Print ISSN: 1738-3110 / Online ISSN 2093-7717
http://dx.doi.org/10.15722/jds.17.07.201907.65

Economical Ventilation Effectiveness to Reduce Hazardous Chemical Emissions for a Nail-Salon Worker*

Woo-Taeg KWON**, Min-Jae JUNG***, Woo-Sik LEE****, Lee-Seung KWON*****, Young-Jin SO*

Received: May 27, 2019. Revised: June 19, 2019. Accepted: July 05, 2019.

Abstract

Purpose – The purpose of this study is to investigate economical ventilation effectiveness to reduce hazardous materials exposure and damage of workers by analyzing exposure amount of noxious substances under various ventilation conditions of nail salon for indoor environments.

Research design, data, and methodology – This study was carried out with cooperation of Nail shop located in SeongNam city to involve an analysis of the environmental impact indoor air quality, pollutant exposure and economical cost-effectiveness in the nail workplace. The hazardous substances were PM-10(Particulate Matter-10㎛), VOCs(Volatile Organic Compounds) and Formaldehyde, which are the major materials of nail workplace.

Results – PM-10 is reduced by about 60% with air cleaner, forced artificial ventilation by 32%, and natural ventilation by about 12%. TVOCs and Formaldehyde showed similar efficiency (80~100%) after natural ventilation and ventilation after 60 minutes. The removal efficiencies of VOCs and formaldehyde were similar to those of natural ventilation and mechanical ventilation system. However, in case of dust, natural ventilation was reduced by artificial ventilation system due to inflow of external dust during natural ventilation.

Conclusions – If the pollution degree of outdoor air is not high, air volume is high, and natural ventilation is performed when the air conditioning and heating system is not operated. Even at the end of the work, it keeps operating for 60 minutes to remove the pollutants generated. Results of this analysis demonstrated that the worker environment can be improved by adopting institutional legislation and guidelines for ventilation.

Keywords: Ventilation, Economical Cost-Effectiveness, Contaminants, Occupational Exposure, Nail Salon

JEL Classifications: D3, H8, I11.

1. Introduction

Nail care salons have become a profitable, familiar business around the world; however, this service business has been linked to occupational exposures and, occasionally, to air pollution(Munguia et al., 2016). Nail salon technicians face chronic exposure to volatile organic compounds (VOCs), which can lead to adverse health outcomes including cancer(Lamplugh et al., 2019).

Efforts to prevent or control ventilator induced lung injury (VILI)have evolved over several decades(Barnes & Enk, 2019). Indoor air quality (IAQ) can affect everybody's life, and is defined as the quality of the air within buildings and structures(Lucattini et al., 2018). From our lives, chemicals occupy a very large share of industrial products, household goods, and building materials. Chemical substances have both abundance and noxious, and when substances harmful

* This research was partially supported by EulJi University in 2018.

** 1st Author. Professor, Department of Environmental Health & Safety, Eulji University, Korea. Tel: +82-31-740-7230. E-mail: awtkw@eulji.ac.kr
*** 2nd Author. Master degree, Department of Environmental Health & Safety, Eulji University, Korea.
Tel: +82-31-740-7230. E-mail: idrjqnrdl@naver.com
**** 3rd Author. Professor, Department of Chemical & Biological Engineering, Gachon University, Korea.
Tel: +82-31-750-5594. E-mail: leews@gachon.ac.kr
***** 4th Author. Professor, Department of Health Care Management, Catholic Kwandong University, Korea.
Tel: +82-33-649-7274. E-mail: leokwon1@cku.ac.kr
* Corresponding Author. Professor, Department of Beauty Cosmetics, Eulji University, Korea.
Tel: +82-31-740-7149. E-mail: yjso@eulji.ac.kr

© Copyright: Korean Distribution Science Association (KODISA)
This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0/) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

to human body leaks, it causes pollution of indoor air and causes diseases to humans. Today, attention to beauty is increasing with appearance management. However, most of the domestic workplaces are small-sized workplaces with less than five employees, and both workers and users are exposed to hazardous chemicals. Indoor air quality may be improved by three basic strategies: contaminant source control, ventilation improvement, and air cleaning(Bayram & Șanci, 2019; Ciuzas et al., 2016).

Contaminant source control is the most effective way to reduce individual contaminants at source, thereby reducing emissions and delivering improved indoor air quality(Shiue et al., 2019; Zheng et al., 2017). However, the chemicals generated in the nail salon can not be removed by various chemical agents, disinfection and/or instrument materials. Obviously, natural ventilation using fresh outdoor air is the most common and cost-effectiveness strategy. However, recently, outside air contains a lot of fine dust. Also, because weather conditions vary from season to season, there is a disadvantage that this method relies on external weather conditions. Therefore, under various circumstances of a nail salon, we would like to study a cost-effective method by practically combining ventilation improvement and air cleaning.

Especially, in the field of nail salon, it is classified as other beauty business and beauty industry, and it is not able to grasp even the accurate count. According to the statistics of the Korean National Statistical Office, the number of nail-related shops increased from 7,600 to 11,388 in the year of 2014 compared to 2016, and the number of employees increased from 13,175 to 17,581, which is 33.44 %, and the number of related companies such as nail shops, specialized companies and academies is continuously increasing.

The nail salon worker in Korea is considered to be in need of health measures because he is being trained in nail technical part without regular safety training or theoretical education about the chemicals of the products used in the field.

Nail salon workers are known to have an average of 8 to 11 hours of working time a day, but they tend to remain exposed to pollutants while staying in a place connected to the workspace, even during actual eating or resting periods. In addition, ventilation is important in the season when the heating and cooling system operates in the summer and winter, because the natural ventilation is not significant enough, so ventilation is important(Aaron et al., 2019). Major harmful substances occurring in the nail work space are mostly generated in TVOCs(Total Volatile Organic Compounds) and formaldehyde(HCHO) products (Pavilonis et al., 2018; Wang et al., 2009). Ventilation is used to reduce air pollution in the indoor space and to promote human health that uses indoor space. Various indoor pollutant standards are set according to the size and usage of space such as working space, multi-use facility, etc(Colman Lerner et al., 2018; Lexuan et al., 2019). Based on this standard, a ventilation system is designed to maintain the pollutant concentration below the standard. However, the present nail work space does not have a ventilator installed, but does not operate or install in most spaces. Based on the above background, this study proposes a ventilation method that minimizes exposure of harmful substances to workers by identifying the amount of harmful substances exposed to nail shop ventilation conditions. And installs ventilation equipment with air purifying function, we aim to reduce pollutant exposure of nail worker through comparative analysis. Measured contaminants were selected from TVOCs, formaldehyde, and fine dust like a PM(Particulate Matter; PM-10, PM-2.5), which are mainly generated in nail work through previous research results(Alaves et al., 2013). The ventilation conditions are based on the normal ventilation conditions of the nail shop, and the amount of pollutants generated by applying natural ventilation (whether the windows are opened or closed and indoor air flow is formed through doors) and the operation of the air cleaner are compared and evaluated. The amount of pollutants generated by the ventilation system is increased. The purpose of this study is to clarify the ventilation conditions that minimizes the exposure of harmful substances and suggest proper ventilation method according to the exposure environment of the workers.

