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Indoor air quality assessment to design a model for indoor air quality management and health impact assessment in Northern Thailand

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Abstract. Indoor air quality (IAQ) has become an important area of concern these days and tends to be more serious to human health as well as resident convenience, especially in smoke haze season (February - April) in Upper Northern Thailand (UNT). Indoor air monitoring and model development for controlling the air quality indoors is necessary for all buildings, particularly in urban areas and polluted areas. This study aims i) to study indoor air quality, ii) to assess health impacts and factors related to indoor air quality, and iii) to develop an effective model for controlling indoor air quality in Sub-district Health Promoting Hospital (HP) and Early Childhood Development Center (ED). Temperature, relative humidity, air movement, $PM_{2.5}$, PM_{10}, Carbon Dioxide (CO_2), Carbon Monoxide (CO), Ozone (O_3), Formaldehyde (CH_2O), Total Volatile Organic Compound (TVOC), Total bacterial and fungal were used to evaluate indoor air quality. It was found that $PM_{2.5}$ and PM_{10} concentrations in all buildings exceeded indoor air quality standards. Moreover, CO_2 concentration was higher than recommended levels, especially during the daytime. HP and ED found high values of total bacteria and total fungi, which were higher than recommended level. The indoor air quality management model of a clean room that involved with the calculation of total airflow in cubic feet per hour was created and a specific size of air cleaner for the room was selected. The results showed that $PM_{2.5}$ and PM_{10} concentrations including other parameters of the selected rooms were reduced to the recommended levels after implementing the rooms. This result indicated the effectiveness of developing an indoor air quality management model. Thus, this model can be used as a successful study case for other HP and ED, leading to a positive impact on building occupant health.

1 Introduction

The indoor air pollution problem tends to increase lately. It has been revealed that 30% of worldwide buildings may have air quality problems and it was 100 times higher than outdoors, especially in urban areas [1]. Climate change can be affected the indoor environment due to the conditions inside the buildings being influenced by conditions outside them. It finds that steps taken to mitigate climate change may cause or exacerbate harmful indoor environmental conditions [2]. Additionally, air pollution can be directly affected children's health around the world. About 93 percent of children live in areas that have excessive levels of air pollution and about one in four children under the age of five died from severe air pollution [3]. Children normally spend time in indoors i.e. houses, schools, or various residential buildings more than outdoors. The main source of indoor pollutants can be influenced by outdoor air pollutants such as traffic emissions, fuel combustion, and industrial area. However, human activities inside buildings i.e. painting houses, cleaning houses, construction and furniture also can cause indoor pollutants [4],[5]. Carbon Dioxide (CO_2), Formaldehyde (CH_2O), Total Volatile Organic Compounds (TVOCs), $PM_{2.5}$, Nitrogen Dioxide (NO_2), and Ozone (O_3) were found in indoor areas and these pollutants can be affected Children's health [6].

This study aims to study indoor air pollution and develop a model for managing indoor air pollution in urban areas. Children who may be affected by the health consequences of exposure to air pollution in the HP and ED in northern Thailand were focused.

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2 Materials and methods

2.1 Sample selection

Five sampling sites of HP and five sampling sites of ED in Lampang province, Thailand were conducted in this study for collecting data on IAQ and the health impact of buildings occupants (Figure 1). These areas were located in urban areas and smoke haze areas, which were affected by traffic emissions, especially in the morning and evening. Therefore, the pollution level was quite high at that time.

