Review of Residential Wood Combustion Data for Mid-Atlantic and New England States

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ABSTRACT

In many of the areas of the eastern United States with elevated $PM_{2.5}$ levels, residential wood combustion (RWC) has been identified as a potential contributor. There are several sources of data that have been published on RWC activity levels, emissions, and practices covering the Mid-Atlantic and New England states. These include: (1) The MANE-VU Residential Wood Combustion Emission Inventory published by the Mid-Atlantic Regional Air Management Association (MARAMA), (2) Residential Energy Consumption Surveys published by the Energy Information Administration, (3) the National Emission Inventory published by the U.S. Environmental Protection Agency, (4) Simmons Marketing Research reports, and (5) American Housing Surveys for the United States published by the U.S. Department of Commerce and the U.S. Department of Housing and Urban Development. In addition, the results of three RWC surveys at the state-level have been published in the last decade for the Mid-Atlantic and New England area, which allow for comparison of data extrapolated from the national- and regional-scale surveys to the state level for these three states. These are (1) 1995 Delaware Fuelwood Survey, (2) Residential Fuelwood Use in Maine, Results of 1998/1999 Fuelwood Survey, and (3) Vermont Residential Fuel Wood Assessment for 1997-1998. In addition to using the states of Delaware, Maine, and Vermont for comparisons of data obtained from the regional and national surveys, data was extrapolated from the regional surveys to the five counties making up the Pittsburgh, Pennsylvania fine particulate nonattainment area. The Pittsburgh area was targeted for this comparison as a woodstove change-out program is being considered for it as part of the actions to bring the area into compliance with the $PM_{2.5}$ standard. The comparability of the results extrapolated from the various national- and regional- scale surveys was poor, confirming the need for targeted local-scale RWC surveys for specific $PM_{2.5}$ nonattainment areas. Further, the fact that the surveys were designed for purposes other than localized RWC emission inventories, namely, regional haze, energy usage, a national multiple source and multiple pollutant inventory, housing characteristics, and marketing, lessened their effectiveness in acquiring appropriate RWC information needed to assess RWC contributions to airshed $PM_{2.5}$ and for woodstove change-out programs.

INTRODUCTION

With approximately 48 million wood burning appliances in homes in the United States, the contribution of residential wood combustion (RWC) needs to be accurately accounted for in emissions inventories. This is particularly important for the Mid-Atlantic and New England states, where RWC due to the ready availability of fuel, colder climate, and large rural populations, is prevalent. Further, an accurate understanding of RWC practices is necessary to make informed regulatory decisions for the control of RWC emissions or for the implementation of mitigation programs such as woodstove change-outs, particularly in $PM_{2.5}$ nonattainment areas. There are several sources of regional or national data that can be applied to the Mid-Atlantic and New England states[1-5]. Notably, the Mid-Atlantic Regional Air Management Association (MARAMA) published, "The MANE-VU Residential Wood Combustion Emission Inventory" to help address the regional haze issue[1]. Three state-sponsored (Delaware, Vermont, and Maine) RWC surveys[6-8], and local data for the Pittsburgh, Pennsylvania metropolitan statistical area (MSA) published by the American Housing Survey[9] were used to compare the efficacy of scaling regional or national data to the state level (Delaware, Vermont, and Maine) or to the local level (Pittsburgh). All data were scaled to the same geographical area and the same base year (2002) by proportioning by the number of households. Ancillary data needed in the process were obtained from the U.S. Census Bureau county level profiles[10], hearth industry surveys[11], and cordwood species and weight data[12-17].

Pittsburgh was selected for the local-level comparison because it is a $PM_{2.5}$ nonattainment area and a woodstove change-out is planned for it. Five counties make-up the Pittsburgh nonattainment area – Westmoreland, Washington, Beaver, Butler, and Alleghany counties. The Pittsburgh MSA is comprised of these five counties plus one more – Fayette County. The data for the Pittsburgh MSA was adjusted to be consistent with the Pittsburgh nonattainment area by removing the Fayette County contribution by using U.S. Census Bureau county level profiles. Delaware, Vermont, and Maine were selected for the state-level comparisons simply because they were the only northeastern states where surveys could be identified as having been conducted within the last decade.

