ASSESSMENT OF INDOOR AIR POLLUTION FROM CHARCOAL COMBUSTION IN DAR ES SALAAM CITY, TANZANIA: A CASE STUDY OF MANZESE WARD.

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Abstract

This study was conducted to determine the level of indoor air pollution due to cooking using charcoal inside the houses of Manzese in Dar es Salaam, Tanzania. A pilot system which was also used in trying to evaluate various technological options with the purpose of reducing indoor air pollution. The structured questionnaire was used to collect the household survey data. Microdust Pro (model 176106A, high range version) and gas analyser KANE900 Plus were used to measure the emissions (PM_{10} CO, NO_x and SO_2) from combustion. The air extraction fan (Vents 100K1 Axial fan) was used in the pilot system for pollutants removal. It was found that the usage of charcoal as the source of energy for cooking was very high in Manzese (82.2% of the dwellers).The number of households representing 53.3% and 95.9% were found to cook their food outside during the dry season and inside during the rainy season respectively. The overall hourly average CO concentration for the selected houses was 134±52 mg/m^3 during cooking which is higher than the hourly recommended WHO guideline of 30mg/m^3. The PM_{10} concentrations during cooking in all houses ranged from 1.22mg/m^3 to 1.46mg/m^3 with an overall hourly average concentration of 1.37 mg/m^3 exceeding the WHO 24 hours guideline mean concentration of 0.05mg/m^3. Also measurements for SO_2 and NO_x concentrations (mg/m^3) were taken in the sampled houses and were found to be higher than the WHO guidelines. Air extraction fan lowered the CO and PM_{10} concentrations from 206mg/m^3 to 28mg/m^3 and 1.14mg/m^3 to 0.26mg/m^3 correspondingly. It was concluded that awareness should be given to the people on the health effects caused by burning charcoal in the indoor environment, the adoption of air extraction fans should be encouraged so as to minimize pollution levels in the indoor environment and encourage Manzese dwellers to have outside facility for cooking whenever possible.

Keywords: *Indoor Air Pollution, Particulate Matter, Gaseous Pollutants, Ventilation*

1.0 INTRODUCTION

Charcoal is a fuel commonly used for household and institutional cooking and heating in different areas of the developing world, especially in Africa and in South-East Asia (Pennise et al., 2001). One-third of the world's population burn organic material such as wood, dung or charcoal (biomass fuel) for cooking, heating and lighting.(Fullerton et al, 2008). This form of energy usage is associated with high levels of indoor air pollution and an increase in the incidence of respiratory infections, including pneumonia, tuberculosis and chronic obstructive pulmonary disease, low birthweight, cataracts, cardiovascular diseases. This lead to increased mortality rate both for adults and children (Fullerton et al., 2008). The variety of unspecific symptoms, such as irritation or dryness of mucous membranes, burning eyes, headache or fatigue were reported as a result of indoor contamination (Maroni et al, 1995). The study by Benjamin, 2008; shows that there is a direct correlation between exposure to biomass combustion pollutants (PM_{10} and CO) and respiratory diseases. The study by Semiono (2005) revealed that poor ventilation contributed to the pollution of the indoor air and hence raised the exposure level the individuals. Indoor air pollution due to incomplete combustion of traditional biomass causes death of 1.45 million people every year, mainly of women and children(Maesa & Verbistb, 2012). The current information (Energypedia, 2012) show that, the usage of charcoal for cooking in Dar es Salaam has gone up compared to other urban areas. For instance, about 400 bags of charcoal are transported from Mkuranga district to Dar es Salaam daily by use of various equipment through formal and informal routes (Minja, 2006). The study on the sources of charcoal for Dar es Salaam (Malimbwi & Zahabu, 2008) showed that the amount of charcoal entering the city was 6777 bags of 56 kg each per day. Burning of charcoal generates gaseous pollutants such as carbon monoxide (CO), oxides of nitrogen (NO_x) and sulphur dioxide (SO_2). The suspended particulate matters are also produced in the course of charcoal combustion(Semiono, 2005).

Problems facing the urban poor include rudimentary housing. Most of the people today in the towns especially in the city of Dar es Salaam are migrants from other parts of thre country with low income and leave in the squatters (Kinabo, 2003). In these squatters, available space per person is small and houses are congested. The ventilation in these houses is therefore very poor. Majority of dwellers in these houses use charcoal for cooking. Charcoal is still a dependable source of energy for cooking because majority of urban dwellers consider it easier to use than firewood and also easily available, easy to store, and still affordable in terms of cost especially as it can be purchased in small quantities.

Manzese is congested and many people live in the poorly ventilated houses, with no designated kitchens. Cooking is mostly done using charcoal, and it is carried out either outside or inside the houses. During rainy season cooking is totally shifted from outdoor to indoor, where the cooking is mainly done in verandas, corridors, and even bed-rooms.

The current study determines the levels of NOx, CO, SO_2 and PM_{10} due to charcoal burning at Manzese households and set out a pilot kitchen for establishing the technological options for reducing indoor air pollution. Measurements obtained from this study can be used to establish the relationship between indoor air pollution from charcoal burning and the frequent health complaints of Manzese residents as well as other areas which simulate conditions at Manzese.

2.0 MATERIAL AND METHODS

1.1 Study Area Description

The study was conducted at Kilimani and Uzuri Streets at Manzese in KInondoni District. Manzese is one of seventy four wards in Dar es salaam City.

The pilot kitchen was built at Ardhi University research site located at 64°5’33” south of equator and 39°12’51” East of Greenwich Meridian line. The system was modified to meet the real site conditions although air movement in Manzese is restricted than it is at Ardhi University. The system (building) has a ceiling board, it is connected to electric power and an air extract fan has been installed for pollutants removal facilitation. The fan is rated at 96 m^3/hr and it is made in China. The fan model number is Vents 100K1 Axial Fan.

1.2 Methods

2.2.1 Household survey

Before the final draft of the questionnaire was made, questions were passed to some randomly selected individuals in order to test their validity. The final questionnaire gathered information from the individuals through face to face interviews. The important information that was captured in the questionnaire is kitchen types, stove types, cooking behavior and time-activity budget for individuals in the area. The collected information was entered in Statistical Package for Social Scientists (SPSS) software for analysis.

2.2.2 Sampling of suspended particulate matter

Microdust Pro instrument, model 176106A (High range version) was used to measure PM_{10} concentration in the five selected houses at Manzese. This instrument has unit range of 0-2500 mg/L. The instrument is a hand-held, data-logging meter for the real-time detection of airborne dusts, fumes and aerosols.

The instrument was positioned in the house before any cooking activities were carried out and the amount of dust present at times when cooking is not taking place registered. The instrument was then placed at a cook’s position (0.5m from the stove and 1m from the ground) during cooking to register the dust levels (PM_{10}) during cooking. Thirty minutes after cooking, the instrument was placed in the house to register the remainders of dust after cooking. The exercise of measuring PM_{10} was carried in the same five houses during the morning, afternoon and evening times, so as to observe variation of concentration of dust at different times of the day. The recorded concentrations were analysed using Microsoft Excel.

2.2.3 Sampling of oxides of nitrogen, sulphur dioxide and Carbon monoxide

The concentrations of CO, NOx and SO_2 were measured directly on the hand held gas analyser KANE900 Plus. The KANE900 Plus has a rechargeable lead acid batteries. The detection ranges for the instrument are: for CO (0-5000mg/m^3), for NOx (0 - 200mg/m^3) and no specifications for SO_2.

The instrument was positioned in the house before any cooking activities were carried out and concentrations of gaseous pollutants present at times when cooking is not taking place registered. The instrument was then placed at a cook's position (0.5m from the stove and 1m from the ground) during cooking to register the concentrations levels during cooking. Thirty (30) minutes after cooking, the instrument was placed in the house to register the remainders of gases after cooking. The exercise of measuring gaseous pollutants was carried in the same five houses for morning, afternoon and evening times so as to observe the variations in the concentration of gases of interest for different times of the day. The recorded concentrations were analysed using Microsoft Excel.

2.2.4 Sample collection from the pilot system

2.2.4.1 Sampling for carbon monoxide, sulphur dioxide and nitrogen oxides

The concentrations of CO, NOx and SO_2 were measured directly on the hand held gas analyser KANE900 Plus. The KANE900 Plus has a rechargeable lead acid. The detection ranges for the instrument are: for CO (0-5000mg/m^3), for NOx (0 - 200mg/m^3) and no specifications for SO_2.