2. Theoretical background

2.1. Natural ventilation

There are many advanced studies for self-esteem and life satisfaction in old age by using hair, skin-care, cosmetic, nail-art among beauty related fields (Jung & Moon, 2018) but studies on economical ventilation effectiveness to reduce hazardous chemical emissions for a nail-salon worker is lacking. Studies have documented that workers in nail salons are regularly exposed to VOCs, including acetone, toluene, ethyl acetate, methyl methacrylate, and formaldehyde (Alaves et al., 2013), which are chemical hazardous emissions in many nail salon products. Indoor air quality refers to the air composition or quality within and around buildings and structures, and its relation to the comfort, health and productivity of building occupants (Muhamad-Darus, Zain-Ahmed, & Latif, 201). According to the plan type of the building, based on the analysis of natural ventilation performance of indoor and outdoor, there is a research result that analyzes the reduction effect of sick house syndrome in residential space. Considering that 52% of the causes of indoor air pollution occur in insufficient ventilation, it is argued that emphasis should be placed on ventilation rather than pollution in indoor space.

As the indoor air quality management method of multi-use facility was implemented, it was obligatory to install a structure or machine ventilation facility with sufficient natural ventilation in the buildings. Most facilities use mechanical ventilation equipment, which causes problems such as an increase in energy consumption and an increase in construction cost(Francisco et al., 2016).

Most of the buildings where the Sick Building Syndrome (SBS) occurs are buildings that use mechanical ventilation. The results of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (Zhuang, Wang, & Tang, 2019) showed that the exposed object in the natural ventilating building feels comfortable over a wider temperature range than the exposed object in the mechanical ventilated building.

Formaldehyde in the tubular planar interior space was 148.75 ㎍/㎥. It was much smaller than Formaldehyde in the other planar form, and showed a tendency to show a different supply of concentration in each space, but the concentration variation was small overall and the highest concentration did not exceed 250 ㎍/㎥.

On the other hand, the average concentration of formaldehyde in the overhead type apartment houses was more than 210 ㎍/㎥, which is the highest value in the tower type indoor space, 464.12 ㎍/㎥. Based on these results, it can be concluded that the indoor air space formed by the plate-like flat surface can be effectively ventilated by natural ventilation, so that the concentration of indoor pollutants is low as much as 30~79 % less than the control. This is due to the formation of the stagnation zone due to the characteristics of the head-top structure. The indoor pollution level shows a large difference according to the ventilation method, the pollutant concentration is reduced when the natural ventilation is executed, and it returns to the original state when the natural ventilation is stopped.

There is no significant difference between the ventilation method and the natural ventilation, but natural ventilation has the advantage of reducing energy consumption. However, there is a disadvantage that it is difficult to provide a certain amount of ventilation.

2.2. Air cleaner

Air purification technology is a technology to purify polluted air and convert it into fresh air. It is a treatment mechanism that removes contaminants by using various filters to filter out fine dust or bacteria and to use adsorbed material or decomposition catalyst.

Air cleaning technology has recently been growing rapidly, with various factors threatening our residential environment, such as dust, sick house syndrome, and fine dust increase, and investment in air cleaning technology development is required to find solutions (Na et al., 2005).

At present, the air cleaning function focuses on the removal of various harmful substances generated in the room and the development of functional filters such as the health field, which is also a requirement of the consumer. Development of a special functional filter for removing Volatile Organic Compounds(VOCs) and formaldehyde removal from apartments and new buildings, removal of substances causing atopic dermatitis and allergic diseases based on the performance of dust collection and deodorization (Na et al., 2005).

In addition, by applying nanotechnology, it is possible to make antimicrobial and sterilizing function and metal having antibacterial ability such as silver(Ag) and copper(Cu) into nano-size to widen the specific surface area, thereby consuming relatively low cost and doubling its effect studies are being conducted recently.

Carbon or photocatalyst(TiO2) is applied to the surface of the filter through which the pollutants pass, and these methods are applied to the air cleaning technology and are gradually expanding (Na et al., 2005).

2.3. Ventilation system

2.3.1. Types and trends of ventilation systems

The ventilation equipment is a device which dilutes the indoor harmful gas such as the harmful substance generated in the building material, carbon dioxide due to breathing to the outside air forcedly or ventilates the indoor air by discharging the contaminated outside air. Recently, in the residential environment, there is a demand for a comprehensive function such as introduction of new outboard, prevention of

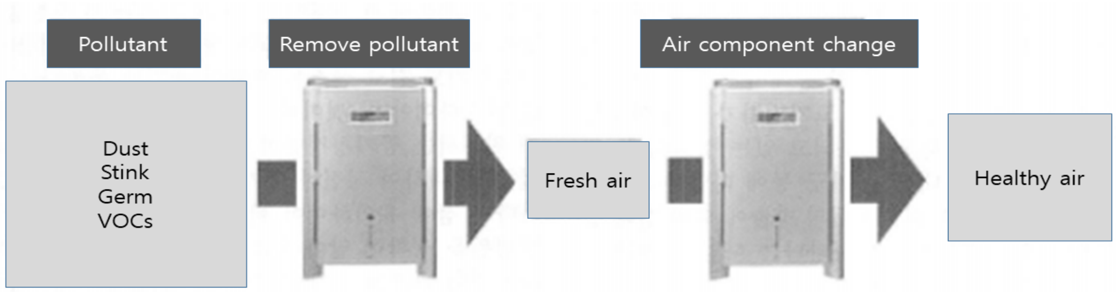

Figure 1: Mechanism of air cleaning technology

dew condensation, removal of fine dust or inflow, as well as a sense of comfort.

