Table 4.2 Studies of Indoor and Outdoor Exposures to SO_2

Reference	Year & Season of Study	Location	Type of Exposure	Number of Sites	Site Description	Number of Measurements	Duration	Sampler Used
Biersteker, de Graaf & Nass, 1965	1964, January to March	Rotterdam, the Netherlands	Indoor and Outdoor (residential)	60	Homes representative of bungalows, multistoried houses, flats, and high rise apartments. indoor samples taken in living room, outdoor samples taken outside same house	~14 to 22/site; half indoors and half outdoors	24 hours	Drechsel bottle with hydrogen peroxide solution, analyzed by titration of total acidity
Spengler, Ferris & Dockery, 1979	(year not reported) one-year period	6 cities in USA: Kingston/ Harriman TN; Portage WI; Steubenville OH; St. Louis MO; Topeka KS; Watertown MS	Indoor and Outdoor (residential or public facilities)	~ 60	Indoor samples taken in main activity room of home (living room, TV room, den) or in public building, outdoor sites are ambient sampling stations.	~ 30-50/site; one taken every 6th day for at least one year	24 hours	Bubblers, analyzed using West-Gaeke method.
Stock, Kotchmar et al., 1985	May to October, 1981	Sunnyside and Clear Lake neighbourhoods of Houston, TX	Indoor and Outdoor (residential)	12	Houses representative of those of participants in an epidemiological study.	2/site; one indoors and one outdoors, providing ~200 hours of data for each site	8-9 days	Pulsed fluorescence continuous gas analyzer
Méranger and Brulé, 1987	(year not reported) March and April	Antigonish, Nova Scotia	Indoor and Outdoor (residential)	2	60 year old house at town centre, site outside town	(not reported, 8 weekly averages per location, in dining room and outside house, outdoors only outside town)	not reported	Flame photometric continuous gas analyzer
Yuhui, Xiaoming et al., 1991	1987, June to August 1987 - 1988, December to February	4 cities in Eastern China: Chengde Shenyang Shanghai Wuhan	Indoor (residential)	120	30 homes/city: 15 coal-burning; 15 gas-burning	16 per site: 4 samples per day, 2 days in summer and 2 in winter, in the kitchen and bedroom at breathing level. 1) 6-8 am 2) 9-11 am 3) 1-3 pm 4) 6-8 pm	2 hours	Pararosanaline
Lee, 1997	1996, January to March	Hong Kong	Indoor and Outdoor (residential)	30	15 units in each of 2 staff quarters: Tsim Sha in a heavy traffic area; and Shatin in a low traffic, but industrial area	8 per site: one in the living room and one on the balcony, one on a weekday morning and one in the evening, one on Sunday morning and one in the evening	20 minutes	Tedlar bag and pump (1 L/min), analysis by pulsed fluorescence SO_2 analyzer
Kukadia & Palmer, 1998	1996, Winter	Birmingham, UK	Indoor and Outdoor (office)	2	1 ground floor office in naturally ventilated building, and 1 third floor office in mechanically ventilated building.	~ 2000 records/site (recorded every 5 minutes over sampling period)	1 week	Data logging continuous gas analyzer

Units	Measured Concentration of SO_2										Results
	Mean					Minimum		Maximum		Standard Deviation	
ug/m^3	I/O Ratio ~0.20					Indoor 0	Outdoor 73	Indoor 246	Outdoor 384		Multiple regression analysis showed increasing % indoor SO_2 with older construction. Smoking in the home, outdoor SO_2, and gas, coal and oil heating (order highest to lowest; versus central) also associated with increased levels. Natural gas in Rotterdam at the time contained 100-250 mg S/m^3
ug/m^3		indoor	outdoor			indoor	outdoor	indoor	outdoor		Indoor concentrations consistently and significantly lower than outdoor. Differences between cities significant.
