Malaysian Journal of Civil Engineering 23(2) :80-91 (2011)

TECHNICAL NOTE

HEALTHY INDOOR AIR ENVIRONMENT FOR PREVENTING NOSOCOMIAL TRANSMISSION OF *MYCOBACTERIUM TUBERCULOSIS* IN SUSTAINABLE HOSPITAL BUILDING DESIGN

Md Rajuna Ahmad Shakri[1,2*], Rozana Zakaria[1], Badrul Hisham Abd Samad[2], Khairulzan Yahya[1], Rosli Mohamad Zin[1], Mushairry Mustaffar[1], Muhd Zaimi Abd Majid[3], Noor Aliza Md Tarekh[4]

[1] *Construction Technology and Management Centre, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310* UTM *Skudai, Johor, Malaysia*

[2] *Johor State Health Department, Suite 12A-02, Level 12A, Menara MSC Cyberport, No.5, Jalan Bukit Meldrum, 80300, Johor Bahru, Johor, Malaysia*

[3] *Construction Research Alliance, Universiti Teknologi Malaysia, 81310* UTM *Skudai, Johor, Malaysia*

[4] *Respiratory Department and specialist consultant, Hospital Sultanah Aminah, 80100 Johor Bahru, Johor, Malaysia*

*Corresponding Author: *mdrajuna@gmail.com*

Abstract: The Sick Building Syndrome is often related to poor indoor air quality. Healthy indoor air environment is needed for a healthy hospital building. Appropriate design elements need to be implemented to accommodate the mass usage of a hospital's various facilities. Tuberculosis (TB) is an infectious disease most commonly caused by *Mycobacterium tuberculosis* (MTB) which can spread via inhalation of infected aerosols. Therefore, Health Care Workers (HCWs) in a hospital are most vulnerable to tuberculosis infection. This paper explicates the sources and factors of TB transmission in the indoor environment of Hospital Sultanah Aminah Johor Bahru, Johor, Malaysia (HSAJB). The study considered the relationship between the physical layout of the TB ward and its indoor air environment quality. This study utilized opinion from HCWs who are directly exposed to this kind of environment. The data was obtained from face-to-face questionnaire surveys. The questionnaire used the Likert scale with five ordinal measures of agreement. From the study, it was found that the source of TB transmission is from positive MTB carriers or active TB patients. Ten Indoor Air Environment Sustainability (IAES) factors related to the transmission and spread of TB which are relatively connected to space area design of TB ward.

Keywords: *Health Care Workers; Healthy Building Hospital; IAES Factors; Qualitative Data; Sustainable Indoor Air Environment, Tuberculosis.*

1.0 Introduction

Healthy indoor air environment is needed for a healthy building including the hospital. In relation to that, the room setting is important to provide better indoor air environment. The room setting takes into account the room facilities, room layout, location of room, interior finishing, air circulation system and accessibility for maintenance purposes which are vital to the design concepts of a room (Yam *et al.*, 2011). Tuberculosis (TB) is primarily an airborne disease (Joel *et al.*, 2007; Riley *et al.*, 1962) whereby the bacteria are transmitted from person to person via tiny microscopic droplets which are expelled and suspended in the air when an active TB patient coughs, sneezes, speaks, sings, or laughs. Individuals with close contact to the patient are at a high risk of acquiring TB infection (Qian *et al.*, 2007; CDC, 2000 and 2003). Health Care Workers (HCWs) refer to personnel working in a hospital. They are most vulnerable to TB infection because of the indoor air environment which contains these bacteria known as *Mycobacterium tuberculosis* (MTB) (ASHRAE, 2009; CDC, 2009).

