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Research Article

Analysis of the Effect of HVAC System Modification towards Indoor Air Quality (IAQ) and Microbiological Growth at Accommodation and Office Buildings in an Oil and Gas Industry

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Abstract
Indoor Air Quality (IAQ) problems, such as high relative humidity and microbiological (bacteria and mold) growth in accommodation and office buildings, can cause health effects for the occupants. People commonly have activities inside the buildings all day long. This study aimed to determine the impact of HVAC systems on IAQ parameters and microbiological growth. The study was conducted in accommodation and office buildings that had been identified with IAQ problems. The research methodology used a quantitative cross-sectional study design with statistical comparison analysis and statistical correlation analysis. The statistic results showed that relative humidity (RH) significantly had a strong correlation (r=0.520, 95% CI) with mold growth in ambient air of accommodation; O_2 had a significantly strong correlation (r=0.541, 95% CI) with bacteria growth in ambient air at the office; VOC (r=0.853, 95% CI) and CO_2 (r=0.803, 95% CI) had a very strong correlation with mold growth at office surface area. High humidity contributed to risk on IAQ (OR=50, 95% CI). Significant improvement was shown in relative humidity at all buildings, especially at the office, but mold and bacteria growth were offered only at the accommodation. Therefore, a comprehensive evaluation was needed to improve the IAQ and modify the HVAC system.

Keywords: HVAC system; IAQ; microbiological growth; mold; relative humidity

1. Introduction

The HVAC system in a building is necessary to control the air quality inside the building so that the building occupants feel comfortable living or working inside it and prevent health problems. An improper HVAC system can cause poor air quality conditions and Sick Building Syndrome (SBS). SBS occurs most often in mechanically ventilated, air-conditioned buildings where the amount or distribution of outdoor (fresh) air is inadequate. In buildings lacking sufficient outdoor air supply, emissions from building materials and other sources can build to levels where occupants notice odors and experience discomfort. There is growing evidence that building moisture problems and dampness lead to adverse respiratory health effects (Anna, 2011). Several issues of poor air quality have long emerged, and until now, a comprehensive solution cannot be found. In the current pandemic situation, poor air quality is critically contributed to COVID-19 virus proliferation inside the building.

Indoor air quality (IAQ) problems caused by the incompatibility of the HVAC system include physical parameters (high humidity, inappropriate air temperature), chemical parameters (VOC, CO, CO_2, O_2), and microbiological parameters (fungi, mold, bacteria, virus including COVID-19 virus). If IAQ problems are not immediately solved, occupational diseases will be difficult to avoid, including the increasing proliferation of the COVID-19 virus in the workplace. The potential COVID-19 exposure in indoor air can occur through droplets from a person infected with COVID-19. Droplets are carried by air movement, fall due to gravity, and stick to the object's surfaces. An effective HVAC system modification is urgently needed to solve the IAQ problems and reduce the spreading of the COVID-19 virus in the workplace (ASHRAE, 2020). The CDC examination of the potential routes of transmission at Guangzhou restaurant concluded that the most likely cause of the COVID-19 outbreak was droplet transmission (Lu et al., 2020).

In most indoor work environments, microorganisms are of the most significant health significance. Several bacteria and fungi are generally found in HVAC system cooling coils, filters, supply, and return air diffusers. The most common bacteria cultured from the HVAC system are *Staphylococcus aureus, E-coli, Pseudomonas sp, Enterococcus sp*, and *Bacillus sp. In contrast,* the most common fungi cultured are *Candida Sp, Aspergillus sp, Aspergillus Niger, Penicillium sp,* and *Cladosporium sp.* (Jones, 2020). Although spores may originate outdoors, *Cladosporium, Aspergillus,* and *Eurotium* can also grow on damp surfaces indoors (Sola, 1998).

Some dead organic material in buildings serves as a nutrient that most fungi and bacteria can utilize for growth and spore production. The mold growth will occur depending on moisture availability. Fungi grow on damp surfaces as obvious mold patches, often clearly indicating moisture problems and potential health hazards in the building. Airborne fungi are much more important than bacteria as causes of allergic disease. Bacteria can grow only on saturated surfaces or in water in HVAC drain pans, reservoirs, and the like. A high count of Gram-positive bacteria indicates overcrowding and poor ventilation. The presence of large numbers of Gram-negative types indicates that there are very wet surfaces or materials, drains, or particularly humidifiers in HVAC systems that are proliferating. Some Gram-negative bacteria have been shown to provoke symptoms of humidifier fever (Sola, 1998).

HVAC systems in mechanically ventilated buildings control IAQ by providing outdoor air, filtering, mixing, distributing outdoor and indoor air, and providing some temperature and humidity control levels. The design system should deliver acceptable air quality to the majority of building occupants. Therefore, the system must be installed, operated, and maintained correctly. Design factors that may adversely impact air quality include insufficient provision for outdoor or fresh air; inefficient filtration; poorly designed fresh air intakes; inadequate cooling and dehumidification; improperly designed drip pans; water spray humidification systems; use of porous insulation near water sources; limited access to maintain HVAC components; use of materials that release VOCs or fibers; and ineffective distribution of air within the occupied space. Neglect and poor maintenance may result in inoperable fans, closed dampers, clogged filters, slimy condensate pans, and dirty ductwork (Anna, 2011).

