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Influence of Interior Decorations on Indoor Air Quality in Fitness Centers †

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Abstract: In order to understand the air quality of fitness centers according to the Environmental Protection Administration's "Indoor Air Quality Standards", as well as to discuss how fitness center air-conditioning ventilation systems can effectively remove indoor air pollutants, this study focused on six Taichung fitness centers in a seven-sample air quality investigation, employing handheld precision instruments in space air testing and using linear regression analyses of the concentrations of indoor chemical pollutants, including factors such as temperature, relative humidity, CO_2, O_3, CO, CH_2O, TVOC, PM2.5, and PM10. The results of this research are as follows: (1) Quantity of indoor decorations: The decorative materials used in each of the sample spaces and their sources are not the same. Even with the same quantity of decorations, the concentrations of CH_2O and total volatile organic compounds (TVOCs) that escaped into the atmosphere were different across the samples, leading to a low correlation (R = 0.0316, R = −0.0976). Our findings on the influence of the fitness center's establishment date on the concentrations of formaldehyde (CH_2O) and total volatile organic compounds (TVOCs) that escaped into the indoor air indicate that this correlation is low and insignificant (R = −0.3598, R = −0.5523), but show that the indoor concentration of formaldehyde decreases with time. (2) Occupants' indoor activities: The CO_2 concentration generated by the static and dynamic activities of indoor occupants is not reflected in real time but will gradually accumulate, resulting in a moderate to low and insignificant correlation between the number of active occupants and the level of CO_2 (R = 0.4343). (3) The PM2.5 and PM10 sources of suspended particles are not only related to the external air and interior decoration materials, but also to coarse surfaces, which can easily attract dust accumulation. Therefore, materials made from fabric and artificial turf should be reduced in order to reduce dust accumulating on the materials' surfaces.

Keywords: indoor air quality; fitness center; ventilation; interior decorators

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1. Background and Purposes

The prevalence of national sports in Taiwan has influenced the increasing emergence of fitness centers in recent years. Expectedly, people have a preference for fitness centers that are convenient and meet their fitness/exercise/health requirements. To reduce the impact of the heavy weight of fitness center equipment on floors, many shock-absorbent mats are usually laid on the floors of fitness centers. Cabinets and walls also have many decorative materials on them. However, these interior decoration materials usually contain formaldehyde and other volatile organic matters. Hence, excessive decoration and improper construction methods in fitness centers lead to increased health risks and the possibility of chemical gas emissions. Moreover, the combination of closed interior spaces and large amounts of carbon dioxide produced after exercise can lead to the accumulation of indoor pollutants [1].

This study aimed to investigate the influence of decoration and usage patterns on indoor air quality in emerging fitness centers. The indoor air quality of six private fitness centers was measured in order to discuss the influence of indoor users, decorations, and air exchange rates on their indoor air quality. This study measured the air quality concentrations of all exercise periods to check whether they met the standards set by the Environmental Protection Administration and to establish their correlation with the measured air pollutant concentrations [2]. It also discusses the relationship between indoor air quality and various factors. The air exchange rates of the spaces that would meet the carbon dioxide concentration standard set by the Environmental Protection Administration were estimated using the mass balance equation, and are provided here for future design organizations or owners to estimate the pollution concentrations of their spaces in advance, so as to make provisions for good and healthy indoor air quality in these spaces. The purposes of this study are as follows:

(1) to investigate the influence of people's activities on the indoor air quality in fitness centers;
(2) to investigate the influence of interior decorations on the indoor air quality in fitness centers;
(3) to understand the rationality behind the air conditioning mechanisms currently operating in fitness centers;
(4) to evaluate the fitness centers' ventilation and propose the best operative method of ventilation according to indoor users' activities.

2. Theories and Methods

This study investigated the indoor air quality of fitness centers, mainly through onsite diachronic monitoring, supplemented by manual records of the number of indoor occupants. It focused on recording and discussing the indoor air quality in fitness centers, so as to understand the influence of indoor space utilization and indoor decorations on indoor air quality. This study can serve as a reference for important decisions on indoor air quality in the future.

