Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 10 (13): 1300-1306, 2010
ISSN 1812-5654

Assessment of Environmental Factors and Thermal Comfort at Automotive Paint Shop

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Abstract: This study highlight the assessment of environmental factors and comfort levels of a ventilated paint shop area. The study was carried out at an automotive components assembly factory. The environment examined was the relative humidity (%), air temperature (°C) and CO_2 (ppm) of the surrounding workstation area. The environmental factors were measured using thermal comfort apparatus, which is capable to measure simultaneously those mentioned environmental factors. The time series data of fluctuating level of factors were plotted to identify the significant changes of factors. Then the thermal comfort of the workers was assessed by using ISO Standard 7730 and thermal sensation scale by using Predicted Mean Vote (PMV). Further Predicted Percentage Dissatisfied (PPD) is used to estimate the thermal comfort satisfaction of the occupant. Finally the PMV and PPD were plotted to present the thermal comfort scenario of workers involved in related workstation. The thermal comfort assessment of this workplace which is warm following by thermal sensation and likely to be dissatisfied by the occupant. Finally, the outcomes of 7 surveys response to the environmental factor questions are discussed.

Key words: Thermal, comfort, environment, satisfaction

INTRODUCTION

Thermal and atmospheric conditions in an enclosed space are usually controlled in order to ensure (1) the health and comfort of the occupants or (2) the proper functioning of sensitive electronic equipment, such as computers, or certain manufacturing processes that have a limited range of temperature and humidity tolerance (Vaughn, 2006). Other than that, ventilation is one of important thing to produce comfortable at the workstation in building. The ventilation of building is used to maintain indoor air quality and thermal comfort. In order to attain these objectives, airflow rate should be controlled. The minimal airflow rate is determined by indoor air quality requirements so that the maximal concentration for every pollutant is lower than the maximum admitted. Thermal comfort is influenced by air parameters (temperature, humidity, velocity and turbulence) and surface temperatures (walls, windows) but also by the type of human activity and clothing.

Thermal comfort has a great influence on the productivity and satisfaction of indoor building occupants (Great Britain Health and Safety Executive Staff, 1999). Thermal comfort is very difficult to define. This is because we need to take into account a range of environmental and personal factors when deciding on the temperatures and ventilation that will make feel comfortable. The best that we can realistically hope to achieve is a thermal environment which satisfies the majority of people in the workplace, or put more simply, 'reasonable comfort' (Parsons, 2000).

Thermal comfort can be defined as that condition of mind which expresses satisfaction with the thermal environment (Son *et al*., 2008). The reference to 'mind' indicates that it is essentially a subjective term; however, there has been extensive research in this area and a number of indices exist which can be used to assess environments for thermal comfort (Shek and Chan, 2008). Fanger (1970) suggested three conditions for comfort; these are that the body is in heat balance and that the mean skin temperature and sweat rate are within limits required for comfort. Conditions required for heat balance can be derived from a heat balance equation. Mean skin temperatures and sweat rates that are acceptable for comfort have been derived from empirical investigation (Holmes and Hacker, 2007).

Predicted Mean Vote (PMV) is a parameter for assessing thermal comfort in an occupied zone based on the conditions of metabolic rate, clothing, air speed besides temperature and humidity. PMV values refer the ASHRAE Handbook (2005) thermal sensation scale (Son *et al*., 2008) that ranges from -3 to 3 as follows:

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3 = hot, 2 = warm, 1 = slightly warm, 0 = neutral, -1 = slightly cool, -2 = cool, -3 = cold.

Predicted Percentage Dissatisfied (PPD) is used to estimate the thermal comfort satisfaction of the occupant. It is considered that satisfying 80% of occupant is good; that is, PPD less than 20% is good (Guan *et al*., 2003).

Without ventilation, a building's occupants will first be troubled by odours and other possible contaminants and heat (Atmaca *et al*., 2007). When we discuss about heat, actually automatically discuss about thermal comfort building's occupant. In most cases, buildings are erected to protect their occupants from the external environment (e.g., extreme temperatures, wind, rain, radiation etc.) and to provide them with a good indoor environment. Proton Factory is using natural ventilation. This ventilation is different with mechanical ventilation. Three objectives of natural ventilation are indoor air quality, thermal comfort and energy savings (Atmaca *et al*., 2007).

