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Project Summary

The Northeast Cooperative Woodstove Study

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This report gives results of a 2-year study in Vermont and New York, monitoring woodstove performance. The objective of the study was to determine the effectiveness of catalytic and non-catalytic low-emissions woodstove technology in reducing wood use, creosote accumulation, and particulate emissions. Wood use and creosote accumulation in chimney systems were measured in 68 houses over two heating seasons. Of these houses, 42 were instrumented to measure particulate emissions and directly measured wood use. Catalytic woodstoves, catalytic add-on/retrofit devices, and non-catalytic low-emission stoves were provided by various woodstove manufacturers for use by volunteer homeowners during the study period. Conventional technology stoves were also included to provide baseline data.

Averaged results indicate that the low-emission non-catalytic stoves and catalytic stoves had lower creosote accumulation, wood use, and particulate emissions than conventional technology stoves, but the range of values was quite large. Particulate emissions reductions by the catalytic and low-emission stoves were not as great as could be expected based on laboratory tests. The many variables affecting stove performance in real world conditions make it difficult to identify causative factors. Additional analysis of data and further tests are currently planned.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in two separate volumes of the same title (see Project Report ordering information at back).

Introduction

Woodstove performance was studied during the 1985-86 and 1986-87 heating seasons in the Northeast. In the Waterbury, VT, and Glens Falls, NY, areas, 68 homeowners were provided with selected "advanced technology" stoves or asked to use their existing (conventional) stoves for the study. The stoves were monitored for wood use, creosote accumulation in the chimney system, and particulate emissions. Three advanced technology stove categories (catalytic stoves, add-on/retrofit devices, and low-emission, non-catalytic stoves) were compared with conventional technology stoves. Objectives of the study were to evaluate the performance of the advanced technology stoves for safety factors (creosote), efficiency (wood use), and environmental impacts (particulate emissions). The effectiveness of catalytic combustors was emphasized.

Creosote and woodpile volumes were measured on all 68 houses. Creosote accumulation was measured by periodically sweeping the chimney system and weighing the collected material. Wood use was monitored by measuring wood piles during the heating season and normalizing for moisture content and fuel species.

Additionally, 34 houses were routinely sampled for particulate emissions over 1-week periods. These houses had data logging systems to record stove temperatures, flue gas oxygen concentrations, and wood weights. Particulate samples consisted of integrated samples collected every half hour during each week-long sampling period. Flue gas flow rates were calculated based on combustion stoichiometry: burn rates, fuel species, flue gas oxygen measurements, and estimated CO/CO_2 levels.

Note that many variables were found in field stove installations: chimney systems, fuel characteristics, user practices, stove maintenance, etc. The range of values recorded in all categories was quite large. Reported data, while representing the values recorded during this study, may not be representative of other climates, fuel woods, stove or catalytic combustor models, chimney systems, or stove use patterns. Great care should be used in extrapolating these findings to other circumstances.

Due to the high variability and large range of data, averages from advanced technology stove groups, in most cases, were not statistically different from the conventional stove group. "Student's t" tests showed that only the low-emission non-catalytic stove group had a mean particulate emission rate with a greater than 90% probability of being different and hence lower than those from the conventional stove group. Emissions from individual stove models, however, often were statistically different from the mean of the conventional stoves. All advanced technology devices (catalytic, add-on/retrofit, and low-emission non-catalytic) showed lower average particulate emission rates, wood use, and creosote accumulation than the conventional technology. Figure 1 summarizes averaged results from the stove technology groups.

The stove technology group data represent averages, and reflect a wide range of values. In general, all stove categories, including conventional stoves, had models and specific installations with low (and high) particulate emissions. It is therefore most appropriate to evaluate stove performance on a model-by-model basis, recognizing that (due to the relatively few installations and stove models) values may not be representative of "typical" stove performance.

Although the number of samples is high, the wide range of values and the many variables make it difficult to identify causative factors. Results given in this report are from a number of stove types and models in different installations, in which homeowners used different fuels and operating procedures. A thorough review of stove burn rates, fuel loading practices, catalyst operation times, and frequencies of alternate heating systems did not identify a single factor responsible for emission patterns. This indicates that, while many factors can affect particulate emission rates, no single factor appears to be dominant in all stove types or models. In general, however, it appears that stoves with smaller fireboxes, regardless of technology type, tend to have lower emission rates.

