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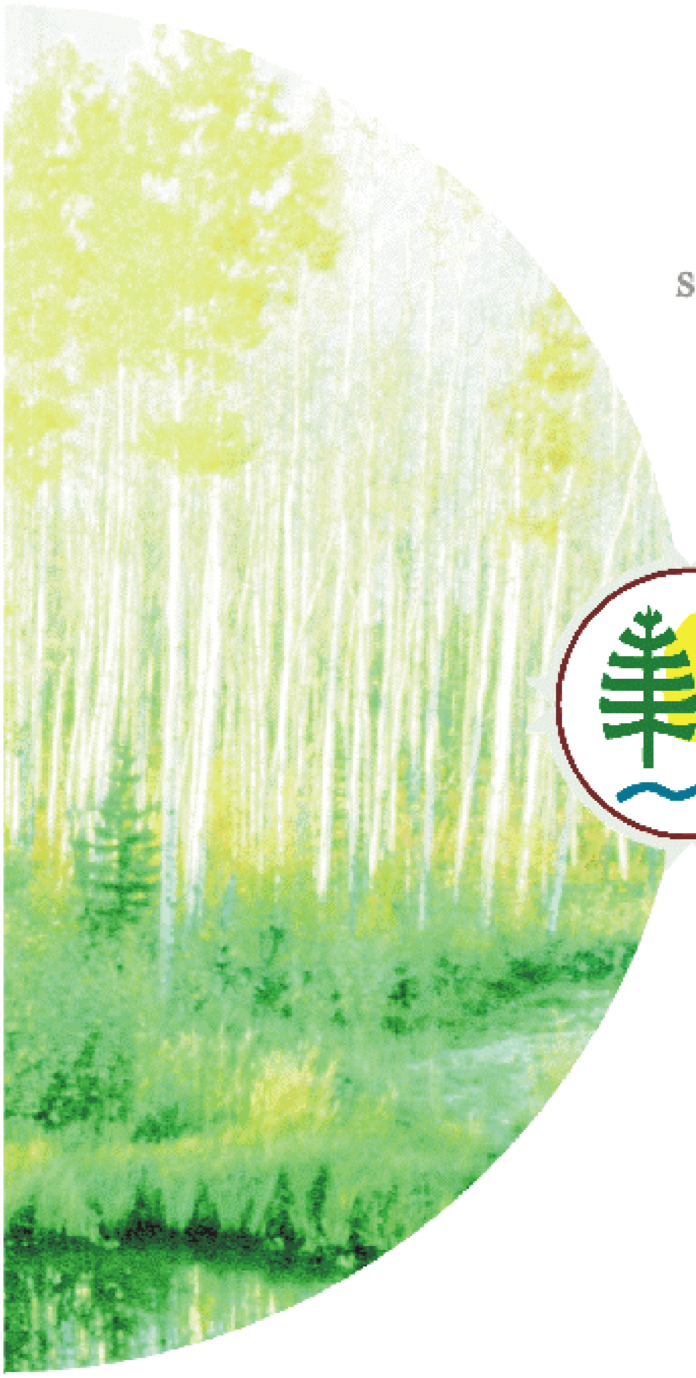

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Rural and Urban Passive Monitoring of Sulphur Dioxide

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Rural And Urban Passive Monitoring of Sulphur Dioxide

SFM Network Project: Exposure Assessment of Air Pollutants
from the Forest Industry

by

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EXECUTIVE SUMMARY

A field study was undertaken to establish indoor/outdoor air quality information for gaseous sulphur dioxide (SO_2) in two Alberta communities, one small rural community (Village of Boyle) and one urban community (Municipality of Sherwood Park). The study was conducted during a time of year in which SO_2 is considered to be the most persistent in the outdoor environment (late fall/early winter). An objective of the study was to establish baseline air quality information on SO_2 in indoor and outdoor air in a community supported by the forest industry sector (Boyle) and a comparison community.

It was found that median SO_2 levels were about a factor of two to three times lower at Boyle compared to Sherwood Park for both indoor and outdoor environments. This may be due to a far greater number of activities occurring in and around Sherwood Park involving SO_2 emissions (vehicle traffic and industrial emissions). Overall, indoor and outdoor SO_2 levels observed in both communities were considered low ($\leq 11\ \mu g/m^3$). Potential human exposure to SO_2 at the levels observed would not be considered important from a human health perspective in light of much higher levels that are reported to be associated with adverse health effects. Similar median indoor/outdoor concentration ratios were observed in both communities (0.08). This trend suggests that factors contributing to the persistence of SO_2 indoors were similar among the communities.

It is judged that results obtained from this study are more representative of conditions in communities of similar demographics compared to data in the existing scientific literature. These results can be used as baseline information in which to evaluate the impact of changes or improvements to industrial activities contributing to SO_2 emissions in communities of similar demographics.

ACKNOWLEDGMENTS

The contributions of Dr. Hongmao Tang, Maxxam Analytics, Inc., Edmonton, Alberta, are acknowledged. Special thanks are acknowledged to Dr. Tang for allowing the use of rain shelters for deployment of outdoor monitors during the study.

Special thanks is given to the Mayor of Boyle, Alberta, Mr. Robert Clark, who assisted in recruiting volunteers for the study.

Lastly, this research was made possible by the kindness of residents of the Village of Boyle and Municipality of Sherwood Park who participated in the study.

INTRODUCTION

The forest industry is an important economic resource for small communities in Canada and an important player in contributing to the growth of these communities. People living in proximity to forest industry activities (e.g. pulp, paper and sawmills) have an increased awareness about the effect that atmospheric emissions from these activities may be having on their health. What is not understood very well is the role that specific industrial activities may have in contributing to people's exposure to air pollutants. Exposure is recognized as an important link in understanding the role between chemicals released into the environment and adverse health effects occurring in a population.

