

# Weekday/Weekend Activity Patterns for Residential and Small Commercial Area Sources in Los Angeles

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## ABSTRACT

Air quality trends for Los Angeles indicate that ozone concentrations can be as much as 55% higher on weekends than they are on weekdays under comparable meteorological conditions. This trend is paradoxical because weekend ozone precursor emissions are low relative to weekday emissions. To study this phenomenon – the “weekend ozone effect” – during the fall seasons of 2000 and 2001, we surveyed Los Angeles residences and small businesses about the frequencies and timings of various emissions-related activities, including residential and/or commercial uses of lawn and garden equipment, barbecues, fireplaces, solvents and chemicals, internal combustion engines, and several other activities. Combined, these types of sources are estimated to contribute about 21% of total ROG emissions and 16% of total NO<sub>x</sub> emissions to the South Coast Air Basin’s year-2000 summertime emission inventory. The purposes of the surveys were (1) to improve diurnal and weekly emissions activity profiles, which are used as inputs to air quality models, and (2) to contribute (in conjunction with other concurrent research efforts) to our general understanding of weekday-to-weekend (WD-WE) variations in emissions patterns, which occur in the Los Angeles Area. The results of the surveys indicated that some residential activities increase on weekends relative to weekdays by as much as 40% to 140%, while business activities decrease by 45% to 95%. These WD-WE variabilities have quantifiable impacts on ROG and NO<sub>x</sub> emissions in Los Angeles. Furthermore, when these quantifiable impacts are considered together with observed WD-WE patterns for mobile and point sources, it appears that overall weekend emissions patterns favor ozone formation in Los Angeles to a greater extent than do weekday emission patterns due to decreased ROG:NO<sub>x</sub> ratios and reduced morning titration capacity of ozone by NO<sub>x</sub>.

## INTRODUCTION

In recent years, Los Angeles has experienced peak ozone concentrations on weekends that are greater than weekday peaks.<sup>1,2,3</sup> This phenomenon, the “weekend ozone effect”, is counter-intuitive because emissions of ozone precursors for weekends are expected to be lower than those for weekdays.<sup>4,5,6,7</sup> In 2000 and 2001, coordinated studies of air quality and emissions-related activity patterns were conducted to generate information to aid the general understanding of the weekend ozone effect.<sup>8,9</sup> The studies that we present in this paper were a part of these coordinated efforts.

During the fall of 2000 and 2001, we surveyed Los Angeles residences and small businesses about frequencies and timings of various emissions-related activities. The objective of the surveys was to characterize weekday-to-weekend (WD-WE) activity patterns for certain types of area sources. The surveys were concurrent and coordinated with other data collection efforts, such as enhanced air quality monitoring at fixed locations, air quality monitoring from a vehicle-mounted mobile platform, monitoring of traffic volumes on surface streets, acquisition of freeway-based traffic volume data, and acquisition of data from the continuous emissions monitoring systems (CEMS) of major stationary point sources.<sup>8</sup> To coordinate with these concurrent studies, the surveys focused on four specific neighborhoods of Los Angeles. We extrapolated the survey results to the greater Los Angeles area and arrived at several preliminary conclusions:

- Certain residential activities increase from 40% to 140% from weekdays to weekends, such as residential use of barbecues and lawn and garden equipment. Other residential activities vary to a much lesser degree.

- Diurnal distributions of some residential activities vary by day of week. For example, weekday use of barbecues occurs primarily in the evening. However, afternoon use increases from 11% of total daily use, Monday through Thursday, to 35% to 50% on weekends. Diurnal patterns for other residential activities vary little by day of week, such as use of personal care products.
- Business activities, such as commercial use of lawn and garden equipment, decline substantially on weekends (from 45% to 95%). Generally, business activities peak in the 8:00 a.m. to 4:00 p.m. time frame on weekdays and Saturdays, but remain flat on Sundays. Exceptions are lawn and garden services, which peak earlier and consistently throughout the week and businesses that use gas ovens, which peak slightly later on weekdays and sustain high levels of activity through the evening.
- There are cases where WD-WE decreases in commercial activities offset corresponding increases in residential activities. An example is lawn and garden equipment, for which a 90% to 95% decrease in commercial use offsets a 40% to 45% increase in residential use.

We combined these conclusions with analyses of WD-WE patterns for mobile and point sources (reported elsewhere<sup>4</sup>) to evaluate the implications for weekend ozone episodes in Los Angeles. From these reflections, we developed improved hypotheses about the weekend ozone effect's governing factors. The analyses suggest that weekend NO<sub>x</sub> reductions are disproportionately larger than corresponding ROG reductions. The expected effects of this are (1) less available NO<sub>x</sub> for titration and removal of morning ambient ozone; and (2) increased ambient ROG:NO<sub>x</sub> ratios, which correlate with increased rates of ambient ozone formation. Thus, it appears that weekend emissions patterns favor ozone formation in Los Angeles to a greater extent than do weekday emission patterns. This is consistent with observations in Los Angeles of enhanced weekend ROG:NO<sub>x</sub> air pollutant ratios, decreased morning NO<sub>x</sub> concentrations, and enhanced peak ozone concentrations.<sup>1,3</sup> Our hypotheses provide helpful guidance for future research efforts. If borne out by additional research, they indicate that ROG controls are effective prevention measures against weekend ozone episodes in Los Angeles.

