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Indoor Air Quality Investigation and Analysis of a Multi-Purpose Building in Manila

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Abstract: Indoor air quality (IAQ) deals with the determination and management of the cleanliness and health and comfort characteristics of the air in human occupied enclosed spaces. In this descriptive-analytical study, IAQ parameters (CO_2, PM 2.5, PM 10, DBT, RH) in a multi-purpose building in Manila were characterized. There were 7 chosen areas, each having different functions – cafeteria, clinic, 3 offices, and 2 reception areas. Two sets of measurements were done: one for the dry season during the month of May 2018 and another one for the wet season from end of June 2018 to start of July 2018.The IAQ instruments utilized were AZ Instrument 77597 and IOM Sampler. In addition, a survey was performed on the occupants to gain subjective information on the said areas. After the investigation process, the data was compared to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards and analyzed statistically. The results show that in the test building, some areas have exceeded CO_2, PM 2.5, DBT, and RH levels set by ASHRAE. In the statistical tests, significant correlations were obtained between indoor CO_2 and number of occupants, indoor and outdoor CO_2, and PM 2.5 and PM 10. Comparisons of IAQ characteristics were also done between wet versus dry season and start-of-workday versus end-of-workday.

Key Words: Indoor Air Quality (IAQ); CO_2 level; Particulate Matter (PM); Air Conditioning

I. INTRODUCTION

1.1 Background of the Study

Indoor air quality (IAQ) affects the comfort and health and thus the productivity of occupants of enclosed spaces. According to the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE, 2016), there are two points to consider when defining the state of indoor air - one is the absence of "known contaminants at harmful concentrations" and two is the satisfaction level of "a substantial majority (80% or more) of the people exposed." ASHRAE Standards 62.1 and 55 are the governing guidelines for the first and second points respectively.

IAQ in the Philippines is a relatively new but expanding field. In a survey done by Anastacio et al (2011) of different local researches on this field, 17 studies were noted of which 7 studies involved IAQ in local transportation systems (i.e. buses), 6 were on IAQ in educational institutions, and 4 were on IAQ in commercial buildings.

In East and Southeast Asia, China, Japan, Hong Kong, Korea, Malaysia, and Singapore have already formulated their own IAQ standards on top of those established by ASHRAE and the World Health Organization (Abdul-Wahab et al., 2015). This is what the Philippines needs to do in the years to come, and this research is intended supplement the baseline data initiative by the Philippine Society for Ventilating, Air-conditioning, and Refrigerating Engineers, PSVARE (Zali et al 2015).

1.2 Statistical Studies

An IAQ study by Ponsoni and Raddi (2010) measured bacterial and fungal counts, DBT, RH, and CO_2 concentration in an office. Significant correlations related to this study were the CO_2 and number of occupants; RH and DBT, particles; and DBT and particles, number of occupants.

The study by Lazovic et al (2015) collected data on CO_2, DBT, and RH of schools in Serbia. The researchers found that CO_2 was increasing with number of occupants and as the day progressed meaning poor ventilation practices. They also determined the CO_2 levels were relatively higher during the colder phases of the year.

A study by Argunhan and Avci (2018) focused on 5 IAQ parameters in a university in Turkey. These are CO_2, DBT, RH, Radon, and 5 sizes of PM (PM 0.5, 1.0, 2.5, 5.0, 10). Their conclusions for the correlation test are as follows:

- Strong relationships
  - for number of occupants and indoor CO_2
  - for outdoor RH and indoor RH
  - Indoor PM parameters (ex. for indoor PM 2.5 and indoor PM 10)
- Medium relationships
  - for outdoor PM 10 and indoor PM 5
  - indoor DBT and indoor RH
  - outdoor DBT and indoor RH
- Weak relationships
  - for indoor DBT and indoor CO_2
  - for indoor DBT and indoor PM 10
- Very weak relationships
  - for number of occupants and indoor PM parameters (ex. for number of occupants and PM 2.5)

1.3. Seasonal Variations

Lawrence et al. (2017) measured the highest concentrations of CO and CO_2 during the winter, followed by the rainy season, and then the summer season in both urban and rural areas. For PM10 and PM2.5 in the urban areas, concentrations were lowest during the rainy season. However, for rural areas, it was lowest for the sunny season. The lesser concentrations of pollutants for the rainy season (except for CO and CO_2) was attributed to the wash out effect. Another study by Mathur et al. (2007) on suspended particulate matter (SPM) in kitchens similarly show a trend wherein the concentrations are highest during the winter season, then followed by rainy and then sunny. This is assumed to be caused by lack of proper of ventilation from closed windows during the winter and rainy season.