A monitoring study was undertaken to establish indoor/outdoor air quality information for gaseous sulphur dioxide (SO_2) in a small Alberta community with a sawmill (less than 1,000 population). SO_2 is recognized as a common air pollutant of sulphur-based wood fibre making processes (e.g. kraft process) and from general industrial burning of sulphur-containing fossil fuels for energy use. The intent of the study was to establish baseline information that could be used by others for a variety of applications. These applications include, but are not limited to:

- Evaluating impacts of changes or improvements in industrial activities with SO_2-related emissions.
- Evaluating environmental and/or health impacts of proposed industrial development projects under the environmental assessment process.

As the study was conducted on a one-time basis, it was judged important to consider another community in which to compare air quality monitoring results to. Urban areas have a predominance of motor vehicles that are recognized as contributors of SO_2 to ambient air (Utell and Renzi 1998). Burning of gasoline in internal combustion engines results in the production of SO_2. Consequently, an urban area of Alberta was also included as a comparison community during the study.

People tend to spend, by far, the greatest amount of their time at home indoors (Leech et al. 1996). Previous work undertaken by Sembaluk (1997) established that the indoor (home) location provided an opportunity for human exposure to SO_2. As a result, indoor air represents an important location in which to consider in relation to potential human exposure to air pollutants like SO_2.

Objective and Scope

A main objective of the study was to establish baseline information on SO_2 in indoor and outdoor air in a community supported by the forest industry sector and in a comparison (urban) community. Previous literature review undertaken by Sembaluk (1997) summarized the current knowledge regarding SO_2 concentrations at indoor/outdoor locations where people spend time. All of previous studies identified by Sembaluk (1997) were for urban settings, indicating a limitation in SO_2 characteristics in rural (small) communities. Results of Sembaluk (1997) are presented to provide a basis for designing the study and comparing study results.

The following approach was used to accomplish the study objective:

- The Village of Boyle, Alberta (population <1,000) and the Municipality of Sherwood of Park, Alberta (population 42,000) were selected for monitoring of SO_2 in indoor and outdoor air.
- A target sample of 15 home locations in each community was established for monitoring in late fall/early winter of 1998. These conditions were chosen to represent a time of year in which SO_2 is the least reactive in the environment (Sembaluk 1997).
- Simultaneous indoor/outdoor air monitoring was conducted at both communities.
- Questionnaires were prepared and administered to an adult occupant at each home to gather information on activities or sources contributing to SO_2 inside the home during monitoring.
- Air monitoring results from the two communities were analyzed and compared to identify any similarities or differences among the communities.

CHARACTERISTICS OF SO_2

SO_2 has long been linked with air pollution because of its production during combustion of sulfur-containing fossil fuels. Prior to the 1970s, SO_2 emissions were very high when little or no emission control technologies were in place. Recognition of adverse health effects associated with SO_2 exposures (Committee 1996a, 1996b) and uncontrolled burning of these fuels prompted industrialized nations to adopt regulations to limit SO_2 emissions (Henry and Heinke 1989). Although levels of SO_2 emissions have decreased substantially over the years, there are still emissions from industrial and natural sources.

When considering adverse health effects of atmospheric pollutants (e.g. SO_2), it is important to consider circumstances contributing to human exposure (Ott 1995; NAS 1991). Therefore it is necessary to consider the role that the indoor environment may have because of the amount of time that humans spend there. Published studies investigating SO_2 levels in indoor/outdoor environments have been very limited and none have been conducted in western Canada (Sembaluk 1997). In studies that have been conducted elsewhere, it has been established that indoor levels of SO_2 are much lower than outdoor levels. It has been shown that indoor levels of SO_2 can be as much as 50-70% lower than outdoors (Spengler et al. 1979). This is reportedly due to:

- Scavenging affects of materials found inside the home on SO_2.
- Limited sources of SO_2 inside the home.

Sources

Volcanoes are the largest natural producers of SO_2. Outdoor sources of SO_2 caused by industrialization are the result of burning sulphur rich fossil fuels such as gasoline (in vehicles), fuel oil (used to heat homes), or coal (used to generate electricity or heat). Indoor sources of SO_2 are limited to kerosene heaters, poorly maintained fuel oil heating systems and some fuels for stoves (Hines et al. 1993). Reduced emissions of SO_2 has occurred in the indoor environment by using cleaner burning fuels so that almost all sources of indoor SO_2 have been eliminated (Yocom and McCarthy 1991). The only current indoor source of SO_2 is caused by tobacco smoke. Infiltration of SO_2 from the outside is presumed to also contribute to SO_2 found indoors.

Environmental Behaviour

Given the number of sources for SO_2 outdoors, this setting tends to have the highest concentrations. The persistence of SO_2 can be affected by environmental conditions, such as high relative humidity and warm temperatures. These factors result in lower levels of SO_2 because they lead to conditions in which SO_2 is more reactive (Wagner 1994). Countries with colder climates, such as Canada, can experience higher levels of SO_2 during the winter because SO_2 is less reactive. In conditions such as these, traffic jams and idling vehicles can produce large amounts of local SO_2 that are not normally experienced during other times.

Sources of SO_2 are limited in the modern home. Usually the only contributor to SO_2 indoors is smoking (Triebig and Zober 1984). Air pollutants can enter the home by infiltration or through the means of ventilation (e.g. open doors, windows, or the HVAC - heating, ventilating and air conditioning system). The persistence of SO_2 indoors is limited because it has a high affinity to react with materials found in buildings (Maroni et al. 1995). Other gases such as carbon monoxide, which is considered to be nonreactive, can penetrate buildings without a reduction in concentration (Andersen 1972). The reactive properties of SO_2 may result in lower concentrations even if it is released indoors.

A better understanding of how SO_2 behaves in the indoor environment is important in understanding the relationship between indoor and outdoor levels. Others have tried to quantify the sorption rate of SO_2 on materials found indoors (e.g., carpet, wallpaper and paint) (Walsh et al. 1977). The authors referred to this as the deposition velocity of SO_2 or the ratio of the rate of sorption per unit area of material to the mean concentration of SO_2 above the surface material (Yocom 1991). The material with the highest deposition velocity was found to be fresh emulsion paint ($0.128\ \text{cm} \cdot \text{sec}^{-1}$), next was carpeting at 0.02 to $0.07\ \text{cm} \cdot \text{sec}^{-1}$ and vinyl wallpaper was lowest at $0.007\ \text{cm} \cdot \text{sec}^{-1}$ (Yocom 1991). It was found that carpeting had an interesting effect on SO_2 because acidic carpets not only had a lower deposition velocity, but sorption of SO_2 on any carpet was irreversible. Others have indicated that the removal of any gas can be expressed as a function of the decay rate or deposition velocity, area of the sink (i.e. material that adsorbs and later re-emits vapor), and the contaminant mass (Maroni et al. 1995).