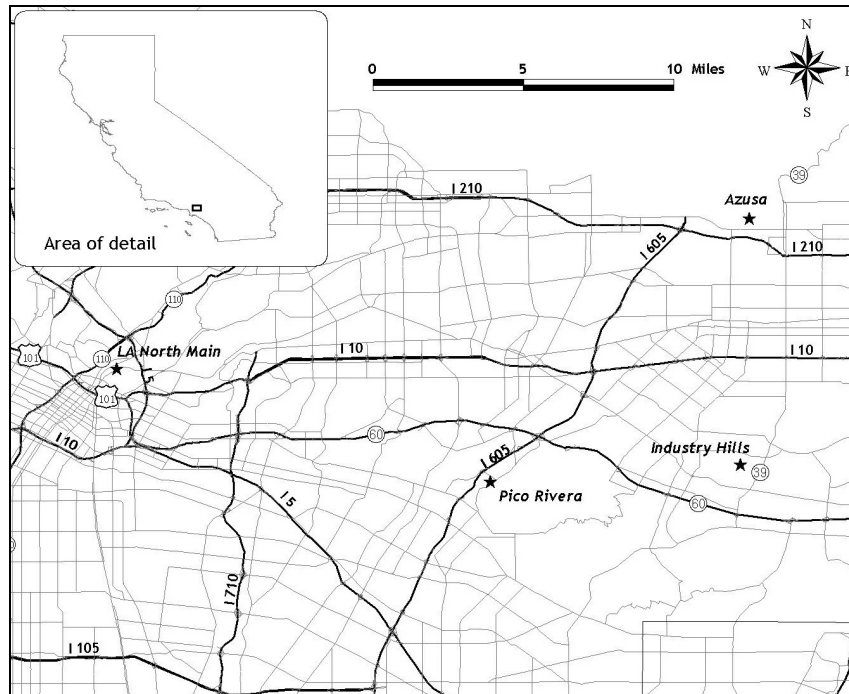
## APPROACH

The primary study period, September 29 through October 8, 2000, coincided and coordinated with other WD-WE data collection efforts in the Los Angeles area. Data collection proceeded via telephone and mail surveys of households and commercial entities in four specific neighborhoods of Los Angeles (see Figure 1). The neighborhoods were 4 by 4 kilometers in dimension and centered on selected air quality monitoring sites. In a coordinated study that is discussed elsewhere,<sup>3</sup> Fujita *et al* equipped the selected monitoring sites with enhanced measurements to study WD-WE concentrations of ozone and ozone precursors.

Households were recruited in advance by telephone and by mail. After initial telephone recruitment, each residential survey participant received a letter, a one-dollar incentive (to encourage continued participation), and a daily activity diary in the form of a booklet of 10 postcards (which were date-stamped and postage-paid). On each day of the study, each participant was to complete one postcard for return by mail. The study period began on a Friday and concluded 10 days later on a Sunday. Thus, postcard data were collected for two Fridays, two Saturdays, two Sundays, and the interceding Monday through Thursday. On the postcards, participants checked off responses to queries about daily and periodic household activities, including usages of barbecues, fireplaces, gas cans, paints/solvents, personal care products, paving/roofing materials, motor oils, lawn and garden equipment, and garden chemicals (pesticides and fertilizers). Response options included "yes or no" (to ascertain any use that day); as well as "check all that apply: morning, afternoon, evening" (to determine all time periods when use occurred). In addition, household participants responded at the time of initial telephone recruitment to a telephone survey that established a number of household characteristics: (1) number of persons in the household; (2) number of household members who regularly attend work or

school outside the home; (3) number of males, females, legal adults, and legal minors who are members of the household; (4) total number of passenger cars, RVs, trucks, SUVs, vans, and/or motorcycles owned by household members; (5) method of home heating; (6) presence of a fireplace or barbecue grill in the home with corresponding fuel types; (7) presence of a yard or garden at the home, which is maintained by household members; (8) type of residence (e.g, single-family, multi-family); and (9) status of home ownership versus rental.

**Figure 1.** Locations of 4 Los Angeles neighborhoods – L.A. North Main, Pico Rivera, Industry Hills, and Azusa – that were included in the residential and commercial surveys.



Commercial entities were contacted during the 10-day study period for participation in a short telephone-only survey. Business entities were asked a series of detailed questions about the number of employees typically on duty during specific time periods. The numbers of employees on duty were established for each day of a 7-day week and for 6 four-hour work shifts starting at midnight. Numbers of employees on duty were taken as indicators of business activity levels. The telephone recruitment and interview of commercial entities included a series of questions to determine several business characteristics: (1) type of workplace (office or other); (2) total number of employees; (3) business hours of operation by day of week; (4) use of surface coatings or solvents (including paints, solvents, thinners, stains, varnishes, or degreasers); (6) use of motor oils (including gear oils, gear fluids, or brake fluids); (7) use of pesticides or fertilizers; (8) use of internal combustion (IC) engines; and (9) use of gas ovens.

A follow-up survey of entities that perform commercial lawn and garden maintenance services was conducted September 6 through September 25, 2001, approximately one year after the primary survey period (see Table 1). For the commercial lawn and garden study, respondents were recruited throughout Los Angeles County. Like the general commercial survey described above, respondents were asked about the number of employees typically on duty for each day of a 7-day week and for 6 four-hour work shifts. In addition, participants responded to questions about several business characteristics: (1) types of residential and non-residential properties served (e.g., cemeteries, airports, etc.); (2) number of properties typically served per week; (3) total land area typically served by the business during a summer week; (4) number of employees typically on duty during a summer workday; (5) types of equipment used (including mowers, tractors, chainsaws, turf equipment, leaf blowers, and

edgers/trimmers/cutters), number owned of each type, and power source of each (e.g., gasoline or diesel fuel, electrical, or manual power); (6) use of pesticides or fertilizers at the business and its likelihood of use on specific days of week, typical duration of application, and frequency of use during the summer.

**Table 1.** Distribution of respondents to the commercial lawn and garden equipment study.

Respondent Category	No. Respondents
Airports	3
Campgrounds	6
Recreational areas	3
Cemeteries	16
Golf courses – private	5
Golf courses – public	16
Landscape contractors	68
Parks	22
Schools, universities, and colleges	12
Total	151

## SUMMARY OF RESULTS

### Summary of Survey Participation

Table 2 tabulates the number of potentially qualified respondents. Refusal rates of around 25% for the business surveys and 50% for the residential telephone survey were observed. (In our experience and in the experience of the market research firm that conducted the surveys, these refusal rates are typical for business and residential surveys.) One hundred thirty one businesses participated in the commercial survey; 151 businesses participated in the lawn and garden equipment survey; and 450 households participated in telephone survey and agreed to be recruited into the mail survey. The commercial survey respondents employed 1914 workers and the lawn and garden survey respondents employed 5436 workers. In aggregate, surveyed lawn care businesses reported that they typically service from 21 to 71 thousand acres of land area per week in the summer, or 1% to 3% of the total area of Los Angeles County. On average, surveyed households had 3.6 household members. Of 450 households that were recruited for the mail survey, 231 successfully completed and returned at least one postcard; 167 completed and returned all ten postcards; and 202 completed and returned at least 8 postcards. Of the 4500 postcards that were mailed to residential survey participants, 2070 (46%) were returned. Similar numbers of postcards were received for each day of the 10-day study (from 189 to 222 postcards per day). Postcard return rates declined slightly but not significantly as the study progressed into its tenth day. Respondents indicated that 1436 (69%) of returned postcards had been completed on the day of interest and that 330 (16%) of returned postcards were completed within one day after the day of interest.

