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The Impact of Adaptive Reusing Heritage Building as Assessed by the Indoor Air Quality
Case study:UNESCO World Heritage Site Penang

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Abstract

Being stated as the UNESCO World Heritage Site, George Town must preserve their heritage buildings according the conservation regulations in order to retain the Outstanding Universal Value (OUV). There were number of buildings that have been preserved and change its usage into new purpose. This happened in buildings, which were adaptively reused into a new usage. However, some buildings were not fully complying the conservation rules and overlooking the occupants' condition in terms of the indoor environmental condition. This inappropriateness has resulted dissatisfactions of the occupants especially the quality of the indoor air that they breathe. This paper studies about the impact of the Indoor Air Quality (IAQ) in adaptively reused heritage buildings in a government office, the George Town City Hall. This building was chosen due to the feasibility and the possibilities to conduct the research. Walk-though inspection, observation as well as 24-hour air sampling were used to collect the data. Airborne mould and chemical sampling were also conducted to monitor the IAQ level. Besides, swab sampling was also performed to confirm any biological growth on the suspected surface. The significant findings of this research noted that there were negative impacts on the occupants of the designated building due to the poor quality of the indoor air. It could be concluded that the occupants' conditions were significantly affected by the improper practice of adaptive reuse, which made worse by the occupants' activities.

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Keywords:adaptive reuse, heritage building, indoor air quality, UNESCO, penang

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1. Introduction

Buildings, as one of the built environment component, are responsible for the broad range impacts to human health and environment. It was also proven that the impact of the building to the environment is around 40 percent high (GBI, 2010). By that, it is also expected that any improvement on the building performance could reduce the negative impacts such as unhealthy occupants that leads to low work productivity. This indicates that building should be healthy, environmentally friendly, functional, low energy, aesthetics, cost affordable, and designed for all users. According to Roulet (2006), building design should ensure a good environment to its occupants where a good indoor environment is one of the main objectives of sustainable architecture. The essential factor in sustainability focuses on the occupants' satisfaction as it is also considered as the most-readily assessed indicator for sustainable factors in built environment. This is also emphasized in the Rio Declaration where human beings are at the center of concerns of sustainable development and the people should be protected.

U.S. Environmental Protection Agency (2004) had stated that in average 90 percent people spent their times indoor and indoor air that they breathe is two to five times higher in pollutant compare to the outdoor air. It could be concluded that the building occupants' health is at the high risk of impairment due to the exposure of indoor air pollution. Along with that, occupancy health in indoor environment (including office) is currently being taken into considerations. The occupants' health as well as their well-being are the main goal of Indoor Environmental Quality (IEQ). IEQ consists of four main parameters: thermal comfort, illumination level, noise level, and Indoor Air Quality (IAQ). Besides, IAQ is one of the important parameters to be assessed in green building assessment worldwide including the Green Building Index (GBI) Malaysia. Thus, this study focuses only on the IAQ of a mechanical-ventilated office building.

Office was chosen as the research object because there were many studies that have highlighted the associations between indoor stressors and comfort as well as health and productivity in an office environment (Bluyssen et al., 2011).Furthermore, office is considered as the most visible index of economic activity of social, technological, and financial progress. Therefore, the employees are required to be healthy and productive to fulfill the economic demand. Occupants' satisfaction in a building is highly concerned according to the main goal of IEQ. This condition is related with the current condition of the Malaysian office workers who spend most of their time working in air-conditioned office space and they are highly prone to hazardous indoor air contaminants during their working hours. Currently, there is a concern regarding the potential pollutant sources in an office environment, whether from the occupants' activities or from the office equipment. According to Wolkoff et al. (1993), office equipment has been found as a source of ozone (O3), particulate matter (PM), Volatile Organic Compounds (VOCs) and Semi Volatile Organic Compounds (SVOCs).

Based on the problem stated previously, there is a need to determine the IAQ level inside the office space, particularly heritage office building. The findings of this research will provide valuable data for the improvement of the heritage conservation studies in George Town, Penang and for the occupants' comfort inside an office.

