# EFFECT OF BUILDING VENTILATION ON INDOOR ENVIRONMENT

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**Abstract:**  Planning healthy indoor environments is a main part of sustainable design. 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 building planning aspects and ventilation rates resulting in indoor environments. Since indoor $CO_2$ concentration can reflect the ventilation rate of built environments, it was monitored in a sample of residential buildings by varying several aspects related to air quality. This includes $CO_2$ levels with void to wall ratio of activity spaces in buildings, operating patterns of windows, and the wind speed inside the building together with the effect of micro-climate. Also the ventilation rates of an air conditioned spaces were monitored with a survey of occupant comfort levels .It was revealed that good ventilation rates by having higher void to wall ratio, higher indoor wind speed and proper window operating schedule can lower the indoor $CO_2$ levels and improve the comfort conditions. Therefore, complying with proper building planning practices such as selecting proper orientations, capturing the wind direction, practicing proper operating schedules for the provided openings and creating better micro-climate would result healthier built environments.

*Key Words: Ventilation, $CO_2$, Wind speed, Microclimate, Building Planning*

## 1.  Introduction

It has become common knowledge that health hazards are developing due to various outdoor pollutant sources. However, most of the people spend about 80% - 90% of their time indoors. Hence, it is important to create better indoor environments for healthy living. There are a number of indoor air pollutants such as CO, $CO_2$, $NO_2$, $SO_2$, $PM_{10}$, $PM_{2.5}$ (particulate matter) and VOCs (volatile organic compounds). Each type of pollutant can cause different levels of health hazards for the occupants. The acceptable concentrations of each of the indoor pollutant have been specified in US Environmental Protection Agency (USEPA) and World Health Organization (WHO) guidelines.

When residential buildings are constructed, various activities can contribute to lower the quality of indoor air. The stages can include; during construction, building materials used, cooking, burning garbage, vehicle emissions from nearby roads, chemicals used in 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, although it is non toxic, can be a direct indication of the ventilation system of the building. Higher concentrations of $CO_2$ also cause discomfort for the occupants.

The research presented in this paper includes the effects of void/wall ratio, window operating schedule, wind speed and microclimate on indoor $CO_2$ levels in free running residential buildings. Also this paper includes a case study carried out in an air-conditional environment on $CO_2$ levels and indoor comfort levels. The study was carried out in Sri Lanka where tropical climatic conditions prerail.

## 2. Building planning and indoor environment

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, there would be many free running buildings designed with passive features to maintain indoor thermal comfort.

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. There is also a need to maintain 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 air 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

Several methods have been developed in evaluating and relating air quality and ventilation in buildings. One of the techniques is analyzing $CO_2$ concentrations in the building, although $CO_2$ cannot be an indicator of overall indoor air quality [1, 2].

There are two concepts that can be used in defining relationships in indoor air quality and ventilation by using $CO_2$ concentration indoors. The first is that the amount of $CO_2$ generated by one person depends on the size and their level of physical activity where it is discussed in ASHRAE fundamentals handbook [3]. The second is to use $CO_2$ as a tracer gas to study the building when the $CO_2$ concentrations are elevated than the outdoors. 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. Carbon dioxide at levels that are unusually high within indoors may cause occupants to grow drowsiness, get headaches, or function at lower productivity levels. Humans are the main indoor source of carbon dioxide. Indoor $CO_2$ level is an indicator of the adequacy of fresh air recharge relative to the indoor occupant density and metabolic activity.

The outdoor acceptable levels of $CO_2$ are ranging from 300 ppm – 500 ppm [4]. When the $CO_2$ levels are over 500 ppm, it indicates that the outdoor air is containing combustion or other contaminant sources. An exposure level of 700 ppm – 1000 ppm is taken as acceptable levels for indoors but the occupants will experience the stuffiness and odours [4].

Since the indoor $CO_2$ level is very important parameter, it would be useful to determine the way that indoor $CO_2$ levels could be influenced by the indoor operating conditions like availability of natural or forced ventilation. It would also be useful to determine the effect that a micro-climate created with a lot of trees could affect it. This paper deals with these aspects.