The good building design characteristic, including both the engineering and non engineering disciplines, might be summarized as follow (Todoroviv, 2004):

- Meets the purpose and needs of the building's owners/managers and occupants
- Meets the requirements of health, safety and environmental impact as prescribed by codes and recommend by consensus standards
- Achieves good indoor environment quality which in turn encompasses high quality in the following dimensions: thermal comfort, indoor air quality, acoustical comfort, visual comfort
- Creates the intended emotional impact on the building's occupants and beholders

Improving workers' productivity, occupational health and safety are major concerns of industry, especially in developing countries. However, these industries are featured with improper workplace design, ill-structured jobs, mismatch between workers' abilities and job demands, adverse environment, poor human-machine system design and inappropriate management programs (Roberto *et al*., 2008). Light, noise, air quality and the thermal environment were considered factors that would influence the acceptability and performance on the occupants of premises (Nishi and Gagge, 1977). ISO 7730 (2006) stated that lower emotional health is manifested as psychological distress, depression and anxiety, whereas lower physical health is manifested as heart disease, insomnia, headaches and infections. These health problems could lead to organizational symptoms such as job dissatisfaction, absenteeism and poor work quality. Irritated, sore eyes and throat, hoarseness, stuffy congested nose, excessive mental fatigue, headache and unusual tiredness were all signs of the negative workplace environmental conditions (Fanger, 1970).

Previous research done by Moss (1998) showed that the work environments were associated with perceived effects of work on health. This research used a national sample of 2048 workers who were asked to rate the impact of their respective jobs job on their physical and mental health. Regression analyses proved that the workers' responses were significantly correlated with health outcomes. In addition to this, Shikdar and Sawaqed (2003) pointed out that there was high correlation between performance indicators and health, facilities and environmental attributes (Nishi and Gagge, 1977). In other words, companies with higher health, facilities and environmental problems could face more performance related problems such as low productivity and high absenteeism. Employees with complaints of discomfort and dissatisfaction at work could have their productivity affected, result of their inability to perform their work properly (Hamdi *et al*., 1999).

Increased attention had focused on the relationship between the work environment and productivity since the 1990s. Laboratory and field studies showed that the physical and chemical factors in the work environment could have a notable impact on the health and performance of the occupants and consequently on the productivity. Workplace environmental conditions, such as humidity, indoor air quality and acoustics have significant relationships with workers' satisfaction and performance (Moss, 1998; Fisk, 2000; Czubaj, 2002). Indoor air quality could have a direct impact on health problems and leads to uncomfortable workplace environments (Ferng and Lee, 2002; Wilson, 2001; Shek and Chan, 2008). Dua (1994) stated that lower emotional health is manifested as psychological distress, depression and anxiety, whereas lower physical health is manifested as heart disease, insomnia, headaches and infections. These health problems could lead to organizational symptoms such as job dissatisfaction, absenteeism and poor work quality. Irritated, sore eyes and throat, hoarseness, stuffy congested nose, excessive mental fatigue, headache and unusual tiredness were all signs of the negative workplace environmental conditions (Tarcan *et al*., 2004). Previous research done by Ettner and Grzywacz (2001), showed that the work environment were associated with perceived effects of work on health. This research used a national sample of 2048 workers who were asked to rate the impact of their respective jobs job on their physical and mental health.

In other words, companies with higher health, facilities and environmental problems could face more performance related problems such as low productivity and high absenteeism. Employees with complaints of discomfort and dissatisfaction at work could have their productivity affected, result of their inability to perform their work properly (Leaman, 1995).