2. Literature review

2.1. Indoor air quality in office environment

Indoor Air Quality (IAQ) is one of the major parameter in determining the quality of an indoor environment, be it is commercial or residential space. Based on the reference, ASHRAE Standard 62-1989 defines the acceptable indoor air quality is air in which there is no known contaminants at harmful concentrations as determined by cognisant authorities, and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction" (Yeang, 2006). IAQ has many impacts on the human comfort, health, and productivity. By improving the IAQ of a building, occupants' productivity will be increased. In most green building assessment tools, IAQ is commonly assessed together with the IEQ. It is widely proven that IEQ (including IAQ) gives a significant impact to the occupants of a building.

There are five main factors affecting IAQ, temperature, humidity, air velocity, pollutant sources, and unmaintained ventilation system (Pilatowicz, 1995).

1. Temperature

Temperature standardization helps to ensure that workers' health and comfort is assured, so that they can work optimally which in turn can increase company productivity. The standard of indoor working climate in Malaysia based on Malaysia Guideline on Occupational Safety and Health (1996) is between 20^o to 26^o Celsius. However, according to the standard established by Malaysian Standard (MS) 1525:2007 and Malaysia Green Building Index, the indoor temperature should falls between 23-36^o Celsius. Thermal discomfort can affect workers' productivity. This means the higher activity of a person, the greater the heat produced by the body.

2. Humidity

In an enclosed space, humidity is considered as a major problem. It may damage the equipment, furniture and building materials. Country with tropical climate like Malaysia has a relatively high humidity, which is equal to 60-95%. However, according to Malaysia Green Building Index and the Code of Practice on Indoor Air Quality (COP-IAQ), the threshold for the relative humidity in a working space is between 40% and 70%. If the humidity falls above 60%dehumidifier is needed to reduce humidity in the room. Excessive moisture in air will cause sense of stickiness in the skin and accelerate the emergence of the fungus on the building walls.

3. Air velocity

Good air circulation will increase the amount of water evaporation, preventing from excessive moisture and corrosion. Other advantage by maintaining good air circulation is suppressing the growth of bacteria. As studied in guidelines for occupational safety and health in office by Malaysia's Department of Occupational Safety and Health, the minimum requirement for fresh air in general office space per second per person is 10 litres for every 10 square meters of floor space and the indoor air movement should not less than 0.1 meters per second.

4. Pollutant source

In general, indoor air pollutants were classified into three major sources: chemical, physical, and biological.

a. Chemical pollutants

It could be defined as a pollutant which build up from chemical reactions and/or generated from human metabolism and combustion product like nitrogen oxide (NOx), carbon monoxide (CO), carbon dioxide (CO2), sulphur monoxide (SO), sulphur dioxide (SO2), also contribute health problems to humans. VOC are organic chemicals that easily evaporate into vapour or gas at room temperature, occasionally odourless fumes or vapours and invisible. It is generally associated with almost any fabricated or natural product. They are commonly found in paints, solvents, air fresheners, hobby supplies, automotive products, dry-cleaned clothing, moth repellents, pesticides, cleaners, disinfectants aerosol sprays, adhesives, manufactured wood panel (pressed board), and fabric additives used in carpeting and furniture. One type of VOC that is widely applied in interior is formaldehyde (HCHO or CH2O).The effects of this pungent gas can last for several hours to several years. It is likely to be more dangerous when newly applied. As the temperature rose, formaldehyde level will increase.

b. Physical pollutants

These types of pollutants are commonly associated with particles. EPA (1997) stated that particles are solid or liquid substances that are light enough to suspend in the air, the largest of which may be visible in sunbeams streaming into a room. Particles of dust, dirt, or other substances may be drawn into the building from outside and can also be produced by activities that occur in building. Particles, which easily inhaled, are generally less than 10μm (PM10). The smaller the size of the particles, the bigger possibilities being inhaled and penetrated into the respiratory system.