About one in every three people carries the TB infection and is at risk for TB disease. In 2008, there was an estimated 9.4 million new cases of TB per year which is equivalent to 139 cases per population of 100,000 globally and two million deaths per year. Most cases of active TB occur in regions of Africa (55%) and Asia (30%), with small proportions of cases in the other regions (CDC, 1994). Sources from Health Fact 2010, Health Informatics Centre, Planning and Development Division, Ministry of Health Malaysia indicate that the tuberculosis communicable disease incidence rate and mortality rate per population of 100,000 are 68.25 and 5.50 respectively (Health Informatics Centre, 2009). In 2010 there were 2,088 recorded TB patients in Johor (WHO, 2009; Health Informatics Centre, 2010). Therefore HCWs are highly susceptible to MTB (Ministry of Health Malaysia, 2010; Alberto Franchi *et al.*, 2007).

The risk of MTB infection is related to several factors: organism load, ventilation of working environment, protective measures taken by the HCWs and duration of exposure to the human body. The quantity of risk varies according to the type of health care setting; the prevalence of TB in the community; the patient population served; the area of the healthcare facility in which the HCWs work; and the effectiveness of TB infection control interventions. Currently TB prevention and surveillance among HCWs under the Ministry of Health, Malaysia follow the second edition of Clinical Practice Guidelines for the Control and Management of Tuberculosis, published in 2002 (Sehulster *et al.*, 2003; Nicas *et al.*, 2005; Ministry of Health Malaysia and Academy of Medicine of Malaysia, 2002).

All these indoor air environmental quality components will come together in an ideal situation to produce an indoor air environment that satisfies all occupants. The TB colony transmission is hypothetically associated with multiple regressions. Area setting such as opening of windows or doors, placement of windows or doors to allow through-flow of air, ceiling height, floor area and wind speed can be used as a control measure of TB transmission (Azarisman *et al.*, 2008 ; CDC, 2005). The above statement invited the key problem of this research which is how can the health care setting factors be controlled in order to provide healthy indoor air environment (Daniel, 2006; Barnhart *et al.*, 1997; Cole and Cook, 1998; Griffith and Kerr, 1996; Escombe *et al.*, 2007). Thus, this study needs to first identify the sources of TB disease to understand the risks of TB infection. Secondly, the factors that influence the health care setting design also need to be considered. This will elucidate the relationship between the sources of TB disease and the factors which influence the design of health care setting that can help to provide a more sustainable indoor air environment quality.

2.0 Tuberculosis Bacteria and Indoor Environment

The risk of TB infection is higher in areas housing hospitals where there are more than 200 sputum smear positive TB patient admissions annually. The current rate of infection for HCWs is 1 to 10 percent each year (CDC, 1994). The prevalence of infection is directly proportional to the duration of employment in the hospital (ASHRAE, 2009; CDC, 2009). A TB patient spreads MTB through coughing, sneezing, speaking, singing or laughing. Only people with active TB can spread the disease to others. Individuals with close contact to the patient are at a high risk of acquiring TB infection. MTB can survive in the human body without showing any signs and symptoms. This means the bacteria is inactive (sleeping) and this is also known as latent TB infection (Qian *et al.*, 2006 ; CDC, 2000 and 2003). If the MTB becomes active, the bacteria will multiply and result in TB disease (Joel *et al.*, 2007; Riley *et al.*, 1962). TB patients who have been treated with the correct drugs for at least two weeks continuously will no longer be contagious (CDC, 2003).

Effective infection control efforts are essential in preventing nosocomial transmission of tuberculosis. Three hierarchy of control measures recommended to prevent TB transmission in health care facilities are as follows (WHO, 2004):

(i) ***Administrative controls*:** Administrative controls are most important in preventing nosocomial transmission of TB. This measure is primarily intended to reduce the risk of exposing the uninfected HCWs to tuberculosis. The measures include developing and implementing effective protocols to ensure rapid identification, isolation and treatment of TB patients. Effective work practices among HCWs should be implemented and there should be education, training and counseling about TB. Finally HCWs should be screened for TB.