Reported Health Effects from Exposure

The health effects of SO_2 are related to increased respiratory symptoms and decreased lung function in healthy adults, patients with chronic obstructive pulmonary disease (COPD), and asthmatics. A more complete discussion of these effects is provided elsewhere (Committee 1996 a and 1996b).

Regulations

In Canada, National Ambient Air Quality Objectives (NAAQOs) are developed by the Working Group on Air Quality Objectives and Guidelines. NAAQOs are benchmark levels intended for protection of people and the environment in Canada. Representatives of federal, provincial and territorial departments of environment and health form this working group. The working group reports to the Federal/Provincial Advisory Committee (FPAC) under the *Canadian Environmental Protection Act*. NAAQOs for SO_2 are provided in Table 1.

Table 1. Summary of National Ambient Air Quality Objectives (NAAQOs) and Alberta Environmental Protection ambient air quality guidelines for SO_2 (after EC 1998 and AEP 1998).

Criterion	1-Hour ($\mu g/m^3$)	24-Hour ($\mu g/m^3$)	Annual ($\mu g/m^3$)
Maximum desirable level	450	150	30
Maximum acceptable level	900	300	60
Maximum tolerable level	n/a	800	n/a
Alberta guidelines	450	150	30

Adoption of NAAQOs is at the discretion of individual provincial environment agencies. For illustration purposes, ambient air quality guidelines adopted by Alberta Environmental Protection in the Province of Alberta are also shown in Table 1. As can be seen from Table 1, Alberta's guidelines for SO_2 are based on maximum desirable levels for NAAQOs.

PREVIOUS INDOOR/OUTDOOR SO_2 RESEARCH

A number of studies have been conducted measuring SO_2 levels indoors. Most of these studies measured SO_2 indoors as well as outdoors. One study by Biersteker et al. (1965) involved taking indoor/outdoor SO_2 samples in 65 Rotterdam homes. Several observations were drawn from this study:

- Indoor levels were lower than outdoor levels because there were few indoor sources of SO_2.
- If kerosene heaters were used indoors then poor ventilation resulted in increased SO_2 levels.
- Materials in the home absorbed SO_2 from the air.
- Absorption of SO_2 appeared to become saturated after some point in time as older homes had higher SO_2 levels than newer homes.

Spengler et al. (1979) conducted research into health effects of sulphur dioxide and nitrogen dioxide found both indoors and outdoors. Six American cities were monitored as part of the Harvard University Six Cities Epidemiological Study. Levels of SO_2 found outdoors ranged from 5 to 52 $\mu g{\bullet}m^{-3}$ and indoor levels ranged from 1 to 22 $\mu g{\bullet}m^{-3}$. These results are summarized in Table 2 below along with results of other similar studies. On average, SO_2 concentrations dropped between 50-70% from outdoors to indoors. The cities with the highest and lowest outdoor SO_2 concentrations also had the highest and lowest indoor concentrations.

As mentioned earlier, one of the few indoor sources of SO_2 is kerosene heaters. Ritchie and Oatman (1983) published laboratory results indicating that kerosene heaters produced emissions of NO_2, CO_2, and SO_2 exceeding ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.) guidelines for indoor air. The goal of their study was to examine how kerosene heaters affected indoor air quality and if ASHRAE guidelines would be exceeded in a residential setting. Using 0.1% sulphur kerosene, samples were taken continuously for five hours so that a pattern of emissions could be established from ignition to decay after one hour of being shut off. It was established that SO_2 was emitted rapidly within the first hour and that SO_2 decreased by 75% one hour after the heaters were turned off. This study provided good information on the effect of kerosene heaters on SO_2 levels indoors. Modern heating systems have almost eliminated the need for kerosene heating, making these observations inappropriate for assessing human exposure to SO_2 today.

Table 2: Summary of indoor and outdoor SO_2 concentrations summarized from scientific literature

Author/Location	Indoor (I) $\mu g{\bullet}m^{-3}$	Outdoor (O) $\mu g{\bullet}m^{-3}$	I/O Ratio	Comments
Spengler et al. 1979				
Portage, WI	5 (n=349)	8 (n=349)	0.67	
Topeka, KS	1 (n=330)	2 (n=389)	0.50	
Kingston, TN	1 (n=386)	13 (n=425)	7.7E-03	Composite average mean for
Watertown, MA	8 (n=471)	24 (n=486)	0.33	24 hr.
St. Louis, MO	12 (n=543)	39 (n=543)	0.31	
Steubenville, OH	22 (n=417)	57 (n=499)	0.39	
Stock et al. 1985				
Houston, TX	13 (n=2425)	7.3 (n=2565)		Mean of continuous sampling
		40 (n=174)		Mean of 12 hr day samples
		15 (n=170)		Mean of 12 hr night samples
		12 (n=183)		Mean of 12 hr night samples
		22 (n=170)		Mean of 12 hr night samples
Chan et al. 1994				
Taipei, Taiwan	6.6 (n=16)	20 (n=15)	0.24	Mean of 12 hr summer samples
	7.1 (n=100)	22 (n=37)	0.23	Mean of 12 hr winter samples
Chan et al. 1994				
Boston, MA	1.1 (n=23)	12 (n=24)		Mean of 12 hr samples

Another study was conducted on potential in home exposure to air pollutants (Stock et al. 1985). Sulphur dioxide, along with other air pollutants were monitored at two locations in Houston, Texas by fixed station sites and a mobile van. Both locations were continuously monitored for approximately one week by the fixed stations and mobile van. The fixed stations were intended to provide general outdoor concentrations and the mobile van provided dual monitoring of indoor/outdoor air. Results from the study are summarized in Table 2 with the continuous monitoring separated by day and night 12-hour periods.

