

The potential risk of sick building syndrome of the emergency department areas in a medical center in Taiwan

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Background: Indoor air pollution is a constant problem in the current society, especially in the emergency department (ED). Dirty and polluted air in hospitals will reduce work efficiency of healthcare staff and could ultimately cause diseases and illness; some serious acute respiratory diseases are liable to become epidemics in the hospital. A solution to organize the medical working environment and prevent the underlying threat of nosocomial infection is becoming an increasingly important issue; therefore, a research project is designed to study the air quality in the ED of a medical center in Taiwan.

Methods: Air quality measuring instruments were used three times a day for a non-continuous monitoring in the ED of the Taipei Mackay Memorial Hospital, including temperature, oxygen, carbon dioxide, ozone, total volatile organic compounds, suspended particulates (PM₁₀) with a particle size of 10 microns or less, and formaldehyde. The emergency areas were classified into four types according to whether medical procedures were performed or not, is there confined space or not. The data collected from different ER zones were analyzed and compared.

Results: The results showed that the oxygen concentration was higher than that of the general environment (20.9%) in all areas of the ED, while carbon dioxide concentration (CO₂) is also higher. The oxygen concentration of most places in ER exceeded 30%. The CO₂ concentration of each unit exceeds 700 ppm, especially in the internal and surgical ED, as well as the negative pressure isolation room, for which the value was close to 800 ppm (P<0.05). A higher formaldehyde value (>0.12 ppm) was detected in the nursing station the observation room and the research office. The highest concentration of ozone was also detected in the nursing station the observation room. As for the suspended particles (PM₁₀) having a particle diameter of 10 µm or less, the level of each zone was quite low. There was a much lower concentration of volatile organic substances (VOCs) in the triage station, research office as well as corridors; while all other areas have exceeded 150 ppb.

Conclusions: Our research indicates that the current emergency environment could be harmful to healthcare staff, and poor air quality in the ER is observed especially during busy hours, in older buildings, at intensive medical disposal areas and also in confined spaces. Some confined medical treatment spaces were prone to higher carbon dioxide (CO₂) concentrations that may cause fatigue and decrease of work efficiency. Therefore, improvement of air quality in ER and maintenance of emergency environment at the ideal air condition is significantly important. The ventilation of outdoor airflow and filtration of particles of the air conditioning systems should be thoughtfully planned as early as when designing an ER construction in order to avoid “sick building syndrome (SBS)”. That said, a healthier working environment to the ER staffs could

ultimately bring more effective work and promote better medical quality.

Keywords: Air pollution; emergency department (ED); sick building syndrome (SBS)

Received: 17 December 2018; Accepted: 25 February 2019; Published: 12 April 2019.

doi: 10.21037/ht.2019.03.01

View this article at: <http://dx.doi.org/10.21037/ht.2019.03.01>

Introduction

Indoor air pollution fits within the risk transition framework (1), in which the modern risks from building materials emerge and the traditional risks of household fuel combustion subside. It has always been a problem in today's modern society, and there is no exception in the emergency department (ED). In recent years, the incidence of respiratory symptoms due to air pollution is higher in the more advanced countries. Therefore, environmental factors are considered to be one of the causes impacting the increase in the incidence of respiratory disease (2). Among environmental factors, it can be divided into allergic factors and non-allergic factors. Allergic factors triggering of acute respiratory disease include dust (3), cockroaches, mold, and etc. On the other hand, non-allergic factors found in hospitals, such as dirty and polluted air, will impact work efficiency of healthcare staffs and cause diseases; even some severe acute respiratory diseases are prone to outbreaks in hospitals. The causative microorganisms often transmit and infect humans/medical staff through air, which could then be further passed on to patients and even worsening the patient's condition. These are all major causes of nosocomial infections. To medical staffs, how to being familiar with the medical working environment, and prevent the threat of nosocomial infection, is a very important issue. Poor indoor ventilation, or excessive generation of tiny particles, can cause substantial discomfort on the human body. Negative effects of unhealthy indoor environment are often accompanied by general symptoms such as headache and inattention. Poor indoor air quality can reduce the performance of office work by 6–9% (4). An approximately linear relationship between the percentage dissatisfied with indoor air quality (from 20–70%) and the measured decrement in performance was observed (5). Therefore, how to improve air quality in ER has become an important issue.