c. Biological pollutants

It derives from any biological or microbial contamination, which generated from people, plants, foods, and other organic substances. The main pollutants are microbes, such as bacteria (notably Salmonella and *Legionella pneumophila*), fungi, viruses, lice, plant pollen, including animal dander. According to WHO, 40 percent of "sick building" originated from microbial contamination (Pilatowicz, 1995).Fungi are one of the common microorganisms found in a damp building fabric such as on the wall or behind the wall cover as well as on the ceiling. Biological agents do contribute to human health consequences that may be described as building related disease. These include infectious disease associated with building services (e.g. Legionellosis), diseases spread from worker to worker including colds and influenza, toxic reaction to chemicals in buildings, and fungi, bacteria or their toxins present in buildings (Crook and Burton, 2010).

Poor air quality inside a building could contribute occupants' discomforts such as fatigue, excess sweating, dehydration and others. Lowered concentration due to this condition can lead to industrial accidents, decreasing productivity, and declining work efficiency. According to Muhič and Butala (2004), mechanical ventilation as well as the ventilation rate of a building is closely related with the prevalence of Sick Building Syndrome (SBS). They also stated that the occupants of the studied buildings, the air-conditioned buildings, are significantly suffered from building-related illness. The absenteeism rate is also higher for those in the air-conditioned buildings. This is also proven by a study by Wargocki et al. (2002) where occupants of air-conditioned buildings may have increased the risk of SBS compared with occupants in naturally ventilated or other mechanical ventilation system without cooling. Moreover, they also concluded that improper building design; operation as well as the maintenance system could be the contributor of the increased prevalence SBS syndrome.

2.2. Adaptively reusing heritage buildings

Heritage buildings are legacy from the past that needs to be conserved in order to prevent from being lost forever, it is also represents the cultural history that should be preserved for the next generation (UNESCO, 1972). As stated in Malaysia National Heritage Act (2005), buildings that are categorized as heritage buildings are believed to be more than 50 years old. Those building should be preserved, protected, and enhanced from being lost forever.

One conservation method that promotes sustainability is by adaptive reusing it. Adaptive reuse can be defined as modifying a place to suit the existing use and compatible in uses, which involves no change to the culturally significant fabric, changes which are significantly reversible, or changes with minimal impact (Burra Charter, Article 1.9). By adapting old building into new purpose, it helps to reduce the demand of virgin materials as well as reducing the carbon footprint. Moreover, there are several positive impacts of adaptive reuse to the influenced area. Henehan and Woodson (2004) stated that adaptive reuse is significantly affecting the economic as well as the quality of the people's life. In order to prolong the lifespan of the building, adaptive reuse can be in the form of building conservation and innovation, and should have minimal impacts on the heritage significances, on the building as well as its setting.

George Town, as one of the historical port cities in Malacca strait was inscribed by United Nations Educational, Scientific and Cultural Organisations (UNESCO) as one of the World Heritage Site because of its Outstanding Universal Value (OUV) in cultural diversity and living heritage.

Heritage buildings are prone to building defects and deterioration such as moisture problems, salt attack, unwanted plant growth, peeling paints, poor installation of air conditioning unit, termite attack, and many more. All these defects could deteriorate the building structure and fabric. Fungal growth, as a result of high moisture content, can be a great threat for the building as well as the occupants, particularly in a hot and humid climate. Fungal stain indicates the growth and proliferation of dust mites, mould, mildew, and bacteria which can result in allergic, infectious health outcomes and other adverse health effects (Mudarri and Fisk, 2007). Moreover fungi can decay building fabrics, degrade the aesthetic value and causing adverse health effects like Sick Building Syndrome (SBS) and Building Related Illness (BRI).

2.3. The selection of case study

This paper focuses only on the office space that was located in the UNESCO World Heritage Site. There were many heritage office buildings inside the UNESCO World Heritage Site in George Town, owned by the government as well as the private sector. Government office was selected as the studied building due to ease of authorization for identification. Besides, government office is expected to be an example for the heritage building conservation in Penang. The Penang City Hall (Dewan Bandaraya George Town), as illustrated in Figure 1, was chosen as the case study of this research.

