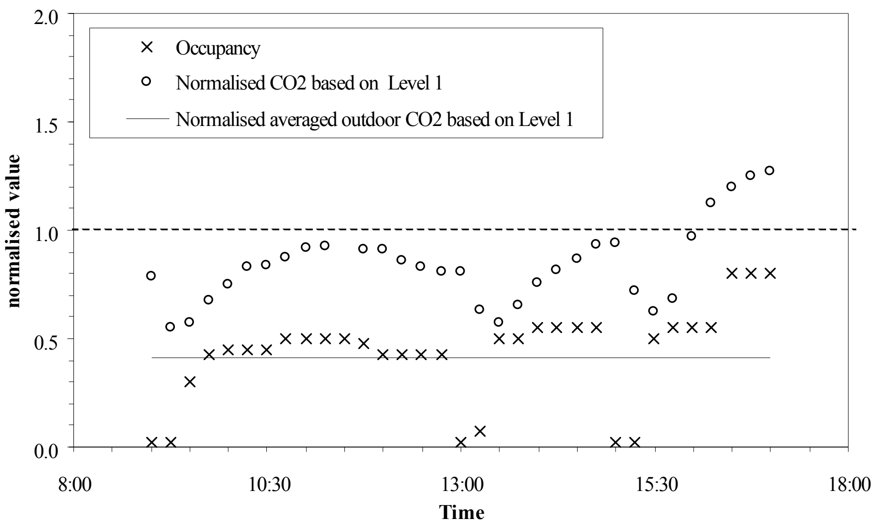


**Figure 1** Correlation of occupancy rate and concentration of $CO_2$ at room A4.

From the view of the engineering aspect, the ventilation system and the supply air flow rate are designed according to the local Code of Practice and the Standard (ASHRAE 62-1989). It was observed in Figure 1 that the ventilation system in this case may not able to provide sufficient fresh air and was weak in diluting the $CO_2$ when the occupancy rate was above 0.5 and constant during the interval from 11:30 to 12:30. It was also found difficult in coping with the sudden increase of the concentration at time interval 9:30, 13:30 and 15:30. The concentration even cannot be held within the Level One limit when the occupancy rate further increases from 0.5 to 0.7 after the time interval 15:30. The concentration of $CO_2$ falls below Level Two after 17:00 and the air quality would worsen if the occupants stay longer inside the room. From the above observation, the air quality deviated from the designed condition. This could be due to ventilation system performance, uneven distribution of the supply air or occupants, or short circuiting when the supply air returns to exhaust/return air duct at the upper part of the room, which is above the breathing zone of the occupants.

## CONCLUSION AND IMPLICATIONS

IAQ in educational establishments, apart from potential health effects, has often been linked with learning ability of students. Given Hong Kong's urban environment, this aspect deserves greater attention from the local research community. Bayer *et al.* (2000) provide a good summary of research work conducted for IAQ in school, highlighting its importance to the learning environment.

Based on $CO_2$ measurements in this study, it was observed that the 8-h averaged IAQ objectives do not present the complete picture of air quality due to the local $CO_2$ concentration changes and the occupancy rate. Meeting the objectives may not guarantee good air quality to those occupants during periods when the concentration exceeds the desired level. The time history of IAQ parameter and the duration of the parameter under consideration exceeding the desired limit should be included in the measurement and analysis. By introducing limitation on the duration of exceedance of control parameters, it could provide better air quality for the designed occupancy rate.

From a ventilation system viewpoint, $CO_2$ accumulation could be an indication of system incapability. In the present study, the over-shoot of $CO_2$ concentration over an appreciable time span suggests that the traditional design criteria for the ventilation system using a litre of fresh air per person or the exchange rate may not be able to provide the desired IAQ. This may affect the performance of students in certain activities such as examinations. The correlation of the dynamic response of the ventilation system and the occupancy rate, the performance of the ventilation system can be evaluated. Furthermore, air flow simulation could be used to assist the design of the ventilation system.

The rate of the increase and decay in $CO_2$ concentration could be an indicator for assessing the performance of a ventilation system. Through a proper dilution of the $CO_2$ concentration by varying the amount of fresh air supply, the indoor air quality could be improved and also energy consumption of the system could be reduced. In the present study, monitoring of physical parameters is only a first step, providing an overview of the prevailing IAQ at two vocational education institutes. For the next phase, a study for the protocol of the performance of ventilation system, the installation of sensors and control device will be proposed, exploring an active control approach to the fresh air supply.

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