More recent data on indoor/outdoor levels of SO_2 comes from Taipei, Taiwan (Table 2) (Chan et al. 1994). Sampling was done over a summer and winter season to include variations in SO_2 concentrations affected by climatic conditions. The summer samples were taken at 12-hour intervals and during the winter one 24-hour sample was taken. Contributing factors to outdoor SO_2 levels were reportedly from large numbers of vehicles in Taipei. There were no known sources of indoor SO_2. In addition to the Taipei data, other studies were presented by Chan et al. (1994) comparing air quality between the U.S. and Taiwan (Table 2).

These studies provide evidence of indoor/outdoor relationships for SO_2. The data from these studies are likely to be less representative of current conditions in the communities proposed for monitoring in Alberta. These data were either acquired at a time when SO_2 emissions were higher than today or from locations which are not representative of the proposed communities, by nature of differences in activities or sources leading to SO_2 emissions.

FIELD STUDY OF SO_2 IN INDOOR/OUTDOOR AIR

A rural and urban community in Alberta were monitored to establish simultaneous indoor/outdoor air quality information on SO_2. These communities consisted of the Village of Boyle and Municipality of Sherwood Park, both in Alberta. The Village of Boyle is located 160 kilometers north of Edmonton, Alberta. For design purposes, Boyle was expected to have lower SO_2 concentration because a majority of land use and activity in and around the immediate community lacked SO_2 sources. Vehicle emissions were expected to only be a minor source of SO_2 since the population of Boyle (862) is relatively small (Athabasca County 1998). The Municipality of Sherwood Park is located immediately east of Edmonton, Alberta, in the County of Strathcona. Sources of SO_2 in the immediate area are more common. Vehicle traffic could be important since Sherwood Park has a population of 42,000 people and Edmonton has a population in excess of 800,000. In addition, the area between Edmonton and Sherwood Park serves as a heavily industrialized area with several petroleum refineries (J. Tennison, Manager of Communications, Strathcona County, Alberta, pers.com.).

The study targeted 15 homes in the Village of Boyle and in the Municipality of Sherwood Park. Each home would have two passive monitors deployed inside and outside for a period of seven days. After the monitoring period, a questionnaire would be administrated to an occupant of each home to acquire information on house and occupant characteristics that may influence indoor SO_2 concentrations.

Passive Monitoring Methodology

Passive Air Monitor

A passive air monitor of the type shown in Figure 1 was used to sample for SO_2 in indoor and outdoor air. Passive monitoring offers advantages over conventional ambient air monitoring techniques for detecting gaseous air pollutants (Brown 1993; Harper and Purnell 1987). As a passive technique, they do not require any pump or airflow regulation system. Their low cost means that they can be deployed simultaneously at a large number of locations and they may be left unattended for long periods if the sorbent selected will firmly bind the gases to its surface. Finally, they can be used to determine long-term time-weighted average pollutant concentrations that are useful for comparing to regulatory criteria.

The inside of the monitor contains a sodium carbonate/sodium bicarbonate-coated glass fiber filter (sampling media) with an exposed surface of 8 cm^2 and a Teflon diffusion barrier. The coated filter and diffusion barrier are separated by a 0.5-cm support ring, creating a diffusion zone. Other than the filter and diffusion barrier, the rest of the monitor is made from polycarbonate plastic. The dimensions of the monitor are 5 cm diameter by 2 cm deep.

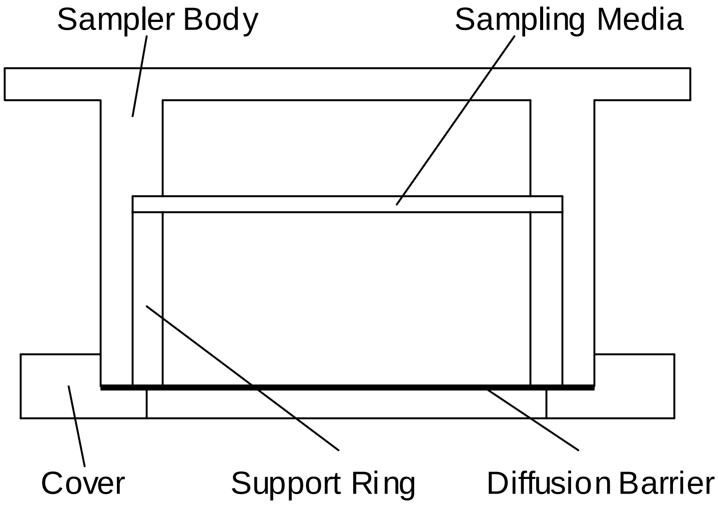

Figure 1: Side view of passive monitor (not to scale)

Passive Monitor Assembly and Handling

The filters were prepared by pipetting 0.5 mL of a solution (0.037% Na_2CO_3 w/v and 0.0084% $NaHCO_3$ w/v dissolved in ultrapure distilled/dionized water) onto the surface and allowing them to air dry by passing purified air over them in a fume hood. After drying, the coated filters were placed into monitor casings in a glove box containing purified air. The loaded monitors were then placed into a protective bottle, capped, and placed in a zip lock bag and stored in a cooler at 4°C until used in the field.

Rain Shelter

A rain shelter was used to shield the monitors when placed outdoors. The shelter was made from a 15.24 cm diameter PVC end-cap. Underneath the cap was a plate with slots to hold three passive monitors. Each passive monitor was installed facing downwards and held into place by a spring-loaded peg that prevents the monitor from sliding out after installation.

Field Procedures

Selection of Areas for Household Monitoring

The selection of homes in both communities was based upon households that met the following criteria:

- Single family (freestanding) dwelling.
- At least one occupant must be over the age of 18 and not have any impairment that would inhibit their understanding of the study.

