ACTIVITY PATTERNS OF CALIFORNIA ADULTS AND ADOLESCENTS: APPLIANCE USE, VENTILATION PRACTICES, AND BUILDING OCCUPANCY

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The California Air Resources Board sponsored a statewide telephone survey of activity patterns of adult and adolescent Californians to obtain data necessary for improving the accuracy of assessments of human exposure to air pollutants. Interviewers asked 1780 respondents in 1596 households to recall their activities and locations in the preceding 24 hours. Additional questions were asked about the respondents' use of and proximity to potential pollutant sources such as heating and cooking appliances. Data were also gathered on the use of cooling appliances and ventilation in the home, housing characteristics, and socioeconomic characteristics. Interviews were conducted throughout the State during each of the four seasons from Fall 1987 through Summer 1988. The sample was representative of California's population as a whole, but may not have been representative of some population groups. These analyses examine the implications of the use of gas stoves, heating and cooling appliances, and ventilation on human exposures to indoor air pollutants. Analyses of these data showed large variations among seasons and much smaller variations among three major regions of the State. Preliminary analyses indicated that the following population groups have greater-than-average use of gas stoves for space heating: low income households; mobile home residents; persons with a high school education level or less; and persons 12-19 years old. Many households used little natural ventilation during the Winter, during the nighttime, or in some parts of the State. These activity pattern data suggest that certain population groups may be more likely to experience high exposures to some indoor air pollutants due to their use (or misuse) of gas stoves, their failure to use much natural or mechanical ventilation, or both causes.

INTRODUCTION

The California Air Resources Board (ARB) is required to assess Californians' indoor air exposures to toxic pollutants and identify the contributions of such exposures to the total exposures to those pollutants (California Health and Safety Code, Section 39660.5). One of the critical information needs for realistic exposure assessments is data on human activity patterns, which often determine the duration, frequency, and intensity of exposures to air pollutants (Ott 1989; Sexton and Ryan 1987). Previous studies of Californians' activities or exposures did not obtain explicit location data or were limited to small, non-representative groups of Californians (Phillips et al. 1989). ARB (1989) therefore funded a statewide survey of Californians' activity patterns.

Human exposure to an air pollutant depends strongly on the amounts of time spent in different locations and the pollutant concentrations in those locations. The indoor concentration of an air pollutant depends on the emission rates of indoor sources of that pollutant, the indoor/outdoor air exchange rate, the pollutant concentration in the outdoor air, and the rates of indoor physical-chemical removal processes. Consequently, a person's exposures to some indoor air pollutants

and the subsequent effects on human health can be affected strongly by pollutant emissions from cooking and heating appliances, and by a person's use of natural and mechanical ventilation. For example, improper operation and maintenance of combustion furnaces has caused numerous deaths from carbon monoxide poisoning (EPA 1989). The use of gas stoves for space heating has produced high indoor concentrations of nitrogen dioxide (Wilson et al. 1986) and carbon monoxide (DOE 1987). Woodstoves and fireplaces can contribute significantly to both indoor and outdoor air pollution (Traynor et al. 1987; Grimsrud 1985; Moffatt 1986). The use of combustion heaters and cooking appliances (including electric stoves) can increase the indoor exposures of residents to particulate pollutants, organic vapors, and mutagens (Sexton et al. 1986). In addition, building occupants themselves exert a considerable influence on the total air exchange rate in their homes through their use of doors, windows, fans, furnaces, and air-conditioners (AIVC 1986). Therefore, this survey included both a detailed activity-location questionnaire and a set of ancillary questions concerning the use of, and proximity to, indoor air pollutant sources and the household's ventilation practices (Wiley et al. 1990).

This paper describes the design and selected results of this survey, focusing on the use of combustion appliances such as gas stoves and the use of mechanical and natural ventilation. The primary objective of the study was to obtain representative information on the activities and locations of Californians older than 11 years of age, and especially on those activities and locations most relevant to air pollutant exposures. The study was also designed to permit some comparisons among socioeconomic and regional subgroups of Californians and among seasons. Younger children were excluded from the study because of cost considerations and the need for a modified study design; a separate study of the activity patterns of younger children is currently being conducted.

