

# Correlation between indoor and outdoor air

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**Abstract:** Both indoor and outdoor air quality in residential areas of Al Hofuf city/Eastern province of Saudi Arabia was studied through a multi-week multiple sites measurement and sampling survey. Concentration levels of five criteria air pollutants, including carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), nitrous dioxide (NO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>) and total volatile organic compounds (TVOC) were measured and analyzed during the study period from January to May 2014. For this survey, three different location points, including roadside RS, urban UR, and rural RU – were selected. Within each site type, six locations were assigned to carry out air quality measurements and to study varying indoor/outdoor air quality. Results indicated that a strong correlation between indoor and outdoor air existed. The I/O ratios for the considered criteria pollutants showed that the strongest relationship between indoor and outdoor air was found by carbon dioxide, CO<sub>2</sub> in the range of 0.88, while the lowest is found by both NO<sub>2</sub> and SO<sub>2</sub> in the range of 0.7.

**Keywords:** air pollutants, indoor/outdoor air pollution, indoor/outdoor ratio, Saudi Arabia.

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## INTRODUCTION

Air pollution is a major environmental risk hazard to health. By reducing air pollution levels, countries can reduce the burden of disease from stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma [1]. Air pollution in Saudi Arabia and in neighboring regions is a major concern for government, health institutions, researchers and public. Sources of air pollution include traffic, industrial plants (from brick making to oil and gas production), power plants, cooking and heating with solid fuels (e.g. coal, wood, crop waste), forest fires and open burning of municipal waste and agricultural residues [1], [2]. The air quality in urban area becomes worse year by year due to the release of pollutants from industrial plants and heavy vehicle traffic and constitutes a serious hazard to human health and environment. Therefore, it is of great importance to monitor and control such dangerous emissions.

Until recently, the health effects of indoor air pollution have received relatively little attention from scientific communities and governmental institutions worldwide. In addition, while most people are aware that outdoor air pollution can damage their health, many do not know that indoor air pollutants can also do the same. Indeed, studies of human exposure to air pollutants [3], [4], [5], indicate that indoor levels of pollutants may be 2 to 5 times – and in some cases more than 100 times – higher than outdoor levels. Indoor air pollutants have been ranked among the top five environmental risks to public health. The problems they cause can be invisible and do not always be easily recognized or produce immediate impacts on health.

Even nowadays, the majority of public concern continues to be directed at the health impacts of outdoor pollution and ignore those of indoor air. These perceptions are established despite the fact that, in all societies, many people spend most of their time indoors. For example in Saudi Arabia and the neighboring Gulf Cooperation Council (GCC) countries, individuals spent 90- 95% of their daytime inside buildings, and 7% inside vehicles. Only 2-5% of individuals time was actually spent outside. Considering these figures, the quality of the air being breathed becomes extremely important. Indoor exposure to air pollutants causes very significant damage to health globally– especially in developing countries. Allergies, asthma, lung cancer and heart and respiration problems all have been reasoned to poor indoor air quality [1].

The biggest reason for ambient air pollution in Saudi Arabia at the moment are emissions from vehicles [6]. Today; traffic pollution is predominant and greatly contributes in the urban air quality problems, especially in roads of crowded traffic. Everywhere in the country cars, trucks and other vehicles are used for transportation. Also, there is migration of people from rural areas to crowded cities looking for jobs, services and better living environment. This has also contributed dramatically to the ambient air quality prevalent in major cities across Saudi Arabia.

Higher rates of air pollution are becoming strongly correlated with economic progress and improving style of living. Saudi Arabia's energy consumption has climbed dramatically over the past two decades. In year 1980, the energy consumption was 1.7 quadrillion Btu (quads), and it jumped to 4.6 quads in year 2000. Saudi Arabia consumes about 1.1% of the world energy consumption. Therefore, Saudi Arabia's carbon emissions from transport sector have jumped in the past 40 years from 3.29 million metric tons in the year 1971 to 104.42 million metric tons in year 2010. In addition, the value for CO<sub>2</sub> emissions from gaseous fuel consumption in Saudi Arabia was recorded as much as 140,500 kt in year 2009, while a minimum value of 0.00 kt was recorded in the year 1960 [6]. In terms of per capita carbon emissions, Saudi Arabia is still a number one in the region. In 2000, the country's per capita carbon emissions were 3.7 metric tons [9]. Recent studies have indicated that the Gulf countries emit about 50% of the total of Arab countries' (254 million metric tons of carbon) emissions of CO<sub>2</sub>.

Air pollution in Saudi Arabia is now recognized as a significant environmental impact of intensive anthropogenic activities. Heavy traffic in the streets of urban areas increases emissions of ozone as a result of the increased emissions of precursors (NO<sub>x</sub> and VOCs). Also, the local Saudi harsh climatic conditions (high temperature, intense solar radiation, clear sky) lead to enhanced formation of photochemical pollutants. The assessment of air quality in the urban environment, using available data will inform pollution control strategies to mitigate health and environmental impacts of poor air quality. In countries total atmospheric emission loads are about 3.85 million tons per year, made of 28% CO, 27% SO<sub>2</sub> and 23% particulates [7, 8, 9]. Recent studies have indicated that the Gulf countries emit about 50% of the total of Arab countries' (254 million metric tons of carbon) emissions of CO<sub>2</sub>.

