ISLAMIC UNIVERSITY OF TECHNOLOGY

UNIVERSITE ISLAMIQUE DE TECHNOLOGIE

الجامعة الإسلامية للتقنية

Experimental And Numerical Study Of Thermal Distribution And Emission In Conventional Kitchen

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Asst. Professor, MCE department, IUT

DECLARATION

This is to declare that the project titled "*Experimental And Numerical Study Of Thermal Distribution And Emission In Conventional Kitchen*" was designed and successfully implemented by us under the supervision of Md. Hamidur rahman, Asst. Professor, MCE Department , IUT. The following thesis has not been submitted elsewhere for the reward of any degree or diploma or for publication.

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ACKNOWLEDGEMENT

At first we would like to express our sheer gratitude to Almighty Allah, without Whose grace ,we wouldn't be able to complete this project so far. We would also like to express our cordial thanks to our project supervisor **Md. Hamidur Rahman** sir, who extended his helping hands in this project before we even asked for it. The directions & advices given by **Prof. Dr. A. K. M. Sadrul Islam** sir helped us enormously in achieving our goal. We are also grateful to **Md. Abu Hossain**, Thermodynamics , Thermofluid, Refrigeration & A/C Lab./Control in charge for assisting us in numerous ways throughout this project.

– **The Authors**

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SECTION A

THERMAL DISTRIBUTION IN URBAN KITCHEN

1.1 ABSTRACT

Building Energy Simulation (BES) programs often use conventional thermal comfort theories to make decisions, whilst recent research in the field of thermal comfort clearly shows that important effects are not incorporated. The conventional theories of thermal comfort were set up based on steady state laboratory experiments. This, however, is not representing the real situation in buildings, especially not when focusing on residential buildings. Therefore, in present analysis, recent reviews and adaptations are considered to extract acceptable temperature ranges and comfort scales. They will be defined in an algorithm, easily implementable in any BES code. The focus is on comfortable temperature levels in the room, more than on the detailed temperature distribution within that room.

1.2 INTRODUCTION

When comparing the effect of changes to buildings, either changes to the building structure, the materials used or the installations, an important boundary condition is that the thermal comfort quality must, in all cases, be maintained. Building Energy Simulation codes often use conventional methods to determine the achieved comfort level: common codes as ESP-r [1], TRNSYS [2] and IDA Ice [3] use the ISO 7730 assessment method. However, when focusing on residential buildings, including zones with variable thermal comfort requirements, less predictable activities and more ways to adapt to the existing thermal environment, the conventional methods are no longer satisfactory. Comfort temperatures as well as acceptable temperature variations are more influenced by parameters not considered by the conventional methods. Therefore, algorithms for determination of the neutral or comfort temperatures in the different zones of a residential building, as well as for the estimation of the thermal sensation of the building occupants in these zones, will improve the resemblance with reality. These algorithms must take into account the knowledge of the traditional methods as well as recent findings in the field of thermal comfort with a focus on residential buildings.

1.3 LITERATURE REVIEW

Chi-ming et al. [1] conducted experiment to study the efficiency of side exhaust system for residential kitchens in Taiwan. They designed the exhaust system in three ways namely single slot, twin slot and fence slot systems. The experiment was conducted with different configurations by varying the heights. They concluded that the side exhaust systems installed close to the pot rims performed well in smoke control at the same exhaust flow rate (7.4 m3/min) which is lower than the 11.6 m3/min required by Chinese national standard 3805 (CNS-3805).

Kajtar et al. [2] studied CFD modeling of indoor air quality and thermal comfort. CFD modeling was made by FLOVENT. Well established turbulence model was used for turbulence closure. Number of cases has been investigated in regard to the amount of air removed by kitchen hood. Supply air has been provided using air terminal devices installed above the windows. Each diffuser (4 x 50cm, with 50% free area ratio) was placed above the windows. The study concluded that the minimum safe carbon-dioxide concentration can be attained at 160 m3/h exhaust airflow, and to meet IAQ requirements considerably higher ventilation rate should be provided. According to calculated results, approximately 4.7 m3/h airflow is sufficient to ensure burning process of natural gas.

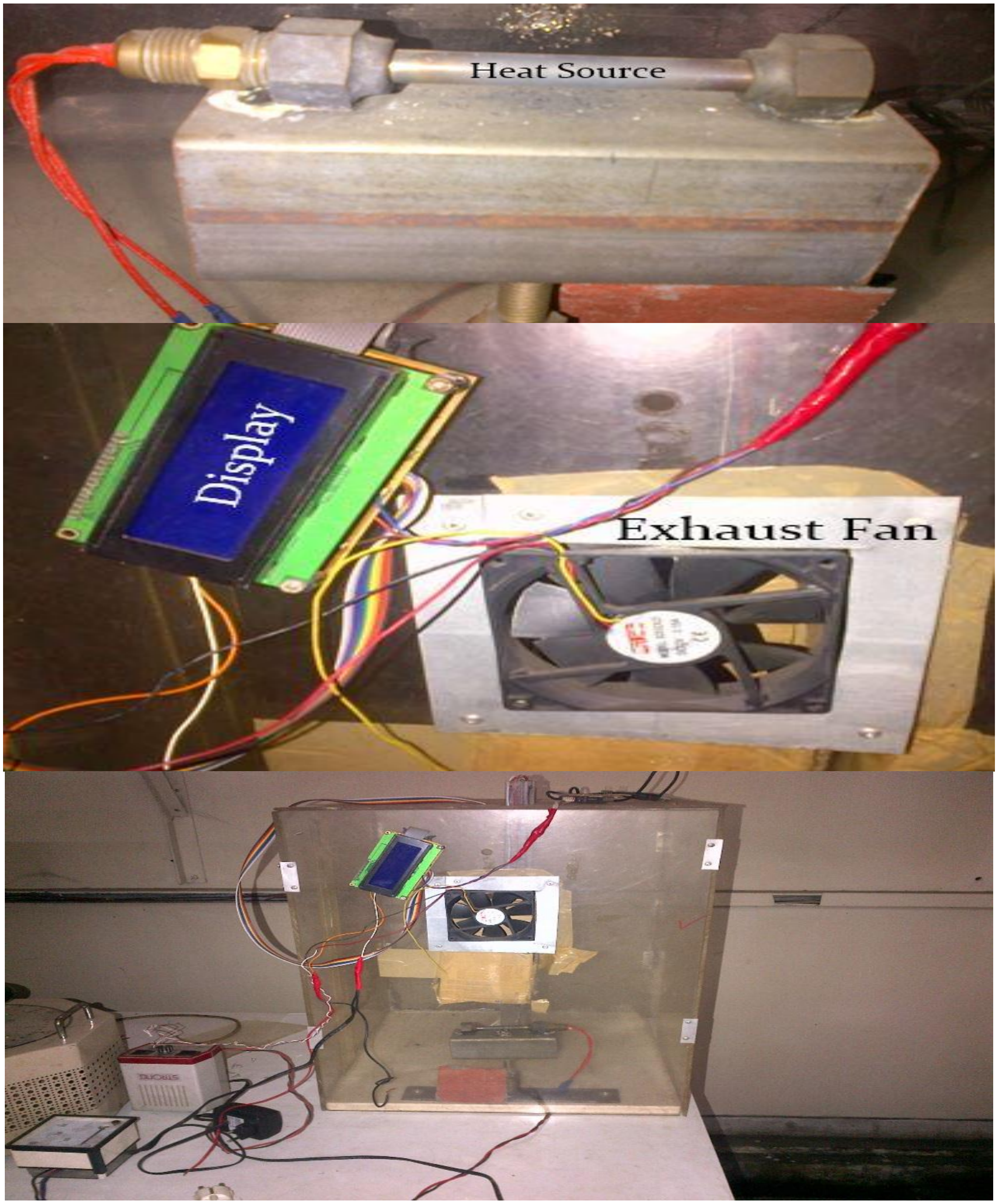
Nantka [3] investigated indoor conditions in Silesian Buildings with Natural Ventilation. Results were obtained by questionnaires, measurements and simulations of ventilation processes in typical blocks of flats and office buildings in Silesia. The effects of airtightness, natural ventilation and some pollutants on the indoor environment were discussed. To determine the air leakage values for windows and doors, the pressurization tests were conducted with the use of a plastic cover tightly taped to the window and door frame (the small-scale tests).There were also large-scale pressurization tests applied in selected rooms, flats and offices. Two types of stands and two methods were used. They found that the indoor air quality depends on the air change rates and the natural ventilation rate depends on airtightness of external walls and especially windows.

Odzune et al. [4] studied the CFD analysis of the effects of the size and location of an Air-Inlet in domestic kitchen extraction. A model kitchen was constructed including a gas range cooker and an extraction hood and the cooking process was simulated. The flow field during the cooking process in the kitchen was modeled using FLUENT Airpak 3.0.12. They concluded that air-inlet location effects both local (cooking zone) and global extraction (breathing and room zones). Depending on the location of the air-inlet, incomplete room air mixing of contaminants can occur.

Villi et al. [5] investigated the computational aspects of modeling different strategies for kitchen ventilation. Their paper dealt with the evaluation of different simulation approaches to kitchen ventilation modeling. Multi-zone, CFD and zonal approach are discussed. Results illustrate the important influence of proper ventilation for kitchen IAQ. The performed investigation demonstrates the applicability of the zonal approach for predicting pollutant indoor concentration with a level of accuracy comparable to CFD predictions.

Park et al. [6] studied the air flow and contaminant distribution in a full-scale kitchen opened to a living room, ventilated by an exhaust hood using commercial CFD program, PHOENICS. The locations of the gas range and the window were chosen as the parameters to investigate the indoor environment. The values of the contaminant index for several layouts of the gas range and the window were calculated and compared. Their results revealed that when the gas range is installed along the wall with specified window location, its position in relation to the wall has unnoticed effect on contaminant index. However, for a fixed gas range location, the indoor air quality deteriorates by the proximity of the window to the gas range.