2.1. Theory Regarding the Concentration of Carbon Dioxide (CO_2) Produced via the Metabolism of Indoor Occupants

The relationship between indoor air quality and the density of indoor occupants and the resulting different indoor air mixing efficiencies can be estimated using the calculation method of the "pollutant mass balance model" under the condition of an existing legal standard for the ventilation of an area [3–5]. This study explored the activities of dynamic and static people indoors, so the equation was modified as follows (Equation (1)):

$$C_i = C_o + \frac{S_i \times \left(met_{st} \times n + met_{dy} \times n\right) \times DF}{K \times Q_0} \quad (1)$$

Ci: indoor CO_2 concentration (ppm)

Co: outdoor CO_2 concentration (ppm)

Si: when the human metabolic rate reached 1 met, the amount of carbon dioxide produced was assumed as a fixed value of 21.6 (m^3/s)

met: metabolic equivalence, which was assumed as 1.2 for static people (st), and 6.0 for dynamic people (¬dy)

n: the number of indoor occupants

DF: people flow rate; the ratio of the maximum number of people in a day to the total number of people on that day for each sample

K: air mixing (0.5)

Q_0: external air volume (m^3/s)

2.2. Theory Regarding Indoor Ventilation

As an empirical coefficient, the air exchange rate is related to not only the nature of air-conditioning in the rooms but also many other factors, such as the room's size, height, location, and mode of air supply, as well as the degree of indoor air deterioration. The air exchange rate per unit hour was estimated using the ACH because it is related to the indoor pollution concentrations, so as to estimate the air exchange rate required to achieve a good air quality in each of the sample spaces (Equation (2)) [5], and serve as reference for owners and design organizations.

$$ACH = Q \times 60/V \quad (2)$$

Q: air flow (m^3/h)
V: indoor volume (m^3)

2.3. Defining the Quantity of Decorations

The "decoration quantity" of each space was measured according to the ISO 16000 standard and then defined based on the "Green Building Evaluation Manual—Basic Version (2015 edition)" (p. 100–104). Walls and ceilings decorated simply by painting, ceilings decorated with simple flat panels under fire-extinguishing pipelines, or ceilings decorated with simple lighting systems specified in the decoration quantity of a sample's basic structure were excluded from the decoration area in this study. Only the decoration area outside of that specified in the decoration quantity of each sample's basic structure was included in this study. However, among the study samples, only the ceiling of one sample was equipped with flat panels. Hence, this flat panel ceiling was included in the decoration calculation herein (Equation (3)) (Figure 1).

$$LF = \sum A_i/V \quad (3)$$

A_i: area of all indoor decoration materials and furniture (m^2)
V: indoor volume (m^3)

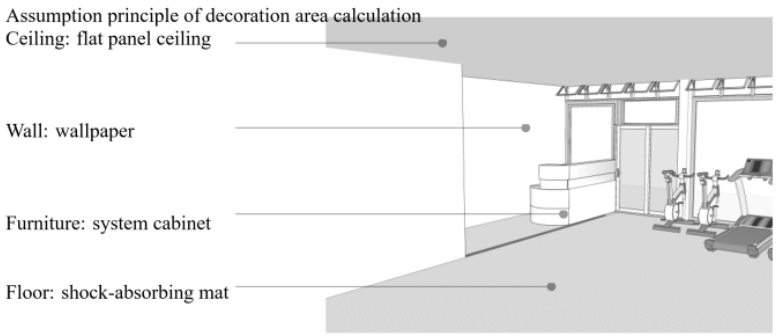


Figure 1. Calculation principle of the decoration area.

3. Measurement Process

3.1. Description of Measurement Method

In this study, portable precision instruments were used for sampling to investigate indoor air quality. These precision instruments can simultaneously detect humidity and six other items specified by the Environmental Protection Administration. They also display all detected data in real time. The concentrations of indoor pollutants specified by the Environmental Protection Administration, including CO, O_3, CH_2O, CO_2, VOC, PM10, and PM2.5, were measured, respectively. The instrument's specifications and accuracy are shown in Table 1. The detection points were set according to the "measures for the management of indoor air quality detection and measurement" of the Environmental Protection Administration. The instruments were placed in areas which could reflect

the main of users' activities within their detection range and which tried to minimize the instruments' influence on the users within the tested area. They were positioned at a distance of at least 0.5 m from indoor hardware structures and facilities and at least 3 m from doors or elevators. The sufficiency of the sample size to represent the level of indoor air pollution in the detected area depended on the changes in the concentration levels of all pollutants. The floor area of each of the seven samples in this study was less than 500 m^2, and according to regulations, at least one sampling point should be selected for each sample. Because our instruments were limited and there was only one instrument of each kind, it was impossible to complete sampling in one day. Therefore, sampling was carried out separately, and the concentration levels were measured within the same week. The measurements were made during business hours, and this lasted for 3–10 h.

Table 1. Ranges and accuracy levels of the measuring instruments.

