International Scholars Journals

Advanced Journal of Environmental Science and Technology ISSN 7675-1686 Vol. 11 (3), pp. 001-011, March, 2020. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

A comparative study on indoor air quality in a low cost and a green design house

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Accepted 20 September, 2019

A study on Indoor Air Quality (IAQ) is important because people spend most of their time inside houses. IAQ was monitored in two different types of rural houses namely a low cost house and a "green" house built with pyramidal shape of roof in the rural area. Carbon monoxide (CO) and Carbon Dioxide (CO_2) concentrations were measured and analysed indoor and outdoor in both the type of houses. A statistical correlation analysis of indoor concentration levels with outdoor concentrations was carried out. The CO concentration in the low cost house 21.5 ppm and CO_2 concentration is 792 ppm. Similarly the CO was maximum with indoor concentrations 0.9 ppm (in Kitchen) and outdoor concentrations 0.4 ppm. CO_2 was maximum with indoor concentrations 435 ppm (in Kitchen) and outdoor concentrations 425 ppm in the green house. It can be seen from the above findings that the pollutant concentration in low cost house was higher than that of green house. The R^2 (statistical correlation) values for the concentration of CO at indoor are 0.56 and 0.47 in the kitchen and living room respectively in the green house. Similarly the value of R^2 for indoor is 0.73 and 0.52 in the kitchen and living room respectively for concentration CO_2 green house.

Key words: Carbon monoxide, carbon dioxide, indoor air quality, low cost house, green house

INTRODUCTION

The majority of households using solid fuels burn them in open fires or simple stoves that release most of the smoke into the home. The resulting indoor air pollution (IAP) is a major threat to health, particularly for women and young children, who may spend many hours close to the fire. Further, the reliance on solid fuels and inefficient stoves has far-reaching consequences on health, the environment, and economic development. Indoor air pollution is recognized as a significant source of potential health risks to exposed populations throughout the world.

Air pollution has become a major concern in India in recent years. The large parts of the Indian urban population are exposed to some of the highest pollutant levels in the world (Smith, 1991: World Health Organization, 1999). New studies around the world on the health effects of air pollution have increased confidence in estimates of the risks posed by air pollution exposures (Lippmann, 2000). The situation in China and a number of other developing countries is similar.

India has more than 20 cities with populations of atleast 1 million. Some of them including New Delhi, Mumbai, Chennai, and Kolkata are among the worlds most polluted. Urban air quality ranks among the world's worst. Of the 3 million premature deaths in the world that occur each year due to outdoor and indoor air pollution, the highest numbers of occurrences are in India. Sources of air pollution, which is severe environmental problem observed in India, occur in several forms, like vehicular emissions and untreated industrial smoke. Continued urbanization has exacerbated the problem of rapid industrialization, as more and more people are adversely affected due to environmental issues. So, cities are unable to implement adequate pollution control mechanisms, because of the huge extents.

Industrialization and urbanization has resulted a dramatic increase in the number of residences, office buildings and manufacturing facilities, together with increase in both the number and density of motor vehicles. This

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Nomenclature: ASHRAE; American Society of Heating, Refrigerating and Air-conditioning Engineers, **CO**; Carbon Monoxide, **CO_2**; Carbon Dioxide, **IAP;** Indoor Air Pollutants, **IAQ**; Indoor Air Quality, **NO_2**; Nitrogen Oxides, **PM**; Particulate Matter, **ppm**; parts per million, **RH**; Relative Humidity, **RPM**; Respirable Particulate Matter, **SO_2**; Sulfur Dioxide and **VOC**; Volatile Organic Compounds.

has had both positive and negative effects on IAQ in many cities of the world (Kim, 1992). People spend most of their time indoors; yet, the majority of data on the concentrations of pollutants are based on measurements coducted outdoors, in one or more central monitoring sites. Outdoor pollutant concentrations may not be reliable indicators of indoor and personal pollutant sources (Wallace et al., 1997). Assessment of risk to the community resulting from exposure to airborne pollutants should ideally include measurements of concentration levels of the pollutants in all microenvironments where people spend their maximum time in a day. Due to the multiplicity of different microenvironments, it is usually, however, not possible to conduct measurements in all of them. In many cases the subdivision is between the indoor and outdoor environment, with questions posed as to what extent indoor exposures could be predicted from measured concentrations of pollutants in outdoor pollutants (Morawska et al., 2001). Early studies on the relationship between indoor and outdoor pollutants conducted in the 1950s. A summary by Anderson (1972) showed that there was great variation between indoor and outdoor ratios. Benson et al. (1972) concluded in their review that, the ratios of indoor and outdoor pollutants concentrations were normally about 1.

The largest exposures to health-damaging indoor pollution probably occur in the developing world. But, this is not the case in case of households, schools, and offices of developed countries where most research and controls efforts have focused to date. As a result, much of the health impacts from air pollution worldwide seem to occur among the poorest and most vulnerable populations (Smith, 2002). Few studies have been conducted in the past by various researchers in India. Khare et al. (1996) conducted an IAQ study in the IIT Delhi library and concluded that the basement and the top floor of the building had poor IAQ. Various hotels/houses in Pune City were found to have higher NO_2 concentrations than the ambient air limit (Jayashree Mohan et al., 1992). Mandal et al. (1997) also studied indoor NO_2 concentrations in some residences of Calcutta and found annual average NO_2 concentrations well below the value prescribed by Euro-pean countries. Jarnstrom et al. (2008) has conducted a study related to indoor air quality on new buildings with the aim of the finish indoor classification to encourage the use of low-emitting building materials and air handling components by providing tentative values for emissions and airborne concentrations of pollutants.