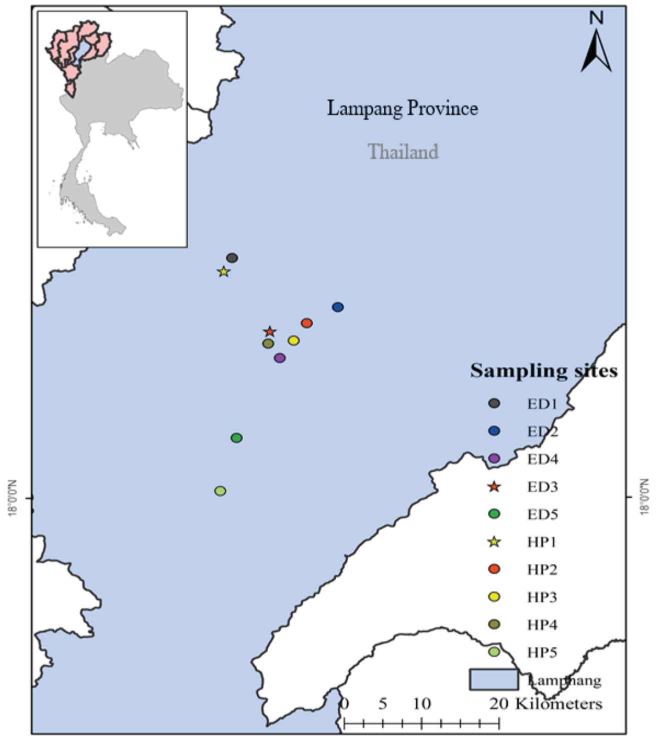

Fig. 1. Sampling Sites.

2.2 Building survey and indoor air quality management system

2.2.1 Sub-district Health Promoting Hospital

The selected locations of HP that are used for measuring and designing a model for improving IAQ are shown in Table 1.

Table 1. Locations of Sub-district Health Promoting Hospital (HP).

Sites	Lat (ºN) and Long (ºE)	Location description
HP1*	18º 18′ 48″ N and 99º 20′ 9″E	Urban community, Pathway
HP2	18º 14′ 30″ N and 99º 26′ 11″E	Urban community, Portage
HP3	18º 13′ 3″ N and 99º 25′ 14″E	Rural area, Agriculture, Traffic
HP4	18º 12′ 50″ N and 99º 23′ 21″E	Rural area, Agriculture
HP5	18º 0′ 38″ N and 99º 19′ 51″E	Rural area, Agriculture

*HP1 = Study sites for indoor air quality development.

2.2.2 Early Childhood Development Center

The locations of ED are shown in Table 2. These selected sites were used to measure IAQ and design a model for improving IAQ.

Table 2. Locations of Early Childhood Development Center (ED).

Sites	Lat (ºN) and Long (ºE)	Location description
ED1	18º 19′ 52″ N and 99º 20′ 45″E	Urban community, Pathway
ED2	18º 15′ 48″ N and 99º 28′ 29″E	Urban community, Heavy Traffic
ED3*	18º 13′ 49″ N and 99º 23′ 29″E	Rural area, Agriculture, Traffic
ED4	18º 11′ 36″ N and 99º 24′ 14″E	Rural area, Agriculture
ED5	18º 4′ 59″ N and 99º 21′ 2″E	Rural area, Agriculture, Burning

*ED3 = Study sites for indoor air quality development.

2.3 Sampling method

2.3.1 Parameters and sampling methods

Table 3 shows the IAQ parameters and types of equipment used to measure each parameter for assessing indoor air quality. Each parameter was performed according to the recommendations of the Thailand Health Department.

Table 3. Air quality parameters and measurement methods.

Parameters	Measurement
- Temperature - Relative humidity - Air movement	Indoor Air Quality Monitor Q-Trak TSI 7545
- PM_{10}, $PM_{2.5}$	Met One: Aerocet 531S
- CO_2 - CO	Indoor Air Quality Monitor Q-Trak TSI 7545
- O_3	Aero Qual Model S500
- CH_2O	Formal Demeter htV
- TVOCs	Gas Detector (MiniRAE)
- Total Bacteria Count - Total Fungal Count	Air-sampler System MAS-100 NT

2.4 Health impact assessment

Health risk assessment was calculated by Hazard Quotient (HQ) from exposure to respiratory air pollutants. This study interested in people who had activities in these study areas and can be classified into three main groups of people (Children, teenagers, and adults) by ranges of age.

HQ is the ratio of potential exposure to pollutants and its level without adverse health effects and can be calculated from Equation (1) [7].

$$HQ = \frac{ADD}{RfD} \quad (1)$$

Where ADD is an average daily dose of inhalation exposure (mg/kg per day) and RfD is an inhalation reference dose (mg/kg per day), which can be used to estimate level of human daily intake without adverse health effects during a lifetime.

The level of hazard was classified by the HQ value as follows: HQ values less than 0.1 means no hazard exists, HQ values in the range of 0.1 to 1.0 means acceptable risk to human health, and HQ values more than 1.0 indicates a hazard risk to human health.