1.4 EXPERIMENTAL SETUP



1.5 EXPERIMENTAL FINDINGS

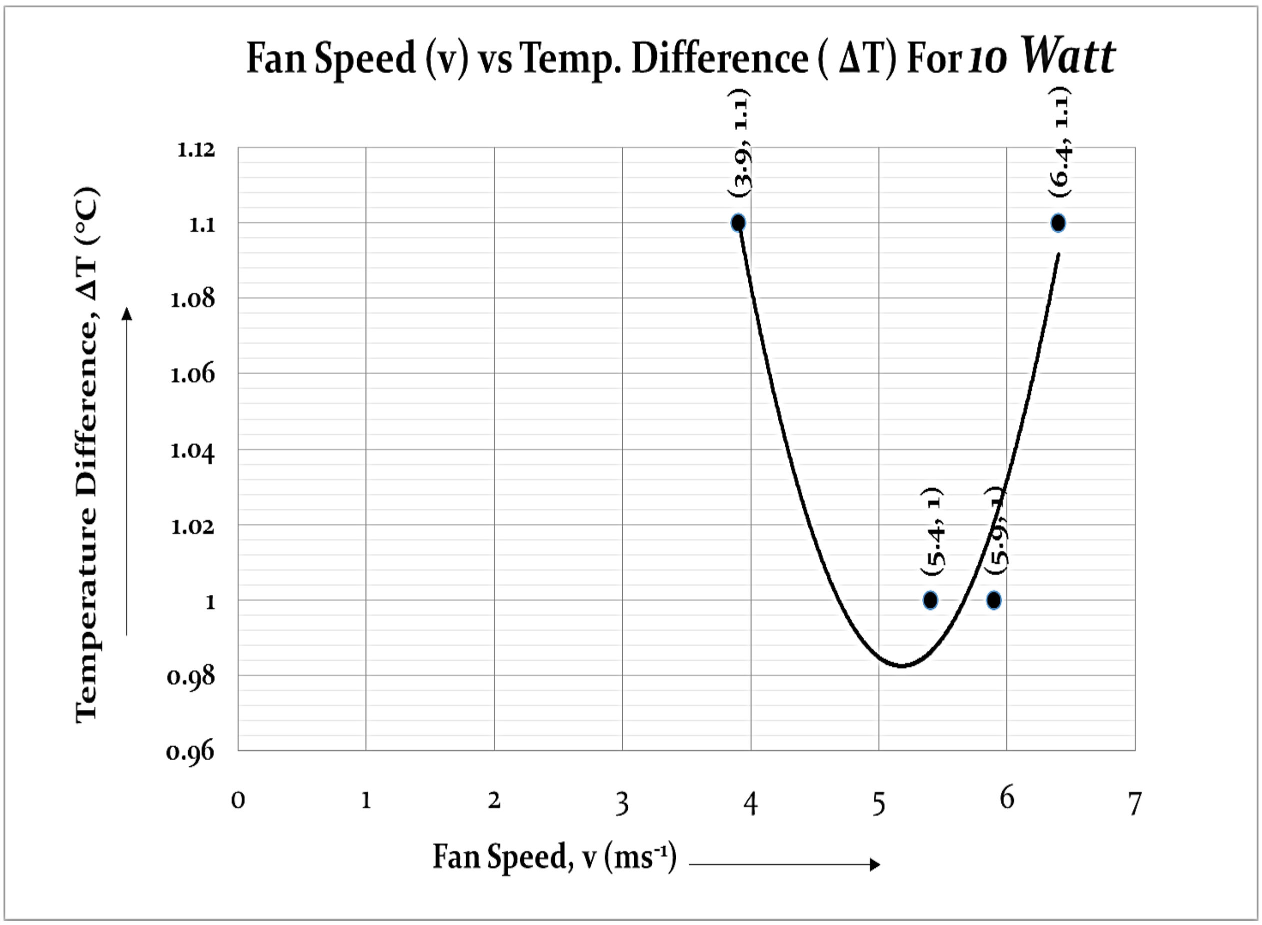


Figure 1.5.1

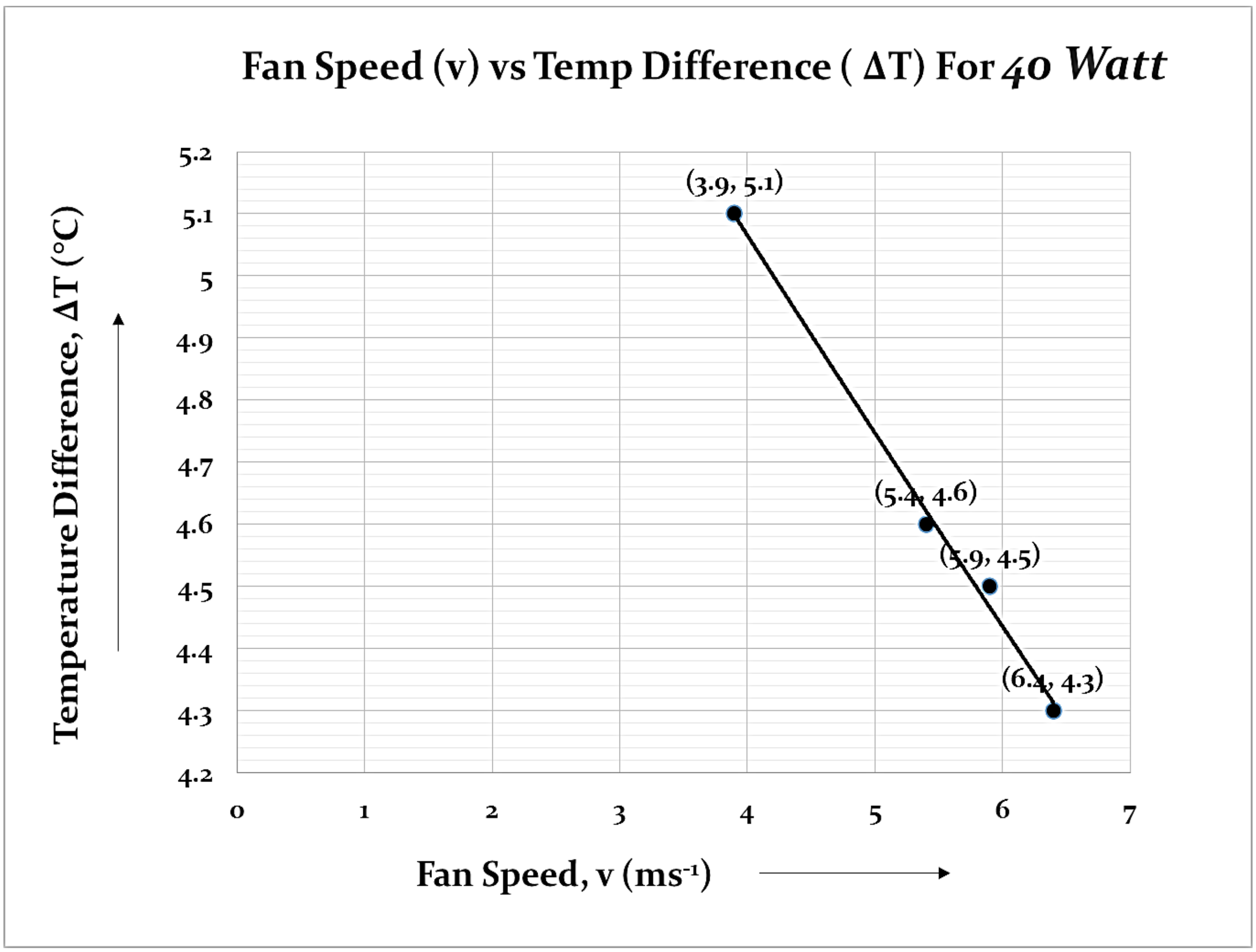
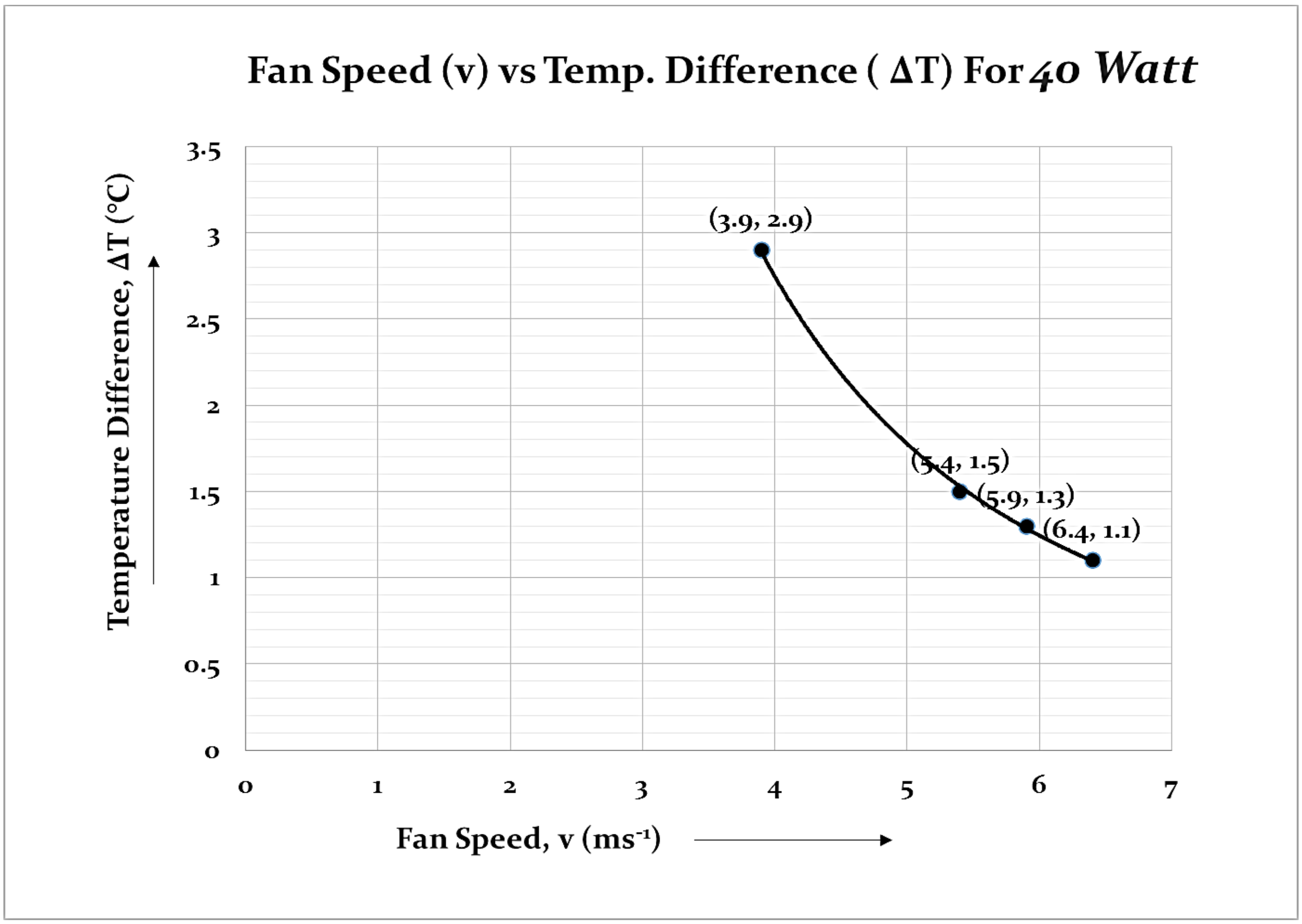
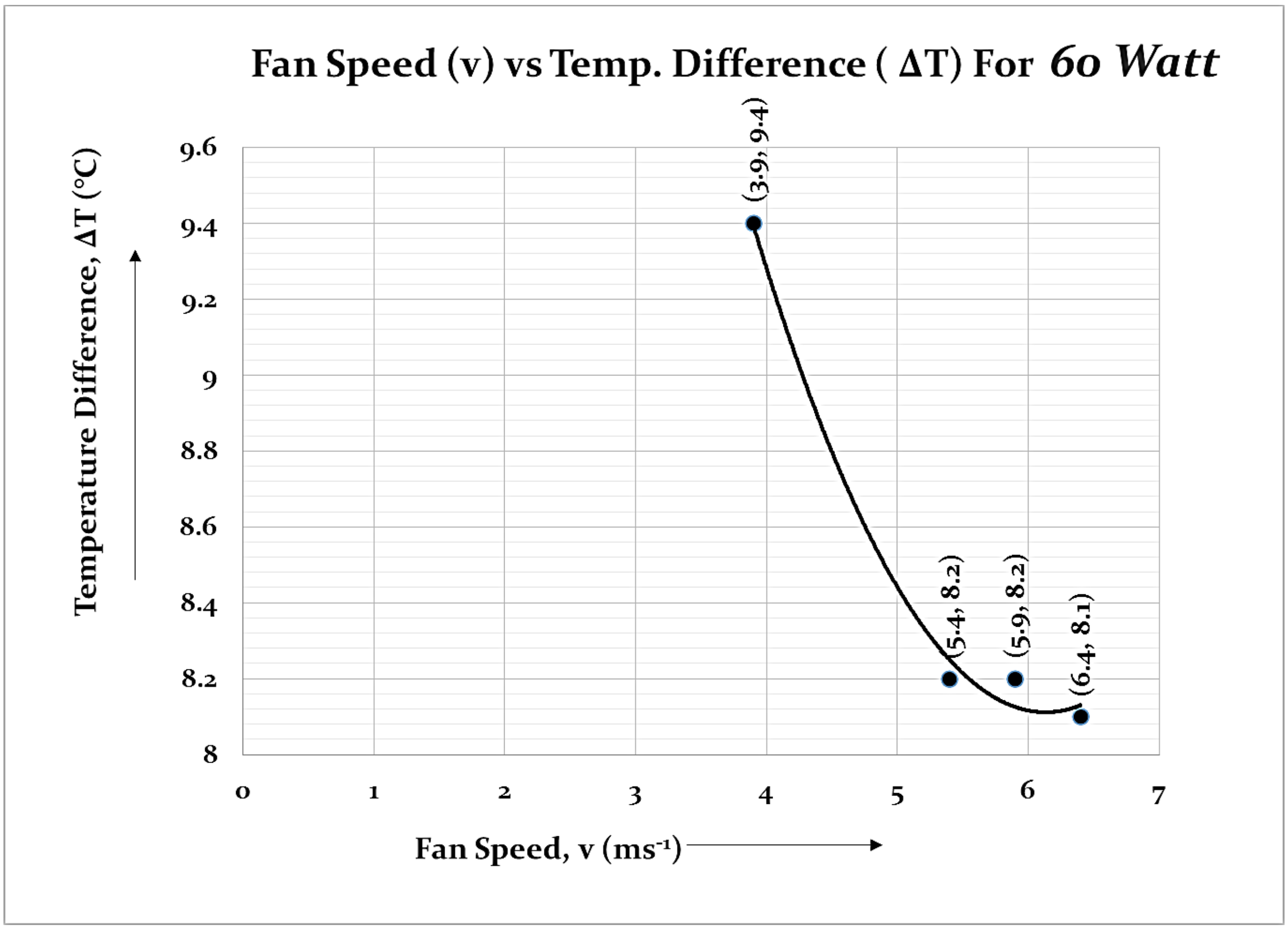