A study by Liu, Wang, Zhang, Hong, and Lin (2015) compared IAQ studies in two hospitals in China. From the comparison of data from the summer and winter seasons, they obtained significant relationships between relative humidity of the hospital areas and the climate. One hospital, which had an RH less than 20%, is in the cold portion of China where the outdoor RH is really low. Meanwhile, the other hospital, which had an RH between 20 and 50% came from a more humid climate along a river. These results obtained by Liu et al. (2015) just exhibited than indoor RH is directly related to outdoor RH.

1.4 Objectives of the Study

In the Philippines, no studies have been done so far on the seasonal variation of IAQ and thermal comfort conditions. These variations and the correlations determined should help in the design, monitoring and control of ventilation and air-conditioning systems.

Thus, in this study, while characterization of IAQ parameters (CO_2, CO, PM 2.5, PM 10, DBT, RH) are similarly done, as in most local and foreign studies, diurnal and seasonal data were collected in a multi-purpose building in Manila. In this building, 7 areas were chosen, each having different functions – cafeteria, clinic, 3 offices, and 2 reception areas. The intention is to measure diurnal and seasonal variations, and differences in IAQ and thermal comfort conditions with space utilization.

2. METHODOLOGY

To perform the investigative and analytical study, 7 areas of the building (cafeteria, clinic, office 1, office 2, office 3, reception area 1, reception area 2) were inspected and profiled individually.

The IAQ parameters were then monitored using AZ Instrument 77597 and IOM Sampler. The summary of the data collection schedule are presented in Table 1.

In the characterization of the various areas in terms of IAQ, the measurements were compared to American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) Standards 55 and 62.1. A survey, patterned after the United States Environmental Protection Agency and ASHRAE Standard 55, was used to identify the thermal environmental satisfaction and health of the occupants.

IAQ Measurements

This investigation measured IAQ-related parameters from 8 AM to 4 PM, give or take 30 minutes due to security reasons for the actual operation hours.

Table 1. Instruments used and frequency of measurement for each IAQ parameter

IAQ Parameter	Equipment	Duration of Measurement
CO_2 (indoor and outdoor)	AZ Instrument 77597	45 data points (per minute collection)
Temperature (DBT, WBT, DPT) (indoor and outdoor)	AZ Instrument 77597	45 data points (per minute collection)
RH (indoor and outdoor)	AZ Instrument 77597	45 data points (per minute collection)
PM 2.5 (indoor)	IOM Sampler	1 data collected for 30 minutes (followed by resting the device for 30 minutes)
PM 10 (indoor)	IOM Sampler	1 data collected for 30 minutes (followed by resting the device for 30 minutes)

3. RESULTS AND DISCUSSION

3.1 Comparison of IAQ Parameters to ASHRAE Standards

According to the ASHRAE standards, the following are the thresholds for the different IAQ parameters used in this study: 1000 ppm for CO_2; between 20 and 25.5°C for DBT; between 30 to 60% for RH; 3 mg/m^3 for PM 2.5; and 10 mg/m^3 for PM 10. A bulleted summary below gives the general assessment per subsection.

Cafeteria

CO_2 – exceeded during lunch time and during events
DBT – exceeded during first few hours of the morning
RH – exceeded majority of the day

Clinic

CO_2 – exceeded majority of the day
DBT – within range but sometimes exceeds
RH – within range

Offices

Office 1

CO_2 – exceeded standard as the day progressed; CO_2 during the dry season was greater than the wet season
DBT – within range
RH – continuously varies above and within maximum value

Office 2

CO_2 – dry season was within range; wet season exceeded standard near the end of the day; CO_2 during the dry season was greater than the wet season
DBT – within range
RH – within range

Office 3

CO_2 – within range
DBT – within range
RH – slightly exceeds standard during the afternoon

Reception Areas

Reception 1

CO_2 – within range
DBT – exceeded standard
RH – dry season was within range; wet season exceeded standard majority of the day

Reception 2

CO_2 – dry season was within range; wet season exceeded standard during the afternoon
DBT – within range
RH – continuously varies above and within maximum value

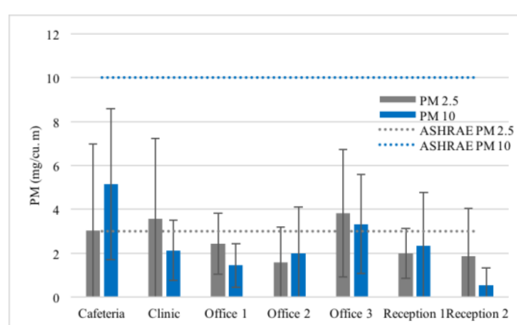

Fig. 1. PM Levels in the Building

Particulate Matter

The PM10 in all floors did not exceed the ASHRAE standard set. For $PM_{2.5}$ however, the means of two areas, the clinic and office 3, exceeded the limits of the ASHRAE standard. The comparative data for all areas are shown in Fig. 1.

