The effect of ventilation on sick building syndrome

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Abstract

It is well known that adverse health conditions could develop due to outdoor air pollutants, such as, CO_2, CO, SO_2, NO_2, PM (particulate matter), VOC (Volatile Organic Compounds), when people are outdoors, while travelling or working. Since most of the people spend 80-90% of their time indoors, at home or place of work, the presence of these air pollutants could adversely their health while indoors, as well. Hence, minimizing the presence of air pollutants, by taking appropriate measures, such as, ventilation and air conditioning are important to ensure that a healthy atmosphere prevails indoors.

In a work place, where a large number of people work within a confined space, CO_2 produced due to human respiration gets accumulated in the air, unless there is good ventilation. Long exposure to higher CO_2 concentrations can cause human discomfort and ill health. The CO_2 concentration, if measured, can be a direct indication of the efficiency of the ventilation system of the building. This paper presents a detailed study on how building planning aspects can affect the indoor environment of a building. The main factor considered was the CO_2 concentration in relation to the ventilation design of the building. In the study, CO_2 concentration was measured and related to the ventilation design of the space in both free running and air conditioned buildings.

The main findings of the study are as follows.

a) Planning aspects of building were found to be very important in minimizing the bad effects of air pollutants.

b) Provision of openings, based on external wind directions and orientation of the building were important, to dilute and remove high internal air pollutant concentrations by natural air currents.

c) Provision of openings in excess of what is provided in the building regulations was found to improve the ventilation system in a free running building.

d) The efficient operation of the natural ventilation system was as important as the ventilation design.

1. Introduction

Planning healthy indoor environments is a main component of sustainable design. Indoor air quality and thermal comfort are considered as major factors of indoor environment. With more and more compact house designs introduced to countries with tropical climatic conditions, health problems related to poor indoor environments are getting aggravated. Therefore, in order to provide better indoor comfort for the occupants, modern building planning and operational practices should be either modified or improved. This study was aimed at correlating building planning aspects to ventilation rates for improved indoor environments.

Air pollutants, such as, CO, CO_2, NO_2, SO_2, PM_{10} (particulate matter of size below 10 microns), $PM_{2.5}$ (particulate matter of size below 2.5 microns) and VOCs (volatile organic compounds), can cause adverse health conditions to occupants. The acceptable indoor concentrations of air pollutant have been specified in USEPA (US Environmental Protection Agency, LEED, 2006) and WHO (WHO, 2005 a;World Health Organization) guidelines.

Indoor air pollution occurs mainly due to human activities, such as, cooking, burning garbage, vehicle emissions from nearby roads, chemicals used in cleaning and sanitation, painting, repair work, maintaining the houses, etc. Building ventilation system plays a very significant role in maintaining a good indoor environment with better air quality. CO_2 concentrations can be a direct indication of the effectiveness of the ventilation system of the building. Higher concentrations of CO_2 also cause discomfort and ill health to the occupants, when exposed over a long period of time.

The research presented in this paper includes two case studies carried out to investigate the variation of CO_2 levels under different ventilation conditions. The selected indoor environments include the office and hospital.

2. Introductions to air pollutants in indoor environments

Various pollutant sources are available in built environments which can either generate short term or long term exposure levels for the occupants. Use of air fresheners, pesticides and cleaning chemicals can create short term exposures where as the pollutants generated from cooking fuel, smoking, chemicals used to clean furniture, carpets, etc., can create long term exposure levels (Weschler, 2008, Smith, 2002).

2.1 Carbon Dioxide [CO_2]

CO_2 is a, non toxic, colour-less and odor-less gas, present in outdoor atmospheric air at an average concentration of 300 - 350 ppm. The outdoor acceptable levels of CO_2 range from 300ppm – 500ppm (*ASHRAE, 2004*). Values over that range indicate fuel combustion or other sources of CO_2 emission. An exposure level of 700ppm – 1000ppm (*ASHRAE Standards*) CO_2, $_{is}$ unusually high and may cause drowsiness, headaches and lower physical activity levels.