"Green" or "sustainable" buildings use key resources like energy, water, materials and land more efficiently than buildings that are just built to code. With more natu-ral light and better air quality, green buildings typically contribute to improved health, comfort, and productivity. It is generally recognized that buildings consume a large portion of water, wood, energy, and other resources used in the economy. Green building is defined as a process that creates buildings and supporting infrastructure that (Karlenzig 2005);

i) Minimizes the use of resources
ii) Reduces harmful effects on the environment,
iii) Provides healthier environments for people

Rural practitioners and other stakeholders identified benefits at all levels from using green affordable housing practices, including:

i) Lower utility and energy costs
ii) Improved occupant health
iii) Higher tenant satisfaction
iv) Minimizing environmental impact
v) Supporting local economies

As such no relevant studies have been carried out to compare the indoor air quality in low cost house and a green house in the areas of southern India. The present work aims to determine the relationship between indoor-outdoor concentrations of CO and CO_2 observed at two houses in rural area of Tamilnadu, India. Statistical analysis was also performed to correlate indoor concentration levels with outdoor concentrations in different microenvironments.

MATERIALS AND METHODS

Keeping the above points in mind, a green house was built at Vilathur village located at Cuddalore district of Tamilnadu, India. This village is located at 15 km from Chidambaram. The household characteristic of the vilathur village is given in Table 1. There are 116 households in the village. Almost all the houses have thatched roofing with un-burnt brick walls and only few houses are tiled ones and 11 houses have only reinforced cement concrete roofing in the study area. As this house is in pyramidal shape roofing, the height of the wall is designed up to 1.52 m and the height of the pyramidal portion of the roof is 1.52 m. The topmost portion of the pyramidal roof is having 1.22 x 1.22 m flat portion to accommodate the solar panel. One of the primary requirements of a green building is that it should have optimum energy performance and provide the desirable thermal and visual comfort. Three systems are adopted to achieve green building concept in this house and they are described in the following sections. Figure 1 show the plan and elevation of green house. The construction cost of the green house 40% less than the low cost house construction. The red oxide is used for floor finishing, having more cooling effect on floor.

Solar passive techniques in a house construction

The Solar Paneled Pyramidal Roof House is constructed for a hot climate should take measures to reduce heat radiation inside the house by orienting house to minimum exposure in west and east and larger size window. Three windows of size 0.9 x 0.6 m and one window of size 1.2 x 0.6 m are provided. Apart from that two ventilators are constructed honey combed brick work (with fly ash bricks) to allow the natural ventilation inside the house. This house roof is constructed in pyramidal shape to have minimum sunlight effect on the building. The total roof area of the pyramidal portion is 16.4 sqm with an angle of 38° inclination to the horizontal. The plinth area of the green house is 8.196 sqm.

Use of low energy materials and methods of construction

An architect should also aim at efficient structural design, reduction

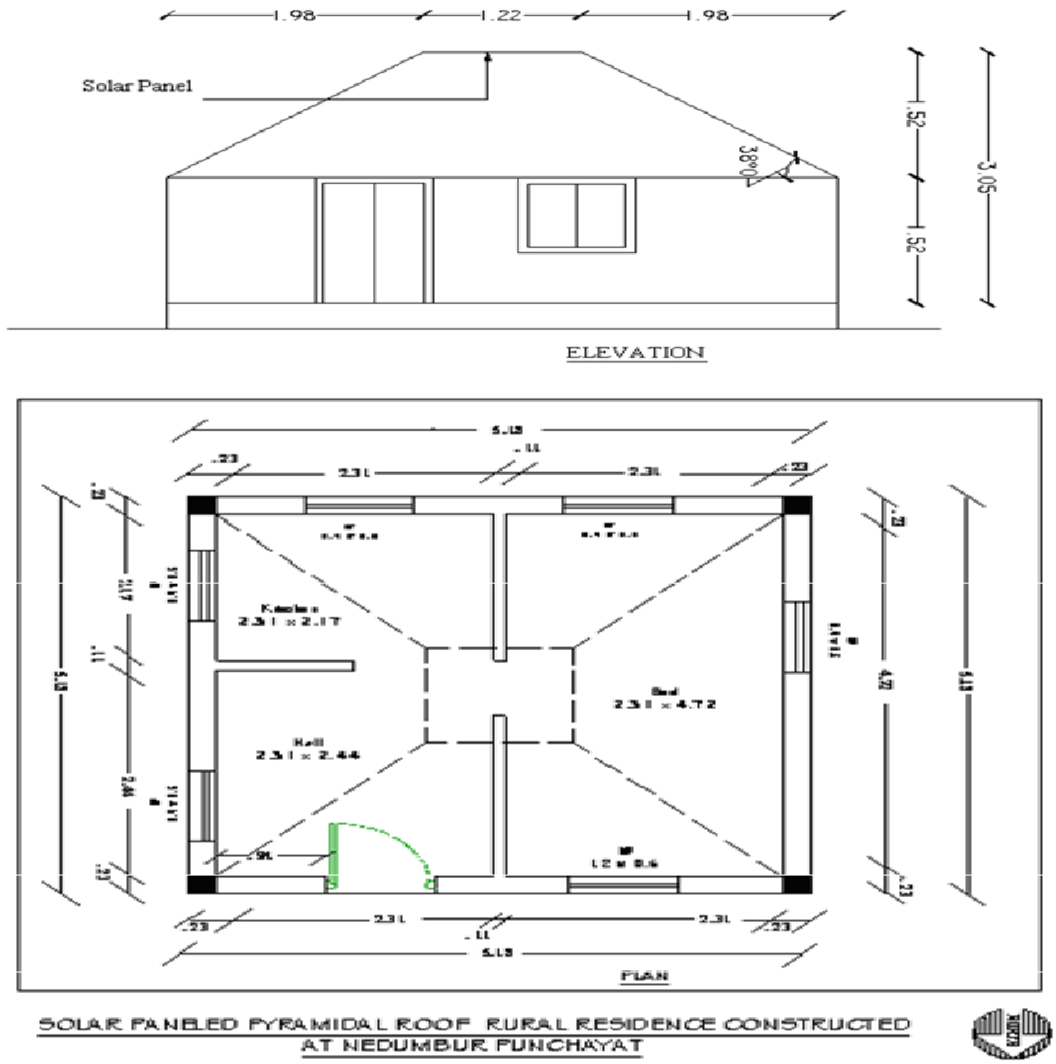

Figure 1. Plan and elevation of green house.

