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Management learning from air purifier tests in hotels: Experiment and action research

Wilco Chan a,⁎, Shun-Cheng Lee b, Alice Hon a, Leon Liu a, Danny Li c, Ningyi Zhu a

a School of Hotel and Tourism Management, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong Special Administrative Region
b Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong Special Administrative Region
c Department of Civil and Architectural Engineering, City University of Hong Kong, Hung Hom, Kowloon, Hong Kong Special Administrative Region

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ABSTRACT

Recently, indoor air quality (IAQ) has become an important issue as it affects people’s comfort and health. To mitigate the problem, application of some innovative air filtering devices has been generally recognized as one of the effective ways. This study adopted an action research-dominated approach to test whether the indoor air quality in the tested hotel rooms meets the recognized standard, and measure the pollutant removal efficiency of three types of air purifiers. Focus group discussion was carried out to ascertain the difference in hotel managers’ understanding of indoor air quality research before the experiment and management response after the experiment. The result of field test indicates that the actual performance of the purifiers is not as good as the manufacturers claim. The management response study also ascertain that hotel department heads’ awareness, exposure and training in relation to IAQ testing is limited.

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1. Introduction

Over the years, numerous studies have been carried out to measure the factors that influence the selection of hotel accommodation by customers. Many researchers have identified that cleanliness is the most important attribute influencing the decision of selecting hotel accommodation (Weaver and Oh, 1993; Callan and Bowman, 2000; Lockyer, 2005). Therefore, it is reasonable to deduce that good indoor air quality (IAQ) should also be an important attribute for hotels. This is especially true as hotel guests typically comprise a high proportion of international travelers and a good mix of dignitaries and officials who demand high IAQ. Equally, inadequate IAQ invariably brings complaints (Bohdanowicz and Martinac, 2002).

More recently, research findings have indicated that air pollution in East and South Asia has been deteriorating due to accelerated economic expansion and population growth. Brauer et al. (2012) found that there is a high concentration of fine particles (PM2.5) in South and East Asia (annual averages >50 μg/m3). PM2.5 is generally considered to be the most robust indicator of adverse (mortality) impacts in epidemiologic cohort studies of long-term exposure. They are so small that they can get deep into the lungs and cause serious health problems. An extensive epidemiological literature relates PM2.5 to adverse health impacts (Pope et al., 2002; Pope and Dockery, 2006; Dockery, 2009). Latterly, the World Health Organization’s International Agency for Research on Cancer (IARC) officially classified air pollution mixing with suspended particles in the air as a level 1 carcinogen. It stated that there is “sufficient evidence” that exposure to outdoor air pollution causes lung cancer and also linked it with an increased risk of bladder cancer. Such exposure has increased significantly in China (IARC, 2013). Since the ventilation systems need to regularly draw outdoor air into buildings, hotel guests who staying indoor still have to breathe the polluted outdoor air if there is no air filtration equipment in hotels. Therefore, travelers who plan to come to China are increasingly concerned about air quality. According to the China National Tourism Administration, from January to June in 2013, the total number of foreign arrivals dropped by 5% to just under 13 million compared with the same period in 2012 (Watt, 2013).

There are also other types of indoor air pollution in China apart from such incoming outdoor air pollutants. One of them is smoking. In China, smoking in hotel guest rooms still prevails except on non-smoking floors. Cigarettes generate high amounts of toxic air pollutants which also include PM2.5. These pollutants may be

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⁎⁎ Corresponding author.

E-mail address: hmwilco@polyu.edu.hk (W. Chan).

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carcinogenic, or may cause other non-cancer-related health problems (Facchini et al., 1992; Rimm et al., 1993; Hu et al., 2001; Komiya et al., 2006). The other possible source for indoor air pollution in hotels is renovation. As stated by Meckler (1996), renovation work could be the greatest source of IAQ problems for buildings. Many interior materials contain volatile organic compounds (VOCs) which cause discomfort to the respiratory system and irritation to eyes (Burton, 1997). The increasing occurrence of poor levels of IAQ may be linked to the shortening length of the renovation cycle in hotels in recent years, and the opening of more new hotels which is set to grow further in coming years. One study has indicated that most new hotels in the Pearl River Delta of China were more polluted than older hotels and residential buildings (Chan et al., 2009a,b). In addition, poorly designed, maintained or operated air-conditioning and ventilation systems can also cause indoor air problems (Kuo et al., 2008). Many studies have shown that ventilation systems may occasionally act as a source of pollutants, such as microbes, chemical compounds or odors (Lyseen et al., 1999; Sundell et al., 1993; Björkroth et al., 1997).