METHODS

A questionnaire was developed which consisted of: (1) a 24-hour recall diary of detailed activities, locations, and proximity to environmental tobacco smoke; (2) questions related to the use of and proximity to potential pollutant sources, such as consumer products and gas appliances; (3) questions regarding housing characteristics and the use of ventilation in the respondent's household; and (4) routine questions on socioeconomic factors. The recall diary resembled those used in previous national and international time-use studies (Juster and Stafford 1985; Szalai 1972), except that it was modified to obtain detailed location data for each activity reported and to meet other study needs related to exposure assessment. The questionnaire was administered using the Computer-Assisted Telephone Interview system (Shanks 1989) because mail questionnaires are less accurate and personal interviews are much more expensive.

The sample consisted of 1780 Californians over 11 years of age who were each interviewed once. It included 184 adolescents (12-17 years of age). Some interview questions, such as those regarding income and housing type, were asked only of adult members of households interviewed. The sample was selected using a modified random-digit-dialing method based on that described by Waksberg (1978). The population being sampled consisted of English-speaking members of households with telephones. The interviews were conducted in four waves from October 1987 through September 1988 to cover all four seasons: October-November (Fall); January-February (Winter); April-May (Spring); and July-August (Summer). The population was oversampled on weekend days in order to capture more of the weekend variation from routine weekday patterns of work and school and to obtain data for exposure-related activities which occur mostly on weekends such as hobbies, housework, and home maintenance.

To capture small but potentially significant regional differences in activity patterns, the State was stratified into three major regions: the Southern Coast (Los Angeles/San Diego area), the San Francisco Bay Area, and the Rest of the State. To avoid having a sample dominated by the Southern Coast region, which includes nearly 50 percent of the State's population, the proportion of selected telephone prefixes was doubled for the San

Francisco Bay region and quadrupled for the Rest of the State region, relative to the proportion in the Southern Coast region. Prefixes were then selected by systematically sampling from a geographically ordered list for each region. Thus, the sampling design may be briefly described as population-based random-digit-dialing with sampling intensities modified to more fully represent all regions of the State.

To generalize the results of the survey to the entire population of the State, the data were weighted to correct for the non-uniform probabilities of including individuals in the sample. These probabilities depended on the region, season, day of the week, and numbers of telephones, adults, and adolescents in the household. All results reported in this paper derive from weighted data.

This paper presents initial analyses of the regional, seasonal, and socioeconomic variations in the use of gas cooking appliances, heating and cooling appliances, and ventilation. The implications for human exposures to indoor air pollutants are also discussed. Further understanding of the diversity of Californians' activity patterns will require the use of analytical statistical methods and additional studies of specific issues.

RESULTS AND DISCUSSION

Representativeness of the Sample

The eligible population for sampling excluded non-English speaking persons and households without telephones because of cost considerations. Non-English-speaking persons accounted for about six percent of the households contacted. Households without telephones accounted for about six percent of California households in 1980 (CSCDC 1989), but some socioeconomic groups in California may have a disproportionately high number of households without telephones (CDC 1987; Personal communication, M. Haan, Department of Health Services California, Berkeley, California).

The representativeness of the sample was evaluated by calculating the response rate and by comparing the socioeconomic status data of the sample to that of all California. The final response rate, defined as the percentage of interviews of eligible adult respondents completed, was 61 percent. This rate is comparable to that of other telephone surveys and personal interview surveys. Such a response rate instills a good level of confidence in the data's representativeness, which would have been hard to improve upon without major cost increases.

The socioeconomic data on age, gender, unemployment, income, education, and housing type for the sample population were compared to available data and estimates for California. The Current Population Survey, conducted by the U.S. Census Bureau in 6,000 California households every March, provided the primary basis for comparison (CSCDC 1988). As shown in Table 1, the sample population generally matched the California proportions in most age and gender categories (within three percent), indicating a reasonable level of representativeness. However, lower income groups and less-educated groups may have been underrepresented. In addition, comparisons with estimates for California's housing stock (DRU 1989) indicate that

Table 1. Socioeconomic Comparison of the Sample to California's Population (weighted)[a]