Table 1. Household characteristics of Villathur village.

Parameter	Total	Male	Female	Percentage
Population	586	289	297	100
Population (0-6)	93	45	48	18.97
Literates	393	213	180	79.91
Illiterates	192	76	116	20.09
Workers	332	175	157	56.66
Main Agricultural labourers	50	47	3	45.1
Non Workers	254	114	139	43.34
Households	116	-	-	-

of use of high energy building materials such as glass, steel, etc. and reducing transportation energy. Use of environmentally sensitive construction materials and techniques reduce embodied energy content of buildings. Some common products are - use of flvash in building materials example, use of blended cement for structural systems; use of flyash based bricks and blocks, etc; use of ferrocement and precast components for columns, beams, slabs, stair-cases, lofts, balconies, roofs, etc; use of wood substitutes for doors/ windows/ cabinet frames and shutters.

In this house fly ash bricks are used to construct the outer walls of 0.23 m thickness and partition walls of 0.125 m thickness. The compressive strength of the bricks used for the construction of wall is 81 N/mm^2. To have cooling effect inside the house, the house is plastered with lime mortar and white washing also done only with lime powder. The pyramidal roof is constructed with ferrocement of 75 mm thickness. Flooring is done with cement mortar of 1:5, waste brick coarse aggregates of 20 mm and thickness of flooring 100 mm with 25 mm floor finishing. The floor is finished with red oxide mixed to have less heat effect on flooring also.

Provision for energy-efficient lighting

Once the passive solar architectural concepts are applied to a design, the lighting load on conventional systems is greatly reduced. Further, energy conservation is possible by efficient design of the

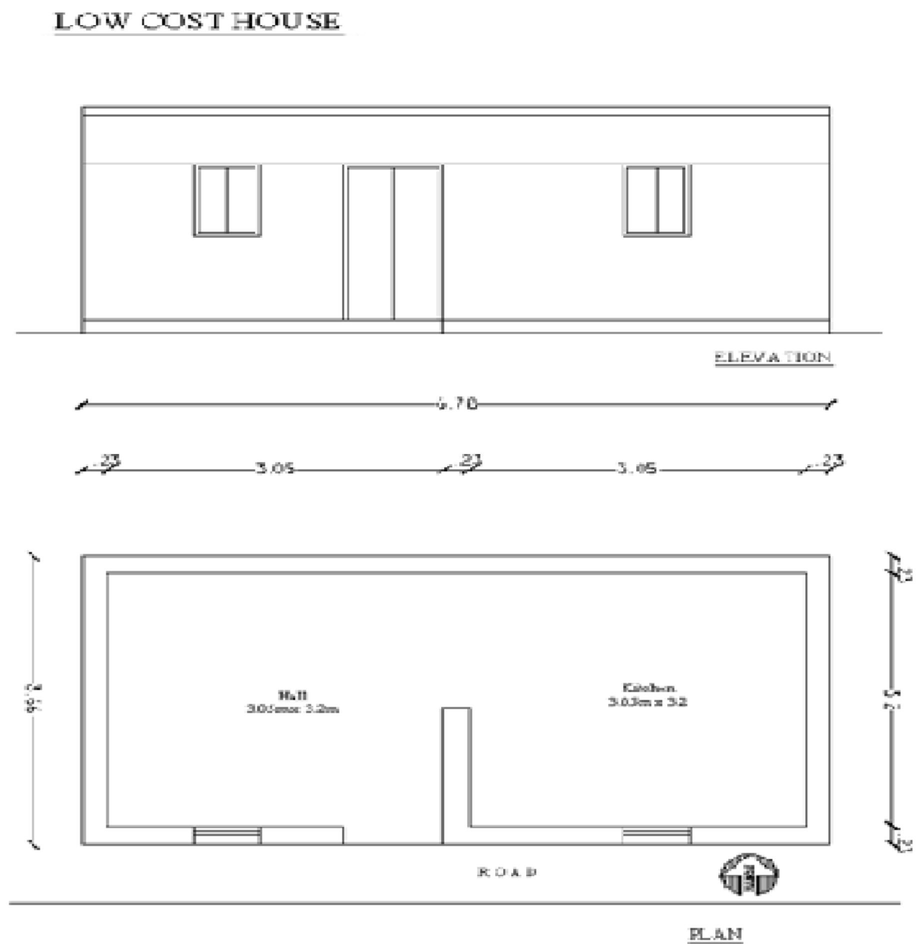

Figure 2. Plan and elevation of low cost house.

artificial lighting using energy efficient equipments, controls and operation strategies. In this model house one light and one fan is provided. This light and fan takes energy from the solar photo electric cell and the same is connected to solar panel. The details of solar energy system provided in the house are given below:

Solar panels size: 0.6 x 0.6 m with two numbers

Photovoltaic Electric Cell: Power capacity – 11V -18 W (Sriram Battery).

Functioning Hours – Night time only but maximum of 18 h. If sun rises the light automatically switches off.

Advantages: Electricity is saved, money is saved. Solar energy is tapped and there is no extra expenditure, no risk of current shock occurrence. Apart from this, a solar lantern is installed to standby for the solar panel. A solar cooker is also available for cooking.

There is another low cost group house is in which the IAQ was monitored to compare the IAQ levels. The floor area of the typical low cost group house under Indra Awisa Yojna (IAY) approved by the Directorate of Rural Development (India) is 15.79 m^2 (Refer Figure 2- plan and elevation of low cost house) . But the floor area of the solar paneled pyramidal roof house is 22.32 m^2. This study has chosen that the volume of the low cost group house and the test house “Solar Paneled Pyramidal Roof House” remain same, that is, volume of the low cost house as 48.14 m^3 and the Solar Paneled Pyramidal Roof House as 48.16 m^3 (1701 cuft). Though the volume of both house remain as same, but the airflow and contaminant dispersion in the solar paneled pyramidal roof house may differ in the low cost house.