## 3. Experimental program and results

The study covered in this paper included the following experimental components:

- Indoor comfort levels were monitored in a randomly selected sample of residential buildings mainly located in urban areas. All the buildings are free running and relying on natural light and ventilation.
- A case study was conducted in an air conditioned environment to investigate the effect of controlled environment on indoor comfort levels. This space is a computer room in the Department of Civil Engineering, University of Moratuwa, Sri Lanka with a floor area equivalent to 125 $m^2$ in which, 40 computers have been kept.

### Measurements

- This study was mainly focused on the indoor environment related to indoor $CO_2$ levels, indoor temperature, relative humidity and wind speed. Planning aspects of the buildings such as area of openings, locations of openings, orientation were also observed. A questionnaire was conducted among the occupants of the houses in the sample and in the air conditioned space considered in the case study in order to investigate whether they have any health problems related to the prevailing indoor environment.
- For each location, spot measurements were taken for all the parameters ($CO_2$ using ZG106 $CO_2$ and temperature monitor, temperature and humidity using a dry and wet bulb thermometer, wind speed) in every 15 minutes for a 3 hours period. All the measurements were taken during the day time. The spot measurements were also taken for CO (Carbon Monoxide) content of the air conditioned environment in 10 minute time intervals for a period of 8 hours.
- Measurements were taken by keeping the windows open and closed positions for free running residential buildings.
- Measurements were also taken in residential buildings in the same vicinity, with varying conditions for microclimate around the houses. Here, the micro climates were categorized as "poor" and "good" depending on the tree cover and presence of plants which are observed as more than 2m tall to act as a barrier to outdoor pollutants. The condition of microclimate was judged as poor or good by observation and not by measurement of coverage of trees, due to practical limitations of the study.

## 4. Results and discussion

### 4.1 Variation of $CO_2$ levels with Void/Wall ratio

Figure 1 shows the variation of the ratio Indoor/Outdoor $CO_2$ level with Void/Wall (V/W) ratio. This clearly shows that the $CO_2$ concentration inside the building would be very close to the outdoor concentration where the amount of active voids (Windows) is high, confirming the findings stated in literature [5, 6].
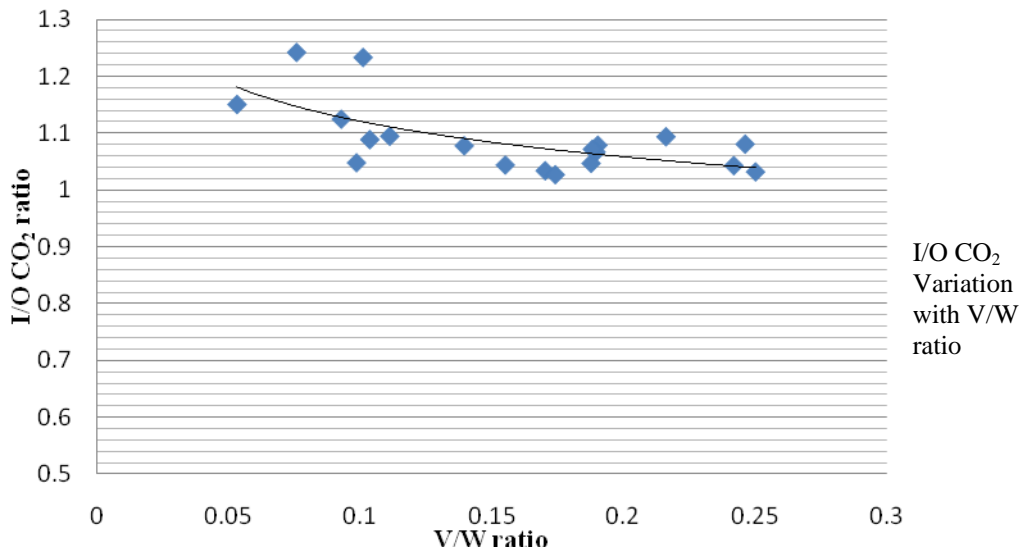
*Figure 1: I/O average CO$_2$ variation with wall to void ratio*

If the building designer can provide adequate number of windows by complying with the building regulations (in excess of the minimum recommended) prevail in the country, a reasonable level of indoor CO$_2$ can be maintained. The minimum is 1/7 of the floor area of any habitable room in Sri Lanka [7]. In order to maintain a reasonable indoor CO$_2$ level, the minimum void to wall ratio of an activity space (room) is proposed to be in the range of 0.15. It is preferable to have these openings in two different walls in order to facilitate cross ventilation.