ADD was calculated from age ranges of children, teenagers, and adults based on standard values of air pollution exposure parameters from the EPA (US. EPA, 2011). The ADD value was calculated from Equation (2) [8].

$$ADD = \frac{C_i \times InhR \times ET \times EF \times ED}{BW \times AT} \quad (2)$$

Where ADD is for pollutants and Ci is the concentration of air pollutants (mg/m^3), which was calculated from an average of that pollutant concentrations, InhR is the inhalation rate of the group (m^3/hour), ET is the exposure time (hours/day), EF is the exposure frequency (days/year), ED is the exposure duration (years), BW is the body weight (kg) and AT is the average time (days).

The RfD can be calculated from Equation (3). Average standard reference concentration of inhalation exposure is 8 hours (based on standard values for The Office of Environmental Health, Department of Health of Thailand).

$$RfD = \frac{RfC \times IR \times ET \times EF \times ED}{BW \times AT} \quad (3)$$

Additionally, the total non-carcinogenic risk was calculated by the hazard index (HI) to estimate the risk from exposure to many pollutants at the same time [9]. It was calculated by Equation (4) [10].

$$HI = HQ_1 + HQ_2 + \ldots + HQ_n \quad (4)$$

where 1–n: specified pollutants in the air.

2.5 Indoor air quality improvement strategies

The main approach to minimize an individual's vulnerability or exposure duration to hazardous air pollutants in the building was used to improve IAQ (Figure 2). This study chose two study sites: HP1 and ED3, which were conducted by positive pressure and air purifiers equipped with filters is high efficiency.

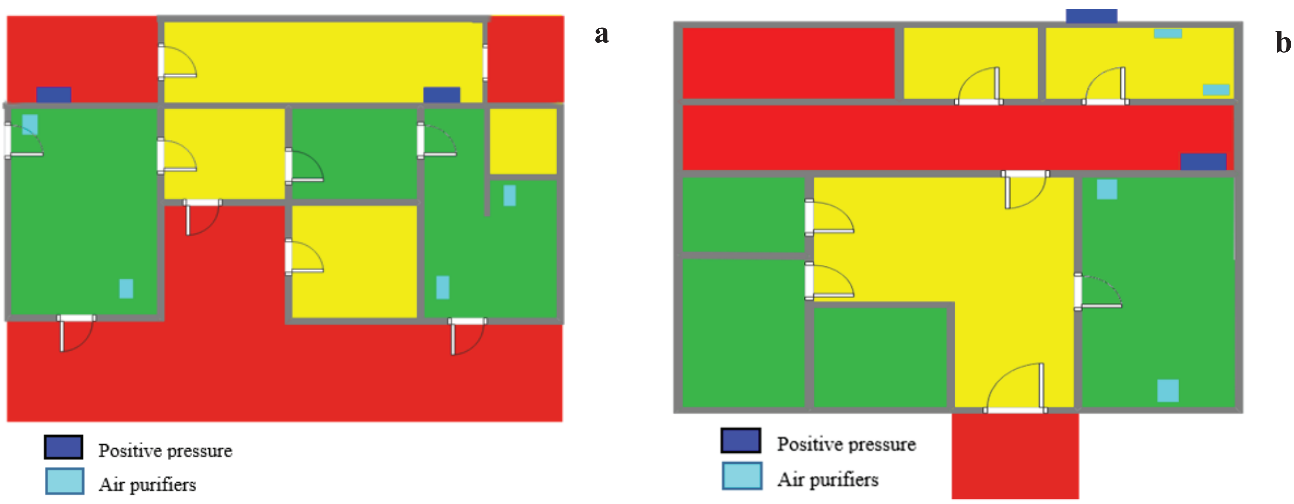

Fig. 2. (a) Building diagram and color classify room of indoor air quality control of HP. (b) Building diagram and color classify room of indoor air quality control of ED.

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3 Results

3.1 Indoor air quality measurement results

3.1.1 Sub-district Health Promoting Hospital

The thermal comfort of sampling period at 8 hours during working time of HP sites was studied. The average of air movement was 0.22±0.26 m/s, relative humidity was 60±5 % and temperature was 26.5±1.2°C. When compared between this study and the quality surveillance of public buildings from the Department of Health of Thailand. It was found that the temperature in some areas was not within the standard ranges (24.0-26.0 °C). Most of the rooms were enclosed and air-conditioned. Although some places did not use air conditioning. Thus, the temperature outside was quite low due to winter.