GrayWolf Sensing instrument is used in this study. This is a fully integrated system for measuring indoor air quality, toxic gases, airspeed and other parameters. A Pocket PC running Wolf Sense™ PPC application software takes readings of air quality, toxic gas, airspeed, moisture or other parameters from a probe connected through the serial port. Wolf Sense PC also assists in the creation of reports, incorporating the data and notes that have been collected. In the Direct Sense™ IAQ PPC kit, the probe (model IQ-410) has four sensors, which provide up to nine measurements: Temperature (°F/°C), Relative Humidity (%RH), Carbon Monoxide (ppm CO), and Carbon Dioxide (ppm CO_2) are the primary measurements. Dew Point Temperature, Absolute Humidity, Wet Bulb Temperature, Humidity Ratio and Specific Humidity are derived from the Tem-perature and Relative Humidity sensor readings. For the measurement of these pollutants for indoor, the instruments were positioned in the center of the living room, bed room and kitchen at a height of 1 m from the ground, it was also kept at least 1 m away from potential sources of air pollutants. For outdoor measurements, sampling was made 5 m away from the boundary of the house. The instruments were kept 1 m above the ground level, and 1 m away from the outdoor source of air pollutant.

This study was conducted during the winter of September 2008 – November 2008. Concentrations of indoor Carbon Monoxide (ppm

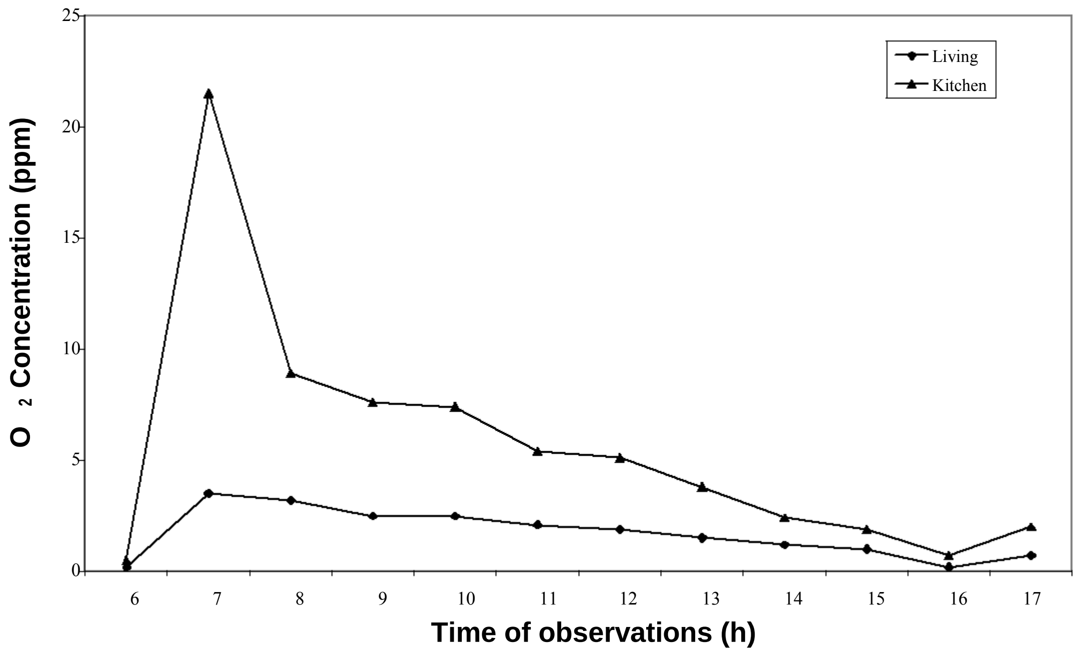

Figure 3. Observed co concentrations in low cost house

CO), Carbon Dioxide (ppm CO_2), Temperature (°F/°C), Dew Point Temperature, Absolute Humidity, Wet Bulb Temperature and Relative Humidity (%RH) were measured in the living room where people spent most of their time in the kitchen and living room. Indoor and outdoor concentration levels of all these pollutants were alternatively measured for a period of 12 h (6:00 – 18:00 h) in a day. Full day sampling of indoor and outdoor was carried out in the house where specific pollutant was maximum. This sampling time covers whole day activities inside and outside of houses.

RESULTS AND DISCUSSIONS

The temperature observed in green house in indoor is between 24 and 30°C and in outdoor is between 24 and 32°C. Similarly the temperature observed in the low cost house in indoor was between 24 and 31°C. On comparing average values it was found that indoor CO concentrations were more than the outdoors. The trend of increased CO indoor pollution during winter months implies that several factors influence IAQ during the winter in addition to outdoor air and meteorological factors.

Such factors include indoor activities, duration of human occupancy and ventilation (Baek et al., 1997). Humidity ratio recorded in indoor is in the range of 13,455 - 15,560 ppmw and in outdoor is in the range of 13,650 – 15,706 ppmw.

The materials used to construct the house are having less impact on environment in terms of energy saving. As the roof is constructed in pyramidal shape the heat effect inside the house is less. Similarly the floor constructed with the red oxide gives more cooling effect in the room. Particularly the solar cooking system and electrical system installed are reducing the indoor air pollution levels.

Low cost house

Figure 3 shows the variation of CO in living room and kitchen at indoor from morning 6:00 - 18:00 h in low cost house. The people in this village have the habit of cooking only in the evening normally between 16:00 and 20:00 h. During the survey it is found that only 20 house-holds cook two times in a day. In the low cost house, the households cook only in the morning hours. It is seen from the graph the indoor concentration is higher in the morning but after 8 am it is lower than the indoor and reaching a maximum at indoor between 9:00 and 10:00 am. The indoor concentration is higher in the morning timings and after that the outdoor concentration is higher. The general trend observed is increasing up to 10:00 am and then decreasing till 16:00 pm and than the concentration increases but not peak like in the morning. Figure 4 shows the variation of CO_2 in low cost house from morning 6:00 – 18:00 h. It is seen from the graph that the indoor concentration is higher in the morning but after 10:00 am it is lower and reaching a maximum at 8:00 am. The indoor concentration is higher in the morning timings and after that at evening times the concentration is higher. The indoor concentration is higher in the evening timings.