Methods

This study is designed to monitor the air quality in ten

locations in the Department of Emergency Medicine of the Mackay Memorial Hospital, which is a medical center that has nearly 200,000 emergency patient visits per year. The Taipei District covers about 140,000 emergency patient visits per year. The ER of Mackay Memorial Hospital, Taipei District, covers an area of approximately 1,500 square meters, which can simultaneously accommodate approximately 160 patients.

The emergency areas were classified into four types and assessed according to whether it was confined or not, and whether medical treatment was performed or not, as follows: (I) open space—triage station, corridors; (II) confined space for semi-open medical treatment area—surgical ER, internal medicine ER, nursing station of the observation room, and corridor of the observation room; (III) confined space for non-medical treatment area—the negative pressure isolation room and research office; and (IV) the pediatric areas—pediatrics rooms one and two. The data collected were analyzed and compared. At least 12 physicians and 24 nurses participated at each session. The ER area was jointly organized by the new building (approximately 1,254 square meters) and the old building (approximately 231 square meters). The nursing station and corridor of the observation room, as well as the research office, are in the 50-year-old buildings, while the other areas are in new buildings constructed within 20 years.

Indoor air quality monitoring equipment (*Figure 1*), provided by the National Taipei University of Technology, was used to perform non-continuous monitoring thrice during the daytime in the Department of Emergency Medicine. These included a thermometer, oxygen, carbon dioxide (CO₂), ozone, total volatile organic compounds, suspended particle matter of 10 micrometers or less (PM₁₀), and formaldehyde.

The scheduled research measurement time was 15:13 pm on 4 October 2010, 10:00 am on 5 October 2010, and 13:30 pm on 5 October 2010. According to the Central Meteorological Bureau, the temperature and humidity were 25 °C and 70% on October 4th, and 24 °C and 59%

on October 5th, respectively. The research monitoring was conducted at the ten monitoring locations and recorded based on the following standard procedures: first, all the monitoring instruments were placed on the test bench, calibrated and then started the measurement. Until the measurement figures showed stability, such data was then recorded.

Results

The monitoring results of this study showed that the concentration of oxygen in the ED was higher than the background value of the general environment (20.9%). The oxygen concentration of most places in ER exceeded 30%.



Figure 1 The monitoring instruments.

The concentration of carbon dioxide we measured in almost the entire area of ER has reached over 700 ppm, which exceeded the recommended standard value (600 PPM). Particularly in the internal medical ER, the surgical ER as well as the negative pressure isolation room, these three areas were found to have exceptionally higher CO₂ concentrations up to 800 ppm ($P < 0.05$) (Tables 1-3). A highest value of formaldehyde (0.14 ppm) was detected in the corridor of the observation room. Our study also showed that in the air of observation room and the research office in ER, there was more measured formaldehyde at different time periods; especially it was up to 0.14 ppm in the midday period (13:30 pm). In addition, the research office and the nursing station of the observation room were detected with a higher concentration of ozone in all three of the scheduled monitoring periods; conversely, ozone concentrations were not detected during the morning and midday timeslots from the air at the triage station. The research also showed fewer volatile organic compounds (TVOC) in the triage station, research office and the corridors, whereas other areas of ER had relatively higher TVOC concentration exceeding 150 ppb (normal 100 ppb). The measured values of suspended particles (PM10) with size less than 10 microns were within normal range at all measured locations.