Thermal comfort surveys in tropical countries near to the equator have been actively assessed by researchers since 1949 (De Dear and Leow, 1990; Zain-Ahmed *et al*., 1998; Feriadi and Wong, 2004). The importance of comfort generally in a building design has been widely translated into several comfort types (Butcher, 2006; ISO 7730, 2006) of which the most influential and most studied is thermal comfort. Naturally ventilated buildings designs can perform efficiently in hot climate countries, like Malaysia because of their low evaporation rate, long hours of sunshine, high relative humidity and very overcast cloud cover (Ahmed *et al*., 2002). In Malaysia, thermal comfort assessments on naturally ventilated building have been conducted in low cost housings, traditional Malay houses, terraced houses, walk-up flats (Jones *et al*., 1993; Zainazlan *et al*., 2007) and class-rooms but none have been conducted in high-rise domestic buildings. Malaysia is a maritime country close to the equator. It has abundant sunshine but it is rare to have a full day with a completely clear sky. The average sunshine is around 6 h. The daily range of temperature in Malaysia is from a low of 24°C up to 38°C with the lowest temperature usually recorded during the night. Relative humidity can be as low as 42% to as high as 94%. Malaysia's annual evaporation rate is about 4-5 mm per day depending on the cloud cover and air temperature. Because of its hot and humid climate, cooler days are often recorded with low evaporation rate, high relative humidity value, cloudier sky (7 oktas) and wet while warmer days are usually the opposite. As a country that is progressing towards an energy consumption conscious target, buildings are designed to enable natural ventilation. However, a naturally ventilated building cannot give a thermally comfortable environment in Malaysia. At the very least a ceiling fan needs to be installed to lessen the heat gain indoors (Zainazlan *et al*., 2007).

The study observed a good environmental factors practices in the paint shop workstation, whereas illuminance, humidity, temperature is available for thermal comfort purposes.

MATERIALS AND METHODS

Malaysia Automotive Industry has offered the team for conducting this study in their Paint Shop Department. This study was conducted from 2007 to 2009. The department unit was manned with 7 staff and working with two shifts operation. The operation shifts are scheduled from 06:45 am to 15:20 pm for the morning shift and 15:00 pm to 23:00 pm is the evening shift. The paint shop activities are to paint the metal parts, plastics parts or combination of plastics and metal parts. The design of the paint shop is using the process based arrangement with the capacity of producing 600 to 700 parts per shifts.

The Thermal Comfort Measurement (TCM) equipment was used to measure physical data for the indoor environment as shown in Fig. 1. This equipment can measured air temperature, radiant temperature, air velocity, relative humidity, room pressure, noise, illumination and CO_2. The TCM machine was placed at the workspace area for duration of approximately 6 h starting from 09:00 am to 16:45 pm to measure the 8 parameters above.

In this study, 7 personnel from paint shop workstation have been involved. The participants' ages is varied between 20 to 25 years old with range of 3-7 years service period with the organization. All personnel in this unit are male. The personal data such as age, gender, weight, height were obtained by questionnaire.

A questionnaire form was distributed to the 7 personnel of morning shift for their anthropometrics data. Due to time constrain and limited sources, the study only focus to the one shift (morning) on November 2009. Table 1 shows the anthropometric data for the respective shift personnel.

The workstations and tools was design and it can be observed from Fig. 2-5. The Fig. 2 below shows the

Table 1: Tabulation of the personnel details

Age	20-25 years old
Gender	Male
Height	155-175 cm
Weight	60-80 kg
Work experience	3-7 years

Fig. 1: Thermal Comfort Measurement (TCM) equipment

Fig. 2: Finished product trolley

Fig. 3: Usage of foldable bin helps operators to transfer product easier and comfort

Fig. 4: Operators sitting on the stool to perform works

finished product trolley after the paint. Figure 3 shows usage of foldable bin helps operators to transfer product easier and comfort. As shown in Fig. 4, operators sitting on the stool to perform works. From the Fig. 5 we can see that operators try to push the bin filled with unfinished product.

Fig. 5: Operators try to push the bin filled with unfinished product

RESULTS

Figure 6 shows the results PMV and PPD obtained from preliminary analysis of thermal comfort. The results PMV index in this station between 2.1 to 2.8. Meanwhile, the PPD is around 81.1 to 97.8%. The thermal comfort assessment of this workstation is almost hot. Following the thermal sensation scale the best or comfort workstation is scale neutral or 0 of PMV. Meanwhile, the metabolic rate was 93 W m^{-2} (light industry) although the clothes value was 0.9 clo. So, as a conclusion, this station is not comfort. This is because the thermal sensation is warm and almost hot. The relative humidity as shown in Fig. 7 almost constant trending throughout the day. It ranges around 60 to 80%. High humidity was observed during morning session and it started to reduce in the before the lunch break. However, after the lunch break, the relative humidity started to increase again due to rainy weather outside the working area. The finding was also consistent with the air temperature profile recorded.