SOCIOECONOMIC CHARACTERISTIC		CALI-FORNIA	ARB SAMPLE
AGE AND GENDER			
% Males	18-34	21.4	21.4
	35-64	22.1	23.4
	≥65	6.1	3.0
% Females	18-34	20.9	20.9
	35-64	22.2	24.9
	≥65	7.6	6.6
UNEMPLOYMENT RATE (% of population ≥ 16 years old)		5.3	5.1
MEDIAN HOUSEHOLD INCOME (1987; $1,000)		30.2	30-40
EDUCATION (Mean years; ≥ 25 years old)		12.6	14.9

(a) *Source of California data: CSCDC 1989.*

residents of single-family detached housing may have been oversampled (data not shown). Therefore, extrapolation of data from this study to some population groups may be invalid if the activity patterns of those groups differ greatly from the average patterns of the sample.

Use of Gas Stoves

Ranges, ovens, and cooktops will be referred to as "stoves" for brevity. Respondents were asked if they used or were near an operating gas stove on the diary day, for what purpose the stove was being used, and if it had pilot lights. Table 2 summarizes the responses to these questions. More than one-third of the sample spent time near an operating gas stove. Greater than average frequencies were reported during the Fall and Winter seasons and in the Southern Coast Region. The proportion of the sample who used the gas stove for cooking peaked in the Fall and reached a low point in the Spring.

Of particular interest for exposure assessment are the three percent of the population (eight percent of the gas stove users) who reported the primary purpose as either space heating or both heating and cooking in the Winter. Based on the percentage of households that reported this type of stove use in

Table 2. Regional and Seasonal Differences in the Use of Gas Stoves and Heating Appliances (weighted)

		REGION			SEASON			
APPLIANCE USE	STATE WIDE	SO. COAST	SAN FRAN.	REST OF STATE	WIN	SPR	SUM	FALL
GAS STOVE								
% Near gas stove in use	38	49	28	33	41	32	35	46
- Cooking	37	48	25	32	37	32	34	44
- Heating	0.8	0.8	1.0	0.5	1.8	0	0.3	0.9
- Both	0.7	0.4	1.6	0.4	1.4	0.4	0.4	0.6
- Other	0.4	0.3	0.4	0.6	0.6	0.1	0.3	0.7
- With gas pilot light on	24	32	16	19	26	19	18	31
Time near gas stove:								
- Mean (min./day)	45	39	51	51	51	41	29	40
- Median (min./day)[a]	30	30	30	30	30	30	30	30
- Maximum (min./day)	841	600	330	841	600	480	540	841
HEATING APPLIANCES								
% With home heating on	39	34	44	42	76	36	4	42
% Using primary heating by:								
- Forced air system	17	15	18	19	30	18	0.8	19
- Wall furnace	10	10	12	8	20	10	1	9
- Floor furnace	4	5	5	3	8	4	0.2	6
- Wood stove	1	0	0.4	3	3	0.4	0	0.9
- Fireplace	0.9	0.2	1	2	3	0	0	0.8
- Space heater	1	1	1	0.8	2	1	0.1	0.8
- Radiator	0.3	0	1	0.2	0.5	0.2	0	0.6
- Gravity furnace	0.2	0	0.4	0.3	0	0.3	0	0.3
- Other	3	2	4	5	7	1	1	4
- Unknown	1	0.5	2	1	3	0.9	0	0.3

(a) The data were not grouped, but the respondents tended to report times in common intervals, e.g., 15, 20, 30, or 60 minutes.

the Winter and on the Department of Finance housing estimates (DRU 1989), California has approximately 352,000 households where gas stoves are used for heating. These households contain approximately 956,000 persons. Given the 24-hour recall method and the probable undersampling of some socioeconomic and housing groups in this study, these results probably underestimate the real extent of space heating by gas stoves in California.

Preliminary analyses indicated that several factors may help to predict the use of gas stoves for space heating. These factors include the following categories, based on their elevated percentages of such usage relative to the annual statewide level of 1.5 percent:

- Household income of $10,000 or less (11.2 percent);
- Mobile home residence (6.0 percent);
- High school education level or less (5.6 percent); and
- 12-19 year-old age group (3.2 per cent).