2. Problem statements

The study of air quality is a relatively new scientific discipline in hotels and in China. Its content and methods are complex and sophisticated. Hotel practitioners, generally speaking, have limited understanding of the research logistics and resources required to test and maintain air quality.

In particular, the sampling technique and analytical method for testing air quality depends on an array of equipment and facilities. Thus a laboratory equipped with these facilities is indispensable to carry out research on air quality. However, the investment required to establish such an independent laboratory is huge. At the time of writing, no hotel chain in the world has established such a laboratory and technical team to monitor the IAQ in hotels and provide technical assistance regarding IAQ issues to hoteliers. While there are a few IAQ consultants available on the market, their independence, technical support and expense have always been barriers to hoteliers achieving better IAQ. Even with the surge in clean air technologies in recent decades, hoteliers often face challenges finding the technical expertise or measuring equipment to verify the pollutant removal effectiveness of the technology (Chen et al., 2005).

An industry leader also expressed concern that there was inadequate reliable and independent data on the environmental improvements delivered by these technologies (Li, 2003). Most data are offered by manufactures. Hoteliers have reservation on their claimed effectiveness and reliability of the green products and facilities. The industry does not want to be subject to passive acceptance of these innovative technologies. Presently, in-depth technical advice about air cleaning and purification technologies from government and hotel management offices remains unavailable. The hotel industry needs valid and interpretable data being provided by independent parties.

Air filtration is one of the crucial technology-based measures to control and mitigate indoor air pollution. In addition, the ventilation system performs a vital role in the removal of these indoor air pollutants. In light of this, the present study aims to (1) test whether the indoor air quality in the tested hotel rooms meets the recognized standard; (2) test the pollutant removal efficiency of three types of air purifiers; and (3) ascertain the difference in hotel managers’ understanding of indoor air quality research before the field test and management response after the field test.

3. Methodology

To better understand innovative technology for removing air pollutants, verify the effectiveness of some commercialized technology and promote the enhancement of hotel IAQ knowledge, the study adopted an action research-dominated approach.

The concept of action research can be traced back to the mid 1940s (Lewin, 1946). Since then, this concept has become divided into a wide spectrum of approaches including action research, action science, system intervention and action inquiry (List, 2006).Our investigation is characterized by the involvement of researchers with a goal to achieve an enhancement of hotel IAQ by using air purification technology in the studied hotel (Baskerville and Wood-Harper, 1996; Baskerville and Pries-Heje, 1999). Differing from the typical consultancy approach and that of contracted research, which usually provides technical or specific deliverables, the action research in this case set out to collect hoteliers’ real responses by direct observation and discussion via participation. The follow-through participation process included initiating the project, participating in meetings, exchanging views, installing air purifiers, cleaning air ducts, providing technical and professional knowledge guidance, checking equipment performance, collecting data, performing analysis, delivering findings and gauging management response. Through the process, researchers were able to professionalize the hotel department heads using three technical meetings, seven semi-technical meetings, six informal discussions and one “wrap-up” focus group discussion. The researchers’ aim was to produce valid knowledge and act as a facilitator by proposing the topic, formulating the action research scenarios and compiling all the collected data (Waser and Johns, 2003). More importantly, the use of action research allowed the investigators to gain an in-depth and thorough understanding of how the company’s management responded to the processes and findings about the application of air-cleaning technology. Compared with other techniques, which use questionnaires and interviews to obtain responses, the action research methodology in this case may greatly reduce “noise” in the data collection process and ensure a high degree of data reality.