### Residential Survey Results

Figure 2 illustrates the positive response rates that were observed for nine residential activities by day of week, calculated as follows:

$$\text{Equation (1)} \quad \text{PRR} = N_{\text{positive}} \div N_{\text{total}} \times 100\%$$

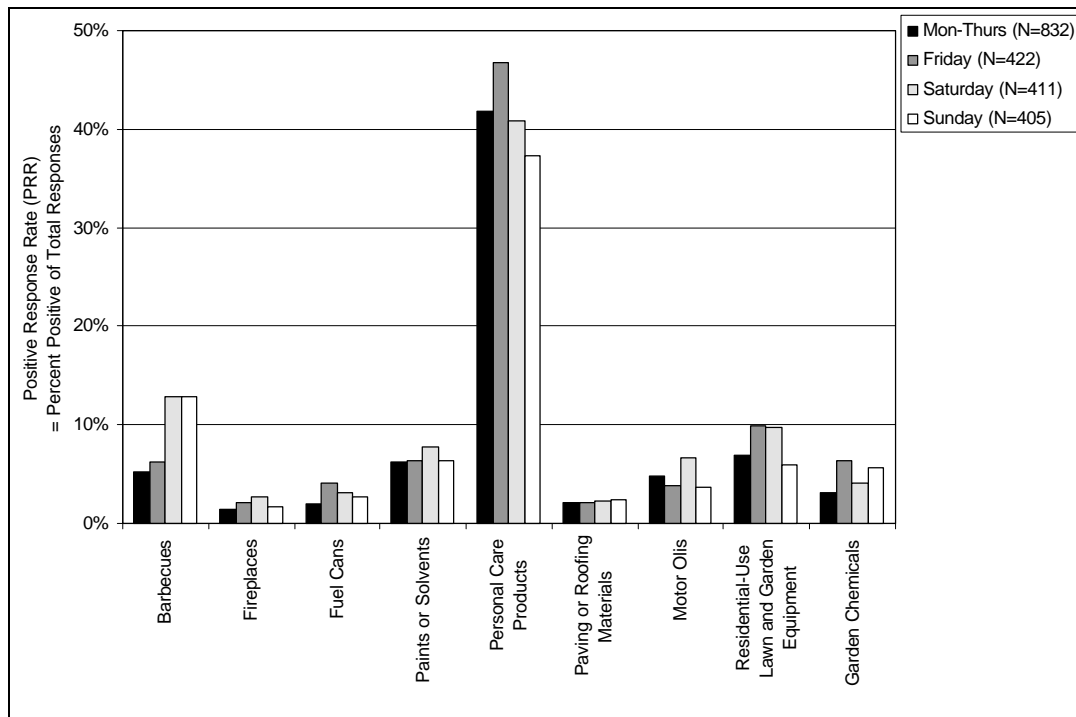
where  $N_{\text{positive}}$  = number of postcards that positively indicated that an activity occurred on the day of interest  
 $N_{\text{total}}$  = total number of postcards received for the day of interest

**Table 2.** Dispositions of contacts made to potentially qualified survey respondents.

Disposition Status	Residential Survey		Business Survey		Lawn and Garden Equipment Survey	
	No. of Respondents	% of Total	No. of Respondents	% of Total	No. of Respondents	% of Total
Potentially qualified	1502	100%	297	100%	1175	100%
Unavailable	360*	24%	95*	32%	733	62%
Refused participation	692	46%	71	23%	291	25%
Participated in telephone survey	450	30%	131	44%	151	13%
Participated in postcard survey	230	15%	NA	NA	NA	NA

\*Could not be reached after 6-8 call attempts.

**Figure 2.** Positive survey response rates by day of week for residential activities.



(N=Total number of postcards received.)

Figure 3 illustrates day-of-week allocation factors ( $AF_{DOW}$ ) that were estimated directly from the residential survey data. These were calculated as follows:

$$\text{Equation (2)} \quad AF_{DOW,i} = PRR_i \div (4 \times PRR_{M-Th} + PRR_{Fri} + PRR_{Sat} + PRR_{Sun}) \times 100\%$$

where  $AF_{DOW,i}$  = day-of-week allocation factor for day  $i$   
 $PRR_{M-Th}$  = positive response rate for the group of days, Mon. through Thurs.  
 $PRR_{Fri}$ ,  $PRR_{Sat}$ ,  $PRR_{Sun}$  = positive response rates for Fri., Sat., and Sun.

Figures 2 and 3 show that several residential activities were enhanced relative to weekdays by 40% to 140% on Fridays and/or weekends of the study period. These activities including use of barbecues, fireplaces, fuel cans, motor oils, lawn and garden equipment, and garden chemicals. Other activities varied little by day of week (less than 25% variation), including use of paints or solvents, personal care products, and paving or roofing materials.