### 4.2 CO$_2$ levels with operating practices of ventilation system

Figure 2 presents the importance of operating the ventilation system properly. The windows provided by the designer, should be opened and allow natural ventilation to happen during the operating cycle of the building. CO$_2$ measurements were taken over a period of five hours at each house in the sample by keeping the windows opened and closed. The I/O ratios for CO$_2$ concentration were evaluated for both conditions for all the locations and the average values are graphically represented in Figure 2. In Figure 2, it is clearly seen that indoor CO$_2$ level can go up when the windows are kept closed.
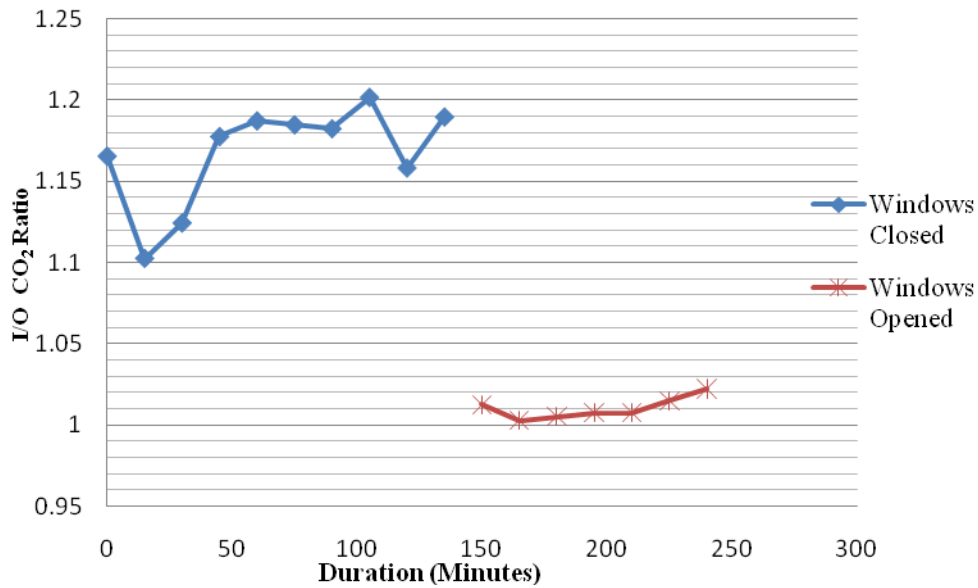
*Figure 2: $CO_2$ variation windows opened and closed*

It is very close to the outdoor $CO_2$ concentration when the windows are properly operated. Therefore, it is very important to provide and operate the means of natural ventilation over the entire life span of the building.