The total heat exchanger, which has a principle of contacting a solid heat storage material with a high temperature fluid to absorb the heat of the high temperature fluid and then transferring the heat to the low temperature fluid by contacting the low temperature fluid, is classified into shell and tube, plate and coil type.

The regenerative heat exchanger combined with the heat storage and heat exchange function is easy to design an efficient ventilation system because it can be manufactured in various sizes and because the price is low, and maintenance is simple. The main role is heat exchange, and the remainder of the energy is stored in a regenerative medium, which can be used as an alternative energy source in case of insufficient energy supply from the heat source.

It is a means for continuous ventilation for 24 hours. It also includes a heat exchanger such as a total heat exchanger to recover indoor heat energy if necessary, while the forced air supply and forced air discharge are performed through filters, blowers and ducts (first type mechanical ventilation) (Figure 2).

There is a hybrid ventilation in a newly designed way. Generally, this is a method of forcibly discharging air by a blower, and supplying natural air through a pressure lane to the outside, thereby performing natural ventilation and mechanical ventilation at the same time, thereby forming a whole ventilation path in the room.

In recent years, there has been a system that automatically performs natural ventilation when the CO_2 concentration in a room becomes higher than a certain level by using a CO_2 sensor, a ventilation window is installed on the ceiling, natural ventilation is performed, and a dehumidifying type radiation panel is installed on the floor.

2.3.2. Ventilation system precedent research

Hou et al.(2018) investigated the ventilation system and measured the concentration of carbon dioxide by controlling the number of passengers in the space where the ventilation equipment was installed and varying the ventilation amount. As a result, 1,791 ppm of maximum 2,190 ppm was observed before ventilation system operation, and this result exceeded 1,000 ppm stipulated in the indoor air quality management law of multi-use facility. The ventilation system was operated at a higher capacity and the measured concentrations were compared. However, the average value was 1,032 ppm and the maximum was 1,145 ppm. It is reported that the required ventilation amount of the building is insufficient compared with the room occupancy, and the CO_2 concentration is 913 ppm and the maximum is 1,009 ppm when the ventilation capacity is 1.40 times/h (900㎥/h).

The ventilation equipment capacity standard proposed in the indoor air quality control law of multipurpose use facilities is 875 ㎥/h which is calculated as 35 redundant persons by 25 ㎥/h regulation per person. Therefore, 900 ㎥/h And the ventilation capacity of the ventilation system is 1000 ppm.

In this study, we emphasized the importance of ventilation capacity and ventilation capacity per person when ventilation system is applied to buildings. In order to improve indoor air quality through ventilation, it is suggested that the amount of pollutants that can be generated in the room should be minimized and the cooling system and the ventilation system, which affect the ventilation airflow, should be integrated.

3. Research method

3.1. Research subject

This study was carried out with cooperation of nail institute located in SeongNam city to study indoor air quality and pollutant exposure environment of workers in the nail salon. The lecture room of the nail school is a space of 5m × 8m × 3m (width × length × height) and uses the central heating system. There was no ventilation system installed separately. The subject of measurement was selected by targeting PM-10, TVOCs, and formaldehyde, which are major materials of nail work space.

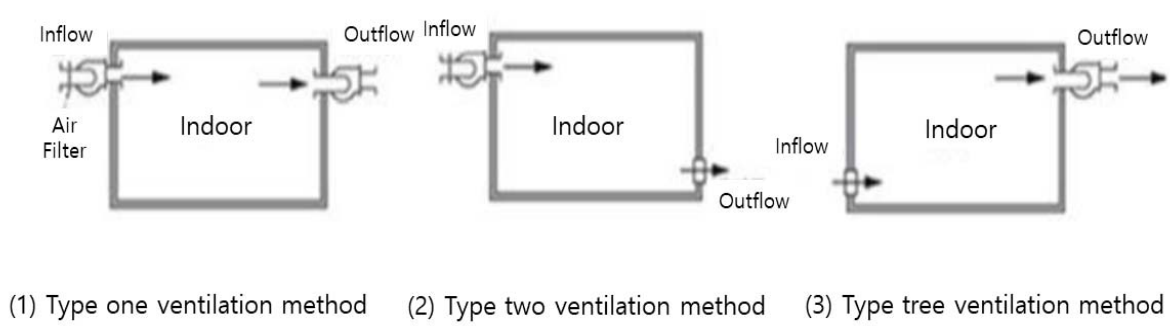

Figure 2: Types of ventilation

In the nail salon, there are variables such as difficulty in controlling the amount of pollutants generated constantly due to the change of the number of attendees and the nature of the lecture method, and the door is opened and closed continuously. Therefore, it is difficult to specify the effective ventilation method. Additional experiments were conducted. The experimental space was designated as a rectangular space of 3m × 8m × 3m (width × length × height). As with the nail school, there was no separate ventilation facility, and the substance to be measured proceeded in the same manner as the substance measured at Nail Institute.

3.2. Composition of measurement environment

3.2.1. Nail salon

In the experiment at the nail school, the nail art institute located on the road side of SeongNam city was asked to cooperate and the pollutant concentration was measured during the class. The room size was 5m, 8m, and 3m (width x height x height), and the items were TVOCs, PM-10, and formaldehyde. The air flow rate in natural ventilation at nail school is 192 ± 86.46 m^3/h, ventilation air condition is 121 m^3/h, and the average condition of air purifier is 121 m^3/h. As shown in Figure 3, ventilation conditions were varied for three days from November 12 to 14, in 2018 (Figure 3).

3.2.2. Experimental space

The measurement progress in the experimental space was conducted from December 1 to 8 for 8 days. To reproduce the contaminants from the nail art institute, the nail pattern is printed, the film is pasted, the model is made, and the process is reproduced with the nail products used in the actual shop to produce 4m, 8m, 3m (width x height x height) space. Three pollutants, TVOCs, PM-10 and formaldehyde, were measured by ventilation conditions. The average air volume during natural ventilation in the experimental space was measured as 369.6 m^3/h, and the air condition of the ventilator and air cleaner was 121 m^3/h.

3.2.3. Ventilation conditions

Ventilation conditions were classified into nature ventilation, air cleaner operation, and ventilation system operation. Natural ventilation at the nail school is set up so that the natural air flowing from the windows can be opened through the doors by opening the windows that are inside the classrooms. When the air purifier is operated, all the windows and doors should be closed. There was a difficulty in controlling because the door was open at all times. When the ventilator was operated, the measurement was carried out with the door open. In the experimental space, natural ventilation was measured by opening a window in the space and opening the door to form a natural air flow. Air purifier and ventilation were controlled in the closed space by controlling windows and doors.