Before starting sampling, the instrument was calibrated. Sampling was done for five sets of conditions. The conditions were: Measurement taken when the room was fully closed, when the room was fully closed with an air extract fan operating, when the door opened with an air extract fan operating adjacent to the door, the door opened with an air extract fan operating opposite to the door and when only the door was opened. For each condition, the measurement was done at three different times (that is, before charcoal was lighted, during lighting of charcoal and when charcoal was steadily burning). The data were stored in the gas analyser as measurements were going on until the end when they were downloaded into the Microsoft excel sheet for analysis and interpretation.

2.2.4.2 Sampling and determination of particulate matter

Microdust Pro instrument, model 176106A (High range version) was used to measure the PM_{10} concentration. This instrument has unit range of 0-2500 mg/L. The instrument is a hand-held, data-logging meter for the real-time detection of airborne dusts, fumes and aerosols. Before sampling was started, calibration was done by passing clean air through the probe. The procedure used during sampling of PM_{10} is the same as the one used for gaseous pollutant sampling above, with similar five sets of conditions and three different times. At the end of sampling, data was downloaded into Microsoft excel for analysis and interpretation.

2.3 Data Types and Sources

2.3.1 Data Types

The main data that were taken during this study were concentrations data (PM_{10}, CO, NOx and SO_2) that affect the indoor air quality.

2.3.2 Data Sources

The source of the emission data collected in this study is the point source. The point sources in this study was elevated and not at ground-level.

3.0 DATA ANALYSIS

The row data for the emissions from the households were grouped and the average calculated. The data were taken during the morning, afternoon and in the evening. For each time of the day, measurements were done before cooking, during cooking and thirty minutes after cooking. The average values for each emission data were compared against WHO values and the discrepancies discussed. The collected data from the pilot system were compared to each other and the system that showed the lowest levels of pollutants was taken as the best system.

4.0 RESULTS AND DISCUSSIONS

4.1 Household survey

4.1.1 Household energy

Most households in Manzese rely on charcoal fuel as their main source of energy for cooking (82.2%) followed by kerosene which accounts for 13.3%. Only 2.2% of the households use gas for cooking. The other 2.2% use both charcoal and kerosene as shown in Fig. 4.1.

There are limitations on the usage of gas and electricity that have promoted the use of charcoal in the area as shown in Fig. 4.2 and 4.3 respectively. 37.8% of the people in the area lamented that the cost, especially the initial cost for using gas is very high and therefore should be reduced. Lack of education on how friendly the gas is (i.e. 26.7% of the people said that they do not like using gas because it can explode). 91.1% of the households said that they cannot afford to cook using electricity because of the high running cost.

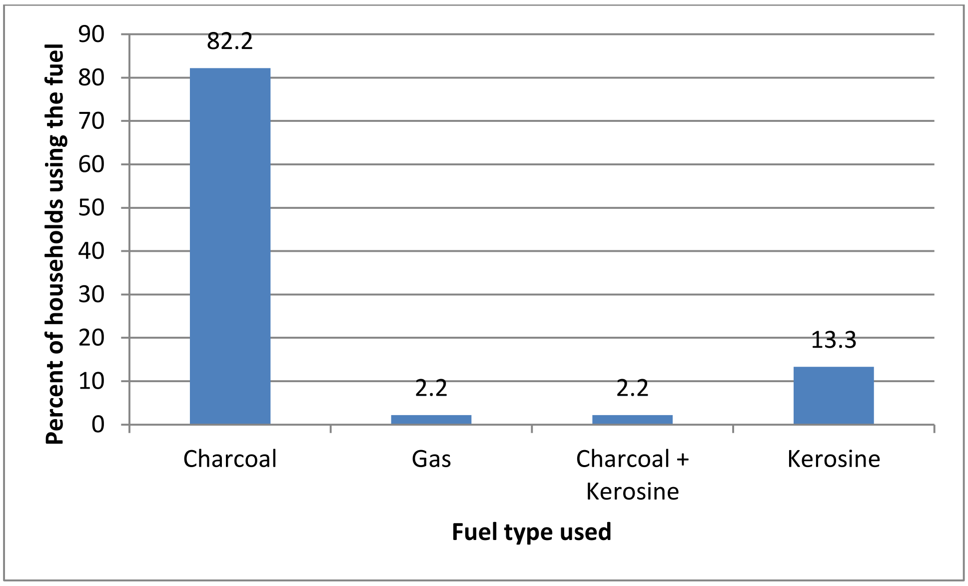

Figure 0.1: Type of fuel used for cooking in the study area (Manzese)

4.1.2 Cooking characteristics

In Manzese ward, the stove type that is commonly used is the charcoal stove (82.2%) because charcoal is the easiest fuel they can afford. Fewer households use kerosene stove (11.1%). Only 2.2% of the people in Manzese use gas stoves. Types of stoves used in the area are depicted in Fig. 4.4.

Mostly, mothers are the ones that are carrying out cooking activities (75.6%) because most women in the area are house wives and therefore spend a larger portion of their time at home taking care of the family, cooking in particular. House girls make 8.9%. Men and grandmothers make 8.9%. Most households in Manzese (80%) take three meals a day (breakfast, lunch and dinner). 13.3% of the households take only two meals a day.

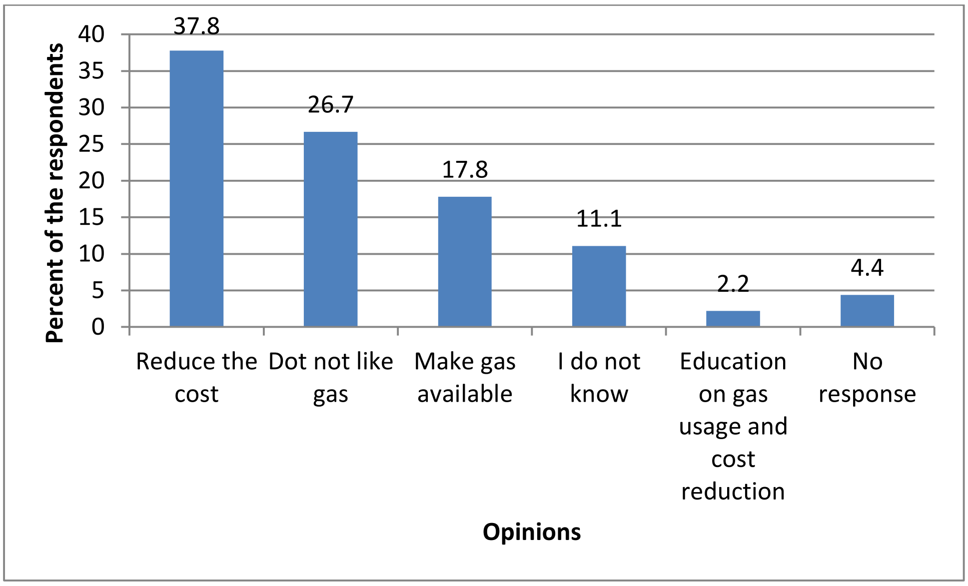

Figure 0.2: Constraints of gas usage in Manzese

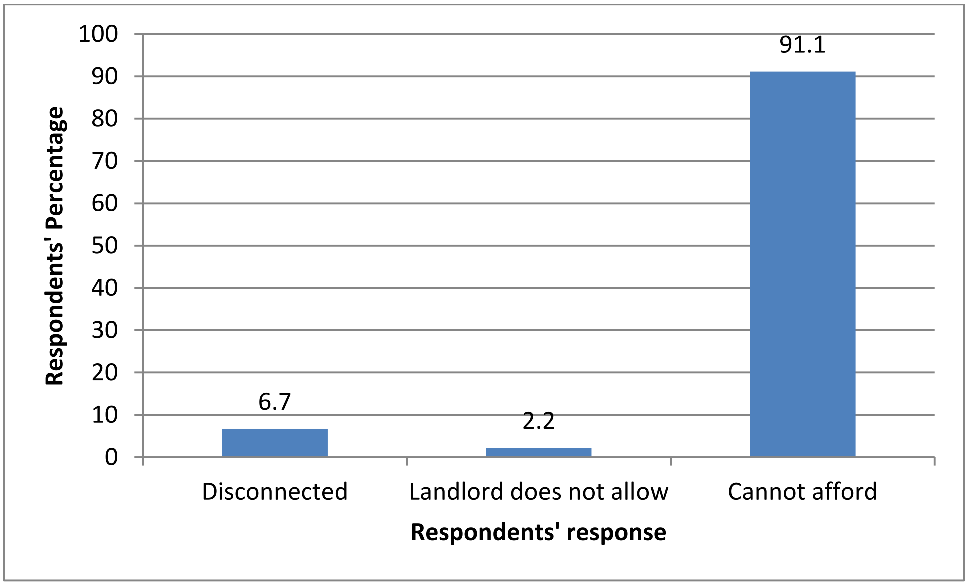

Figure 0.3: Reasons for not using electricity for cooking in Manzese

4.1.3 Time activity budget

The total time weighted average of 49.9% was spent in the indoor (at home) environment at Manzese (Tab 4.1). This percentage does not include the entire time spent in the indoor environment, but only involves time spent in the homes. Children of years 0 to 5 years spent more time in the indoor environment (69.0%) than any other group because most of them are under the school age and would therefore spend time at home. The overall time pattern for each age group spent inside the houses is shown in Table 4.1