CO₂ level is an important indicator in air-quality monitoring. According to the statistics we obtained in various areas of the ER, we drew a scatter plot (Figure 2). In

Table 1 The measurement results of daytime at 10:00 on October 5, 2010

Locations	Parameters						
	Temperature (°C)	O ₂ (%)	CO ₂ (ppm)	O ₃ (ppb)	VOC (ppb)	PM10 (μm/m ³)	Formaldehyde (ppm)
Triage station	26.9	30.3	646	0.00	104	39	0.05
Surgical emergency room	26.5	30.3	708	0.00	244	63	0.05
Internal emergency room	26.9	30.4	723	0.00	186	28	0.00
Pediatrics room 1	26.8	30.3	724	0.00	647	21	0.06
Pediatrics room 2	26.2	30.3	818	2.10	317	0	0.02
Corridors	24.4	30.3	687	3.70	145	22	0.08
Negative pressure isolation room	24.2	30.4	767	7.20	441	2	0.08
Nursing station of the observation room	23.1	30.5	782	14.90	521	93	0.10
Corridor of the observation room	23.7	30.5	789	4.10	264	10	0.10
Research office	26.7	30.3	758	6.70	235	8	0.05

VOC, volatile organic substance.

Table 2 The measurement results of daytime at 13:30 on October 5, 2010

Locations	Parameters						
	Temperature (°C)	O ₂ (%)	CO ₂ (ppm)	O ₃ (ppb)	VOC (ppb)	PM10 (µm/m ³)	Formaldehyde (ppm)
Triage station	26.7	30.3	650	0.00	166	0	0.02
Surgical emergency room	27.5	30.3	800	4.00	254	50	0.03
Internal emergency room	26.5	30.3	747	3.40	321	18	0.03
Pediatrics room 1	26.2	30.3	653	4.90	469	23	0.02
Pediatrics room 2	25.9	30.3	664	0.00	294	16	0.00
Corridors	25.7	30.3	644	0.00	106	27	0.08
Negative pressure isolation room	24.1	30.4	796	3.90	361	38	0.09
Nursing station of the observation room	24.9	30.4	757	3.30	326	26	0.07
Corridor of the observation room	23.7	30.4	783	0.00	217	6	0.14
Research office	23.3	30.3	788	5.60	187	5	0.12

VOC, volatile organic substance.

Table 3 The measurement results of daytime at 15:13 on October 5, 2010

Locations	Parameters						
	Temperature (°C)	O ₂ (%)	CO ₂ (ppm)	O ₃ (ppb)	VOC (ppb)	PM10 (µm/m ³)	Formaldehyde (ppm)
Triage station	26.8	20.9	694	5.3	193	61	0.02
Surgical emergency room	27.8	20.9	812	4.2	268	55	0.03
Internal emergency room	28.4	30.4	883	0.0	329	28	0.01
Pediatrics room 1	28.5	30.4	751	0.2	255	29	0
Pediatrics room 2	28.4	30.4	824	5.9	271	38	0
Corridors	28.4	30.4	682	12	364	37	0
Negative pressure isolation room	27.8	30.5	851	4.8	465	25	0
Nursing station of the observation room	28.4	30.5	836	8.6	483	47	0.06
Corridor of the observation room	28.5	30.5	809	7.6	608	24	0.1
Research office	28	30.4	741	6.1	431	21	0.1

VOC, volatile organic substance.

addition to the research office, CO₂ concentration in most areas in the afternoon was relatively higher than morning and noon time. There was no significant difference in average concentration of CO₂ measured in the districts of ED at the three times slots during 1 day (740, 728, and 788 ppm; $P>0.05$) (Table 4). Comparing the average CO₂ concentration in the open space with the confined space,

the former had better air quality (667 vs. 785 ppm; $P<0.05$) (Table 5). Open space had a relatively lower accumulation of CO₂, due to air circulation and absence of medical activity in this area. Therefore, the air quality was better in the semi-open medical treatment area than a confined space. Except for the research office, the CO₂ concentration in the afternoon was highest in all districts (15:13) (Figure 2).

