Emissions Inventory Oriented Residential Wood Combustion Survey

Chun Yi Wu
Minnesota Pollution Control Agency, 520 Lafayette Road North, St. Paul, MN 55155

Ronald Piva
U.S. Department of Agriculture, Forest Service, North Central Research Station, 1992 Folwell Ave., St. Paul, MN 55108

David R. Broderick, James E. Houck
OMNI Environmental Services, Inc., 5465 SW Western Ave. Suite G, Beaverton, Oregon 97005

John Crouch
HPBA - Hearth Patio,& Barbecue Association, Sacramento Office, 7840 Madison Ave, Suite 185, Fair Oaks, CA 95628

ABSTRACT

Residential wood combustion (RWC) measurably contributes to air pollution in many areas of the country. To provide a credible accounting of pollution sources, emission inventories need to include RWC. The type and number of RWC appliances, each with their own characteristic emission factors, and the amount and type of fuel-wood used vary significantly on a local scale. Temporal patterns in RWC have also been shown to vary significantly, related in a complex way to energy supply and costs, weather patterns, power-outage history, socioeconomic parameters, and housing age. Regulatory control of RWC has and will continue to be considered to mitigate air pollution. Wood heater "change-outs," which entail the replacement of old uncertified wood space heaters, producing higher air emissions, with new EPA-certified units with lower air emissions, reduces air pollutants from RWC and is being evaluated for $PM_{2.5}$ nonattainment areas. Current and local-scale RWC surveys provide the only acceptable source of information for planning and decision-making. The application of dated, regional-scale, or national-scale data to current state or local needs has generally proven to be unsatisfactory or qualitative at best.

Although many local, state, regional, and federal surveys of residential wood combustion have been conducted in the United States, only a limited number of these surveys have been focused on emission inventory development needs. Many surveys appear to have been conducted primarily for other reasons (e.g., natural resource utilization, local ordinance compliance evaluation, opinion polls, GIS-based modeling, energy consumption studies, etc.) or have not asked the necessary questions to allow for quality emission inventory development due to lack of familiarity with the specifics of home heating as it relates to air emissions. Further, the lack of standard appliance type, fuel type, and fuel metric nomenclature and the prevalence of regional, hearth industry, and air quality jargon has often resulted in confusion and misunderstanding on the part of the survey respondents, survey staff, hearth product industry personnel, air quality regulators, and emission inventory specialists.

This paper describes and analyzes the results from a residential wood combustion survey conducted in Minnesota for the 2002-2003 heating season, conducted, in part, to specifically improve the state's emission inventory. Minnesota air quality regulators, natural resource personnel, air quality scientists specializing in home heating issues, and hearth industry personnel collaborated to produce the survey questionnaire and in the interpretation of the results. The results of the survey provide solid documentation of the key issues relating to appliance types and fuel usage, which it turn will allow for an emission inventory development when emission factors are applied and will allow for air quality mitigation strategies to be developed. The results of the survey are consistent with and confirm many of the wood heating trends and patterns that have been speculated or that have been suggested by the results of other studies and industry records.

INTRODUCTION

During the summer and fall of 2003, the Minnesota Department of Natural Resources (MDNR), the Minnesota Pollution Control Agency (MPCA), the United States Department of Agriculture, Forest Service (USFS), and the Hearth, Patio and Barbecue Association (HPBA) participated in a survey to assess residential wood combustion (RWC) practices in the State of Minnesota during the 2002-2003 heating season[1]. Similar surveys were conducted during the 1979-1980, 1984-1985, 1988-1989, and the 1995-1996 heating seasons[2-4].

While development of data to allow for the estimation of air pollutant emissions from residential wood combustion was a key objective, the survey had other objectives as well. These were:

- Estimation of the total volume of residential fuel-wood harvested and consumed in Minnesota during the 2002-2003 heating season.
- Identification of the sources of residential fuel-wood (if fuel-wood was purchased, given free, or self-harvested).
- Estimation of the volume of residential fuel-wood harvested from different land ownerships, live and/or dead trees, logging residue and/or scrap lumber.
- Determination of the geographic distribution of households burning fuel-wood by type of usage (primary heating source, supplemental heating source, or for pleasure) and the type of wood burning appliance used.
- Identification of trends in residential fuel-wood consumption over time.