Regardless of the exact calculation or the statistical manipulations methods used, an emission inventory for RWC is fundamentally the sum of the products of activity levels for the various RWC appliance types and their respective emission factors. For RWC, since wood use is generally reported by volume (cords) and emission factors are generally in the units of mass of pollutant per mass of dry wood (g pollutant/kg dry wood), an additional fundamental step is needed – the conversion of wood volume to dry wood mass. This paper focuses on activity levels and the volume-to-mass conversion. There is a paucity of quality emission factors for most RWC pollutants and a review of the limitations these pose to RWC emission inventories is outside the scope of this review.

APPLICABILITY OF THE MANE-VU SURVEY TO STATE AND LOCAL LEVELS

The MANE-VU survey is notable as it is recent, it specifically targeted RWC, it has gained wide exposure through an internet posting and through presentations at national conferences, and it is especially illustrative of the problems associated with using regional data to apply to state or local areas. Its primary objective (regional haze) is inconsistent with the need for state and local data, which has become a topical issue in part due to $PM_{2.5}$ nonattainment areas. The MANE-VU survey was conducted without regard to state boundaries or important sociodemographic factors, i.e., the 11 MANE-VU states (plus Washington DC) were divided into 24 test matrix cells based on solely urban/suburban, forested/unforested, single-family/multiple-family, and heating-degree day (HDD) characteristics. State and local differences in social and economic factors, regulations, forest management practices, availability of woodburning appliance dealers, prevalence and availability of other fuels, e.g., coal, fuel oil, and natural gas, all effect the number and usage of RWC appliances beyond the simplistic test matrix cell breakdown. Again, while the MANE-VU survey may provide useful insight for its primary objective – regional-scale haze, its application to specific state and local areas is inappropriate as RWC practices change with political boundaries and with many local factors.

The "n" values, i.e., the number of survey responses and the number of respondents indicating that they use RWC are illustrated in Table 1 for the MANE-VU survey. Complex and sophisticated statistical analyses are not needed to understand the limitations of applying the MANE-VU data to the state or local level. Simply and succinctly put, the "n" values are far too small. For example, for the three states (Delaware, Vermont, and Maine) and for the sum of the five counties making the Pittsburgh nonattainment area, which are specifically being evaluated here, the number of respondents indicating that they use RWC were: 2, 12, 45, and 11 as compared to 342,437, 293,708, 650,090, and 906,531 total households in each geographic area, respectively.

Table 1
Mane-Vu RWC EI – Number of Responses and Households
for Each State and for the Pittsburgh Nonattainment Area

Geographical Area	Total Number of Households in Geographical Area	Number of Survey Responses	Number of RWC Households that were Surveyed
Connecticut	1,385,361	74	12
Delaware	342,437	35	2
Washington, DC	274,561	4	2
Maine	650,090	186	45
Maryland	2,144,554	201	45
Massachusetts	2,621,366	127	23
New Hampshire	546,239	83	15
New Jersey	3,309,488	115	21
New York	7,673,327	550	79
Pennsylvania	5,245,052	449	85
Rhode Island	439,713	24	7
Vermont	293,708	57	12
Total	**24,925,896**	**1905**	**348**
Pittsburgh NAA	906,531	47	11