**Figure 3.** Survey-based estimated day-of-week allocation factors for residential activities.

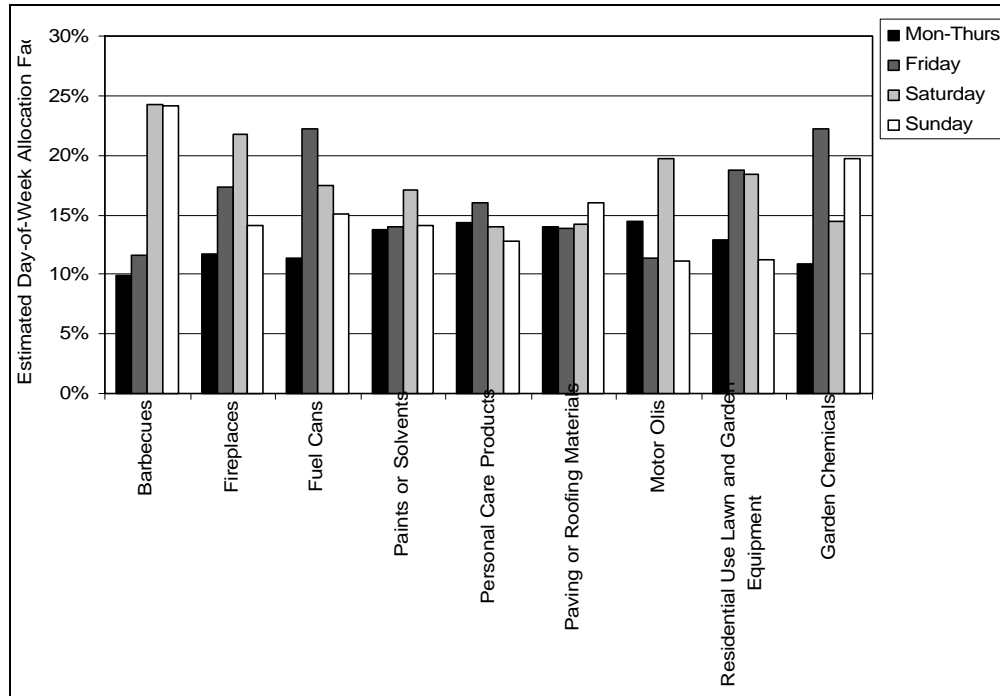


Figure 4 illustrates the distribution of positive responses by time of day for various residential activities. Some activities tended to occur in the evenings (such as weekday use of barbecues), while other activities tended to occur in the mornings (such as the use of personal care products). Activities that tended to occur during mornings and afternoons, but rarely in the evenings, included residential use of paints or solvents and residential use of lawn and garden equipment. Diurnal patterns of some activities varied somewhat by day of week. On weekdays, 60% to 80% of barbecue use occurred during the evenings. However, afternoon use of barbecues increased from 11% of total daily use, Monday through Thursday, to 35% to 50% on weekends. In contrast, diurnal variations for residential uses of personal care products and residential use of lawn and garden equipment were fairly constant and not WD-WE dependent. Survey respondents infrequently indicated the use of fireplaces, gas cans, paving or roofing materials, motor oils, and garden chemicals. Therefore, too few time-of-day observations are available for these activities to draw conclusions about day-of-week variability in their diurnal patterns.

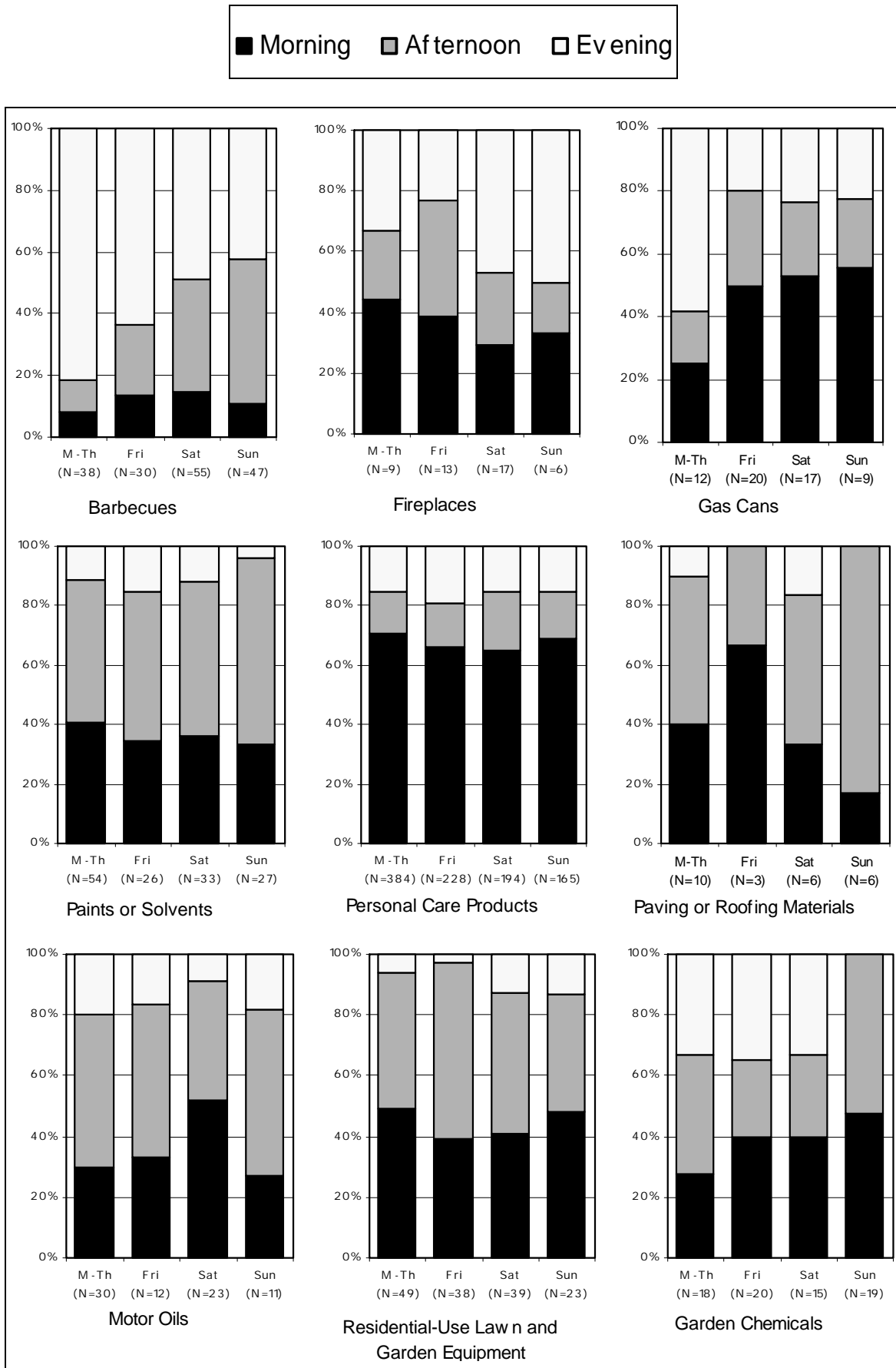
### Business Survey Results

Figure 5 illustrates business activity levels, or estimated person-hours worked, by day of week and time of day for various types of businesses, including all surveyed businesses (which comprised offices and other workplaces), workplaces that reported equipment in use, and businesses that responded to the survey of commercial lawn and garden services. The number of person-hours worked ( $W$ ) was estimated as follows:

$$\text{Equation (3)} \quad W = E \times t$$

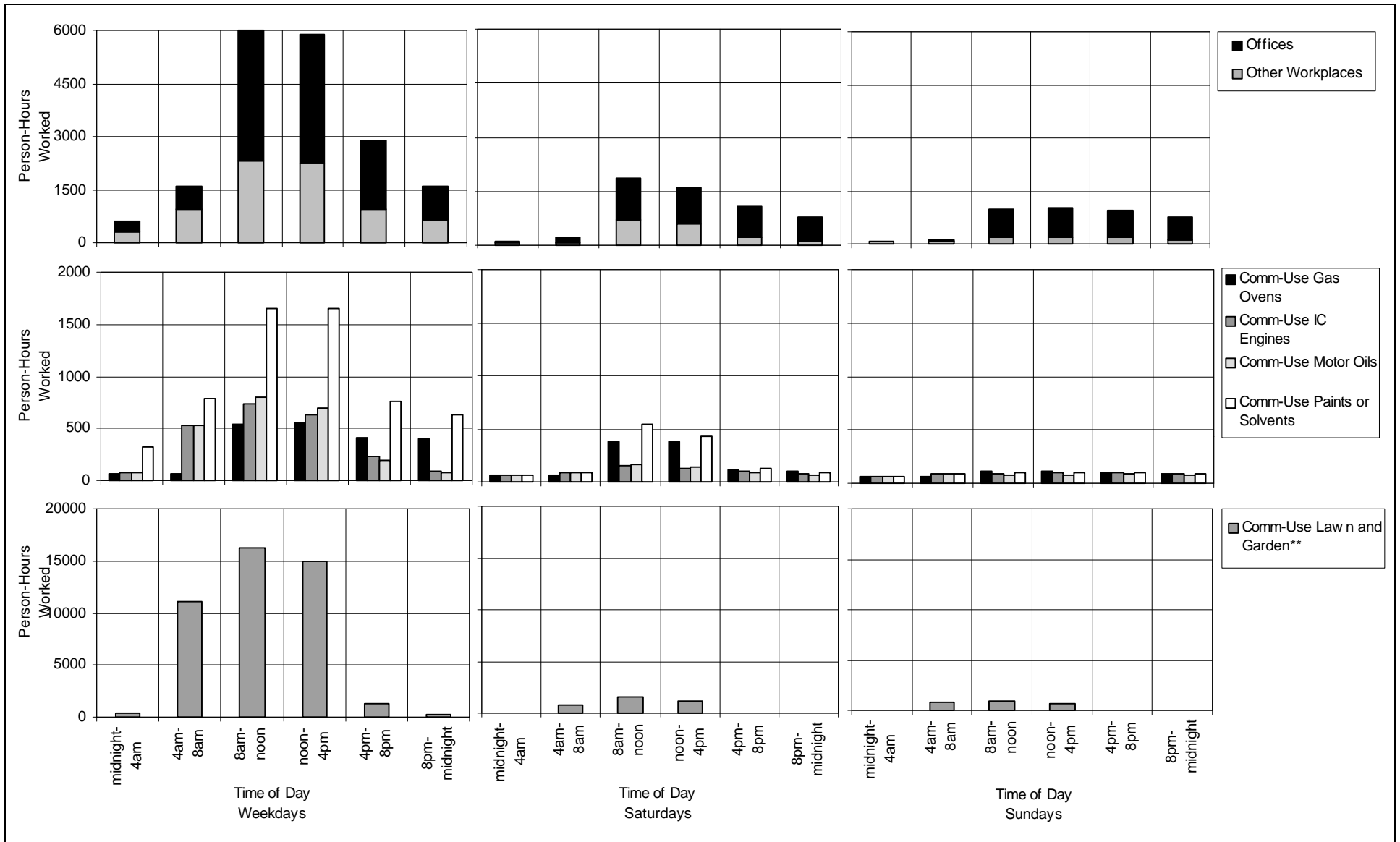
where  $E$  = number of employees on duty for the time period of interest  
 $t$  = length of the time period of interest (hours)

**Figure 4.** Distributions of positive survey response rates by time of day for residential activities.



N=Total number of time-of-day responses received. Note: Not all positive responses (Figure 2) were associated with time-of-day responses, presented above.

**Figure 5.** Survey business activity levels (or person-hours worked) by day of week and time of day for (1) all businesses by type of workplace (top), (2) workplaces with equipment in use (middle), and (3) businesses surveyed for commercial lawn and garden equipment (bottom).



In this matrix of 9 plots, each row of 3 plots shares the y-axis and each column of 3 plots shares the x-axis.

\*\*Commercial-use lawn and garden data were collected during a separate, follow-up survey.



For all types of businesses in aggregate, weekend activity levels declined from weekday levels by 70% and 79% on Saturdays and Sundays (see Table 3). However, weekend declines in activity levels varied somewhat by type of business. At one extreme, businesses that perform lawn and garden care services experienced reductions in activity levels of 92% and 95% on Saturdays and Sundays. At the other extreme, businesses that operate gas ovens had activity levels that were 45% lower on Saturdays. Figure 6 illustrates day-of-week allocation factors (AFDOW) that were developed for commercial activities, which were calculated as follows:

$$\text{Equation (4)} \quad \text{AF}_{\text{DOW},i} = W_i \div (4 \times W_{\text{M-Th}} + W_{\text{Fri}} + W_{\text{Sat}} + W_{\text{Sun}}) \times 100\%$$

where  $\text{AF}_{\text{DOW},i}$  = day-of-week allocation factor for day  $i$   
 $W_{\text{M-Th}}$  = average no. of person-hrs. worked for the days Mon. through Thurs.  
 $W_{\text{Fri}}, W_{\text{Sat}}, W_{\text{Sun}}$  = average no. of person-hrs. worked for Fri., Sat., and Sun.

**Table 3.** Weekend reductions in activity for various types of surveyed businesses.

Type of Business	N	NE	Percent Reduction in Activity Level Relative to Weekdays	
			Saturday Reduction	Sunday Reduction
All businesses	131	1914	70%	79%
Offices	88	1138	65%	72%
Other workplaces	44	776	76%	89%
Businesses with equipment in use	26	651		
Gas Ovens	8	245	45%	74%
IC Engines	12	192	73%	77%
Motor Oils	12	204	74%	80%
Paints or Solvents	18	569	77%	90%
Lawn and Garden Equipment**	151	5436	92%	95%

N = Number of businesses sampled; NE = Number of workers employed by sampled businesses.