Many of the causes of poor IAQ that result from HVAC equipment are addressed in the current version of ASHRAE 62.1 (ASHRAE, 2010). ASHRAE has recognized that UV-C wavelength inactivates effectively all microorganisms living on HVAC surfaces depending on the intensity of the UV-C and the length of exposure (ASHRAE, 2015). High humidity levels can cause condensation in building structures and on interior and exterior surfaces, which can cause mold growth on walls (Jansz, 2011). In 2009, there was IAQ problem in a company dormitory at Papua Barat, Indonesia. The dormitory had high humidity conditions and fungi growth inside the building (Athari, 2014).

One of the oil and gas industries in East Kalimantan, Indonesia, has IAQ problems in accommodation and office buildings that have inadequate HVAC system design for tropical areas, such as insufficient fresh air incapacity, no fresh air unit in office, insufficient flow for exhaust, limited access area for maintenance and building are designed with fixed windows. These problems had arisen since 2012 when the building started operating.

The relative humidity (RH) is very high and causing mold and bacteria growth in the parts of the room such as walls, ceilings, furniture, shoes, chair, and other surfaces. The wall surfaces are condensating. Even clothes, blankets, and sheets are cold or wet. Based on the measurement result, the temperature and RH level inside the room is above standard, and the total count of bacteria and mold is detected above average in the air. The bacteria identification result shows that *E-coli* and *Staphylococcus Aureus* are detected in ambient air.

IAQ standard for accommodation buildings refers to Minister of Health Regulation 1077/2011 with detail for each parameter. For instance, the standard of temperature is 23-26°C; relative humidity (RH) is 40-60%, air movement is 0.15 - 0.25 m/s; VOC is below 3 ppm; CO is below 9 ppm; CO_2 is below 1,000 ppm; total bacteria count is below 700 CFU/m^3; and total mold count is 0 CFU/m^3 (Minister of Health, 2011). IAQ standard for office buildings refer to Minister of Manpower Regulation 5/2018 with detail standard value of each parameter, such as temperature is 23-26°C; RH is 40-60%; air movement is below 0.3 m/s; VOC is below 261 ppb; CO is below 9 ppm; CO_2 is below 1,000 ppm; O_2 is 19.5 - 23.5%; total bacteria count is below 500 CFU/m^3; and total mold count is below 1,000 CFU/m^3 (Minister of Manpower, 2018).

The company has carried out continuous modification of the HVAC system in these buildings. The central HVAC system at the accommodation building uses VRF (Variable Refrigerant Flow) with fresh air unit. The last modification in the HVAC system and building construction was implemented in 2017 and finished in 2021. Several improvements were made, such as replacement of the broken compressor, repair of the heating coil, increase of the fresh air and exhaust flow rate, damper adjusting and balancing, regular maintenance, repair of leaking plumbing, modification of fixed window with locked window, revamping of the floor with water-resistant material and partial mold remediation (cleaning and repainting the wall).

The HVAC system type at the office building is ceiling concealed duct. This HVAC system is not equipped with a fresh air unit, and the office building has fixed windows. The last modification in the HVAC system and building construction was implemented in 2019 and finished in 2021. Several modifications are fresh air unit installation (HVAC system modified from duct split HVAC into central HVAC system), exhaust installation to dilute the air inside the room (only operating if the HVAC system is switched off in the evening), an increase of fresh air flow, regular maintenance, repair of leaking ceiling, modification of fixed window with a locked window and partial mold remediation. Various improvements have been implemented, but the problem is still not resolved now. The relative humidity is still high, while bacteria and mold are still found in the room. Therefore, the effectiveness of improvement needs to be analyzed to solve this problem comprehensively.

Based on building problem investigations, dampness is sufficient to cause problems from a series of events. Indoor buildings should always be dry with maintained relative humidity. When building interiors get damp and stay damp, problems often emerge for occupants and the building's structure, materials, and furnishing (ASHRAE, 2019a).

This study aimed to determine the effect of HVAC system modification on air quality conditions and microbiological growth (bacteria and mold) and the association between each parameter of IAQ at the accommodation and office buildings in an Oil and Gas Industry. There are two research hypotheses in this study: the air quality parameters, especially temperature and RH, correlated with fungi and bacteria growth in accommodation and office buildings; the HVAC system modification affected air quality conditions and reduced the microbiological growth inside buildings. This research needs to be conducted to evaluate the acceptable IAQ conditions and apply solutions to IAQ problems (exceptionally high humidity, mold growth, and bacteria growth) in these buildings.