The average measured indoor and outdoor concentrations of CO and CO_2 were compared with the American Society of Heating; Refrigerating and Air-Conditioning Engineers (ASHRAE) standards for indoor air pollutants (ASHRAE, 1989) (Table 2).

The average indoor levels of CO and CO_2 were influenced by the presence of indoor combustion sources,

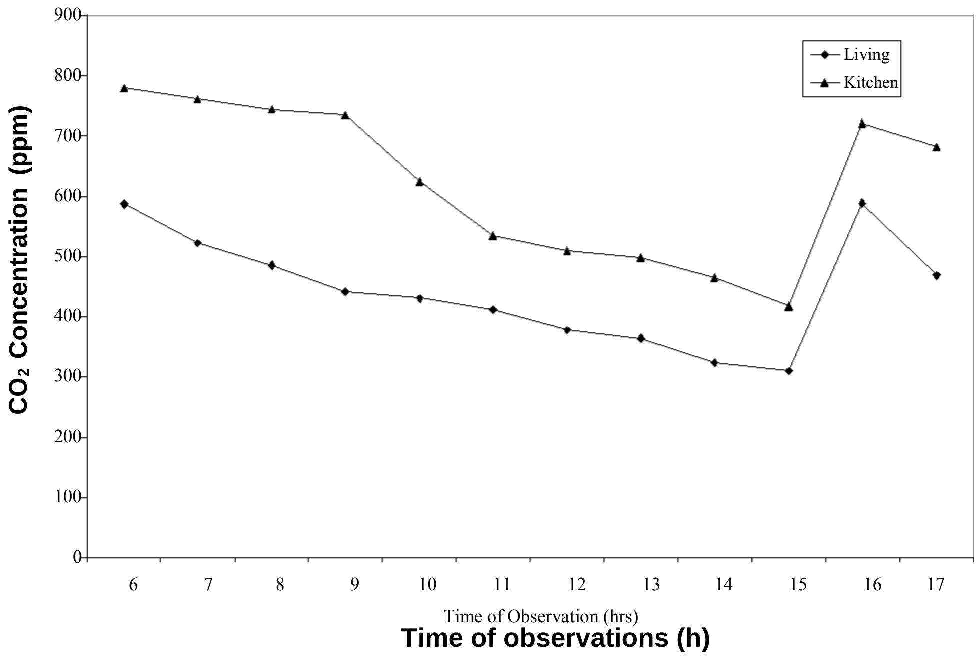

Figure 4. Observed co_2 concentrations in low cost house.

Table 2. Indoor and outdoor air standards used in the study

Pollutant	Unit	ASHRAE Standard
CO	ppm	9
CO_2	ppm	700
NO_2	ppm	0.05
PM	$\mu g.m^{-3}$	260

specifically smoke. For locations where there was burning of wood, indoor levels of CO and CO_2 exceeded the corresponding standard and were higher than the corresponding outdoor levels. While indoor CO levels exceeded the average ASHRAE standard by 138%, with a pollution concentration value of 21.5 ppm during cooking time in the low cost house in the villages. But other than cooking hours the indoor pollutants are less than the ASHRAE standards. The indoor CO_2 levels exceed the comfortable human living standard by 13% with a pollution concentration of 792 ppm during morning hours in the village.

The relationship established between indoor and outdoor concentrations for CO is presented in Figure 5. A good relationship was observed between indoor and outdoor. Due to specially constructed houses, air circulation is found in the Vilathur villages. The equation obtained and R^2 value for the each room is presented in Table 3 for CO and CO_2. Figure 6 presents the relationship between the indoor and outdoor concentration for CO_2. With correlation factors less than 0.5, indoor CO and CO_2 level exhibited weak correlation with corresponding outdoor concentrations. It was found that there is better correlation with a higher R^2 value of 0.91. This reflects a source relationship between indoor and outdoor CO and CO_2 levels. In fact, lot of specific indoor CO and CO_2 sources were identified at the sampled locations of rural area of the study. CO levels are attributed primarily to coal/wood burning from kitchen and poor ventilation in the rural houses.

The equation obtained and R^2 for the each concentration is presented in Table 3 for CO and CO_2. As shown in Table 3, the presence of indoor sources for a specific pollutant diluted the effect of any proximity to outdoor sources. For example, for CO and CO_2 (both of which are emitted from indoor sources), stronger correlation (R^2 values between 0.89 and 0.91) was exhibited when locations were separated based on their indoor source type. Highest correlation factors were associated with cases when indoor and outdoor pollutants are emitted from the same source. This corresponds to locations either without indoor sources of pollution or with indoor sources that are under control.

Green house

Figure 7 shows the indoor concentration variation of CO in hall (living room) and kitchen from morning 6:00 - 18:00 h. It is seen from the graph the indoor concentra-tion in the living room is lesser than that of kitchen in ge-neral. The concentration of CO in the living room chang-es with respect to outdoor concentration and also due to