To gauge the hotel management’s response to the demonstration via technical research processes – planning, sampling, analysis and report – the study conducted a post-research focus group discussion with hotel department heads including the director of engineering, purchasing managers, the executive housekeeper, the front office manager, the executive and GM assistants.

Focus groups are an in-depth group interview technique employing relatively homogenous groups to provide information about topics specified by the researchers (Hughes and DuMont, 1993). They provide an opportunity to solicit true views from participants freely and in a flexible way. Such a method also allows for the exploration of beliefs and attitudes toward something new (Procter, 2000). In addition, focus group discussions have the merit of allowing participants to react to the responses of other participants, encouraging a series of subsequent discussions, causing a snowball effect (Wilkinson, 2004). Due to the exploratory nature of this research and the aforementioned advantages, the focus group method was adopted to explore the following two probing topics: (1) differences in the group’s understanding about the investigation of air duct cleaning and its removal effectiveness before and after the research intervention; and (2) their response to the observed research process.

3.1. Sampling site and testing objectives

The test was carried out in a five-star hotel building with approximately 300 rooms and two restaurants, in a city in Southern China. The international hotel selected is a 27-storey building with a vertical ventilation system. The air pump is located in the roof of the hotel building, meaning that the lower the floor is the less fresh air it receives. These rooms are all standard two-bed rooms with separated fan coil units (FCU). The room area is about 40 m² with most
of the floor covered by carpet, which is a potential pollutant source for total volatile organic compounds (TVOC), except the entrance area and wash room which are paved with marble. The hotel had 22 guest floors and 8 of them were non-smoking floors. Our study was taken in a non-smoking floor.

Three types of air cleaners and the effectiveness of air duct cleaning were tested in this research. Due to the restriction of the field condition, the air duct cleaning is confined to the cleaning of the air duct in the sampled rooms only. L brand fixed air cleaner was installed on the ceiling of Room 1 in front of the fresh air supply duct. L brand movable air cleaner and P brand movable air cleaner were placed in the corner of Room 2 and Room 3 respectively. The remaining room, Room 4, was used to test air duct cleaning. Specifications of the three air cleaners are listed in Table 1. All the air cleaners and associated filters are brand new before testing. Currently there is no compulsory national standard on for air purifiers in China, therefore many air purifier manufactures have taken advantages of this loophole and failed to accurately inform consumers about the functions and capabilities of their products. In this study, both L brand and P brand are vague about their product specifications in terms of removal efficiency. Information about under what conditions for efficiency are not available in their product manuals.

3.2. Sampling and analysis methods

A four-day sampling plan was scheduled. Day 1 deals with outdoor air measurement and cleaning one studied room’s ventilation system. In Day 2, the cleaned air duct room’s IAQ measurement was undertaken after 12 h operation of the cleaned ventilation system. In the same day, background IAQ was measured in two other studied rooms. Then, movable air cleaners (brand P and L) were placed in these rooms to test their removal efficiency. On the third day, fixed air cleaner (brand L) was installed on ceiling top and was tested for their pollutant removal efficiency on the fourth day.

The L brand fixed air cleaner is an in-duct filter, such unit cannot be used without forced air systems. Therefore, the air conditioning has to be turned on when operating the L brand fixed air cleaner. For the testing of cleaning effects of the ventilation system and brand L fixed air cleaner, indoor and outdoor air samples were taken simultaneously. The indoor air temperature and the air velocity of air conditioning were set at 25°C and middle level (1.85 m/s), respectively. Indoor/outdoor ratio was used to calculate the removal efficiency in order to rule out the influence of outdoor fluctuations in pollutant levels.

We also interested in knowing whether there were indoor pollutant sources in sample rooms and how well can portable air cleaners mitigate the indoor air pollution. Therefore, we chose to close the windows and doors and shut down the air conditioning in sample rooms in order to limit the air exchange rate with outdoor environment, and no one was allowed to enter the rooms except for mask wearing researchers during measurement. As shown in previous studies, the performance of air cleaner strongly depends on the air exchange rate (Cheng et al., 1998; Green et al., 1999; Fisk et al., 2002), thus limiting the air exchange rate is crucial for identifying the actual performance of air cleaners at realistic indoor conditions.