Several environmentalists in Saudi Arabia are proposing new ideas to find a solution that can help in fighting pollution in air through extensive development of pollution and environment laws. They are also considering various specifications and standard measures that can bring some improvement in such calamity [9], [10a], [10b]. Unfortunately, the health issues are just one aspect of the problems which may arise due to air pollution. The impact of pollution is not just limited to endangering human health conditions; it is also affecting the flora and fauna, water bodies and even marine environment. Some of the water channels in Saudi Arabia have already turned into acidic swamps and declared unlivable as result of high levels of pollution. It has caused serious damage to economy as it has attributed to gradual devastation to infrastructure, including transportation and communication, residential buildings and installation of electrical posts [11], [12], [13].

Therefore, special attention to monitoring and reducing such emissions through concerted efforts should be immediately under taken at both national and international levels alike. These conclusions are supported by several investigations [14], [15], [16], [17], [18]. This research was carried out to help in assessing the status of indoor and outdoor air pollution in Al Hofuf city/ eastern province of Saudi Arabia and to discuss measures on reducing indoor air pollution and the associated health effects on humans and environment.

## METHODOLOGY

The main objective of the present study is to assess the outdoor and indoor air quality and to evaluate the relationship between indoor and outdoor air. A comprehensive study is conducted in residential areas of Al Hofuf city/ eastern region of Saudi Arabia through a multi- week multiple sites sampling survey. Five of air pollution indicators, together with relevant meteorological parameters were simultaneously monitored for indoor and outdoor within a period of four months. The monitoring of indoor and outdoor air include streets, homes, flats, and restaurants. The particularly important air quality indicators including: total volatile organic compounds (TVOCs), carbon monoxide (CO) and carbon dioxides (CO<sub>2</sub>), which were measured in parts per million (ppm); sulfur dioxide (SO<sub>2</sub>), Nitric Oxide NO<sub>2</sub> are measured in µg/m<sup>3</sup>.

Three site-types – roadside RS, urban UR, and rural RU – were selected for this study to carryout air quality measurements and to assess varying indoor/outdoor air quality. Two locations are assigned to represent each site type. All selected sites are residential areas. Three (points) are assigned and selected at each location to take sample measurements. At each assigned point three measurements are randomly taken for indoor and three measurements for outdoor air. Roadside sites RS were selected in heavy traffic roads (Riyad road, RS1) and Qayssariah Market, RS2), which have some of the highest traffic flows in Al-Hofuf downtown. Two urban sites (UR1 and UR2) were selected near (Village Market), which is a rapidly developing area outside the dense populated old city. Rural sites (RU1) and (RU2) are selected far away from the roadside and urban areas.

Detailed description of the selected six sites is shown in Table 1. All the homes and residences were using classical air conditioning ventilation (window or split-units types).

Table 1: description of sites assigned for air quality (outdoor and indoor) monitoring scattered throughout Al Hofuf city

Site	Description of site	Building type	Age yrs	Living area	Nr. Of occupants	Nr. Of smoking occupants	Type of Oven
RS1	Near main road with heavy traffic flow	Residen.+ Commer.	30	70	3	0	Nat. gas
RS2	(Down Town, shopping Centre).	Residen.+ Commer.	35	60	1	1	Nat. gas
UR1	Near construction site and road with medium traffic flow	Private residential building	5	150	4	1	Nat. gas
UR2	Near road with medium traffic flow	Private residential building	5	120	3	3	Nat. gas
RU1	Far from road side	Private residential building	20	200	8	2	Nat. gas
RU2	Near Park (garten)	Private residential building	5	250	6	0	Nat. gas

For the measurements the instrument **direct Sense IAQ meter, manufacturer Gray Wolf sensing solutions** is used.

Average hourly measurements were taken over the sampling period, (January, 2014 – April, 2014). To consider the effect of traffic density on the AQ, the data have been collected over different periods of time, T1: from 15 January – 20 January, 2014, T2: from 30 January - 4February, T3: from 15 February – 20 February, Time 4: from 30 February – 4 March, Time 5: from 15 March – 20 March, T6: 30 March – 4 April. All measurements are conducted starting from 1000 – 2000 on daily basis. The concentrations of air pollutants were recorded in real time at 20-min intervals. During the measurements, indoor air is supplied directly from outdoor air, so that air pollutants found in indoor air are resulted from outdoor emissions only.

## RESULTS

### Assessment of air quality

The daily range and average concentrations of the measured pollution indicators during the periods of study for all selected locations (RS1, RS2, UR1, UR2, RU1 and RU2) are summarized, simultaneously with the I/O ratios in table (2). It shows additionally the averages of all min. and max. readings. From this table, it is to predict that each pollutant has almost the same daily fluctuation trend during the time of measurements, and that the lowest concentrations are recorded at the early hours of the day and increase at the end of the day.

### Analysis of TVOC concentrations

Table 2 shows that the hourly recorded concentrations of total volatile organic compounds (TVOC) for indoor air at all locations (RS1, RS2, UR1, UR2, RU1 and RU2) ranged between the lowest value of 15.00 ppb and the max. value of 69 ppb. For outdoor air the values fluctuated between 21.0 to 84.0 ppb. The overall average of indoor readings equals 27.56 ppb and for all outdoor values 34.16 ppb. The I/O ratio for all locations ranged from 0.51 to 1.00 with an overall average of 0.8. In general, it is to notice that values are high at the sites RS1 and RS2 and low at the sites UR1 and UR2.