2. Methods

This research methodology used a quantitative cross-sectional study at 2 (two) accommodation buildings and 1 (one) office building in the Oil and Gas Industry identified with IAQ problems. Sample data was taken for Indoor Air Quality (IAQ) parameters and microbiological sampling before and after HVAC system modification at rooms, corridor, and HVAC system (supply air diffuser, main ducting, fresh air inlet, and outlet). In accommodation buildings, data were taken before modification in October 2017 and after improvement in February 2021. In office building, data were taken before modification in January 2019 and after improvement in March 2021.

IAQ measurement methodology refers to NMAM – NIOSH (Ashley and Fey O'connor, 2017). IAQ measurement was conducted using direct reading measurement with IAQ meter (AreaRAE Plus Monitor). The measurement variable of physical and chemical parameters is temperature, relative humidity (RH), air movement, CO, VOC, CO_2, and O_2. Microbiological sampling was conducted using bioaerosol sampling and swab test.

Bioaerosol sampling methodology refers to NIOSH 0800 to determine Total Plate Count, Yeast and Mold and Yeast and Mold Identification using Biostage Sampling Pump Kit and agar media (NIOSH, 1998). Swab test sampling methodology refers to ISO 18593:2018 to determine Total Plate Count, Yeast, and Mold, Bacteria Identification (*E.Coli, Legionella sp, S. aureus,* and *Salmonella*) using surface wipe samplers or swab test kit (ISO 18593, 2018). All samples were sent to an accredited laboratory to analyze the microbiological contaminant. During the pandemic situation, the laboratory cannot analyze yeast and mold identification. Therefore, there is no data on yeast and mold identification after improvement in 2021.

Statistical sampling strategy refers to NMAM – NIOSH (Ashley and Fey O'connor, 2017). With occupancy above 50 persons, the minimum sampling size was 22 samples for each building type with a confidence level of 90%. The measurement was conducted inside the room, corridor, and HVAC system (supply air diffuser, fresh air diffuser, main ducting, fresh air inlet, and fresh air outlet) with total sampling point at accommodation buildings of 77 samples and the office building of 52 samples. Data variables for IAQ and microbiological parameters were numerical data, and data variables for HVAC modification were categorical data. HVAC modification was classified as before and after the modification. The IAQ parameters were also classified into two standard groups: ≤ standard and > standard.

Statistical analysis used Pearson Correlation and Linear Regression (normal distribution data) to determine the association of each parameter. Comparison statistical analysis was used to determine differential between two groups of HVAC modification. The comparison statistical analysis was Independent T-test (normal distribution data/parametric test) and Mann-Whitney Test (non-normal distribution data/non-parametric test). Finally, to determine the risk value of each parameter in standard group data (categorical data), the Chi-square test was used as statistical analysis.

3. Result and Discussion

In risk management, the previously determined risk level is designated as acceptable or unacceptable in the IAQ standards and threshold values/acceptable levels. If risks are decided to be unacceptable level, either the building is improved, evacuated, or demolished. IAQ of existing buildings can be improved, while IAQ of new buildings can be considered during the design stage, eliminating the need to make corrections or improvements later (Goyal and Khare, 2011). Research study results in banking sectors at Samarinda, East Kalimantan, the existence of bacteria and fungi still exceeds the maximum standard of Indonesian Regulation. The bacteria and fungi growth was supported by temperature, humidity, and wind speed (Setia Pamungkas et al., 2019).

Measurement result in this study shows that there are IAQ problems inside the building before improvement. It is proven that several IAQ parameters are above the Indonesian regulation standard in Table 1. Before improvement, the dominant parameter contributing to IAQ problems are RH (44.8%), total bacteria count (50%), and total mold count (44.4%) at accommodation building; and RH (86.2%) and total bacteria count (69.2%) at the office building. This condition occurred because the HVAC system was inadequate. The broken compressor in the HVAC system of accommodation buildings resulted in insufficient fresh air flow in each room and corridor. The ceiling concealed duct HVAC system type at the office could not give fresh air inside the room. These situations increased the relative humidity and generated bacteria and mold growth.

At the accommodation building, the improvements were seen in the IAQ parameter of temperature, RH, CO_2, and total bacteria count (TPC). However, the value of RH and total mold count was still above standard in some rooms. The improvements were seen in RH, and total bacteria count at the office building, but air movement and TPC were still above standard in some rooms. All data of VOC, CO, and O_2 were within standard before and after improvement. Pathogen bacteria identification was not detected in all areas. Based on the Chi-Square analysis result, the improvement of the RH parameter was significant (p=0.0005, 95% CI) and OR value = 50 (95% CI: 8.2-305.4), which meant that high RH had 50 times more risk compared to standard RH in office air quality.