Recruiting participants from households in both communities initially involved selecting which community areas to canvass. This was done by obtaining maps with lot numbers for each community. Once a map for each community was received appropriate sampling areas were determined. The Village of Boyle was divided into four quarters. Three of the quarters contained numerous single family dwellings so an attempt was made to get an equal number of dwellings in each of these quarters. In Sherwood Park, the subdivision of Mills Haven was chosen because of its close proximity to the heavily industrialized area between Sherwood Park and Edmonton.

Participant Recruitment at Boyle

A noninvasive approach was developed to canvass potential participants in Boyle by initially distributing an information pamphlet with reply card (Appendix A). The pamphlet was designed to provide the following information:

- Identify that the University of Alberta would be conducting a study in their area.
- Provide a brief explanation of the study in simple terms.
- Identify how many volunteers would be needed for the study.
- Describe what will be required of the participants, including the amount of their time, use of their home, and having then complete a questionnaire.

The pamphlet asked the recipient to fill in the pop out reply card and drop it in the mail. On the reply card, space was provided for the volunteer to write their name, telephone number, and the best time to be contacted.

The pamphlets were distributed door-to-door in Boyle among 10 homes in each of three previously mentioned quarters (30 in total). Brief door to door canvassing was conducted just to raise people's attention to the study and to make sure they received the pamphlet. At homes where no one answered the door, pamphlets were left between the doors because none of the houses in Boyle had mailboxes. Houses that received pamphlets were marked off on a map so no duplicate visits would be performed if a second round of canvassing was required. Pamphlets were also left at the Town Hall.

Reply cards started to come in at the University of Alberta within a few days. Out of 30 pamphlets distributed, only five were returned all indicating a willingness to participate in the study. Although it was a good start, it did not have the anticipated response (target of 15 homes). Upon returning to Boyle a second type of canvassing approach was used. The first five confirmed volunteers were asked for referrals. Another four volunteers were recruited in this manner. A visit was also paid to the Mayor of Boyle. The Mayor was very receptive to the study being conducted in the community and he provided six additional names as potential volunteers. In hindsight, contacting the Mayor earlier and identifying him in the pamphlet as supporting the study may have increased participant response. Using the two canvassing approaches, a total of 14 homes were recruited into the study. This was less than that the target of 15 homes, however it was all that could be recruited in the three-week period scheduled for this task.

Participant Recruitment at Sherwood Park

The Sherwood Park subdivision of Mills Haven encompasses a large area. Only homes in the northwest section of the subdivision, closest to the heavily industrialized area, were canvassed. These homes were approximately 1.5 km away from the nearest industries in Edmonoton. Pamphlets were given to homeowners using the same technique as in Boyle. However, after a few days it was clear that this method did not have the same success as in Boyle. Out of 30 pamphlets distributed, only one was returned. Upon follow-up, it was determined that there might have been a problem with the mail after some homeowners stated they had sent in their reply card. No explanation of why cards were not returned properly to the University of Alberta was found. Therefore, a second trip was made to Sherwood Park using a different canvassing approach. The following information was communicated to prospective volunteers in the selected area using a door-to-door approach:

- Brief personal introduction.
- Provided a brief outline of the study and gave them an information sheet (Appendix B).
- Requested their participation and explained the time commitment.
- Asked for their name, telephone number, and the best time to contact them (for volunteers interested in participating in the study).

This canvassing approach proved to be very effective with only two rejections out of 15 homes canvassed. Reasons that the pamphlet strategy did not work in Sherwood Park may have been because the homeowners viewed the pamphlets as junk mail. Using more direct (door-to-door) canvassing apparently was more successful than the pamphlet approach. A total of 14 homes were recruited into the study. This was again less than that the target of 15 homes, however it was all that could be recruited in the time allotted for canvassing (three weeks).

Follow Up

After canvassing was complete, there were 14 volunteers in each community. Three days prior to the first scheduled sampling day, volunteers were contacted by phone. After informing them of who was calling, they were asked the following questions:

- Were they still interested in participating in the study?
- If yes then at what time on the sampling days were they available?
- Would they be available a week from that day so that the SO_2 samples could be picked up?
- Were there any additional questions they had about the study?

A conflict arose with two volunteers in Boyle and one in Sherwood Park because they could not participate during the sampling period. It was decided that the study would be reduced to a sample size of 12 in each community so that the study could still be completed during the late/fall/early winter period.

Deployment of Passive Monitors

Two monitors were placed outside in the rain shelter near each house at a location with unobstructed air movement. Concerns with the outside monitors were that inclement weather conditions (e.g. wind, precipitation, wind blown debris) and tampering could destroy the monitor. The rain shelters prevented precipitation and debris from fouling the monitors as well as insuring proper air movement across the face of it. The shelters were deployed outside using wooden stakes pounded into the ground and fastening the shelter to the stake with a nylon strap while the shelter rested on a quarter inch screw. This technique proved to be a sturdy support for the shelters and was quick to set up.

Two monitors were placed indoors on an inside wall in a main living area. Quick and easy deployment was a goal for installation of these monitors to minimize inconvenience to the occupants. The monitors were hung from string attached to a wall. One end of the string had a loop so that it could be wrapped around the monitor. Carpenters tape was then used to fasten the string to the wall. The carpenters tape would prevent any damage to paint or wallpaper on the wall when removed.

Deciding where to place the monitors inside the homes proved to be a difficult task. The difficulty related to consideration of the air sampling rate for the monitor. The air sampling rate of SO_2 is affected by wind face velocity across the monitor and no equipment for measuring air movement existed. A minimum face velocity of 0.55 $cm\bullet s^{-1}$ was required in order for air sampling to be representative of conditions in which the monitors were validated (Tang et al. 1997). The use of a fan or other artificial means of providing sufficient face velocity would be impractical because of increased inconvenience to volunteers. It was judged that an acceptable would be in a constant traffic/main living area. An attempt was made to place monitors in hallways leading to kitchen areas, otherwise they were placed in a dining room.