Fig. 1. Penang City Hall
Source: Author's documentation (2011)

The Penang City Hall is included as the Category I building, where the designated building was declared as ancient building and gazetted formerly under the Antiquities Act 1976 (now National Heritage Act 2005). This Palladian-style building was constructed between 1900-1903 and located at the Jalan Padang Kota Lama, facing the Esplanade (refer to Figure 2). Due to the strategic location, this highly ornamented building once was occupied by the British as their administrative office. To prevent being left abandoned, currently this building is occupied by the Penang Municipal Council (Majlis Perbandaran Pulau Pinang/MPPP). This building was selected as a case study of this study due to the characteristic of the open-plan office type (refer to Figure 3).Open-plan office was designed to reduce the cost of work environment and to promote interaction among the workers by eliminating physical walls. However, open-plan offices were prone to major problems such as lack of privacy and acoustic matters (Lee, 2010).

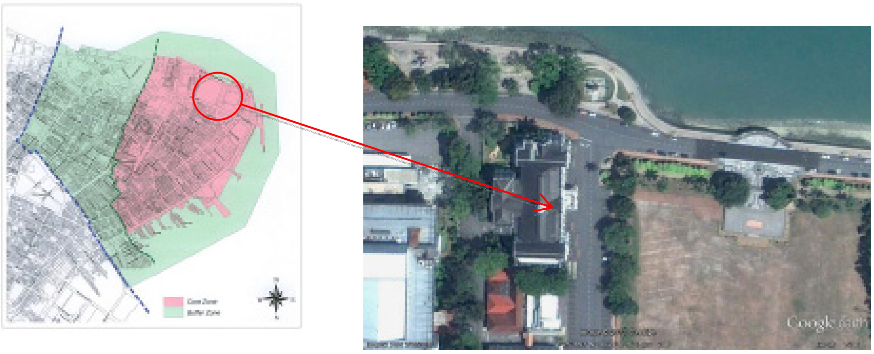

Fig. 2 The Location of the Penang City Hall
(Source: Google Earth)

Fig. 3. The selected casestudy
Source: Author's documentation (2011)

3. Methodology

To determine the quality of the indoor air in the designated office, this cross-sectional research employs both qualitative and quantitative methods.

3.1. The qualitative method

There are two qualitative methods include in this research. Firstly, site observation and the walk-though inspection. These methods were performed as a preliminary survey in order to record the physical condition of the interior and the exterior of the studied building before the IAQ sampling. The observation focused on the inside of the building that is occupied with the main concern on the potential pollutant sources emitted inside the buildings, the building layout after being adaptively reuse, the occupants' density and their activities, office equipment used, indoor vegetation, water features, position of openings, interior furnishings and furniture, evidence of water damage, and level of custodial care. The condition outside the building needs to be observed since the quality of the indoor air depends on the surrounding of the buildings, including the building location, orientation, possible external pollutants, external water resources, and the building envelope. The type, position, cleanliness of the grills/diffusers, thermostat controller, and the location of the outdoor unit of the applied Mechanical Ventilation and Air Conditioner (MVAC) systems were also inspected. Secondly, a semi-structured interview was conducted in order to gain more information regarding the occupants' activities as well as the maintenance issue. These qualitative data were used to support the air sampling result.

3.2. The quantitative method

In this research, the quantitative data was obtained from the air quality monitoring. The air quality monitoring was conducted inside and outside of the building. In the inside of the building, the measurements were taken in two spots, the highly dense occupants where the most activities occurred The parameters of the measurements were derived from the Code of Practice on Indoor Air Quality Sampling. This guideline was established by the Department of Occupational Safety and Health Malaysia in 2010.