In the absence of good ventilation, indoor CO_2 concentrations can be higher than 350 ppm, due to, human respiration and other activities, such as, cooking with fossil or biomass fuels, as well as, burning of garbage, that produces large quantities of CO_2. When CO_2 concentration is too high, it can be unpleasant and unhealthy to building occupants. CO_2 concentration is an indicator of the quality of ventilation and indoor air quality [LEED, 2006].

2.2 Carbon Monoxide [CO]

CO is a colourless, odorless and tasteless gas. Carbon Monoxide is produced as a result of incomplete combustion. Once released to the atmosphere it can last for a few months and will eventually oxidize to CO_2. CO directly interferes with the oxygen carrying red blood cells of the human body, significantly reducing the supply of oxygen to the heart and other organs, by creating a permanent bond with red blood cells called Carboxyhemoglobin. Exposure to CO can cause weakness, dizziness, nausea, disorientation, confusion and fatigue in healthy people (Nathanson, 2000, WHO, 2005), as well as, to cardiovascular diseases and heart attacks. Patients with coronary artery disease are considered as most sensitive to CO exposure, with the possibility of aggravation of angina. Almost 70% of CO emissions come from vehicles. The maximum permissible CO concentration for 8 hour exposure levels is 9 ppm as recommended by USEPA.

2.3 Nitrogen Dioxide

Concentrated NO_2 is a dark brown gas with a strong odor. NO_2 is mainly formed by fossil fuel combustion at high temperatures. In the presence of sunlight NO_2 can further react with hydrocarbons to form smog. Smog is harmful and NO_2 also reacts with water to form nitrous acid (HNO_2) which contributes to the problem of acid rain. Exposure into NO_2 can cause respiratory problems of various magnitudes depending on the level of exposure. Short term exposure can cause skin and eye irritation whereas long term exposure into NO_2 can affect the lungs, chest, burning sensation, etc. Nitrogen Dioxide can irritate lungs and lower resistance to respiratory infections such as influenza, but frequent exposure into high concentrations could lead to increased incidents of acute respiratory illnesses, where the children are the main victims (Stieb et. al, 2002).

2.4 Sulphar dioxide

SO_2 is a colourless, acidic gas with a suffocating odour. It is a primary pollutant discharged into the atmosphere by fossil fuel combustion in power plants and vehicles. Other sources of SO_2 emissions are petroleum refineries and cement factories. Much lower concentrations can be expected from burning firewood (Hedley et.al, 2002).

SO_2 can react with oxygen and water vapour in the presence of sunlight to form sulfuric acid, which is a secondary pollutant and is a constituent of acid rain. Since SO_2 is soluble in water, once inhaled, SO_2 is dissolved and forms sulfuric acid, sulfurous acid, and bisulfate ions, which can cause respiratory problems such as bronco-constriction.

2.5 Particulate matter

Particles with diameters less than 10 micrometers are classified as PM_{10} and those with diameters less than 2.5 micro meters are classified as $PM_{2.5.}$ PM_{10} particles take a long time to settle down and hence will be inhaled by people in the vicinity, causing respiratory tract diseases. $PM_{2.5}$ is so fine that they will remain in air forever without settling down. If inhaled, they enter the lungs and cause lung diseases. Major sources these fine particles are, industrial processes which manufacture and/or handle powders (cement, minerals, chemicals, etc.,), as well as coal or oil burning power plants (which emit very fine particles of soot and ash) and highway vehicles (which emit very fine particles of soot). Air born particulate matter is often generated in large quantities during demolition and construction of buildings. The outdoor air which enters the building can also be a significant source of indoor airborne particulate matter (HEI, 2004, WHO, 2005).

2.6 Lead particulates

This toxic metal in the form of fume (less than 0.5 micrometers in size) is a harmful pollutant. With the introduction of unleaded gasoline, the lead levels emitted have been drastically reduced. However, lead is still emitted from petroleum refining, battery recovery and other industrial activities. Young children can be at a higher risk from lead poisoning.

2.7 Volatile Organic Compounds

Volatile Organic Compounds (VOC) are carbon containing compounds that could readily evaporate at room temperature and are found in many housekeeping products, maintenance products, and building products made with organic chemicals.