### 4.3 $CO_2$ variation with wind speed

The study conducted by Heidari [8], has shown that the air movement could affect the human comfort and the human comfort is the main point in building design. It was found that preferred speed at $28^0C$ is 1.0 $ms^{-1}$, at $29.6^0C$, it is 1.2 $ms^{-1}$ and at $31.3^0C$, 1.6 $ms^{-1}$.
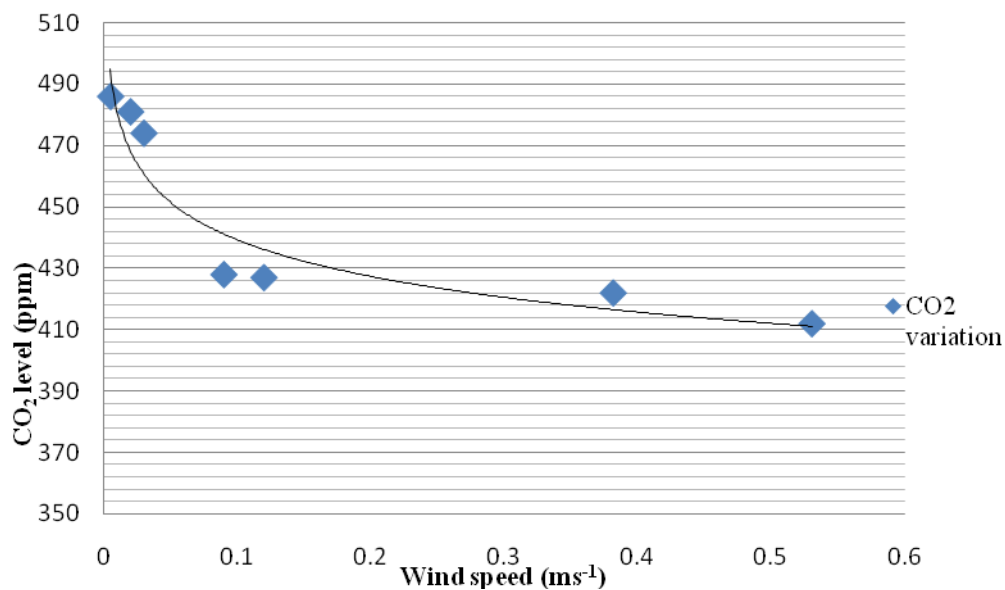


*Figure 3: $CO_2$ variation with wind speed in the urban setting*

Figure 3 shows the importance of providing adequate cross ventilation and air movement inside the activity spaces. This allows dilution of air pollutants collected indoors. It can be seen in Figure 3 that average indoor $CO_2$ levels decrease with the wind speed.

Therefore providing adequate cross ventilation is a very important factor in the design process of activity spaces. Better air circulation in all activity spaces of a building can be facilitated by implementing proper building planning practices such as selecting correct orientation by considering wind direction, paths of solar radiation, creating microclimate etc. Air movement in the night can be facilitated by providing strategically located court-yards inside the houses. This can also improve the thermal comfort inside the house.