The air contaminants from an 8 hours sampling period during working time were studied. The results found the concentrations of CO_2 and CO were 491±54 ppm and 4.3 ± 4.6 ppm, respectively. The average concentrations of PM_{10}, $PM_{2.5}$ and PM_4 were 87.5±19.6 μg/m^3, 46.1±18.4 μg/m^3 and 55.6±19.5 μg/m^3, respectively. The concentrations of TBC and TFC were 217±103 CFU/m^3 and 493±187 CFU/m^3, respectively. However, the values of TVOCs, O_3, and CH_2O were not detected (Table 4).

Both of PM_{10} and $PM_{2.5}$ concentrations were higher than the standard value of 8 hours of PM_{10} at 50 μg/m^3 and $PM_{2.5}$ at 25 μg/m^3 for indoor air quality in office buildings specified by the Ministry of Public Health, Thailand. It might be caused by the influence of dust outside the building.

3.1.2 Early Childhood Development Center

The thermal comfort from an 8 hours sampling period during the study in the classrooms of ED sites was determined. The average air movement was 0.1±0.1 m/s and relative humidity was 58±11 %. The relative humidity inside the room was higher than the standard (50-65%) with the average temperature at 27.7±2.5°C.

However, when compared to indoor air quality in office buildings specified by the Department of Health, it was found that some temperatures of this study were not within the standard (24-26 °C).

The air contaminants of sampling period at 8 hours during a working time were studied. It was found that the CO_2 concentration was 614±149 ppm and CO concentration was 3.1±3.5 ppm. The average of concentration PM_{10}, $PM_{2.5}$ and PM_4 were 112.1±58.3 μg/m^3, 49.0±20.4 μg/m^3 and 62.3±26.4 μg/m^3, respectively, which were almost higher than the standard. The TBC was 515±234 CFU/m^3 and TFC was 548±196 CFU/m^3. However, the values of TVOCs, O_3, and CH_2O were not detected. The PM_{10} of all ED sites was higher than the surveillance value of ≤50 μg/m^3. It might be caused by the influence of dust outside the building and almost all places did not turn on air-conditioned but there used windows to ventilate instead (Table 4).

Table 4. Indoor air quality of HP and ED.

Parameters	HP			ED		
	mean	±	SD	mean	±	SD
Air Movement (m/s)	0.2	±	0.3	0.1	±	0.1
RH (%)	60	±	5	58	±	11
Temp. (°C)	26.5	±	1.2	27.7	±	2.5
CO_2 (ppm)	491.0	±	54.0	614.0	±	149.0
CO (ppm)	4.3	±	4.6	3.1	±	3.5
CH_2O (ppm)		ND*			ND*	
O_3 (ppm)		ND*			ND*	
PM_4 (μg/m^3)	55.6	±	19.5	62.3	±	26.4
$PM_{2.5}$ (μg/m^3)	46.1	±	18.4	49.0	±	20.4
PM_{10} (μg/m^3)	87.5	±	19.6	112.1	±	58.3
$TVOC_s$ (ppm)		ND*			ND*	
TBC (CFU/m^3)	217.0	±	103.0	515.0	±	234.0
TFC (CFU/m^3)	493.0	±	187.0	548.0	±	196.0

*ND = Not detected

After IAQ improvement of HP1 and ED3, the concentration of indoor parameters can be reduced within the limits required in office buildings specified by the Department of Health, Thailand.

3.2 Health risk assessment

3.2.1 Sub-district Health Promoting Hospital

Assess the Hazard Quotient (HQ) values were used to estimate the non-carcinogenic risks for indoor CO_2, CO, PM_{10}, and $PM_{2.5}$ exposure. It was observed that the HQ values for children (1 to <2 years), (2 to <3 years), (6 to <11 years), teenagers (11 to <16 years), (16 to <21 years), and adults from exposure to CO_2 in the HP were 0.6, 0.8, 0.5, 0.3, 0.2, and 0.2, respectively. The HQ value for exposure to CO of children, teenagers, and adults were 0.3, 0.4, 0.2, 0.2, 0.1, and 0.1, respectively. The HQ value for exposure to PM_{10} of children, teenagers, and adults were 1.5, 2.1, 1.2, 0.9, 0.8, and 0.6, respectively. The HQ value for exposure to $PM_{2.5}$ of children, teenagers, and adults were 1.0, 1.4, 0.8, 0.6, 0.5, and 0.4, respectively (Table 5) (Figure 3).