Day of Deployment

On the day of deployment, between five and seven homes were prearranged to receive monitors. Appointments for deployment of monitors were made in 30-minute blocks so as to give enough time to deploy monitors, answer questions, and travel to the next home. Upon arriving at the home, each volunteer was asked if the monitors could still be deployed. In the 24 homes sampled in Boyle and Sherwood Park, no volunteers declined. Prior to setting up for deploying of the monitors, the volunteers were asked to sign a consent form indicating they were willing to participate in the study and understood what was being requested of them. A sample of the consent form can be found in Appendix C.

Once in the home, an investigation into a suitable location for the monitors was conducted. Taking into account the face velocity problem mentioned earlier, the next concerns for deployment were pets and children. If the home had either pets or children, the monitors were hung higher off the floor than normal to keep it out of their reach. Normal heights for the monitors were about 130 cm above the floor. In homes with children or pets, the monitors were hung at a height of approximately 150 cm. In some cases, the volunteer didn't want the monitors hung on the wall. This was solved by hanging the monitors from a picture frame or some kind of decoration already on the wall. When hung from a picture frame, the monitor was taped to the back of the frame. Volunteers appreciated this method since it didn't damage the front of the picture and if any marks were left behind by the tape it was hidden behind the picture. Temperature and humidity were then measured near the monitor.

After deployment of the monitors indoors, the volunteer was asked if they wanted to book a time for pick up of the monitors or to make it when they get a call two days before the end of the seven day sampling period. Most wanted to wait for the two-day notification. The outdoor monitors were then deployed. They were placed in the rain shelters that varied in heights of 80 to 110 cm above ground. Condition of the ground was the biggest factor affecting the height of the shelters. Some homes had raised flowerbeds around the house, which added to the height, and others had concrete sidewalks against the house. Pets kept outdoors was a concern, so caution was taken in trying to place the rain shelters above their reach.

Pick Up

The monitors were picked up approximately seven days after deployment. On day five, volunteers were contacted and an appointment was made to pick up the monitors. In one case an emergency arose and the monitors could not be picked up as planned. The volunteer was asked to place the monitors in a zip lock bag and place them outside on the door just before they left in the morning. It was expected that the short time the monitors were removed from the indoor environment, and the fact they were sealed in a bag, would have a minimal effect on the results.

Each volunteer was asked to complete a 14-page questionnaire about house characteristics and their activities. For reasons of space limitation, a sample of the questionnaire is not included in this report. Administering this questionnaire took about five to fifteen minutes and all volunteers were receptive. While the volunteer was filling out the questionnaire, humidity and temperature of the house was taken again. After the questionnaire, the indoor monitors were taken down and prepared for transport back to the lab. Only one home had damaged monitors and in that case, both indoor monitors had broken diffusion barriers.

Regardless of the condition of the monitor, each monitor was placed in a small airtight bag and placed in a plastic container with a screw on lid. Teflon tape was wrapped around the lid of the container to make it airtight and the sealed container was put into another airtight bag with four other containers. The same procedure was done with the outside monitors and none were damaged.

Analytical Methods

Analysis was performed at Maxxam Analytics Inc., Edmonton, Alberta. The monitors were disassembled in a glove box under purified air. The filters were placed in extraction vials to which 10 mL of ultra pure distilled/deionized water and 1 mL of 1.8% v/v H_2O_2 solution were added. After shaking for 30 minutes, the vials were warmed at 50ºC for 10 minutes and left standing until they returned to room temperature. Solution from the vials was analyzed for dissolved sulfate using ion chromatography following EPA method 300.1 (U.S. EPA 1997). Pooled laboratory filter blanks analyzed using this methodology were used to establish a limit of detection equivalent to 0.33 $\mu g/m^3$ for a seven-day exposure period. One-half of this value (0.17 $\mu g/m^3$) was used to report the concentration of SO_2 for samples below this limit.

FIELD STUDY RESULTS

Air Sampling Rates

All air concentrations determined from the field study were corrected for standard temperature and pressure. Sulphate concentrations determined from ion chromatography were obtained and sample calculations were performed to estimate SO_2 concentrations recorded by the passive monitors. Initially, the air sampling rate of the passive monitor must be calculated (refer to Equation 1). Equation 1 was an empirically-derived relationship from laboratory chamber experiments with SO_2 and the same passive monitor (Tang et al. 1997).

Equation 1: Sampling Rate (Tang et al. 1997)

$$R_S = 12.8 \bullet T^{1/2} - 0.540 \bullet RH + 0.276 \bullet WSP - 135 \qquad [1]$$

Where,

R_s = SO_2 sampling rate ($mL \bullet min^{-1}$)
T = average temperature (K)
RH = average relative humidity (%) (if RH>80, then RH=80)
WSP = average wind speed ($cm \bullet sec^{-1}$) (if WSP>130, then WSP=130)

The sampling rate (R_s) expresses the rate at which SO_2 diffuses through the barrier and is absorbed onto the collection media (filter) in the monitor. Factors affecting the sampling rate in Equation 1 are temperature, relative humidity, and wind speed. The monitors were previously tested for temperature effects with temperatures ranging from –16 to 25°C (Tang et al. 1997).

The sampling rate was found to increase with temperature, consistent with diffusion theory. Temperatures experienced during the field study were all within this range. Relative humidity also affects the sampling rate because it is believed that chemical reactions between water and available free SO_2 inhibits diffusion of the gas as relative humidity increases. Indoor levels of relative humidity were all below 80% during the sampling period. Outdoor levels were at times higher than 80%. The last variable affecting the sampling rate is wind speed. Wind speed would affect the sampling rate since it is necessary to air containing SO_2 to continuously pass by the barrier to allow a constant supply of SO_2 to diffuse through the barrier. A very low wind speed could create an artificial situation where the monitor is starved of SO_2. A constant wind speed value (130 $cm{\bullet}sec^{-1}$) was used to estimate air sampling rates outdoors.

When considering indoor locations, difficulties arise in not knowing how long wind speeds are maintained where the monitor is located. Indoor winds speeds can be affected by movement of people, exhaust systems, open windows, and other activities. A large portion of the time indoors will have very small amounts of air movement, e.g. during times when residents are sleep. A minimum wind speed value (0.5 $cm{\bullet}sec^{-1}$) was used to estimate air sampling rates indoors (the minimum value used by Tang et al. 1997, to validate the monitors).

