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Director Research & Development

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ADDRESSING THE ISSUE OF WOOD LOADING FACTORS OF WOODSTOVES:
How Much Wood Do Homeowners Load into Their Stoves?

The wood load issue has become a hotbed between the WHA and Oregon's DEQ. Both groups recognize that emissions testing should utilize wood loads that agree closely with homeowner wood loading patterns. The DEQ has adopted 7 pounds of wood per cubic foot of usable firebox volume in their protcol. However, the WHA claims that a dramatically larger value (about 17 pounds per cubic foot of firebox) is a more realistic value.

The data supporting the WHA's position was obtained in laboratories except in one case where it was from a test run in a home by laboratory techinicians. All of the WHA data is in surprisingly close agreement and supports their claim of 17 pounds per cubic foot of fiberbox. However this data is open to question. The laboratory wood loading practices used makes the applicability of this data to real world home burning practices highly suspect. The WHA did not use data from actual in-home tests, claiming that it was too difficult to collect this kind of data. As you shall see, the lack of in-home data has seriously biased the WHA's position on wood loading densities.

I have been conducting in-home stove testing using homeowners as the stove operators since 1979, and have found "real world" data easy to obtain because homeowners are very cooperative about participating in stove testing. Wood loading data was collected for me by homeowners in 1979 though 1982. Ironically none of this extensive collection of in-home test data was cited by the WHA, even though it was presented by the DEQ in both their own testimony in June 1984 and in testimony to the ASTM in October.

In 1984 and 1985 I obtained enough additional in-home test data to serve as documentation for a definitive statement on wood loading in real world wood burning practices. The following section describes the data collecting procedures used and presents the data.

<u>The Project Procedures</u>: Nine homeowners were selected for this project to represent as wide a range of homeowner income levels, house designs, stove types and stove sizes as practical. To ensure load densities would, if anything, be biased as much as possible in support of WHA claims, all homeowners participating in the tests burned dense hardwoods (beech and maple), and they were located in cold northern climates where large amounts of wood would likely be used. Five houses were in a 6000 degree day climate and four in an 8000 degree day climate. All homeowners were told to operate their stoves the way they normally do, the only difference being that they would record the load weights and time of loading. They were not informed of the objective of this project.

The project was to be considered complete when a highly statistically significant sample size (40 loads) was reached.

All but one sample exceeded this value.

The homeowner survey data was compiled on computer and reduced to a lb/cu ft of usable firebox value with wood moisture (measured by drying wood crossections) adjusted to 20% to conform to DEQ protocol. The results for each house were subjected to complete statistical analysis, examining all loads as well as selecting just the overnight loads. The following statistical breakdown is presented in the appendix:

- Minimum
- Maximum
- Range
- Mean
- Median
- Confidence limits (95% and 99%)
- Histogram pictorially displaying loading distributions.

A summary of the results is displayed in Tables 1 and 2 and in Figure 1.

TABLE 1. Woodstove Woodloading Patterns of Homewoners in Their Homes

House #	Homeowner occupation	House location	Stove type	Number working spouses	Period data recorded	House type
1	College professor	Plattsburgh N.Y.	2 door step	1	Jan-Feb.'79	Energy efficient
2	Car Salesmen	Plattsburgh N.Y.	Horizontal baffel	2	Nov-Dec.'80	Log home
3	Executive small co.	Cleveland OH	Catalytic	1	Dec-Jan.'85	Century farmhouse
4	Executive small co.	Cleveland OH	2 door step	1	Dec-Jan.'85	Century farmhouse
5	Company bookkeeper	Cleveland OH	catalytic	2	Dec-Jan.'85	1950's ranch
6	State employee	Montpelier VT	cast crossdraft	1 full 1 part	Dec-Jan.'85	Century farmhouse
7	State employee	Montpelier VT	catalytic	1 full 1 part	Dec-Jan.'85	Century farmhouse
8	Draftsman	Cleveland OH	catalytic	1	Dec-Jan.'85	Century farmhouse
9	Welder	Cleveland OH	2 door step	2	Dec-Jan.'85	Mobile home

TABLE 2. Woodstove Woodloading Patterns of Homeowners in Their Houses.