\*\*Commercial-use lawn and garden data were collected during a separate, follow-up survey.

**Figure 6.** Survey-based estimated day-of-week allocation factors for business activities.

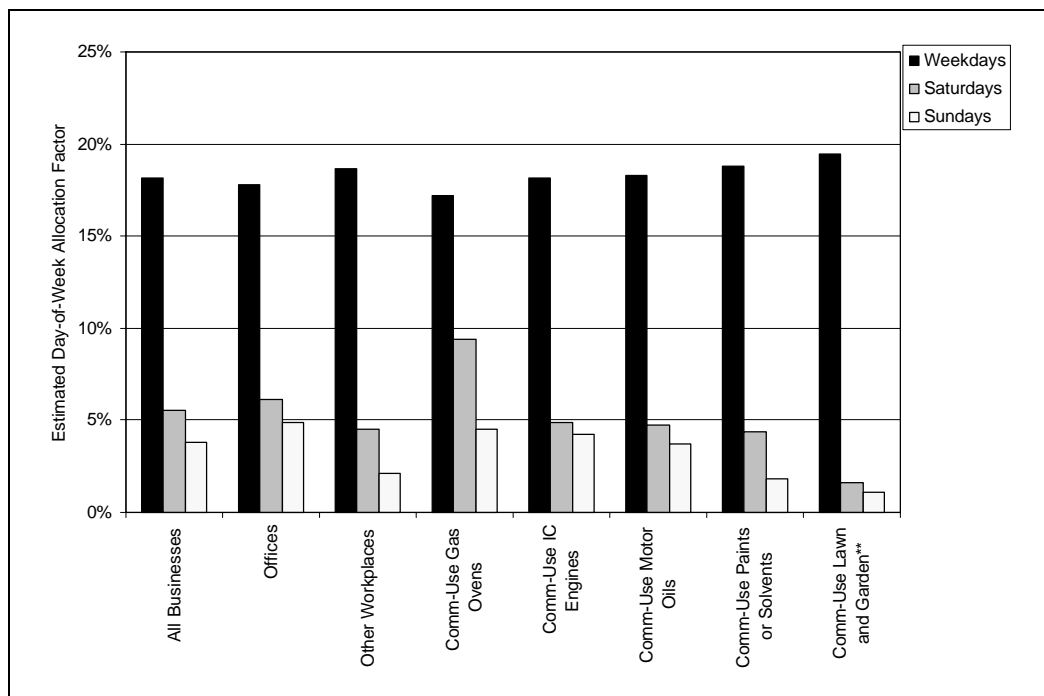


Figure 7 shows distributions of person-hours worked by time of day for weekdays, Saturdays, and Sundays. On weekdays and Saturdays, daily business activity levels peak during the period from 8:00 a.m. to 4:00 p.m. However, individual types of businesses differ from the aggregate pattern. Businesses that use gas ovens peak in their activity levels later in the day, from noon to 4:00 p.m., and sustain activity levels at around 70% of peak until late in the evening on weekdays (or, through the 8:00 p.m.-to-midnight work shift). Activity levels for lawn and garden care services peak much earlier in the day. Commercial lawn services reach 70% of peak activity during the period from 4:00 a.m. to 8:00 a.m.; peak during the periods from 8:00 a.m. through 4:00 p.m.; and precipitously drop in activity levels after 4:00 p.m. to less than 10% of peak. On Sundays, the diurnal activity profiles of offices and lawn care services resemble the corresponding weekday diurnal patterns. In contrast, Sunday activity levels for non-office workplaces were fairly flat and evenly distributed across all time periods.

## DISCUSSION

The survey results described above were analyzed together with observations of WD-WE activity patterns for traffic volumes and point sources in Los Angeles.<sup>4</sup> Through this analysis, preliminary category-specific scaling factors were developed by day of week and time of day.<sup>4</sup> (Scaling factors were set equal to one for emissions categories that were not directly studied.) These scaling factors were applied to summertime daily average emissions to approximate WD-WE variabilities in emissions. (Emissions were acquired from the California Air Resources Board,<sup>10</sup> but adjusted to reflect EMFAC2000-based mobile source emissions.) Figures 8 and 9 summarize the results of the analysis. Figure 8 shows that estimated ROG and NO<sub>x</sub> emissions decrease on Saturdays relative to weekdays, and they decrease even more on Sundays. Mobile sources and small commercial businesses were the largest and second largest contributors to these reductions. Decreases in point source emissions somewhat offset increases in off-road mobile source emissions (e.g., emissions from residential lawn and garden equipment, recreational boats, etc.). Based on these emissions estimates, Figure 9 illustrates the resultant WD-WE changes in the molar ratio of ROG:NO<sub>x</sub> emissions. The ROG:NO<sub>x</sub> ratio is important because it is an indicator of ozone formation potential, where higher ratios generally are more favorable for ozone production. The estimated ROG:NO<sub>x</sub> emissions ratio increases on weekends relative to weekdays, especially during the hours of primary importance for rapid ozone formation, which are from 6:00 am through 12:00 p.m. The increases occur because predicted weekend reductions in NO<sub>x</sub> emissions are larger than the corresponding reductions in ROG emissions. The estimated increases in ROG:NO<sub>x</sub> emissions ratios are consistent with ratios of measured air pollutants reported by Fujita et al. and others for the Los Angeles area.<sup>2,3</sup>