As noted, the factor to convert the volume of wood burned (cords) into the dry mass of wood burned is very significant in the development of activity levels used to produce a RWC emission inventory because typically survey respondents report the amount of wood that is burned in the units of cords whereas emission factors are typically in the units of mass pollutant per dry mass of wood burned. The mass of a cord of wood varies with tree species, with hardwoods (wood from deciduous trees) generally weighing more than softwoods (wood from coniferous trees). The correlation between cords and mass is not a true density correlation because of the spacing associated with stacking of fuelwood pieces. Table 2 illustrates the typical range in conversion factors, with the lower values associated with areas that burn more softwood and higher values associated with areas that burn more hardwood. Composite estimates of conversion factors from all of the species that were identified from the various surveys were made. National values and values for several Mid-Atlantic states, for which independent data were available (New Jersey, Maryland and New York)[12] are shown in Table 2. The National values are lower (approximately 1.2 tons/dry cord) due to more softwood being burned in the western United States. The three Mid-Atlantic states for which data were available and the state of Minnesota predominately burned hardwoods and their conversion factors were higher (approximately 1.4 tons/dry cord). (Minnesota is shown because a quality statewide RWC survey was recently completed there[18].) Conversion factors are also shown for West Virginia and Virginia due to the availability of data for them[14], their proximity to the Mid-Atlantic states, and the fact they show the effect that the varying hardwood/softwood mix has on conversion factors. West Virginia burns about 75% hardwood and

25% softwood and its conversion factor is 1.29 tons/dry cord. Virginia burns about 65% hardwood and 35% softwood and its conversion factor is 1.23 tons/dry cord. The conversion factors for West Virginia and Virginia compare favorably to the three Mid-Atlantic states shown in Table 2 when the facts that the three Mid-Atlantic states burn 93% to 97% hardwood and their conversion factors range from 1.37 to 1.44 tons/dry cord are taken into consideration. The authors calculated a conversion factor from the MANE-VU raw survey data (predominately hardwood is burned in the states covered by MANE-VU) as being 1.45 tons/dry cord. An unexplainably high conversion factor of 1.8 tons/dry cord was used in the Mane-VU emission inventory calculations[1]. It needs to be emphasized that an accurate (particularly accurate locally) conversion factor needs to be used because the conversion factor has a direct one-to-one effect on the final emission inventory results.

Table 2
Cord Wood Conversion Factors

Geographic Area	Source	Tons/Dry Cord*
National	EIA/NEI	1.16
National	Caltech	1.23
MANE-VU	MANE-VU Survey, MARAMA Calculated	1.8
MANE-VU	MANE-VU Survey, OMNI Calculated	1.45
New Jersey	U.S. Forest Service	1.44
Maryland	U.S. Forest Service	1.44
New York	U.S. Forest Service	1.37
Minnesota	State Survey	1.41
West Virginia	Southern States Energy Board	1.29
Virginia	Southern States Energy Board	1.23

*tons are English (short) tons, i.e., 2000 lbs.

PREDICTION OF WOOD USE AT THE STATE AND LOCAL LEVELS

While activity levels (wood usage) are needed for each individual RWC appliance type (i.e., wood heaters, fireplaces, centralized heating systems, etc.) for an emission inventory since emission factors are different for different appliance types, the comparison of the overall total amount of wood used for residential heating predicted from the various databases allows for a direct and perhaps the most fundamental assessment of the level of agreement among them. Table 3 shows total wood usage calculated by six different methods utilizing different survey data and/or calculation methods. The Pittsburgh nonattainment area and the three states for which there are state surveys available are included in the table. The state of Pennsylvania was also included since the five counties that make up

the Pittsburgh nonattainement area are, in terms of the number of households, a significant fraction of the state (17%).

Table 3
Wood Use By Example States and the Pittsburgh Nonattainment Area,
Dry Tons/Year

Geographical Area	MANE-VU (back calculated from final report*)	OMNI (calculated from Mane-Vu EI raw data, 1.45 tons per cord conversion factor)	EIA 2002 (adjusted from 2000 survey, 1.163 tons/cord conversion factor)	NEI 2002 (from NEI database)	State Survey (adjusted to 2002)	AHS/Census/ EIA
Delaware	74,900	72,900	60,500	75,400	67,500	29,000
Maine	820,600	533,000	150,500	285,800	580,200	91,900
Pennsylvania	2,628,800	1,944,600	588,500	889,800	-	1,718,300
Vermont	387,300	242,200	69,800	126,500	276,700	42,900
Pittsburgh	323,800	235,900	111,800	152,400	-	169,800

*Wood use was not presented; these data were back calculated from final emission inventory results.