House #	Overall ave. lb/cu ft load factor	Number of wood loads	Night load factor ave.lb/ft3	Number of wood loads	# spouses working	Ave. moisture wet basis	Firebox volume (cu.ft)
1	3.5	97	5.2	22	1	20%	3.8
2	8.1	149	9.6	44	2	26	2.6
3	4.8	56	5.7	12	1	29	2.8
4	5.7	41	6.3	10	1	23	3.7
5	7.3	43	7.6	12	2	27	2.85
6	5.9	57	7.0	10	1-2	36	3.64
7	5.6	34	7.0	10	1-2	36	2.8
8	3.3	45	4.9	10	1	30	4.8
9	4.8	49	4.6	11	2	34	4.0
	$\bar{x}$= 5.44	569	$\bar{x}$=6.43	141		$\bar{x}$=29.0	$\bar{x}$=3.44
	95% confidence limit = ±1.2		95% confidence limit =±1.2				

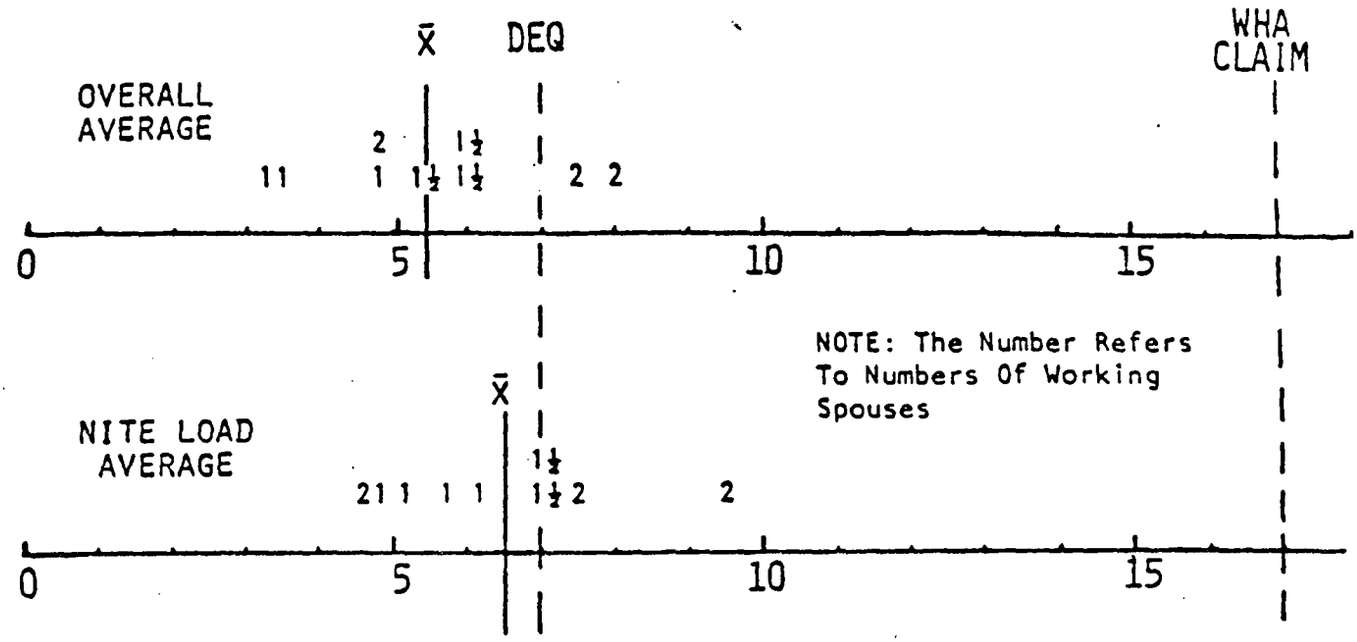
NOTE: These loading density values are based on DEQ firebox volume protocol measurements. Following proposed ASTM criteria loading densities are 6.5 and 7.6 lb./cu. ft.

Results: The data bank contains a total of 569 loads with 141 night loads. The overall average load factor is 5.4 lb/cu ft with the night load factor averaging 6.4 lb/cu ft of usable firebox. The 95% confidence limits are a narrow ± 1.2 lb/cu ft.

Figure 1 shows these averages as well as the rather tight distribution of data. Also clearly shown is the close correspondence between these results and the DEQ's protocol, and the gross overestimation the WHA has made. Not only was no single house average even close to the WHA estimate, but the largest single load of the 569 loads was only 14 lb/cu ft.

The conclusions are clear - reliable homeowner data of wood loading densities can be obtained readily; and measured densities agree very closely with the DEQ's protocol. The WHA's position on wood loading density is grossly overstated.