Table 1. The percentage of compliance standard on IAQ result at buildings, Oil, and Gas Industry in Kalimantan Timur, Indonesia

Building Type	Variables[1]	HVAC Modification n (%)				Total
		Before[2]		After[3]		
		≤ Standard	> Standard	≤ Standard	>Standard	
Accommodation*	Temperature	12 (38.7)	3 (75%)	19 (61.3%)	1 (25%)	35
	RH	2 (33.3%)	13 (44.8%)	4 (66.7%)	16 (55.2%)	35
	Air movement	-	-	7 (100%)	13 (100%)	20
	CO_2	9 (36.0%)	0 (0%)	16 (64.0%)	4 (100%)	29
	Total bacteria Count	10 (41.7%)	6 (50.0%)	14 (58.3%)	6 (50%)	36
	Total Mold Count	0 (0%)	16 (44.4%)	0 (0%)	20 (55.6%)	36
Office**	Temperature	27 (57.4%)	0 (0%)	20 (42.6%)	0 (0%)	47
	RH	2 (11.1%)	25 (86.2%)	16 (88.9%)	4 (13.8%)	47
	Air movement	9 (47.4%)	18 (64.3%)	10 (52.6%)	10 (35.7%)	47
	CO_2	27 (57.4)	0 (0%)	20 (42.6%)	0 (0%)	47
	Total bacteria Count	2 (33.3%)	9 (69.2%)	4 (66.7%)	4 (30.8%)	19
	Total mold Count	11 (57.9%)	0 (0%)	8 (42.1%)	0 (0%)	19

[1] Standard refer to Paragraph 9. [2] $n_{IAQ*} = 15$, $n_{bioaerosol*} = 16$, $n_{IAQ**} = 27$, $n_{bioaerosol**} = 11$. [3] $n_{IAQ*} = 20$, $n_{bioaerosol*} = 20$, $n_{IAQ**} = 20$, $n_{bioaerosol**} = 8$.

Means analysis of each parameter showed an improvement after modification, such as in temperature, RH, VOC, and total mold count (bioaerosol and swab result) at the accommodation, as seen in Figure 1. Temperature level decreased after modification except at A.B 1st-floor room, but all rooms were within a standard. RH level decreased after modification and within the standard, except on the 2nd floor. Average VOC before and after modification was within the standards. At all rooms, the total mold count decreased after improvement but was still above standard. From the swab sampling result, mold and bacteria contaminants decreased at the surface area in several rooms. Before improvement, yeast and mold identification results showed *Aspergillus Flavus, Aspergillus spp, Cladosporium Cladosporioides, Curvularia sp,* and *Penicillium Citrinum* were detected in ambient air accommodation.

Figure 2 shows an improvement in several parameters, such as RH, air movement, CO_2 and total bacteria (bioaerosol) at the office. RH level decreased after modification and was below standard, except on the 2nd floor. Air movement and CO_2 before and after modification met the standards with decreasing air movement rate and CO_2 level after modification. Total bacteria count declined after improvement but still above standard except at 1st-floor room. Before improvement, yeast and mold identification results showed that *Fusarium sp*, *Cladosporium sp*, *Penicillium chrysogenum*, and *Penicillium sp* were detected in ambient air office buildings. Poor ventilation and surface temperature inhomogeneity can produce water condensation points and humid conditions. These circumstances are favorable to some fungal species; as a result, these can proliferate in places (Nedved, 2011).