The conditions of the ventilator and the air purifier used in the measurement are shown in the Table 1. The purpose of this study was to compare the pre-ventilation concentration and the post-ventilation concentration for 15 minutes according to the ventilation condition. In the experimental space, the nail work was reproduced and the pollutants were generated for 30 minutes. To observe the decrease of the concentration according to the ventilation state over time, 5 times total measurement was performed at 0 minute, 15 minute, 30 minute, 45 minute and 60 minute section.

The size of the window in the nail work space was 0.8m × 0.4m (width × length), and the window size in the experimental space was 0.5m × 0.7m (width × length). The air volume during natural ventilation for each experiment was calculated(Figure 4).

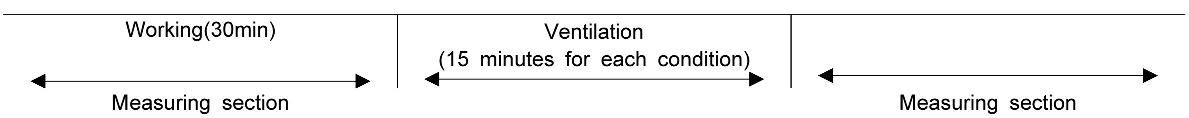

Figure 3: Nail academy experiment measurement point

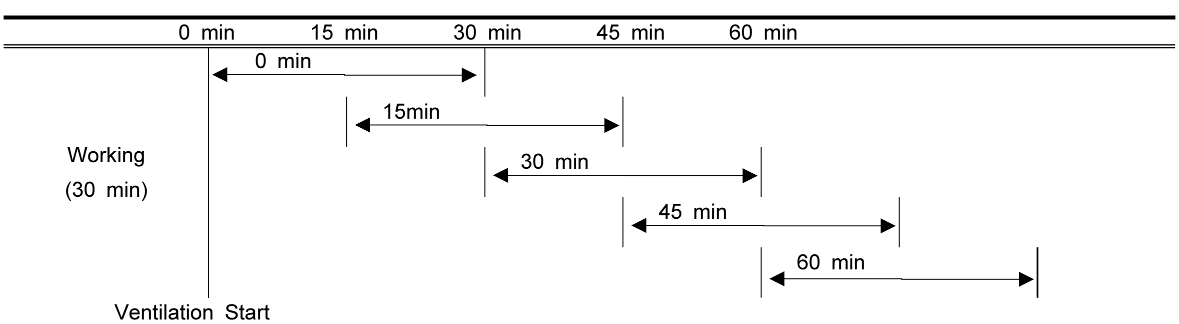

Figure 4: The experiment area measurement point

Table 1: Condition of ventilation system and air cleaner

Ventilation system	
Processing capacity(m^3/h)	57~121
Power Consumption(w)	25~45
Heat exchange efficiency(%)	65~75
Air cleaner	
Processing capacity(m^3/h)	57~121
Power Consumption(w)	25~45

3.3. Measurement Method

3.3.1. Sampling method

3.3.1.1. Measurement equipment

Table 2: Measurement equipment

Metrics	Measuring devices	Remarks
PM-$_{10}$		**Sensor Type** 90° light scattering **Particle Size Range** 0.1 to 15 μm **Resolution** ±0.1% of reading or 0.001 mg/m^3, whichever is greater **Flow Accuracy** ±5% of factory set point, internal flow controlled **Operational Humidity** 0 to 95% RH, non-condensing
TVOCs	 	**Sibata MP-Σ30** **Variable Flow Range** 0.050-0.150 ℓ/min **Accuracy** Within ± 5% of set flow value **Tenax-TA Tube** **Material** stainless steel TD tube **O.D. × L** 1/4 in. × 3 1/2 in. **Particle size** 60-80 mesh
Formaldehyde	 	**ibata MP-Σ100** **Variable Flow Range** 0.30-1.50 ℓ/min **Accuracy** Within ± 5% of set flow value **DNPH Cartridge** **DNPH Loading** TS-300 : 0.5% (1.5 ㎎/cartridge) **Particle size** 60~100 mesh

3.3.1.2. Particulate Matter(PM)

DUSTTRAK DRX AEROSOL MONITOR 8534 was used to measure fine dust. It is a real-time aerosol monitor developed by TSI of USA and it uses light scattering technology to measure real-time mass concentration. This equipment measures the PM-1, PM-2.5 and PM-10 simultaneously by measuring the dispersed aerosol through the photodetector by injecting the measured aerosol into the inside and dispersing it with the laser light generated inside, small in size and light in portability. It is suitable for personal exposure measurement, manual programming and data logging. It is a device capable of measuring the particle size range of 0.1~10 ㎛ and the concentration range between 0.001~150 mg/㎥.

3.3.1.3. TVOCs

Tenax-TA tubes were connected by suction flow of Sibata MP-Σ30H pump. The Sibata MP-Σ30H is an air suction

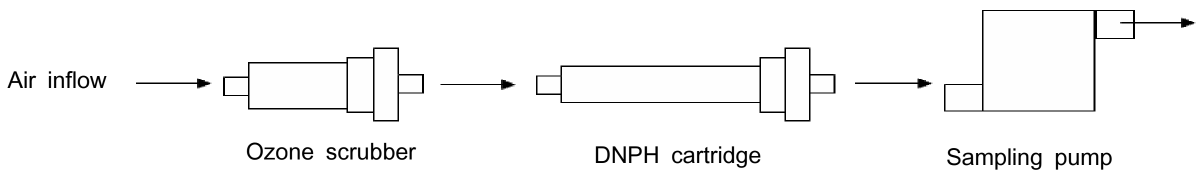

Figure 5: Formaldehyde measurement schematic

pump with built-in integral flow measurement function. It can display the measured value of the instantaneous flow rate and can be displayed digitally. The static flow function prevents the decrease of the suction flow when the suction pressure increases due to dust collection. Tenax-TA tubes applied in this study are used. It is a stainless steel tube with an inner diameter of 3~5 mm and a length of 100 nm. It can be sealed at both ends. In addition, this is an adsorption type tube based on 2,6-diphenyl-p-phenylene oxide, which is aged to zero air or high purity helium gas at high temperature before use. Using the instrument, the nail was sucked in the Tenax-TA tube at a rate of 100 ml per minute using a flow meter for 30 minutes at the center of the workspace.