However, health risks from indoor pollution in HP sites were assessed. Exposure to carbon dioxide (CO_2) and carbon monoxide (CO) with HQ<1 were found, meaning the health risk was acceptable. Additionallt, PM_{10} and $PM_{2.5}$ with HQ>1 were also found, indicating there had the risk to human health. However, childhood and teenagers had more health risks than in adults.

While the hazard index (HI) for children were from 5.4 to 9.1, for teenagers were from 3.2 to 3.8 and for adults were 2.8. Which can be classified as a moderate hazard. However, the values of the children and adult groups were lower than 1 This indicated that children have higher adverse health effects from exposure to indoor air pollutants than others. Due to the pollutant intake per unit body weight of children being higher than that of adults.

3.2.2 Early Childhood Development Center

Assess the Hazard Quotient (HQ) values were used to estimate the non-carcinogenic risks for indoor CO_2, CO, PM_{10}, and $PM_{2.5}$ exposure. It was observed that the HQ values for children, teenagers, and adults from exposure to CO_2 in the ED were 1.0, 1.4, 0.8, 0.6, 0.5, and 0.4, respectively. The HQ value for exposure to CO for children, teenagers, and adults were 1.0, 1.4, 0.8, 0.6, 0.5, and 0.4, respectively. The HQ value for exposure to PM_{10} for children, teenagers, and adults were 1.7, 2.3, 1.3, 0.9, 0.8, and 0.7, respectively. The HQ value for exposure to $PM_{2.5}$ for children were 0.8, 1.1, and 0.6, teenagers were 0.5 and 0.4, in adults were 0.3.

Moreover, health risks from indoor pollution in HP sites were assessed. Exposure to carbon dioxide (CO_2) and carbon monoxide (CO) with HQ<1 were found. It means the health risk is acceptable. For PM_{10} and $PM_{2.5}$ with HQ>1 were found, meaning that there has the risk to human health. However, adults had lower health risks than in childhood and teenagers.

The hazard index (HI) for children were from 6.1 to 10.4, teenagers were from 3.7 to 4.3, and adults were 3.1. Which can be classified as a moderate hazard. However, the values of the children and adult groups were lower than 1, revealed that children have higher adverse health effects from exposure to indoor air pollutants than others. It was most likely due to the pollutant intake per unit body weight of children being higher than that of an adult. Therefore, in the long term, children will be absorbed dust in the indoor air into the respiratory tract more than adults.

Table 5. The HQ values for indoor air quality of HP and ED.

Parameters/Development			Children				Teenagers		Adults
			1 to <2 year	2 to <3 year	3 to <6 year	6 to <11 year	11 to <16 year	16 to <21 year	21 to<70 year
HP1	CO_2	Before	0.4	0.6	0.8	0.3	0.2	0.2	0.2
		After	0.6	0.8	0.7	0.5	0.3	0.2	0.2
	CO	Before	0.2	0.3	0.6	0.2	0.1	0.1	0.1
		After	0.3	0.4	0.8	0.2	0.2	0.1	0.1
	TVOC	Before	0.4	0.5	0.4	0.3	0.2	0.2	0.2
		After	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CH_2O	Before	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		After	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PM_{10}	Before	2.7	3.7	3.1	2.1	1.5	1.3	1.1
		After	1.5	2.1	1.8	1.2	0.9	0.7	0.6
	$PM_{2.5}$	Before	1.9	2.7	2.2	1.5	1.1	0.9	0.8
		After	1.0	1.4	1.2	0.8	0.6	0.5	0.4
ED3	CO_3	Before	0.9	1.3	0.5	0.7	0.5	0.5	0.4
		After	1.0	1.4	0.7	0.8	0.6	0.5	0.4
	CO	Before	1.3	1.7	0.2	1.0	0.7	0.6	0.5
		After	1.0	1.4	0.3	0.8	0.6	0.5	0.4
	TVOC	Before	0.2	0.3	0.2	0.2	0.1	0.1	0.1
		After	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CH_2O	Before	0.5	0.7	0.6	0.4	0.3	0.2	0.2
		After	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PM_{10}	Before	2.2	3.0	3.1	1.8	1.3	1.1	0.9
		After	1.7	2.3	1.8	1.3	0.9	0.8	0.7
	$PM_{2.5}$	Before	1.9	2.6	2.2	1.5	1.1	0.9	0.8
		After	0.8	1.1	1.2	0.6	0.5	0.4	0.3