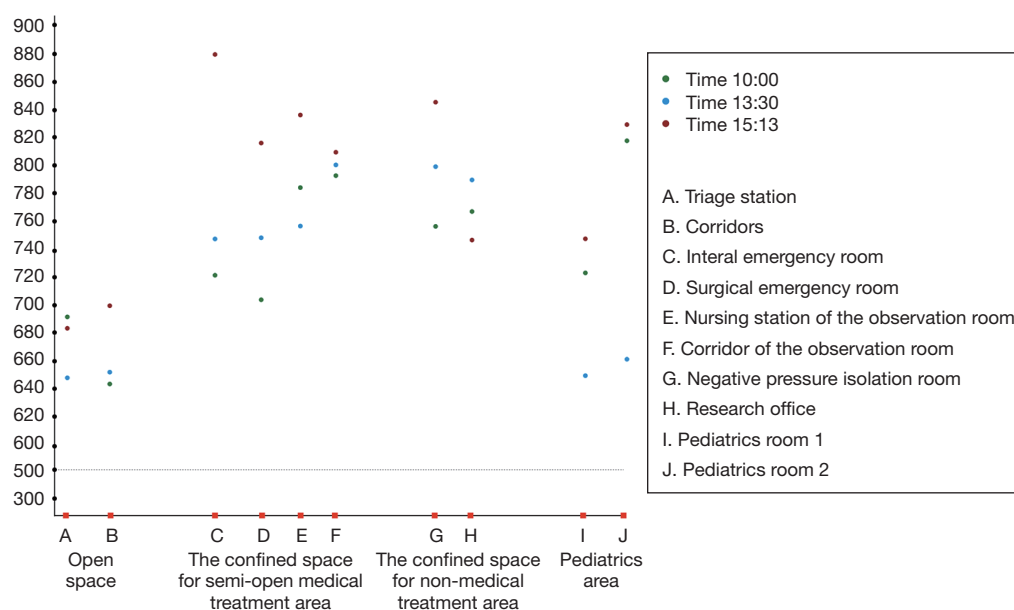


Figure 2 CO₂ level in different areas of ER in three time slots.

Table 4 Data analysis of the concentration of CO₂ of the three daytime slots ($P > 0.05$)

Time	Maximum	Minimum	Average	SD
10:00	646	818	740	52
13:30	644	800	728	67
15:13	682	883	788	68

SD, standard deviation.

Table 5 Statistics of the concentration of CO₂ between the confined space and open space

Variable	Locations		P
	Confined space	Open space	
Time			
10:00	750±41	666±29	<0.05*
13:30	771±24	647±4.2	<0.05*
15:13	835±34	688±8.4	<0.05*
Average value	785	667	<0.05*

*, $P < 0.05$. Data were presented as mean \pm SD. SD, standard deviation.

The research office had poorest air quality at 13:30 in the afternoon; however, the air quality was better in the open area and the pediatric area at the same time. The confined

space for semi-open medical treatment area had better air quality at 10:00 am in the morning.

Discussion

The concentration of indoor air pollutants varies greatly depending on living habits. For example, in the RIOPA study (6), which was conducted in an US urban residential area, about 60% of the fine particulate matter (PM_{2.5}) mass came from outdoor atmosphere, and 40% resulted from indoor activities. On the other hand, the study in urban industrial areas of Kocaeli City, Turkey showed that contribution of outdoor pollutant sources to indoor pollution was about 70%, making these sources the most significant for indoor heavy metal pollution, whereas other sources of indoor pollution included smoking and cooking activities (7). Other indoor activities also generated PM_{2.5} in the work environment. In the emergency medical environment, the air composition and concentration were influenced by the use of oxygen, volatile compounds, alcohol, and some other medical treatments, such as putting on a plaster cast.

Our study found that, compared with the environmental background values (20.9%), the oxygen concentration was much higher in the ER, which may be caused by the high utilization of oxygen. In our measurement results, it was found that the value of concentration of formaldehyde

was slightly higher (>0.12 ppm) in the space with more compartments, such as the area around the observation room and the research office. The research office had the highest concentration of ozone. The reason may be that the laser printers work all day long and produce much more ozone substances into the environment. Contrarily, the medical treatment room had poor air quality at 13:30 in this study due to more staffs working at that time. However, the air quality becomes better at 15:30 as working staffs decreases.