The data in Table 3 illustrate two things. With the exception of the state of Delaware, the wood usage predicted from the MANE-VU data is markedly the highest. This is in large part due to the high 1.8 tons/dry cord conversion factor used. Secondly, for each geographical area the range of predicted wood usage is large, for example, in the worst case (Vermont), there is almost an order of magnitude difference between the lowest and highest predicted wood usage. Because there are a number of complex factors that contribute to the amount of wood predicted to be consumed by RWC it is beyond the scope of this paper to address all the problems in detail. There are, however, several obvious causes for the large variations; (1) As noted, the differences in the tons to dry cords conversion factors can make a significant difference. (2) The confusion over the term dry wood has potentially caused some errors in the prediction of wood usage. The dry wood usage values shown in Table 3 are tons of wood adjusted to 0% moisture because emission factors are in the units of mass pollutant per tons of dry (0%) wood. On the other hand, dry wood to a home user or a fuelwood supplier often simply means wood with a moisture content of about 20% or less. Additionally, the lack of awareness in the difference or confusion between the terms moisture on a “dry basis” or on a “wet basis” can cause considerable differences in wood use numbers. Finally, confusion and errors can be caused by the fact that natural resource or energy related wood use values often reflect a mass number that is different than the “dry” mass number since the average moisture of cordwood in the U.S. is 24.1%[19](dry basis) making actual wood mass numbers higher than those reported as dry wood. (3) Differences in the regional state groupings unrealistically influence the results of wood use calculations. For example, Delaware is grouped into the South U.S. Census region and the South Atlantic Census division.

Because these include states with very mild climates, such as Florida, the mean wood usage from which the Delaware state values are derived based on these grouping are unrealistically low. (4) Virtually all data were obtained from surveys that were not primarily designed for emission inventory purposes; therefore considerable assumptions and extrapolations are needed to apply the data for wood use calculations.

In summary, the wide variation in the wood use values predicted by the various surveys, confirms that the existing database for the Mid-Atlantic and New England states is of limited value when applied to the state or local levels. Local surveys designed specifically for emission inventories are needed to provide acceptable wood use data (activity levels) for state or local emission inventories in the region.

PREDICTION OF RWC APPLIANCE TYPES AT THE STATE AND LOCAL LEVELS

Knowing the number of appliances by type that are used is important for two reasons. First, it is essential in the development of emission inventories as different appliance types have different emission factors. Second, the efficacy of regulatory control options or mitigation strategies can only be judged when the magnitude of their effect can be estimated by the number of appliances involved. For example, the magnitude of the effect of a woodstove change-out program is directly related to the number of older conventional stoves that are available for replacement with low-emitting certified stoves. Tables 4-6 show the number of RWC appliances by type in use for the three states for which there are RWC surveys available that were conducted in the last decade (Delaware, Maine, and Vermont)[6-8]. Table 7 shows the number of RWC appliances in use by type for the Pittsburgh nonattainment area, which has as a local source of data, the 1995 American Housing Survey conducted in the Pittsburgh MSA[9]. It needs to be remembered that there are more appliances that are owned than the number in use. For example, roughly one-quarter to one-third of fireplaces are not used in any given heating season and about 20% of woodstoves are not used. To be consistent with emission inventory, regulatory decision-making, and planning needs, four primary RWC appliance categories are included in Tables 4-7. These are (1) fireplaces, (2) central heating units, (3) all wood heaters (sum of woodstoves and fireplace inserts), and (4) pellet. The “all wood heaters” category was further broken down into certified wood heaters (woodstoves and inserts) and conventional wood heaters (woodstoves and inserts). (There are also minor RWC categories such as masonry heaters, firepits, cookstoves, and water heaters but their contribution to RWC emission inventories is insignificant.)