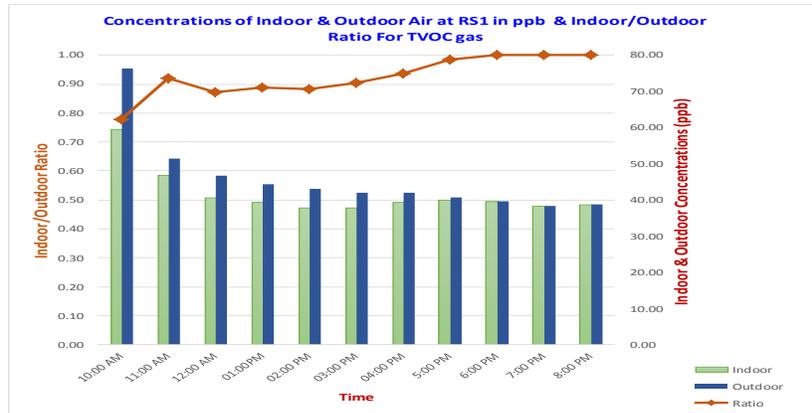


Figure 1: Concentrations of indoor & outdoor in (ppb) and I/O ratio for TVOC measured at RS1.

Figure 1 shows that the TVOC values for both indoor and outdoor are high in the mornings and decrease gradually toward the end of the day. And because the site RS1 represents a downtown area with crowded traffic, the indoor and outdoor concentrations are close to each other, indicating the strong correlation as shown in figure 1.1.

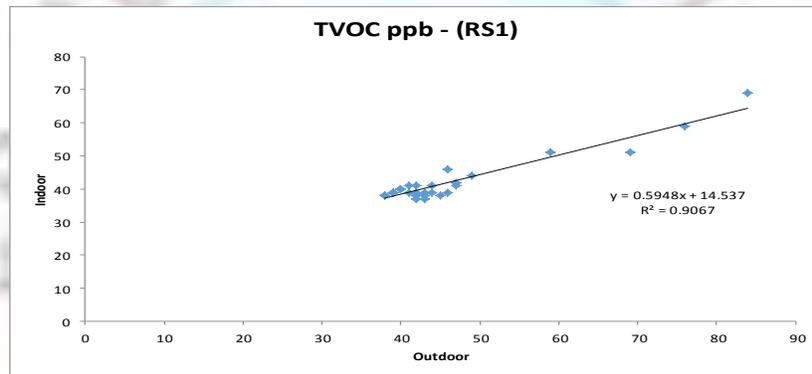


Figure 1.1: Correlation curve between indoor and outdoor concentrations of TVOC at RS1.

For comparison purposes, Figure 2 represents results of an urban area with little traffic density. Here, the outdoor concentrations of TVOC are clearly higher than the indoor concentrations, especially between 1000 am and 300 pm. The magnitude of air pollution in regard to TVOC couldn't be evaluated because there are no standards for TOVC to compare with.

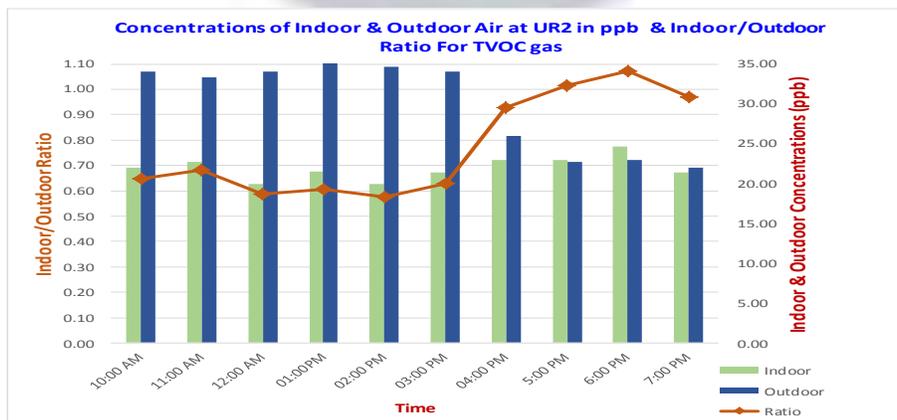


Figure 2: Concentrations of indoor & outdoor in (ppb) and I/O ratio for TVOC gas at UR2.

Table 2: Min., Max., and Average concentrations of measured air pollutants as well as the I/O ratio of pollutants for all locations (RS1, RS2, UR1, UR2, RU1 and RU2).