The radiant temperature profile is also consistence with air temperature profile recorded during the experiment. Low radiant temperature is observed during the morning session and start to increase after 11:00 am. This is consistence with increasing air temperature inside the working area and also starting of oven operation for drying the products. However, after the lunch break, the radiant temperature started to reduce due to rainy weather outside the working area and increase back when the rains stopped.

Starting with values, slightly above 50 lux the illuminance as illustrated in Fig. 8 increases to values around 100 to 200 lux during the remaining day by trending. It is contributed by the sunny weather outside the working area. During the lunch break time, it is again clearly indentified that the illuminance level decreases to

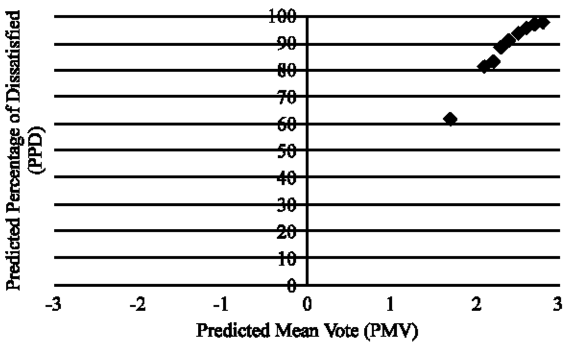

Fig. 6: PPD as a function of PMV measured at the paint shop station

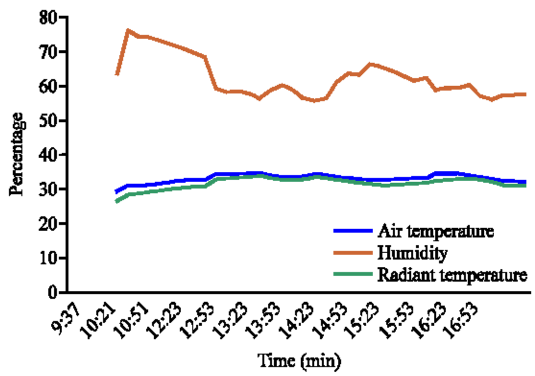

Fig. 7: Humidity, radiant temperature and air temperature measured at the paint shop station1

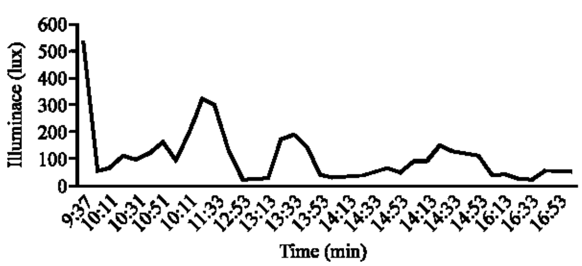

Fig. 8: Illumination measured at the paint shop station

less than 50 lux since they switch off the light. After the lunch break, the illuminance level remains quite constant between 50 to 100 lux. The level is reduced since weather outside the working area is rainy even though all lights were switched on.

DISCUSSION

In this section of the study, improving workers' productivity, occupational health and safety are major concerns of Automotive Industry, especially in Malaysia. This statement is in agreement with Vaughn (2006) findings which showed that maximum productivity occurs under this condition and that industrial accidents increase at higher and lower temperatures. He also said postural awkwardness due to a cold feeling. But contrast at Malaysia industries situation postural awkwardness occurs because of hot feeling. The reason for this is the climate of Malaysia. Malaysia industries are featured with improper workplace design, ill-structured jobs, mismatch between workers' abilities and job demands; adverse environment, poor human-machine system design and inappropriate management programs. A strong relationship between light, noise, air quality and the thermal environment were considered factors that would influence the acceptability and performance on the occupants of premises has been reported in the literature. For example, Dua (1994) stated that lower emotional health is manifested as psychological distress, depression and anxiety, whereas lower physical health is manifested as heart disease, insomnia, headaches and infections. The most interesting finding was that these health problems could lead to organizational symptoms such as job dissatisfaction, absenteeism and poor work quality in 10 years coming. Irritated, sore eyes and throat, hoarseness, stuffy congested nose, excessive mental fatigue, headache and unusual tiredness were all signs of the negative workplace environmental conditions. Asked to rate the impact of their respective jobs job on their physical and mental health. What is surprising is that the regression analyses proved that the workers' responses were significantly correlated with health outcomes. This finding is in agreement with Shikdar and Sawaqed (2003) indings which showed that there was high correlation between performance indicators and health, facilities and environmental attributes. In other words, companies with higher health, facilities and environmental problems could face more performance related problems such as low productivity and high absenteeism. Employees with complaints of discomfort and dissatisfaction at work could have their productivity affected, result of their inability to perform their work properly.