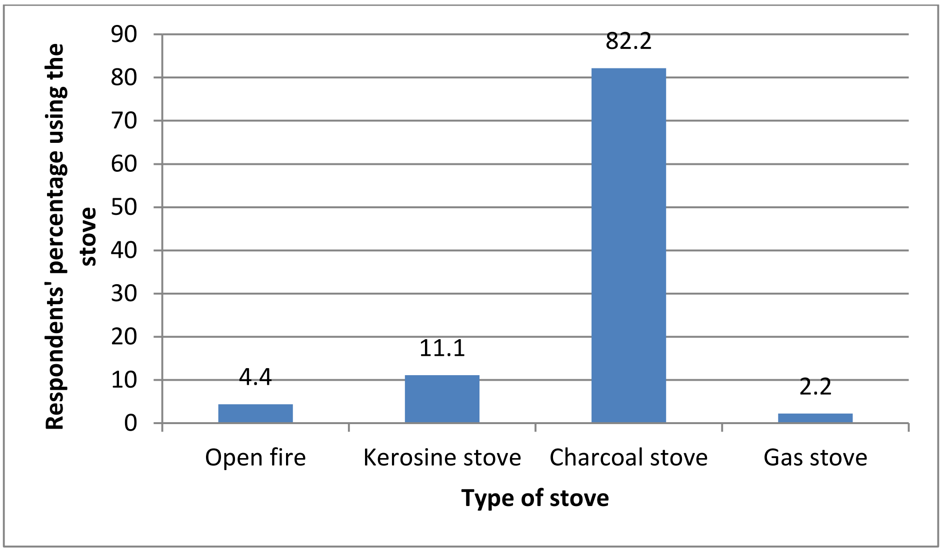

Figure 0.4: Type of stove used for cooking in Manzese

Majority of the households at Manzese (82%) spend from up to 4 hours per day in cooking (Fig. 4.5). Exposure to emissions originating from cooking activities, can go far beyond the four hours due to gradual dilution of pollutants especially when relying on natural ventilation.

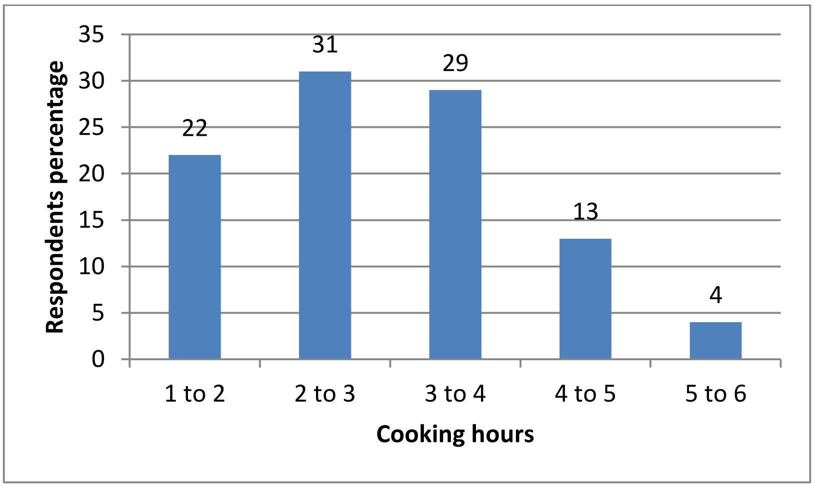

Figure 0.5: Cooking duration for the meals in Manzese

Table 0.1: Summary of the time pattern for the age groups in the indoor (at home only) environment at Manzese

Age group	Individuals in group	Average time spent indoor (hrs)		% of Individuals	Time fraction out of 24hrs	Weighted Average %
		Mean	Std deviation			
0 - 5yrs	19	16.53	1.467	20.88	0.69	14.38
6yrs - 17 yrs	27	12.48	0.849	29.67	0.52	15.43
18yrs - 54 yrs	44	9.55	1.823	48.35	0.40	19.24
55yrs & above	1	18		1.10	0.75	0.82
Total	91					**49.87**

4.1.4 Kitchen design

Most households (97.8%) (Almost all) in Manzese do not have designated places called kitchens. They either cook outside their houses or in the houses. Fig.4.6 shows the percentages of the response to the question posed to know how many households had kitchens. Amongst the households, 53.3% of the households cook their meals outside their houses, 37.8% cook their food inside the corridor and 6.7% cook their food inside their bed rooms as shown in Fig. 4.6. During rainy season, most of the cooking activities are carried out in the houses as shown in Fig.4.7.

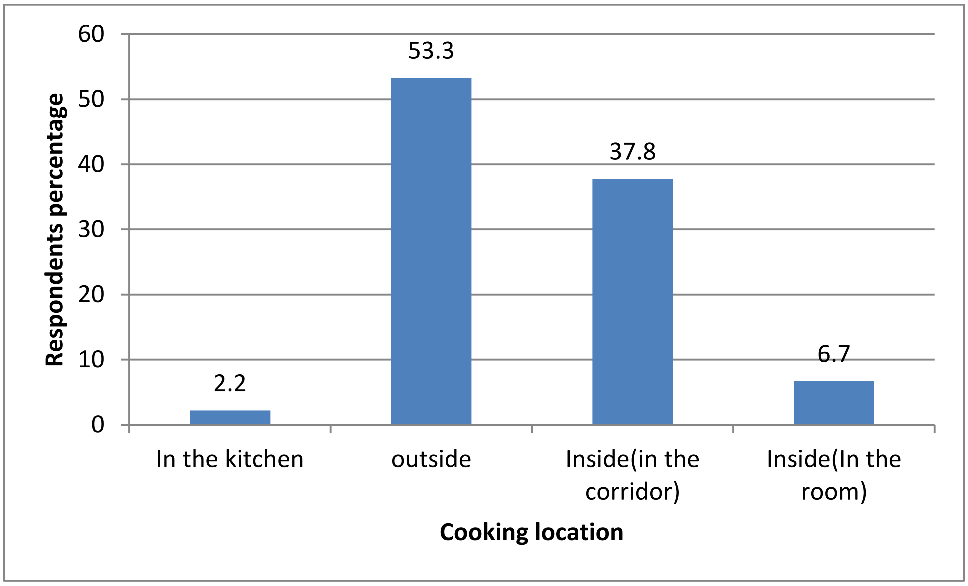

Figure 0.6: The summary for the distribution of cooking places for households in Manzese during the dry season.

When cooking is done inside the houses, it is done in the place where there is very minimum ventilation. In the corridor, normally the combustion smoke is extracted through the door or through the windows of the adjacent bed rooms. Very often when cooking is done in the corridors, pollutants ends up the bed rooms and sitting rooms.