Measuring Instruments	Measured Gas	Measurement Range	Location
Portable air quality tester YesAir Datalog Session YA1807K00903	CO	0–50.00 ppm	Indoor
	O_3	0–01.00 ppm	
	CH_2O	0–05.00 ppm	
	CO_2	0–9999 ppm	
	VOC	0–30.00 ppm	
Direct-reading instrument for measuring suspended particles Aerocet- 831 Aerosol	Suspended particle size PM_1, $PM_{2.5}$, PM_4, PM_{10}	0–1000 $\mu g/m^3$	Indoor
Carbon dioxide tester TES-1370CO/CO_2	CO_2	0–6000 ppm	Outdoor

3.2. Basic Introduction of All Sample Spaces

According to the field investigation, the average area of all samples was 160 m^2. Their decoration situations were as follows: their walls and ceilings were mainly painted; their floors were mainly laid with shock-absorbent mats and artificial turf; their quantity of decorations varied from 0.03 to 0.42 m^2/m^3; their establishment dates were all within the last three years; and the measurement time was between 3 and 10 h (Table 2).

Table 2. Sample spaces overview.

Sample Code	Establishment Date (year)	Construction Area (m^2)	Interior Volume (m^3)	Decoration Rate (m^2/m^3)	Overview of Interior Decoration	Measurement Time
FL5	2017	198.35	595.05	0.42	Ceiling: basic paint Wall: basic paint, wall paper Floor: artificial turf, shock-absorbing mats	10:00–22:00
CY	2005	72.56	277.11	0.26	Ceiling: light steel joist ceiling Wall: basic paint, some wooden sideboards Floor: plastic flooring	17:00–20:00
FL4	2017	88.30	264.90	0.40	Ceiling: basic paint Wall: basic paint Floor: artificial turf, plastic flooring	10:00–12:00 14:00–15:00 19:00–20:00
IW	2018	145.00	580.00	0.28	Ceiling: basic paint Wall: basic paint, wall paper Floor: shock-absorbing mats	14:30–22:00

Table 2. *Cont.*

Sample Code	Establishment Date (year)	Construction Area (m^2)	Interior Volume (m^3)	Decoration Rate (m^2/m^3)	Overview of Interior Decoration	Measurement Time
HU	2019	294.31	1177.24	0.25	Ceiling: basic paint Wall: basic paint Floor: artificial turf, shock-absorbing mats	10:00–22:00
EF	2017	110.00	308.00	0.03	Ceiling: basic paint Wall: basic paint, some cabinets Floor: plastic flooring	10:00–12:00 14:00–20:00
PS	2018	211.80	868.38	0.24	Ceiling: basic paint Wall: basic paint Floor: shock-absorbing mats	10:00–12:30 14:30–21:00

3.3. Current Indoor Air Quality of All Samples

This study investigated indoor air quality from both physical and chemical perspectives by referring to the concentration levels specified in the 2012 "Indoor Air Quality Standards" from the Environmental Protection Administration. The diachronic measurement results are shown in Table 3. The average CO_2 concentration in CY was 2209 ppm, which was the highest, while the average CO_2 concentration in IW was 1492 ppm; both of these were higher than the standard of 1000 ppm recommended by the Environmental Protection Administration. The reasons for these excessive CO_2 concentrations were imperfect indoor ventilation and a large number of indoor occupants. The average concentrations of CO and O_3 in all sample areas were lower than the standards of 9.00 ppm and 0.06 ppm, respectively. The average CH_2O concentrations in all of the sample places were higher than the standard of 0.08 ppm, and the average VOC concentrations in CY, FL4, and IW were higher than the standard of 0.56 ppm, mainly because their decoration materials contained CH_2O and VOC and their indoor ventilation was perfect. The average concentrations of PM2.5 and PM10 in FL5, FL4, and EF were higher than the standards of 35 $\mu g/m^3$ and 75 $\mu g/m^3$. These excessive PM2.5 and PM10 concentrations in FL5 and FL4 were mainly attributed to improper use of interior floor materials and inadequate cleaning, and the EF concentration was mainly due to the external air.

Table 3. Diachronic measurement of the current indoor air quality of each sample.