This study confirms that environment factor more influence the productivity is associated with Fisk (2000) They find the productivity was one of the most important factors affecting the overall performance to any organization, from small enterprises to entire nations. These findings further support the idea by Ismail *et al.* (2008). From the result of their study, it can be said that working environment that caused heat/sweat is the most significant discomfort in the job satisfaction analysis. Increased attention had focused on the relationship between the work environment and productivity since the 1990s. Laboratory and field studies showed that the physical and chemical factors in the work environment could have a notable impact on the health and performance of the occupants and consequently on the productivity. Workplace environmental conditions, such as humidity and indoor air quality have significant relationships with workers' satisfaction and performance. Indoor air quality could have a direct impact on health problems and leads to uncomfortable workplace environments. These finding are rather disappointing. When we are referring to air temperature in the context of thermal comfort, we are discussed about the temperature in the space where the person is located. This temperature changes from head to toe and can change with time depend on workplace and metabolism. The present findings seem to be consistent with other research (Vaughn, 2006) which found heat is produced in the body as a result of metabolic activity. The age of workers in this workstation is under 25 and youth. In this level of age, the metabolism rises to peak production. In this workplace the workers sitting is close from large window on a cloudy. There is reason air temperature higher than radiant temperature. Furthermore, environmental factors are not only the reason of dissatisfaction in this workstation but the facilities in this workstation also the reason discomfort of occupant. For example, the fan is not enough for this workstation.

Future studies on the current topic are therefore recommended. Further research should be done to investigate the environment factor weakness for increase productivity and getting occupant health and safety. This is an important issue for workers in the industry.

CONCLUSIONS

Based on the study, it can be concluded that personal awareness on the environment factor knowledge plays a vital roles in determining the correct action and practices during the working activities. Finally, due to limitation of data, the study unable to address thermal comfort and to identify the thermal comfort effect to the operators and it productivity. Thermal interactions between human body and its environment are very influence.

This research has thrown up many questions in need of further investigation. After the observation several point of jobs can be improve as follows:

- Study the ventilation system to bring down the air temperature lower than 30°C
- Re evaluate the plant process layout and minimize the product movement between one station to another but give spaces to workers to stretch their body correctly
- Increase number of fan to increase wind circulation especially for baking oven area
- Increase the luminance is the most important part to consider since the analysis results the lighting at workplace far beyond the recommend value 750 lux base on IESNA (Rea, 2000)

REFERENCES

Ahmed, A.Z., K. Sopian, Z.Z. Abidin and M.Y.H. Othman, 2002. The availability of daylight from tropical skies a case study of Malaysia. Renewable Energy, 25: 21-30.

ASHRAE Handbook, 2005. Fundamentals, American Society of Heating, Refrigerating Air-Condition. Engineers Inc., Atlanta.

Atmaca, I., O. Kaynakli and A. Yigit, 2007. Effects of radiant temperature on thermal comfort. Build. Environ., 42: 3210-3220.

Butcher, K., 2006. Chapter 1: Environmental Criteria for Design. 7th Edn., Chartered Institution of Building Services Engineers, London.

Czubaj, C.A., 2002. School indoor air quality. J. Instruct. Psychol., 29: 317-321.

De Dear, R.J. and K.G. Leow, 1990. Indoor climate and thermal comfort in high-rise public housing in an equatorial climate: A field-study in Singapore. Atmos Environ. Part B Urban Atmos., 24: 313-320.

Dua, J.K., 1994. Job stressors and their effects on physical health, emotional health and job satisfaction in a university. J. Educ. Administrative, 32: 59-78.

Ettner, S.L. and J.G. Grzywacz, 2001. Workers perceptions of how jobs affect health: A social ecological perspective. J. Occup. Health Psychol., 6: 101-113.

Fanger, P.O., 1970. Thermal Comfort. Danish Technical Press, Copenhagen, ISBN: 0-07-019915-9, pp: 21-23.

Feriadi, H. and N.H. Wong, 2004. Thermal comfort for naturally ventilated houses in Indonesia. J. Energy Build., 36: 614-626.