3.3.1.4. Formaldehyde

In the DNPH cartridge, the aldehyde in the exhaust gas reacts with 2, 4-DNPH, which is an absorption liquid, to convert the hydrazone derivative into a form and to produce water as a by-product. The resulting hydrazone derivative is analyzed. Ozone reacts with DNPH and its derivatives in the cartridge to act as an inhibitor to the concentration. Therefore, the ozone scrubber (ozone scrubber) is connected in series to the front of the DNPH cartridge(Figure 5).

Sampling is carried out at a flow rate of 1.0 L/min for 30 minutes. The cartridges that were refrigerated prior to sampling are removed from the container and allowed to warm to room temperature. When the cartridge is at room temperature, remove the cap from the cartridge and connect the cartridge to the sampling device. Immediately after the sampling is complete, remove the cartridge from the sampling device, plug the cartridge using its own plug, and place the cartridge in its original labeled container. The container containing the cartridge is sealed with tape and stored in a container filled with granular activated carbon or once again in a padded container. Sampling cartridges were kept refrigerated until analysis, and DNPH cartridges were prevented from being exposed to light by using aluminum foil during sample collection.

3.3.2. Sample analysis method

3.3.2.1. Particulate matter

The measurement data were analyzed without a separate preprocessing by measuring by continuous measuring device by sensor. In the nail academy experiment, the air was measured for 30 minutes in the room air before the start of the ventilation, and the ventilation was measured after each ventilation condition for 15 minutes. The mean and standard deviation were displayed, and the data were visualized and the numerical values were compared according to the ventilation conditions.

3.3.2.2. TVOCs

The collected Tenax-TA tube is thermally desorbed by heating at 300 to 350°C. The target components are re-concentrated and introduced into a gas chromatograph, the mixed components are separated using a separation column, and the separated substances are detected through a mass spectrometer. Quantitative analysis is performed with the information of chromatogram and spectrum of the detected substance.

3.3.2.3. Formaldehyde

Acetonitrile is passed through the collected DNPH cartridge to transfer the DNPH from the cartridge detachable. The final volume is adjusted to 5ml using acetonitrile. A portion of the volume required for analysis in the extracted solution is aliquoted and the remaining volume is stored in the refrigerator. Quantitative analysis is performed with the information of chromatogram and spectrum of the detected substance.

Table 3: GC analysis condition

TD	
Initial temperature	35 ℃
Rate	60 ℃/min
Final temperature	260 ℃
Final time	5 min
Transfer temperature	300 ℃
Cooled Injection System	
Initial temperature	-40 ℃
Rate	12 ℃/s
Final temperature	260 ℃
GC/MSD	
Inlet temperature	250 ℃
Column	VOCOL
Oven temperature	35℃(4℃/min) → 15℃(20℃/min)->220℃, 5 min
Detector	MSD
Ion source temperature	200 ℃
Ionization	Electron Ionization(70 eV)
Mass range	Scan, m/z 35 to m/z 260

Table 4: HPLC analysis condition

HPLC	
Flow	1.0 mL/min
Carrier liquid	60% Acetonitrile / 40% Water(Volume ratio)
Column	C-18 Column (Inside diameter 3.9 mm × 300 mm)
Detector	UV, Wavelength 360 nm
Hold up time	7 min

4. Research results

4.1. PM-10

The PM-10 in nail-school experiments decreased from about 92.18 ± 4.33 ㎍/㎥ before natural ventilation to 81.27 ± 3.81 ㎍/㎥ after natural ventilation by about 12%. PM-2.5 was reduced by about 12% from 76.46 ± 3.67 ㎍/㎥ before natural ventilation to 67.49 ± 3.23 ㎍/㎥ after ventilation.

In the operating condition of the air purifier, PM-10 decreased by about 60% from 35.66 ± 1.78 ㎍/㎥ before operation to 13.86 ± 0.71 ㎍/㎥ after operation. PM-2.5 decreased by about 60% from 26.07 ± 1.30 ㎍/㎥ before operation to 10.46 ± 0.54 ㎍/㎥ after operation.

In the ventilation system, PM-10 decreased by about 27 % from average 54.2 ± 2.710 ㎍/㎥ to 39.55 ± 1.97 ㎍/㎥ after operation. PM-2.5 decreased from 42.98 ± 2.02 ㎍/㎥ before operation to 28.88 ± 1.35 ㎍/㎥, respectively. Since natural ventilation is a method of removing indoor air pollutants by the inflow of outdoor air, the air containing PM-10 is introduced and the removal efficiency of PM-10 is not as efficient as about 12%. The air purifier was the most effective for removal of PM-10 because it was mainly used for removal of PM-10. The ventilation system showed a reduction efficiency of about 30%. The concentration of PM-10 in the experimental space was 0.009~0.042 ㎍/㎥, which was lower than that of the multipurpose facility PM-10 of 100 ㎍/㎥. The mean PM-10 concentration was 0.009~ 0.038 ㎍/㎥ before ventilation and 0.009~0.056 ㎍/㎥ after ventilation. In the natural ventilation state, the concentration of PM-10 contained in the outside air increased, and the air purifier and ventilator showed a slightly increased concentration at the very low PM-10 concentration. Measurements at the nail school were taken as a measure of PM-10 abatement efficiency. Since measurements at nail schools are difficult to repeat at the same occurrence conditions, the initial concentration values were different, but the reduction efficiency of fine dust was evaluated through comparison between before and after operation.

4.2. TVOCs

In the nail school experiment, TVOCs decreased by about 39% from 2262.52 ± 1703.21 ㎍/㎥ before ventilation to 1442.98 ± 1076.37 ㎍/㎥ after ventilation in natural ventilation. In the condition of operating the air cleaner, it decreased by about 6% from 2431.97 ± 1744.60 ㎍/㎥ before operation to 2265.36 ± 1582.04 ㎍/㎥ on average. The TVOCs before the operation of the ventilation system decreased by about 30% from 2270.56 ± 1502.64 ㎍/㎥ to 1716.72 ± 1133.15 ㎍/㎥ after 15 minutes of operation.