(ii) ***Engineering and environmental controls*:** This measure will prevent the spread of TB and reduce the concentration of infectious droplet nuclei. These controls include local exhaust, ventilation, unidirectional airflow, general ventilation and air cleaning via filtration or ultraviolet germicidal irradiation (UVGI). Biological safety cabinets Class II should be used by laboratory personnel handling infectious material. The primary objective of designing a work place is to provide an environment that sustains the activities to be carried out within as HCWs spend most of their time in hospital facilities.

(iii) ***Personal Respirator Protection*****:** Appropriate respirator masks should be worn by HCWs when performing high risk procedures such as cough induction and bronchoscopy.

Indoor air quality is generally described in terms of air freshness and this is based on carbon dioxide level and by air purity whereas the acceptable level of health and comfort is dependent on the lack of sensory of chemical or toxicological effects of compounds in the air (ASHRAE, 2007, 2008). ASHRAE 62-2007 has defined acceptable indoor air quality as air in which there are no known contaminants at harmful concentration which is determined by cognizant Authorities and with which a substantial majority (80% or more) of the people exposed do not express a dissatisfaction (ASHRAE, 2007, 2008).

Ventilation is a process of supplying fresh air to an enclosed space in order to refresh, remove and replace the existing atmosphere. It is commonly used to remove contaminants such as fumes, dust or vapors and to provide a healthy and safe working environment. An acceptable and recommended level of ventilation is at 20 cubic feet per minutes per person for maximum indoor comfort (Mundt, 2001; Cermak and Melikov, 2006). The physiological limit on CO_2 is around 4% (40,000 ppm) by volume before people in the building's experience breathing problems. Sufficient ventilation is also needed to dispel moisture. Optimum humidity levels are reached at 30% to 60% and air temperature should not exceed 23 to 26°C (Mundt, 2001). A relative humidity higher than 60% will promote mould spore growth (Melikov, 2004; Kowalski *et al.*, 1999). Thermal comfort is a condition of mind that expresses satisfaction with the thermal environment. Thermal environments are considered together with other factors such as air quality, light and noise level in determining indoor comfort levels (Olesen and Brager, 2004). Two conditions must be satisfied to maintain indoor thermal comfort. The first involves the appropriate environmental factors and the second involves the fulfillment of the body's energy balance. These factors contribute to the complexity of evaluating thermal comfort (Olesen and Brager, 2004).

3.0 Research Methodology and Methods

This paper entailed the administration of a questionnaire survey as means of gathering the opinion of HCWs. A face-to-face questionnaire survey was selected to have respondents who are involved as the health care workers for TB related treatment.

Respondents were required to fill in only one questionnaire form. Table 1 show the questionnaire form was structured into four (4) sections.

Table 1: Structure of Questionnaire Informations

Section	Questionnaire Informations
1.0	Background data of the respondents • Respondent's Demographic.
2.0	General information on the sources of tuberculosis in hospital. • View on the main causes of tuberculosis.
3.0	Transmission of tuberculosis in hospital. • Dissemination and transfer of the tuberculosis disease.
4.0	Factors of sustainable indoor air environment for protection and control of tuberculosis transmission. • Control factors for sustainable indoor air environment. • Preference of Heating, Ventilation and Air Conditioning (HVAC) systems. • Type of protection and air disinfection system

.

The result of the data collected was summarized by using Mean value index analysis. In the data analysis, Likert's scale with five ordinal measures of agreement ranging from strongly disagree (1) to strongly agree (5) has been used in the questionnaire. The mean value index analysis for each variable was calculated by using the similar classification of the rating scale proposed by Abd. Majid (1997) and Likert scaling as follows:

$$\text{Mean Value Index} = \left[\frac{\sum_{i=1}^{5} \alpha_i x_i}{\sum_{i=1}^{5} X_i}\right] \textit{for five scale rating} \qquad \text{Eq. (1)}$$

Where,

a_i = constant expressing the weight given to i,
x_i = variable expressing the frequency of the response for i;
i = 1, 2, 3, 4, 5 and illustrated as follows:
X_1 = frequency of the 'strongly disagree' response and corresponding to $a_1 = 1$;
X_2 = frequency of the 'disagree' response and corresponding to $a_2 = 2$;
X_3 = frequency of the 'not sure' response and corresponding to $a_3 = 3$;

X_4 = frequency of the 'agree' response and corresponding to $a_4 = 4$; and
X_5 = frequency of the 'strongly agree' response and corresponding to $a_5 = 5$.