The testing parameters for air pollutants included carbon dioxide (CO2), fine suspended particulate matters (PM2.5), total volatile organic compounds (TVOC), bacteria and fungi. Indoor air samples (for 8 h) were collected as near to the central positions of the guest room as possible. The measuring instruments were placed at 1.5 m above the floor and at least 1 m away from potential sources of air pollutants indoors (details of instruments can be found in Table A2). Outdoor air samples (for 2 h) were taken on the rooftop near the fresh air intakes. Background air sampling was carried out in each room for 2 h. Background air sampling was carried out in each sample room before testing the air cleaner or cleaned air ducts, the measuring parameters are exactly the same as the 8 h indoor air sampling afterwards. The room conditions for background air sampling were also the same as the following air cleaner test. The background levels were used as the “before cleaning/running” data in the findings. The reported levels were not adjusted for background levels. Original data were checked and no apparent skewed distributions were found. Therefore arithmetic means were used in this study.

The concentration of carbon dioxide (CO2) was measured using a portable Q-Trak monitor. A Dust-Trak air monitor (Model 8520, TSI Inc.) was used to measure PM2.5 concentrations in both the indoor and outdoor environment. Different devices were used to measure the TVOC and individual VOC. For measuring the TVOC, A ppbRAE 3000 monitor was used for continuous recording of TVOC concentrations for eight hours. The ppbRAE 3000 can detect a very wide range of VOCs, including benzene, isobutene, methylene chloride, hexane, toluene, trichloroethylene, styrene, heptane, perchloroethylene, and etc. The lamp and sensor of ppbRAE 3000 were manually cleaned before the testing in order to avoid the drift of photoionization detector. Prior to sampling, the ppbRAE 3000 monitor was calibrated by a calibration gas (isobutylene) with a known concentration of 10 ppb supplied by the manufacturer. For individual VOC sampling, a canister sampling method was used. A batch of pre-cleaned canisters for sample collection was evacuated before sampling. Time-integrated VOC air samples were obtained by using mass flow controllers at a flow rate of 0.0042 l/min for 8 h. After sampling, the canisters were immediately transported to an authorized air laboratory supplier for GC/MS (gas chromatography/mass selective) analysis. A NUTECH Cryogenic Concentrator was used for sample pre-concentration and followed by an Agilent 6890/5873 GC/MSD system to conduct the analysis. VOCs in ambient air were collected by specially prepared canisters with subsequent analysis by gas chromatography.

A portable air sampler for agar plates was used for bacteria and fungi sampling. Tryptic soy agar (TSA) was used as the medium for the collection of bacteria, while malt extract agar (MEA) was used for the collection of fungi. Each of the microbiological samples was taken over a period of 5 min. After incubation was completed, the concentration of bacteria and fungi was counted and expressed in terms of colony-forming units per cubic meter of air (cfu/m3).

There are a number of IAQ national standards available. The U.S. Environmental Protection Agency (EPA) developed the National Ambient Air Quality Standards (NAAQS) under the Clean Air Act. These enforceable standards were developed for outdoor air quality, but they are also applicable for indoor air contaminant levels.

| Table 1 | Specifications of three tested air cleaners. |
|---------|--------------------------------------------|
| Specifications | L brand fixed air cleaner (Room 1) | L brand movable air cleaner (Room 2) | P brand movable air cleaner (Room 3) |
| Size | 310 mm × 310 mm × 600 mm | 550 mm × 550 mm × 1500 mm | 440 mm × 275 mm × 715 mm |
| Removal mechanism | Activated carbon filter | Electrostatic precipitator | Activated carbon filter |
| Clean air delivery rate | 600 m3/h | 120 m3/h | 310 m3/h |
| Claimed removal efficiency | 99.5% (particles >0.1 μm) | 99.5% (particles >0.1 μm) | 99.5% (particles >0.1 μm) |
| | | | 95% (formaldehyde) |
(see Table A1). The concentrations are set conservatively in order to protect the most sensitive individuals, such children, the elderly, and those with asthma. However, the EPA standard doesn’t have parameter about bacteria. After the SARS (a viral respiratory illness caused by a coronavirus) disaster, the Chinese guests are very concerned about the indoor air quality. Therefore the Hong Kong indoor air quality standard was employed in this study. The “excellent class” of indoor air quality level according to the Hong Kong Environmental Protection Department was used in the analysis as a benchmark (HKEPD, 2003).