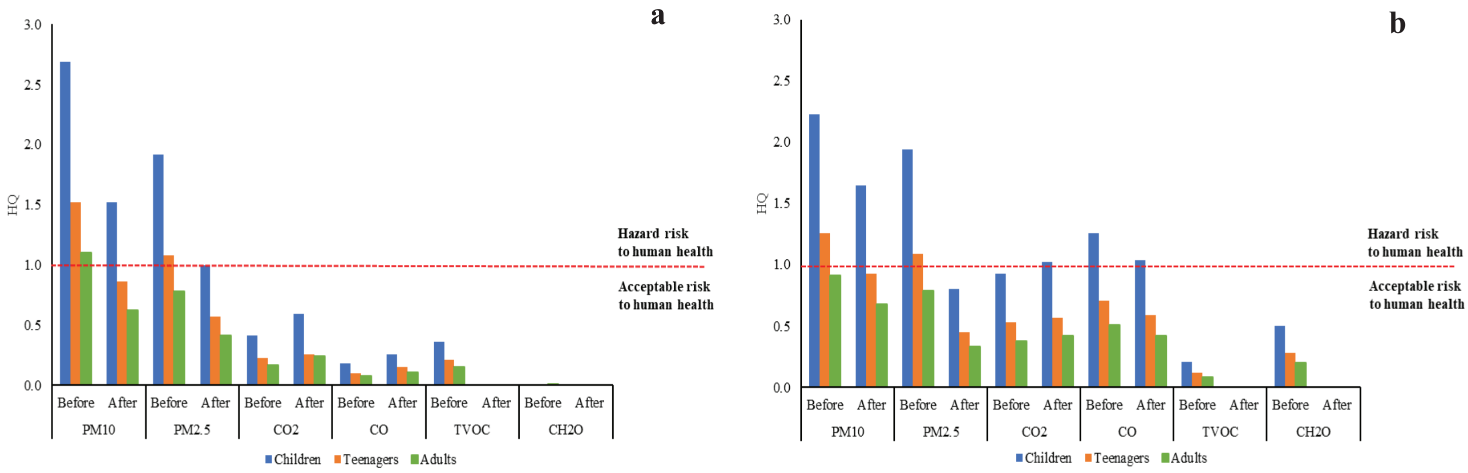

Fig. 3. (a) The HQ values from non-carcinogenic risk calculations for indoor air quality exposure in the HP. (b) The HQ values from non-carcinogenic risk calculations for indoor air quality exposure in the ED.

4 Discussions

Concentrations of indoor air pollutants were estimated in this study. The measured concentrations were later applied to assess the non-carcinogenic risks for building users who were exposed to indoor air pollutants at the HP and ED sites. Air pollutants after model development for IAQ were concerned. The concentrations of indoor parameters (PM_{10}, $PM_{2.5}$, CO_2, CO) were within the quality standards. Even though both concentrations of indoor air quality were within the air quality standard values, the HI value indicated that the children's exposure to indoor air pollutants was above the recommended limits for human health. Long-term and daily exposure of young children to air pollution at such levels could cause respiratory disease.

This study has witnessed the problem of PM_{10} and $PM_{2.5}$ accumulation within the buildings of both areas. Therefore, there was the development of clean air room for IAQ management. But the accumulation of carbon dioxide was still increasing. Although this value was not higher than the air quality measurement value of the Bureau of Environmental Health, Department of Health of Thailand it is likely to accumulate in the future. However, there should be a comprehensive study of air pollution management and building styles, such as building design, and ventilation. To find suitable building design guidelines for ventilation of indoor air pollution.

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