Pollutants		TVOC (ppb)			CO <sub>2</sub> ****(ppm)			CO* (ppm)			NO <sub>2</sub> ** (µg/m <sup>3</sup> )			SO <sub>2</sub> *** (µg/m <sup>3</sup> )		
Location	Relation	I	O	I/O	I	O	I/O	I	O	I/O	I	O	I/O	I	O	I/O
RS1	Min.	37.00	38.00	0.74	351.00	345.00	0.65	1.20	1.80	0.29	12.50	22.60	0.31	134.70	234.70	0.38
	Max.	69.00	84.00	1.00	430.00	571.00	1.17	3.10	5.10	1.00	31.70	54.50	1.00	284.70	456.60	1.00
RS2	Min.	29.00	38.00	0.62	301.00	331.00	0.81	1.20	2.80	0.29	14.50	23.70	0.42	166.10	244.70	0.44
	Max.	42.00	59.00	0.95	531.00	571.00	1.17	3.40	5.40	0.97	38.40	63.20	1.00	376.10	466.60	1.00
UR1	Min.	24.00	27.00	0.71	261.00	339.00	0.65	1.60	3.20	0.34	18.10	28.40	0.62	166.10	297.80	0.44
	Max.	37.00	37.00	1.07	386.00	430.00	0.93	2.40	5.30	0.69	43.20	53.20	1.00	376.60	426.00	1.00
UR2	Min.	18.00	22.00	0.51	261.00	362.00	0.64	1.60	1.20	0.39	24.50	28.40	0.46	216.60	297.80	0.52
	Max.	26.00	36.00	1.13	386.00	503.00	1.02	2.30	5.30	1.33	37.40	68.40	1.00	346.00	426.00	1.00
RU1	Min.	21.00	22.00	0.62	185.00	206.00	0.83	1.30	1.60	0.34	24.50	34.50	0.47	179.50	297.80	0.48
	Max.	27.00	36.00	1.09	325.00	385.00	1.01	2.70	4.70	1.25	48.40	68.40	1.00	326.10	446.00	1.01
RU2	Min.	15.00	21.00	0.65	200.00	240.00	0.78	2.30	1.30	0.62	31.40	34.50	0.56	197.80	276.10	0.51
	Max.	22.00	27.00	1.00	234.00	275.00	0.95	3.60	4.20	1.77	48.40	68.40	1.00	356.00	476.10	1.00
All	Avg.	27.57	34.16	0.81	316.73	360.68	0.88	2.13	3.51	0.65	30.59	44.27	0.70	257.52	372.97	0.70

CO\*: 1 ppm = 1.15 mg/m<sup>3</sup>, NO<sub>2</sub>\*\* : 1 ppm = 378.5 ppb = 1880 µg/m<sup>3</sup>. SO<sub>2</sub>\*\*\*: 1 ppb = 2.6 µg/m<sup>3</sup> and 1ppm = 2860 µg/m<sup>3</sup>. CO<sub>2</sub>\*\*\*\*: 1 ppm = 1.83 mg/m<sup>3</sup>

### 1. Analysis of CO concentrations

The lowest recorded hourly outdoor carbon monoxide concentration is 1.2 ppm found in the early morning at both sites RS1 and RS2, while the highest recorded concentration of 5.3 ppm is found at sites (UR1 and UR2). The average for all outdoor readings and for all sites is 3.5 ppm and the average for indoor readings is 2.13 ppm. The I/O ratio for all readings ranged from 0.286 to 1.77 with an overall average of 0.65. It is clear from the results that all indoor as well as outdoor values recorded were below 5.3 ppm. Similar values for carbon monoxide I/O ratios are reported in [19], [20], [21]. Comparing all the recorded measurements with the available standards presented in Table 3, It is clear that all concentrations of carbon monoxide for both indoor and outdoor were below the 1-h average standards (ranged between 13 ppm of Alberta guidelines and 35 ppm of both PME standard and NAAQSs, USA).

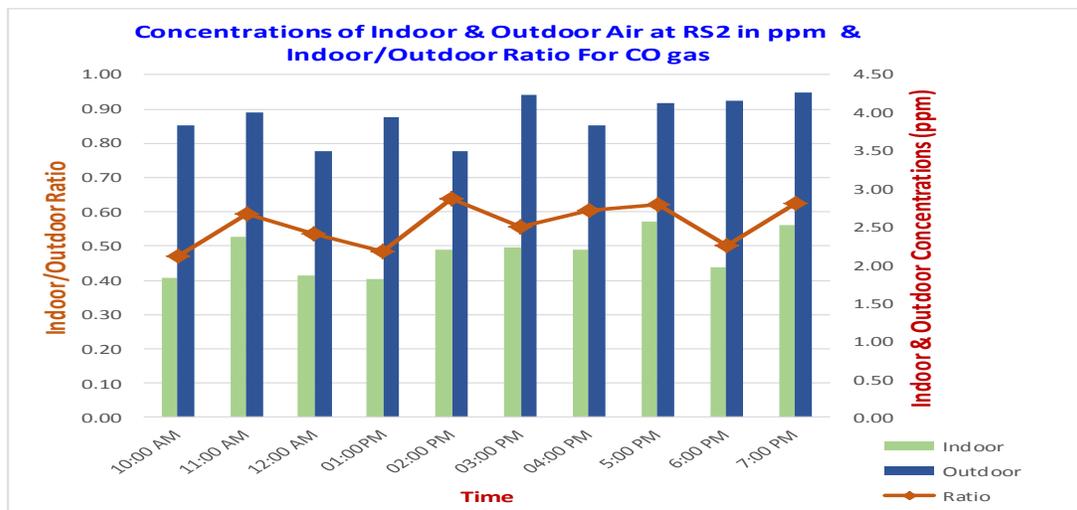


Figure 3: Concentrations of indoor & outdoor in (ppm) and I/O ratio for CO gas at RS2.