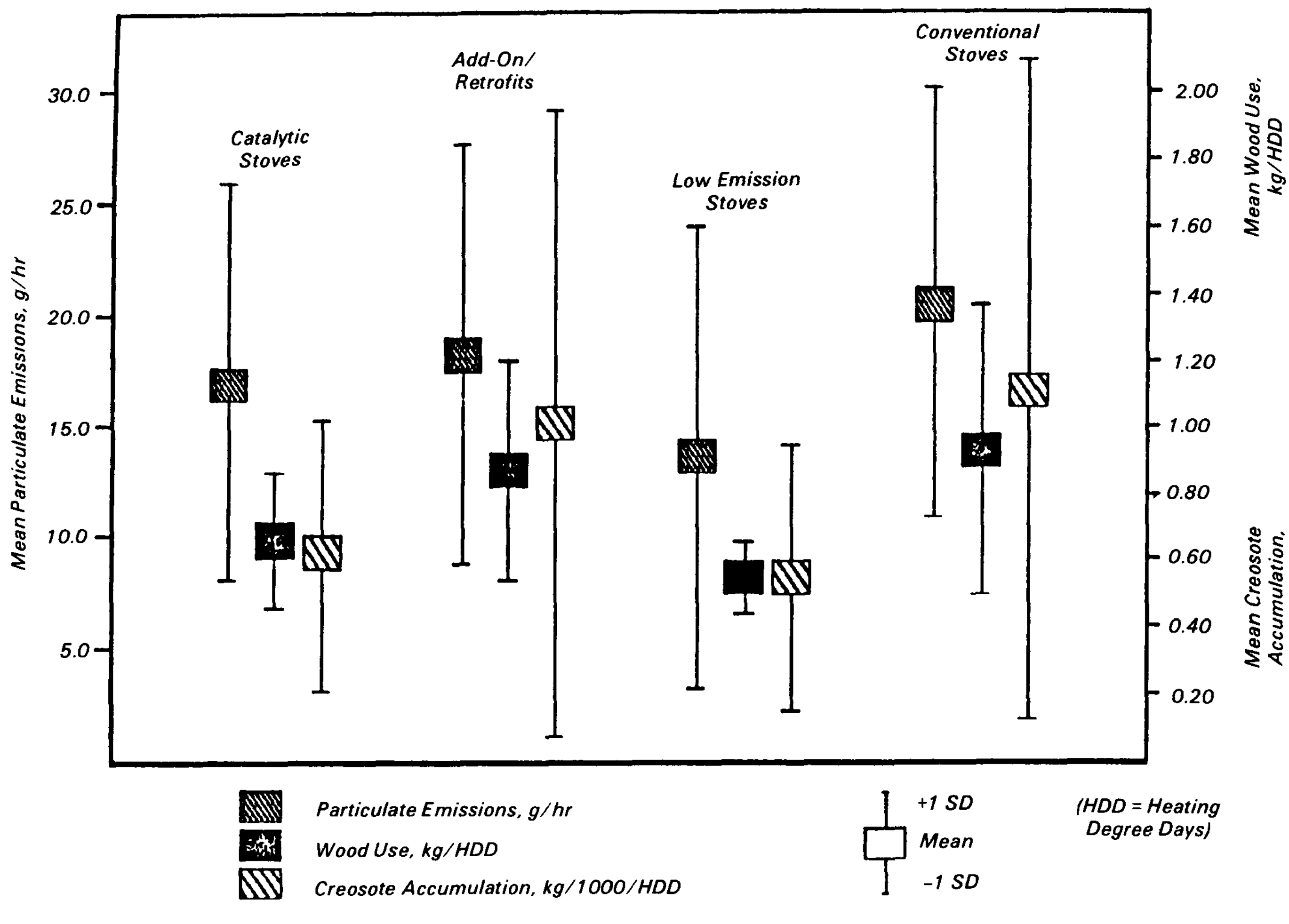

Figure 1. Performance comparison by stove technology.