The survey questionnaire was designed to be mailed. The questions in the survey questionnaire were kept simple and brief. The survey sample size was based on the total number of households statewide obtained from the 2002 data from the Minnesota State Demographic Center[5]. The population and housing data from the Minnesota State Demographic Center indicated that there was no significant change in the number of households from the previous fuel-wood study in 1996. To be consistent with previous studies, which were designed to have a sampling error of plus/minus six percentage points at a 95% confidence level, the same approach was used for the 2003 survey. The state was divided into five units, four were based on USFS units and the fifth unit was the seven metropolitan counties around Minneapolis and St. Paul. The five units are referred to as: Aspen-Birch, Northern Pine, Central Hardwoods, Metro, and Prairie (Figure 1). Based on calculations from the Minnesota Center for Survey Research at the University of Minnesota, it was determined that 267 completed surveys for each region would result in an acceptable sampling error. The survey was administered by Survey Sampling, Inc. (Fairfield, CT), which provided the mailing list and estimated the number of survey questionnaires to be mailed out by factoring in the rate of deliverable mail at 85% and the expected response rate at 35%. The total number of questionnaires mailed was 6,600. To mitigate the typical low response rate for mailed survey questionnaires, postcards were mailed in May 2003, two weeks before the survey questionnaires were sent out, to alert potential respondents of the upcoming survey questionnaire. When the expected number of responses was not obtained from the mailed survey questionnaires, a selection of names were picked at random from the mailing list and a telephone interview was conducted to complete the study.

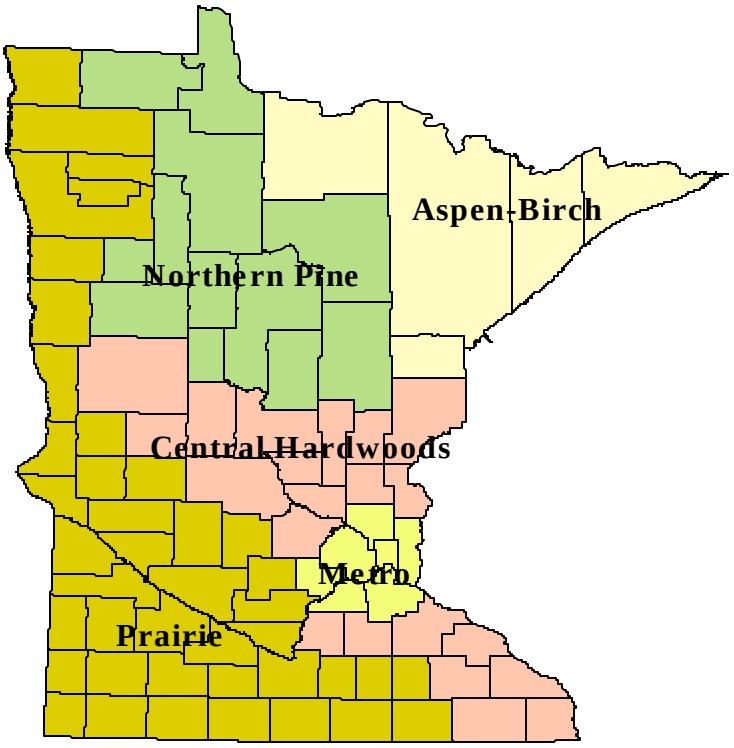

Figure 1 Map of Survey Units.

OVERALL SURVEY RESULTS

A total of 1,408 households responded to the survey either by mail or telephone. Table 1 summarizes, for each region and for the entire state, the total number of survey responses, the number of respondents reporting having RWC appliances, the total number of households, and the population. Table 2 summarizes the percentage and number of households projected from the survey as having RWC appliances, the number and percentage reporting using them, and the overall amount of wood burned in the 2002-2003 heating season. Figure 2 illustrates the change in the overall amount of wood burned in residences since the 1984-1985 heating season.