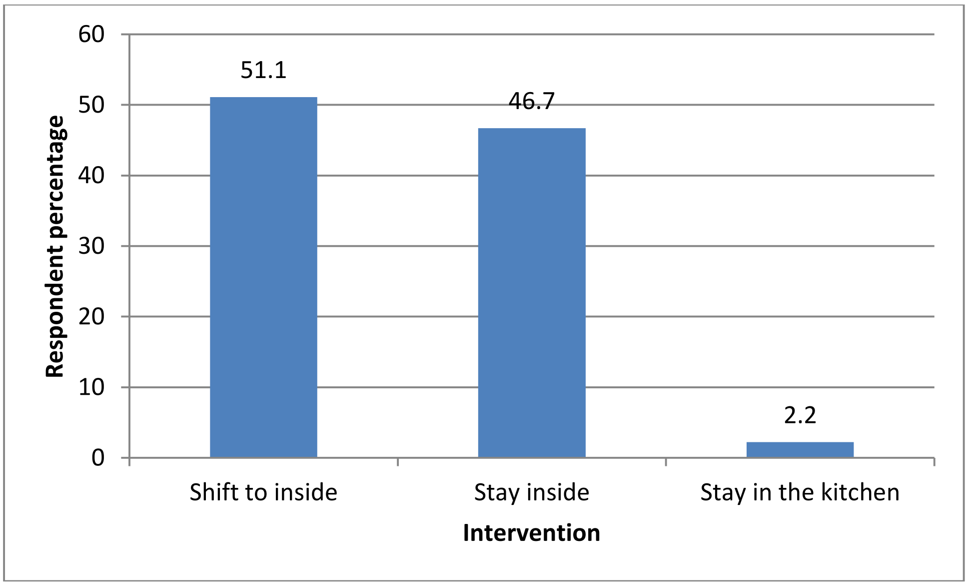

Figure 0.7: Cooking places during the rainy season

4.2 Concentrations of particulate matters and gaseous pollutants in Manzese

4.2.1 Particulate matter (PM_{10})

The levels of PM_{10} inside the selected houses in Manzese were found to be much higher than the WHO 24 hours average concentration of 0.05mg/m^3 even before the charcoal stove was lighted (Fig. 4.8). The main reasons for this scenario are due to poor ventilation which hinder air movement that could dilute the indoor air. Also there is contribution of other sources, dust from the road and emissions from the motor equipment. There are also variations of PM_{10} levels for the same house but different times of the day. The levels are much higher in the morning and evening than they are in the afternoon. This is due to the fact that there is much motor vehicle traffic in the morning and evening that contribute to the pollution. People staying in these houses are constantly being exposed to levels of particulate matter higher than the WHO limit even when there is no any stationary source of pollution in the house. Maximum PM10 concentration is observed during cooking (Fig. 4.8). This imply that, the additional PM10 concentration is very much higher, compared to the background concentration; and such it is many times higher than WHO recommended average concentration.

4.2.2 Gaseous Pollutants

4.2.2.1 Carbon monoxide

It has been found that, even in the absence of the burning charcoal, there existed concentrations of CO in all selected houses (Fig.4.9). This could be due to pollution coming from other sources such as motor vehicle traffics emissions. The levels of CO before lighting the charcoal stove and 30 minutes after cooking are relatively low than the WHO guideline for the exposure of 8 hours mean of 10mg/m^3 especially in the mornings and evenings. The values could be higher in these times of the day due to the existence of other sources of pollution such as car traffics since the traffics are more serious during these times.

It was also found that, the CO concentrations are extremely high in all selected houses during cooking (Fig 4.9).

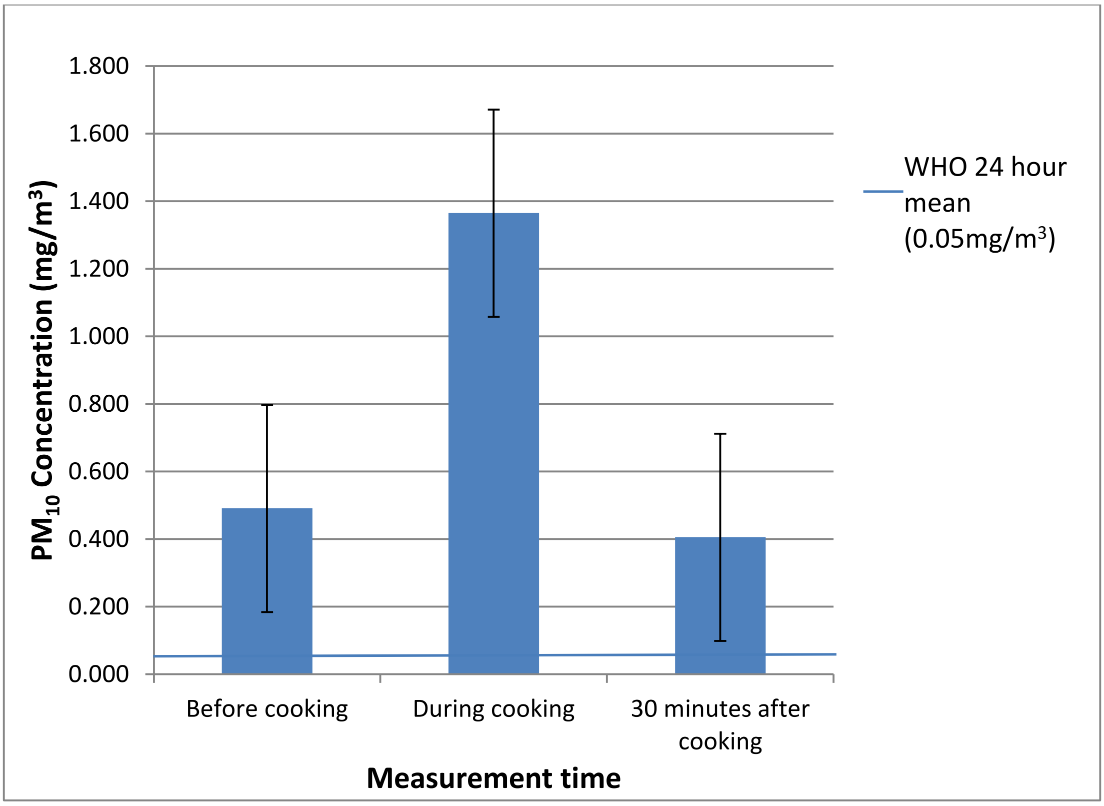

Figure 0.8: The average PM_{10} levels for five selected houses in Manzese for three different times of a day

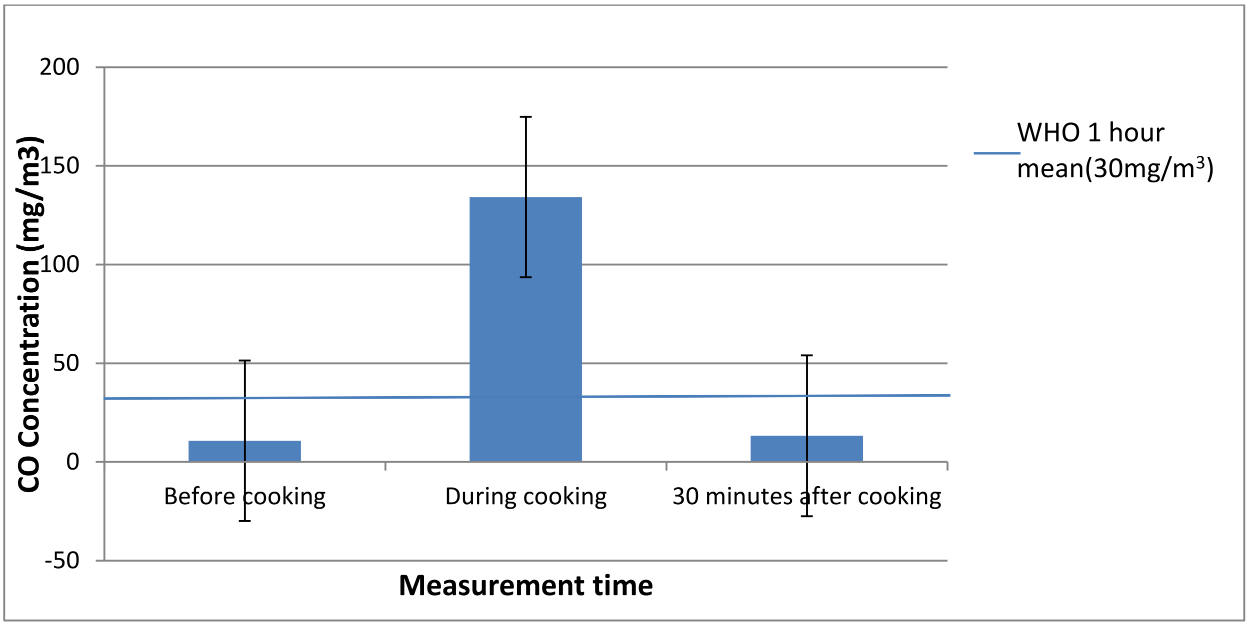

Figure 0.9: The average CO levels in selected houses of Manzese for three different times of a day

The main reason for the observed elevated concentration may be due poor ventilation in the houses. The place is very congested and hence air movement is restricted in this area.