Ferng, S.F. and L.W. Lee, 2002. Indoor air quality assessment of day-care facilities with carbon dioxide, temperature and humidity as indicator. J. Environ. Health, 65: 14-18.

Fisk, W.J., 2000. Health and productivity gains from better indoor environments and their relationship with building energy efficiency. Ann. Rev. Energy Environ., 25: 537-566.

Great Britain Health and Safety Executive Staff, 1999. Thermal Comfort in the Workplace Guidance for Employers Health and Safety Executive (HSE). 1st Edn., Health and Safety Executive (HSE), Norwich, pp: 20.

Guan, Y., M. Hosni, B.W. Jones and T.P. Gielda, 2003. Literature review of the advances in thermal comfort modeling. ASHRAE Trans., 109: 908-916.

Hamdi, M., G. Lachiver and F. Michand, 1999. A new predictive thermal sensation index of human response. Energy Build., 29: 167-178.

Holmes, M.J. and J.N. Hacker, 2007. Climate change, thermal comfort and energy: Meeting the design challenges of the 21st century. Energy Build., 39: 802-814.

ISO 7730, 2006. Ergonomics of the Thermal Environment-Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria. 3rd Edn., International Standard Organisation for Standardisation, Geneva, Switzerland, ISBN: 0580472078.

Ismail, A.R., M.R.A. Mansor, C.B. Kim, M.M. Tahir and I.M.S. Usman *et al*., 2008. The relation between the discomfort level of automotive industries operators towards their workstation design and work environment. J. Achievements Mater. Manuf. Eng., 31: 756-761.

Jones, P.J., D.K. Alexander and A.M. Rahman, 1993. Evaluation of the Thermal Performance of Low-Cost Tropical Housing. IBPSA, England, pp: 137-144.

Leaman, A., 1995. Dissatisfaction and office productivity. Facilities, 13: 13-19.

Moss, K.J., 1998. Heat and Mass Transfer in Building Services Design. E and FN Spon, London, pp: 248.

Nishi, Y. and A.P. Gagge, 1977. Elective temperature scale useful for hypo- and hyper-baric environments. Aviation Space Environ. Med., 48: 97-107.

Parsons, K.C., 2000. Environmental ergonomics: A review of principles, methods and models. Applied Ergon., 31: 581-594.

Rea, M.S., 2000. The IESNA Lighting Handbook Reference and Application. 9th Edn., Illuminating Engineering Society of North America, New York, ISBN: 0-87995-150-8.

Roberto, Z.F., G.H.C. Oliveira and N. Mendes, 2008. Predictive controllers for thermal comfort optimization and energy savings. Energ. Build., 40: 1353-1365.

Shek, K.W. and W.T. Chan, 2008. Combined comfort model of thermal comfort and air quality on buses in Hong Kong. Sci. Total Environ., 389: 277-282.

Shikdar, A.A. and N.M. Sawaqed, 2003. Worker productivity and occupational health and safety issues in selected industries. Comput. Ind. Eng., 45: 563-572.

Son, H., H.L. Rosario and M.M. Rahman, 2008. Thermal comfort enhancement by using a ceiling fan. Applied Thermal Eng., 29: 1648-1656.

Tarcan, E., E.S. Varol and M. Ates, 2004. A qualitative study of facilities and their environmental performance management of environmental quality. Manage. Environ. Qual: Int. J., 15: 154-173.

Todoroviv B., 2004. Envelopes of building: The most influential factor of its energy efficiency. Proceedings of the TTMD 6th International HVAC + R Technology Symposium, (IHRTS'04), Istanbul, Turkey, pp: 409-413.

Vaughn, B.P.E., 2006. The Building Environment: Active and Passive Control Systems. 3th Edn., John Wiley and Sons Inc., New Jersey, ISBN-13: 9780471689652.

Wilson, S., 2001. Graduating to better IAQ. Consult. Specify. Eng., 29: 24-28.

Zain-Ahmed, A., A.A.M. Sayigh, P.N. Surendran and M.Y. Othman, 1998. The bioclimatic design approach to low-energy buildings in the klang valley, Malaysia. Renewable Energy, 15: 437-440.

Zainazlan, M.Z., M.N. Taib and M.S.B. Shahrizam, 2007. Hot and humid climate: Prospect for thermal comfort in residential building. J. Desalin., 209: 261-268.