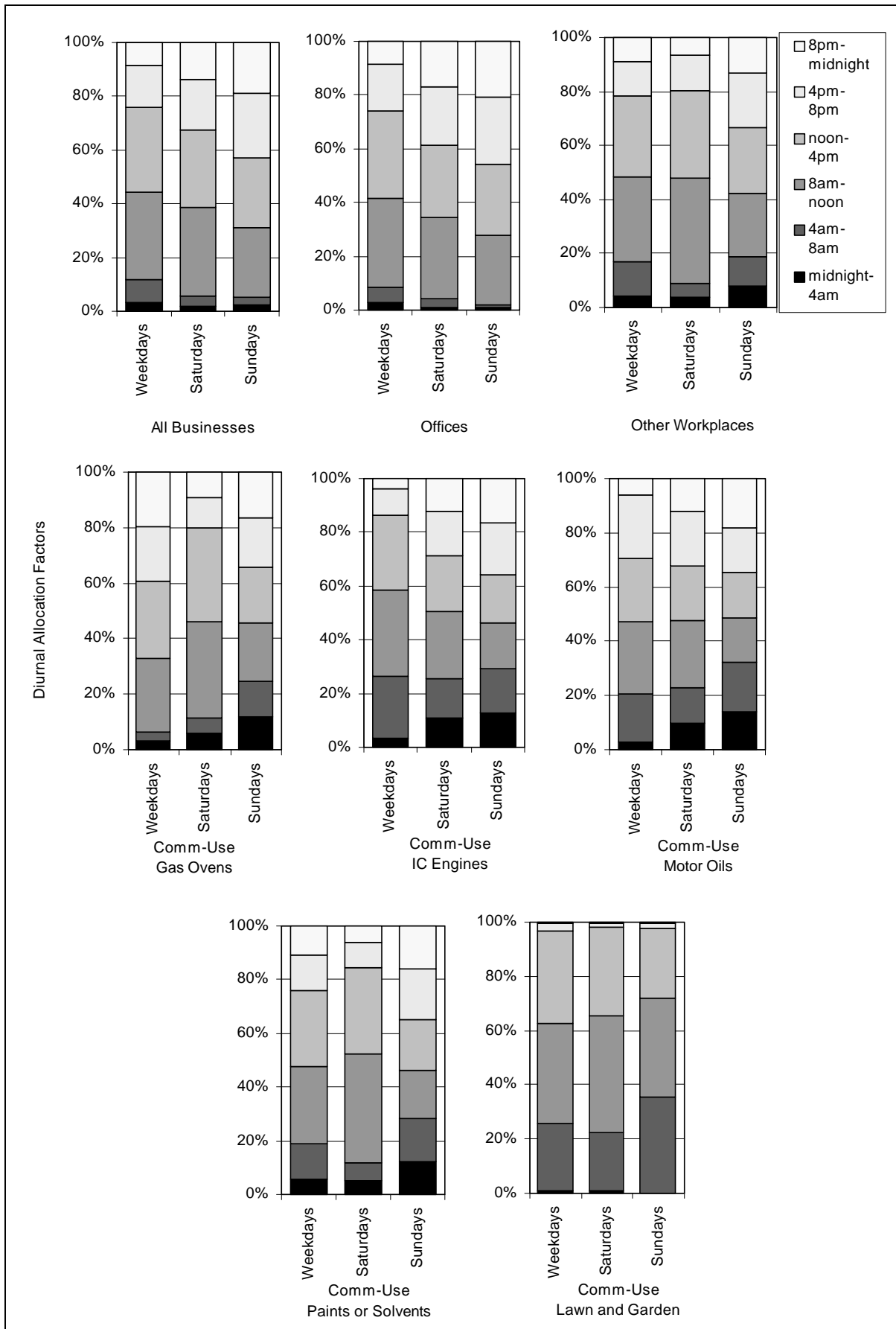
Limitations of these analyses are due to the facts that most of the data were collected (a) for specific neighborhoods of Los Angeles, which may not be representative of the entire Los Angeles Air Basin and (b) in September and October of 2000 or 2001, which may not be representative of summertime conditions. In addition, sample sizes were small for businesses when segregated by equipment type in use (e.g., only 8 businesses used gas ovens). Therefore, these conclusions should be considered preliminary and used only as a guide for further research efforts.

## CONCLUSIONS

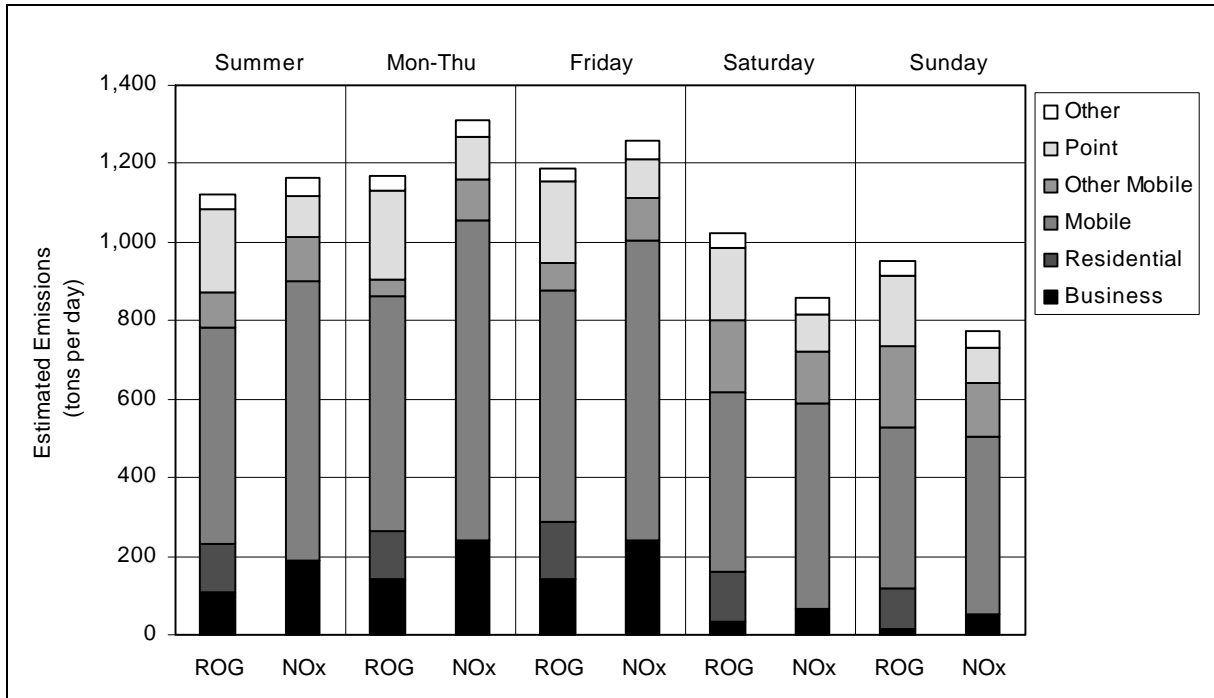
Survey data presented here and common sense suggest that aggregate variations in human behaviors, which follow WD-WE patterns, affect WD-WE emission rates of ozone precursors and ambient ozone levels. The following conclusions were drawn from the survey data:

- Some residential activities increased from 40% to 140% from weekdays to weekends. This included residential use of barbecues, fireplaces, fuel cans, motor oils, lawn and garden equipment, and garden chemicals. Other types of activities varied less than 25% by day of week, including residential use of paints or solvents, personal care products, and paving or roofing materials.