The literature contains few data on the use of gas stoves for space heating. Wilson et al. (1986) found that occupants of 6 of 50 homes (12 percent) in the Los Angeles Basin reported the use of a gas stove for space heating; the sample was limited to gas-fueled homes with the highest indoor NO_2 concentrations. In a follow-up study, Beals et al. (1987) reported that 20 percent of approximately 6800 respondents to a telephone survey in that area reported heating by gas stoves. They also found that about 30 percent of the participants in a field monitoring survey of approximately 1,050 homes with wall or floor furnaces reported such usage to varying degrees. Sterling and Kobayashi (1981) and Kaarakka et al. (1986) found similar results in other states. Thus, the rate of space heating by gas stoves observed in this study (eight percent of Winter gas stove users) appears to be slightly less than that observed in other large surveys, but the differences may be due to differences in study designs and populations sampled.

Pilot light use in stoves was reported for about one-half of those occasions where an operating gas stove was present. A few (0.6 percent) of the respondents who were near a gas stove volunteered the information that they used matches or sparkers to light the stove. This suggests that households with stove pilot lights could reduce indoor pollutant concentrations by turning off the pilot lights and using sparkers instead each time the stove is used.

Time Spent Near Operating Gas Stoves

Respondents were also asked *how much time* they spent near an operating gas stove on the diary day. The results are summarized in Table 2. It is interesting to note that among the regions, the Southern California region had the lowest mean time spent near a gas stove. However, it also had the highest percentage of gas stove use, suggesting that duration of stove proximity may not correlate well with frequency of stove proximity. These data on the times spent near an operating gas stove may be used to improve risk estimates for exposure to pollutants known to be emitted during gas stove use. Since Californians average nearly an hour a day near an operating gas stove during the Winter season when reduced air exchange may increase indoor pollutant concentrations, adverse exposures may result even from rather low emissions from the stoves.

It is worth noting that, because the sampling periods did not include major holidays such as Thanksgiving and Christmas, which often involve extensive cooking, the results of this study may underestimate peak and mean times spent near a gas stove in use. Similar underestimates may also result if some socioeconomic groups who may spend more time cooking or who lack a microwave oven are undersampled. Further analyses of the data on time spent near a stove, in conjunction with the data on purpose of stove use and ventilation, appear warranted.

Use of Heating Appliances

Table 2 also summarizes the primary types of home heating appliances which were reported to be in use on the diary day. The annual statewide frequency for home heating appliance use was 39 percent, of which forced air furnaces and wall furnaces represented the major share (69 percent). Several appliance types which can pose special indoor air quality problems, such as unvented kerosene and gas space heaters and gravity furnaces, were each used in one

percent or fewer of the households. The largest differences by far in total heating appliance use (over 70 percent) occurred among seasons, as expected. Among regions, total heating appliance use in the Southern Coast region was lowest by about 10 percent; much larger differences in heating appliance use probably occur among California's highly diverse climate zones.

Although not shown here, the primary heating fuel reported by those using heating appliances was natural gas (74 percent). Fifteen percent used electric heating appliances, and all other fuels, including wood, accounted for the remaining 11 percent. Regional differences in the type of heating fuel used were approximately 3-4 four percent. However, there are probably some smaller regions in which heating fuel use is much different than the statewide average. For example, large proportions of households in colder climate zones are known to use wood fuel.

Use of Cooling Appliances

Respondents were also asked about their use of home cooling appliances on the diary day. Table 3 summarizes that data for the State, and by region and season. The reported proportion of households in which cooling appliances were used was relatively small (11 percent annually statewide). Residents of the San Francisco region used cooling appliances less frequently than residents of the other regions. Among seasons, as expected, the Summer season had the highest frequency of use.

Use of Ventilation

Mechanical Ventilation. Household respondents were asked about the types of fans used in their home on the diary day (see Table 3). Annually, about 24 percent of the population used fans, and the largest difference in fan use (26 percent) occurred between the Winter and Summer seasons.