One must ask how the WHA erred technically to such a large extent. The most likely conclusion is that their data, obtained under lab conditions rather than field tests, does not account for the loading restraints that homeowners face. WHA loading measurements fail to account for the significant amount of ash bed that is present in homeowners' stoves and the usually significant space occupied by coals when wood is added. These greatly reduce the amount of wood that can be loaded. Other factors are the inconsistent length of wood pieces and the irregular shape of the pieces both of which restrict how densely wood can be loaded. Another important factor (especially during high draft conditions common in cold or windy weather) is that as the wood is loaded onto hot sparking coals it ignites and creates extreme heat. Under these conditions it is too hot for stoveowners to spend time selecting and carefully packing the wood load. Sparking, and the ensuing chimney fire threat and



AVERAGE LOAD FACTOR (LB/CU FT OF FIREBOX) IN 9 HOUSES

FIGURE 1.

fear of property damage or skin burns, also prevents the stoveowner from spending much time loading. Additionally the accompanying data documents that stoveowners often do not choose to load a woodstove densely, even when conditions permit.

Homeowner Woodloading Patterns: Figure 1 shows that stoves owned by working couples generally display the largest loading densities. Working couples load the stove for the day and load it again when they return home after work. If one person stays home during the day, smaller loads are placed in the stove. Interestingly, this same pattern holds for night loads as well.

To a lesser extent, firebox volume is also significantly correlated with load size. The larger the firebox the smaller the average load per cubic foot for firebox volume.

SUMMARY: Data acquired from nine representative northern climate homes all using hardwood fuel, indicate that wood load factors average 5.7 lb/cu ft of firebox volume, with night loads averaging 6.7 lb/cu ft. Confidence limits are narrow. These values are slightly less than, but do support the DEQ's usage of 7 lb/cu ft in emissions testing. They clearly demonstrate that the WHA's claim of 17 lb/cu ft is incorrect.

Wood loading density is greatest for working couples and for stoves with small fireboxes. Unquestionably 7 lb/cu ft of firebox would be the most appropriate standard for accurate and realistic emissions testing results.

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 1, 1979,STEP STOVE,3.8 CU. FT.,20% MOIST

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	.79
Maximum	=	7.11
Range	=	6.32
Sum	=	340.95
Mean	=	3.515
Median	=	2.89
Mode	=	2.11
Variance	=	2.771
Standard deviation	=	1.665
Standard error of the mean	=	0.170
95 Percent confidence interval around the mean	=	3.182 - 3.848
99 Percent confidence interval around the mean	=	3.077 - 3.952