Samples	CO ppm	O_3 ppm	CH_2O ppm	VOC ppm	$PM_{2.5}$ $\mu g/m^3$	PM_{10} $\mu g/m^3$
Standards	9.00	0.06	0.08	0.56	35	75
FL5	0.56	0	0.57 *	0.05	55.3 *	102.6 *
CY	3.51	0	1.36 *	0.65 *	6.2	26.0
FL4	0.03	0	0.51 *	0.66 *	35.9 *	82.3 *
IW	2.41	0	0.91 *	0.57 *	8.6	28.2
HU	0.79	0	0.62 *	0.20	21.2	34.6
EF	0.41	0	0.56 *	0.17	95.1 *	188.7 *
PS	0.07	0	0.37 *	0.09	25.0	61.6

Table 3. *Cont.*

Samples	CO_2 ppm	Number of Static People	Number of Dynamic People	Decoration Rate m^2/m^3	Indoor People Flow Rate
Standards	1000	-	-	-	-
FL5	776	6	6	0.42	0.63
CY	2209 *	3	16	0.26	1.00
FL4	519	1	4	0.40	0.26
IW	1492 *	6	11	0.28	0.89
HU	951	0	11	0.25	0.57
EF	563	10	8	0.03	0.94
PS	573	3	8	0.24	0.57

* indicates that the result is higher than the standard recommended by the Environmental Protection Administration.

3.4. Relationship between the Indoor Air Quality and Various Factors

This section discusses the CO_2 concentration of IW and the suspended particles of FL5, which both exceeded the standards of the Environmental Protection Administration. This discussion is based on the data presented in Table 3. According to our diachronic measurements, the CO concentrations in IW and EF5 were lower than the Taiwan Environmental Protection Administration standard of 9 ppm.

- Carbon dioxide (CO_2)

The number of users in a space influences its CO_2 concentration. In the FL5, CY, IW, and HU sample spaces, after 17:00, the CO_2 concentration exceeded the Environmental Protection Administration standard of 1000 ppm due to the increasing number of users after that time. Also, due to the awful indoor ventilation in the CY sample space, the concentration accumulated to 3680 ppm within a short time. In the other sample spaces (i.e., FL5, IW, and HU), due to the large number of people there at night and poor ventilation, the CO_2 accumulated and its concentration exceeded the standard (Figure 2).

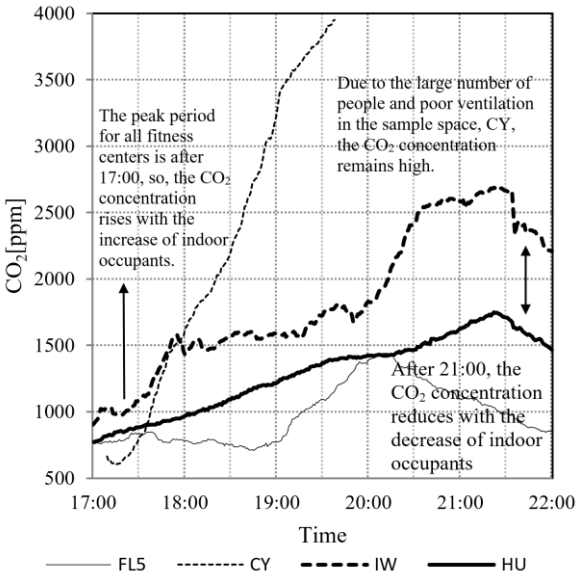


Figure 2. Diachronic monitoring of variations in the CO_2 concentration across the samples.

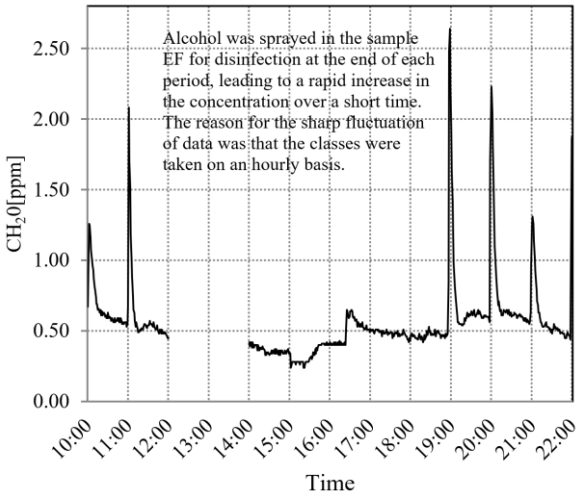


Figure 3. Diachronic monitoring of variations in the formaldehyde (CH_2O) concentration across the samples.

- Formaldehyde (CH_2O)

The CH_2O concentrations in all samples exceeded the standard of 0.08 ppm given by the Environmental Protection Administration, due to CH_2O in the decoration materials. The tested samples were all new fitness centers established within the last four years; therefore, the CH_2O in these spaces had not yet been dispersed, thus resulting in excessive CH_2O concentrations. For example, in sample EF (Figure 3), not only did the building materials release formaldehyde, but also, spray cleaners caused the CH_2O concentration to rise sharply within a short time. The reason for this sharp fluctuations of data in the EF sample within certain periods was that this fitness center's classes were taken on an hourly basis, and students entered and leaved the space on the hour.