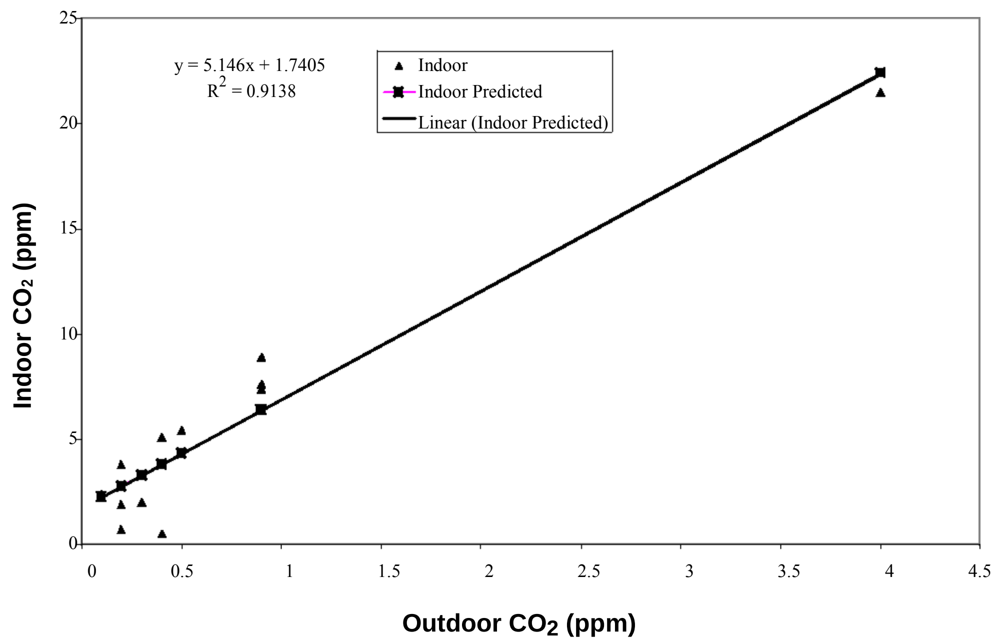

Figure 5. Relationships between indoor and outdoor concentration of co in kitchen at low cost house.

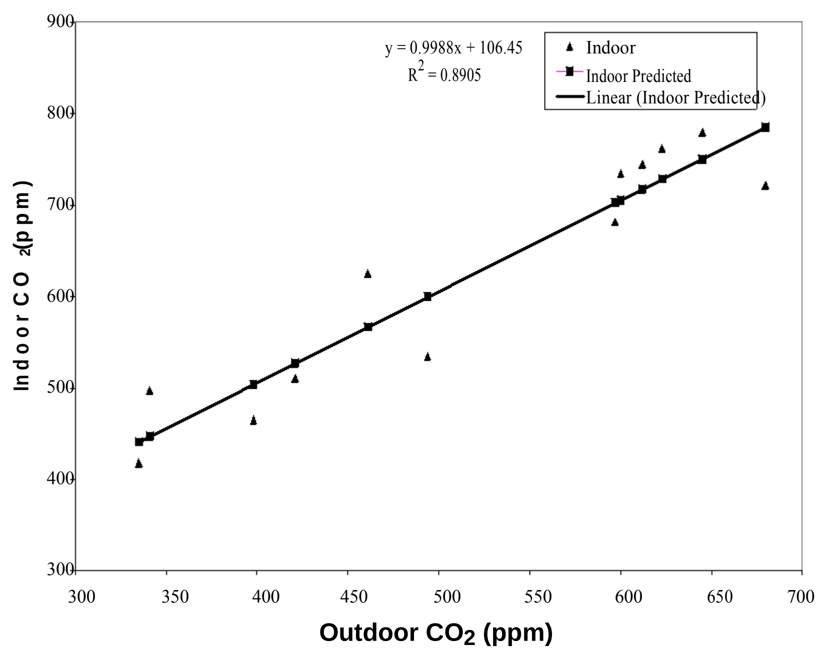

Figure 6. Relationships between indoor and outdoor concentration of co_2 in kitchen at low cost house.

Table 3. Relationship between indoor and outdoor air quality in rural house in kitchen.

Type of concentration	Village name	Relationship	R^2
CO	Vilathur	y = 5.146x + 1.7405	0.91
CO_2	Vilathur	y = 0.9988x + 106.45	0.89

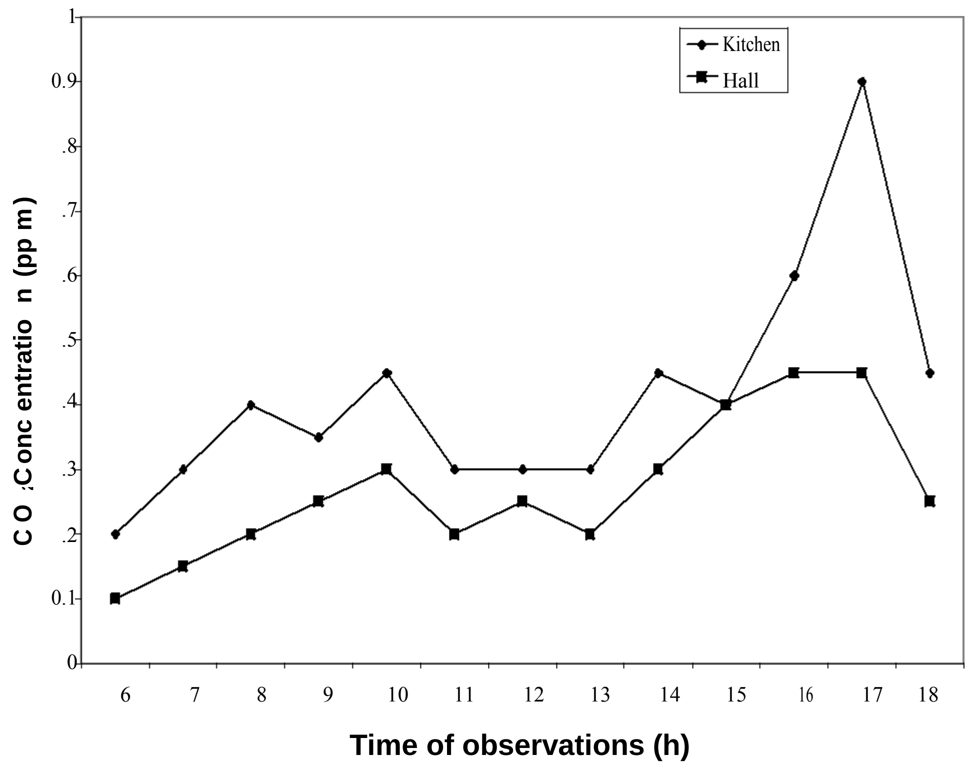

Figure 7. Observed indoor concentration of co in the green house.