4.2.2.2 Oxides of nitrogen

For the same reasons as for the case of CO, the concentrations of NOx in all selected houses at all times were extremely high as shown in Fig. 4.10 even when the charcoal stove was not in place.

Studies done earlier on by Semiono (2005) and Rugaika (2011) on charcoal combustion showed that the level of NOx was zero before cooking which does not compare with this study. The reasons could be that the levels found in this study were attributed to among others things to traffic pollution. It is worth mentioning that both Semiono and Rugaika conducted their studies in rural areas, where background concentration due to traffic pollution were insignificant. This study was conducted in an urban area where there is super imposition of pollutants emission from cooking and traffic.

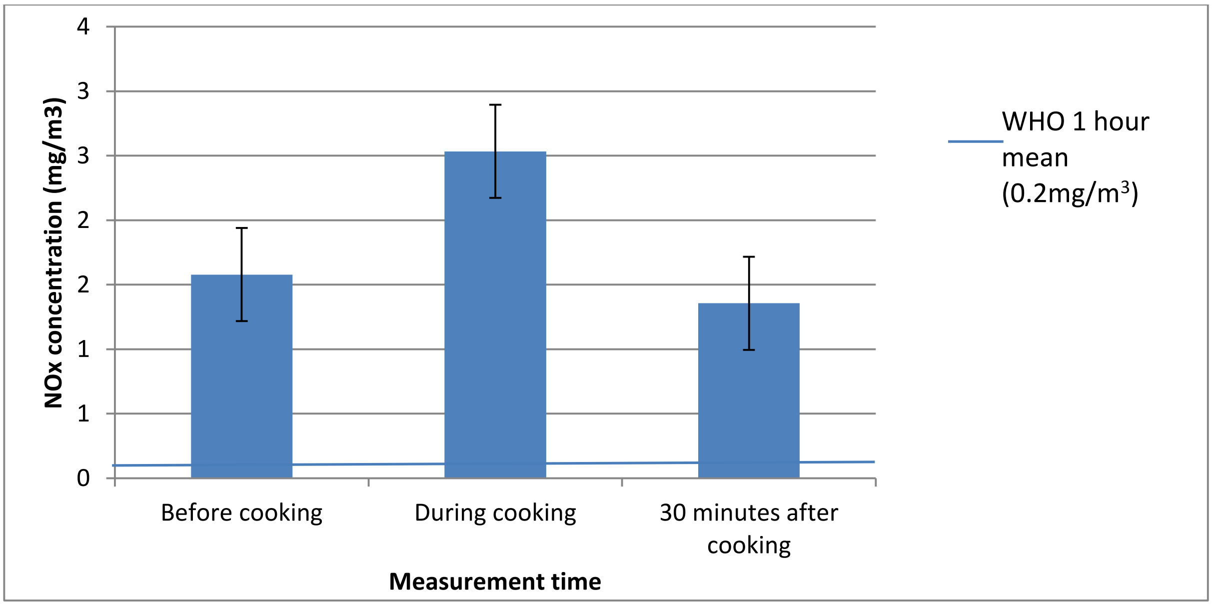

Figure 0.10: The average NO_x levels in selected houses of Manzese for three different times of a day.

4.2.2.3 Sulphur dioxide

The concentrations of SO_2 in all selected houses are higher than the WHO 10 minutes mean of 0.5mg/m^{3}even at times when the charcoal stove was not in place as shown Fig 4.11. Other sources such as traffic emissions could have contributed to this effect.

The study done by Semiono (2005) on *The assessment of indoor air pollution from combustion of cooking fuel wood, charcoal and kerosene in rural areas of Tanzania* showed that the SO_2 concentration was 17μg/m^3 when charcoal was used for cooking in Coast Region while this study observed an average SO_2 concentration at 19mg/m^3. Observed SO_2 concentration in the current study compare with the findings in the previous study.

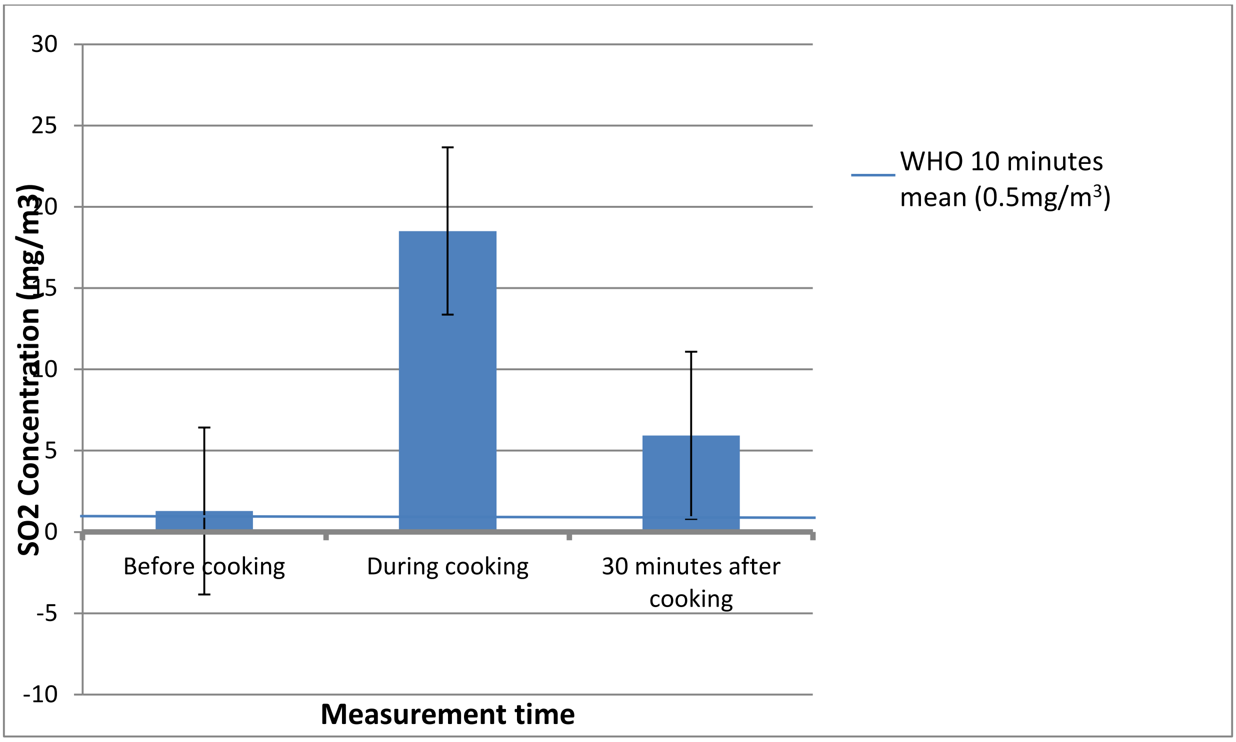

Figure 0.11: The average SO_2 levels in selected houses of Manzese for three different times of a day.

The error bars in Fig. 4.9 and Fig. 4.11 show that there were big variations among the data being collected.

4.3 Pollution monitoring in the pilot system

The discussion under this section is to show the association between indoor air quality (i.e. levels of NO_x, CO, SO_2 and PM_{10}) due to charcoal burning and ventilation systems in the pilot system

4.3.1 Particulate matter (PM_{10})

There was a clear variation in the concentrations of PM_{10} as ventilation systems were being changed (Fig 4.12). The Fig. 4.12 was split into other two Figures, Fig. 4.13 and Fig. 4.14 for more clarification on the variation of PM10 concentration during lighting charcoal and when charcoal was steadily burning.