- Total volatile organic compounds (TVOCs)

The total volatile organic compounds (TVOCs) were mainly found in building materials, furniture, and cleaning materials. Their concentrations in the CY and IW samples occasionally exceeded the Environmental Protection Administration standard of 0.56 ppm. The air conditioning in IW kept this sample under a constant temperature and humidity, but the total volatile organic compounds (TVOCs) in this space increased gradually, because the humidity rose slightly with increases in the number of indoor occupants (Figure 4). As mentioned in the literature review in Section 2, the diffusion coefficient of total volatile organic compounds increases under high humidity (Kun-Chih Huang: 'A study on the influence of indoor thermal environment variation on adsorption and reduction of formaldehyde from building materials', 2011). In sample CY, the awful indoor ventilation led to a serious accumulation of indoor pollutants.

- Suspended particles (PM2.5, PM10)

The suspended particles (PM2.5, PM10) mainly arose from the accumulation of indoor pollutants and the external air. The suspended particle (PM2.5, PM10) concentrations in the FL5, FL4, and EF samples exceeded the Environmental Protection Administration standards of 35 $\mu g/m^3$ and 75 $\mu g/m^3$, respectively. The excessive suspended particle concentrations in samples FL5 and FL4 can be attributed to the improper use of indoor floor materials (plastic turf that is prone to dirt accumulation was used), which caused the pollutants to release dust as people moved around; the concentrations rose as the number of indoor users increased (Figures 5 and 6). The excessive suspended particle concentrations in sample EF can be attributed to the external air. This sample space was naturally ventilated all day long, leading to an excessive suspended particle (PM2.5, PM10) concentration, because the polluted outdoor air entered the room.

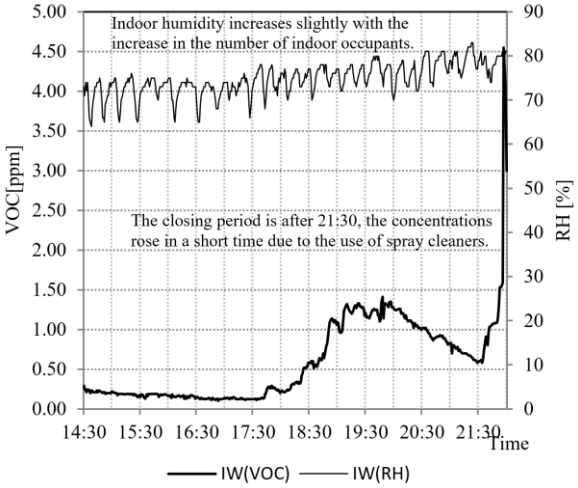


Figure 4. Diachronic monitoring of variations in the total volatile organic compound (TVOC) concentration and humidity (RH) in the IW sample.

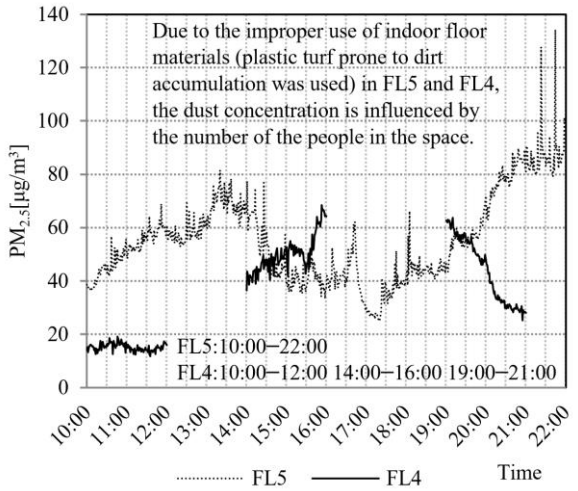


Figure 5. Diachronic monitoring of variations in the suspended particle (PM2.5) concentration across the FL5 and FL4 samples.

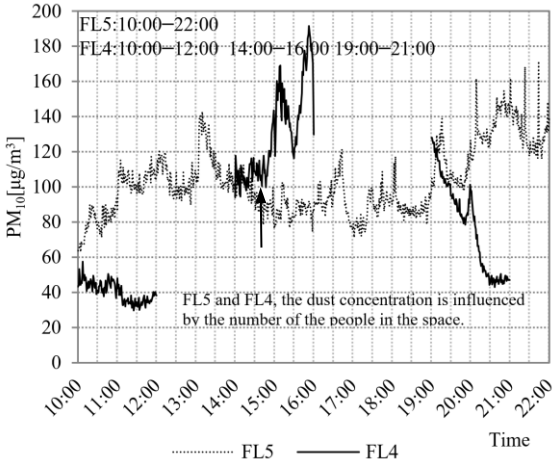


Figure 6. Diachronic monitoring of variations in the suspended particle (PM10) concentration across the FL5 and FL4 samples.