The data shown in Tables 1 and 2 and in Figure 2 illustrate several key points: (1) Residential woodburning in Minnesota, as it is in many states, is potentially a significant source of air pollutant emissions in that 27.1 % of state residents report owning a woodburning appliance and 20.7% reported using them during the 2002-2003 heating season. (2) The substantial change (decline) in the amount of wood used illustrates the need for updated surveys for accurate emission inventories. (3) The amount of wood burned in any given location is affected by a number of parameters besides simply climate. For example, both the percentage of households owning and using RWC appliances is the highest in the Northern Pine survey unit and lowest in the Prairie survey unit, therefore, availability of fuel probably plays a significant role in

explaining the differences. Another example is that the total amount of wood burned is the highest in the Metro survey unit. In this case, the higher population of that survey unit is the most likely explanation. With local factors, such as fuel availability, urban/rural lifestyle differences, and population density being pivotal for RWC, the Minnesota data illustrate the value of local-scale survey units and the difficulty in applying regional- or even state-scale survey data to the local level.

Table 1
Households Sampled by Survey Unit

Survey Unit	Number of Households Responded	Number of Respondents with RWC Appliances	Total Number of Households in 2002[5]	Population in 2002[5]
Aspen-Birch	301	105	108,747	262,653
Central Hardwoods	348	75	375,520	1,008,558
Metro	252	73	1,053,853	2,708,916
Northern Pine	306	124	112,973	282,585
Prairie	257	50	302,543	770,949
Total	**1,464**	**427**	**1,953,636**	**5,033,661**

Table 2
Households Burning Wood by Survey Unit

Survey Unit	Number of Households With RWC Appliances	Percent of Total Households with RWC Appliances	Number of Households Reporting Burning	Percent of Total Households Burning Wood	Amount of Wood Burned (Cords)
Aspen-Birch	37,900	34.8	32,500	29.9	109,100
Central Hardwoods	80,900	21.5	65,800	17.5	150,900
Metro	305,300	29.2	225,800	21.4	184,200
Northern Pine	45,800	40.5	36,900	32.7	142,800
Prairie	58,900	19.5	42,400	14.0	79,500
Total	**528,800**	**27.1**	**403,500**	**20.7**	**666,500**