Table 2: Descriptions of the rating scale and Mean Value Index (I) of agreement which respondents used in the study.

Ordinal Numbers	Agreement	Mean Value Index (I)	Rating Scale
1	"Strongly Disagree"	$1.00 \leq (I) < 1.50$	Insignificant
2	"Disagree"	$1.50 \leq (I) < 2.50$	Less Significant
3	"Not Sure"	$2.50 \leq (I) < 3.50$	Moderately Significant
4	"Agree "	$3.50 \leq (I) < 4.50$	Significant
5	"Strongly Agree"	$4.50 \leq (I) \leq 5.00$	Very Significant

After the compilation of responses, all types of data received under different questions had been separated and gathered to answer different research objectives. The data were categorized under different variables to represent the result of the research objectives. Analysis of data according to different objectives was done by using different statistical methods such as frequency analysis and Mean value analysis. The empirical data was collected and then analyzed using the Statistical Packages for Social Sciences or SPSS 15.0 and Microsoft Office Excel 2003 software. The SPSS software established comprehensive and efficient statistical analysis of data in the form of percentage, mean, standard deviation, variance and total number of questionnaire feedbacks.

4.0 Results and Discussions

The answer selection for the questionnaire consists of predetermined answers. A total of 28 questionnaire forms were collected and then analyzed. The frequency of the answer was calculated in the form of percentage. The percentage is used to review the actual situation and the significance of the sources and factors of Tuberculosis transmission at a hospital for indoor environment sustainability. In Figure 1 below are the proportions of 23 respondents who are HCWs in two (2) categories of service working in the hospital. In this study it consists of 17.86% male and 53.57% female from the skilled worker group Support 1 such as registered staff nurses and assistant medical officers; and, 3.57% male and 25.00% female of professionals such as doctors, medical specialist officers and medical officers.

The respondents' demographic is extracted from the questionnaire forms distributed at the TB Isolation Ward and Respiratory Clinic at HSAJB. Figure 1 was presented based on the gender distribution of respondents of which 22 (78.57%) were female and 6 (21.43%) were male, and also based on the categories of service of the HCWs which comprised of 8 (28.57%) professionals and 20 (71.43%) skilled workers.

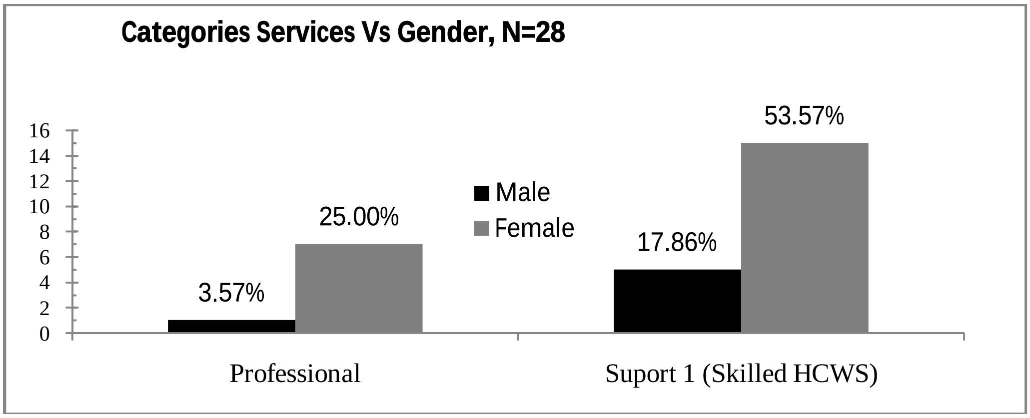

Figure 1:Respondents (HCWs) by Gender and Job Category.