Fan Speed (v) vs Temp Difference (ΔT) For 40 Watt
Temperature Difference, ΔT (°C)
Fan Speed, v (ms-1)
(3.9, 5.1)
(5.4, 4.6)
(5.9, 4.5)
(6.4, 4.3)
5.2
5.1
5
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
0
1
2
3
4
5
6
7

Figure 1.5.2



Fan Speed (v) vs Temp. Difference (ΔT) For 40 Watt
Temperature Difference, ΔT (°C)
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
(3.9, 2.9)
(5.4, 1.5)
(5.9, 1.3)
(6.4, 1.1)
Fan Speed, v (ms-1)

Figure 1.5.3



Fan Speed (v) vs Temp. Difference (ΔT) For 60 Watt
Temperature Difference, ΔT (°C)
9.6
9.4
9.2
9
8.8
8.6
8.4
8.2
8
(3.9, 9.4)
(5.4, 8.2)
(5.9, 8.2)
(6.4, 8.1)
0
1
2
3
4
5
6
7
Fan Speed, v (ms-1)

Figure 1.5.4

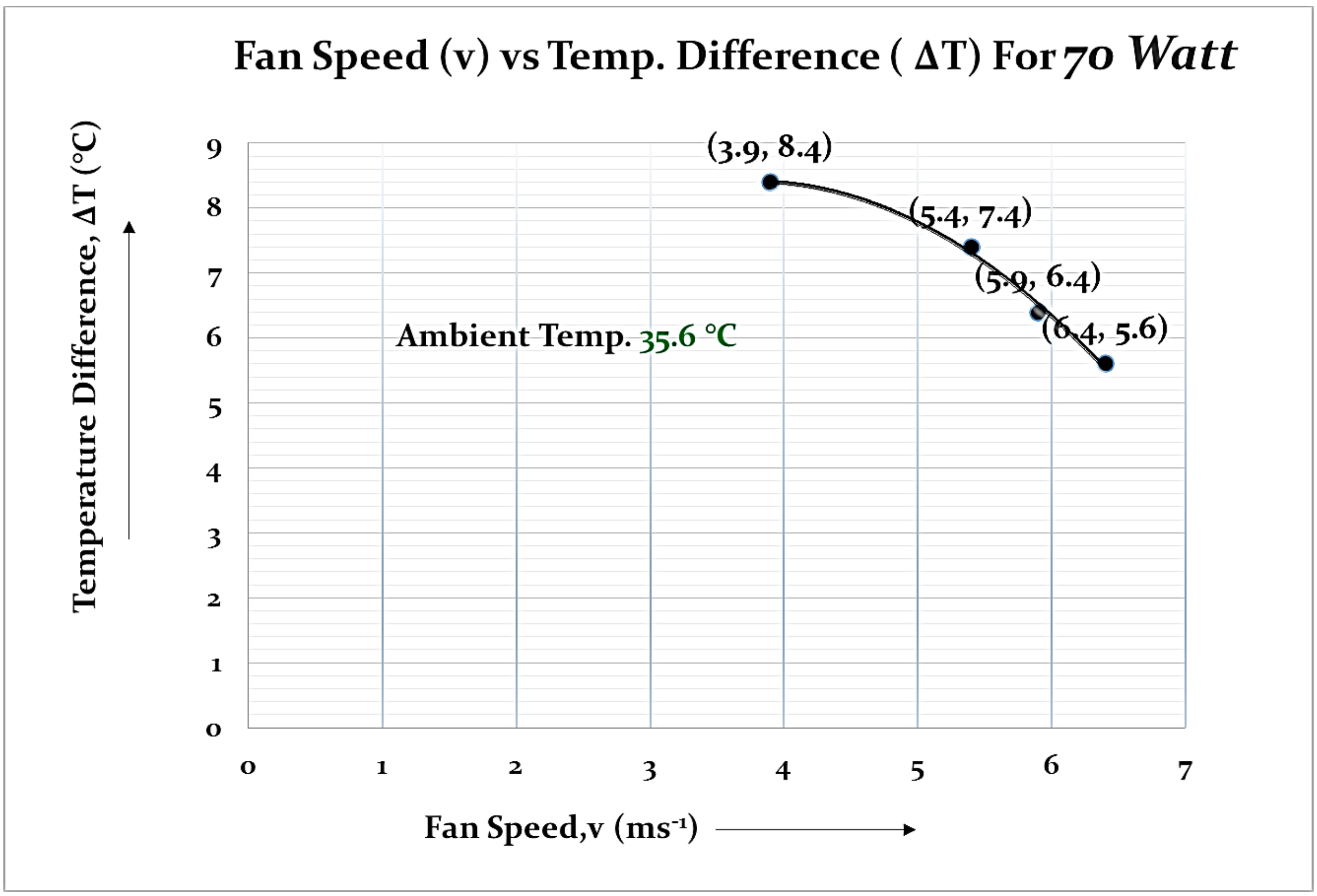

Fan Speed (v) vs Temp. Difference (ΔT) For 70 Watt
Temperature Difference, ΔT (°C)
Fan Speed,v (ms-1)
Ambient Temp. 35.6 °C
(3.9, 8.4)
(5.4, 7.4)
(5.9, 6.4)
(6.4, 5.6)
0
1
2
3
4
5
6
7
8
9

Figure 1.5.5

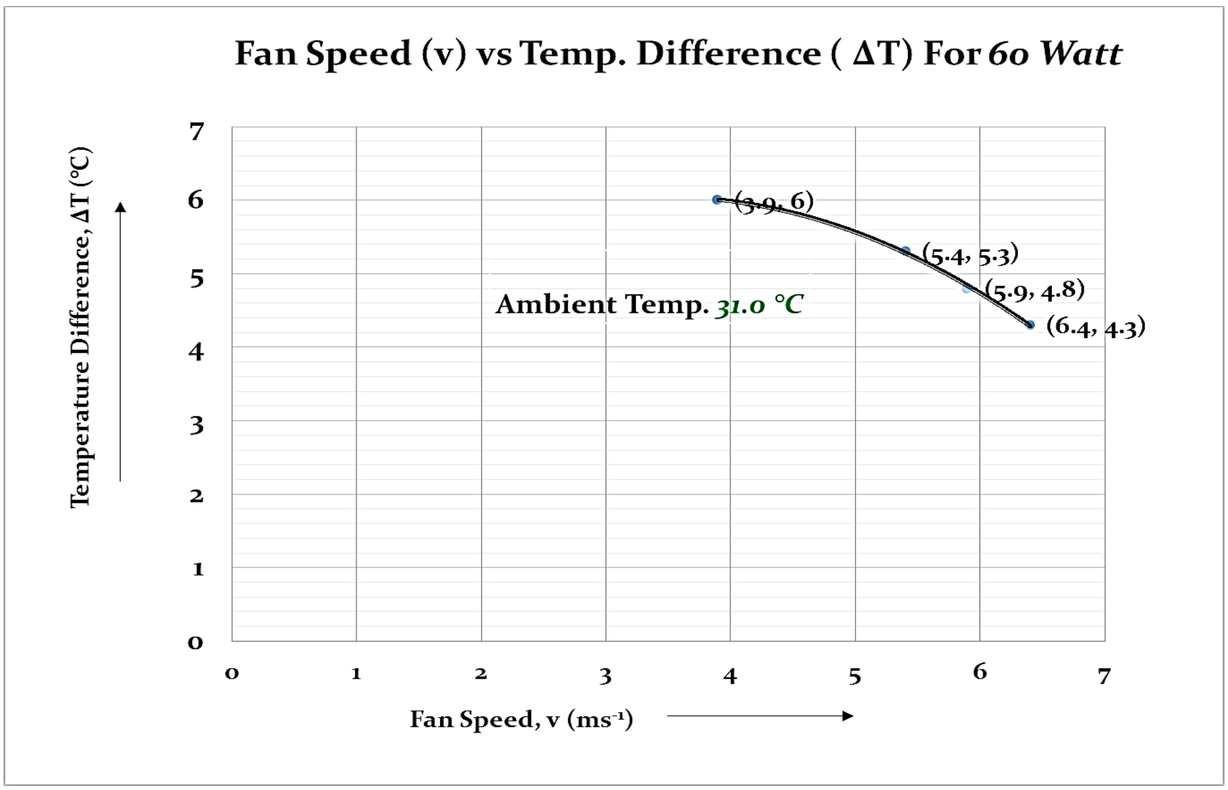

Fan Speed (v) vs Temp. Difference (ΔT) For 60 Watt
Temperature Difference, ΔT (°C)
Fan Speed, v (ms⁻¹)
Ambient Temp. 31.0 °C
(3.9, 6)
(5.4, 5.3)
(5.9, 4.8)
(6.4, 4.3)
0
1
2
3
4
5
6
7

Figure 1.5.6

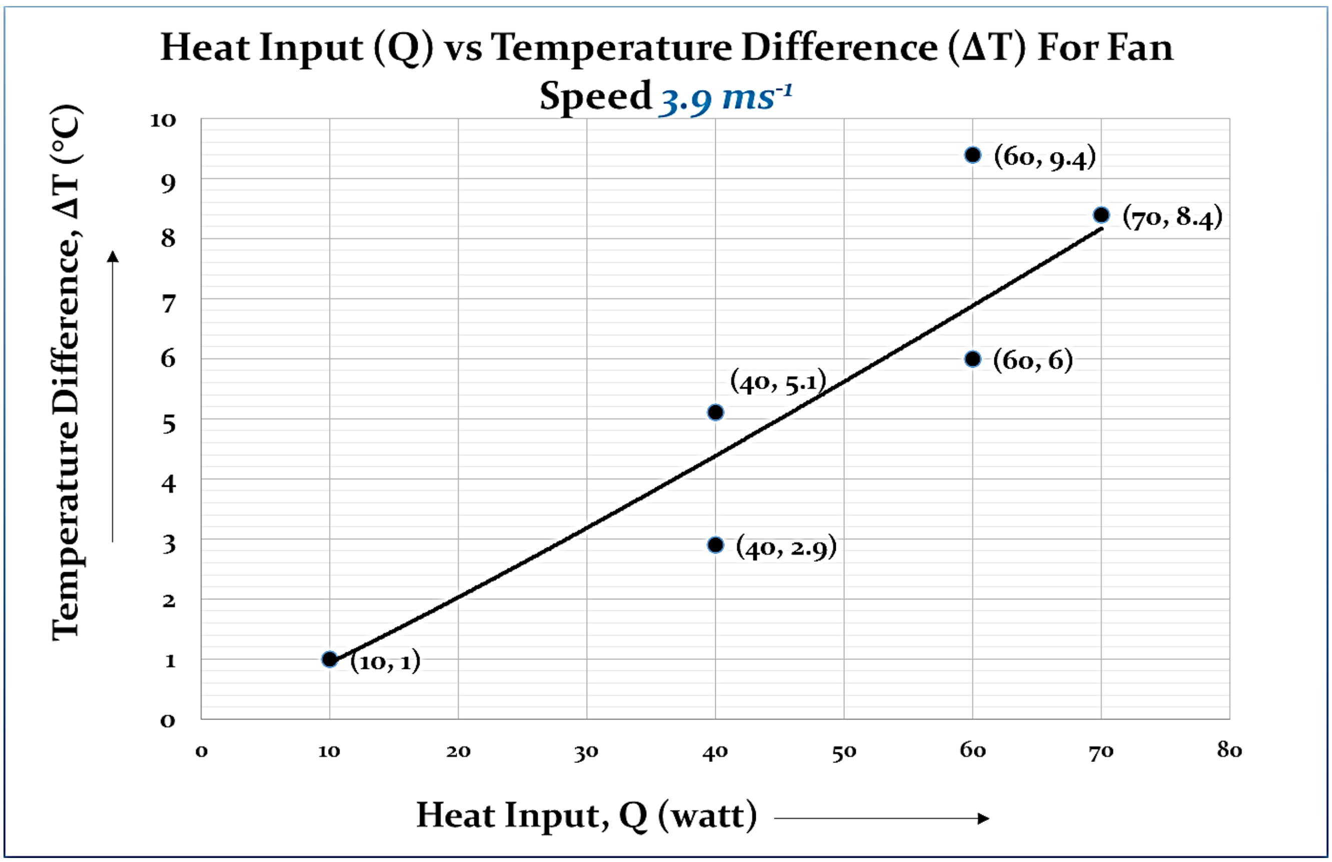

Heat Input (Q) vs Temperature Difference (ΔT) For Fan Speed 3.9 ms-1
Temperature Difference, ΔT (°C)
Heat Input, Q (watt)
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
60
70
80
(60, 9.4)
(70, 8.4)
(60, 6)
(40, 5.1)
(40, 2.9)
(10, 1)