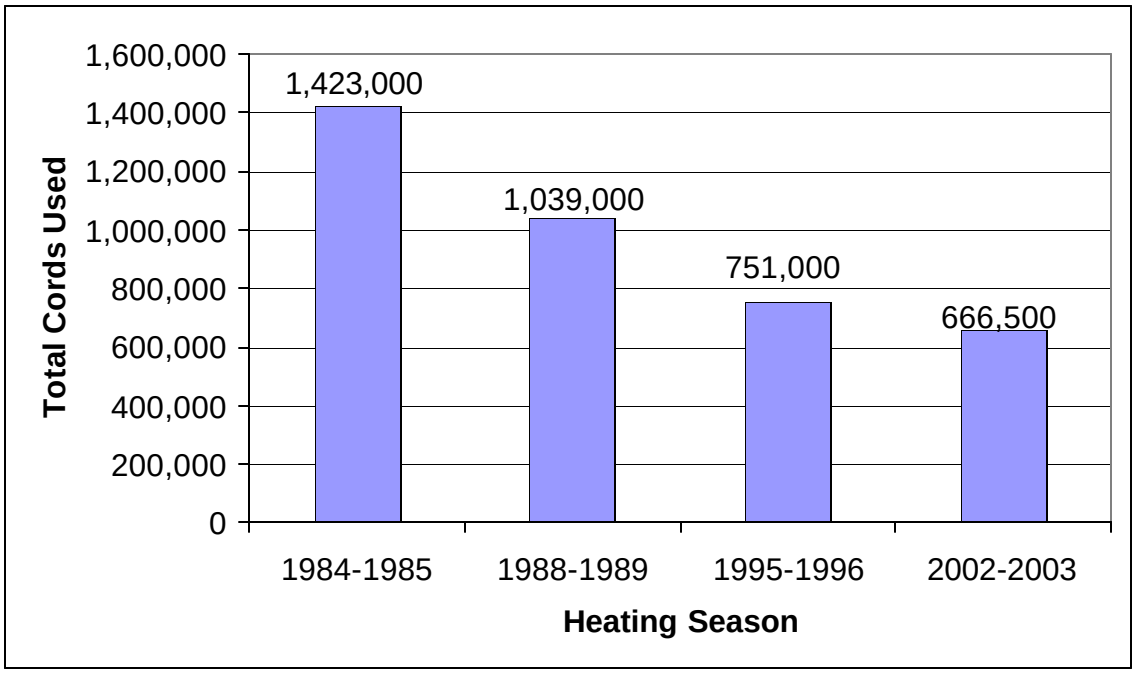

Figure 2 Total Residential Wood Use Trend
Data from references 1-4.

APPLIANCE OWNERSHIP AND USAGE

The data in Tables 3, 4, 5, and 6 illustrate appliance ownership and usage patterns that are essential for realistic emission inventory calculations, for informed regulatory decisions, and for mitigation actions such as wood heater change-out programs.

Table 3
Ownership and Use by Appliance Type

Appliance Type	Number of Appliances Owned	% of Total Appliances Owned	Number of Appliances Used	% Used
Conventional Woodstove	82,000	11.6	64,000	78.0
Certified Catalytic Woodstove	12,700	1.8	12,000	94.3
Certified Non-Catalytic Woodstove	23,700	3.4	22,200	93.9
Conventional Insert	58,800	8.3	56,200	95.6
Certified Catalytic Insert*	361	0.1	361	100
Certified Non-Catalytic Insert*	7,420	1.1	7,420	100
Wood-burning Furnace	46,000	6.5	43,300	94.1
Wood-burning Boiler	15,600	2.2	14,200	90.8
Fireplace	422,100	59.9	308,100	73.0
Firepit	35,800	5.1	35,100	98
Total	**704,700**	**100**	**563,000**	**79.9**

*The values for certified catalytic inserts and certified non-catalytic inserts should be used with caution because they are based on only one and four responses, respectively.

Table 4
Ownership and Use by Appliance Group

Appliance Group	Number of Appliances Owned	% of Total Appliances Owned	Number of Appliances Used	% Used
All Woodstove (Conventional, Certified Catalytic, and Certified Non-Catalytic)*	118,400	16.8	98,200	82.9
All Inserts (Conventional, Certified Catalytic, and Certified Non-Catalytic)*	66,600	9.5	64,000	96.1
All Central Heating (Furnace and Boiler)	61,700	8.8	57,500	93.2
All Uncontrolled Appliances (Fireplace and Firepit)	458,000	65.0	343,200	74.9
Total	**704,700**	**100**	**563,000**	**79.9**

*The total number of wood space heaters (all woodstoves and inserts) is 185,000, which corresponds to 26.2% of the total number of appliances owned. Of the 185,000 space heaters, 162,200 were used, or 87.6%.

Table 5
Ownership of Wood Space Heaters (Woodstoves and Inserts) by Appliance Type

Appliance Type	Number of Appliances Owned	% of Total Number Owned
Conventional Woodstove/Insert	140,800	76
Certified Catalytic Woodstove/Insert	13,100	7
Certified Non-Catalytic Woodstove/Insert	31,100	17
Total	**185,000**	**100**

Table 6
Burning Purpose by Appliance Group

Appliance Group	Did Not Burn	Primary Heat	Supplemental Heat	Pleasure Only
All Wood Space Heaters (Conventional, Certified Catalytic, and Certified Non-Catalytic, Woodstoves and Inserts)	13.1%	18.4%	46.7%	21.7%
All Central Heating (Furnaces and Boilers)	11.8%	63.8%	24.3%	0.0%
All Uncontrolled Appliances (Fireplaces and Firepits)	37.4%	0.1%	9.7%	52.7%
Total	**29.5%**	**9.9%**	**19.7%**	**40.9%**

Note: Only surveys with only one appliance type could be use because the question was not asked on an individual appliance level, this represents approximately 70% of the surveys.