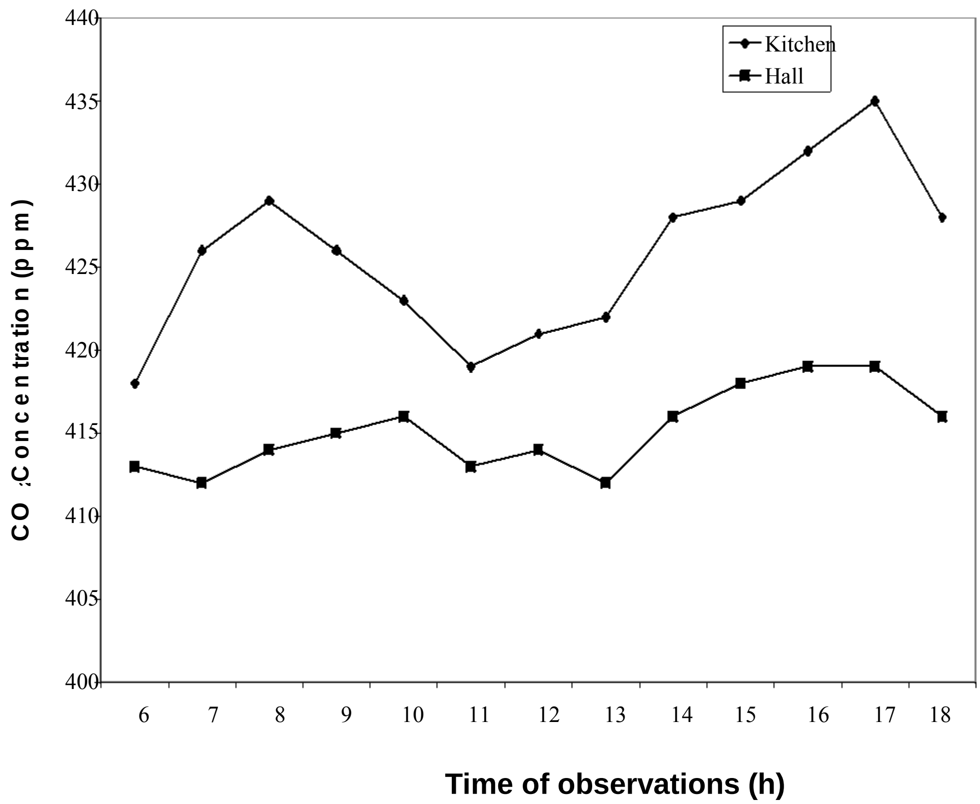

Figure 8. Observed indoor concentration of co_2 in the green house.

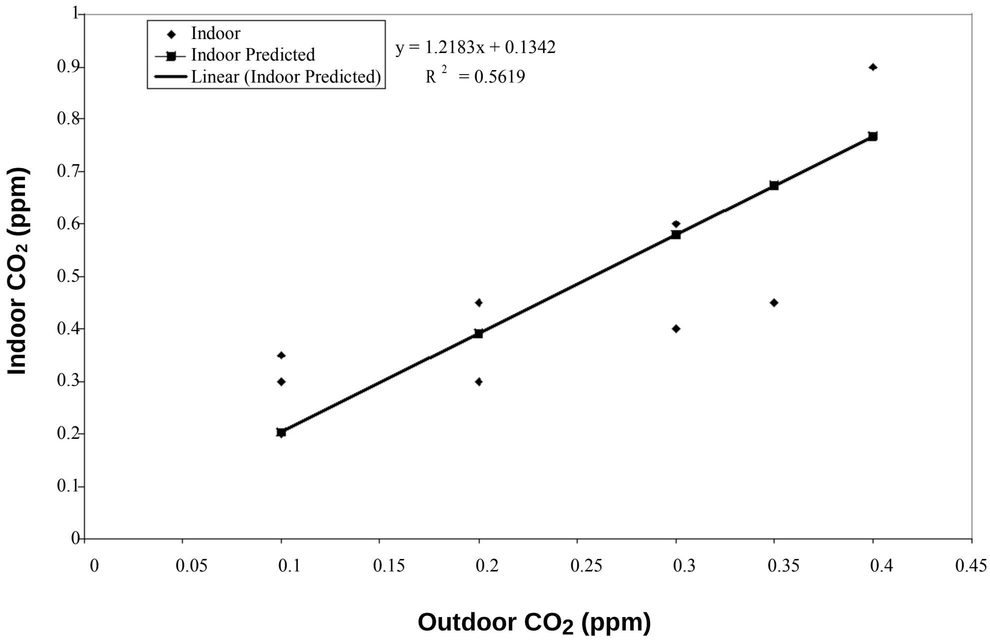

Figure 9. Indoor and outdoor relationship in kitchen for co in the green house.

Table 4. Relationship between indoor and outdoor air quality.

Type of Concentration	Room	Relationship	R^2 Value
CO	Living	y = 0.6819x + 0.1119	0.47
	Kitchen	y = 1.2183x + 0.1342	0.56
CO_2	Living	y = 0.8214x + 68.511	0.53
	Kitchen	y = 2x - 418.15	0.73

due to cooking in the kitchen. In the sustainable model home there are 4 people living. Out of 4 people, 3 of them going for agricultural works and one is going to school. The data were collected in working days and holidays for the green house. Though there is no holiday for the agricultural workers but they have the habit of taking leave themselves either on Saturdays or Sundays.