### 4.4  *Effect of micro climate on indoor environment*

The building orientation and the microclimate play a key role in the thermal comfort of a building. Measurements were taken in the residential buildings considered in a sample for, with and without microclimate around different activity spaces. One such example is shown in Figure 4 where the TV lobby is surrounded by a good microclimate whereas the living room has a poor microclimate around it. Similar cases were monitored in the study and the results for the example considered are complied in Figure 5.
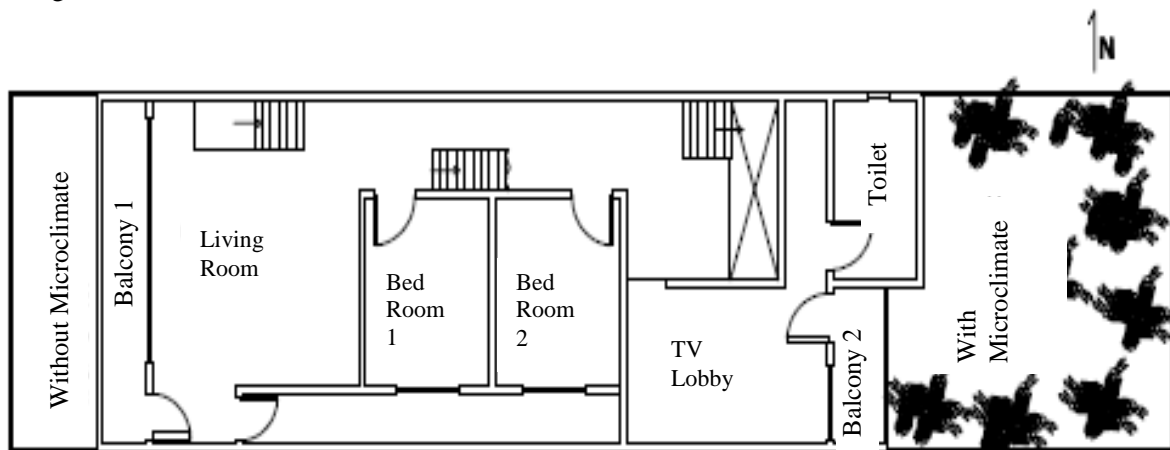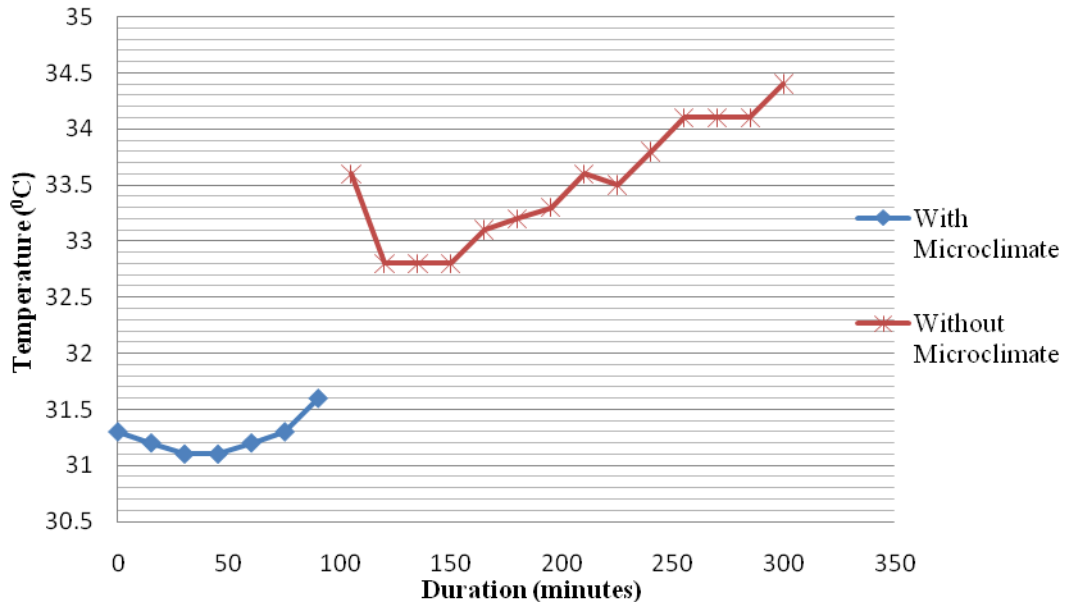


*Figure 4: First Floor Plan of the house*

*Figure 5: The temperature variation with and without Microclimate*

The effect of the microclimate can be clearly seen in Figure 5. The indoor temperature is reduced by $2^0 - 3^0C$ when there is proper microclimate around the houses. The orientation of the house is important as well and the placing of windows that will affect the thermal comfort of the building [8].

In order to provide better outdoor comfort levels in tropical cities, it was proposed to include shading in street canyons, covered walkways and tree plantation, since microclimate plays a very important role in providing comfort conditions [9].

### 4.5 *A case study in an air conditioned environment*

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 mean 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.

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 Department of Civil Engineering, University of Moratuwa, Sri Lanka.

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 6.
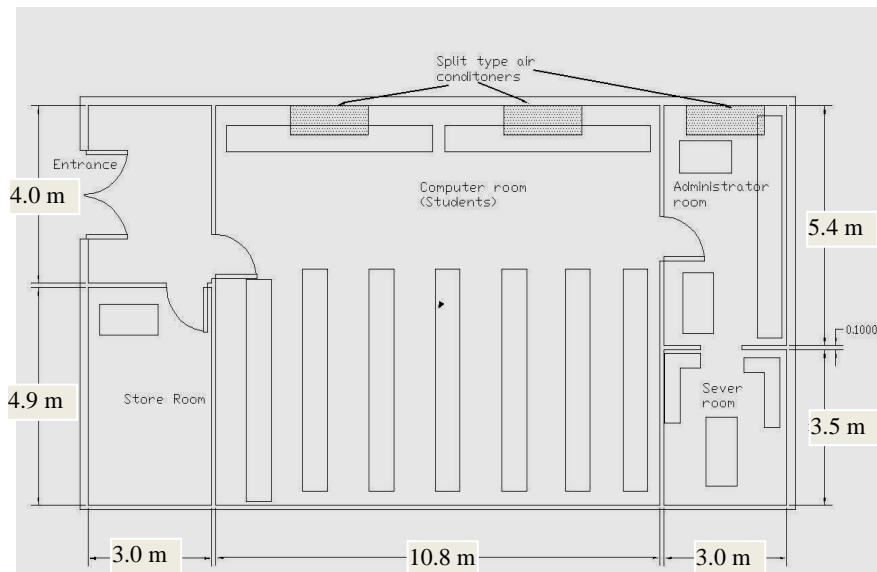