Residential wood burning appliances in use in Minnesota can be broken down into four general categories: (1**) Wood space heaters –** wood space heaters are woodstoves and fireplace inserts. Fireplace inserts are essentially woodstoves designed to fit into existing fireplace cavities and woodstoves and fireplace inserts can be grouped together for emission inventory considerations, as their emission factors are the same. There are two basic types of wood space heaters – those manufactured after 1988 which are EPA-certified and those that were manufactured before the EPA certification requirement which are generally referred to as conventional woodstoves or inserts. Further, EPA-certified wood space heaters are of two technology types – catalytic and non-catalytic. Conventional, EPA-certified catalytic, and EPA-certified non-catalytic wood space heaters all have different emission factors assigned to them. (2**) Uncontrolled appliances** – Uncontrolled appliances include fireplaces and firepits. Fireplaces can be either freestanding or built into the wall. Those that are built into the wall are far more common and are either site-built masonry units or are factory-built installed units. Emission factors for all fireplaces and

firepits are, at the current level of definition, the same. (3) **Centralized heating systems** – Centralized heating systems include warm air furnaces and boilers (more accurately now referred to as hydronic heaters). There are two basic types of hydronic heaters – outdoor and indoor systems. There have been few measurements of emissions from centralized heating systems and they, as a group, are generally assigned the same emission factors as conventional wood space heaters. (4) **Minor RWC Categories** – The usage of minor RWC appliance types such as masonry heaters, cookstoves, hot water heaters, pellet stoves, pellet inserts, and modified fireplaces were either too small in Minnesota to add significantly to the inventory and were ignored or their small contribution to appliance numbers and wood usage were added to the most similar appliance type values, e.g., modified fireplace values (only four survey responses) were added to the conventional fireplace insert values. Similarly, there may be a limited number of phase 1 certified wood space heaters in use but no attempt was made to distinguish them from the far more common phase 2 appliances. (Phase 1 heaters were primarily manufactured between 1988 and July 1990. Appliances manufactured after July 1, 1990 were/are required to be phase 2 certified.)

Table 3 illustrates the ownership and usage of wood burning appliances by type, which is useful data for regulatory decision-making and mitigation strategies, as well as, for emission inventory development. A key point that is often not taken into consideration is the fact that not all wood burning appliances that are owned are used in a given heating season and that fraction is characteristically different for different appliance types. For example, it has anecdotally been suggested that conventional woodstove owners typically use their woodstoves less than the owners of certified appliances as evidenced by the cost associated with purchasing a new certified appliance reflecting a greater intent to heat with wood. The data in Table 3 confirms this perception with 73% of conventional woodstove owners reporting using their appliance as compared to approximately 94% of the owners of certified woodstoves. The data in Table 3 also confirms the observation made from other surveys that about 30% of fireplaces are never used and, in contrast, that fireplace inserts and centralized heating systems have a high usage rate as they were specifically and purposely purchased to fulfill heating needs.

Table 4 (with its footnote) provides the number of appliances owned and used by appliance group. The data illustrated in Table 4 is very consistent with the results of other surveys and industry records, particularly when the facts that fireplaces are less common in colder climates than in milder climates and that historically the highest per capita usage of wood-burning centralized heating systems has been in the upper Midwest are taken into consideration. In summary, the data in Table 4 show that even in the colder climate characteristic of Minnesota, fireplaces (along with firepits) are still the most common wood-burning appliance group (65.0%), that 8.8% are centralized heating systems, and that 26.2% are space heaters (woodstoves plus inserts).

Wood space heater change-out programs have become a well-recognized approach for mitigating high ambient particulate concentrations and new change-out programs are being planned for $PM_{2.5}$ nonattainment areas. Pivotal to wood heater change-out programs is that there are enough older high-emitting conventional heaters in an airshed to allow for a significant difference to be made when they are replaced with new lower-emitting certified units. Industry records suggest that between 70% and 80% of wood heaters nationwide are still older conventional units. The

data from the Minnesota survey show that 76% are still conventional heaters (Table 5). Industry records have also shown that about one third of certified wood space heaters are catalytic and two thirds are non-catalytic. The data illustrated in Table 5 for Minnesota confirms this approximate breakdown. The fraction of certified wood space heaters that are catalytic is important to air quality in that catalysts degrade with use and periodic catalyst inspection and replacement is necessary to maintain low emissions from them.