With the room fully closed, the PM_{10} level went up to 2.07mg/m^3 during lighting the charcoal but the option of opening the door and installing the air extract fan opposite to the door, dropped this value to 0.359mg/m^3. The option of the door opened with an extract fan fitted opposite to the door is better that when the door is opened with an extract fan fitted adjacent to the door because it would be very easy for any fluid to travel straight than when it negotiates a corner. There are much energy loses during turning. The WHO 24 hours mean concentration of 0.05mg/m^3 was never attained even with this option due to small capacity of the air extract fan that was available for this study.

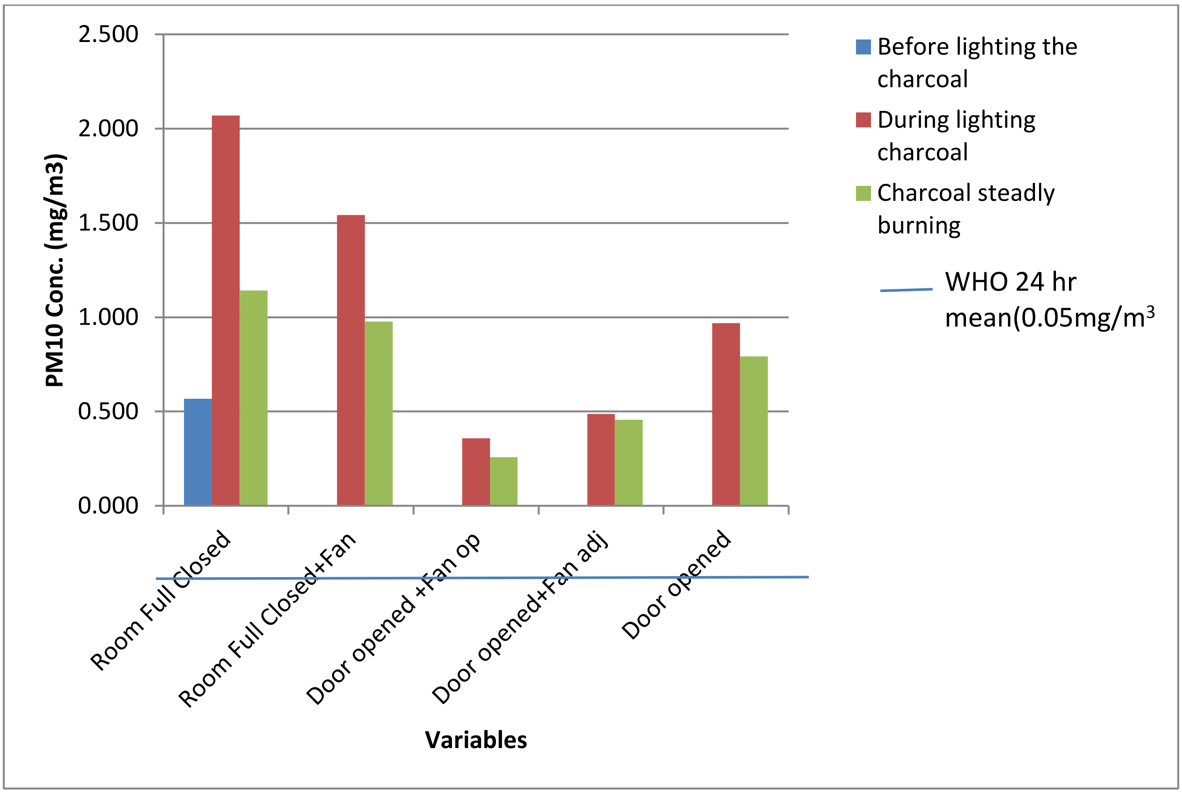

Figure: 0.12: The trends of PM_{10} levels in the pilot system

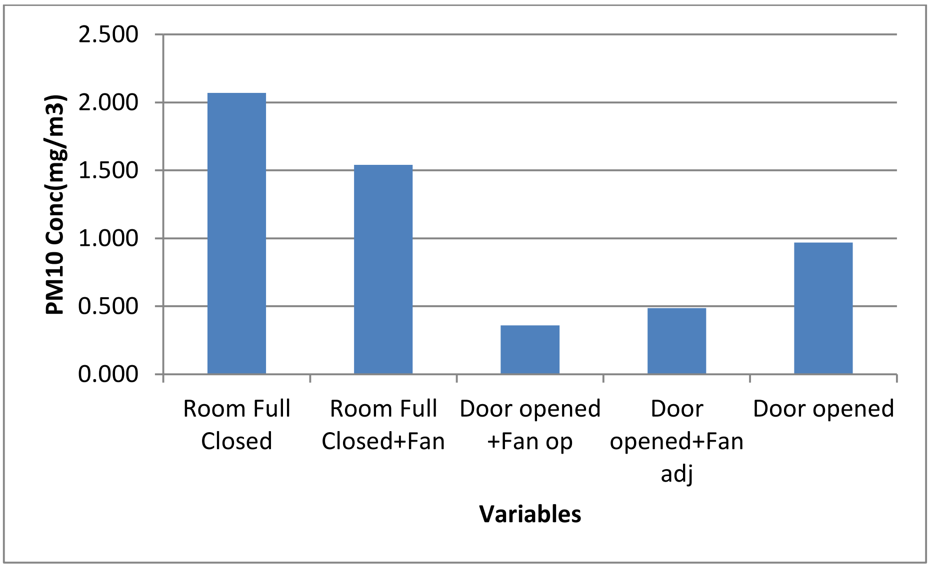

Figure 0.13: The trends of PM_{10} levels in the pilot system during lighting charcoal

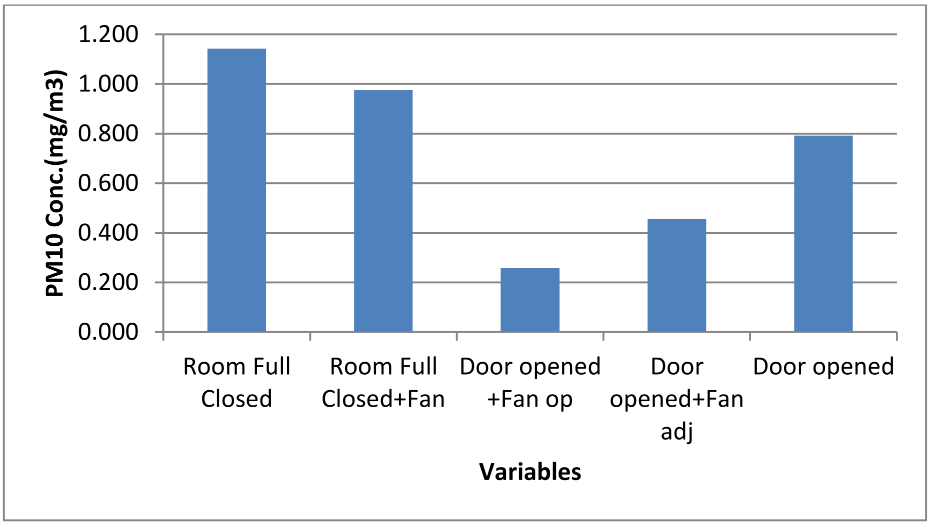

Figure 0.14: The trends of PM_{10} levels in the pilot system when charcoal was steadily burning

4.3.2 Gaseous Pollutants

4.3.2.1 Carbon monoxide

In this study, it was found that for both during lighting charcoal and when the charcoal was steadily burning, the concentrations of CO was higher than 15 minutes WHO guideline of 100mg/m^3 in all three options (with room fully closed, room fully closed with extract fan operating and when the door was opened) (Refer Fig.4.16).The reason for these high values is due to inadequate air movement for pollution dilution and removal. But with the door opened and an air extract fan operating opposite to the door, the concentrations were lowered to 28 mg/m^3, a value that is lower than the WHO guideline for 1 hour mean concentration of 30 mg/m^3 when charcoal was steadily burning (Fig 4.15). No option could give the CO concentration lower than the WHO guideline for 8 hours mean concentration of 10 mg/m^3 due to the limited capacity of the air exchange equipment that was available for the study.