The main source of TB disease is from presence and spread MTB and followed by carriers who delay seeking treatment, both of which resulted in significant mean value index of 4.75 (95.00%) respectively. Illegal immigrants also contributed to the high incidence rate of TB as they are usually carriers who have not undergone TB infection screening. The level of agreement resulted in a mean value index of 4.46 (89.29%). Figure 2 shows the findings for the main sources of active TB disease in indoor air environment.

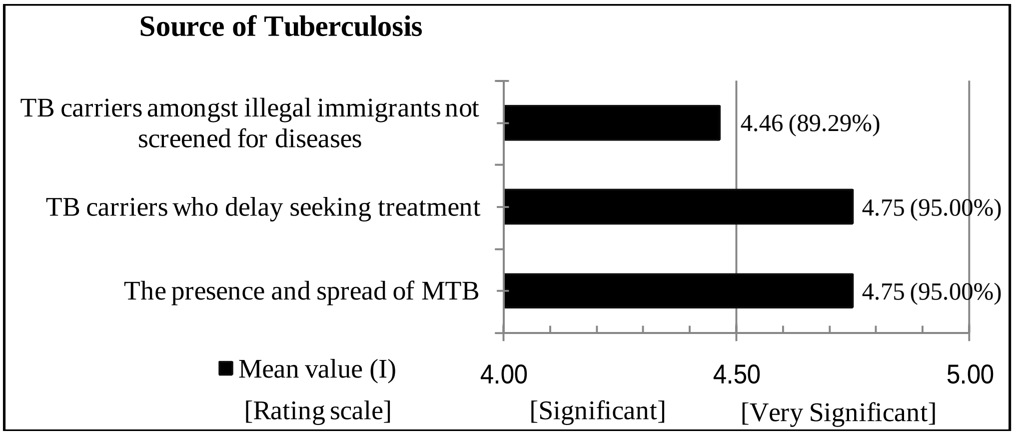

Figure 2: Main Source of active TB disease in indoor environment.

The transmission medium of MTB is the droplet nuclei suspended in the air which are produced when a TB carrier coughs or sneezes. Air contaminated with MTB droplets will be inhaled by people in the surrounding and infect the lung. Figure 3 shows the significant level of agreement for the transmission medium with the highest mean value index of 4.93 (98.57%) recorded for TB spread via droplet nuclei in the air. This is followed by MTB spread by cough or sneeze droplet nuclei with a mean value index of 4.86 (97.14%). The third most significant transmission medium is inhalation of MTB by surrounding people with mean value index of 4.71 (94.29%) and lastly MTB infection in the lung at mean value index of 4.39 (87.86%).

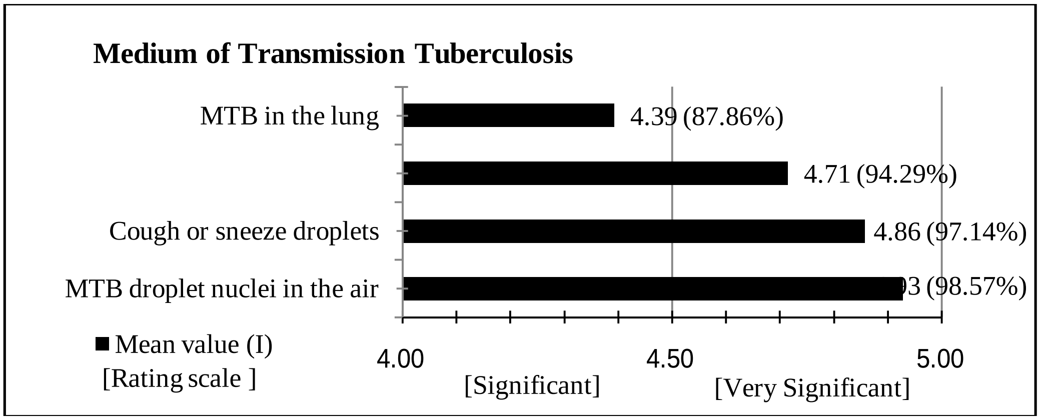

Figure 3: The mean value and rating scale of significant level of agreement from respondent for transmission medium of TB disease infection.