4. Results and discussion

4.1. Effectiveness of ventilation system cleaning

From Table 2 it can be observed that the average concentrations of CO₂ and fungi were constantly below the recommended indoor air quality standards, both before and after the ventilation system had been cleaned. The average concentrations of PM2.5 and Bacteria exceeded the recommended threshold levels before cleaning the ventilation system. After the ventilation system was cleaned, their average concentrations were both decreased by 25% and were lower than the recommended indoor air quality standards. The average concentration of CO₂ was also reduced by 12.9%. Since the air duct was usually blocked by dust and dirt which result in accumulation of air pollutants, cleaning the air duct can improve the ventilation and reduce these indoor air pollutants. Although the result of this study suggested that cleaning the ventilation system may help to improve the IAQ in guest rooms, a controlled experimental design was required to prove this finding in future research.

The average concentration of TVOC in this study was almost three times higher than the non-mandatory indoor air quality standard, which indicated that TVOC was the most significant pollutant in the studied hotel room. This study found out that cleaning the air duct did not have any effect on TVOC. Therefore, in order to remove TVOC and fungi, other possible improvement measures, for instance air purifiers, are required to be tested.

4.2. Effectiveness of air purifiers

4.2.1. Fine particulate matter (PM2.5)

The recommended value for fine particulate matter (PM2.5) is 35 μg/m³ in Taiwan. Table 3 shows that the average concentration of PM2.5 in the tested rooms ranged between 18 and 25 μg/m³ before running the air cleaners. After running the air cleaners for 24h, it was reduced to between 13 and 19 μg/m³. It is also noted that the average concentration of fine particulate pollutants was always below the threshold level in all tested guest rooms. Although this field test indicates that the fixed and movable L brand air cleaners may have better removal efficiency of PM2.5 than the P brand air cleaner, solid evidence from controlled experiment are required in future studies.

| Pollutants | Unit | Before cleaning | After cleaning | Improvement (%) | Indoor air quality guideline |
|------------|------|-----------------|----------------|-----------------|-----------------------------|
| CO₂        | ppm  | 590             | 514            | 12.9            | <800²                   |
| PM2.5      | µg/m³| 40              | 30             | 25.0            | <35³                    |
| TVOC       | ppb  | 226             | 232            | −2.7            | <87³                    |
| Bacteria   | cfu/m³| 640             | 480            | 25.0            | <500⁴                   |
| Fungi      | cfu/m³| 510             | 510            | 0.0             | <1000⁴                  |

Table 2: Measurements before and after cleaning the ventilation system.

4.2.2. Total volatile organic compound (TVOC)

To meet the “excellent class” for indoor air quality, Hong Kong EPD (2003) guidance stipulates that the threshold value for TVOC in the indoor environment is 87 ppb. Table 4 shows that the average concentrations of TVOC of Room 1, Room 2 and Room 3 are 185, 166 and 118 ppb before running the air cleaners. Each of these values exceeds the threshold value. After running the air cleaners for 24h, the average concentrations of TVOC in these three tested rooms were still above the recommended values. The value in Room 1 and Room 2 reduced from 185 ppb to 156 ppb and 166 to 150 ppb, respectively. However, the average concentration of TVOC in Room 3 increased from 118 to 245 ppb. This implies that either there is an indoor source of TVOC in these guest rooms, or the sorbent filters of the air cleaner in Room 3 had reached saturation and released trapped pollutants back into the indoor air, or both (United States Environmental Protection Agency, 2009). The background level of TVOC in the studied rooms ranging from 116 to 185 ppb, which are far lower than those measurements (1035 μg/m³ ≈ 260 ppb) in earlier studies in eight hotels in factory region (Chan et al., 2009a,b). When the result was compared with the TVOC findings (62 μg/m³ and 120 μ g/m³ = 16 ppb and 30 ppb) in home and hostels, the study observed that the result is higher than the measured levels of TVOC in homes and hostels (Kumar et al., 2014). This is probably due to the use of more decorative materials with adhesive agents. Because there are indoor TVOC pollutant sources and the air conditioning was turned off for movable air cleaners, another method of calculating the removal efficiency of air cleaners was employed in this study, as shown in Table 5. The TVOC accumulation rate was measured before and after running the air cleaners.