	Kingston, TN	1	12			0	4	1	12		
	Portage, WI	6	8			5	7	10	10		
	Steubenville,OH	22	52			16	35	26	59		
	St. Louis, MO	10	40			10	28	26	60		
	Topeka, KS	1	2			0	1	2	5		
	Watertown, MS	8	25			0	11	10	31		
ppb	indoor 5.1	outdoor 2.8								Indoor 5.3	Outdoor 5.0	Despite higher indoor than outdoor SO_2 levels, authors caution that this result may be confounded by differences between homes and diurnal patterns.
ug/m^3	indoors in town		2 - 10								Usually lower levels indoors than outdoors at town site. Outdoor concentrations depended on direction of prevailing winds, compared to pollutant sources (oil-burning power plants at the hospital and university).
	outdoors in town		3 - 16								
	outdoors control		0 - 30								
ug/m^3	SUMMER	Chengde	Shenyang	Shanghai	Wuhan						Winter exposure higher than summer; kitchen higher than bedroom, and coal higher than gas. In the 4 cities studied, concentrations of SO_2 in kitchens and bedrooms in homes using coal stoves in winter almost all exceeded national standard (150 ug/m^3 - daily average). In summer, all levels met requirement except for Shanghai.
	Kitchen/coal	71	75	694	174						
	Bedroom/coal	60	51	334	67						
	Kitchen/gas	47	74	53	76						
	Bedroom/gas	39	53	33	87						
	WINTER	Chengde	Shenyang	Shanghai	Wuhan						
	Kitchen/coal	482		860	173						
	Bedroom/coal	274		502	87						
	Kitchen/gas	163		65	70						
	Bedroom/gas	140		37	41						
nL/L (ppb)		indoor	outdoor	I/O Ratio		I/O		I/O		indoor	outdoor	Outdoor levels higher than indoor levels, but indoor and outdoor levels were significantly correlated. Outdoor levels at Tsim Sha highest for all times of day, likely due to traffic. No differences observed between morning and afternoon, except that lower levels seen on Sunday evenings.
	Tsim Sha	4.3	6.0	0.72		0.54		0.85		1.4	2.5	
	Shatin	3.9	4.3	0.91		0.86		0.97		1.0	1.3	
ppb		Nat Vent	Mech Vent	Outdoor				Nat.	Mech.			Outdoor levels greater than indoor. No distinction between natural and mechanical ventilation with regards to indoor air quality,
	Mean	4.4	3.9	11				10.6	13.4			
	I/O Ratio	0.4	0.4					0.3	0.3			

Reference	Year & Season of Study	Location	Type of Exposure	Number of Sites	Site Description	Number of Measurements	Duration	Sampler Used
Bailie, Pilotto et al., 1999	Winter (year not reported)	(not reported: possibly South Africa, based on acknowledge-ment)	Indoor (residential)	72	Houses, none with chimneys, some with no paraffin use, some with use of paraffin for heating, lighting, and/or cooking	(not reported)	(not reported)	Exotox 75 continuous gas analyzer
Camuffo, Brimble-combe et al., 1999	1996, February and August	Venice, Italy	Indoor and Outdoor (museum)	1	Correr museum: 3 outdoor sites around the museum and 6 rooms indoors	15 total for the site: 1 in winter only at three of the locations and 2 (one winter and one summer) at 6 of the locations	2 to 4 weeks	Diffusion tubes, with stainless steel mesh coated with potassium hydroxide, analysis by ion chroma-tography
Lee, Chan & Chui, 1999	1996 - 1997, October to March	Hong Kong	Indoor and Outdoor (public places)	14	3 restaurants, 2 libraries, 3 recreation sites, 3 shopping malls, 2 sports centres, and 1 car park, in rural areas and in commercial and residential urban areas	2 per site: indoors (in most densely occupied area) and outdoors (near fresh air intake during peak hours) at each	20 minutes	Teflon bag and pump (1 L/min), analysis by pulsed fluorescence SO2 analyzer
Sanyal & Maduna, 2000	1995 - 1996, February to December	South Africa	Indoor (residential)	115	50 very low income households, 40 low income households, and 25 middle income households; in cooking and living areas of each home	6 per site: 3 days per site (fall, spring and winter), twice per day (once in the morning and once in the afternoon)	6 hours	Exotox 75 continuous gas analyzer
Zhou & Cheng, 2000	(not reported)	(not reported: possibly New Mexico, US, based on authors' location)	Indoor (tent)	1	Vinyl-backed canvas army tent inside clamshell structure, with unvented kerosene/jet fuel heaters inside (2 convection type, and 1 radiant type) modelled to simulate Gulf War conditions of 1990-1991	36 test runs under various conditions inside and outside clamshell. Sampling probes positioned close to breathing zone of a sleeping person.	5 hours	Draeger Multi-gas Multiwarn II continuous gas analyzer
Chao, 2001	1997, May to June	Hong Kong	Indoor and Outdoor (residential)	10	Apartments of non-smokers in different areas of city, 20 -140 m^2, 2 - 5 occupants and from 2^{nd} to 35^{th} floors	8 per site: 4 outdoors by fresh air intake of air-conditioning unit, 4 in middle of living area	48 hours	Ogawa PS-100 passive samplers
Kindzierski & Sembaluk, 2001	1998, Late Fall	Boyle and Sherwood Park, Alberta	Indoor and Outdoor (residential)	25	12 single-family homes in Boyle (rural, population 860) and 13 in Sherwood Park (population 42,000 and near Edmonton, population 800,000, refineries and power generating facilities nearby)	4 per site: 2 indoors in main living area near kitchen and 2 outdoors under rain shelter	7 days	Diffusion monitor with glass fibre filter coated with sodium bicarbonate, analysis by ion chroma-tography

Units	Measured Concentration of SO_2							Results
	Mean					Minimum	Maximum	Standard Deviation	
ppm	0.54					0	6.8		After electricity, paraffin was the most commonly used fuel (69% of households and 64%, respectively). Fuel use not associated with SO_2 levels.