Figure 4 represents the finding for sustainability factor of TB disease transmission protection and control. The mean value index from Table 2 was used to determine the response for each factor related to the TB disease in Figure 4. The lighting shows the highest mean value that is 4.18 (83.57%) while the lowest is humidity with mean value of 3.75 (75.00%). All the factors are significant causes of tuberculosis transmission as all ten results show mean value index of more than 3.50 (70.00%).

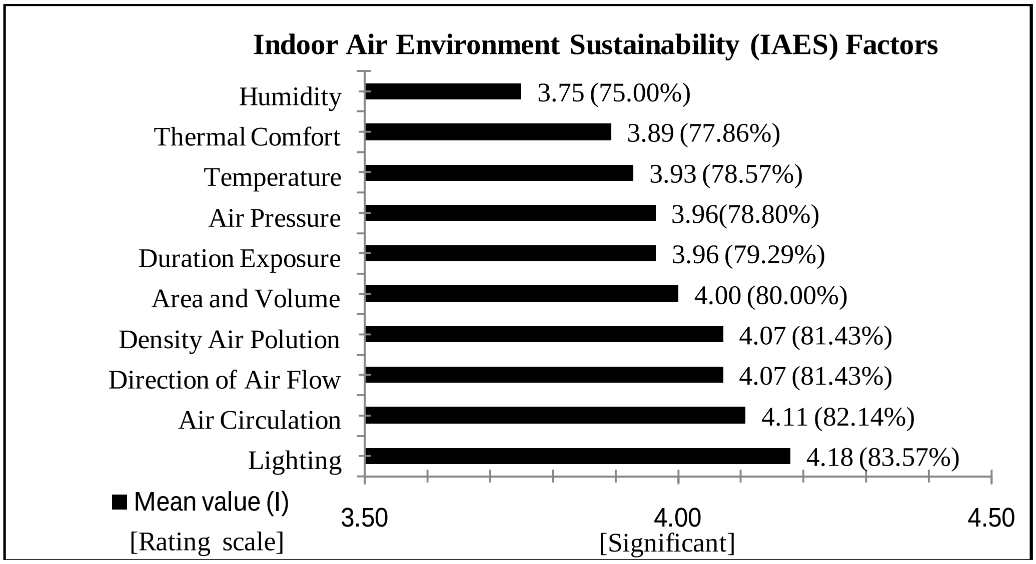

Figure 4: The mean value index and rating scale of significant level of agreement from respondents for Indoor Air Environment Sustainability (IAES) factors related to the transmission and spread of tuberculosis.

5.0 Conclusions

The findings of this study identifies the various sources and factors of MTB transmission in an indoor environment. The Ministry of Health Malaysia, HWCs and other governing agencies (such as Department of Occupational Safety and Health (DOSH)) need to combine forces in order to prevent the spread of TB. This can be done by controlling the health care setting layout of hospitals especially for the TB isolation ward. Lack of consideration for sustainable indoor environment will result in increased exposure of TB to HCWs and the public. It is found that TB transmission starts from TB carriers who produce MTB droplet nuclei which are suspended in the air when coughing and sneezing. Thus, when humans inhale the contaminated air, the MTB will sit in their lungs and become active if no proper medication is administered. This study also determined that there are various factors which influence the transmission of TB. Lighting, air circulation and exchange, direction of air flow, density of MTB in indoor air and duration of exposure are among the significant factors that need to be considered in designing the layout of TB wards. Elements of thermal comfort and its related factors such as air pressure, room temperature and humidity are also important aspects to be justified in designing the health care setting for TB isolation wards. The control of the physical design of TB isolation wards has to be given utmost attention by the Ministry of Health Malaysia. This study therefore recommends detailed measurement of optimum ventilation and thermal comfort related to room setting such as room size, presence of window and door, floor area and height of ceiling. This study will benefit future TB isolation ward development which will provide healthier and safer indoor air environment.