Air sampling rates were also estimated based on theoretical considerations from Fick's first Law of Diffusion (Equation 2), air temperature effects and monitor dimensions.

Equation 2: Fick's First Law of Diffusion

$$flux = -D \bullet \left(\frac{dc}{dl}\right) \qquad [2]$$

Where,

$flux$ = amount of substance migrating through a unit area in a unit time ($g{\bullet}cm^{-2}{\bullet}s^{-1}$)
D = diffusion coefficient ($cm^2{\bullet}s^{-1}$)
dc = external concentration ($g{\bullet}cm^{-3}$) – concentration at interface (assumed equal to 0)
dl = length of diffusion path (cm)

Shields and Weschler (1987) restated Fick's First Law of Diffusion in terms of a passive monitor's air sampling rate (Equation 3).

Equation 3: Fick's First Law of Diffusion restated by Shields and Weschler (1987)

$$R_s = \frac{m}{tC_a} = D \bullet \left(\frac{A}{l}\right) \qquad [3]$$

Where,

R_s = air sampling rate ($cm^3{\bullet}s^{-1}$)
m = mass of substance that diffuses (µg)
t = sampling interval (s)
C_a = ambient concentration of substance ($\mu g{\bullet}cm^{-3}$)
D = diffusion coefficient ($cm^2{\bullet}s^{-1}$)

A = cross-sectional area through which diffusion occurs (cm^2)
l = path over which diffusion occurs (cm)

Fish and Durham (1971) reported a relationship for estimating the diffusion coefficient of SO_2 in air based on temperature and atmospheric consideration (Equation 4).

Equation 4: Diffusion coefficient for sulphur dioxide (Fish and Durham 1971)

$$D = \frac{0.00482 \bullet T^{1.75}}{P} \qquad [4]$$

Where,
D = diffusion coefficient ($cm^2 \bullet s^{-1}$)
T = temperature (K)
P = pressure (torr) (assumed to be standard pressure of 760 torr)

Diffusion coefficient value range from 0.117 $cm^2 \bullet s^{-1}$ at 0ºC to 0.132 $cm^2 \bullet s^{-1}$ at 20ºC using Equation 4 (Fish and Durham 1971). During actual monitoring, the lowest outdoor temperature experienced was –8.5ºC, which according to Equation 4, corresponds to a diffusion coefficient of 0.110 $cm^2 \bullet s^{-1}$. Although Equation 4 was reported for temperatures above 0ºC, it was assumed that the difference in diffusion coefficient for values at 0ºC and –8.5ºC was not significant.

According to Equation 3, the air sampling rate can be calculated using the diffusion coefficient (*D*), cross-sectional area of monitor (*A*) and diffusion path length (*l*). Using Equations 3 and 4, air sampling rates were estimated based on average indoor and outdoor temperatures, respectively. Table 3 summarizes average air sampling rates using both methods (Equation 1 and Equations 3 & 4).

Table 3: Average air sampling rates for Boyle and Sherwood Park

Location	Sampling Rate ($ml \bullet min^{-1}$) after Equation 1	Sampling Rate ($ml \bullet min^{-1}$) after Equations 3 & 4
Boyle		
Indoor	57	136
Outdoor	67	116
Sherwood Park		
Indoor	53	137
Outdoor	66	115

From inspection of Table 3, it is observed that air sampling rates derived from theoretical considerations (Equations 3 and 4) were consistently higher that those derived from an empirical relationship (Equation 1). Theoretical considerations only considered Fick's First Law of diffusion, air temperature and monitor dimensions. Whereas, Equation 1 also considered effects of relative humidity and wind (face) velocity. The difference in air sampling rates between the two methods is within a factor of two. The magnitude of this difference is not considered to be substantial for low air pollutant concentrations such as those anticipated in this study.

Indoor/Outdoor SO_2 Concentrations

Equation 5 was used to calculate seven-day average SO_2 concentrations.

Equation 5: SO_2 Concentration (Tang et al. 1997)

$$C_{SO_2} = 47.1 \bullet 10^3 \bullet (C_s - C_b)/(H_r * R_s) \qquad [5]$$

Where,

C_{SO2} = ambient SO_2 concentration (ppb)

C_s = concentration of monitor from ion chromatography ($\mu g \bullet mL^{-1}$)

C_b = concentration of field blank obtained from ion chromatography ($\mu g \bullet mL^{-1}$)

H_r = exposure time of monitor in the field (hour)

R_s = SO_2 sampling rate ($mL \bullet min^{-1}$)

A total of eight field blanks were collected during the study. The results from monitoring in Boyle between November 20 and December 4, 1998 are summarized in Table 4. Out of 48 monitors deployed at 12 homes in Boyle, two indoor monitors at one home (ID# 410) had the barriers punctured. All the outside monitors were intact. The results from simultaneous monitoring in Sherwood Park between November 26 and December 8, 1998 are also summarized in Table 4. All 48 monitors in Sherwood Park were undamaged during the field study. As can be observed in Table 4, indoor levels were much lower than outdoors. This is consistent with findings of others (Table 2). All results for individual monitors are tabulated in Appendix D.

Table 4: Summary of indoor and outdoor SO_2 concentrations in Boyle and Sherwood Park[1]

Community	Location	Number of Homes	Median	Range
Boyle	Indoor (I)	11	0.26	0.17 – 2.6
	Outdoor (O)	12	4.2	3.7 – 4.2
	I/O Ratio	11	0.07	0.03 – 0.43
Sherwood Park	Indoor (I)	12	0.70	0.17 – 5.2
	Outdoor (O)	12	10	8.4 - 11
	I/O Ratio	12	0.08	0.03 – 0.31

[1] $\mu g \bullet m^{-3}$ unless otherwise noted

Table 4 indicates that median outdoor levels of SO_2 were a factor of two to three times lower in Boyle than in Sherwood Park. Recall, it was indicated that infiltration of SO_2 from outdoors could represent a source for SO_2 indoors (Triebig and Zober 1984). This, in part, may explain higher SO_2 levels observed at homes in Sherwood Park compared to Boyle. These results are supported by the fact that there are a far greater number of activities occurring outdoors in and around Sherwood Park with SO_2–related emissions than in Boyle (i.e. vehicle traffic and industrial emissions). The outdoor SO_2 levels observed in both communities (≤ 11 $\mu g/m^3$) are considered low in comparison to benchmark levels intended for the protection of people in Canada (Table 1).