Table 3. Regional and Seasonal Differences in the Use of Residential Cooling Appliances and Ventilation (weighted)

		REGION			SEASON			
APPLIANCE/ VENTILATION USE	STATE WIDE	SO. COAST	SAN FRAN.	REST OF STATE	WIN	SPR	SUM	FALL
COOLING APPLIANCES								
% Using home air cooling	11	12	3	15	0.2	7	29	7
- Refrigeration	6	6	2	7	0	4	15	3
- Evaporation	2	0.4	0.2	4	0	0.9	4	1
- Other & unknown	4	0.5	0.3	4	0.2	1	10	2
MECHANICAL VENTILATION								
% Using fan	24	20	23	29	13	21	39	22
- Portable fan	9	10	6	10	3	7	19	7
- Ceiling fan	9	7	6	13	4	9	12	9
- Exhaust fan	3	1	7	2	5	2	1	3
- Window fan	0.4	0.3	0.2	0.6	0	0.3	1	0.1
- Other	3	2	5	4	0.9	3	6	4
NATURAL VENTILATION								
% With doors/windows:								
- Closed	29	15	17	68	43	13	18	26
- Open > 1-2 min.	71	85	83	32	57	87	82	74
- Open 1440 min. (all day)	29	33	34	25	15	28	38	33

Peak use occurred during the Summer (39 percent) and was mainly associated with increased use of portable fans and, to a minor extent, ceiling fans. Regional variation in total fan use was relatively small. In the Rest of the State region, 6-9 percent more people used fans; the increase was greatest for ceiling fans.

The use of exhaust fans is of particular interest for exposure assessment because it can greatly reduce indoor concentrations of pollutants emitted from gas stoves. As shown in Table 3, a very small percentage of the population used exhaust fans: three percent statewide; five percent in the Winter (perhaps due to increased cooking, showering, or humidity); and seven percent in the San Francisco region. The relatively low use of exhaust fans is consistent with data reported in the literature (Wilson et al. 1986; Kaarakka et al. 1986). Window fans, which are often considered as an alternative to stove venting, are used very rarely (0.4 percent statewide). These data suggest that Californians use exhaust or natural ventilation to control stove emissions infrequently.

Natural Ventilation. The percentages of households that had their doors or windows closed, open for more than 1-2 minutes at a time, or open all day on the diary day are shown in Table 3. Statewide, substantial door or window opening occurred in 71 percent of the households, which is almost three times the percentage of households using fans. In fact, many people volunteered the response that they kept their doors or windows open all day. On the other hand, 29 percent of the population did not open their doors or windows substantially; higher percentages in the Rest of the State region and in the Winter season did not open their doors or windows.

Respondents were also asked to estimate the *length of time* during the daytime (6 a.m.-6 p.m.) and the nighttime (6 p.m.-6 a.m.) that windows or doors were open for more than a few minutes at a time. Table 4 summarizes the statewide, regional, and seasonal data for daytime, nighttime, and daily use of natural ventilation. The diurnal medians indicate that daytime natural ventilation use greatly exceeds that for nighttime, except for the Winter season where both values are very low. The daily 25th percentile values indicate that a large proportion of the population uses very little or no natural ventilation. The daily medians, and to a lesser extent the daily means, display large regional differences and even larger seasonal differences. As expected, the lowest daily median among the seasons occurred in the Winter, and the Rest of the State had the lowest median value among regions. These data are consistent with California's seasonal patterns of the lowest temperatures occurring in the Winter and regional patterns of the lowest temperatures occurring in the mountain and northern coastal climate zones found in the Rest of the State.

These data have important implications for assessing exposure to indoor pollutants because they provide the first statewide data base on Californians' use of residential ventilation, especially the use of natural ventilation. In general, the data for mechanical ventilation (fan use) and natural ventilation (doors and windows) indicate that many Californians did not maintain a supply of fresh air to their homes, especially in the colder seasons and regions and in the nighttime. The very low use of exhaust fans suggests that mechanical ventilation was used primarily for cooling rather than for control of indoor pollution. Natural ventilation appeared to be the preferred method for supplying fresh air. Thus, under certain conditions, a sizeable number of households may have had only a few minutes a day of natural ventilation. These data also have important implications for improving energy efficiency and maintaining indoor air quality through building standards which assume certain levels of natural ventilation for the entire population.