Acknowledgements

This survey was funded by a scholarship from the Ministry of Health Malaysia (MoH) and Construction Technology and Management Centre, Faculty of Civil Engineering, Universiti Teknologi Malaysia with the University Research Grant (GUP-UTM): PY/2011/0078, Vot: Q.J130000.7122.00J87 and Ministry of Higher Education Malaysia (MoHE). The authors confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. The National Institutes of Health registration number is NMRR-10-68-5182 approved by the Director of Institute for Medical Research (IMR) to conduct research in the MoH. The authors gratefully acknowledge and thank the Johor State Director of Health Department; Hospital Director of Hospital Sultanah Aminah Johor Bahru, Johor, Malaysia; Chairman of Medical Research and Ethics Committee, MoH, for the permission and support in this survey.

References

Abd.Majid, M.Z. (1997) Non-Excusable Delays in Construction. Department of Civil and Building Engineering, *Loughborough University*, Leicestershire, UK, Ph.D. Thesis.

Alberto Franchi, Luca Richeldi, Giovanni Parrinllo and Giuliano Franco. (2007) Room size is major determinant for tuberculin conversion in health care workers exposed to multidrug resistant tuberculosis patient. *Int Arch Occup Environ Health*, **80,** 533-538.

ASHRAE (2007) Ventilation for Acceptable Indoor Air Quality, Atlanta GA. *American Society of Heating, Refrigerating and Air Conditioning Engineers*, (ASHRAE Standard 62-2007).

ASHRAE (2008) Ventilation for Health Care Facilities, Atlanta GA. *American Society of Heating, Refrigerating and Air-conditioning Engineers*, (ASHRAE Standard 170-2008).

ASHRAE (2009) ASHRAE Position Document on Airborne Infectious Diseases. *Atlanta GA, American Society of Heating, Refrigerating and Air Conditioning Engineers.*

Azarisman SMS, Hadzri HM, Fauzi RA, Faizal M.P.A., Roslina M.A. and Harun R. (2008) Compliance to national guideline on the management of chronic obstructive pulmonary disease in Malaysia: a single center experience. *Singapore Med J*, **49** (11), 886-896.

Barnhart, Sheppard, Beaudet, Stover B. and Balmes J. (1997) Tuberculosis in health care setting and the estimated benefits of engineering control and respiratory protection. *J Occup Environ Med*, **39** (9), 849-885.

Centers for Disease Control and Prevention (1994) Guidelines for the preventing the transmission of mycobacterium tuberculosis in Health Care facilities. *American Thoracic Society, CDC and Infectious Diseases Society of America*, MMWR 1994; **43** (No. RR-13).

Centers for Disease Control and Prevention (2000) Targeted tuberculin testing and treatment of latent TB infection. *American Thoracic Society, CDC and Infectious Diseases Society of*

America, *MMWR 2000*; **49** (No. RR- 6).

Centers for Disease Control and Prevention (2003) Treatment of Tuberculosis. *American Thoracic Society, CDC and Infectious Diseases Society of America, MMWR 2003*; **52** (No. RR-11).

Centers for Disease Control and Prevention (2005) Guidelines for preventing the transmission of Mycobacterium tuberculosis in health-care settings. *American Thoracic Society, CDC and Infectious Diseases Society of America*, *MMWR* 2005; **54** (No. RR-17).

Centers for Disease Control and Prevention (2009) Questions and answers about Tuberculosis. s.I., s.n.