The difference in the concentration of TVOCs before ventilation in the nail school experiment was caused by the difference in the number of trainees. Due to the nature of self-enrollment, it was difficult to control the number of participants. In the nail school experiment, the TVOCs tried to see only the tendency of the decrease in the amount of generation by each ventilation condition because the actual pollution source and environment were difficult to control. Natural ventilation and ventilation systems showed a large deviation but the decrease of TVOCs concentration after ventilation was about 30~40%, but the air cleaner system did not decrease TVOCs such as 6% decrease.

In the natural ventilation, TVOCs were 1303.06 ㎍/㎥ after 15 minutes, 807.03 ㎍/㎥ after 30 minutes, 530.35 ㎍/㎥ after 45 minutes, and 150.59 ㎍/㎥ after 60 minutes from 1837.08 ㎍/㎥. When TVOCs was operated at the air purifier, it was 1758.92 ㎍/㎥ at the time of 0 minute, 1670.97 ㎍/㎥ after 15 minutes, 1635.79 ㎍/㎥ after 15 minutes, 1583.02 ㎍/㎥ after 45 minutes, and 1600.61 ㎍/ after 60 minutes.

At the operation of the apparatus, the concentrations were 1814.26 ㎍/㎥ at the time of 0 minute, 1451.40 ㎍/㎥ at 15 minutes, 1269.98 ㎍/㎥ at 30 minutes, 689.41 ㎍/㎥ at 45 minutes and 380.99 ㎍/㎥ at 60 minutes. The results showed that natural ventilation and ventilation were reduced by 85~99% after 60 minutes of ventilation, and air purifiers showed almost no decrease in TVOCs after 60 minutes of operation, similar to the experiments at Nail School. At this time, the air volume of natural ventilation was 192 ± 86.46 ㎥/h in nail work space and 396.6 ± 233.13 ㎥/h in experimental space. The decreasing trend is shown in Figure 6.

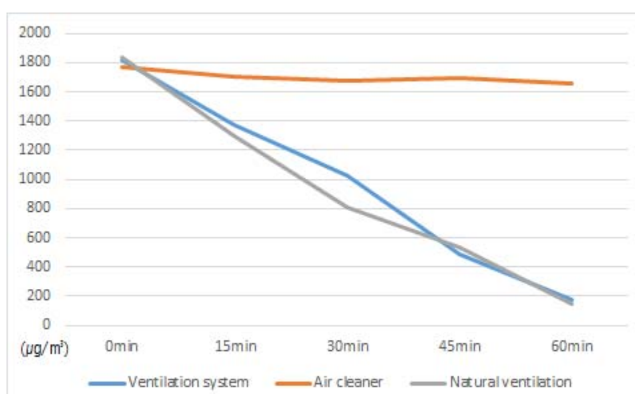

Figure 6: Decrease of TVOCs by ventilation condition

4.3. Formaldehyde

Formaldehyde at nail institute showed 199.35 ± 121.64 ㎍/㎥ before ventilation and 143.43 ± 119.86 ㎍/㎥ after ventilation. The air conditioner was operated at 187.65 ± 96.33 ㎍/㎥ before operation and 180.67 ± 91.52 ㎍/㎥ after operation. The ventilation system was operated at 195.98 ± 119.72 ㎍/㎥ before ventilation operation and 159.58 ± 105.49 ㎍/㎥, an average of about 21%.

Formaldehyde in the experimental space was 110.70 ㎍/㎥ after 15 minutes, 69.75 ㎍/㎥ after 30 minutes, 40.77 ㎍/㎥ after 45 minutes, and 12.22 after 60 minutes at 169.36 ㎍/㎥. The concentration of air was 159.45 ㎍/㎥ at the time of 0 minute, 160.97 ㎍/㎥ after 15 minutes, 157.58 ㎍/㎥ after 30 minutes, 152.5 ㎍/㎥ after 45 minutes, and 154.19 ㎍/㎥ after 60 minutes. At the operation of the apparatus, the concentrations were 173.17 ㎍/㎥ at the time of 0 minute, 138.56 ㎍/㎥ at 15 minutes, 121.21 ㎍/㎥ at 30 minutes, 65.8 ㎍/㎥ at 45 minutes and 36.36 ㎍/㎥ at 60 minutes. At this time, the air volume of natural ventilation was 192 ± 86.46 ㎥/h in nail work space and 396.6 ± 233.13 ㎥/h in experimental space.

As a result, the natural ventilation and ventilation system showed a similar tendency to decrease by 80~100% after 60 minutes ventilation, and the decreasing trend by ventilation condition is shown in Figure 7. Formaldehyde declined more slowly than TVOCs, but decreased rapidly in ventilation and natural ventilation, and air purifiers showed almost the same tendency as TVOCs.

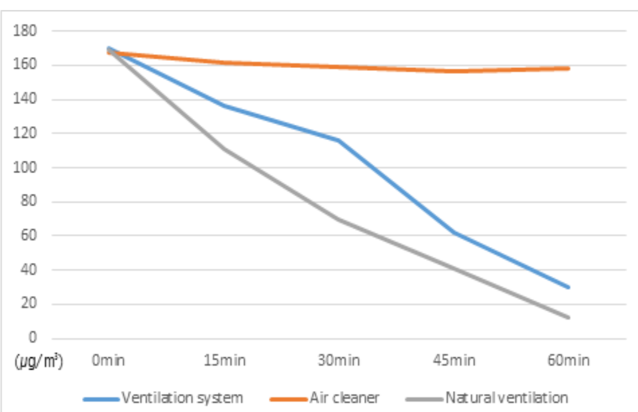

Figure 7: Decrease of formaldehyde by ventilation condition

4.4. Number of ventilation and ventilation in natural ventilation

4.4.1. Amount of ventilation

The wind speeds of the nail schools were 0.17 ± 0.075 m/s, 0.09 ± 0.014 m/s and 0.24 ± 0.021 m/s, respectively. The airflow rates were 48.96 ㎥/h, 25.92 ㎥/h and 69.12 ㎥/h respectively. In the experiment space, the wind speed for each cycle was 0.13 ± 0.012 m/s and 0.11 ± 0.010 m/s, 0.08 ± 0.008 m/s, respectively. The mean air velocity was 33.6 ㎥/h for 30 minutes and 67.2 ㎥/h for 30 minutes, 45 minutes, 100.8 ㎥/h, and 60 minutes 134.4 ㎥/h, respectively. The airflow and TVOCs concentrations are shown in Table 5~7. In the case of natural ventilation, the wind speed was not constant and the difference in the amount of pollutant reduction according to the air volume was compared. Formaldehyde was also measured in the ventilation of the same conditions and the results are shown in Table 5. As a result of comparison of measurement data, natural ventilation shows lower removal efficiency than 1 or 2 times of high air flow rate when the air flow rate is low like the third time result. It is considered that the natural ventilation is affected by the external wind speed, and the flow volume is influenced. In other words, natural ventilation which does not supply enough air volume is considered to be inefficient.