Time Spent in Indoor Locations (Building Occupancy)

The results of the 24-hour diary responses (not shown here) indicate that the population spent an average of 87 percent of their time indoors, 8 percent in-transit, and 5 percent outdoors (Wiley et al. 1990; Jenkins et al. 1990). Californians aged 12 years and older spent most of their time (62 percent) in residential indoor locations, with most of that time spent in the bedroom and family/living room. The mean time spent in the kitchen by

Table 4. Diurnal and Daily Residential Use of Natural Ventilation (Minutes/day with windows/doors open ≥ 1-2 min.; weighted).

	DIURNAL USE[a]		DAILY USE		
SAMPLE GROUP	DAY Median	NIGHT Median	25%ile	Median	Mean
STATEWIDE	150	30	0	300	614
SO. COAST REGION	300	180	15	600	638
SAN FRAN. REGION	240	120	10	465	660
REST OF STATE	120	0	0	180	549
WINTER	5	0	0	11	383
SPRING	180	60	15	360	608
SUMMER	480	360	120	722	812
FALL	180	60	0	300	655

(a) Daytime is 6 a.m. - 6 p.m.; nighttime is 6 p.m. - 6 a.m.

persons who spent time in that location ("doers") was 96 minutes/day, with a maximum of 930 minutes/day. Recent national surveys found that people, especially women and the elderly, spend a great deal of time in their kitchens not only for cooking and meal preparation but also for reading, socializing, and other activities (Burros 1988; GE 1989). Thus, this study's findings together with those of several other studies suggest that many Californians spend a great deal of time in residential locations where they may be exposed to elevated pollutant concentrations.

CONCLUSIONS

This study provides unique data on the use of heating and cooking appliances, ventilation practices, and building occupancy. It obtained statewide, regional, and seasonal data through a telephone survey of 1780 adults and adolescents throughout California. The sample appears to be representative of the California population, but it may not be very representative of population subgroups. Initial analyses of the data have shed a great deal of light on when, where, and how Californians may experience elevated exposures to indoor air pollutants due to the use (or misuse) of gas stoves and the lack of ventilation, and on which groups may be most likely to experience those exposures.

About 38 percent of the population use or are near operating gas stoves on an average day. Gas stoves are misused for space heating by about three percent of the population in the Winter season, which translates to a conservative estimate of approximately one million persons in 1989. Preliminary analyses indicate that gas stoves are misused for space heating more frequently by several groups including: low income households; mobile home residents; persons with a high school education or less; and persons aged 12-19 years. These groups may be especially likely to experience high exposures to indoor pollutants from gas stove misuse. In addition, nearly one-fourth of the population are near gas stoves with pilot lights each day; it would appear that indoor air quality and energy efficiency could be enhanced by using sparkers instead of pilot lights or by installing pilot-less stoves as replacements.

Analyses also show that natural ventilation is used much more often than fans or air conditioning. Many persons leave their doors or windows open all day. However, a sizeable number of households in the population only use natural ventilation for a few minutes a day at most, especially during the Winter, in the Rest of the State region, and during the nighttime. In addition, very few households use exhaust fans. This lack of natural or mechanical

ventilation in the home suggests that many households may be susceptible to high concentrations of indoor pollutants, especially in homes with low infiltration rates and significant indoor pollutant sources. These findings have significant implications for public health and energy efficiency issues such as energy standards, ventilation standards, emission standards, epidemiological study design, health risk assessment, and public education.

Additional analyses of ARB's activity patterns data, especially in conjunction with analyses of other data bases, are recommended. For example, the socioeconomic factors associated with gas stove misuse need to be further analyzed, perhaps by multivariate statistical methods; the linkage of use patterns for gas stoves with the purpose of use and the use of ventilation should also be analyzed. Further research to estimate appliance emission rates and indoor pollutant concentrations and to learn why people misuse gas stoves or fail to use ventilation methods is also recommended. Such analyses and research will improve the efficiency of efforts to assess and reduce indoor air pollutant exposures by identifying and characterizing the worst-case conditions in the real world. In the meantime, public education efforts should be mounted to modify the behavior of population groups most likely to misuse gas stoves, leave the stove pilot lights on continuously, or fail to use natural or exhaust ventilation.

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DISCLAIMER

Opinions and conclusions expressed in this paper are those of the authors and do not necessarily reflect the views of the California Air Resources Board.

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