Table 3: Average concentration of PM2.5.

| PM2.5 (µg/m³) | L brand fixed air cleaner (Room 1) | L brand movable air cleaner (Room 2) | P brand movable air cleaner (Room 3) |
|---------------|----------------------------------|-------------------------------------|-------------------------------------|
| Before running| 25                               | 18                                  | 21                                  |
| Running 24 h  | 19                                | 13                                  | 19                                  |
| Change in pollutant levels | 24.0%                      | 27.8%                                | 9.5%                                |

Table 4: Average concentration of TVOC.

| TVOC (ppb) | L brand fixed air cleaner (Room 1) | L brand movable air cleaner (Room 2) | P brand movable air cleaner (Room 3) |
|------------|-----------------------------------|-------------------------------------|-------------------------------------|
| Before running | 185                              | 166                                 | 118                                 |
| Running 24 h | 156                              | 150                                 | 245                                 |
| Change in pollutant levels | 15.7%                        | –                                   | –                                   |

Table 5: Removal capacity of L and P brand movable air cleaner on TVOC.

| Cleaner brand | TVOC increase rate (ppb/h) | Before running | After running | TVOC removal capacity (ppb/h) |
|---------------|-----------------------------|----------------|---------------|-------------------------------|
| L brand movable air cleaner | 82.2                      | 14.4           | 67.8          |
| P brand movable air cleaner   | 117.6                      | 15             | 102.6         |

Table 5: Removal capacity of L and P brand movable air cleaner on TVOC.

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Table 6
Concentrations of bacteria and fungi.

|                | L. brand fixed air cleaner (Room 1) | L. brand movable air cleaner (Room 2) | P. brand movable air cleaner (Room 3) | Outdoor |
|----------------|--------------------------------------|---------------------------------------|---------------------------------------|---------|
| Bacteria* (cfu/m³) |                                      |                                       |                                       | 730     |
| Before running  | 930                                  | 700                                   | 280                                   |         |
| Running 24 h    | 460                                  | 380                                   | 450                                   |         |
| Change in pollutant levels | 50.5%                               | 45.7%                                 | −60.7%                                |         |
| Fungi* (cfu/m³) |                                      |                                       |                                       | 1040    |
| Before running  | 670                                  | 610                                   | 330                                   |         |
| Running 24 h    | 340                                  | 610                                   | 330                                   |         |
| Change in pollutant levels | 49.3%                               | 0%                                     | 0%                                    |         |

*“Excellent class” indoor air quality standards, EPD of Hong Kong (2003).
Indoor air quality standards of Taiwan, EPA of Taiwan (2012).

It could also be observed that both air cleaners were slowing down the increase rate of TVOC in rooms. L. brand movable air cleaner removed the TVOC concentration by 67.8 ppb per hour, while the P. brand movable air cleaner reduced the TVOC concentration by 102.2 ppb per hour.

4.2.3. Bacteria and fungi

The recommended threshold value for bacteria and fungi is 500 cfu/m³ and 1000 cfu/m³, respectively (EPD of Hong Kong, 2003; EPA of Taiwan, 2012). The measured data are shown in Table 6 and these results indicate that the microbial pollution in guest rooms could be controlled by air cleaners. Before running the air cleaners, the highest concentrations of bacteria and fungi were both found in Room 1, at 930 cfu/m³ and 670 cfu/m³ respectively. After running the air cleaner for 24 h, the concentrations dropped to 460 cfu/m³ and 340 cfu/m³, which were below the recommended values. In addition, the values for outdoor bacteria and fungi concentrations were generally higher than the indoor concentrations, which indicated that these microbial pollutions were more serious in the outdoor environment than in the indoor space. The bacteria and fungi in rooms are more likely to be transferred from the outdoor environment, rather than originating indoors. It should be noticed that the bacteria concentration in Room 3 increased after the cleaner had been running. Considering that the TVOC level in Room 3 also increased after running the P. brand air cleaner, it is likely that the P. brand movable air cleaner in Room 3 had reached its saturation and was releasing trapped pollutants back into the indoor air. This reflects the main problem with mechanical filters that they act as a pollution source if they are not properly used (Zhang et al., 2011).