In indoor environments, there can be many different VOC substances in varying concentrations. There are six major classes of VOCs such as aldehides (formaldehyde), alcohols (ethanol, methanol), aliphatic hydrocarbons (propane, butane, hexane), aromatic hydrocarbons (benzene, toluene, xylene), ketones (acetone) and halogenated hydrocarbons (methyl chloroform, methylene chloride) (Nathanson, 2000).

Formaldehyde is highly reactive and can irritate body surfaces containing moisture such as eyes and upper respiratory tract. Materials containing formaldehyde release formaldehyde gas into the air. Short term effects include eye, nose, throat and skin irritation, headaches and allergic sensitization (Charles et. al, 2008).

VOCs usually come from the building itself. In most instances, the VOC sources are building materials used in the construction and decoration of the building and include carpet, upholstery, adhesives, paint, and varnish. Other commonly found sources are cleaning chemicals, disinfectants, and tobacco smoke etc. Many common emitters of indoor VOC's are polymer materials used within buildings. For most polymer materials, the emission of VOC's begins at some initial concentration that diminishes over time. Some polymer materials, like paints, initially emit VOC's at significantly high rates; where as other, such as varnishes and vinyl, have relatively low initial emission rates. The emission rates of most volatile organic compounds have a direct relationship with changes in both relative humidity and temperature (Dols

3. Building planning and indoor environment

Creating air tight buildings with more enclosed spaces in tropical climatic conditions is becoming common in planning of residential buildings. Air tight buildings make heat to stay inside and poor ventilation creates problems with thermal comfort and indoor air quality. In tropical climatic regions, the buildings with more enclosed spaces would need active means of lighting and ventilation for thermal and visual comfort. However, active means such as air conditioning would need significant amount of energy which would make the buildings unsustainable. Therefore, creating buildings as free running, which rely on natural light and ventilation, would be more desirable for the tropical climates. Especially in a developing country like Sri Lanka, free running buildings which are designed with passive features to maintain indoor thermal comfort are needed. However, with natural ventilation, providing better indoor air quality could be little challenging since outdoor air quality also could have some influence.

When the built environment is designed as free running in tropical climates, the designers expect the external air to penetrate indoors through the openings provided, creating natural ventilation. This needs maintaining proper wind speeds in the indoors which enhances the comfort levels. However, most of the openings of residential buildings are kept closed during day time since majority of the household occupants are at the workplaces or at school due to prevailing social setup. By the time the occupants return home, the building is heated up and the indoor environment is stuffy. If they do not open the windows in the night time as well, owing to their busy schedules, it might pollute the indoor environment further. The stagnant air collected over a period of time would create more and more indoor pollutants and long term exposure would create health problems to the occupants (Oosthuizen, 1999). When designers create air tight buildings in tropical climates, the need for mechanical ventilation for the building is foreseeable, where it increases the energy demand to function the building. The air tight buildings can also raise the indoor humidity, where high humidity levels will lead to bacterial growth, building material decay and the occupants' discomfort. If these microorganisms reproduce in buildings, they can adversely affect indoor air quality, create hazardous health conditions for the occupants and contribute to the deterioration of building components.

A variety of methods have been adopted in evaluating indoor air quality and the ventilation in a building, and one of the best techniques that is easy to analyze is the CO_2 concentration in the building, but CO_2 cannot be used as an indicator of overall indoor air quality(Persily, 1996). Indoor CO_2 is sometimes referred to as an indicator of indoor air quality without describing a specific association between CO_2 and air quality, and number of relationships are available including the health effect of elevated CO_2 concentrations (Knudstrup et.al, 2009).

3.1 Ventilation design

Ventilation is necessary to dilute and exhaust indoor pollutants such as a Sulphur dioxide, Nitrogen dioxide, Carbon monoxide, carbon dioxide and volatile organic compounds. There are mainly two different forms of ventilation; natural and mechanical. Natural ventilation relies either on air entering through cracks in the building envelope or direct ventilation due to open windows and other designed entry and exit points which is also called the passive ventilation (through cross ventilation) to introduce fresh air into a building's interior. Mechanical ventilation, on the other hand, requires use of fans to introduce fresh air and exhaust fans to expel fusty air.