The first parameter is physical parameter that consists of air temperature, relative humidity, and the air velocity. The measurement of the physical parameter in the studied building is by using all-in-one BABUC/A data logger.The sampling probe was located in the middle of the working spaces where the respondents are (Figure 4). The measurements ran continuously with one minute interval for 8 hours (9 am until 5 pm) in weekday, measuring the room temperature, relative humidity, and air velocity at the same time.

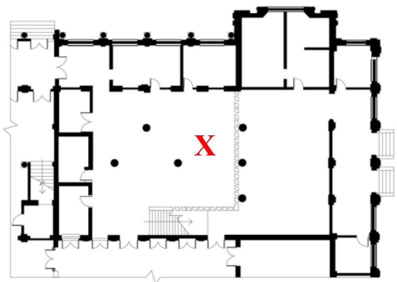

Fig. 4. Air sampling position
Source: Author's analysis (2011)

The second parameter is the chemical parameter, that is PM_{10}, CO, CO_2, and formaldehyde.CO_2 and CO was measured by using direct reading instruments, 8554 TSI Indoor Air Quality Meter. Formaldehyde also measured by using direct reading HAL-HFX 105 Formaldehyde meter. The PM10 or dust was measured by using the aerosol monitor (8520 DUSTTRACK). Figure 4 describes the position where the sampling apparatus was located for air quality monitoring.

The last parameter is the biological parameter, the Total Fungal Count (TFC) and the Total Bacterial Count (TBC). The quantity of airborne mould spore was measured by using single stage air impactor and culture plate as the growth medium. Andersen N-6 was used as the air impactor in this study. It is widely used for sampling viable and culturablemould spores. Malt Extract Agar (MEA) and Potato Dextrose Agar (PDA) were chosen as the growth medium due to its ability to isolate, cultivate and enumerating moulds, especially *Aspergillussp* and bacteria.

According to Hess-Kosa (2001), control variable is required in each sampling method as a comparison of the result at the main sampling area. It has to be in the same building and outside the building. The air impactor was located at the same point as the other sampling devices (Figure 5-X).In this research, the control variables in the studied building are the unoccupied room (Figure 5-X1) and the outside the building (Figure 5-X2). The chosen control room is determined by the similar size of the main variable (main sampling area) and the location, which is still in the vicinity of the main sampling area. The microbial agents from outdoor air has the possibility to contaminate the indoor air and generally the outdoor air has greater number than in the indoor space.

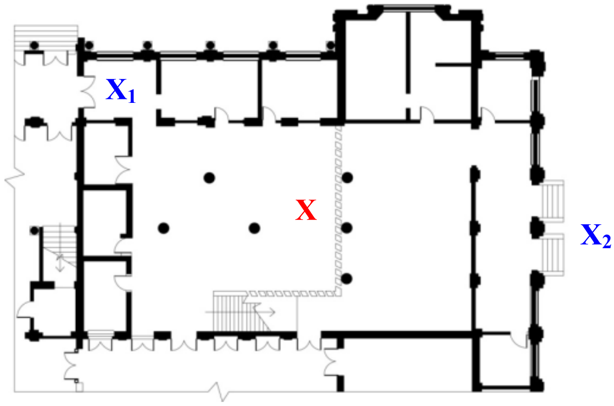

Fig. 5. Biological airsamplingposition
Source: Author's analysis

In order to collect more data on the presence of fungal spores, swab sampling was used. Swab or surface-wash sampling is a non-destructive technique and the most convenient methods of surface sampling for the determination of possible microbial contamination. In this research, swab sampling is performed using a sterilized cotton swab that can be strike to agar plates for direct examination the presence of spores. After performing all the microbial samplings, the agar plates were cultured for 3 to 4 days under an artificial lighting in a room temperature, which resembles to the human body normal temperature. In this study, the colonies were quantified starting on the first 24 hours post sampling period until the third/fourth day. Later, the colonies of the bacteria as well as the mould were quantified by using the colony forming unit per cubic meter (cfu/m3) air formula.