5. Management unawareness and actions from learning

The findings from the focus group discussion were summarized as shown in Table 7. Eight different areas about managers’ knowledge of IAQ investigation before and after their observation of the research were identified.

Since guest rooms are an asset for generating revenue, hotel managers usually have tight control over this aspect of their business. During the interviews, the executives mentioned that the number of room nights required for sampling was more than they originally expected due to the need for two eight-hour measurement periods of both pre-installation, cleaning and post-installation. The executives originally thought that the measurement could be finished within one day and had allocated 10–20 room nights for this purpose.

They had little awareness that the sampling time standard is up to 16 h excluding the transient time for many types of pollutant testing. They were further unaware that the cleaning and sampling activities run non-stop (24 h a day) until the service is complete. Thus, the number of free room nights required for testing, testing team accommodation and equipment storage is more than expected – the requirement turns out to be almost double that anticipated. About 80 free room nights and staff canteen meals in two different periods in a year are needed to be on plan for this kind of research. The participants also agreed that the wide variety and bulky size of the cleaning and measuring equipment also entails the allocation of one guest room for storage on the same floor as testing is to be carried out.

Another lesson was that instruction should be given to hotel staff that the sampling and cleaning team should move testing equipment in and out using the staff passage and lift. In addition, participants expressed concern that the sight of canisters may cause concern to hotel guests, and it would be better to use a special bag to contain and transport these about the hotel premises.

Alongside the participation of the Engineering team in this research, the participants agreed that there is a need for staff from other departments to be involved. For instance, Front Office is required to plan room blocking for house use, Housekeeping is needed to assist in some cleaning activities, the Personnel Office arranges meals in the staff canteen, and even the Executive Office is required to provide assistance in clearing custom excise for sampling equipment, which is classified as imported goods for tax purposes (although special consideration will be given to research equipment).
6. Conclusion and implications

The study has measured the field effectiveness of three types of air purifiers, identified managers' knowledge about IAQ research before and after the field testing, and examined managers' action in response to the change of knowledge after field tests. The findings of the tests represent an independent reference for hotel practitioners, while the management response provides another type of practical reference for hoteliers who have an interest in conducting IAQ research.

The results indicate that although the manufacturers' published figures for the air pollution removal efficiency of their air purifiers have always been in the range of 80–99%, the actual performance of the products is not as good as they claim. Because the market for air purifiers is booming, the manufacturers may exaggerate the capability and in doing so, mislead consumers. There is therefore a need for the relevant government departments to push forward the development of standards for air purifiers.

Secondly, the Taiwan IAQ standard has already included fungi as a criterion, as fungi prevails in tropical and subtropical area. Some people, for example foreign hotel guests with low resistance, may for various reasons be particularly susceptible to harm from exposure to fungi. Thus, it is recommended that a maximum level for fungi should be specified in the IAQ standard.

Lastly, this action research reveals aspects relating to IAQ that hotel operators were not fully aware of, and identifies lessons that may assist similar types of research in future. The contrast between participants' limited understanding before the research implementation and their subsequent learning provides a practical reference to hoteliers who have an interest in similar types of research into indoor air quality in future.

The management response study also ascertained that hotel department heads' awareness, exposure and training in relation to IAQ testing is limited, even though most of them have received hospitality-related education at degree level. This finding may be due to the fact that current hospitality training programs focus on visible cleanliness standards, and do not contain detailed knowledge on IAQ. It is thus recommended that IAQ components should be incorporated in future revisions to training programs. In addition, hospitality education administrators should monitor the teaching coverage of this topic. To support this suggested future development, trade councils and hotel schools should allocate resources to provide short courses to update and enrich existing staff knowledge into this area.