In Sri Lanka, the climate creates a possibility for houses to utilize natural ventilation for ventilation needs. Purely natural ventilation systems consume little energy, require little maintenance, lower cost, and are environmentally friendly. However, natural ventilation should only be used in areas where outdoor air is suitable for indoor air, such as locations situated away from the industry, construction, or other known air pollution sources (Jong and Lee, 2008).

4. Experimental study

Ventilation and climate control refers to the provision of clean outdoor air and properly conditioned supply of air into the occupiable spaces of a building. Outdoor air is provided as a means of diluting occupant generated bio effluents and other indoor contaminants, and conditioned air is provided to maintain occupant comfort. Outdoor air can be provided either mechanically or via openable windows or vents.

There were two case studies conducted to investigate the effect of ventilation design on indoor CO_2 concentration. One case study was conducted in an office environment where computers are kept and the other one was in a hospital environment.

4.1 Case study 1 (Office environment with computers and printers)

A case study was carried out in a room with a floor area of 125 m^2 which is entirely run on active means of ventilation. This is the main computer room of a large academic department in a Sri Lankan University.

The room has about 50 computers, three laser printers, four line printers and three severs. Usually it is occupied by 40 students and five staff members, at a given time. A questionnaire survey was conducted in order to investigate whether the occupants have any sickness or discomfort related to the indoor environment.

It was found that the occupants who spend around six hours in this room have sicknesses such as head ache, drowsiness and lethargy, mainly in the afternoon.

The room was fitted with three split type air conditioners which are in full operation during the day time. The air conditioners are located in the places indicated in Figure 1.

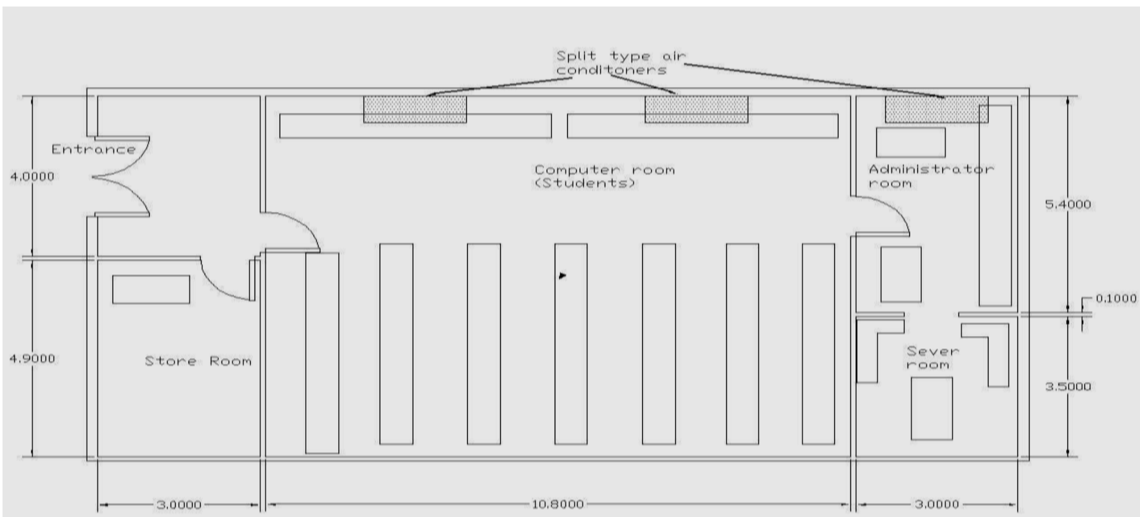

Figure 1: Plan view of the computer room

The levels of CO_2, CO, SO_2 and NO_2 were measured inside the room together with temperature and relative humidity. It was found that only CO_2 levels are relatively high and CO, SO_2 and NO_2 are negligible. Measurements were taken in every 15 minutes for a period of 3 days.