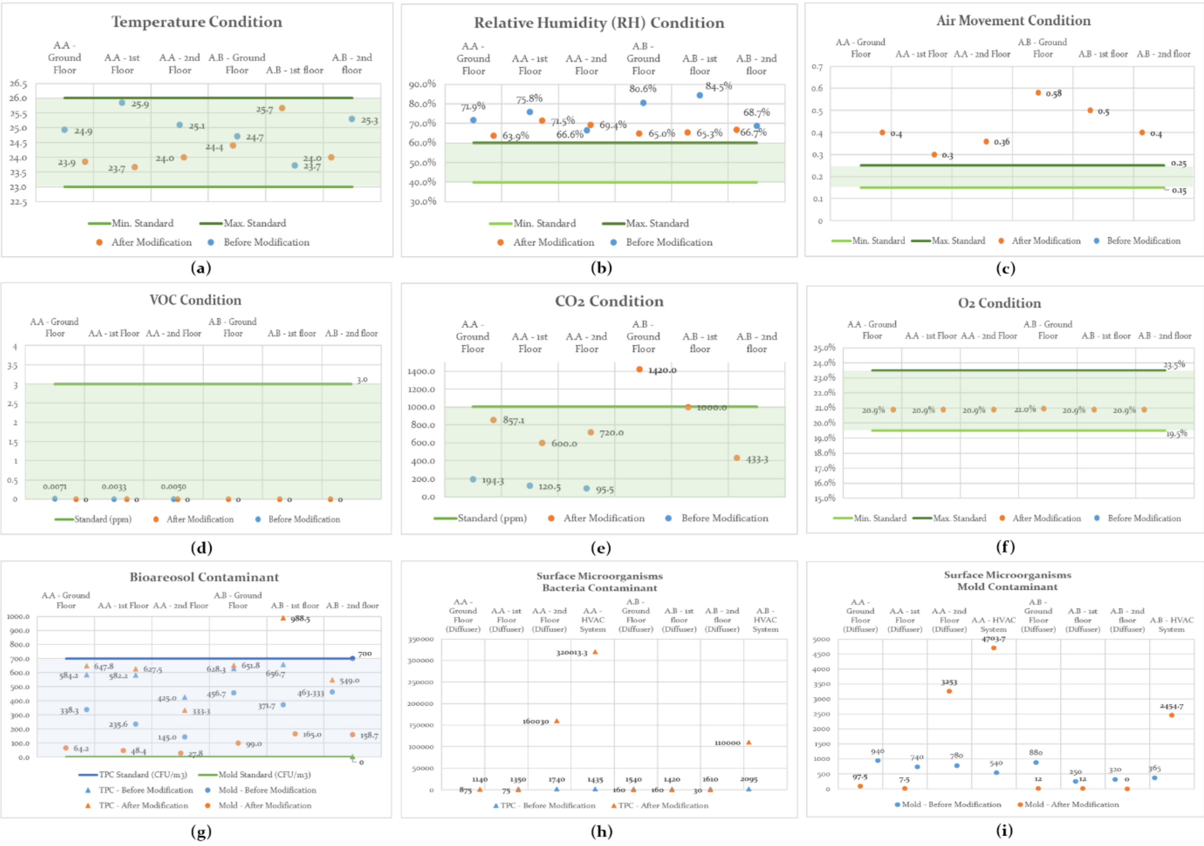
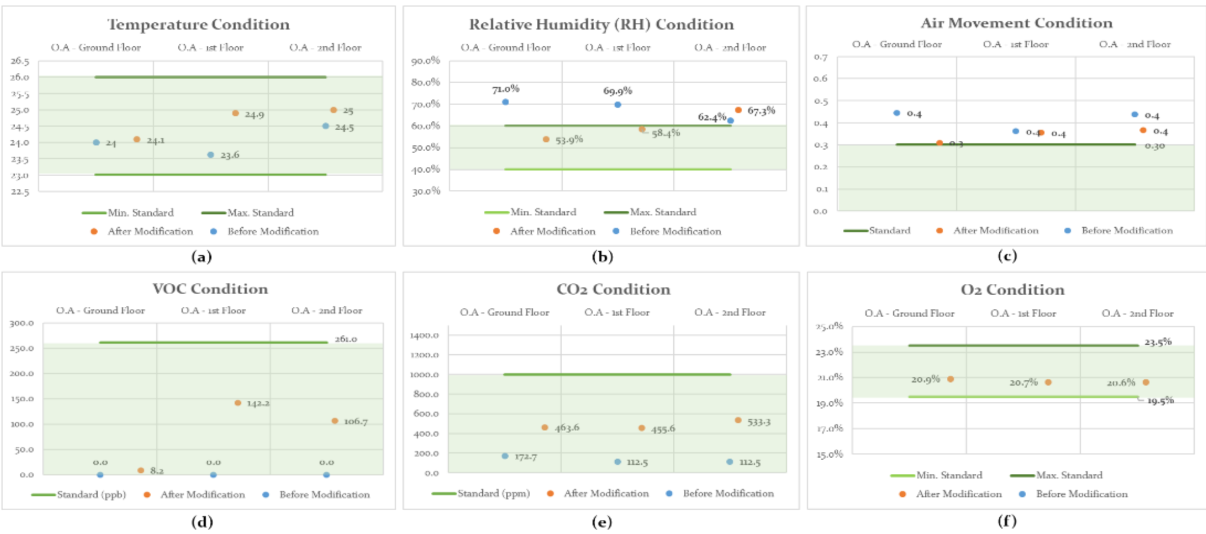


Figure 1. The average result of IAQ parameters (a-f) and microbiological contaminant (g-i) at accommodation buildings, Oil and Gas Industry in East Kalimantan, Indonesia

(a. Temperature in °C; b. RH in %; c. Air Movement in m/s; d. VOC in ppm; e. CO_2 in ppm; f. O_2 in %; g. Bioaerosol Result in CFU/m³; h-i. Swab Result in CFU)