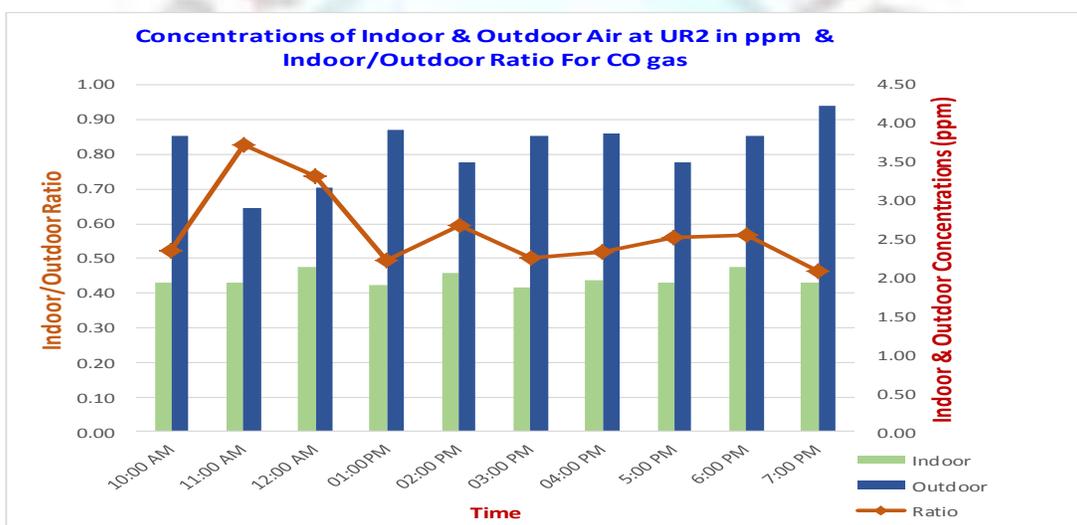


Figure 4: Concentrations of indoor & outdoor in (ppm) and I/O ratio for CO gas at UR2.

Figure 3 and 4 demonstrate the average CO concentrations of indoor and outdoor air at both locations RS2 and UR2. From these figures it is to see that the I/O ratio fluctuates between 0.8 to 1.00 and from 0.92 to 0.97 for RS2 and UR2 respectively, indicating the strong correlation between indoor and outdoor air at both sites.

### 1. Analysis of CO<sub>2</sub> concentrations

The recorded concentrations of CO<sub>2</sub> indoors and outdoors are laying close together. The indoor concentrations ranged from 200 to 351.0 ppm with an overall average of 316.73 ppm, while the outdoor concentrations range from 206 to 571 ppm with an average of 360.68 ppm. The I/Q values range from 0.65 to 1.17 forming an overall average of 0.88. Figure 5 shows an example of indoor and outdoor concentrations recorded at RU2. Figure 5.1 shows the relationship between indoor and outdoor CO<sub>2</sub> concentrations measured at RS2. The correlation coefficient R<sup>2</sup> is found as high as 0.6.

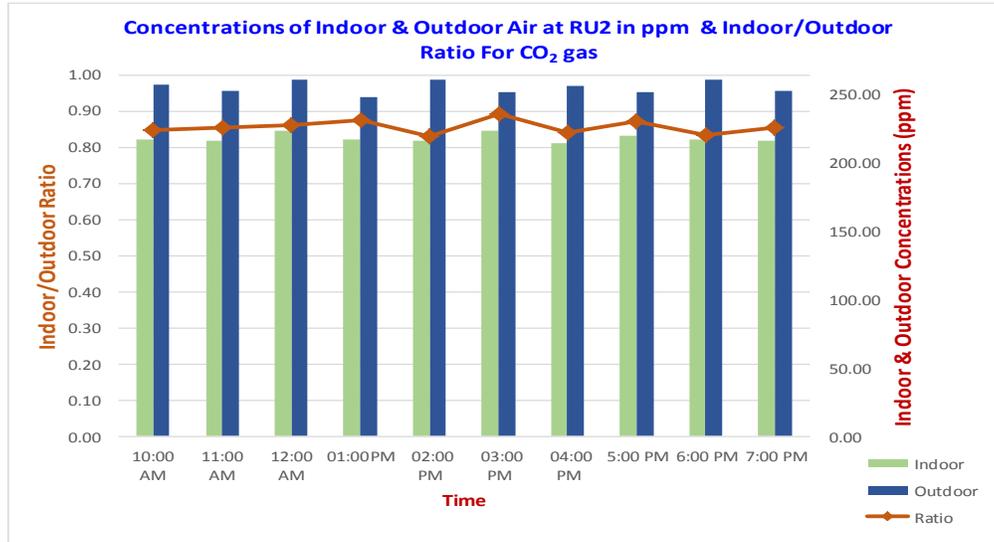


Figure 5: Concentrations of indoor & outdoor in (ppm) and I/O ratio for CO<sub>2</sub> gas at RU2.