4. Analyses of the Measured Results

To understand the relationship between various indoor factors and the indoor air quality in fitness centers, our analyses involved a pairwise comparison with the factors identified in seven samples. This analysis was carried out to establish the correlations between indoor air quality and air pollutant concentrations and provide a basis for future design organizations or owners to estimate the pollution concentrations of their buildings in advance. The correlation analysis of various factors is shown in Table 4.

4.1. Summary of the Correlations between Various Pollutants and Indoor Air Quality

- Temperature (temp.): temperature was moderately correlated to various pollutant factors ($0.3 < R < 0.7$). Since the sample spaces were under constant temperature control via air conditioning systems, temperature was not the main factor influencing the pollution factors.
- Humidity (RH): humidity was moderately correlated to the VOC concentration ($0.3 < R < 0.7$), indicating that high humidity aids gas dispersion [6].
- CO: the indoor CO concentrations were lower than the corresponding Environmental Protection Administration standard, but the CH_2O, CO_2, and VOC were highly correlated ($R > 0.7$), indicating that they mutually influenced one another.
- O_3: the indoor O_3 concentrations were all 0 ppm, which did not correlate to any of the various pollutants.
- CO_2: due to the nature of air concentration accumulation, the CO_2 concentration generated through the activities of indoor occupants could not be measured in real time, resulting in a moderate correlation ($R = 0.4343$).
- Suspended particles: the suspended particles (PM2.5 and PM10) only had a moderate and positive correlation with the temperature ($0.3 < R < 0.7$), and had a low correlation with all other factors, indicating that external air mainly influenced the suspended particles.

Table 4. Results of the correlation (R) analysis for the concentrations of various factors in indoor air.

	Temp.	**RH**	**CO**	**O_3**	**CH_2O**	**CO_2**	**VOC**	**$PM_{2.5}$**	**PM_{10}**	**People**
Temp.	1.00	0.22	0.28	N/A	0.12	0.37	0.33	0.52	0.42	0.41
RH		1.00	0.19	N/A	0.16	0.21	0.37	0.22	0.21	0.29
CO			1.00	N/A	0.89	0.70	0.89	0.28	0.28	0.25
O_3				1.00	N/A	N/A	N/A	N/A	N/A	N/A
CH_2O					1.00	0.69	0.90	0.21	0.23	0.20
CO_2						1.00	0.62	0.41	0.39	0.43
VOC							1.00	0.33	0.29	0.22
$PM_{2.5}$								1.00	0.96	0.29
PM_{10}									1.00	0.26
People										1.00

4.2. Influence of Indoor Decorations on Indoor Air Quality

The CH_2O and VOC concentrations in the samples were different even when they had the same quantity of decorations, leading to a low correlation between the decoration quantity and the CH_2O and VOC concentrations ($R = 0.0316$, $R = -0.0976$) (Figures 7 and 8). The establishment date had a low and negative correlation with the CH_2O and VOC ($R = -003598$, $R = -0.5523$) (Figures 9 and 10); this is consistent with the concept that gas concentrations indoors decrease with time. Due to the awful environment in the CY sample space, the concentrations were several times higher than those of the other samples, so the CY data were excluded from this analysis.

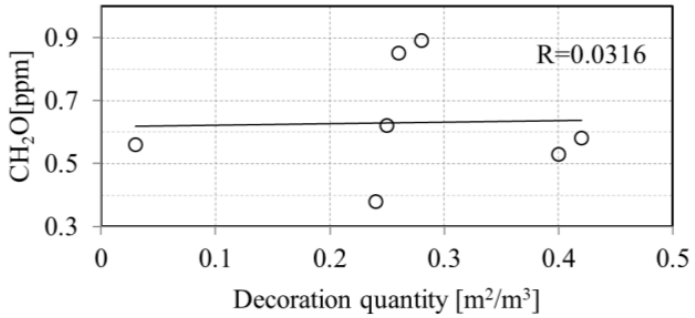


Figure 7. Correlation between the quantity of decorations and the CH_2O concentration.