4.4.2. Number of ventilation

Table 5~7 shows the comparison of the number of ventilation by comparing the volume of ventilation in natural ventilation and the volume of ventilation in ventilation system. According to the decrease amount of pollutants according to the number of times of ventilation, most pollutants were removed when the minimum number of times of ventilation was 1.2 times.

Basically, PM-10, TVOCs and formaldehyde concentration in the air can be diluted by ventilation. Several previous researchs showed a significant negative correlation between indoor formaldehyde concentration and ventilation rate(Nirlo et al., 2014; Hult et al., 2015). However, disadvantages of ventilation as a decontamination method include, a lack of control over fresh air volume, unwanted outdoor contaminants, and increased air conditioning load, resulting in restrictive use of ventilation as a control method(ZHU, LV, & Yang, 2019).

Table 5: Comparison of TVOCs concentration in natural ventilation (Unit, Capacity ㎥, Compose ㎍/㎥)

Division	15 min		30 min		45 min		60 min	
	Capacity	Compose	Capacity	Compose	Capacity	Compose	Capacity	Compose
1st test (Wind Speed : 0.13 m/s)	40.95	1187.98	81.9	584.72	122.85	309.30	163.8	7.760
2nd test (Wind Speed : 0.11 m/s)	34.65	1017.89	69.3	521.59	103.95	185.61	138.6	7.80
3rd test (Wind Speed : 0.08 m/s)	25.2	1703.31	50.4	1314.77	75.6	1096.15	100.8	436.22

Table 6: Comparison of Formaldehyde concentration in natural ventilation (Unit, Capacity ㎥, Compose ㎍/㎥)

Division	15 min		30 min		45 min		60 min	
	Capacity	Compose	Capacity	Compose	Capacity	Compose	Capacity	Compose
1st test (Wind Speed : 0.13 m/s)	40.95	100.72	81.9	51.03	122.85	14.72	163.8	0.30
2nd test (Wind Speed : 0.11 m/s)	34.65	89.38	69.3	50.85	103.95	17.38	138.6	N.D
3rd test (Wind Speed : 0.08 m/s)	25.2	141.99	50.4	107.36	75.6	90.22	100.8	36.36

Table 7: Number of ventilation (Unit, Capacity ㎥)

Division	15 min		30 min		45 min		60 min	
	Capacity	Ventilation No.	Capacity	Ventilation No.	Capacity	Ventilation No.	Capacity	Ventilation No.
1st test (Wind Speed : 0.13 m/s)	40.95	0.42	81.9	0.85	122.85	1.27	163.8	1.70
2nd test (Wind Speed : 0.11 m/s)	34.65	0.36	69.3	0.72	103.95	1.08	138.6	1.44
3rd test (Wind Speed : 0.08 m/s)	25.2	0.26	50.4	0.52	75.6	0.78	100.8	1.05

5. Conclusion and Implications

Hair and nail salons offer a wide range of services including manicures, pedicures, applying artificial nails, eyebrow/waxing services, and hair styling/coloring, and the products and techniques used for salon services can put both the salon technicians and clients at risk of exposure to hazardous chemicals(Milich, Shendell, & Graber, 2017). This research tested the efficiency of economical air purification systems designed for indoor environments. Each system was tested for removal efficiency of PM-10, TVOCs and formaldehyde.

The concentrations of fine dust in the nail salon were not high enough to be detrimental, but TVOCs and formaldehyde exceeded the recommended indoor air quality standards. In this study, experiments were conducted to regulate pollutants by reproducing the nail work. Experimental results show that the removal of TVOCs and formaldehyde, except fine dust, has higher removal efficiency than natural air ventilation and mechanical ventilation system. Also, natural ventilation is about 5~10% more efficient than mechanical ventilation. In the comparative evaluation study between natural ventilation and mechanical ventilation in consideration of actual indoor air environment, natural ventilation is difficult to maintain continuously good indoor ventilation, but natural ventilation is better than mechanical ventilation through mechanical equipment in relation to the costs and sound. However, the natural ventilation is influenced by the design of the building and the external air volume, and it is difficult to achieve a certain ventilation efficiency.

In this experimental condition, the ventilation amount was measured as 192 ± 86.46 ㎥/h in the nail work space and 134.4 ± 31.70 ㎥/h in the experimental space. In actual measurement results, there was a difference in the reduction rate of pollutants when the wind speed was low (0.09 m/s for nail work and 0.08 m/s for work space). This result shows that natural ventilation alone has difficulties in maintaining a certain amount of required ventilation. Mechanical ventilation and natural ventilation showed a similar pattern of pollutant removal efficiency except fine dust. In the case of fine dust, the efficiency of reduction is reduced due to the inflow of fine dust contained in the outside air during mechanical ventilation and natural ventilation. But, it is considered that the air purifier ventilates the outside air through the filter to remove the fine dust when the outside air is introduced. The air purifier showed a slight tendency to remove TVOCs and formaldehyde. This is because the air purifier does not have the function of removing TVOCs and formaldehyde during the filter function while circulating the air through the filter by circulating the air without introducing outside air or exhausting the inside air.

Since there was no additional occurrence of harmful substances after the occurrence, it is expected that the levels of noxious substances occurring in actual nail work space will be higher. This means that the harmful substances mentioned above are exposed for a short time in the case of the customer, but it is highly likely that the worker is continuously exposed to the worker and it is necessary to present an appropriate ventilation method in order to minimize the exposure of the workers.

Based on the results of this study, we propose a proper ventilation method for nail work space as follows.

1) It is not high pollution degree of outdoor air (use of meteorological information such as fine dust and ozone). If air temperature is high and air conditioning and heating is not operated, natural ventilation should be performed.

2) In consideration of the size of the work space, a ventilation system having a processing capacity capable of satisfying the minimum number of times of ventilation 1.2 times per 60 minutes should be provided to create an environment in which natural ventilation is not suitable.

3) Continue to operate during operation. Keep working for at least 60 minutes from the end of the work to remove pollutants and minimize workers exposure to pollutants.