Table 4

Number of Appliances Used by Geographic Area – Delaware*

	MANE-VU	State Survey**	AHS	Simmons Research
Fireplaces	26,900	67,500	25,600	-
Central Heating Units	0	11,800	-	-
Pellet	1,970	1,890	-	-
All Wood Heaters (Woodstoves and Inserts)	12,000	20,400	52,000	34,800
Certified Woodstoves or Inserts	4,570	8,390	-	-
Conventional Woodstoves or Inserts	7,470	12,000	-	-

Note: Simmons Research reports number of wood heaters owned, so that number was adjusted to 90% to reflect those households that do not use their appliances.

*There were 74 responses within the state of Delaware in the MANE-VU survey of which two were wood appliance users. The state survey was based on 879 responses.

**The Delaware survey only reported appliances owned, so that data was adjusted using best professional judgment to reflect the number of households that use their appliances (fireplaces 73%, central heating units 93%, pellet and certified appliances 96%, and conventional woodstoves and inserts 80%)

Table 5

Number of Appliances Used by Geographic Area – Maine*

	MANE-VU	State Survey	AHS	Simmons Research
Fireplaces	46,300	-	18,800	-
Central Heating Units	18,900	17,800	-	-
Pellet	4,090	3,820**	-	-
All Wood Heaters (Woodstoves and Inserts)	78,600	112,040	97,900	85,600
Certified Woodstoves or Inserts	32,200	-	-	-
Conventional Woodstoves or Inserts	46,400	-	-	-

*There were 186 responses within the state of Maine in the MANE-VU survey of which 45 were wood appliance users. The state survey was based on 407 responses.

**Includes other minor RWC appliance types in addition to pellet-fuel appliances

Note: Simmons Research reports number of wood heaters owned, so that number was adjusted to 90% to reflect those households that do not use their appliances.

Table 6

Number of Appliances Used by Geographic Area – Vermont*

	MANE-VU	State Survey	AHS	Simmons Research
Fireplaces	21,400	13,700	8,760	-
Central Heating Units	9,700	17,800	-	-
Pellet	2,120	-	-	-
All Wood Heaters (Woodstoves and Inserts)	36,900	61,500	45,700	39,800
Certified Woodstoves or Inserts	15,200	18,800	-	-
Conventional Woodstoves or Inserts	21,700	42,700	-	-

*There were 57 responses in the state of Vermont in the MANE-VU survey of which 12 were wood appliance users. The state survey was based on 482 responses.

Note: Simmons Research reports number of wood heaters owned, so that number was adjusted to 90% to reflect those households that do not use their appliances.

Table 7
Number of Appliances Used by Geographic Area – Pittsburgh Nonattainment Area*

	MANE-VU	Pittsburgh AHS	Simmons Research
Fireplaces	91,600	82,500	-
Central Heating Units	1,810	-	-
Pellet	5,440	-	-
All Wood Heaters (Woodstoves and Inserts)	40,800	50,000	113,000
Certified Woodstoves or Inserts	13,600	-	-
Conventional Woodstoves or Inserts	27,200	-	-

*There were 47 responses in the Pittsburgh nonattainment area in the MANE-VU survey of which 11 were wood appliance users. The AHS survey for the Pittsburgh MSA was based on 4153 responses. When reduced in proportion to population to remove Fayette County and make it consistent with the Pittsburgh nonattainment area this corresponds to 3895.
Note: Simmons Research reports number of wood heaters owned, so that number was adjusted to 90% to reflect those households that do not use their appliances.

The estimation of the number of appliances by type using the various databases showed poor correlation in all four geographical areas. As with the prediction of wood usage from surveys, there are a number of complex factors that can effect the prediction of the number of appliance types from the survey data. Again it is beyond the scope of this paper to address them in detail, however there are several obvious causes. These include: (1) Fireplaces with and without inserts are often confused and/or double counted. (2) The term fireplace insert is often confused with manufactured built-in fireplaces as they are "inserted" into the wall. (3) The recognition of EPA certified appliances by home occupants is often inaccurate since many have safety labels that are not associated with EPA low emission certification. (4) Home occupants are often not the original purchaser of a wood heater and the date of purchase is not known (certified wood heaters were phased into use almost 15 years ago). (5) Large woodstoves are frequently incorrectly referred to as furnaces. (6) Ten to twenty percent of households have multiple woodburning appliances that may not be adequately counted. (7) Gas-fired fireplaces are common and can easily be confused with woodburning fireplaces or inserts.