4. Findings and discussion

4.1. Observation

Based on the observations that had been done, it could be concluded that there were dampness found on the building fabric and there were visible fungal stains on some area (refer to Figure 6). Dusts were heavily accumulated especially on the classical building ornaments and on the ceiling fan (refer to Figure 7). Some existing doors were obstructed due to the space limitation for accommodating the users' daily activities (refer to Figure 8).In this case, inappropriate space planning also could degrade the quality of the indoor air, especially when air ventilation needs to be blocked. Due to complying the State's heritage building conservation rules, it is strictly prohibited to alter the designated building. As a result, space planning for the office workers was taken for granted.

Fig. 6. Dampness and fungalstain
Source: Author's documentation (2011)

Fig. 7. Accumulated dusts
Source: Author's documentation (2011)

Fig. 8. Obstructed door
Source: Author's documentation (2011)

4.2. Indoor air quality measurement

1. Physical parameter

Based on the results obtained from the thermal monitoring (Table 1), it shows that the indoor temperature of the studied building is above the standard stipulated, 27.5-29.7^{o}C. The measurement shows the humidity range from 56.2-74%, which is also above the standard. According to Malaysia Green Building Index, the maximum limit for indoor humidity is 70%. If the humidity falls above 70%, it is considered the ideal condition for mould spores to grow (Godish, 2001).

Table 1.Indoor airqualitymeasurementresult

Variables	Units	Result	*Benchmarks**
Physical			
Temperature	°C	27.5 - 29.7	*23 - 26*
Relative Humidity	%	56.2 - 74.0	*40 - 70*
Air Velocity	m/s	0.01 - 0.17	*0.1 - 0.5*
Chemical			
PM_{10}	mg/m^3	0.08	*0.15*
CO	ppm	0	*10*
CO_2	ppm	716	*1000*
HCHO	ppm	0	*0.1*
Microbial			
Total Fungal Count	cfu/m^3	486.8	*500*
Total Bacteria Count	cfu/m^3	303.9	*1000C*

Note: Benchmarks are referring to COP-IAQ (2010) ; C is the ceiling limit and shall not be exceeded at any time

The air velocity speed in this building is far below the standard, 0.01-0.17m/s. Low air velocity below 0.05 m/s the occupants will feel stagnant air (Bradshaw, 2006). However, air velocity speed also depends with the speed of the ventilation (mechanically and/or naturally), the building occupants' movement, and the location of the data logger. As the ambient temperature rise and natural air velocity flow is insufficient, mechanical ventilation must be increased. Nevertheless, rapid air velocity will cause unpleasant draft. Air velocity not only affects air temperature and humidity, but also removes odours and other air contaminants. This building is utilized by 9 ceiling fans, 3 wall mounted fans and centralized air conditioner system. Since the air conditioner unit is improperly functioning (low air flow), the building occupants (in this case is the employees and the clients/visitors) rely on the ceiling and wall fans. Unfortunately, there were no operable windows in this building, therefore the flow of the outdoor air is very limited. The only source of outdoor air is only from the main entrance of this office and air vent on the upper wall.

2. Chemical parameter

The first parameter is Particulate Matter (PM) or dust. It measures the inhalable dust concentration inside all five buildings. The acceptable limit for PM is 0.15 mg/m3 (COP-IAQ, 2010). Although this building is heavily accumulated with dust, the measurement shows that the PM10level is below the standard. However, the thickness of the dust deposited on a surface indicates the regularity of the cleaning service. Inhalation to dust can lead to further health disturbances such as allergies, asthma, and other building related illness, especially dust containing organic material, i.e. fungi (Storey, et al., 2004).

The second parameter in IAQ test is the chemical parameter. It consists of CO, CO_2, and HCHO. The acceptable level for indoor CO level is 10 ppm (COP-IAQ, 2010). This colourless and odourless gas is known as an emission from all combustion by-products. It occurred when there is an incomplete combustion of kerosene, gasoline, fuel, wood, plastic, and others. Unfortunately, CO was undetected in this building. This may caused by very low concentration in the air, so the presence could not detected by direct reading instruments during the air sampling period. Besides, this gas is lighter than the air (Kubba, 2009).