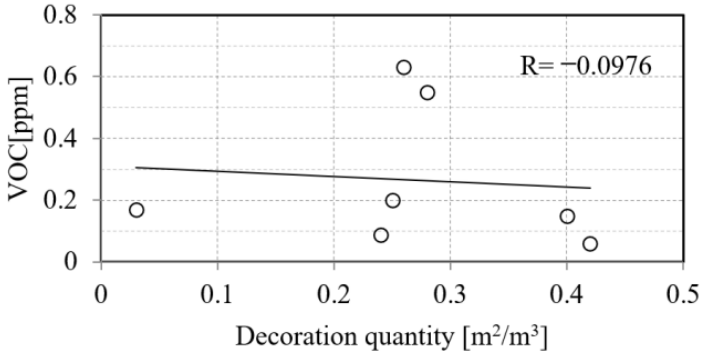


Figure 8. Correlation between the quantity of decorations and the VOC concentration.

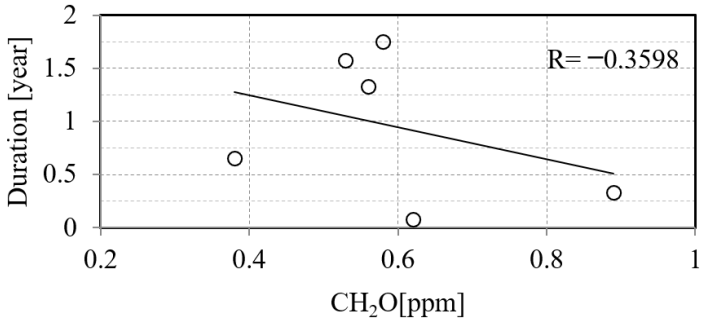


Figure 9. Correlation between the establishment date and the CH_2O concentration.

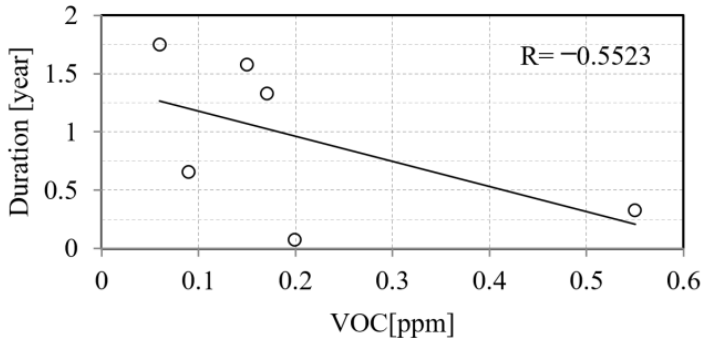


Figure 10. Correlation between the establishment date and the VOC concentration.

4.3. Air Exchange Volume Estimation for the Sample Spaces

Based on the measured data, the air exchange volume decreased during the periods when the average CO_2 concentrations in fitness centers exceeded the estimated standard. The reasons for these excess concentrations were the maximum number of indoor occupants allowable, and more importantly, the imperfect ventilation of the indoor air conditioning.

The air exchange volume during the periods when the concentrations exceeded the standard was modified and evaluated according to the calculation method of the "pollutant mass balance model" and the theory of indoor ventilation. The FL5 sample entered its peak period at 19:00, and its air exchange rate was only 0.79 h^{-1} at an indoor CO_2 concentration of 1104 ppm. To reduce the CO_2 concentration in FL5 to below the 1000 ppm standard set by the Environmental Protection Administration, the air exchange per hour (ACH) should be increased from 0.79 h^{-1} to 1.00 h^{-1}, which is equivalent to 53 min of continuous operation of an exhaust fan with an exhaust air rate of 680 m^3/h, so as to achieve good air quality. Due to the small space and large number of people, the indoor CO_2 concentration exceeded the standard when the CY sample opened at 17:00 and violently rose to 3680 ppm at 19:00, and the air exchange rate was only 0.34 h^{-1} at this concentration. To reduce the CO_2 concentration in CY to below the standard of 1000 ppm set by the Environmental Protection Administration, the ACH should be increased from 0.34 h^{-1} to 2.22 h^{-1}, as shown in Table 5, which is equivalent to 55 min of continuous operation of an exhaust fan with an exhaust air rate of 680 m^3/h, so as to achieve good air quality.

Table 5. Air exchange volume estimations before and after modification.