Not only are there these aforementioned inherent issues associated with estimating appliance numbers, most surveys have not been primarily designed for emission inventory development and simply do not include appliance-specific questions. As with predicting wood usage, accurate numbers of appliances

by type can only be obtained by emission-inventory focused local surveys. For the Mid-Atlantic and New England states these surveys currently do not exist.

CONCLUSIONS

The application of regional surveys, such as the MANE-VU survey, to local areas does not provide the quality data needed for RWC emission inventories, air quality planning, or mitigation programs. In addition, even state and local surveys not designed with emission inventory or RWC mitigation programs as their primary objective often do not provide the database that is needed. Local or state surveys however can be designed, as evidenced by the recent Minnesota survey[18], to provide appropriate RWC information. To the author's knowledge, such information is not currently available for any of the relevant $PM_{2.5}$ nonattainment areas in the Mid-Atlantic and New England states.

REFERENCES

1. Final Report: MANE-VU Residential Wood Combustion Emission Inventory, E.H. Pechan & Associates, Inc. prepared for MARAMA, June 22, 2004.

2. Residential Energy Consumption Surveys, 2001 Consumption and Expenditures Tables, Energy Information Administration, Washington, DC, 2001.

3. American Housing Survey for the United States: 2001, American Housing Survey, October 2002.

4. 2002 National Emission Inventory, U.S. Environmental Protection Agency: Research Triangle Park, NC, March 2005.

5. National Consumer Study, Spring 2003: Adult Full Year (June 2002-May 2003), Simmons Market Research Bureau, New York, NY, 2003.

6. Report on the 1995 Delaware Fuelwood Survey, Delaware Forest Service, May 1995.

7. Vermont Residential Fuel Wood Assessment 1997-1998, Vermont Department of Public Service, December 2000.

8. Residential Fuelwood Use in Maine, Results of 1998/1999 Fuelwood Survey, Maine State Planning Office, November 1999.

9. American Housing Survey for the Pittsburgh Metropolitan Area in 1995, American Housing Survey, 1995.

10. Profile of General Demographic Characteristics: 2000, data for Pennsylvania counties, U.S. Census Bureau, Census 2000.

11. Fireplace and Freestanding Stove Usage and Attitude Study 2002, Hearth, Patio & Barbecue Association, 2002.

12. Residential Fuelwood Demand Assessment, United States Forest Service, Northeastern Area, October 1981.

13. Extension Circular 1023, Hansen, H.J., Oregon State University, Corvallis, Oregon, Sept. 1980.

14. Residential Fuelwood Consumption in the Southeastern United States, The Gallup Organization, prepared for the Southern States Energy Board, August 1991.

15. Chemical Characterization of Fine Particle Emissions from Fireplace Combustion of Woods Grown in the Northeastern United States, Fine, P.M., California Institute of Technology, published in Environmental Science and Technology, Vol. 35, No. 13, 2001.

16. Estimates of U.S. Biomass Energy Consumption 1992, Energy Information Administration, Washington, DC, May 1994.

17. Documentation for the 2002 Draft Nonpoint Area Source National Emission Inventory for Criteria and Hazardous Air Pollutants, U.S. Environmental Protection Agency: Research Triangle Park, NC, March 2005.

18. Emissions Inventory Oriented Residential Wood Combustion Survey, Minnesota State Survey, Wu, C.Y., Piva, R., Broderick, D.R., Houck, J.E., and Crouch, J., 14th Annual Emission Inventory Conference, March 2005.

19. Updated Emissions Data for Revision on AP-42, section 1.9, Residential Fireplaces, Houck, J.E., Crouch, J., report prepared by OMNI Consulting Services, Inc. and Hearth, Patio and Barbecue Association, December 18, 2002.