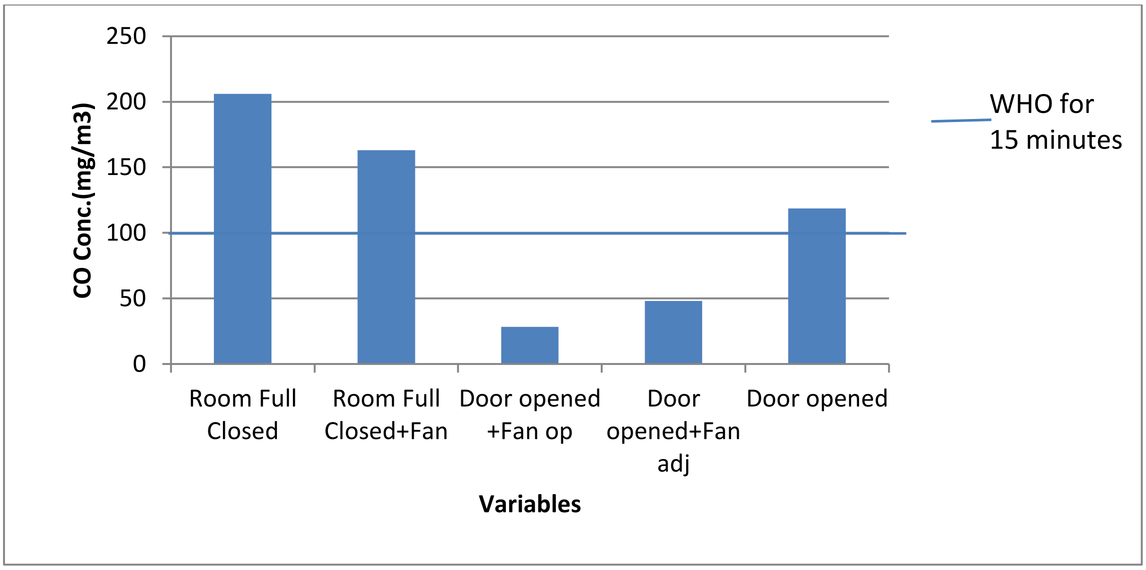

Figure 0.15: The trends of CO levels in the pilot system when charcoal was steadily burning

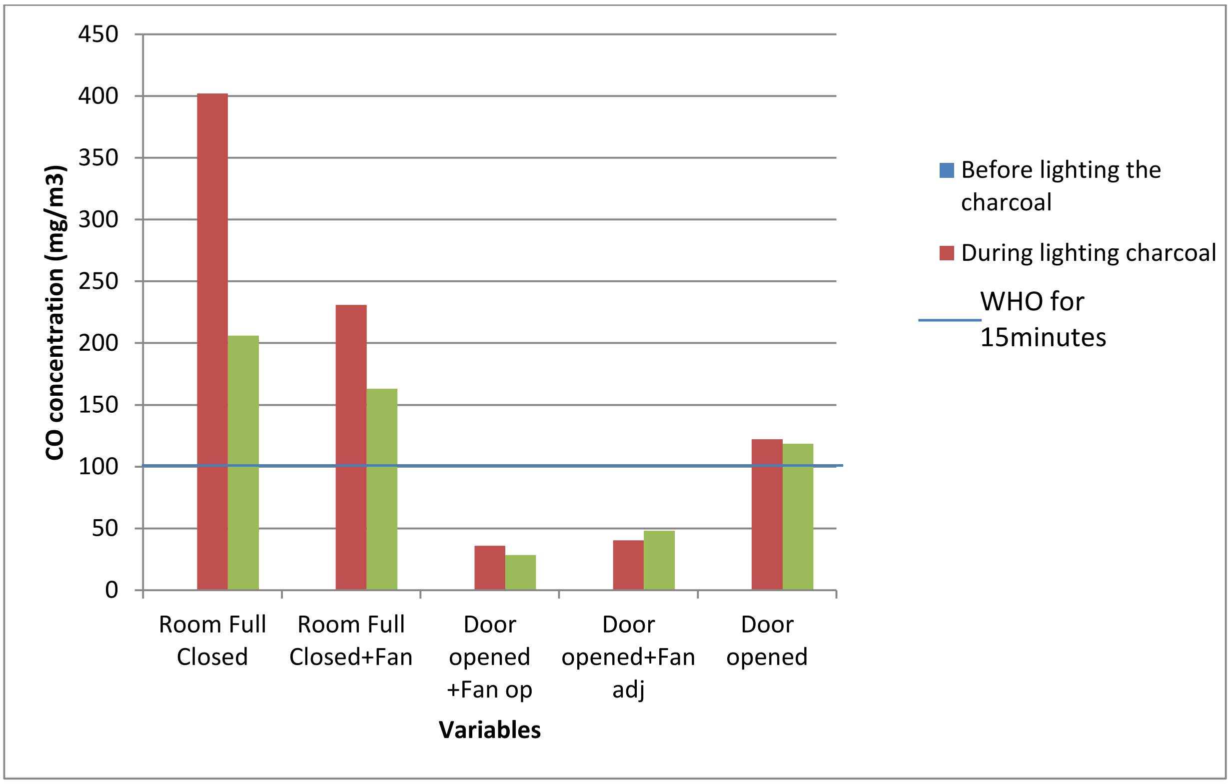

Figure 0.16: The combined trends of CO levels in the pilot system

4.3.2.2 Oxides of nitrogen

The trends of NOx concentrations in this study were not different from those discussed for the case of CO. The better results were obtained when the door was opened with an air extract fan operating from an opposite side to the door (Fig 4.17). This option could reduce the NOx concentration in the room to 0.82 mg/m^3 when charcoal was steadily burning from a value of 4 mg/m^3 when the room was fully closed. Due to some study limitations stipulated earlier on, the WHO 1 hour mean guideline of 0.2 mg/m^3 was not met by either option.

The levels of NOx before lighting charcoal were zero in the room. This compares well with the studies done by Semiono (2005) and Rugaika (2011) where the concentration of NOx before cooking using charcoal was zero. The concentrations of NOx when charcoal was steadily burning (Refer to Fig. 4.18) are higher than those reported by Semiono(2005) and Rugaika (2011) with level of 10 μg/m^3 and 375μg/m^3 respectively during cooking using charcoal. This scenario again raises questions to be answered by more research works.