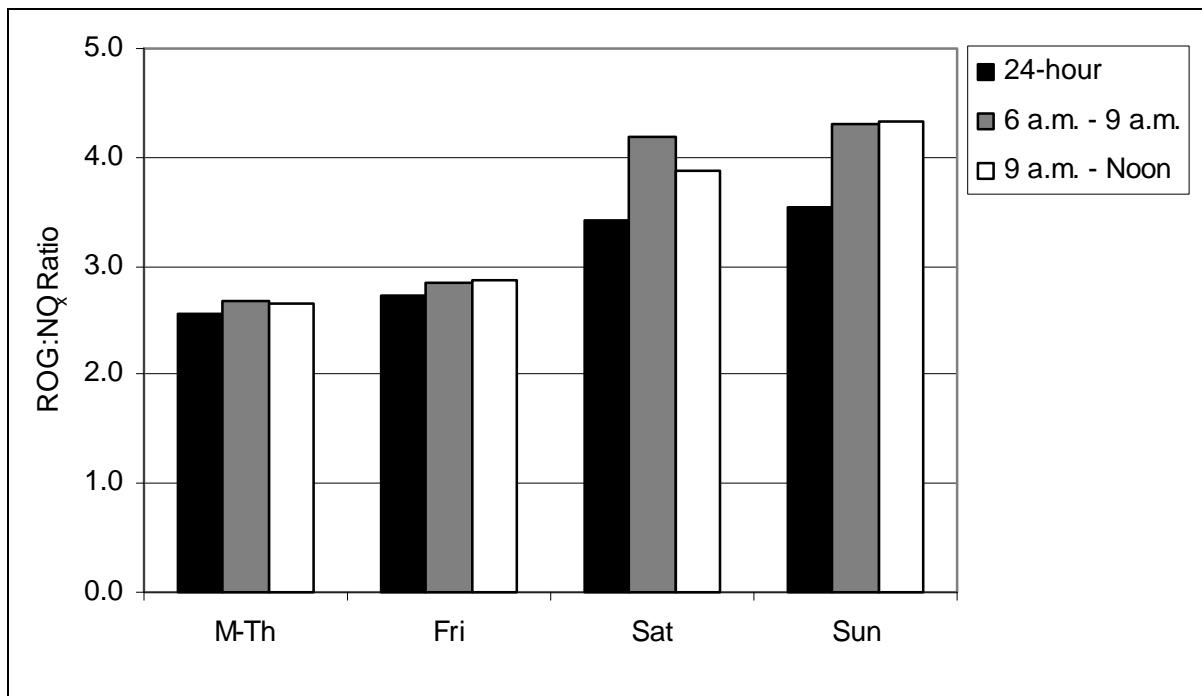
**Figure 7.** Survey-based diurnal distributions of person-hours worked for business activities.



**Figure 8.** Estimated year-2000 summer emissions for the South Coast Air Basin by day of week and emissions source category.



**Figure 9.** Estimated year-2000 emissions-based ROG:NO<sub>x</sub> ratios for the South Coast Air Basin by day of week and time of day.



- Diurnal distributions for some residential activities varied by day of week. On weekdays, 60% to 80% of barbecue use occurred during the evenings. But on weekends, afternoon use of barbecues increased to 35% to 50% of total daily use. No WD-WE dependence was observed in the diurnal patterns for personal care products use and lawn and garden equipment use.
- Business activities declined substantially on weekends (from 45% to 95%). Most types of businesses experienced peak activity levels from 8:00 a.m. through 4:00 p.m. on weekdays and Saturdays and flat activity levels on Sundays. Exceptions are lawn and garden businesses, which peak in activity from 4:00 a.m. through 4:00 p.m. on all 7 days of the week; businesses that use gas ovens, which on weekdays peak slightly later in the day and sustain high levels of activity through the evening hours; and offices, which on Sundays sustain high levels of activity into the evening hours relative to their Sunday peak.
- Some WD-WE decreases in commercial activities offset increases in residential activities. For example, commercial use of lawn and garden equipment decreases from 90% to 95% on weekends relative to weekdays, while residential use increases by 40% to 45%.

We combined these findings with analyses of WD-WE patterns for mobile and point sources (which have been reported elsewhere<sup>4</sup>) to evaluate their potential impacts on weekend ozone formation in Los Angeles. These analyses suggest that weekend emissions patterns in Los Angeles favor ozone formation to a greater extent than do weekday emission patterns, despite predicted weekend reductions in total emissions of ozone precursors. The reason is that weekend NO<sub>x</sub> reductions are larger than the corresponding ROG reductions, which lead to lessened early-morning titration of ozone by fresh NO<sub>x</sub> emissions and increased ambient ROG:NO<sub>x</sub> ratios. (Higher ROG:NO<sub>x</sub> ratios tend to favor ozone production.) This is consistent with observations of enhanced weekend ROG:NO<sub>x</sub> air pollutant ratios for the Los Angeles area<sup>2,3</sup> and supports the hypothesis that ROG controls are effective measures to reduce occurrences of weekend ozone exceedances in Los Angeles.

We consider as preliminary the conclusions based on the survey data because they are derived from surveys conducted in September and October of 2000 or 2001 for small areas of Los Angeles. As such, they may not represent the greater Los Angeles area or the summertime ozone season of Los Angeles. However, they are adequate to help guide further research efforts that are planned for the summer of 2002 by the California Air Resources Board.<sup>9</sup> ARB research efforts planned for 2002 include partial repeats of the data collection efforts presented here but during the summer months; expansion of the geographic study area to the entire Los Angeles air basin; re-design of the surveys to target additional source categories of interest (such as construction) and to better capture infrequent activities (such as fireplace use); and modification of the study period to occur during the summer ozone season. The findings of the 2002 ARB studies will be used to affirm, revise, and augment the preliminary findings presented here.

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