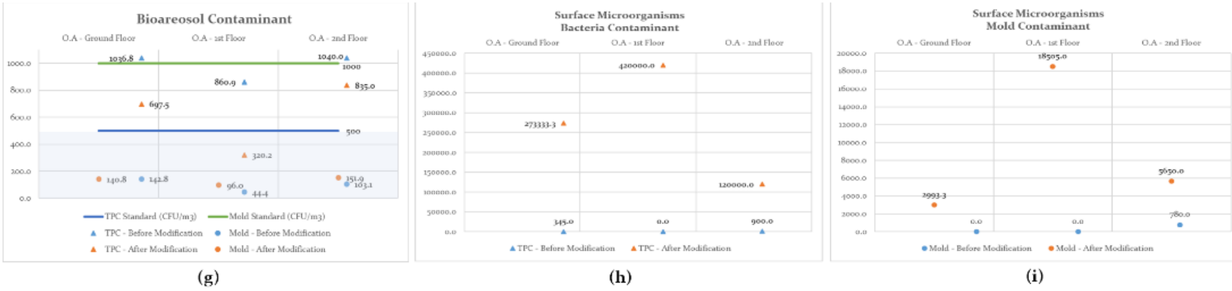


Figure 2. The average result of IAQ parameters (a-f) and microbiological contaminant (g-i) at office building, Oil and Gas Industry in East Kalimantan, Indonesia
(a. Temperature in °C; b. RH in %; c. Air Movement in m/s; d. VOC in ppm; e. CO_2 in ppm; f. O_2 in %; g. Bioaerosol Result in CFU/m³; h-i. Swab Result in CFU)

Controlling relative humidity is essential to limit the growth of microorganisms such as mold and dust mites; keeping relative humidity below 60% (to control mold) and 50% (to control dust mites), including during unoccupied hours, is necessary. High relative humidity can foster the proliferation of mold and dust mites. Microbiological sampling results (bioaerosol and swab method) confirmed that bacterial and fungi had growth and distributed spores in all rooms, corridors, and ducting systems at the accommodation and office buildings.

Table 2 shows the result of correlation analysis in accommodation and office buildings. The plot of linear regression is indicated in Figure 3. At accommodation buildings, the relationship between RH and mold bioaerosol result showed strong correlation (r = 0.520, 95% CI) with the positive scheme, meaning the increase of RH had a significant effect on the increase of total mold count in the air. The coefficient value with determinacy 0.270 represented the linear regression equation which explained the 27% variance of total yeast and mold. RH variables affecting the total yeast and mold variable were about 27%. The statistical result showed significant correlation between RH and total yeast and mold (p=0.001, 95% CI). In line with the research result of mold contamination in indoor air dormitories, the relative humidity was confirmed to have a significant direct relationship with the total mold colony (Athari, 2014).

At the office building, statistical analysis results showed that TPC bioaerosol had significant correlation with VOC, CO_2, and O_2. TPC and VOC had negative correlation with medium level (r = -0.469, 95% CI), which meant that the increase of TPC significantly affected the decreasing of VOC with p-value of 0.043. TPC and CO_2 had a negative correlation with strong level (r=-0.535, 95% CI), meaning that the increase of TPC had a significant effect on the decreasing of CO_2 with p-value of 0.018. TPC and O_2 had positive correlation with a strong level (r=0.541, 95% CI), meaning that the increase of TPC significantly affected the increase of CO_2 with p-value of 0.017. These results implied that bacteria growth depends on O_2 level because the bacteria had more supply to proliferate.

Pearson correlation between IAQ parameters and microbiological swab results showed that mold and VOC have very strong correlation (r=0.853**, 95% CI) with p=0.007. There was very strong correlation between mold and CO_2 (r=0.803*, 95% CI) with p=0.016. These results implied that VOC and CO_2 influenced the mold growth in the surface area at an office building. Bioaerosol particles may also be volatile organic compounds that emanate from living organisms. It is commonly known as microbial volatile organic compounds (MVOCs) (Sola, 1998).

Table 2. Association of IAQ parameters on microbiological growth at Oil and Gas Buildings, East Kalimantan, Indonesia (Pearson correlation)

Building Type	Variable		r	R^2	Regression Equation	P-value
	Dependent	Independent				
Accommodation (n=35)	Mold - bioaerosol	RH	0.520**	0.270	Mold = (-477.53) + 9.67*RH	0.001
Office (n=19)	VOC	Temperature	0.513*	0.263	VOC = (-930.5) + 39.5*Temp	0.025

Building Type	Variable		r	R^2	Regression Equation	P-value
	Dependent	Independent				
	Air movement	RH	0.522*	0.272	Air Movement = (-0.28) + 1.1*RH	0.022
	O_2	RH	0.607**	0.368	O2 = 10.05 + 21.29*RH	0.006
	CO_2	VOC	0.536*	0.287	CO2 = 259.89 + 2.34*VOC	0.018
		O_2	-0.706**	0.498	CO2 = 2054.77 – 72.06*O2	0.001
	O_2	VOC	-0.664**	0.441	O2 = 24.757 – 0.028*VOC	0.002
	TPC - bioaerosol	VOC	-0.469*	0.220	TPC = 930.29 – 3.09*VOC	0.043
		CO_2	-0.535*	0.286	TPC = 1095.1 – 0.8*CO2	0.018
		O_2	0.541**	0.293	TPC = -1159.94 + 83.34*O2	0.017