Figure 1.5.7

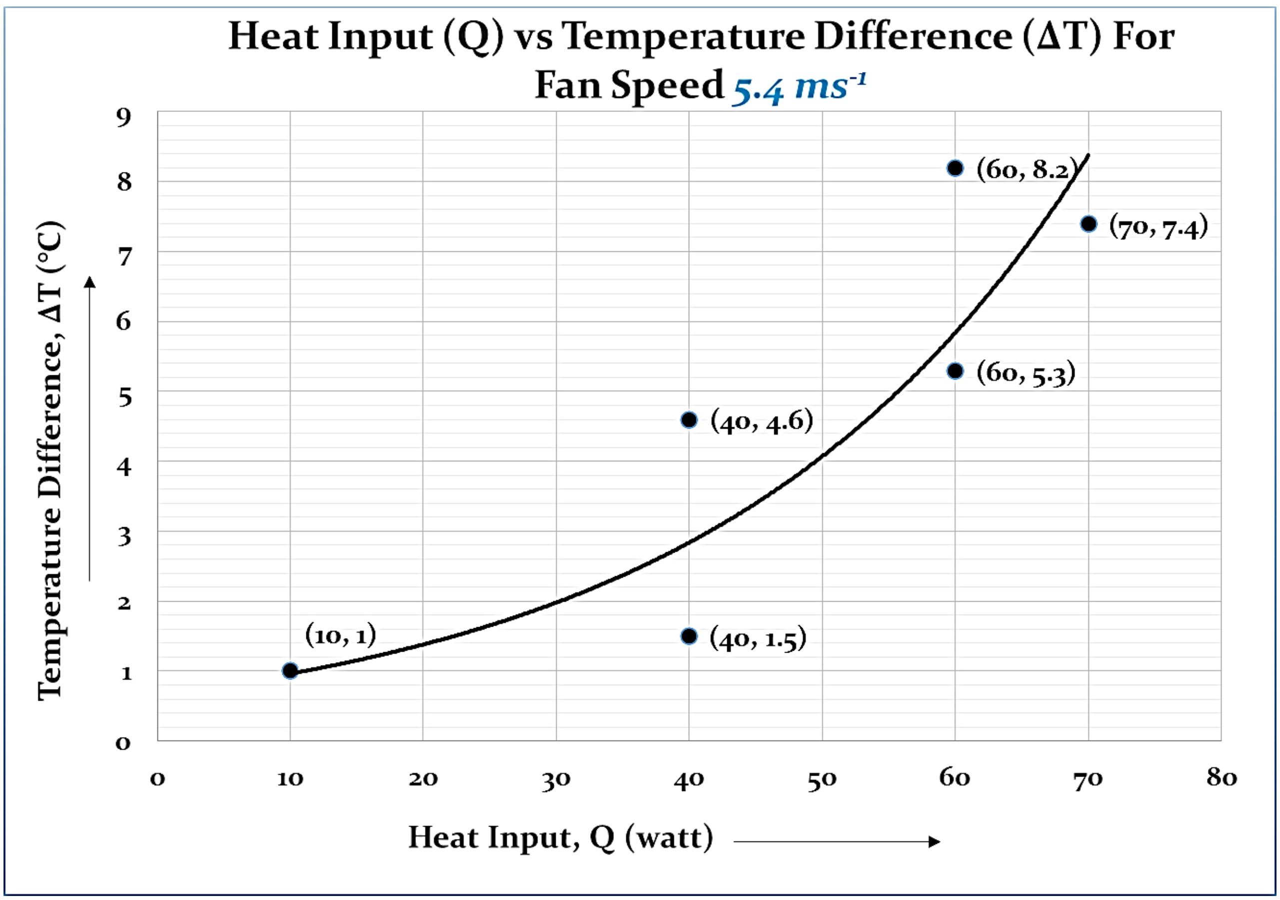

Heat Input (Q) vs Temperature Difference (ΔT) For Fan Speed 5.4 ms-1
Temperature Difference, ΔT (°C)
Heat Input, Q (watt)
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40
50
60
70
80
(10, 1)
(40, 1.5)
(40, 4.6)
(60, 5.3)
(60, 8.2)
(70, 7.4)

Figure 1.5.8

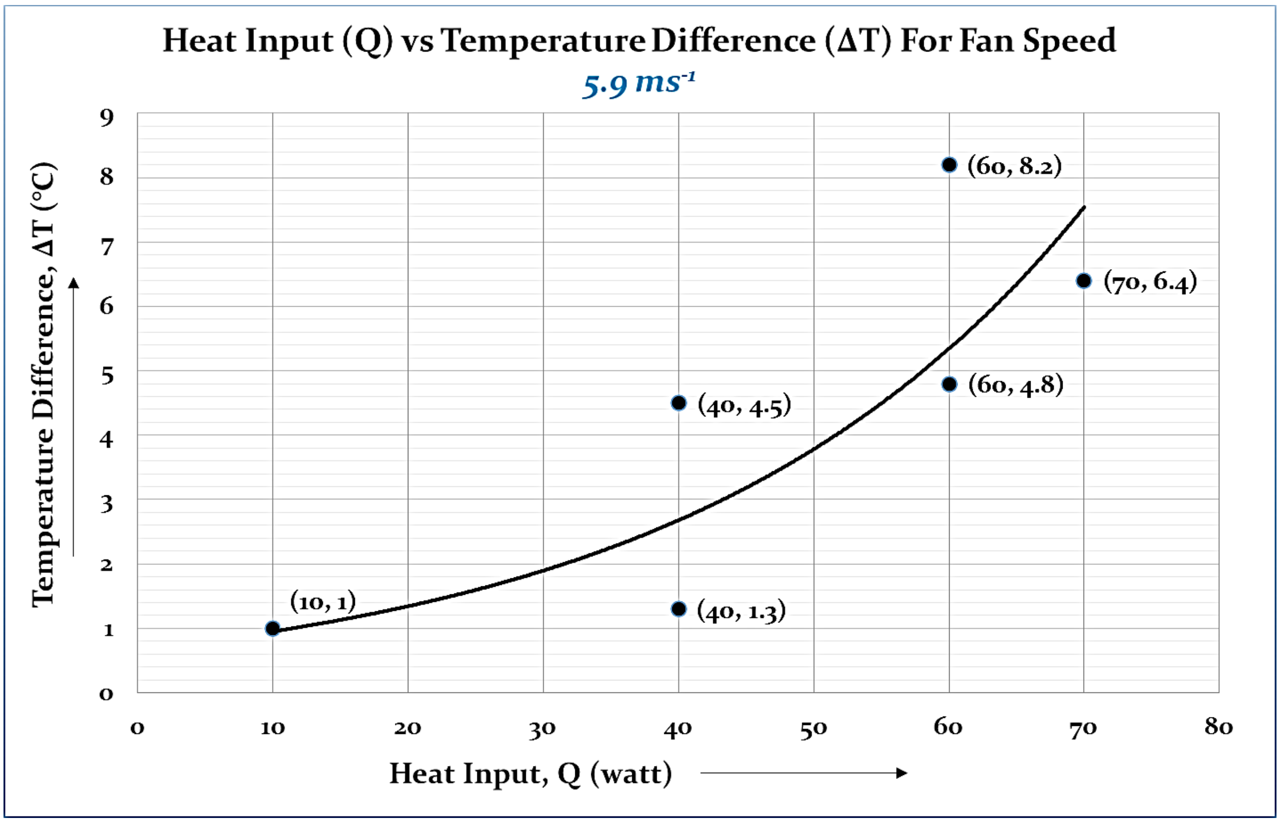

Heat Input (Q) vs Temperature Difference (ΔT) For Fan Speed
5.9 ms-1
Temperature Difference, ΔT (°C)
Heat Input, Q (watt)
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40
50
60
70
80
(60, 8.2)
(70, 6.4)
(60, 4.8)
(40, 4.5)
(10, 1)
(40, 1.3)

Figure 1.5.9

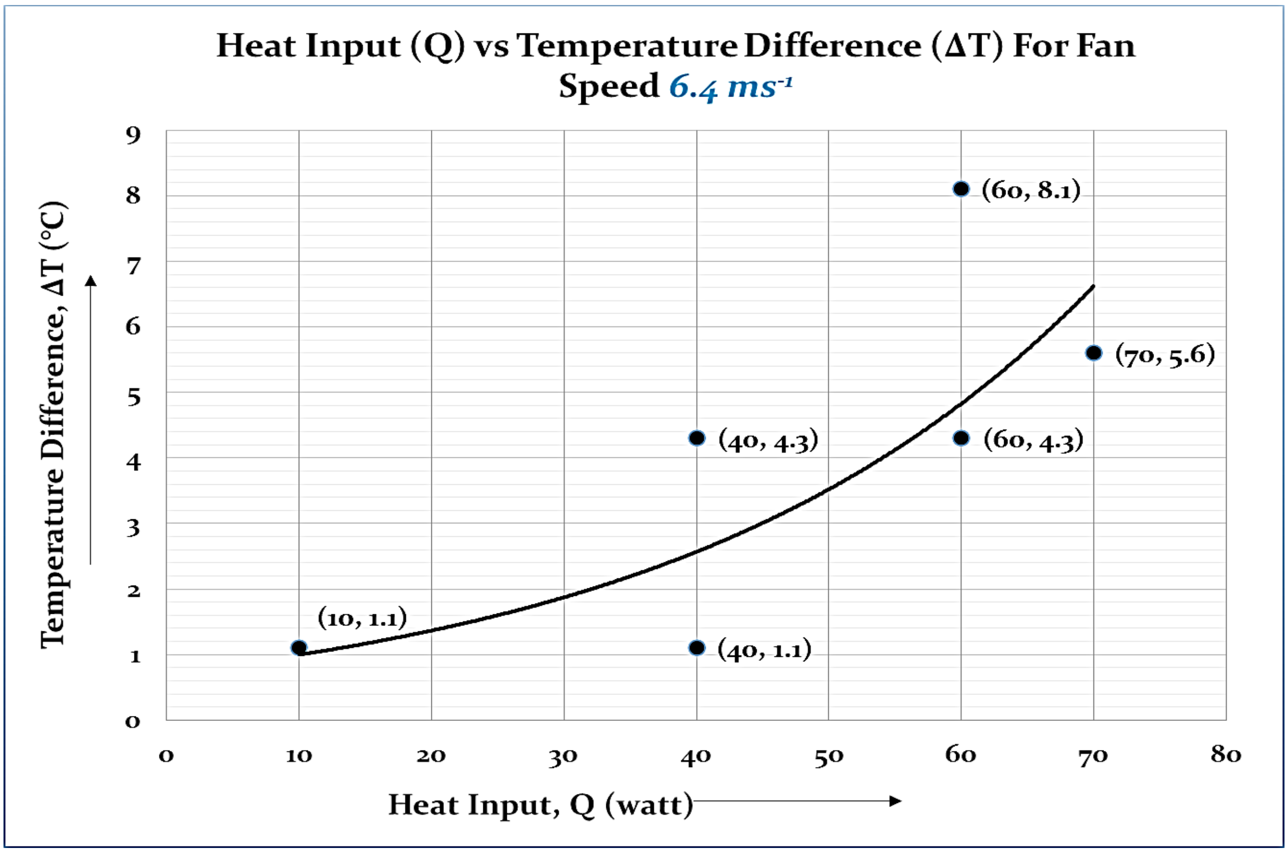

Heat Input (Q) vs Temperature Difference (ΔT) For Fan Speed 6.4 ms-1
Temperature Difference, ΔT (°C)
Heat Input, Q (watt)
(60, 8.1)
(70, 5.6)
(40, 4.3)
(60, 4.3)
(10, 1.1)
(40, 1.1)
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40
50
60
70
80

Figure 1.5.10

1.6 RESULT ANALYSIS

- It can be seen from the graphs that with the increase of fan speed the gap between the ambient temperature & the final temp. at breathing point becomes less.
- This implies that with the increase of exhaust fan speed the ventilation effect becomes more. Thus rendering more comfort to the kitchen.
- From the graphical plots a trend can be found that with the increase of heat input at a const. exhaust fan speed, the difference between the final temperature of BP at that fan speed & ambient temperature increases.