Conclusions

General conclusions are listed below by category: Advanced Technology Performance, Catalyst Performance, Operator Practices, Technology Factors, and Other Findings.

Advanced Technology Performance

1. Most stoves in the advanced technology categories (catalytic, add-on/retrofit, low-emission non-catalytic) episodically demonstrated lower emissions than the baseline conventional stoves under field use conditions. Good performance in at least one installation for most of the stove models indicates that factors, such as stove maintenance and fueling practices, may be as important as stove technology features in achieving low emission rates. Stove firebox size, regardless of technology group, was a prime factor in determining emission rates; smaller stoves had lower emissions.

2. In general, performance of the stove technology groups appeared to be consistently ranked in terms of particulate emission rates, wood use, and creosote accumulation; low-emission non-catalytic stoves had the lowest particulate emission rate, wood use, and creosote accumulation, while conventional stoves had the highest. Note that only low-emission non-catalytic stoves showed a mean emission rate which was statistically different from that of conventional stoves. Also note that creosote accumulation is strongly influenced by flue system type, and wood use appears to be influenced by burning patterns and firebox size.

3. All advanced technology stove groups averaged lower wood use and creosote accumulation rates when households switched from conventional stoves between heating seasons. Average reductions by stove group ranged from about 10 to 35% for creosote, and from about 15 to 30% for wood use.

4. The low-emission stoves, as a group, had the lowest average emissions. Each model had different burning characteristics; most showed relatively good performance. Average results from this technology group are strongly influenced by the good performance of two stoves (M and N) which may be EPA 1990-certifiable. Furthermore, excluding one high-emission house (V18, using non-EPA-certifiable Stove K) would reduce average emissions in this category from 13.4 to 10.0 g/hr, and reduce the standard deviation (σ) from 10.2 to 5.7.

5. User satisfaction was generally high with the advanced technology stoves provided to study houses. In particular, homeowners with catalytic and low-emission stove models were frequently pleased with the units. (In some cases, user satisfaction remained high even though the catalytic combustor had deteriorated.) Some add-on devices also received positive comments. The add-on with the lowest average particulate emission rate also received homeowner complaints about smoke spillage.

Catalyst Performance

1. Catalytic stoves showed variable performance. Most individual models performed well in some houses. Other installations had relatively high emissions. Overall, performance of these stoves did not match the expectations created under ideal laboratory conditions, although only one of the catalytic models may be EPA 1990-certifiable. The mean emission rates of existing catalytic stoves and new catalytic stoves were virtually identical User education and further technology refinements remain possible factors which could help improve the performance of catalytic stoves.

2. Add-on/retrofit devices did not perform well overall, but two devices reduced emissions considerably. The stoves on which these devices were mounted are a major factor in measured emission rates. Retrofit F, which consistently had high emissions, is no longer being produced.

3. Catalyst durability was quite variable. Rapid deterioration was noted in some combustors, all of which were cordierite-based, with corresponding increases in emissions. In one stove model (which apparently accelerated combustor deterioration), replacement with second generation, non-cordierite combustors appeared to virtually eliminate the deterioration trend. Emissions from this stove model were reduced by about 30% by using second generation combustors during the second year, although it is not clear whether this was from improved catalytic performance or reduced degradation.

4. Overall, there did not appear to be a consistent increase in particulate emissions from catalytic devices over the 2-year testing period. No clear trend of long-term loss of effectiveness was noted. However, a number of combustors (cordierite-based) were discovered to be deteriorating. These combustors were replaced; emission values reported in this study reflect relatively frequent catalyst inspections and replacement when necessary. Note, however, that not all cordierite-based combustors in the study indicated signs of deterioration of the substrate. A cordierite-based combustor from an existing stove with an estimated 6000 hours of use showed relatively low emissions in laboratory retesting. All combustors retested in the laboratory had reduced performance relative to new combustors.