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

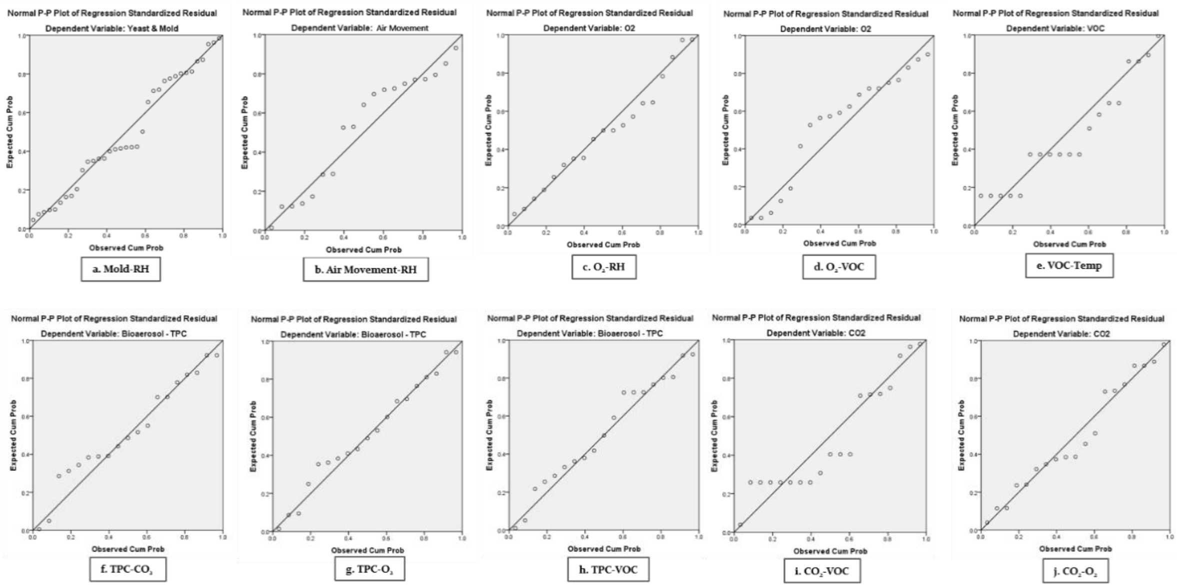


Figure 3. Regression plot between IAQ and microbiological parameters at accommodation buildings (a) and office building (b-j), Oil and Gas Industry in East Kalimantan, Indonesia

Table 3 and Table 4 show the statistical result of means comparison between two groups of HVAC modification. Independent T-test result showed significant means differences between two groups of HVAC system modification on RH and mold bioaerosol at accommodation buildings and RH, VOC, CO_2, O_2, TPC bioaerosol at the office building with p-value of < 0.05 (95% CI). Mann-Whitney test result showed significant means differences between 2 groups of HVAC system modification on mold swab at the accommodation and office buildings and TPC swab at office buildings with p-value of < 0.05 (95% CI). The statistical analysis result showed improvements after modification in RH and mold parameters at accommodation buildings and RH and bacteria parameters at the office building. This result indicated that sufficient fresh airflow inside the building affected the decrease of relative humidity, bacteria, and mold growth.

Air movement is needed inside the room to remove bacteria and odors produced by human existence. The microbial can be removed by adequate ventilation. To maintain comfort conditions, it is generally desirable to keep air movement between 0.1 and 0.3 m/s (Nedved, 2011). Humidity influences the general thermal comfort of the body. For higher temperatures and activities, the influence is more significant. The air velocity in space controls the convective heat exchange between a person and the environment. This affects heat loss and the local thermal discomfort due to drought (ISO 7730, 2005). Excess heat, odors, and contaminants can often be controlled by dilution or replacement with outdoor air.

In humid climates, extra moisture removal from ventilation air is required. The concentration of airborne contaminants can be reduced by introducing large quantities of fresh air (Nedved, 2011).

Table 3. Differences between HVAC modification groups of IAQ parameters and ambient air microbiological growth at Oil and Gas Buildings, East Kalimantan, Indonesia (Independent T-test)

Building Type	Variable	HVAC Modification	Mean	Standard Deviation	n	P-value
Accommodation (n=35)	Temperature	Before	24.54	1.36	15	0.198
		After	24.00	1.08	20	
	RH	Before	74.71%	8.95%	15	0.0005
		After	65.05%	5.74%	20	
	TPC - bioareosol	Before	588.22	153.41	15	0.656
		After	616.60	204.63	20	
	Mold - bioaerosol	Before	331.11	144.07	15	0.0005
		After	86.77	64.75	20	
Office (n=22)	Temperature	Before	24.27	0.65	11	0.089
		After	25	1.18	11	
	RH	Before	69%	5.34%	11	0.001
		After	58.18%	7.68%	11	
	Air movement	Before	0.49	0.15	11	0.072
		After	0.36	0.16	11	
	VOC	Before	0	0	11	0.001
		After	106.36	71.03	11	
	CO2	Before	172.73	148.94	11	0.0005
		After	581.82	252.26	11	
	O2	Before	25.83	1.41	11	0.0005
		After	20.73	0.14	11	
	TPC - bioaerosol	Before	989.7	448.16	11	0.011
		After	551	255.01	11	
	Mold - bioaerosol	Before	105.15	63.48	11	0.534
		After	122.45	64.75	11	