The ER is a high-risk and harsh environment. Although varying concentrations of CO_2 were detected in different areas, the average value was greater than 700 ppm, which exceeds both the concentration of CO_2 in the atmosphere and the EPA-recommended value of CO_2 (600 ppm) in hospitals. Overall, the open space has less CO_2 gas accumulation than confined space due to the relatively better air circulation and no medical behavior performed there. The monitoring data we collected from all the three timeslots showed that the concentration of CO_2 was high. The CO_2 concentration we measured was close to 800 ppm in the internal and surgical ER, as well as in the negative pressure isolation room. Except for the above areas, there were no significant differences between the remaining areas. What really affected the air monitoring data should be the people in the tested space at the time of the monitoring, including medical staffs, patients, and visitors. In addition, the humidity could be reduced due to regularly cleaning of the floor by cleaning works. The air quality of the open space was better than that of the confined space of the semi-open medical treatment area. This might be because people exhaled a great amount of CO_2 in the ER, so that the amount of ventilation given by hospital air conditioner was insufficient to purify the air, resulting in confined space confinement (8,9). Another study showed that the frequent access to the tested space of wheelchairs or hospital beds also increased the number of suspended particles (10–12). We should reduce the number of people in the space or increase the ventilation of hospital air conditioner in order to improve CO_2 indicators of ER in the future. Our study showed better air quality at 10:00 am, possibly because there was a lower number of patient visit during this period and relatively lowering CO_2 accumulation. The sources of indoor CO_2 were mainly from human breathing, smoking, and other burning activities (13). The concentration of indoor CO_2 had a propensity to accumulate, due to high personnel density or inefficient ventilation efficiency (14). At the same time, the concentration of other pollutants

was relatively increased. Therefore, CO_2 is regarded as the most important chemical indicator of indoor air quality. Furthermore, it is an important indicator for assessing whether the indoor personnel density is too high and whether the ventilation efficiency is good. Carbon dioxide in the normal atmosphere is between 350 and 400 ppm, and it stimulates the respiratory center and cause dyspnea when it exceeds 400 ppm. High indoor CO_2 concentrations in an office environment cause sleepiness during cognitive work (15). The accumulation of CO_2 also significantly reduces decision-making performance (16), which is one of the most important ability of ER staffs. Previous studies have shown that architectural design was significantly associated with some symptoms, meaning that people feel uncomfortable in an environmentally poor building, a phenomenon known as “sick building syndrome (SBS)” (17). Symptoms of SBS include dizziness, headache, fatigue, dry throat, stinging eyes, wheezing, dizziness, nasal sensitivity, sneezing, nasal congestion, inability to concentrate, nausea, upper respiratory mucosal irritation, etc. (18). These symptoms are not related to allergies, and most occur in buildings with a confined space, closed windows, good insulation, and central air conditioning system. The symptoms reduced, or even disappeared, when people are away from the building. In addition, a survey conducted by the National Institute for Occupational Safety and Health, using 2,435 questionnaires to analyze 80 poorly designed buildings in order to understand the effects on the human body, from sensory irritation symptoms (eye fatigue and pain irritation) to general symptoms (headache, fatigue), discovered that SBS has a greater influence on females (30–37%) than males (11–23%) (19). In a set of studies of the associations between questionnaire symptom reports, a study analyzed 160 buildings, and observed that low outdoor airflow rate and presence of certain pollution sources, such as copying machines, tended to be associated with an elevated prevalence of SBS. The SBS presented as more than one general symptom, one mucosal irritation symptom, and one skin symptom occurred weekly, and also affected females (29.6%) more than males (19.8%) (20). Therefore, if the office’s concentration of CO_2 is too high, the employees’ work efficiency will be significantly reduced. Air ventilation of office environment might be considered in any building plan to reduce indoor air-related symptoms (19). In addition to some dust, the ER has a propensity to produce not only air pollution, but also a high concentration of CO_2 , in view of the high density of population.