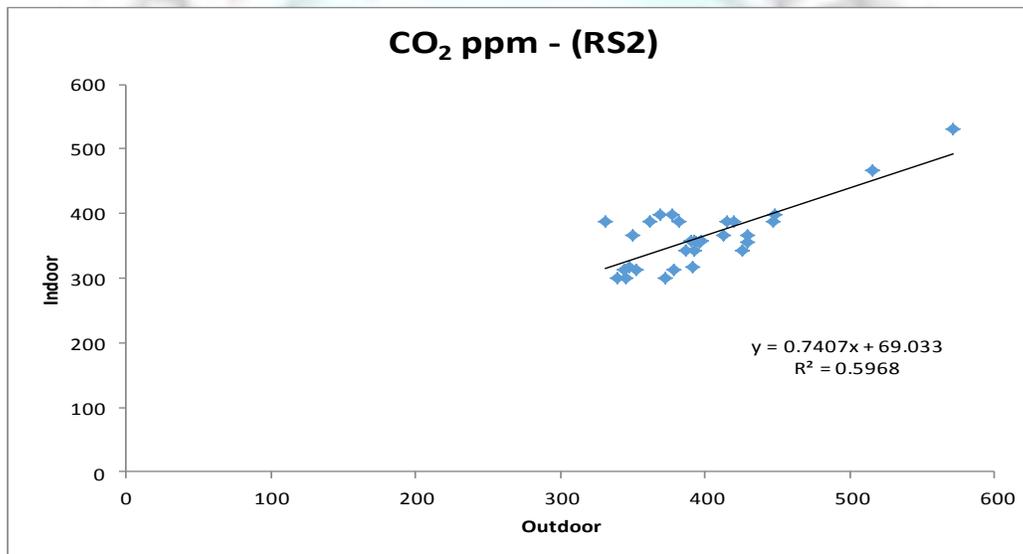


Fig. 5.1: Correlation curve between indoor and outdoor concentrations of CO<sub>2</sub> at RS2

## 2. Analysis NO<sub>2</sub> concentrations

The recorded hourly concentrations of nitrogen dioxide, NO<sub>2</sub> for outdoor air fluctuated between the lowest value of (22.6 µg/m<sup>3</sup> = 0.012 ppm) is found at RS1 and the highest value (68.4 µg/m<sup>3</sup> = 0.036 ppm) found at the sites UR2, RU1 and RU2. The overall average for outdoor values is 44.7 µg/m<sup>3</sup> (0.023 ppm). For indoor air concentrations placed between the min. concentration of 12.5 µg/m<sup>3</sup> (0.007 ppm) measured at RS1 and the maximum concentration of 48.4 µg/m<sup>3</sup> (0.045 ppm) found at both locations UR1 and UR2, with an overall average of 30.59 µg/m<sup>3</sup> (0.016 ppm). The I/O ratio ranged from 0.306 to 1.00 with an overall average of 0.702. Comparatively, similar values for NO<sub>2</sub> I/O ratios are reported in previous investigations [22], [23], [19], [24].

The recorded concentrations for both outdoor and indoor shows an increasing trend starting with low values in the early hours of the day and increase during the late hours.

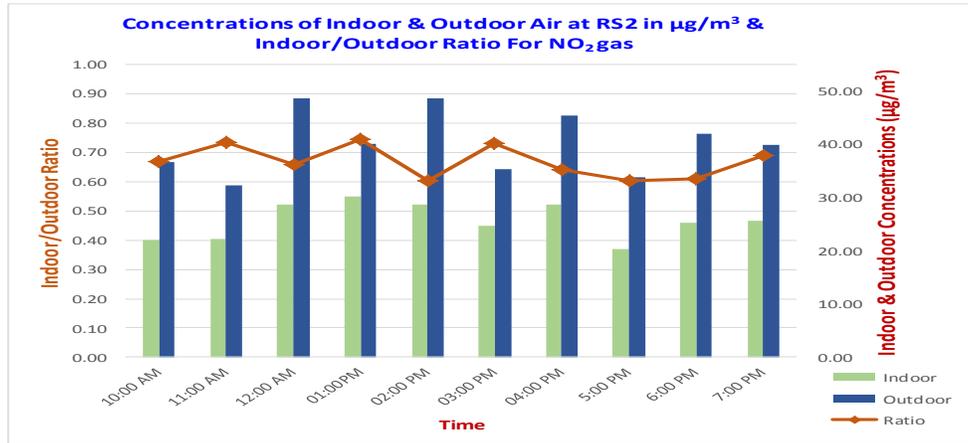


Figure 6: Concentrations of indoor & outdoor in (µg/m<sup>3</sup>) and I/O ratio for NO<sub>2</sub> gas at RS2.

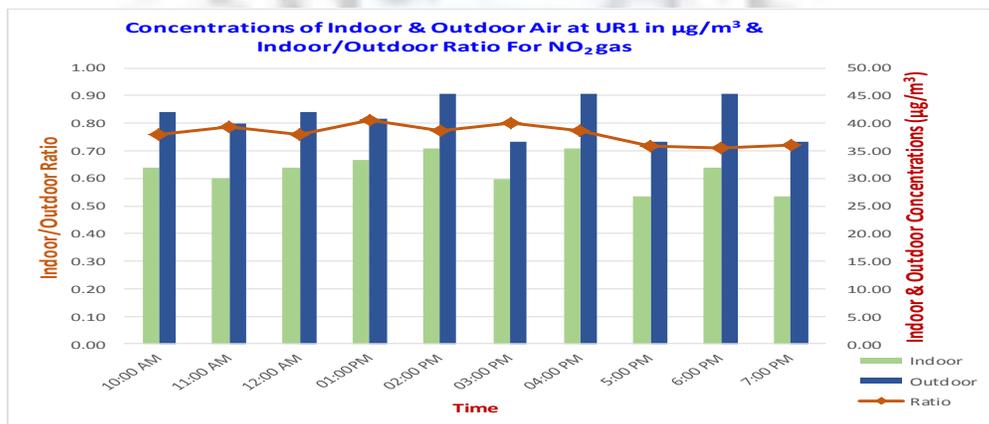


Figure 6.1: Concentrations of indoor & outdoor in (µg/m<sup>3</sup>) and I/O ratio for NO<sub>2</sub> gas at UR1.