3.2 Correlations between Parameters

The Spearman's Rho non-parametric test was chosen to correlate IAQ parameters using a significance value (α) of 0.05. The null hypothesis set was: there is no correlation between the two variables.

Correlating input and output variables, CO_2 was determined to have a weak correlation with DBT and RH but a moderate correlation with number of occupants. The equations for these are as follows:

CO_2 (in) vs DBT (in)

$$CO_{2,in} = 1555.20 - 29.53(DBT_{in}) \quad \text{(eqn. 1)}$$

CO_2 (in) vs RH (in)

$$CO_{2,in} = 1129.02 - 4.80(RH_{in}) \quad \text{(eqn. 2)}$$

CO_2 (in) vs Occupants

$$CO_{2,in} = 710.26 + 13.60(NO) \quad \text{(eqn. 3)}$$

Correlating output and noise/outdoor variables, CO_2 was determined to have a weak correlation with outdoor DBT, outdoor RH, and outdoor CO_2. Additionally, PM 10 had a moderate correlation with outdoor RH at 0.4316.

CO_2 (in) vs DBT (out)

$$CO_{2,in} = 1709.89 - 26.63(DBT_{out}) \quad \text{(eqn. 4)}$$

CO_2 (in) vs RH (out)

$$CO_{2,in} = 648.14 + 3.44(RH_{out}) \quad \text{(eqn. 5)}$$

CO_2 (in) vs CO_2 (out)

$$CO_{2,in} = 400.68 + 0.69(CO_{2,out}) \quad \text{(eqn. 6)}$$

PM 10 (in) vs RH (out)

$$PM_{10,in} = 12.99 + 0.16(RH_{out}) \quad \text{(eqn. 7)}$$

where:

CO_2 = carbon dioxide level in ppm
DBT = dry bulb temperature in °C
RH = relative humidity in per cent
NO = number of occupants
PM = particulate matter in mg/ cu. m

3.3 Comparison of Seasonal Effects

The Wilcoxon Signed-Rank Test was used. The significance value was set at 0.05, and the null hypothesis was: the median difference is equal to 0. Two one tailed tests were studied, and their respective alternative hypothesis were: (1) the median difference is greater than 0 and (2) the median difference is less than 0. For (1), the statistical expression of this is Prob > t, and this descriptively means that the dry season observation is greater than the wet season observation. For (2), the statistical expression is Prob < t, and this leads to a conclusion opposite of (1). Table 2 summarizes the effects of the season to IAQ.

Table 2. Wilcoxon Signed-Rank Test for Seasonal Analysis (α= 0.05)

Parameter	Accepted One-Tailed Test Statistic	Conclusion on the Seasonal Effects to the Given Parameter
Difference of CO_2 (IN)	Prob < t	Dry < Wet
Differce of DBT (IN)	Prob > t	Dry > Wet
Difference of RH (IN)	Prob < t	Dry < Wet

3.4 Start vs. End of Workday Comparison

The final statistical tests were performed in comparing the first hour to the last hour of the data gathered in each area. Figures 2, 3, and 4 show the visual summary of the IAQ changes from the first to last hour. In addition, Table 3 summarizes the observable trends from the results of statistical tests.

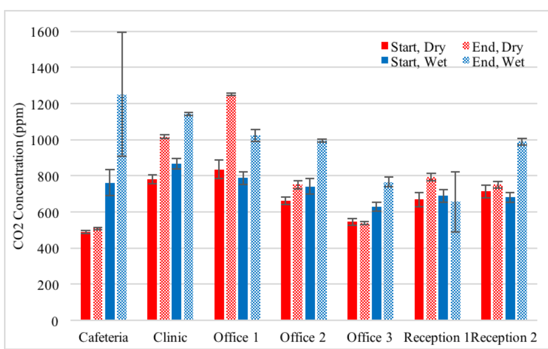

Fig. 2. CO_2 for Start vs End of Workday

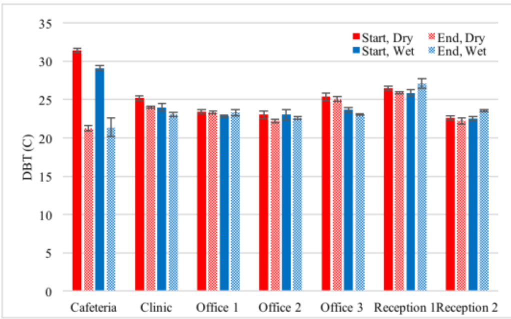

Fig. 3. DBT for Start vs End of Workday

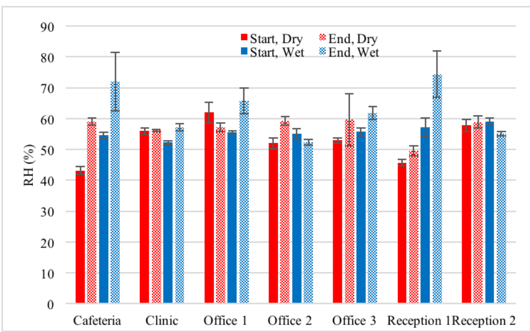

Fig. 4. RH for Start vs End of Workday

Table 3. Visual Representation of Indoor IAQ Parameters from the 1st Hour to the 8th Hour