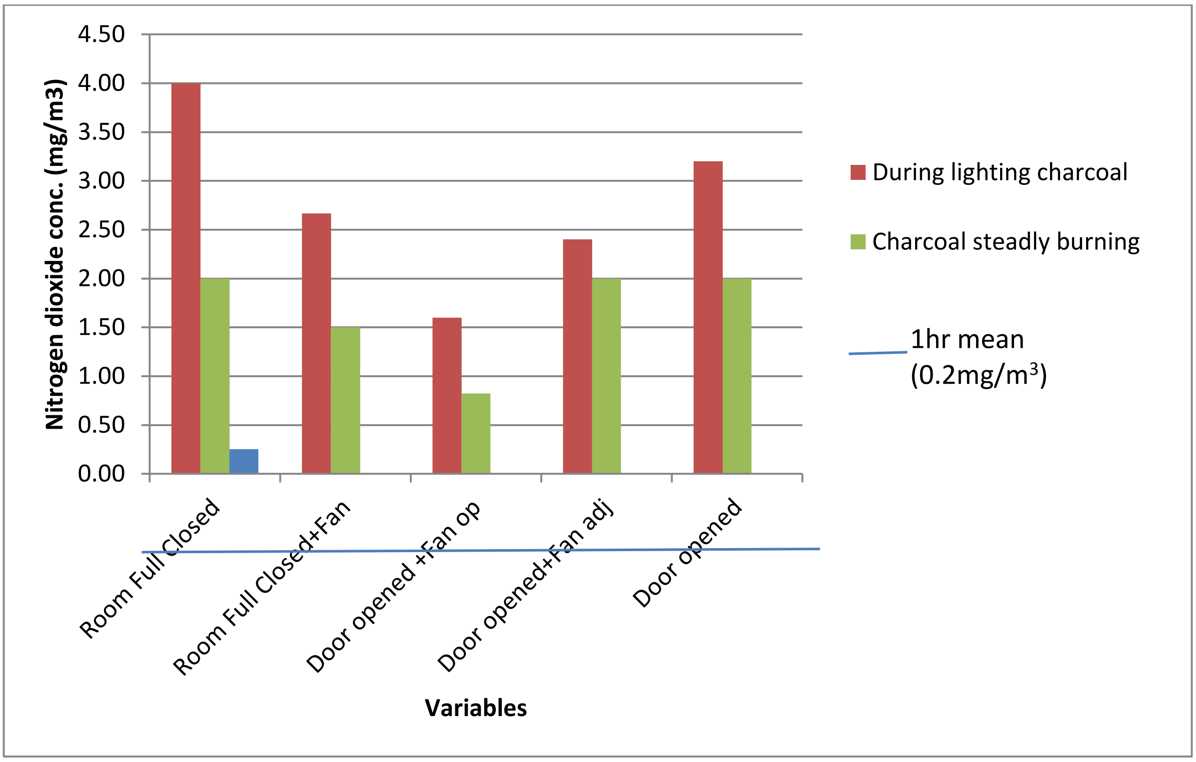

Figure 0.17: The trends of NO_x levels in pilot system

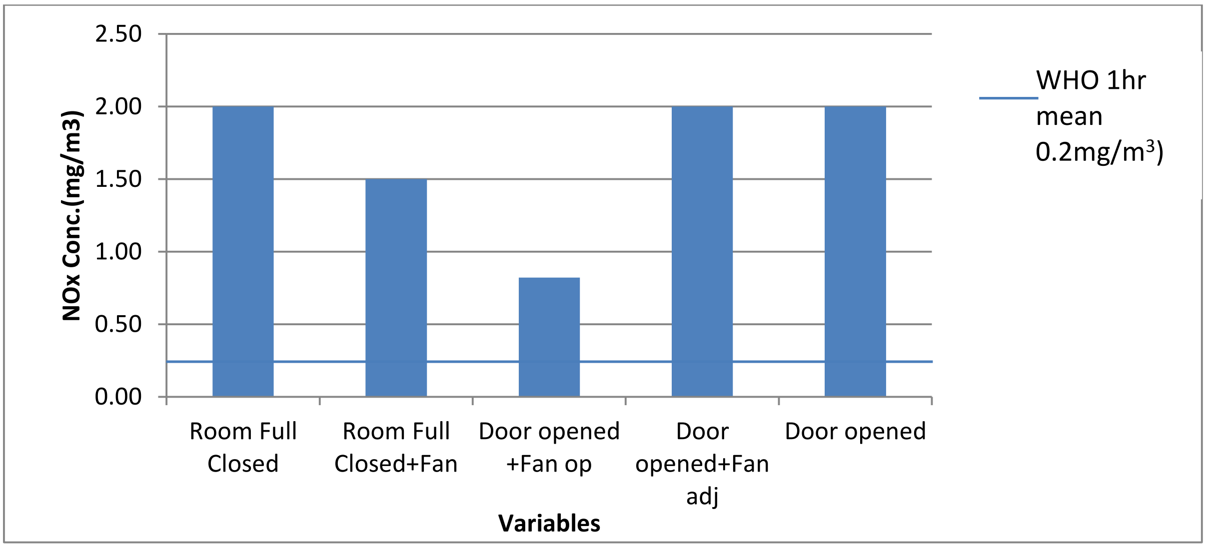

Figure 0.18: The trends of NOx levels in pilot system when charcoal was steadily burning

4.3.2.3 Sulphur dioxide

This study found out that charcoal being used in Dar es Salaam is one of the sources of sulphur in the air (Fig.4.19)

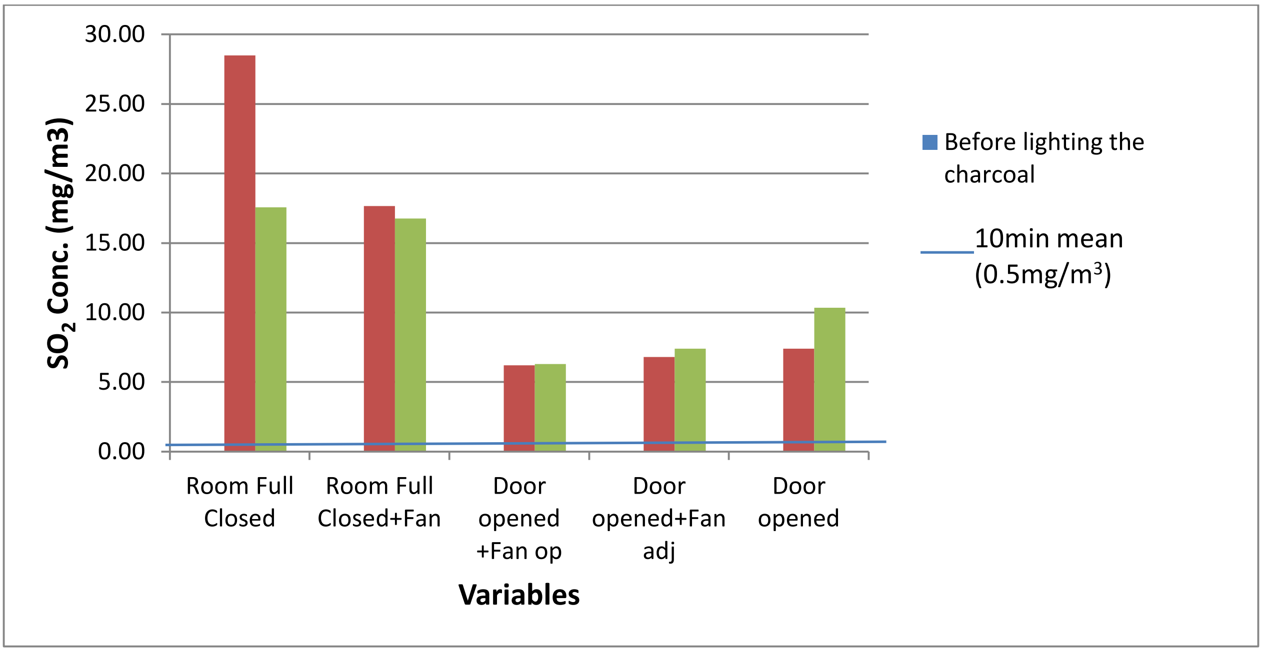

Figure 0.19: The combined trends of SO_2 levels in pilot system

The concentration level of 28.50mg/m^3 was encountered during lighting charcoal when the room was fully closed but was lower as much as 6.20 mg/m^3 when the door was opened with an extract fan operating from an opposite side to the door. It is in this option where air exchange between the room and outside is optimal for this study.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The main objective of this paper was to assess the indoor air pollution from combustion of charcoal in Dar es Salaam and determine methods of reducing it. An extensive literature review was carried out on the pollution caused by burning biomass fuels (wood and charcoal) and the health effects associated with it. It was found from literature that the information on the burning of charcoal in the urban areas of Tanzania is scarce. To fill this gap, the study was carried out which involved site monitoring of gaseous pollutants and particulate matter emanating from burning charcoal in Manzese. Then manipulation of variables/parameters for ventilation were carried out in the controlled pilot system set at Ardhi University to have the optimal parameters that could minimize the pollution in the indoor environment caused by charcoal burning.

The purpose of this concluding chapter is to summarize the results of the study and put forward the work to be done in future.

5.1 Conclusions

i. Gaseous (CO, SO_2 and NOx) concentration in the selected houses in Manzese are higher than all WHO guidelines
ii. It was found that the levels of pollution in the pilot system were minimum when the air extract fan was operating from the opposite side of the opened door
iii. Most households in Manzese use charcoal as their main source of energy for cooking (82.2%) and the type of stove used is traditional charcoal stove.
iv. Mothers and children are the groups mostly exposed to pollution resulting from charcoal burning. The women (75.6%) were responsible for cooking food.
v. The total time weighted average of 49.9% was spent in the indoor (at home) environment at Manzese by Manzese residents
vi. Most households (97.8%) in Manzese do not have designated places called kitchens. They either cook outside their houses or in the houses
vii. Many respondents (37.8%) suggested that initial cost of the gas for cooking should be reviewed so that they can afford and 91.1% of them cannot afford to cook using electricity.

5.2 Recommendations

Basing on the findings of this study, the following recommendations were made:

i. Air extraction fan could offer the best solution to minimizing the pollution in the indoor environment where natural ventilation is relatively impossible.
ii. Awareness should be given to the people on the serious health effects caused by burning charcoal in the indoor environment
iii. Encourage Manzese dwellers to have outside facility (kitchen) for cooking whenever possible
iv. Households in the less ventilated areas of the city should be encouraged to use air extraction fans so as to minimize pollution levels

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