1.6.1 EFFECT OF KITCHEN HOOD SYSTEM ON VENTILATION

Power input	Ambient temp.	Final temp. difference. (w.r.t to ambient Temperature)
70 watt (without hood)	35.6°C	5.6°C
70 watt (with hood)	37.7°C	2.9°C

Using a hood above the heat source at a given heat input provides better ventilation effect.

1.6.2 EFFECT OF AMBIENT TEMPERATURE ON VENTILATION AT SAME HEAT INPUT

Ambient temperature (For 40 Watt)	Final Temperature difference (With respect to Ambient Temp.)
37°C	4.3°C
30.1°C	1.1°C

Ambient temperature (For 60 Watt)	Final Temperature difference (With respect to Ambient Temp.)
34°C	8.1°C
31°C	4.3°C

From the tables above it can be seen that with the decrease in ambient temperature the effect of ventilation becomes more visible.

So it can be inferred that ventilation i.e. exhaust fan is more effective at winter than summer.

1.7 CONCLUSION

The cumulative understanding of the experimental data upto now highlights the following aspects –

- With the increase in exhaust fan speed, the air exchange rate increases thus making the kitchen environment more comfortable.
- With the increase in heat input at a const. exhaust fan speed, the deviation from ambient temperature becomes more.
- The addition of a hood above the heat source at a given heat input provides better ventilation effect.
- With the decrease in ambient temperature the effect of ventilation becomes more visible meaning that in winter the ventilation will be more effective.

1.8 REFERENCES

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[5] Villi G., Pasut W., and Carli M., D., Computational Aspects of Modeling Different Strategies For Kitchen Ventilation: A Comparison Between The Multi-Zone Approach And CFD Modeling With Reference To Predicted Indoor Pollutant Concentrations, Eleventh International IBPSA Conference Glasgow, Scotland, July 27-30, 2009- 1574.

SECTION B

EMISSION OF FLUE GASES IN RURAL KITCHEN

2.1 ABSTRACT

Lack of proper ventilation of exhaust fumes from gas fired stoves in rural kitchens is a major health concern for some populations. It could even cause destruction of property, reduced quality of life and lifespan. In this study, a typical rural kitchen model was used. Steady state simulations were performed using a three dimensional CFD code with appropriate boundary conditions. The present numerical method was validated by comparing with the experimental data reported by Posner et al. [1]. The comparison showed very reasonable agreement. A grid independence test was also performed to determine the optimum grid resolution reflecting the accuracy of the numerical solution. A comparative analysis between the ventilation (natural and forced) and no ventilation conditions is also reported in this study. Very high concentration (above 5000 PPM) of carbon dioxide gas was observed at the plane passing the breathing zone. Exposure to this environment for longer time may cause serious health damage of the occupants [2]. As per Wisconsin Department of Health Services of USA [2], over 5,000 PPM exposures to CO_2 lead to serious oxygen deficit resulting in permanent brain damage, coma and even death.

2.2 INTRODUCTION

Indoor air quality (IAQ) and thermal comfort are the important health safety measures for the room occupants. It is a common problem in the majority of the residential buildings in developing countries due to poor architectural design of the living places, specially the kitchen, which is not properly followed by the optimum code of design for comfort ventilation. There is very little attention paid by the researchers in this particular sector. Few studies have been reported on the indoor air quality and pollutant dispersions within the living spaces. However, a review of the literature reveals that the kitchen has been given a much lower importance with regard to the proper ventilation and the efficient exhaust system.

Chi-ming et al. [3] conducted experiment to study the efficient side exhaust system for residential kitchens in Taiwan. They designed the exhaust system in three ways namely single slot, twin slot and fence slot systems. The experiment was conducted with different configurations by varying the heights. They concluded that the side exhaust systems installed close to the pot rims performed well in smoke control at the same exhaust flow rate (7.4 m3/min) which is lower than the 11.6 m3/min required by Chinese national standard 3805 (CNS-3805).

Kajtar and Leitnar [4] studied CFD modeling of indoor air quality and thermal comfort. CFD modeling was made by FLOVENT. Well established turbulence model was used for turbulence capture. Number of cases have been investigated in regard to the amount of air removed by kitchen hood. Supply air has been provided with air terminal devices installed above the windows. Each diffuser (4 x 50cm, with 50% free area ratio) was placed above the windows. The study concluded that the minimum safe carbon-dioxide concentration can be attained at 160 m3/h exhaust airflow, and to meet IAQ requirements considerably higher ventilation rate should be provided. According to calculated results, approximately 4.7 m3/h airflow is sufficient to ensure burning process of natural gas.

Nantka [5] investigated indoor conditions in Silesian Buildings with Natural Ventilation. Results were obtained by questionnaires, measurements and simulations of ventilation processes in typical blocks of flats and office buildings in Silesia. The effects of airtightness, natural ventilation and some pollutants on the indoor environment were discussed. To determine the air leakage values for windows and doors, the pressurization tests were conducted with the use of a plastic cover tightly taped to the window and door frame (the small-scale tests).There were also large-scale pressurization tests applied in selected rooms, flats and offices. Two types of stands and two methods were used. They found that the indoor air quality depends on the air change rates and the natural ventilation rate depends on airtightness of external walls and especially windows.

Odzune et al. [6] studied the CFD analysis of the effects of the size and location of an air-inlet in domestic kitchen extraction. A model kitchen including a gas range cooker and an extraction hood was constructed and the cooking process was simulated. The flow field during the cooking process in the kitchen was modeled using FLUENT Airpak 3.0.12. They concluded that air-inlet location effects both local (cooking zone) and global extraction (breathing and room zones). Depending on the location of the air-inlet, incomplete room air mixing of contaminants can occur.

Villi et al. [7] investigated the computational aspects of modeling different strategies for kitchen ventilation. Their paper dealt with the evaluation of different simulation approaches to kitchen ventilation modeling. Multi-zone, CFD and zonal approach are discussed. Results illustrate the important influence of proper ventilation for kitchen IAQ. Their study demonstrates the applicability of the zonal approach for predicting pollutant indoor concentration with a level of accuracy comparable to CFD predictions.

Park et al. [8] studied the air flow and contaminant distribution in a full-scale kitchen opened to a living room, ventilated by an exhaust hood using commercial CFD program, PHOENICS. The locations of the gas range and the window were chosen as the parameters to investigate the indoor environment. The values of the contaminant index for several layouts of the gas range and the window were calculated and compared. Their results revealed that when the gas range is installed along the wall with specified window location, its position in relation to the wall has unnoticed effect on contaminant index. However, for a fixed gas range location, the indoor air quality deteriorates by the proximity of the window to the gas range.

In a report of "UN Millennium Development Goal"[9], CO_2 emission recorded in 1990 is 21.7 billion metric tons which increases to 30.2 in 2008 and 30.1 in 2009. It reveals that the global emission is decreased by 0.4% between the year 2008 and 2009. It also shows that the trends of CO_2 emission is decreasing for developed regions and increasing for developing regions. Therefore, the present study and its implementation will certainly help to reduce CO_2 emission rate of the developing regions and assist United Nations (UN) to achieve their target by 2015.

From the above literature study, it is apparent that a number of investigations have been devoted both numerically and experimentally to account the effective way of predicting contaminant concentrations and dispersions within the kitchen space. Some specific design methodologies have also been recommended to reduce hazardous components to a level of minimum standard. Thus, improve the safe activity as well as comfort of the occupants. However, very few studies have been conducted that could explain details of CO_2 dispersion characteristics with or without ventilation systems. Moreover, a real combustion heat sources in the cooking bench have not been taken into account in any of the numerical studies. Therefore, this paper aims to investigate the indoor air contamination and heat transfer characteristics under natural, forced and no ventilated conditions. A real combustion of the natural gases in the kitchen stoves is also employed along with the effect of buoyancy in order to provide deep insight of the real physical indoor flow behavior.

2.3 INDOOR IAQ THREATS – BANGLADESH SCENARIO

- DHAKA , 18 June 2009, Andrew Trevett, acting country representative for the World Health Organization (WHO) reported, Over 46,000 people die of acute lower respiratory infections (ALRI) in Bangladesh each year due to indoor air pollution (IAP).

- 4 percent of all diseases in Bangladesh can be attributed to IAP

- Women and children are particularly vulnerable as they spend most of their time indoor.

2.4 POTENTIAL HEALTH RISK POLLUTANTS ~ INDOOR/OUTDOOR

- CO_2
- CO
- NO
- NO_2
- SO_2
- Airborne particles (Particulate matter, $PM_{2.5}$, PM_{10})

2.5 EXPOSURE TO OTHER POLLUTANTS ~HEALTH RISK

CO_2	250 – 350 ppm~Background (normal) outdoor air level
	350 – 1,000 ppm ~ Typical level found in occupied spaces with good air exchange.
	1,000 – 2,000 ppm ~ Level associated with complaints of drowsiness and poor air.
	2,000 – 5,000 ppm~Level associated with headaches, sleepiness, and stagnant, stale, stuffy air. Poor concentration, loss of attention, increased heart rate and slight nausea may also be present.
	>5,000 ppm ~Exposure may lead to serious oxygen deprivation resulting in permanent brain damage, coma and even death.
CO	Headaches; Dizziness; Confusion; Nausea 0.5 to 5 (ppm) / 5 to 15 ppm / 30 ppm or higher.
NO	Relatively non irritating gas No health threat at ambient levels Oxidized to NO_2 which has a much higher toxicity.

NO_2	Eye, nose, and throat irritation, respiratory infections Air Quality Standards 0.053 ppm in outdoor air Inside air without stoves 50% With stoves exceeds the outdoor
SO_2	High concentrations SO_2 exposures can cause chronic bronchitis Standard 0.03 ppmv (80 μg/m3)
PM	Eye, nose, and throat irritation; Respiratory infections and bronchitis; Lung cancer.

Source: Wisconsin Department of Health Services of USA [2]

2.6 MOTIVATION

- IAP has been the major concern of EPA.
- IAP has got the potential health effect for the developing countries.
- Numerical codes are capable of predicting indoor contaminants concentrations and dispersions.
- Specific recommendations are possible to reduce hazardous components to a level of minimum standard.
- Understanding of indoor air flow characteristics.
- Different sources of indoor pollutants.

2.7 OBJECTIVES

- To establish a numerical methodology of kitchen air quality using the commercial CFD code ANSYS-CFX-14.
- To investigate the level of pollutants concentration for typical models of the rural kitchen in Bangladesh.
- To analyze the possible health hazards at different contamination levels.

2.8 EXPERIMENTAL SETUP

The components that were used for conducting this experiment are as follows :

- An improved burner from “Grameen Shakti”.
- Firewood, cow-dung, rice husk as fuel.
- A simple kitchen structure that resembles common rural kitchens used in Bangladesh.
- Metal duct for concentrating the Combustion gas flow.
- CO_2, CO and PM sensors.


Duct
Grameen Shakti
Burner


CO2 Meter
CO Meter
EXTECH
6843
EXTECH
513
ON/OFF
Carbon Monoxide

2.8 DATA ACCUMULATION PROCEDURE

- We have burnt each type of fuel separately and also in mixed mode.
- For each type of fuel, we have taken two types of readings; 1.5 feet from the source and 3 feet from the source.
- We have taken readings of each type every minute for half an hour.
- We have used a metal duct for concentrating the Combustion gas flow towards our sensors.
- We used a stand to hold the sensors together so that they can give readings from same position.
- For each type of fuel, we took the average value of readings for CO, CO_2 and particulate matter & took it as input for our simulation in ANSYS CFX.