The observations revealed that the CO_2 levels are higher than the recommended ASHRAE standards for an indoor environment.

Due to these findings the room was fitted with two exhaust fans with a discharge rate of 180 cfm bringing in the fresh air from the outdoors to the indoors. A same set of measurements were taken in the computer room after improving the ventilation system.

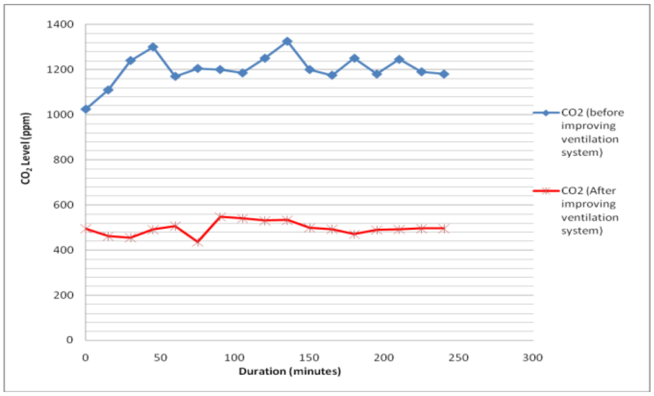

Chart 1: The CO_2 variation with time

The CO_2 levels before and after improving the ventilation system is shown in Chart 1 and it can be clearly seen CO_2 levels are higher than 1000ppm recommended by ASHRAE before the improvement. After the improvements it had come down to about 400 – 500 ppm.

4.2 Case Study 2

Two wards in a hospital close to Colombo were selected as the second case study. Ventilation design of the two wards is different to each other, with one having air-conditioned indoor environment and the other one is operating as a free running space.

In order to make the results consistent the following factors were kept constant:

i. The wards under investigation were all of similar size.
ii. Each ward was to have the same occupant density
iii. Temperature of the air-conditioner was set at 24◦C.

Two sets of readings were taken at one activity space over a period of one hour. The CO_2 levels in the air conditioned and free running wards are shown in Chart 2. This clearly shows the effect of building ventilation on indoor CO_2 concentration. The higher wind speeds inside free running spaces dilute the pollutants (CO_2 concentration in the case study), whereas lower wind speeds were observed in air conditioned spaces. That clearly indicates higher CO_2 concentration in air conditioned spaces which could have the number of air changes per hour less than 0.5 ach (air changes per hour) as recommended by ASHRAE (2004).

Chart 2 represents the CO_2 concentration with time in the air conditione dand free runnign wards which indicates CO_2 levels more than 1000 ppm and around 400 ppm respectively. This shows the wards which are air conditioned needs to have improved ventilation design.