While air filtration and air cleaning may remove the air pollutants to a certain extent, it is also important to identify and control sources of pollution originated from cooking, smoking, dry laundry, renovation and photo copying activities in hotels. However, it is worthy to note that some air purification process equipped in air cleaners may induce chemical reaction that lead to the formation of carcinogenic compound – nitrosamines (Seitam et al., 2010; Boeniger, 1995). Thus, hoteliers should also be educated in this area or be provided with more information about these aspects. Resources for training and knowledge transfer in this area can be acquired from the following channels: university, industry, trade councils, government and green bodies (Chan and Ho, 2006).

In addition, it has to be acknowledged the following limitation. Owing to the tiny size of particles including nicotine and 3-ethenylpyridine originated from tobacco smoke, the particles are able to spread to more distant rooms in non-smoking floor via air ducts, hallways, window and utility ducts (Bohac et al., 2011; Kaster et al., 2012). Matt et al. (2013) further confirms the former assertion by measuring tobacco smoke pollutants in 40 hotel rooms in California. Their research finds that non-smoking guests staying in non-smoking rooms of hotels without complete smoking bans showed significantly higher levels of nicotine on their fingers than after staying in hotels with complete smoking bans. Future research should take note of this influence.

The study was carried out in a relatively low-traffic city in South China which experiences less severe outdoor air pollution than cities with heavy traffic and North Eastern China, where smog is frequent. Thus, future research may opt to study hotels in those areas which are notorious for air pollution. The prospective research findings will therefore be more meaningful and applicable in the search for methods to improve IAQ in local hospitality units.

7. Future research

Since guests use most of their time in hotel when they sleep in guest room, it is reasonable to pay more attention on IAQ in room. However, it is worthy to compare the IAQ being probed in hallways and return air duct. Future sampling and analysis in these three areas may provide hoteliers a deeper understanding and an objective yardstick for improving IAQ in accommodation area. In addition, the significant impact of smoking on IAQ is also an important topic, especially for Chinese hotels. Firstly, the number of smokers is very large. Secondly, a hotel guest room is a small and enclosed environment. It is generally a single room with doors and windows that are usually kept closed. Therefore smoking could cause more damage in hotel rooms than in other indoor environment. Future research may consider carry out experiment in this area.

Appendix A.

Table A1

| Pollutant   | Primary/secondary | Averaging time | Level   |
|------------|------------------|---------------|---------|
| Carbon monoxide | Primary          | 8-h           | 9 ppm   |
| Lead       | Primary and secondary | Rolling 3 month average | 0.15 µg/m³ |
| Nitrogen dioxide | Primary         | 1-h           | 100 ppb |
| Ozone      | Primary and secondary | Annual       | 53 ppb  |
| PM2.5      | Primary          | Annual        | 12 µg/m³ |
| PM10       | Primary and secondary | 24-h         | 15 µg/m³ |
| Sulfur     | Primary          | 1-h           | 75 ppb  |
| Sulfur     | Secondary        | 3-h           | 0.5 ppm |

Table A2

| Instruments            | Parameter | Detectable mechanism        | Detectable range | Low detection limit |
|------------------------|-----------|-----------------------------|------------------|---------------------|
| Q-Trak 8552            | CO₂       | Non-dispersive infrared     | 0–5000 ppm       | 1 ppm               |
| Dust-Trak 8520         | PM2.5     | Light scattering            | 0.001–100 mg/m³  | 1 µg/m³             |
| ppbRAE 3000            | TVOC      | Photoionization sensor      | 0–9999 ppb       | 1 ppb               |
| Agilent 6890/5973      | VOCs      | VOC air sample trapped by cryogenic concentrator, analyzed by GC/MS system using TO-14 method | 0.2–5000 µg/m³ | 0.2 µg               |
| Portable air sampler   | Bacteria/ fungi | Impacting on agar with incubation, followed by colony counting | 0–2200 cfu/m³ | 8 cfu/m³             |
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