ppb	OUTDOORS		Feb.	Aug.					Outdoor concentrations higher than indoor. Higher levels than those recorded at the V&A Museum in London and at the Residenz in Wurzburg.
	Piazza San Marco		40	25.8					
	Enclosed Courtyard 1		34.2						
	Enclosed Courtyard 2		19.9	16.8					
	INDOORS								
	Bellini Room 1		5.8	<6					
	Bellini Room 2		5.9						
	Lotto Room 1		4.8	<6					
	Lotto Room 2		4.4						
	Lotto Room 3		5.0	<6					
	Lotto Room 4		5.6	<6					
uL/L (ppm)		Indoor	Outdoor	Site Comments					Rural SO_2 concentrations about half of those in urban areas. Differences between indoor and outdoor levels were small (I/O Ratio = 0.92), and there was reasonable correlation between indoor and outdoor values (R^2 = 0.56). Outdoor and indoor concentrations were well below the ASHRAE recommended 24-hour average of 0.14 uL/L and the NAAQS annual average of 0.03 uL/L.
	restaurant 1	0.006	0.006						
	restaurant 2	0.006	0.007						
	restaurant 3	0.003	0.003	rural					
	library 1	0.006	0.007						
	library 2	0.003	0.003	rural					
	recreation site 1	0.005	0.005						
	recreation site 2	0.003	0.003						
	recreation site 3	0.012	0.009	diesel machine outside site					
	shopping mall 1	0.003	0.009						
	shopping mall 2	0.003	0.003						
	shopping mall 3	0.008	0.008						
	sports centre 1	0.006	0.006						
	sports centre 2	0.003	0.003	rural					
	car park	0.003	0.005						
mg/m^3			June - Sept	Oct - Dec	March - May				SO_2 values significantly higher in kitchen than in living room from June-September (winter in South Africa).
	Very low income	cooking	60	35	27.5				
		living	33	28	35.5				
	Low income	cooking	42.5	16.5	16.5				
		living	20	20	24				
	Middle income	cooking	21.5	11.5	11.5				
		living	12.5	9.5	12				
ppm	0 - 1.5 depending on heater, fuel, and air exchange rate								SO_2 concentrations rose throughout time heaters were on and decreased rapidly after they were turned off. Convection heaters produced higher concentrations than the radiant heater.
ug/m^3	Indoor	6.3				2.6	10.4	2.2	SO_2 levels low inside and outside residential apartments; authors indicate that levels now are lower than previously due to the implementation of restrictions on sulfur content in fossil fuels
	Outdoor	8.1				2.6	15.7	3.8	
	I/O Ratio	1.01				0.25	3	0.78	
ug/m^3	(MEDIANS)	Boyle	Sherwood			Boyle	Sherwood	Boyle	Sherwood		Indoor levels much lower than outdoor. Higher indoor and outdoor (2x) levels in Sherwood Park than Boyle due to increased traffic and industrial emissions.
	Indoor	0.5	1.4			0.2	0.9	2.3	5.2		
	Outdoor	4.3	9.9			3.7	8.2	5.6	13		
	I/O	0.13	0.13			0.05	0.08	0.52	0.4		