5. Condensation of moisture and organic material in flue systems and subsequent drainage or leaching of condensate was a problem in some houses during very cold (< 20°C) weather Only catalytic stoves experienced this problem. This appears to be related to inappropriate installation and is not necessarily a technology limitation

6. Catalyst ΔT (temperature change across the combustor) and percent operation time are not good indicators of stove particulate emissions Factors such as fueling cycles (long burn-down "tails") and measurement difficulties may preclude the use of these parameters for predicting emission rates.

Operator Practices

1. Operator practices, in combination with other parameters, appear to

be a significant factor in stove performance. Specific practices which may result in lower emissions from all stoves have not been identified from available data. However, routine maintenance inspections of the combustor, gasketing, and overall stove system can help identify deteriorated components in need of repair or replacement.

2. *Burn rates did not demonstrate a* strong correlation with emission rates for any of the stove technology groups, although general trends were observed. Often, as with conventional stoves, the trend was opposite that which was expected; emissions increased with burn rate. This may be related to field conditions, in which lower burn rates may include longer "charcoal phase" burning periods.

3. Mean fuel loading frequencies were identical for the low-emission and conventional stove groups, although the average low-emission stove fuel load was 56% that of the average conventional stove fuel load. This indicates that smaller firebox capacity (typically associated with low-emission stoves) does not necessarily require more frequent fueling of the stove. User satisfaction was generally high with the low-emission stoves.

4. Average emission factors (g/kg) for all the stove categories were quite similar. Differences in average emission rates (g/hr) were therefore driven by burn rates. The low average burn rate of the low-emission stoves, and resulting low average emission rate, may be due to more frequent "charcoal phase" burning periods.

5. Fuel loading frequencies did not correlate well with particulate emissions. However, loading frequencies did increase with smaller fuel loads for all technology groups, as was expected.

6. Fuel loading frequencies were significantly different between houses, even those using the same stove model.

7. The lack of strong correlations between particulate emissions and other variables indicated that many parameters have significant, if unquantified, effects on stove performance. Fueling and burning cycles are thought to be areas for further investigation.

Technology Factors

1. Firebox size is a major factor in determining particulate emissions from woodstoves; emission rates increased with firebox volume, regardless of stove technology.

2. *Preliminary results from stove* inspections conducted after the second heating season (September 1987) indicate that significant leakage of smoke around combustors may be a cause of high emissions in some stoves. (A separate report on this work will be issued.) Stove inspections showed that gasketing, especially around the bypass damper and combustor, was the most frequent component in need of maintenance and the apparent cause of leakage. Leakage rates and particulate emissions do not appear to correlate well overall, but show some correlation for individual stove models.

3. Using a qualitative measurement methodology, insulated metal chimney systems accumulated the least amount of creosote. Masonry chimneys located on outside walls accumulated the most.

Other Findings

1. This study did not show that one stove model is necessarily better than another. As stated previously, a wide range of results were recorded. For a given stove model, the most emission samples was 19; the fewest was 1. The most installations for a given stove model was four; the fewest was one. The high degree of variability in performance and the relatively small sample populations make comparisons inappropriate.

2. Conventional stoves in this study may be cleaner-burning heaters *than are "typical."* Four of the six conventional stoves had relatively small fireboxes (< 2.4 ft^3), and two of these had small *effective* fireboxes (< 1.5 ft^3). Emissions from these stoves therefore may not be typical of existing stove technology. Additionally, the cold Northeast climate and commensurately higher burn rates preclude direct comparison to stove performance in milder climates.

3. Alternate heating system use did not correlate well with particulate emission rates or burn rates, although heating system use was monitored only in the room with the stove. In general, most houses in the study used their alternative heating system less than 3.5% of the time (while the stove was operating). This amounts to less than 1 hour per day. Many of the houses used no backup heat at all.

4. Polycyclic organic material (POM) emissions were variable and nonconclusive. Testing method and analytical method limitations, and a very limited database, preclude any ranking of POM emissions by stove type.

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The complete report consists of two volumes, entitled "The Northeast Cooperative Woodstove Study:"
"Volume I," (Order No. PB 88-140 769/AS; Cost: $32.95)
"Volume II. Technical Appendix," (Order No. PB 88-140 777/AS; Cost: $19.95)
The above reports will be available only from: (costs subject to change)
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