This green house is located in the village and hence the outdoor pollution is not high as like that of urban Maximum of 0.9 ppm CO concentration is recorded at 17:00 h in the kitchen and 0.45 ppm in the living room which is recorded between 16:00 and 17:00 h. In village the people normally cook in the evening from 16:00 to 19:00 h and hence the CO concentration high in the kitchen as compared to the living room. The This CO value is much less than the CO values (Maximum of 5 ppm) observed in another study conducted for rural areas in central part of India by Lawrence et al. (2004). In this green house the partition wall is built between living room and kitchen up to a height of 1.52 m only and hence the effect of smoke from kitchen is there to some extent in the living room also. That is the reason; the living room CO concentration is higher at 17:00 hrs as like in the kitchen. Figure 8 represents the concentration of CO_2 for the kitchen and living room. The concentration of CO_2 is higher in the kitchen and lesser in the living room. It is seen from the graph the maximum CO_2 is recorded with a value of 435 ppm in the kitchen and 419 ppm in the living room. Similarly the minimum CO_2 concentration observed in the kitchen and living rooms is 419 and 412 ppm respectively.

To investigate relationships between indoor and outdoor air quality linear regression was performed on the indoor vs. outdoor concentrations of each pollutant in the green house. The relationship established between indoor and outdoor concentrations for CO is presented in Figure 9 for kitchen. In the kitchen room it is found that a good relationship with indoor and outdoor pollutants. The correlation coefficient R^2 value is 0.56 for the kitchen. The established equation for kitchen and living for CO is presented in Table 4. The relationship esta-

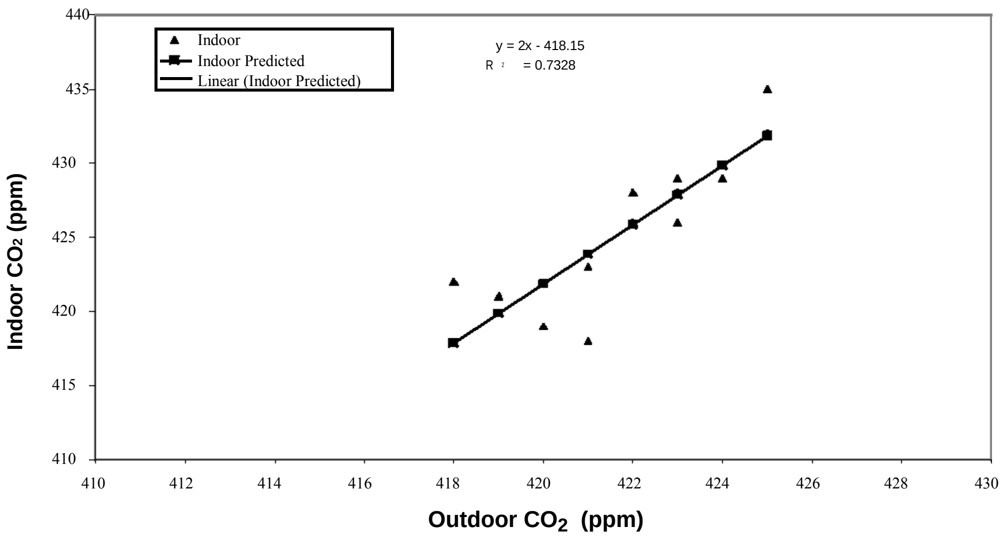

Figure 10. Indoor and outdoor relationship in kitchen for co_2 in the green house.

blished between indoor and outdoor concentrations for CO_2 is presented in Figure 10 for kitchen. In the kitchen room it is found that a good relationship with indoor and outdoor pollutants. The correlation coefficient R^2 value is 0.73 for kitchen. The established equation for kitchen and living room for CO_2 is presented in Table 4.

Conclusions

In the present study the relationship between indoor and outdoor concentration of pollutants were observed at green house built in Cuddalore district of Tamilnadu In-dia. The observed values of CO and CO_2 are much lesser than the study conducted for low cost house. The Statis-tical analysis was used to correlate indoor concentration levels with outdoor concentrations of CO and CO_2. Indoor and outdoor CO and CO_2 concentrations show a signi-ficant positive correlation except kitchen room for CO_2. The coefficient of correlation of the regression curve bet-ween indoor and outdoor the maximum value is obtained at the kitchen with R^2 = 0.56 for CO and R^2 = 0.73 for CO_2. The observed values CO and CO_2 pollution concen-tration are presented in the form of graphs to understand the variations of pollution daily. Also found that the kit-chen pollution concentration is higher than that of living room in rural areas.

The design parameters considered to have good living conditions such as ventilation, building materials used for construction, use of energy saving technique etc., are also discussed for green house. In this study area where CO and CO_2 concentration were maximum in indoor due to cooking in the kitchen and that will affect the living room concentration. This study is being continued to ob-serve the trends of all these pollutants and their effects on seasonal variation. Long-term database of the pol-lutants levels in indoor air of study area (India) will help decision makers to formulate and implement policies to a National level acceptable measures and scales of varying pollutant levels. The sustainable home concept can be extended to all rural people and a better living condition can be created for the rural India as they are the back bone of agricultural.

The Indoor Air Quality parameters in the low cost house exceed the ASHRAE standards. Especially the concentrations of CO exceeded as 138% (9 ppm accep-table but observed 21.5 ppm) during cooking time in the low cost house in the villages. Though, the Levels of in-door air quality parameters in the low cost houses in the study area were less than the huts, but it is still objection-able. It has been found that the ventilation and contami-nant transport in the pyramidal roof house is better than the low cost house. The indigenous low cost sustainable green house, that is, Solar Paneled Pyramidal Roof house is highly ventilated. Therefore, the dispersion of in-door contaminated in this type of house is highly dispers-ed. Hence, this type of house is most suitable for living in the rural environment. The best way to achieve accept-able air quality is to control contaminants at the source and to ventilate properly. Ventilation provided in the green house will control the pollution in the indoor. The indoor air quality of a building directly impacts the health and productivity of its occupants.

It is concluded that the maximum indoor CO concen-tration in the green house was nearly 1 ppm and in the low cost house 21.5 ppm. Similarly the CO_2 concentration in the green house was 435 ppm and in the low cost house 792 ppm. Hence to protect rural poor people from the indoor pollutants in India, a green house construction is suggested.

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