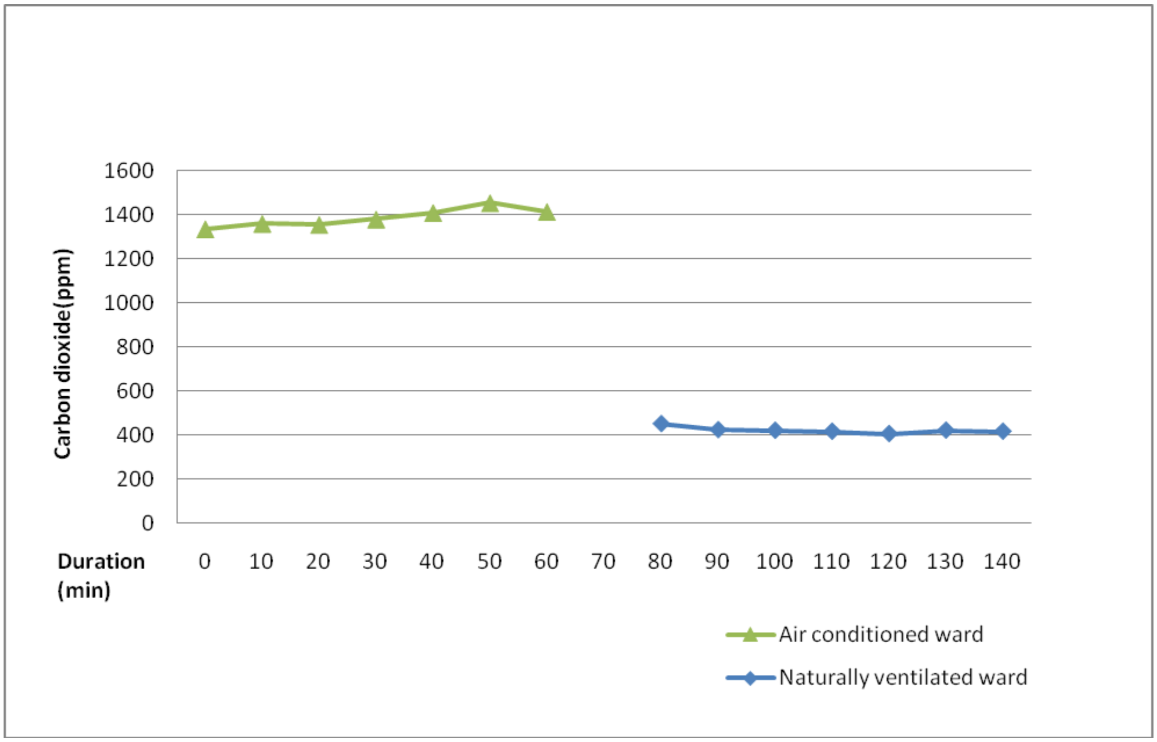

Chart 2: CO_2 concentration in air conditioned and free running wards in a hospital

6. Discussion and Conclusions

The results obtained from the experiments clearly state that the building planners can take proactive actions in addressing IAQ concerns by their proper building design. The properly designed buildings should reduce occupant exposure to harmful or annoying substances and should enhance the indoor comfort among the occupants.

In the naturally ventilated buildings IAQ can be manipulated by using the openable area and locations of windows. As shown in the results the openable percentage of the windows improves the air circulation in the building. This is one of the major factors which contribute to the indoor carbon dioxide level.

For a tropical country like Sri Lanka, better indoor performance can be obtained by designing buildings with natural ventilation with proper orientation, to capture the maximum air movement and minimum solar radiation. However, some compact buildings like office spaces and hospitals need air conditioning. In the air conditioned buildings, proper maintenance should be practiced to minimize the indoor carbon dioxide levels. Few air-conditioning types do not allow fresh air circulation inside the building. In such cases carbon dioxide level is increased. So that necessary steps should be taken to allow fresh air movement inside the building. Exhaust fans, opening windows at regular intervals such as, in the morning for a reasonable time period such as one hour, will improve the indoor environment.

The study also revealed that Sri Lankans still prefer the naturally ventilated spaces with comfortable temperature and better air movement, compared to the air conditioned ones. Better awareness is needed to improve the indoor comfort levels in air conditioned spaces.

According to building regulations used in Sri Lanka, a void/floor area ratio of 1/7 has to be provided. Since there may be only one or two walls that would be facing outdoors in a typical occupied area (a bed room, kitchen, etc.), the void to wall ratio can also provide a reasonably good indicator for various comparison purposes. Another important aspect is opening and closing of windows. When all the windows are closed, the void area can be reduced to zero. Thus, void/ wall ratio can be considered as a reasonably good indicator to depict the typical scenarios that can usually occur under general operational conditions.

The outdoor air quality is also of importance in free running buildings. It is found that in Sri Lanka, still the outdoor air is not polluted to significant levels except close to busy highways. Therefore, outdoor air quality has been considered as acceptable for this study and the Indoor/ Outdoor ratios (I/O ratios) have been considered as indicative of the indoor performance. It should be noted that some concerted efforts will be needed in future to ensure that the favourable outdoor conditions will prevail as they are now. This will be essential to ensure satisfactory performance of free running built environments with substantially low carbon foot prints being appreciated in future as well. The main occupied areas investigated as indicated above includes living rooms, bed rooms, kitchens and garages. In addition the effect of desirable micro climates with plenty of trees has also been investigated.