Indoor/outdoor ratios reflect the potential indoor level of SO_2 based on the outdoor concentration. Spengler et al. (1979) reported indoor/outdoor ratios in six American cities in the range of 0.077-0.67 during a time when outdoor SO_2 concentrations were higher than today. More recently, Chan et al. (1994) found the indoor/outdoor ratio during winter to be 0.23 when the outdoor concentration averaged 20 $\mu g \cdot m^{-3}$ for residences in Taipei, Taiwan. Given lower outdoor SO_2 levels in Alberta, the resulting median indoor/outdoor ratios for Boyle and Sherwood Park, 0.07 and 0.08, respectively are considered reasonable.

The Wilcoxon signed-rank test (Montgomery and Runger 1994) was used to test for significant differences between SO_2 concentrations measured in Boyle and Sherwood Park. Using this test, the following hypotheses were examined:

- Indoor levels for Boyle and Sherwood Park were significantly different.
- Outdoor levels for Boyle and Sherwood Park were significantly different.
- Indoor/outdoor ratios for Boyle and Sherwood Park were significantly different.

Results of the test, summarized in Table 5, suggest that differences exist between the two communities in terms of indoor and outdoor SO_2 concentrations.

The previous scientific literature provides evidence of indoor/outdoor relationships for SO_2 (Table 2). These data are restated in Table 6 along with results from the current study in Boyle and Sherwood Park, Alberta. Results from earlier research (i.e. Spengler et al. 1979; Stock et al. 1985; Chan et al. 1994) are judged to be less representative of conditions in Boyle or Sherwood Park. These earlier data were either acquired at a time when SO_2 emissions were higher than today or from locations which are not representative of locations sampled in Alberta, by nature of differences in activities or sources leading to SO_2 emissions. These earlier data only reflect SO_2 quality for those locations monitored.

Table 5: Wilcoxon signed rank test for significant differences between sample sets

Check For Significant Difference	Results
Boyle Vs. Sherwood Park (Indoor)	+
Boyle Vs. Sherwood Park (Outdoor)	+
Boyle Vs. Sherwood Park (Indoor/Outdoor Ratio)	+

\+ Significant difference between sample sets

\- Not a significant difference between sample sets

Similar median indoor/outdoor ratios observed between the two communities (Table 4) tend to suggest that factors contributing to persistence of SO_2 indoors were similar among the communities (e.g. reactivity with indoor surfaces such as carpets, wallpaper and paint: and effects of temperature and relative humidity).

MANAGEMENT APPLICATIONS

The field study results indicated that background outdoor SO_2 levels in Boyle, Alberta were lower than in Sherwood Park during a time of year in which SO_2 is considered to be the most persistent in the outdoor environment. A similar trend was also observed for the indoor environment among the two communities. Potential human exposure to SO_2 at levels observed in the study (≤11 µg/m^3) would not be considered important from a human health perspective in light of much higher levels that are reported to be associated with adverse health effects (Committee 1996a, 1996b). It is judged that these results are more representative of conditions in communities of similar demographics compared to data from the scientific literature. These results can be used as baseline information in which to evaluate the impacts of changes or improvements in industrial activities contributing to SO_2 emissions in communities of similar demographics.

Table 6: Revised summary of indoor and outdoor SO_2 concentrations

Author/Location	Indoor (I) µg•m^{-3}	Outdoor (O) µg•m^{-3}	I/O Ratio	Comments
Spengler et al. 1979				
Portage, WI	5 (n=349)	8 (n=349)	0.67	
Topeka, KS	1 (n=330)	2 (n=389)	0.50	
Kingston, TN	1 (n=386)	13 (n=425)	7.7E-03	Composite average mean for 24 hr.
Watertown, MA	8 (n=471)	24 (n=486)	0.33	
St. Louis, MO	12 (n=543)	39 (n=543)	0.31	
Steubenville, OH	22 (n=417)	57 (n=499)	0.39	
Stock et al. 1985				
Houston, TX	13 (n=2425)	7.3 (n=2565)		Mean of continuous sampling
		40 (n=174)		Mean of 12 hr day samples
		15 (n=170)		Mean of 12 hr night samples
		12 (n=183)		Mean of 12 hr night samples
		22 (n=170)		Mean of 12 hr night samples
Chan et al. 1994				
Taipei, Taiwan	6.6 (n=16)	20 (n=15)	0.24	Mean of 12 hr summer samples
	7.1 (n=100)	22 (n=37)	0.23	Mean of 12 hr winter samples
Chan et al. 1994				
Boston, MA	1.1 (n=23)	12 (n=24)		Mean of 12 hr samples
Current study, 1998				
Boyle, AB	0.26 (n=11)	4.2 (n=12)	0.07	Median of 7 day samples
Sherwood Park, AB	0.70 (n=12)	10 (n=12)	0.08	

CONCLUSIONS

A field study of indoor/outdoor concentration of SO_2 in two Alberta communities, one rural and one urban, found that indoor and outdoor levels of SO_2 were lower in the small rural community (Boyle, Alberta) than in the urban community (Sherwood Park, Alberta). Median SO_2 concentrations were about a factor of two to three times lower at Boyle compared to Sherwood Park for both indoor and outdoor environments. This may be due to a far greater number of activities occurring outdoors in and around Sherwood Park involving SO_2 emissions than in Boyle (vehicle traffic and industrial emissions). Indoor and outdoor SO_2 levels observed in both communities were considered low (≤ 11 $\mu g/m^3$) in comparison to levels that are reported to be associated with adverse health effects. Similar median indoor/outdoor ratios were observed for the two communities (0.08). This finding tends to suggest that factors contributing to persistence of SO_2 indoors were similar among the communities.

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