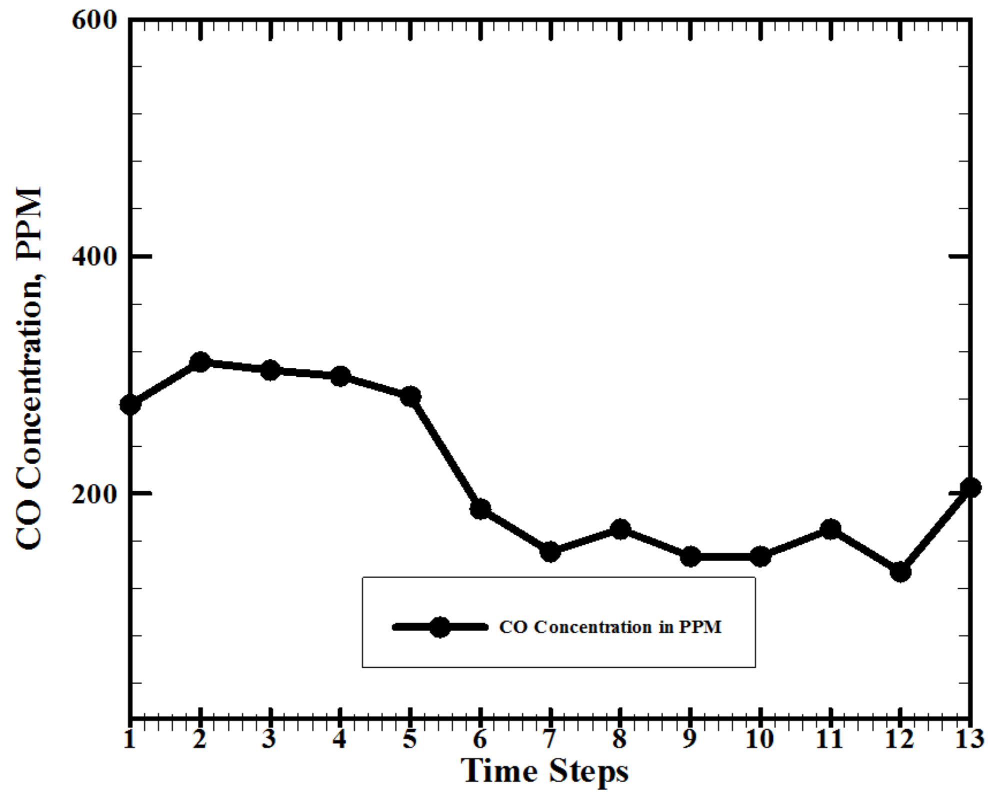

Figure 2.8.1

Concentration Of CO (Using Cowdung)

1.5 feet From The Source

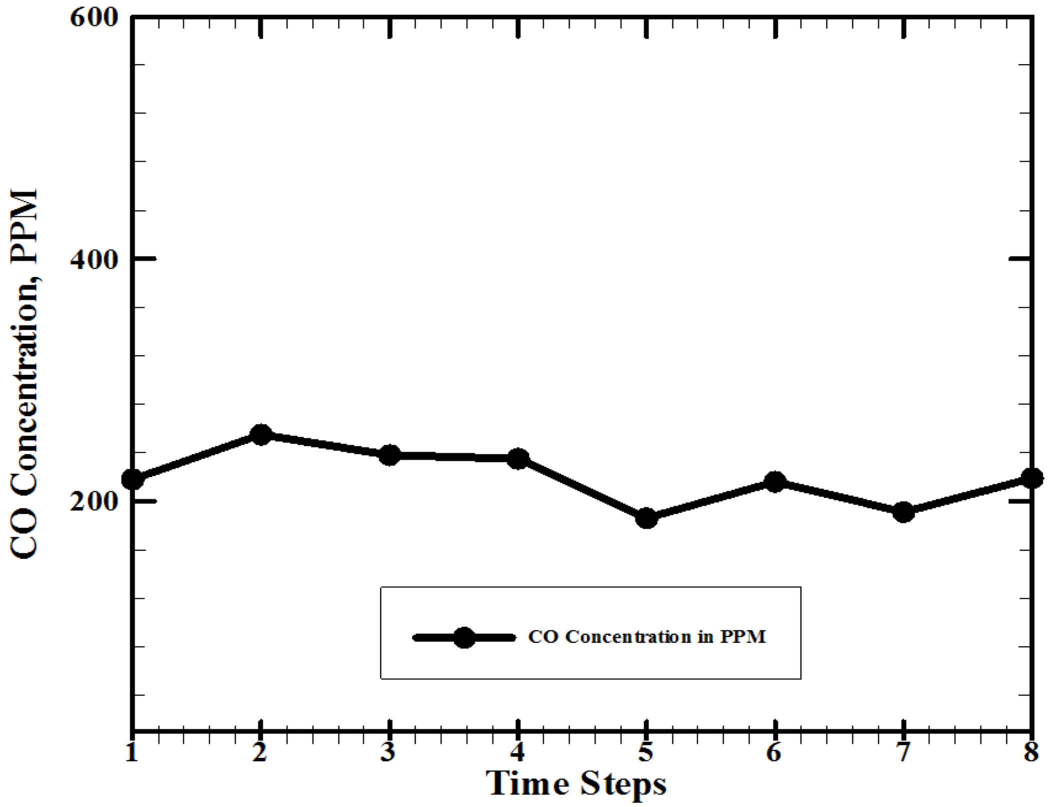

Figure 2.8.2

Concentration Of CO (Using Cowdung)

3 feet From The Source

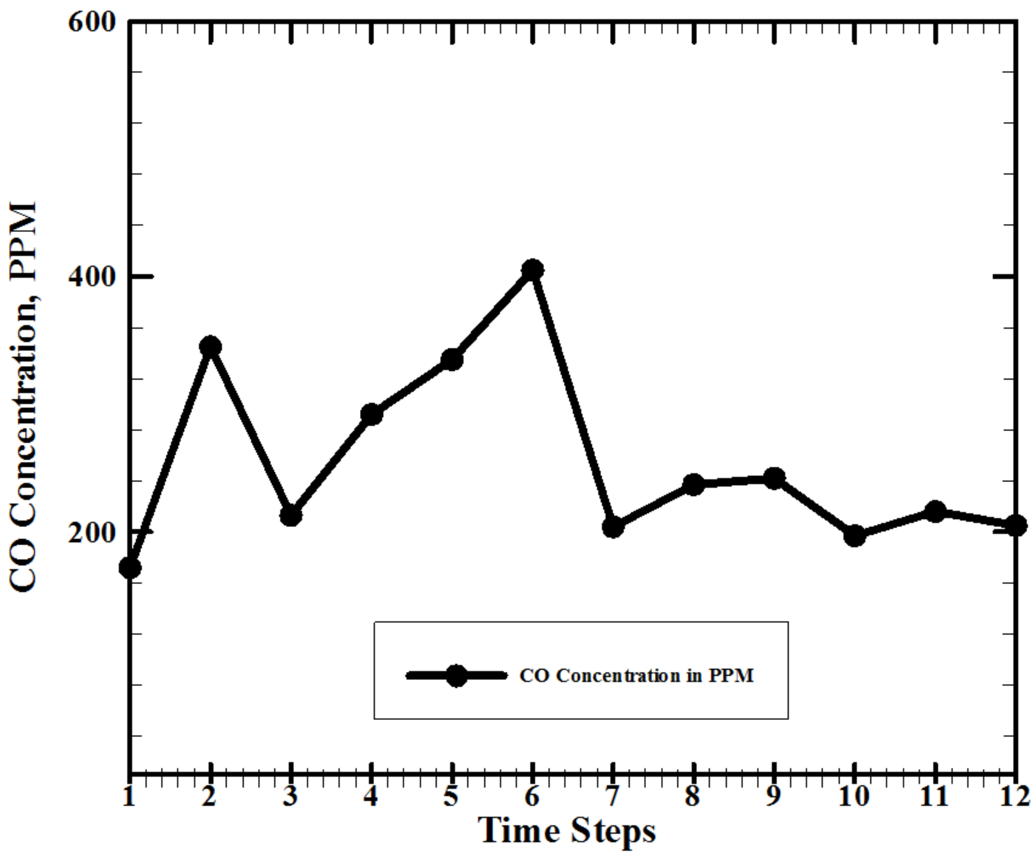

Figure 2.8.3

Concentration Of CO (Using Cowdung & Rice Husk)

1.5 feet From The Source

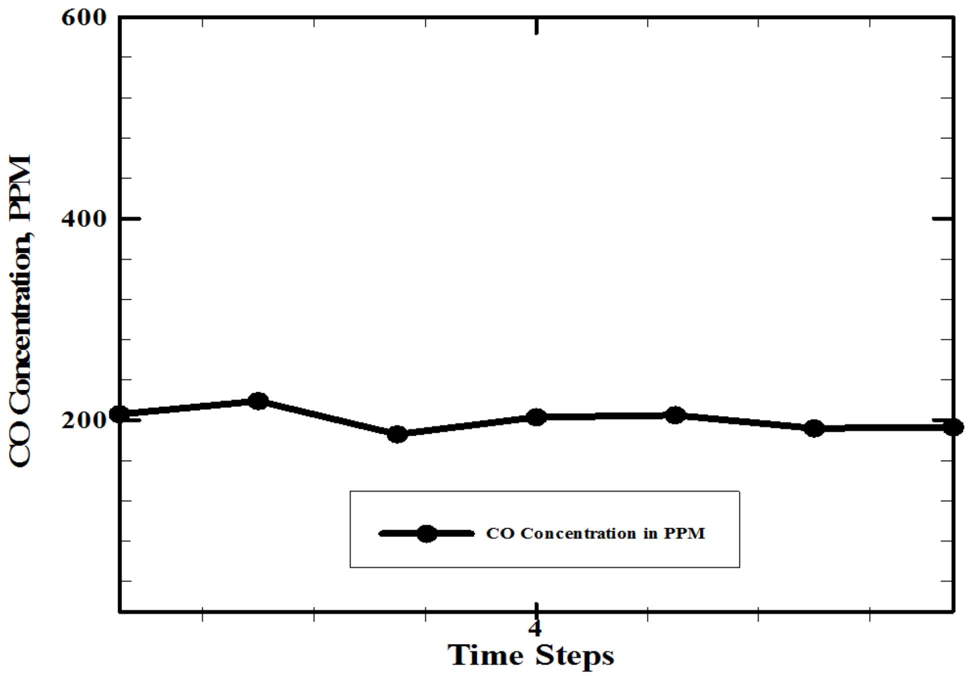

Figure 2.8.4

Concentration Of CO (Using Firewood & Cowdung)

3 feet From The Source

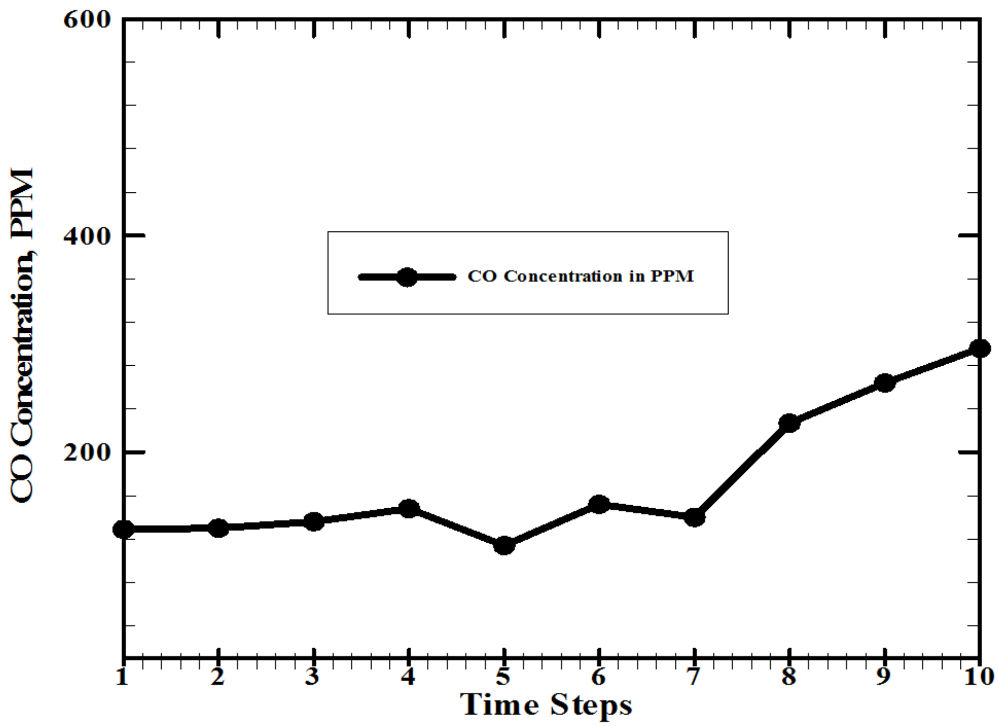

Figure 2.8.5

Concentration Of CO (Using Firewood)