Sri Lanka is a country blessed with a reasonable wind speed though the air can become almost stagnant for few days in April when the monsoon patterns change form one to the other. Therefore, reliance on natural ventilation with supplementary forced ventilation provided with pedestal or ceiling fans is practically viable. However, the way that the voids are provided can play a vital role in the degree of turbulence created within a room. Thus, the provision of adequate openings, the directions that the shutters open and also the angle in which the openings are located with respect to the main wind direction can be vital in ensuring sufficient ventilation to dilute the CO_2 levels to that of outdoors.

It should be noted that split type air conditioners have become very popular in Sri Lanka due to considerably lower costs incurred than packaged units. It is usual to have about 2 – 3 split type air conditioners than a small packaged unit with recharge. This situation can be found not only in houses, but also in buildings that are planned as free running, but air conditioned subsequently due to various reasons. This study has shed light on this not so desirable practice that has been implemented inadvertently, though it may have serious health related implications. This is also another area that can be strongly recommended for further detailed studies due to the widespread usage of this not so desirable practice.

When all these findings and conclusions are considered it is reasonable to state that this detailed study has revealed many important facts related to indoor environments, their designs, the desirable practices as far as free running built environments mainly consisting of houses are concerned. It has also shed light on one serious problem that exists in enclosed spaces air conditioned with split type machines.

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References

1. WHO (2005 a), WHO Air Quality Guidelines Global update 2005, http//www.euro.who.int/document/E90038. pdf.

2. LEED for New Construction Version 2.2, Reference Guide, Second Edition 2006, US Green Building Council.

3. Weschler, C. J., Nazaroff, W. W., (2008) "Semivolatile organic compounds in indoor environments" *Atmospheric Environment 42 (2008) 9018-904.*

4. Smith, K. R., (2002) "Indoor air pollution in developing countries: recommendations for research", Indoor Air 12 (2002) pp. 198 – 207

5. ASHRAE, 2004, Standard 62.1 -2004, "Ventilation for acceptable indoor air quality", *American Society of Heating, Refrigerating and Air-Conditioning Engineers, In.*

6. Nathanson, J. A., *Basic environmental technology – water supply, waste management and pollution control,* Prentice Hall, USA, 2000, 496p.

7. WHO, (2005), "WHO Air quality guidelines for particulate matter ozone, nitrogen dioxide and sulphur-dioxide".

8. Stieb, D., Judek, S., Burnett, R., (2002) "Meta-analysis of time-series studies of air pollution and mortality: effects of gases and particles and the influence of cause of death, age, and season."Journal for Air Waste Management Association 52(4):470-84.

9. Hedley, A.J., Wong, C.M., Tach T.Q. Ma, S., Lam, T.H., and Anderson, H.R., (2002), Cardio-respiratory and all cause mortality after restrictions on sulphar content of fuel in Hong Kong: an intervention study, Lancert, 360: 1646 – 1652.

10. HEI (2004) Health Effects of outdoor air pollution in developing countires of Asia: A literature Review, Health effects Institute, Special Report 15, Boston.

11. Charles J., Weschler, William W. Nazarrff, "Semivolatile Organic Compounds in indoor environments", Atmospheric Environment, 42 (2008), 9018 – 9040.

12. Oosthuizen A.D., (1999) "Indoor A Case Study for the Domestic Application of Natural Ventilation in Sydney ", *Presented at the first International One day Forum on Natural and Hybrid Ventilation, HybVent Forum' 99, 09/1999, Sydney, Australia.*

13. Persily, A.K., (1996) "The relationship between indoor air and Carbon Dioxide" – *In Proceedings of Indoor air '96*, Nagoya, The 7th International conference on Indoor Air Quality and Climate, Vol. 2, pp. 961- 966

14. Knudstrup, M. A., Hansen, H. T. R., Brunsgaard, C., (2009) "Approaches to the design of sustainable housing with low CO_2 emission in Denmark", Renewable Energy 34 (2009) pp. 2007-2015

15. Jong-Hoon, K., Lee, S. J., (2008) "Improvement in natural ventilation in a large factory building using a louver ventilator", Building and Environment 43 (2008) pp. 2132-2141