Both Figures 6 and 6.1 demonstrate the average NO<sub>2</sub> concentrations of indoor and outdoor air found at both locations RS2 and RU1. The I/O ratio fluctuates between 0.6 to 0.75 and from 0.70 to 0.80 for RS2 and RU1 respectively. From these figures it is to see that when outdoor concentrations increase, the indoor values also increase, indicating that indoor air is directly affected by outdoor air. The correlation coefficient  $R^2$  between indoor and outdoor for NO<sub>2</sub> is found as much as 0.7631 indicating a strong and positive correlation function.

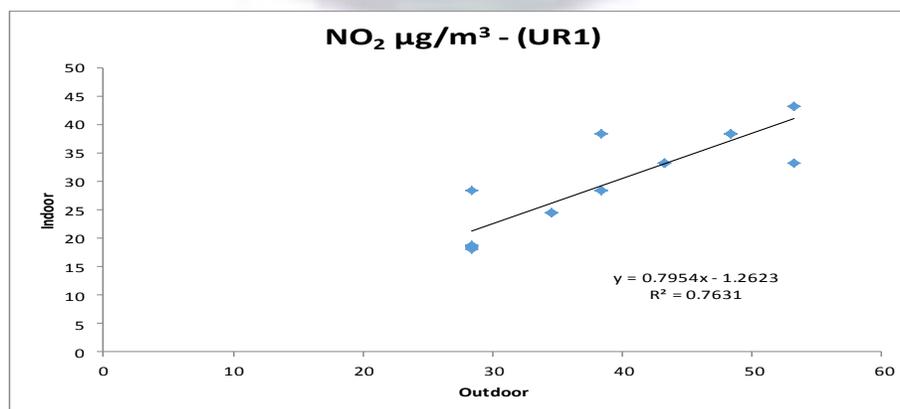


Fig. 6.2: Correlation curve between indoor and outdoor concentrations of NO<sub>2</sub> at UR1.

### 3. Analysis of SO<sub>2</sub> concentrations

From Table 2, it can be seen that the hourly indoor SO<sub>2</sub> concentration ranged from 134.7 µg/m<sup>3</sup> (0.047 ppm) to 284.7 µg/m<sup>3</sup> (0.1 ppm) with an overall average of 257.51 µg/m<sup>3</sup> (0.09 ppm) and that the outdoor concentrations ranged from 234.7µg/m<sup>3</sup> (0.08 ppm) to 456.6µg/m<sup>3</sup> (0.16 ppm) with an overall average of 372.97µg/m<sup>3</sup> (0.13 ppm). The I/O of all readings ranged from 0.38 to 1.00 with an overall average of 0.696. It has been noticed that all the recorded results were fluctuating in a narrow range (Fig. 7). Comparing the results with the available standards presented in Table 3 showed that all the results of the current study for 1- and 24-h are below the standards most of the time. NAAQs and WHO standards were violated only once throughout the year.

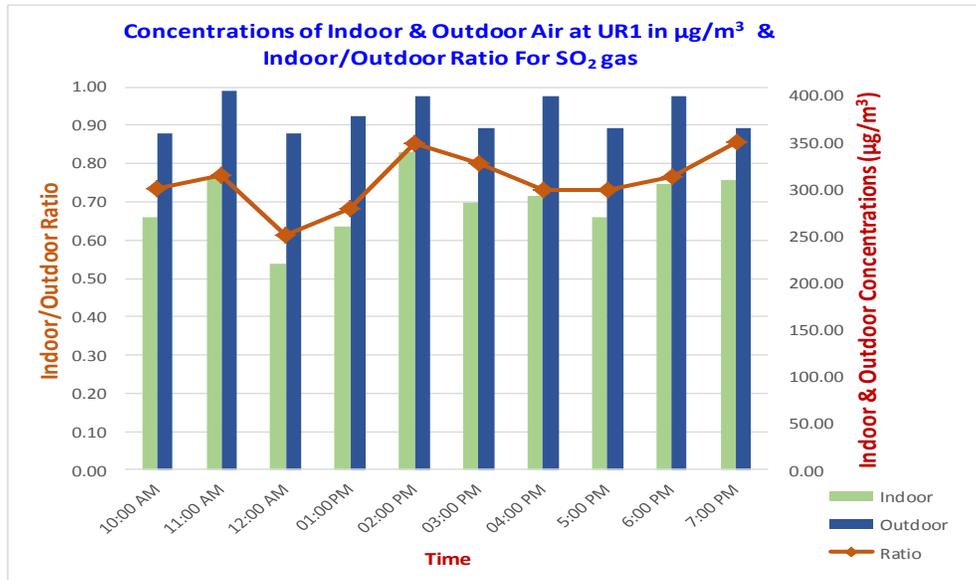


Fig. 7: Correlation curve between indoor and outdoor concentrations of SO<sub>2</sub> at UR1