In this study, we tried to make nail worker aware of their harmful environment and to improve the exposure environment of harmful substances through the proposed ventilation method. In order to improve the exposure environment, it is important to install a ventilator, but there are many nail shops that do not have a ventilator because the ventilator is not systematically installed. If institutional legislation is prepared and guidelines for ventilation are provided, it will be possible to improve the worker's exposure environment.

References

Aaron, L., Megan, H., Feng, X., Janice, T., Arsineh, H., & Lupita, D. M. (2019). Occupational exposure to volatile organic compounds and health risks in Colorado nail salons. *Environmental Pollution, 249*, 518-526.

Alaves, V. M., Sleeventilationth, D. K., Thiese, M. S., & Larson, R. R. (2013). Characterization of indoor air contaminants in a randomly selected set of commercial nail salons in Salt Lake County, Utah, USA. *International Journal of Environmental Health Research, 23*(5), 419-433.

Barnes, T., & Enk. D. (2019). Ventilation for low dissipated energy achieved using flow control during both inspiration and expiration. *Trends in Anaesthesia and Critical Care, 24,* 5-12.

Bayram, B., & Şanci, E. (2019). Invasive mechanical ventilation in the emergency department. *Turkish Journal of Emergency Medicine, 19,* 43–52.

Ciuzas, D., Prasauskas, T., Krugly, E., Jurelionis, A., Seduikyte, L., & Martuzevicius, D. (2016). Indoor Air Quality Management by Combined Ventilation and Air Cleaning: An Experimental Study. *Aerosol and Air Quality Research, 16,* 2550–2559.

Colman Lerner, J. E., Sanchez, E. Y., Sambeth, J. E., & Porta, A. A. (2012). Characterization and health risk assessment of VOCs in occupational environments in Buenos Aires, Argentina. *Atmospheric Environment, 55,* 440-447.

Francisco, P. W., Jacobs, D. E., Targos, L., Dixon, S. L., Breysse, J., Rose, W., & Cali, S. (2016). Ventilation, indoor air quality, and health in homes undergoing weatherization. *Indoor Air, 27*(2), 463-477.

Hou, C., Hou, J., Kang, Q., Meng, X., Wei, D., Liu, Z., & Zhang, L. (2018). Research on urban park design combined with the urban ventilation system. *Energy Procedia, 152,* 1133–1138.

Hult, E. L., Willem, H., Price, P. N., Hotchi, T., Russell, M. L., & Singer, B. C. (2015). Formaldehyde and acetaldehyde exposure mitigation in US residences: in-home measurements of ventilation control and source control. *Indoor Air, 25(2015),* 523-535.

Jung, M. H., & Moo, J. S. (2018). A Study on the Effect of Beauty Service of the Elderly on Successful Ageing: Focused on Mediated Effect of Self-esteem. *Journal of Asian Finance, Economics and Business, 5(4),* 213-223.

Kim, U. J., Wang, Y., Li, W., & Kannan, K. (2019). Occurrence of and human exposure to organophosphate flame retardants/plasticizers in indoor air and dust from various microenvironments in the United States. *Environment International, 125,* 342–349.

Lamplugh, A., Harries, M., Xiang, F., Trinh, J., Hecobian, A., & Montoya, L. (2019). Occupational exposure to volatile organic compounds and health risks in Colorado nail salons. *Environmental Pollution, 249, June,* 518-526.

Lexuan, Z., Stuart, B., & Chad, W. M. (2019). VOC sources and exposures in nail salons: a pilot study in Michigan, USA. *International Archives of Occupational and Environmental Health, 92*(1), 141-153.

Lucattini, L., Poma, G., Covaci, A., Boer, J., Lamoree, M. H., & Leonards, P. G. (2018). A review of semi-volatile organic compounds (SVOCs) in the indoor environment: occurrence in consumer products, indoor air and dust. *Chemosphere, 201*(2018), 466-482.

Milich, L. J., Shendell, D. G., Graber, J. M. (2017). Safety and health risk perceptions: A cross-sectional study of New Jersey hair and nail salon clients. *Journal of Chemical Health and Safety, 24(6),* 7-14.

Munguia, N., Ozuna, G., Giannetti, F. B., & Velazquez, L. (2016). A more sustainable nail care service. *Journal of Cleaner Production, 133(1),* 803-811.

Muhamad-Darus, F., Zain-Ahmed, A., & Latif. M. (2016). Preliminary Assessment of Indoor Air Quality in Terrace Houses. *Health and the Environment Journal, 2(2),* 8-14.

Na, K. H., Son, J. S., Sung, K. J., & Jang, Y. K. (2005). Comparative Efficiency Evaluation of Air Cleaners for Improving Indoor Air Quality. *Journal of Environmental Impact Assessment, 14*(3), 109-115.

Nirlo, E. L., Crain, N., Corsi, R. L., & Siegel, J. A. (2014). Volatile organic compounds in fourteen U.S. retail stores. *Indoor Air, 24,* 484-494.

Pavilonis, B., Roelofs, C., & Blair, C. (2018). Assessing indoor air quality in New York City nail salons. *Journal of Occupational and Environmental Hygiene, 15*(5), 422-429.

Shiue, A., Hu, S-C., Tseng, C-H., Kuo, E-H., Liu, C-Y., Hou, C-T., & Yu, T. (2019). Verification of air cleaner on-site modeling for PM2.5 and TVOC purification in a full-scale indoor air quality laboratory. *Atmospheric Pollution Research, 10(1),* 209-218.

Wang, S. W., Mohammed, A. M., Chu, P. L., & Lin, H. C. (2009). Characterizing relationships between personal exposures to VOCs and socioeconomic, demographic, behavioral variables. *Atmospheric Environment, 43(14),* 2296-2302.

Zheng, X., Qiao, L., Covaci, A., Sun, R., Guo, H., Zheng, J., Luo, X., Xie, Q., Mai, B., (2017). Brominated and phosphateflame retardants (FRs) in indoor dust from different mi-croenvironments: implications for human exposure via dust ingestion and dermalcontact. *Chemosphere, 184,* 185–191.

Zhu, X., Lv, M., & Yang, X. (2019). A test-based method for estimating the service life of adsorptive portable air cleaners in removing indoor formaldehyde. *Building and Environment, 154,* 89-96.

Zhuang, C., Wang, S., & Tang, R. (2019)., Optimal Design of Multi-zone Air-conditioning Systems for Buildings Requiring Strict Humidity Control. *Energy Procedia, 158,* 3202–3207.