There were fewer large volatile organic compounds

(VOCs) in the triage station, research office and the corridors, while other areas exceeded 150 ppb, due to medical treatment activities. It means that the large VOCs were generated during the medical implementation in a confined space, easily leading to respiratory diseases of the medical personnel in the future. Therefore, medical staff working in the ED should regularly receive chest X-rays to detect potential lung problems early. There are quite variety types of VOCs, and hundreds of organic substances have been tested in the studies of general indoor environments. Concentration of VOCs in new buildings was much greater, often by an order of magnitude or more, and appeared to arise from construction materials and building contents (21,22). Most of them are irritating to the skin or respiratory tract, while others have effects on the central nervous system, causing symptoms such as dizziness and fatigue. Other symptoms could also result from some of them, and yet more substances have been confirmed as carcinogens (23).

Formaldehyde is the most common fugitive contaminant in indoor VOCs (24). It is associated with SBS. Formaldehyde may play a role as the irritant of the nasal mucosa by increasing the expressions of adhesion molecules on HMMECs and by enhancing the adhesiveness between HMMECs and eosinophils (25). Another study indicated that exposure to chemical emissions from indoor formaldehyde was related to asthma, and that some VOCs may cause inflammatory reactions in the airways (26). Our study revealed that, compared to other areas, there was slightly higher formaldehyde concentration (>0.12) around the nursing station the observation room and the research office, which belong to the old building, where the problem of pipeline leakage sometimes occurs. It may be caused by formaldehyde in the solvent or adhesive used by the construction manufacturer.

Indoor ozone (O_3) is mainly produced by the use of ultraviolet light and air ionization, so photocopiers and laser printers are the main sources of ozone. The hypothesis was further confirmed by the observation of the correlations among VOCs, ozone, and particles concentrations during a print job with measurable ozone emissions (27). Ozone is an intrinsically toxic gas that is extremely irritating to the eyes and respiratory tract, causing symptoms such as coughing and chest discomfort, and other symptoms. Recent epidemiologic and animal inhalation studies suggest that current ambient levels of ozone are sufficient to cause premature aging of the lungs, although the effects

of long-term chronic exposure to ozone remain poorly defined (28). Moreover, symptoms may be aggravated by the stimulation of ozone, for sensitive groups of people such as asthma and respiratory diseases. A study showed that short-term exposure to ozone can increase bronchial allergen responsiveness in subjects with mild allergic asthma or rhinitis (28). With the implementation of computerized physician order entry, the objective called for on-demand barcode printing in a wide variety of settings. In the department of emergency medicine that we studied, more than 20 printers are in operation around the medical staff; however, the space is too small to maintain a proper distance between personnel and printers, meaning that the staffs will inevitably come into contact with ozone. Although the measured concentration of ozone was not high, the measurements might have been affected as a result of the character of ozone, which exists in a very unstable and reactive state that readily and naturally decomposes to oxygen. Concentration of ozone was not easy to accumulate. In the present study, higher concentration of ozone was measured in the research office and the nursing station of the observation room, as a result of the high demand for relevant printers.

Suspended particles have different effects on the respiratory tract depending on their particle size. Generally, PM with a particle size of $10\text{ }\mu\text{m}$ or less are called respirable suspended particulates, or PM₁₀, which can enter the respiratory system with respiration. According to their particle size, it settles in the nasal cavity, respiratory tract and alveolar cells from large to small, and is hazardous to the respiratory tract. Concentrations of PM₁₀ are positively associated with increased numbers of admissions for respiratory diseases (29). The sources of respirable suspended particulates in indoor environments are smoking, cooking, asbestos in synthetic materials, artificial mineral fibers, plant pollen, animal allergens, microbial bacteria, fungi, viruses, and etc. (30). These are harmful to humans in different ways, depending on their characteristics. The survival of aerosolized pathogens depends upon environmental conditions, such as indoor building environment. After all, the worse the ventilation of the hospital is, the longer the same aerosol particles are suspended in the air, the higher the dose of health personnel inhaling the pathogen per unit time, and the higher the chance of infection (31). In the present study, we found the suspended particles level of less than 0.06 mg in the ER, representing that the air conditioning system in the ED of this medical center is qualified in the overall

filtration system.

Limitations

This study faced some difficulties, as described below.