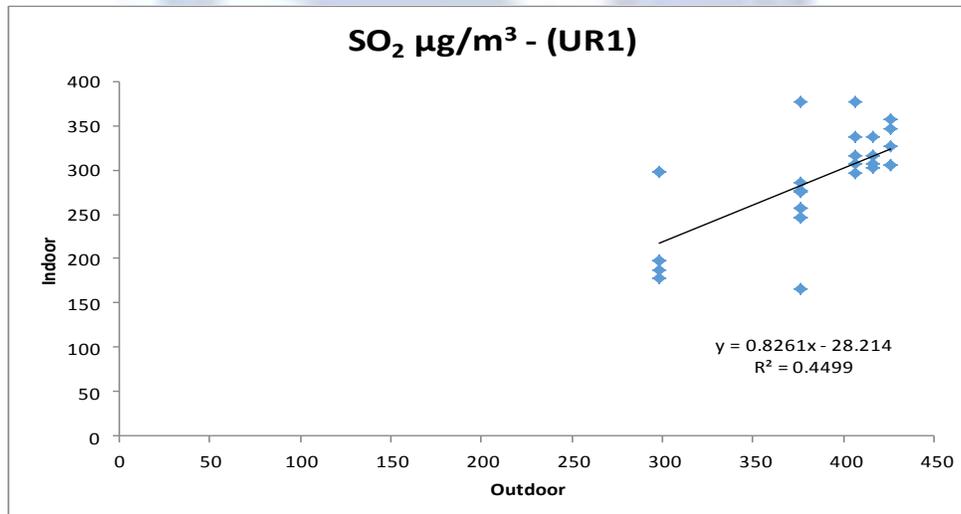


Fig. 7.1: Correlation curve between indoor and outdoor concentrations of SO<sub>2</sub> at UR1.

Figure 7.1 shows the correlation function between indoor and outdoor for SO<sub>2</sub> with a correlation coefficient = 0.45.

**Table 3: Air quality standards in different countries (PPM)**

<b>Standards</b>	<b>CO</b>	<b>NO<sub>2</sub></b>	<b>O<sub>3</sub></b>	<b>SO<sub>2</sub></b>
NAAQSs (USA) 1-h average	35	0.246		0.12
NAAQSs (USA) 1-8h average	9			
NAAQSs (USA) 3-h average				0.5
NAAQSs (USA) 24-h average				0.14
NAAQSs (USA) annual average				0.14
NAAQSs (Canada) Desirable 1-h average	13.1		0.051	0.172
NAAQSs (Canada) Desirable 24-h average			0.051	0.057
NAAQSs (Canada) Acceptable 1-h average	30.6	0.213	0.082	0.334
NAAQSs (Canada) Acceptable 24-h average		0.106		
WHO 1-h average	26	0.07	0.5-0.1	0.13
WHO 24-h average				0.038-0.058
WHO annual average		0.014		
EU guidelines 1-h average	0.14			0.28
EU guidelines 24 h average	0.028			0.017
Alberta Guidelines 1-h average	13	0.21	0.082	0.17
Alberta Guidelines 24-h average		0.11	0.025	0.06
NAAQSs (Korea) 1-h average	25	0.15	0.1	0.015
NAAQSs (Korea) 24-h average	35	0.35	0.15	0.14
PME (MEPA) 1-h average	35	0.35	0.15	0.28
PME (MEPA) 24-h average				0.14

## DISCUSSIONS

The levels of measured concentrations for the five investigated pollutants changed simultaneously outdoors and indoors specially during traffic rush hours, demonstrating the importance of outdoor infiltration into the indoor air quality. The maximum recorded concentrations were less indoors and outdoors respectively than the allowable limits given in table 2. Total VOC's (such as formaldehyde and polycyclic aromatic hydrocarbons (PAH) and benzene) levels were relatively high outdoors and indoors, outdoor levels being generally higher than those indoors. These results suggest that in downtown Al Hofuf, infiltration might be the main source of indoor pollution. Fluctuations in the I/O ratio generally indicate either the presence of indoor sources or changes in the air exchange rate. The actual measurements found a clear positive relationship between the concentrations, with outdoor levels generally higher than those indoors. As expected, may be due to attenuation by the building, the variation of indoor concentrations was smaller and more gradual than that outdoors. The I/O ratios for measured pollutants, of which more than 85% in the atmosphere is traffic-related, indoor concentrations have been shown to closely follow outdoor levels, especially near busy roads. Indoor peak concentrations have been measured to be slightly dampened and to lag behind outdoor peaks. An exception represents Carbon dioxide.

## CONCLUSIONS

Based on the results of measurements and experiments obtained in this study, the following conclusions can be demonstrated:

1. The results of this study have confirmed the importance of ambient air in determining the quality of air indoors and that there is a strong correlation between outdoor and indoor air.
2. Although the existing concentrations for the critical air pollutants in outdoor/indoor air of Al-Hofuf city didn't exceed the allowable limits described in national and international standards, the existing pollution is significant and can't be ignored.

3. The strongest relationship between indoor and outdoor air was found by carbon dioxide, CO<sub>2</sub> in the range of 0.88, while the lowest is found by both NO<sub>2</sub> and SO<sub>2</sub> in the range of 0.7.
4. Nitrogen oxides and Carbon monoxide concentrations increased at the starting hours of the day, then, they fluctuated within a limited range of concentrations during the remaining hours of the day, but with decreasing trend. The reason of reduction can be attributed to the effect of the meteorological conditions.
5. Sulfur dioxide showed a relatively constant and low concentration.

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