The reasons for using a wood-burning appliance vary with appliance group. It is generally recognized that fireplaces (and firepits) are used mostly for pleasure, many are not used in a given heating season, and they are virtually never used in colder climates as the primary heating source. The data for Minnesota (Table 6) confirms this pattern with 52.7% of users stating that they use them for pleasure, 37.4% stating that they never use them, and only 0.1% state that they use them as a primary heating source. Similarly, the most common use for wood space heaters, on a national basis, is for supplemental heat and, not surprisingly, centralized heating systems are used in most settings as the primary heating source. The Minnesota data shown in Table 6 confirm these points. In Minnesota, 46.7% of wood space heaters are used for supplemental heat and 63.8% of centralized heating systems are use as a primary heating source. The purpose for use is important for regulatory control as it progressively becomes more difficult to restrict the use of a wood-burning appliances moving from pleasure use, to supplemental heating use, to primary heating use.

ACTIVITY LEVELS

The activity level (dry mass of wood used) by appliance type when multiplied by the appliance-specific emission factor provides the emission results needed for an emission inventory. Table 7 provides the activity level in dry short tons by appliance type and Table 8 provides it by appliance group derived from the Minnesota survey. The average number of cords burned per year, the total number of cords burned, and the percentage of the total wood burned by appliance type and group are also shown in Tables 7 and 8, respectively. As with the other survey results, the average number of cords burned per appliance annually, derived from the survey, are consistent with national average values in the case of wood space heaters and uncontrolled appliances (fireplaces and firepits). In addition, the results are consistent with the general expectation for centralized heating systems. (There is no data on which to base national average levels for centralized heating systems.) The average number of cords burned per appliance in wood space heaters is 1.34 cords/yr, the average number of cords per year burned in fireplaces and firepits is 0.55 cords/yr, and the average number of cords burned per year in centralized heating systems is 4.54 cords/yr.

Table 7
Amount of Wood Burned by Appliance Type

Appliance Type	Average Cords per Year per Appliance	Total Cords Burned per Year	Total Mass of Wood Burned (short tons)*	% of Total Wood Burned
Conventional Woodstove	1.29	82,600	116,500	12.4
Certified Catalytic Woodstove	1.17	14,100	19,800	2.1
Certified Non-Catalytic Woodstove	1.53	34,100	48,100	5.1
Conventional Insert**	1.37	77,100	108,700	11.5
Certified Catalytic Insert**	0.50	181	255	0.03
Certified Non-Catalytic Insert	1.23	9,200	12,900	1.4
Wood-burning Furnace	3.54	153,500	216,400	23.0
Wood-burning Boiler	7.57	107,600	151,700	16.1
Fireplace	0.54	166,300	234,500	25.0
Firepit	0.62	21,700	30,600	3.3
Total	**1.18**	**666,300**	**939,500**	**100**

*Approximate mass calculated using 1.41 short tons/cord conversion, dry basis. See reference 6.
**The values for certified catalytic inserts and certified non-catalytic inserts should be used with caution because they are based on only one and four responses, respectively

Table 8
Amount of Wood Burned by Appliance Group

Appliance Group	Average Cords per Year per Appliance	Total Cords Burned per Year	Total Mass of Wood Burned (short tons)**	% of Total Wood Burned
All Woodstove (Conventional, Certified Catalytic, and Certified Non-Catalytic)*	1.33	130,900	184,600	19.6
All Inserts (Conventional, Certified Catalytic, and Certified Non-Catalytic)*	1.35	86,400	121,800	13.0
All Central Heating (Furnace and Boiler)	4.54	261,100	368,200	39.2
All Uncontrolled Appliances (Fireplace and Firepit)	0.55	188,000	265,100	28.2
Total	**1.18**	**666,300**	**939,500**	**100**

*The average amount of wood burned in each wood space heater (all woodstoves and inserts) is 1.34 cords per year. The total amount of cords burned in all wood space heaters is 217,300 cords or 32.6%.
**Approximate mass calculated using 1.41 short tons/cord conversion, dry basis. See reference 6.