In this research, CO_2 is detected in this building with the concentration more than 500 ppm. These numbers is an indicator of an inadequate ventilation rate in the respective buildings. This number is also associated with the presence of occupants since CO_2 is an end product of respiratory in human beings. Based on the site observation, the studied building was lack of operable windows and depends on MVAC. The last chemical parameter is formaldehyde (HCHO). Formaldehyde is a common irritant to the eyes, nose, throat and sinuses (Godish, 2001). Fortunately, formaldehyde was undetected in this building. According to Pilatowicz (1995) and Bingelli (2006), the concentration of any airborne chemical pollutants depends on multiple factors, i.e. ventilation system, size of the building, pollutant sources (from the buildings and/or from the occupants itself), maintenance system, and many other contributing factors.

3. Biological parameter

Which quantifies the number of airborne mould spore and bacteria. As stipulated by the standard, COP-IAQ (2010), the limit for airborne fungal count is 500 cfu/m3 and 1000 cfu/m3 for airborne bacteria count. Table 2 describes the comparison between the control variable and the main variable.

Table 2. Comparison between main variable and control variable

	Main Variable	**Control Variable**	
		Unoccupied Room	**Outside the Building**
Colonies of Fungi (cfu/m^3)	486.8	202.6	851.1
Colonies of Bacteria (cfu/m^3)	303.9	364.7	405.3

Although there are numbers of visible dampness on the building fabric and accumulated dusts, the number of the airborne fungal spore in this workspace is still below the acceptable limit. Based on the measurement, the number of airborne fungal spore is 486.8 cfu/m3, where the acceptable limit is 500 cfu/m3. The total airborne bacteria count is also below the benchmark, 303.9 cfu/m3.

To confirm any fungal growth on a building fabric, swab sampling is used. The specimens were taken from the dampness on the column, swabbed into the agar plate, and then incubated for 3 to 4 days in room temperature. The incubated plate as in Figure 9 shows the colonies of fungi and other microorganisms (bacteria, yeast) were appeared. Based on the appearance of the biological agents on the incubated agar plate, it could be concluded that there were colonies of mould and other microorganisms growing on the damp wall.

Figure 9. Incubated agar plate
Source: Author's documentation (2012)

4.3. Interview

From the semi-structured interview with the building occupants, there were no cleaning services provided. Therefore, they have to clean their own workstation based on their personal initiatives. This statement also agreed by the head of the department.

Conclusion

This research is intended to measure the IAQ level in an office environment; particularly heritage building that has been adaptively reused. In order to assess the IAQ conditions, this study employed the IAQ assessment based on the green building rating system, in this case referring to the Malaysia Green Building Index (MGBI), particularly the Non-Residential Existing Building (NREB).

Based on the sampling and observation result, it could be concluded that this building is absolutely lack of maintenance in terms of the custodial matters. This heritage building should be maintained regularly and conserve it according to the guideline for heritage building conservation, both interior and the exterior. The local authority, building manager, as well as the occupants should be more aware in maintaining the heritage significance of this building. A regular maintenance is required to prolong the aesthetic as well as the lifespan of this building, and concern in terms of the occupants' satisfaction. The significant findings of this research that improper adaptive reuse could be very problematic in terms of the occupants' comfort. Based on the air sampling measurements, it shows that some of the parameters measured were in an alarming condition. Although being adaptively reused to a new purpose, the interior of the designated building must be well designed to meet the occupants' daily activities without jeopardizing their comfort. Besides, it should comply the conservation guidelines as well.

There were numbers of heritage buildings that needs to be conserved in George Town, Penang. Therefore, it needs a good collaboration from all aspects for maintaining and conserving the heritage buildings. Further research is needed to assess the IAQ of adaptively reused buildings within the vicinity of UNESCO World Heritage Site as well as Post Occupancy Evaluation

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