Cermak R and Melikov AK. (2006) Air quality and thermal comfort in an office with underfloor, mixing and displacement ventilation. *International Journal of Ventilation*, **5** (3), 323-332.

Cole E and Cook C. (1998) Characterization of infectious aerosols in health care facilities: an aid to effective engineering controls and preventive strategies. *Am J Infect Control*, **26** (4), 453–64.

Daniel TM. (2006) The history of tuberculosis, *Respiratory Medicine*, **100** (11), 1862-1870.

Department of Building Services Engineering of Hong Kong Polythechnic University. (1998) Indoor Environment Quality.

Escombe AR, Oeser CC, Gilman RH, Navincopa M, Ticona E, Pan W, Martínez *C.* Chacaltana J, Rodríguez R, Moore DA, Friedland JS and Evans CA. (2007) Natural ventilation for the prevention of airborne contagion. *PLoS Med.*, **4** (2), e68.

Griffith D and Kerr C. (1996) Tuberculosis: disease of the past, disease of the present. *J Perianesth Nurs*, **11** (4), 240–5.

Health Informatics Centre (2010) Planning and Development Division, Ministry of Health Malaysia, *Health Fact 2010*, p.6. s.I.,s.n.

Joel DE, Giraldina TN, Niaz B. (2007) Genomics and evolution, pathogenesis and diagnosis of tuberculosis. *The Journal of Clinical Investigation*,117 (7), 1738-1745.

Kowalski, ladyslaw W, Bahnfleth, William P. and Whittam, T.S. (1999) Filtration of Airborne Microorganisms: Modeling and Prediction. *ASHRAE Transactions*, Part **2**, 105,

Melikov AK. (2004) Personalized ventilation. *Indoor Air*, **14** (Suppl. 7), 157–167.

Ministry of Health Malaysia (2010) Annual Report of TB registry 2010.s.I., s.n.

Ministry of Health Malaysia and **Academy of Medicine of Malaysia**. (2002) *Clinical Practice Guidelines for the Control and Management of Tuberculosis 2nd Edition*, 45-47.

Mundt E. (2001) Non-buoyant pollutant sources and particles in displacement ventilation. *Building and Environment*, **36**, 829–836.

Nicas M, Nazaroff WW, Hubbard A. (2005) Towards understanding the risk of secondary airborne infection: emission of respirable pathogens. *J Occup Environ Hyg*, **2** (3), 143–54.

Olesen BW and Brager GS. (2004) A Better Way to Predict Comfort: The New ASHRAE Standard 55-2004. *ASHRAE Journal*, 21-26.

Qian H, Li Y, Nielsen PV, Hyldgaard C.E., Wong T.W., and Chwang A.T.Y. (2006) Dispersion of exhaled droplet nuclei in a two-bed hospital ward with three different ventilation systems. *Indoor Air*, **16**, 111–128.

Riley RL, Mills CC, O'grady F, Sultan, L. U., Wittstadt, F. and Shivpuri,. D. N. (1962) Ultraviolet irradiation of infected air: Comparative infectiousness of different patients, Infectiousness of air from a tuberculosis ward, *Am Rev Respir Dis*. 1962 Apr; **85**, 511-25

Sehulster L, Chinn RY, CDC, HICPAC (2003) Guidelines for environmental infection control in health-care facilities. *Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC), MMWR* Recomm Rep. 2003 Jun 6; **52** (RR-10): 1-42.

World Health Organization, Regional Office for South-East Asia and Regional Office for Western Pacific (2004) Practical guidelines for infection control in health care facilities, *SEARO Regional Publication* No. 41.

World Health Organization. (2009) *Global tuberculosis control: a short update to the 2009 report.* Geneva, WHO/HTM/TB/2009.426, p.4. s.I., s.n.

Yam R, Yuen PL, Yung R, and Choy T. (2011) Rethinking hospital general ward ventilation design using computational fluid dynamic. *Journal of Hospital Infection*, 77, 31-36.