*Figure 6: Plan view of the computer room*

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 from 09:00 to 13:00 hrs.

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.
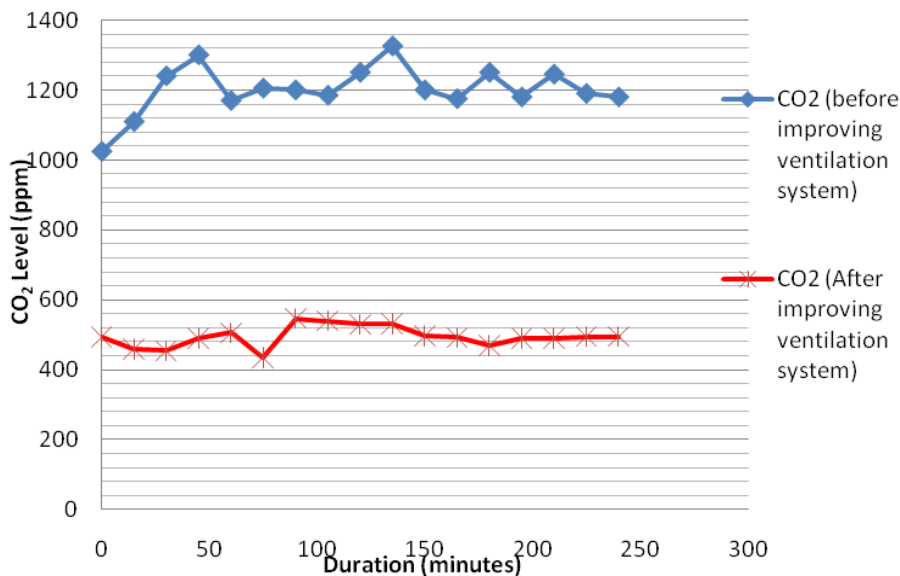


*Figure 7: The $CO_2$ variation with time*

The $CO_2$ levels before and after improving the ventilation system is shown in Figure 7 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.

## 5. Conclusion

The study covered in the paper was aimed at determining the effect of void to wall ratio, indoor wind speed, operating schedule of openings on the ventilation rates and the occupant comfort. It was revealed that the indoor $CO_2$ levels can drastically go up with low void to wall ratio. Therefore it is recommended to provide window area at least equal to the minimum provided in the building regulations.

The orientation of the building should be selected by considering the direct solar radiation and the wind direction. It could be clearly seen that $CO_2$ levels inside the building goes down with higher wind speeds and would approach the outdoor levels

The operating schedule of the openings in a naturally ventilated building has been identified as another important parameter which contributes immensely towards the indoor comfort. Although the adequate number of windows is provided in the design, the expected comfort levels cannot be achieved unless the proper operating schedules are maintained.

In order to provide better indoor thermal comfort, creating a good microclimate around the house can greatly contribute. It was found in the study that there is a $2^0C$ to $3^0C$ reduction in the indoor temperature with better microclimate around the house. Therefore the planners are encouraged to design the landscaping of the built environment to achieve better indoor thermal comfort.

When considering artificially ventilated spaces, the acceptable comfort levels can be maintained with better rates of ventilation with recharge of fresh air. With a better ventilation system, is was able to achieve lower $CO_2$ levels around 500ppm and better occupant comfort with no complaints about sicknesses related to indoor air quality. Therefore, even if the building is air conditioned, it is essential to check the adequacy of ventilation rates which could be linked with the indoor $CO_2$ levels.

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