Samples	Indoor Volume (m^3)	Periods When Standards are Exceeded	Indoor CO_2 Concentration (ppm)	Outdoor CO_2 Concentration (ppm)	Dynamic and Static People	Original ACH (h^{-1})	Ideal ACH (h^{-1})
FL5	595.05	19:00–20:00	1104	612	14, 4	0.79	1.00
		20:00–21:00	1286	557	9, 3	0.24	0.40
CY	277.11	17:00–18:00	1003	547	12, 4	1.26	1.27
		18:00–19:00	2322	527	15, 4	0.47	1.78
		19:00–20:00	3680	514	19, 1	0.34	2.22
IW	580.00	17:00–18:00	1180	498	21, 8	0.89	1.21
		18:00–19:00	1544	504	9, 6	0.14	0.29
		19:00–20:00	1693	514	11, 3	0.13	0.31
		20:00–21:00	2330	505	15, 5	0.16	0.60
		21:00–22:00	2523	498	7, 7	0.05	0.22
HU	1177.24	18:00–19:00	1098	529	12, 0	0.14	0.17
		19:00–20:00	1350	526	8, 0	0.04	0.07
		20:00–21:00	1495	520	23, 0	0.30	0.61
		21:00–22:00	1638	524	24, 0	0.28	0.67

5. Conclusions

More and more people have a preference for fitness centers that are convenient and meet their fitness/exercise/health requirements. However, indoor fitness centers are often overdecorated with heavy sports activities and have an over-concentrated number of occupants, hence their concentrations of CO_2, CH_2O, and volatile organic compounds (VOCs) are high. Inadvertently, people will be affected by prolonged exposures to these poor quality environments even if they are in good health. This study examined the current air quality in Taiwan's fitness centers and proposes measures for the prevention of poor air quality and for proper operation management in such centers. These are to serve as references for owners and designers in the future, so that the concept of good and healthy air quality can be implemented and extended to all fields.

5.1. Influence of Indoor Decorations and Occupants' Activities on Fitness Center Air Quality

Indoor decoration quantity: The decoration materials used in all sample spaces and their sources are not the same. Even with the same decoration quantity, the concentrations

of CH_2O and total volatile organic compounds (TVOCs) that escaped into the atmosphere were different in each of the samples, leading to a low correlation (R = 0.0316, R = 0.0976). Our findings on the influence of the establishment date on the concentrations of CH_2O and total volatile organic compounds (TVOCs) that escaped into the indoor air indicate that the correlation is low and insignificant (R = 0.1968, R = 0.4429), but show that the indoor concentration decreases with time. Indoor occupants' activities: The CO_2 concentration generated via the static and dynamic activities of indoor occupants can not be reflected in real time but will gradually accumulate.

5.2. Indoor Ventilation Predictions and Improvements

Indoor ventilation: The indoor volume, number of indoor occupants, and the various factors causing indoor pollution were not the same in all fitness centers. In planning, designing, and selecting ventilation facilities, attention should be paid to decoration materials and the ventilation effects of facilities. The suspended particles we recorded were not only from the external air but also from interior decoration materials, and rough and uneven surfaces that easily attracted dust accumulation and pollution; therefore, materials made from fabric and artificial turf should be reduced in order to achieve less dust accumulation on material surfaces. While most of the tested sample spaces were equipped with air purifiers, the effects of these were insignificant. Due to the large areas of fitness centers, the air purifiers could not purify the indoor air effectively, resulting in the accumulation and high concentration of indoor pollutants. Indoor ventilation improvements: CO_2 was 60% correlated to indoor CH_2O and total volatile organic compounds (TVOCs) (R = 0.6856, R = 0.6156), 40% correlated to suspended particles (PM2.5, PM10) (R = 0.3924, R = 0.413), and 70% correlated to CO (R = 0.7045), indicating that CO_2 is highly correlated to various indoor air pollution indicators. By establishing real-time indoor CO_2 measurement systems, fitness centers can reduce their indoor concentrations of CO_2 and other pollutants with effective ventilation.

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References

1. Andrade, A. Indoor air quality of environments used for physical exercise and sports practice Systematic review. *J. Environ. Manag.* **2018**, *206*, 277–286. [CrossRef] [PubMed]
2. Cianfanelli, C. Environmental Quality in Sports Facilities: Perception and Indoor Air Quality. *J. Phys. Educ. Sports Manag.* **2016**, *3*, 57–77. [CrossRef]
3. *ANSI/ASHRAE Standard 62.2-2019*; Ventilation and Acceptable Indoor Air Quality in Residential Buildings. ASHARE: Peachtree Corners, GA, USA, 2019.
4. *ANSI/ASHRAE Standard 62.1-2022*; Ventilation and Acceptable Indoor Air Quality. ASHARE: Peachtree Corners, GA, USA, 2019.
5. Li, Y.-Y. *A Study on Indoor Air Quality Management Strategies in Office Space*; Department of Architecture, National Cheng Kung University: Tainan, Taiwan, 2004.
6. Huang, K.C. A study on the influence of indoor thermal environment variation on adsorption and reduction of formaldehyde from building materials. In Proceedings of the 23rd Second Architectural Research Achievement Presentation Conference, Tainan, Taiwan, November 2011.

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