3 feet From The Source

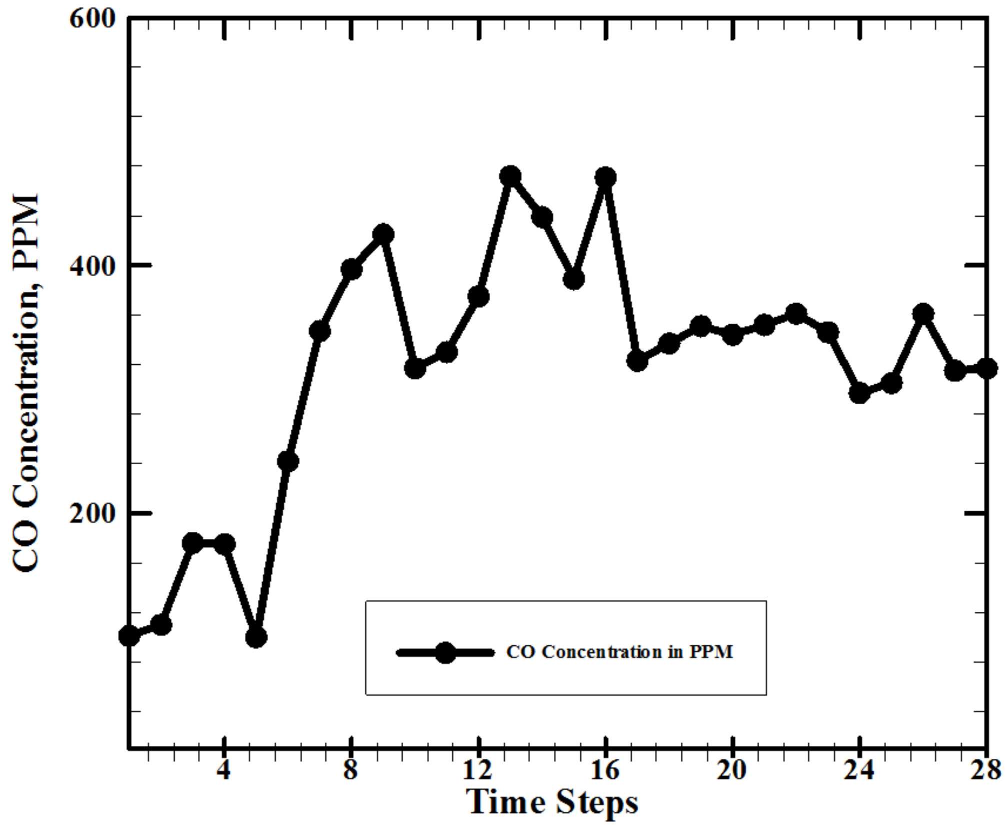

Figure 2.8.6

Concentration Of CO (Using Firewood)

1.5 feet From The Source

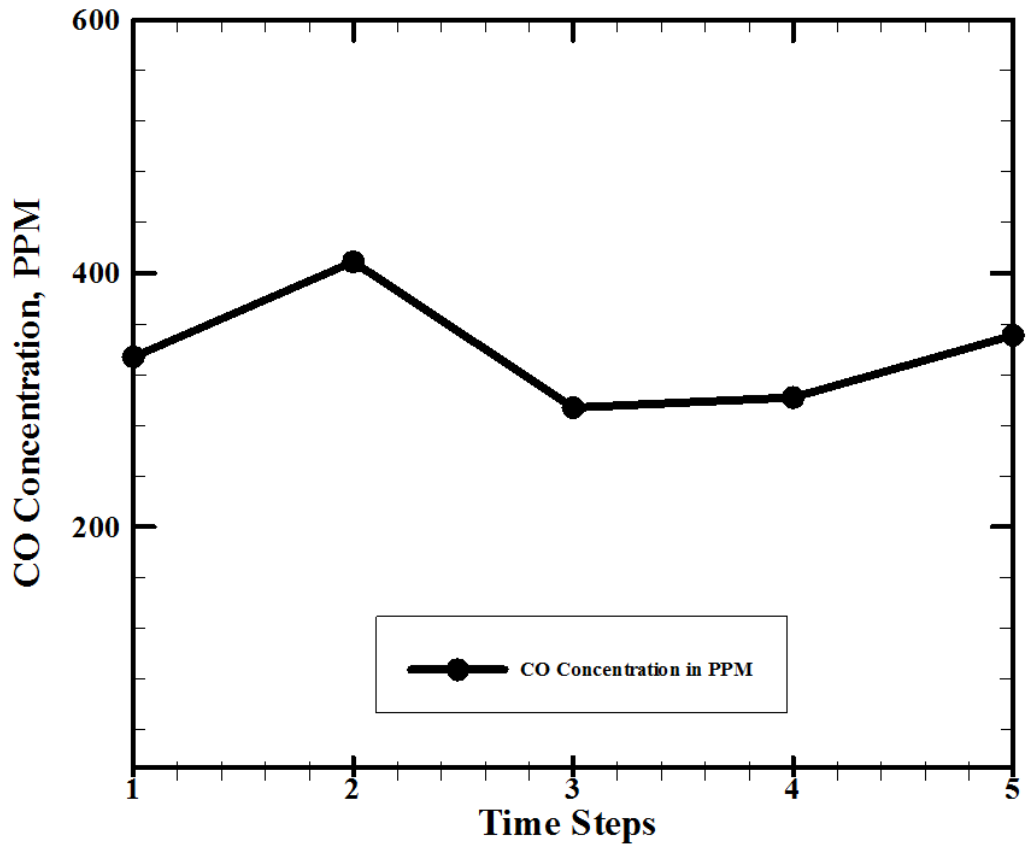

Figure 2.8.7

Concentration Of CO (Using Husk)

1.5 feet From The Source

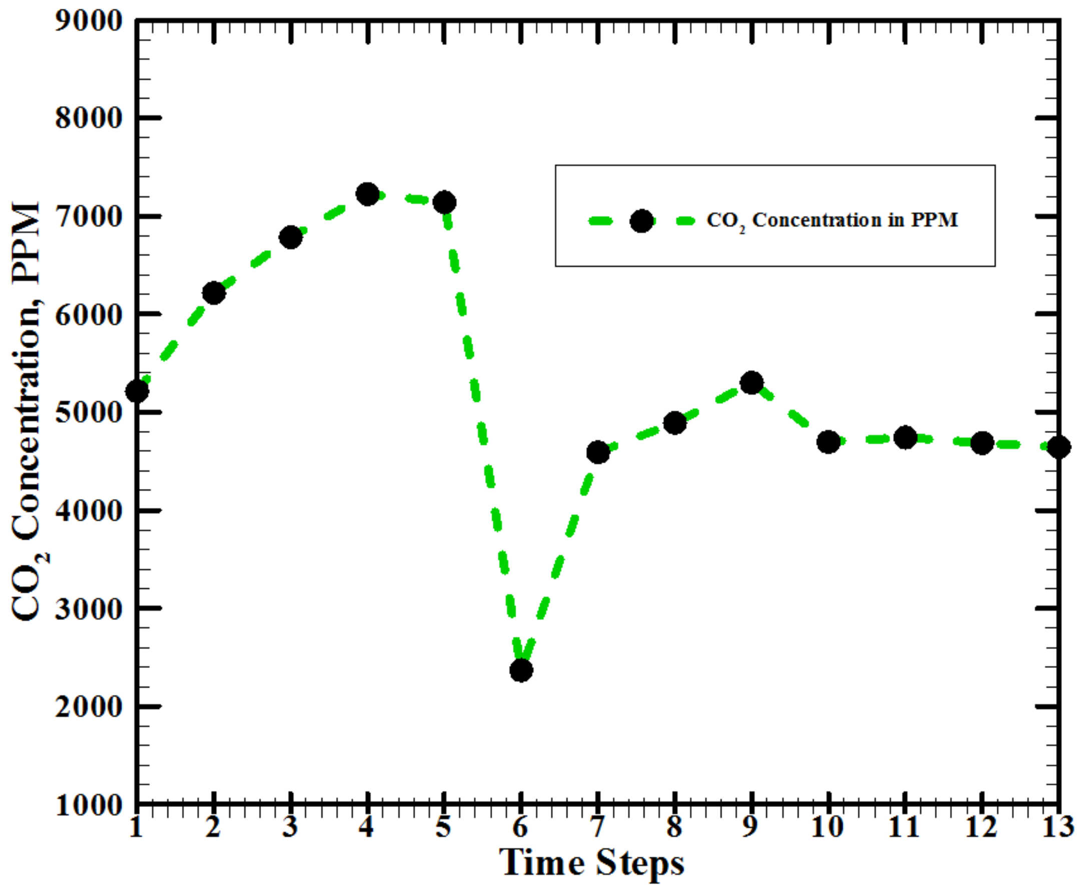

Figure 2.8.8

Concentration Of CO_2(Using Cowdung)

1.5 feet From The Source

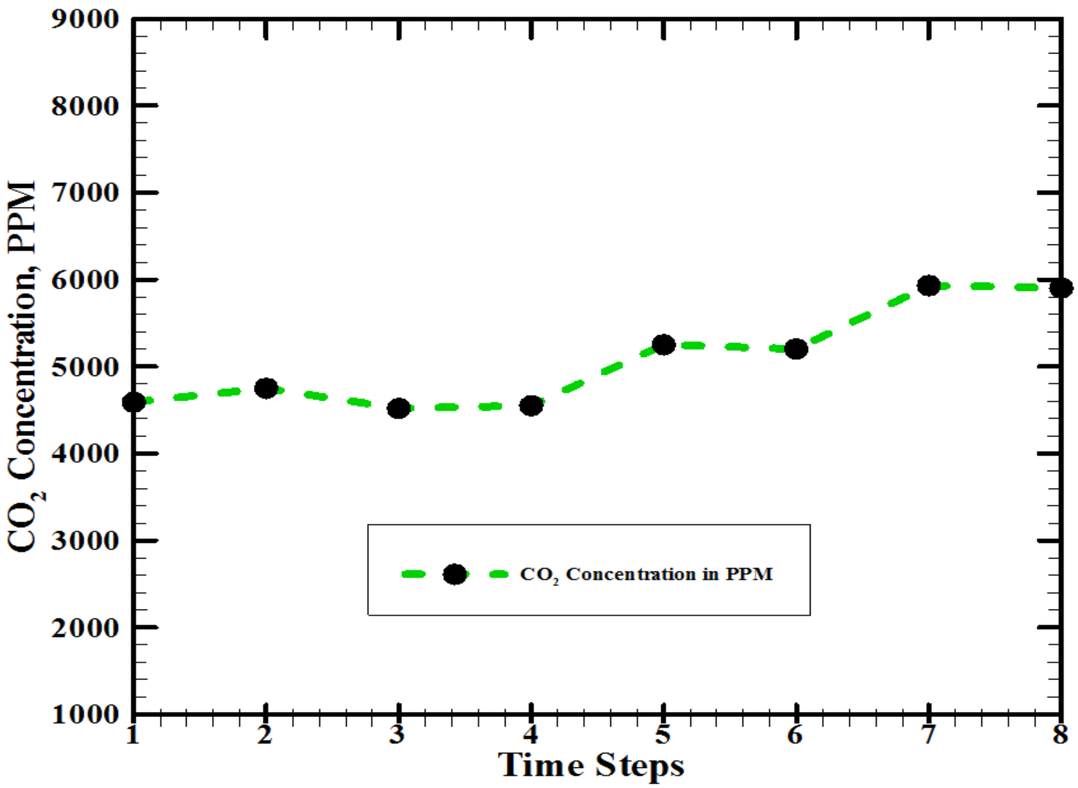

Figure 2.8.9

Concentration Of CO_2(Using Cowdung)