Table 4. Differences between HVAC modification groups of IAQ parameters and ambient air microbiological growth at Oil and Gas Buildings, East Kalimantan, Indonesia (Mann-Whitney test)

Building Type	Variable	HVAC Modification	Mean Rank	Sum of Rank	n	P value
Accommodation (n=22)	TPC - swab	Before	15	150	10	0.021
		After	8.58	103	12	
	Mold - swab	Before	17.20	172	10	0.0005
		After	6.75	81	12	
Office (n=10)	TPC - swab	Before	3.38	13.5	4	0.069
		After	6.92	41.5	6	
	Mold - swab	Before	3.13	12.5	4	0.037
		After	7.08	42.5	6	

Perceptions of poor IAQ result in more complaints as temperature and humidity increase (Fang and Clausen, 1997). Additionally, formaldehyde and other VOCs tend to be emitted at greater rates from building materials and furnishings at higher indoor temperature and humidity. The growth of microorganisms on surfaces and the survival of the house dust mite is facilitated by high RH (>60%) (Anna, 2011). Remediation of microbial contamination requires: (a) removal of porous materials that show extensive microbial growth, (b) physical removal of surface microbial growth on nonporous materials to typical background levels, and (c) reduction of moisture to levels that do not support microbial growth (Plog and Quinlan, 2012).

The statistical analysis above shows that mold growth in ambient air significantly depended on relative humidity, while mold growth in the surface area significantly depended on VOC and CO_2. The IAQ parameter of temperature and O_2 significantly influenced the bacteria growth in ambient air. Significant improvement was shown in RH, mold, and bacteria at all buildings.

The suitable improvement depended on the HVAC system, building condition, quality of microbial remediation or disinfection, maintenance, and IAQ problems in each building. Although there had been a slight improvement, some parameters were still above the standard, so further improvement would be needed to improve air quality conditions to meet the IAQ standard by Indonesian Regulation. To remove SBS symptoms in workers, the standard of mold in the office should be evaluated. The mold standard in 1.000 CFU/m^3 is classified into high level by AIHA, moderate level by ACGIH, and CEC (Piasecki et al., 2020). The further recommendation of the HVAC system is addressed in the current version of ASHRAE Standard 2009 Fundamental and ASHRAE Standard 62.1-2019. The recommendation of mold remediation is addressed in ANSI/IICRC S520-2015.

In this pandemic situation, surface and air disinfection using UV-C light can be an alternative improvement. UV-C wavelength can kill 99% or more of all microorganisms living on HVAC air ducts and evaporator coils (ASHRAE, 2019b). The bacteria and mold concentration decreased by 99.7% and 96.7%, respectively, in 3 hours after in-duct UVGI operation. *Penicillium sp.* were predicted to be inactivated by 99.9% with UV-C exposures of 6 s and 15 min 57 s (Bang et al., 2020). Several recommendations shall be implemented in accommodation and office building, such as installation of UV-C light in HVAC ducting system to inactivate bacteria, mold, and virus; entire mold remediation or surface disinfection using UV-C light portable; cleaning of the diffuser; and maintaining of a physical parameter of IAQ in the HVAC system.

4. Conclusions

The IAQ parameters were related to microbiological growth. Relative humidity significantly influenced mold growth in accommodation buildings. High relative humidity significantly increased the mold growth in ambient air with strong correlation (r=0.520, 95% CI). VOC and CO_2 significantly influenced mold growth in office surface area (building and HVAC system component) with very strong correlation [VOC (r=0.853, 95% CI) and CO2 (r=0.803, 95% CI)]. Temperature and O_2 significantly influenced bacteria growth in office ambient air with strong correlation (r=0.541, 95% CI). High relative humidity contributed to IAQ risk in office air quality (OR=50, 95% CI).

After modification, there were significant changes in relative humidity and mold growth in ambient air and surface area. At accommodation buildings, the building and HVAC system modification could improve RH and mold growth in room and HVAC systems. At office buildings, the HVAC system modification did not significantly improve the indoor air quality in the room and HVAC system, but there was RH improvement. Significant improvement was indicated in relative humidity at all buildings, especially at the office, but mold and bacteria growth were only shown in accommodation.

IAQ parameters were still above the standard of Indonesian Regulation in several rooms after modification, especially for relative humidity (63-71.5%), air movement (0.3-0.58 m/s), total mold count (27.8-165 CFU/m^3), and total bacteria count (988.5 CFU/m^3). The performed HVAC improvement was not able to entirely solve IAQ problems inside the building. Therefore, several recommendations should be wholly implemented, including microbiological remediation or air and surface disinfection by UV-C light with the appropriate procedure. For further research, a comprehensive analysis shall be conducted to give detailed recommendation to solve the IAQ problem completely.

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