	CO_2		DBT		RH	
	Dry	Wet	Dry	Wet	Dry	Wet
Cafeteria	↑	↑	↓	↓	↑	↑
Clinic	↑	↑	↓	↓	↔	↑
Office 1	↑	↑	↓	↑	↓	↑
Office 2	↑	↑	↓	↓	↑	↓
Office 3	↓	↑	↓	↓	↑	↑
Reception 1	↑	↔	↓	↑	↑	↑
Reception 2	↑	↑	↓	↑	↔	↓

Note: ↑ - increase, ↓ - decrease, ↔ - constant

To illustrate, from Figure 2, for the CO_2 comparison for start versus end of day, it can be seen that the CO_2 increase in the cafeteria is smaller during dry season compared to that during wet season. Also, it can be seen that the general trend is an increase in CO_2 toward the end of the day and higher CO_2 during wet season for all areas tested.

The rest of the comparisons are summarized in Table 3.

3.5 Survey Results

Survey questionnaires were handed out to the occupants for all areas except for the cafeteria since no one stays there the whole day. These surveys were based from ASHRAE and USEPA.

Table 4. Number of survey respondents

Area	Male	Female	Total
Clinic	3	5	8
Office 1	13	11	24
Office 2	4	9	13
Office 3	0	4	4
Reception1	6	0	6
Reception2	1	3	4

Irritated Eyes, Wheezing, Throat Issues, Chest Tightness/Pain, Colds, Cough, Sneezing, Shortness of Breath

Most respondents from the Clinic, Office 1, and Office 2 answered that they frequently experience colds and sneezing. Additionally, most Office 2 respondents exhibit symptoms of colds, cough, and sneezing, while Reception 1 respondents answered, colds and cough. Furthermore, reception 2 respondents have the highest number of experienced symptoms, namely throat issues, colds, cough, and sneezing. It is noted that in these areas high levels of particulate matter were recorded.

Headache, Drowsiness/ Tiredness, Dizziness/ Lightheadedness, and Shortness of Breath

The areas with respondents who experience headaches almost every workday are those staying in the Clinic and Reception 2. But in total, the area with the most number occupants that experience headaches are found in Office 1. It is also noted that based on the data gathered, the CO_2 concentrations in the Clinic, Office 1, and Reception 2 showed some instances where they have exceeded ASHRAE standards.

Numbness in Hands, Shivering, Sweating, Dry Skin

Temperature in the workplace can have certain effects on its occupants. Moreover, humidity also plays a huge role in these effects. Based on the survey, only the occupants of Reception 1 experienced this condition. It was noted that relatively higher temperature and relative humidity were recorded in this area.

Strained Eyes, Irritability, Neck/Back/Shoulder Pain, Difficulty Concentrating, Feeling of Depression

Based on the responses obtained from the occupants of each floor, it was observed that neck/back/shoulder pain is the most commonly experienced issue. This is followed by strained eyes, irritability, difficulty concentrating, and feeling of depression. Long hours spent staring at a computer screen can cause the occupants to experience strained eyes.

6. CONCLUSION

This study highlighted three targets: trends comparing different areas of the building, statistical results comparing the data from the dry and wet season, and statistical results comparing data from the start and end of operating hours in the building.

Generally, the building studied in this paper is clean in accordance to ASHRAE standards. However, there are instances when the standards go beyond the threshold limits. For example, the CO_2 in the cafeteria, clinic, and office 1 consistently and majority of the time went beyond the 1000 ppm limit.

In the statistical analysis, the most important correlation was that of indoor CO_2 concentration and the number of occupants. Other relationships like indoor CO_2 and outdoor CO_2 were also deemed to have a significant relationship backed with pertinent literature.

On seasonal variations, CO_2 and RH were noted to be higher during the wet season while indoor DBT was noted to be higher during the dry season. On diurnal variations, CO_2 and RH had an increasing trend as the day progressed in each area, but on the contrary, indoor DBT was measured to decrease instead.

Finally, adding to the trends comparing different areas of the building, aside from comparison to ASHRAE standards, survey results provided the common symptoms experienced by occupants in each area. Common ones were colds, cough, sneezing, headache, and drowsiness. In addition to that, the thermal satisfaction was also determined from the survey, and results showed that the building passes thermal standards based from ASHRAE Standard 55.

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