3 feet From The Source

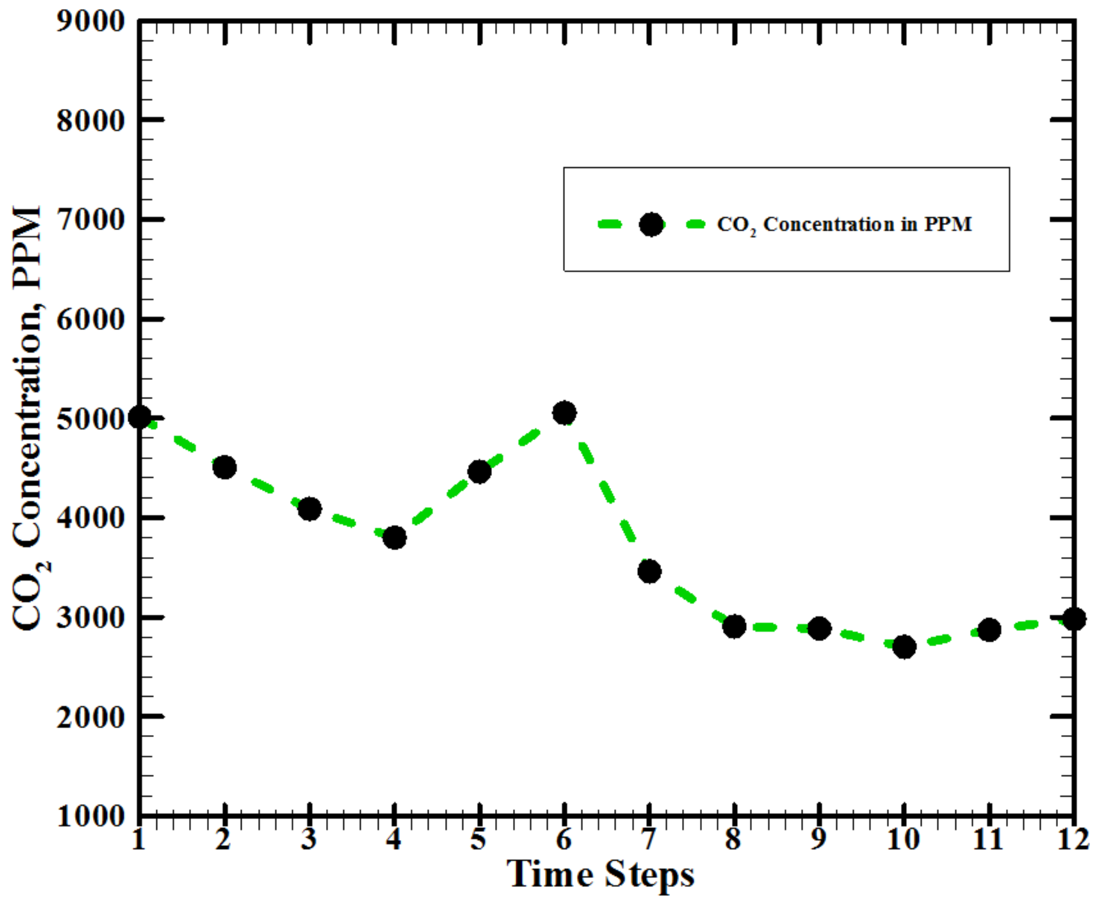

Figure 2.8.10

Concentration Of CO_2(Using Cowdung & Rice Husk)

1.5 feet From The Source

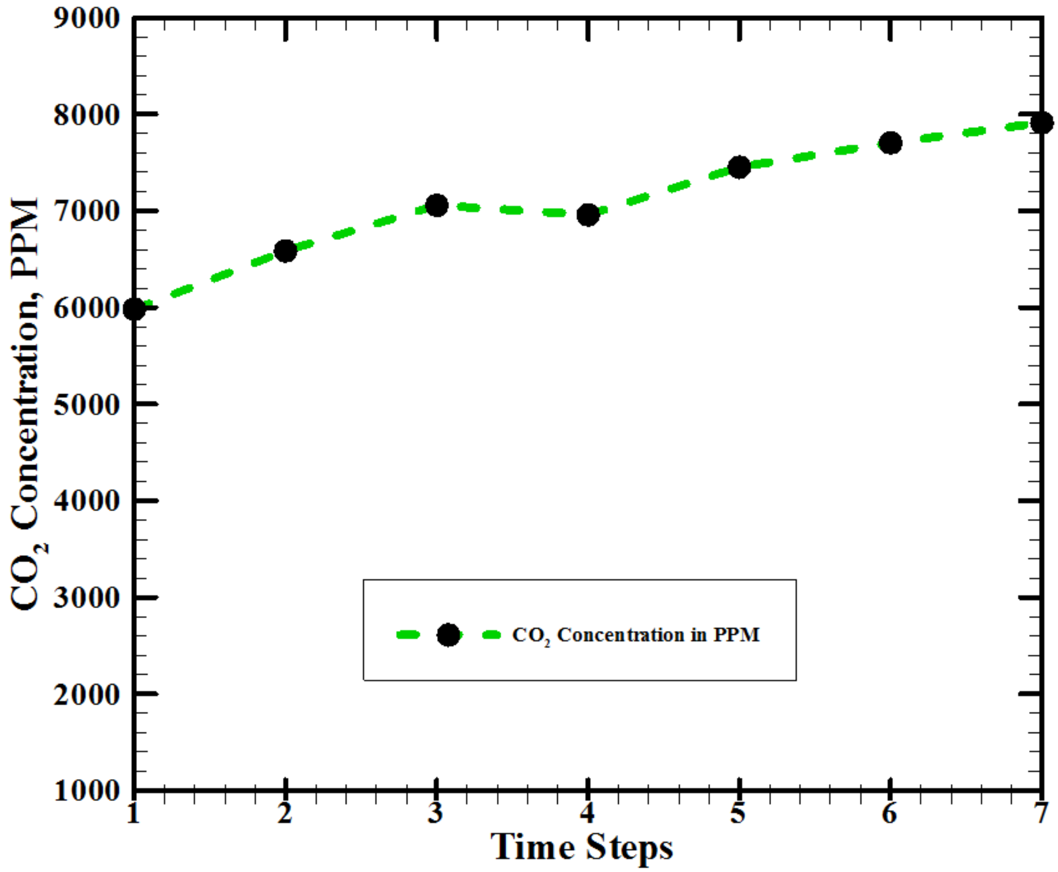

Figure 2.8.11

Concentration Of CO_2(Using Cowdung & Firewood)

3 feet From The Source

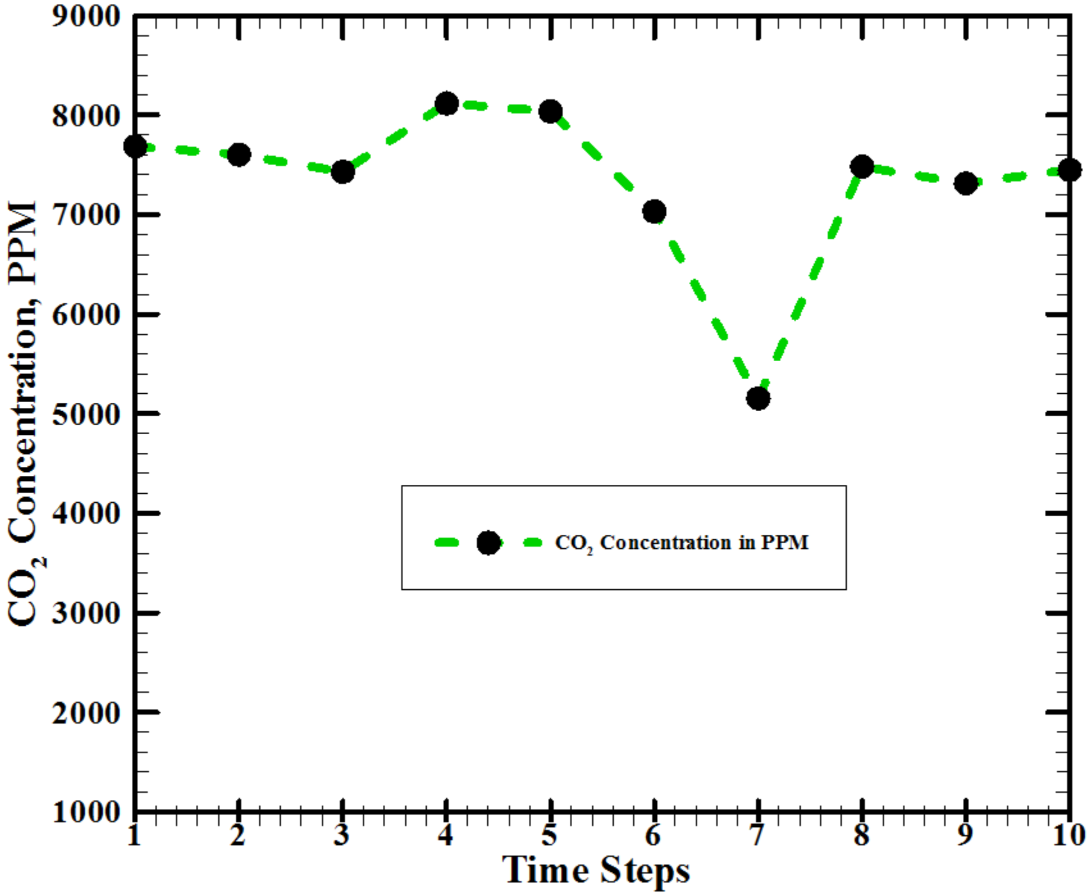

Figure 2.8.12

Concentration Of CO_2 (Using Firewood)

1.5 feet From The Source

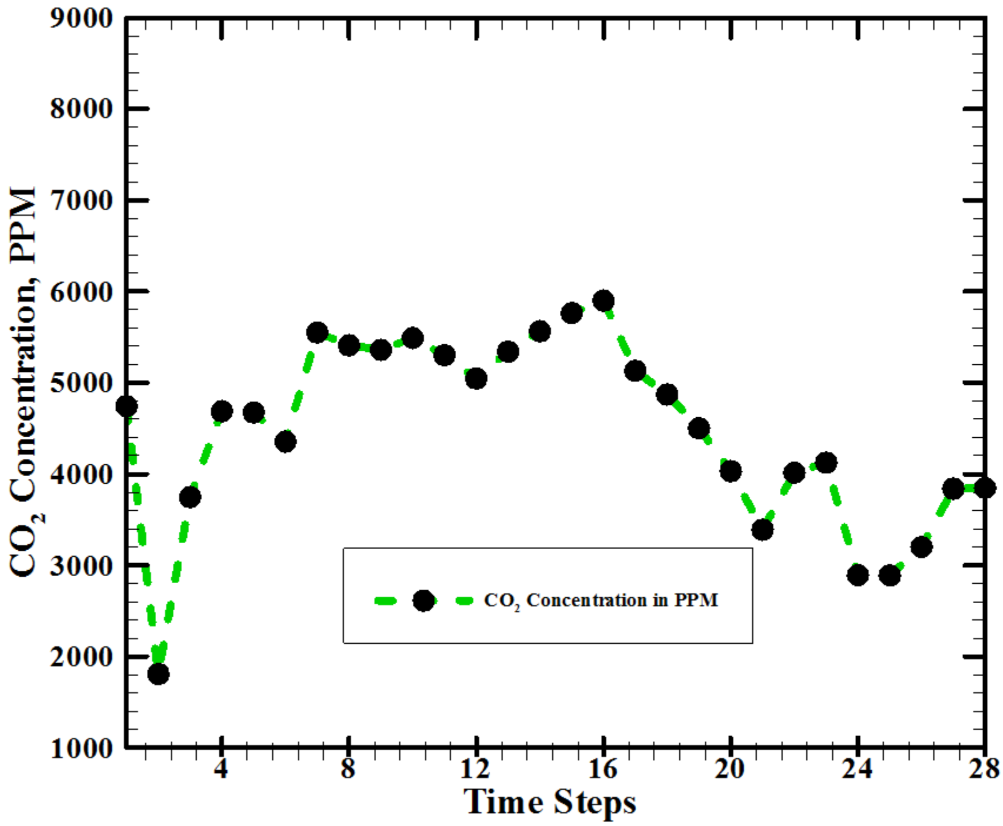

Figure 2.8.13

Concentration Of CO_2 (Using Firewood)

3 feet From The Source

2.9 RESULT ANALYSIS

In case of CO, it has been observed that among all the fuels, firewood emits highest amount of CO gas and cowdung offers lowest emission.

In case of CO_2, mixture of cowdung and firewood emits highest concentration of gas when burnt and combination of cowdung and rice husk offers lowest emission.

According to Wisconsin Department of Health Services of USA, when CO_2 concentration exceeds 5000 ppm, prolonged stay in that environment may cause permanent brain damage, coma and finally death. And the lowest concentration we got is 5000 ppm at 1.5 feet which is a vehemently alarming health risk.

For CO , more than 50 ppm could cause serious damage to respiratory system and brain tissues and our lowest concentration was 320 ppm.

We can easily understand that rural women and children who uses these fuels are greatly exposed to this deadly emission.

2.10 CONCLUSION

The concentrations we found in the improved oven was supposed to be dispersed in atmosphere through the chimney. But in most of the rural kitchen, there is no chimney, so people are exposed to the whole concentration of flue gas.

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