Even though the centralized heating systems represent only 8.8% of the total appliances in use in Minnesota (Table 5), due to the higher average cord per appliance usage characteristic for them, centralized heating systems, as a group, consume more wood than either wood space heaters or uncontrolled appliances. Similarly, even though the uncontrolled appliance group is the largest in terms of numbers owned (65% – Table 5), the lower cords per appliance usage characteristic of them makes the total amount of wood consumed by the group the lowest. The total amount of wood consumed by wood space heaters, centralized heating systems and the uncontrolled appliance group are 32.6%, 39.2% and 28.2%, respectively (Table 8). Because centralized heating systems consumed the largest amount of wood among the appliance groups and the current best estimate for their air pollutant emission factors is that for conventional wood space heaters, it is likely that, as a group, they currently produce the most emissions in Minnesota. This may prove to be a regulatory or mitigation problem for three reasons: (1) They are most commonly used as a primary heat source. (2) There is no low-emission certification program for them as there is for wood heaters. (3) There is a lack of accurate emission factors for them.

It should be noted that the amount of wood burned in the units of cords was converted to the mass of wood burned in short tons (2000 lbs) on a dry basis by using a conversion factor of 1.41 short tons/cord. This conversion factor was derived from the specific mixture of tree species used for fuel that was obtained from the survey questionnaire (percentage breakdown by species) and the characteristic mass per cord of wood for the various species[6]. It also should be noted that the survey questionnaire provided the homeowner with the option of reporting the amount of wood used in the units of "pickup trucks." Factors have been developed for converting wood usage in "pickup trucks" to cords[7] and were used here. Because the overwhelming type of fuel burned was cordwood, the small effect of the very small relative amount of non-cordwood used was ignored in the calculation of the conversion factor. One exception should however be noted, 31,794 households (10.3% of fireplace users) reported using manufactured wax/sawdust logs at least some of the time. Emission factors for manufactured wax/sawdust firelogs are quite different than for cordwood and should be taken into consideration in the calculation of the final emission inventory.

Emission factors are generally in the units of mass of pollutant per dry mass of wood burned therefore the compilations shown in Tables 7 and 8 are on a dry basis. Surveys of residential woodpiles at various locations in the United States have shown that the average wood moisture in residential woodpiles is approximately 24% on a dry basis, therefore the 939,500 tons of wood on a dry basis corresponds to 1,165,000 tons of actual wood burned in Minnesota during the 2002-2003 heating season.

CONCLUSIONS

RWC activity surveys need to be carefully designed in order to deliver meaningful results for emission inventory development and to provide data for air quality planning. The Minnesota survey produced data that addressed these needs well.

The amount of RWC has declined in Minnesota. It is estimated from comparing the 2002-2003 survey with the 1995-1996 survey that there was an overall reduction of air pollutants from RWC of 12%. This illustrates the necessity of current survey data for emission inventory development and mitigation planning.

Differences in RWC usage patterns in localized areas within the state of Minnesota illustrates the value of local-scale (or local-scale units within a larger survey) rather than a state-, regional-, or national-scale surveys applied to local areas.

The mass of fuel-wood burned in conventional space heaters and centralized heating systems is very high in Minnesota. Therefore, regulatory or voluntary management actions, such as woodstove change-out programs, can reduce emissions from RWC.

The Minnesota survey provided quality RWC activity levels for emission inventory development. With quality activity levels such as obtained from the Minnesota survey, the limitations in the emission factor database will be responsible for the greatest uncertainty in the final RWC emission inventory. The results of the Minnesota work illustrates the need for improved RWC emission factors.

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KEY WORDS

Residential wood combustion, Fuel wood, Emission inventory, Minnesota