A limitation on monitoring locations

In consideration of the medical processing of a large number of emergency patients, we selected monitoring positions that would not affect the patients and medical staffs. Therefore, some of the monitored positions were located on the routes with fewer patients, meaning that the monitoring data obtained might be lower than the actual value. On the other hand, we didn't setup a measurement control point outside the ER building, due to lack of suitable place. A measurement control point would be more precise and meaningful than global environmental background values, such as the concentration of oxygen (20.9%).

An inadequate monitoring time

The inadequate method-design of this study was the monitoring time, which focused only on three daytime slots. Therefore, fewer statistics data and random area monitoring are both shortcomings. In the future, we should strengthen the analysis of more time periods and spaces, and take it as the basis of assessment in hospital space transforming and planning.

An inadequate data of ER visits

The distribution of ER visits number by time, which allows establishing the relation between time periods and minimum/maximum number of patient visit should be collected. There should be inverse correlation between personnel density and air quality.

The impact of weather

The data of weather as a potential impact factor should be collected, which may affect some results like O₃ and PM₁₀ (32).

Conclusions

The ER is a high-risk and harsh environment where it is easy to generate air pollution, as well as a high concentration of CO₂. Therefore, maintaining emergency environment and improving air conditioning is a very important issue.

The ventilation of outdoor airflow and filtration of particles of air conditioning systems should be well-designed since the initial construction of ER building to

avoid SBS. Current environmental requirements for air conditioning systems are from the beginning to lower the temperature, and later to control the indoor temperature at a comfortable temperature, to the point that it requires a healthy and clean air function. Today's emergency environment is harmful to the health of medical personnel, because the accumulation of carbon dioxide in some medical treatment spaces can easily lead to fatigue and hypoxia for long-term work of medical staff. Therefore, it is relatively important to improve the air quality, and create a friendly and healthy environment, as well as optimize the air conditioning system functions, so that let the medical staff work with peace of mind.

Future directions

In order to maintain a high-quality healthcare environment in the workplace, a new type of air conditioning system, applied in hospitals and medical facilities, could combine with gas adsorption equipment and nano-photocatalyst air purification technology, to enhance the safe and comfort of working staffs. As a result, the next objective of this study is to develop ideal aerobic air conditioning equipment and modularity in the system, which will maintain the average level concentration of oxygen and reduce the concentration of CO₂. Air purification would use titanium dioxide (TiO₂) as a catalyst, as it can perform its function even under weak light source, such as an indoor fluorescent lamp. In theory, TiO₂ is self-cleaning and pollutant-degrading, so it can purify all types of harmful gases at any time to keep the surrounding air fresh and healthy. Compared with conventional air purification methods (such as physical adsorption method, ultraviolet fixation method, and ozone decomposition method), photocatalyst has the characteristics of simple equipment, strong purifying ability, a wide application range, a long-lasting and effect, no secondary pollution, and low maintenance cost. It can be used for medical areas with major pollution.

In addition, the air conditioning can be combined with real-time monitoring of CO₂ concentration, using a computer to calculate the optimal exchange rate of external air, so that it would become an immediate response system, not only providing clean and comfortable air, but also protecting the medical staffs from hazardous substances. At the same time, it can meet the needs of energy saving. In the 21st century, we expect greater artificial intelligence and more energy saving. The statistics show that the air conditioning system accounts for about 40% to 50% of the electricity consumption of

medical centers. Consequently, it is necessary to establish an air conditioning trend toward clean air and energy-saving, in order to meet future expectations.

Acknowledgments

The author acknowledges the assistance of the experimental team of Prof. Ching-Song Jwo, a member of the National Taipei University of Technology, in making the project run smoothly.

Funding: None.

Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at <http://dx.doi.org/10.21037/ht.2019.03.01>). WHC serves as an Editor-in-Chief of *Health Technology*. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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doi: 10.21037/ht.2019.03.01

Cite this article as: Chen PY, Kung LC, Tsai W, Chien DK, Chang WH. The potential risk of sick building syndrome of the emergency department areas in a medical center in Taiwan. *Health Technol* 2019;3:3.