* Unbiased estimates of population *

Variance	=	2.800
Standard deviation	=	1.673

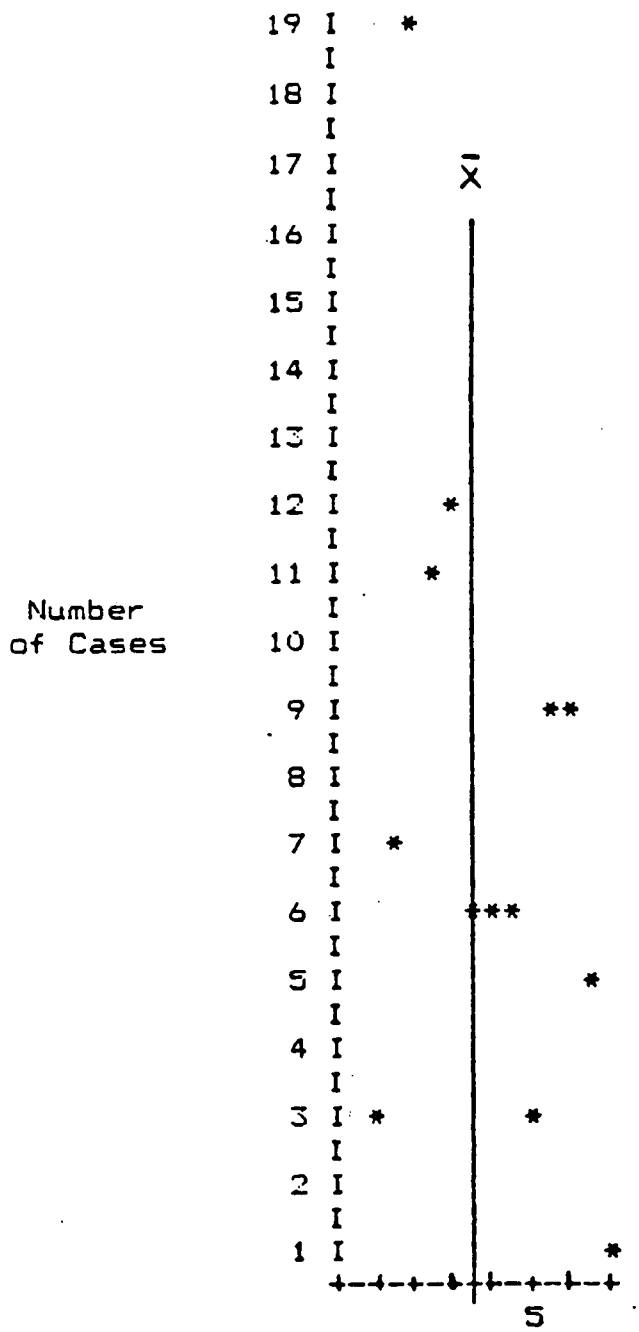
* Data distribution coefficients *

Skewness	=	0.387
Kurtosis	=	1.880

Valid cases	=	97
Missing cases	=	0
Response percent	=	100.0 %

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 1, 1979,STEP STOVE,3.8 CU. FT.,20% MOIST



POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 1, 1979,NITE LOADS ONLY, STEP STOVE

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	1.84
Maximum	=	7.11
Range	=	5.27
Sum	=	113.68
Mean	=	5.167
Median	=	5.53
Mode	=	5.79
Variance	=	1.941
Standard deviation	=	1.393

Standard error of the mean = 0.304

95 Percent confidence interval around the mean = 4.571 - 5.763

99 Percent confidence interval around the mean = 4.384 - 5.950

* Unbiased estimates of population *

Variance	=	2.033
Standard deviation	=	1.426

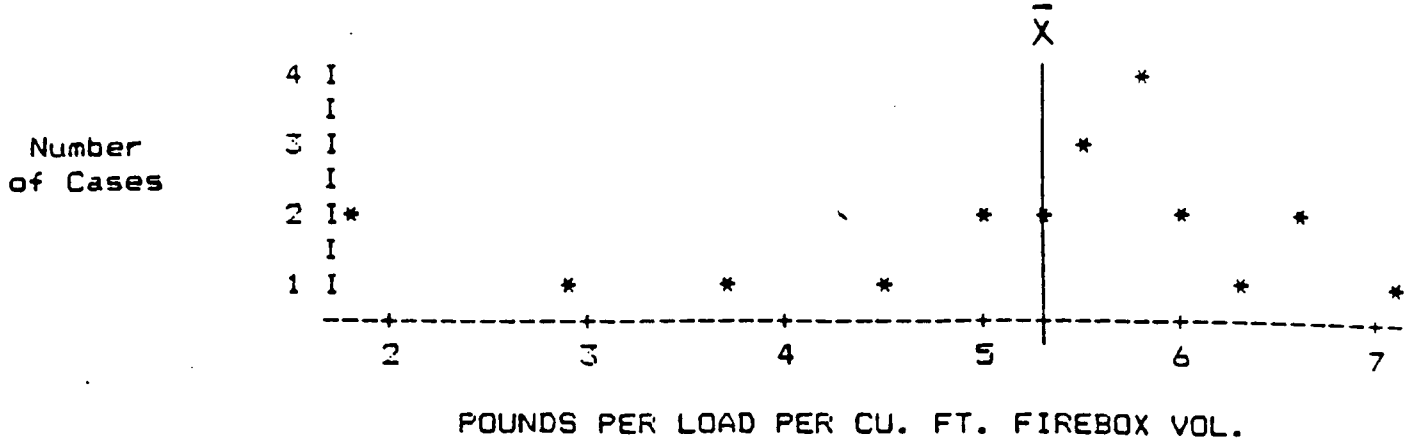
* Data distribution coefficients *

Skewness	=	-1.213
Kurtosis	=	3.656

Valid cases = 22
Missing cases = 0
Response percent = 100.0 %

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 1, 1979,NITE LOADS ONLY, STEP STOVE



HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 2,1980, HORIZ. BAFFLE STOVE,2.6 CU.FT.,26% MOIST

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	1.42
Maximum	=	14.05
Range	=	12.63
Sum	=	1210.09
Mean	=	8.121
Median	=	8.29
Mode	=	10.07
Variance	=	6.831
Standard deviation	=	2.614

Standard error of the mean = 0.215

95 Percent confidence interval around the mean = 7.700 - 8.542

99 Percent confidence interval around the mean = 7.568 - 8.675

* Unbiased estimates of population *

Variance	=	6.877
Standard deviation	=	2.622

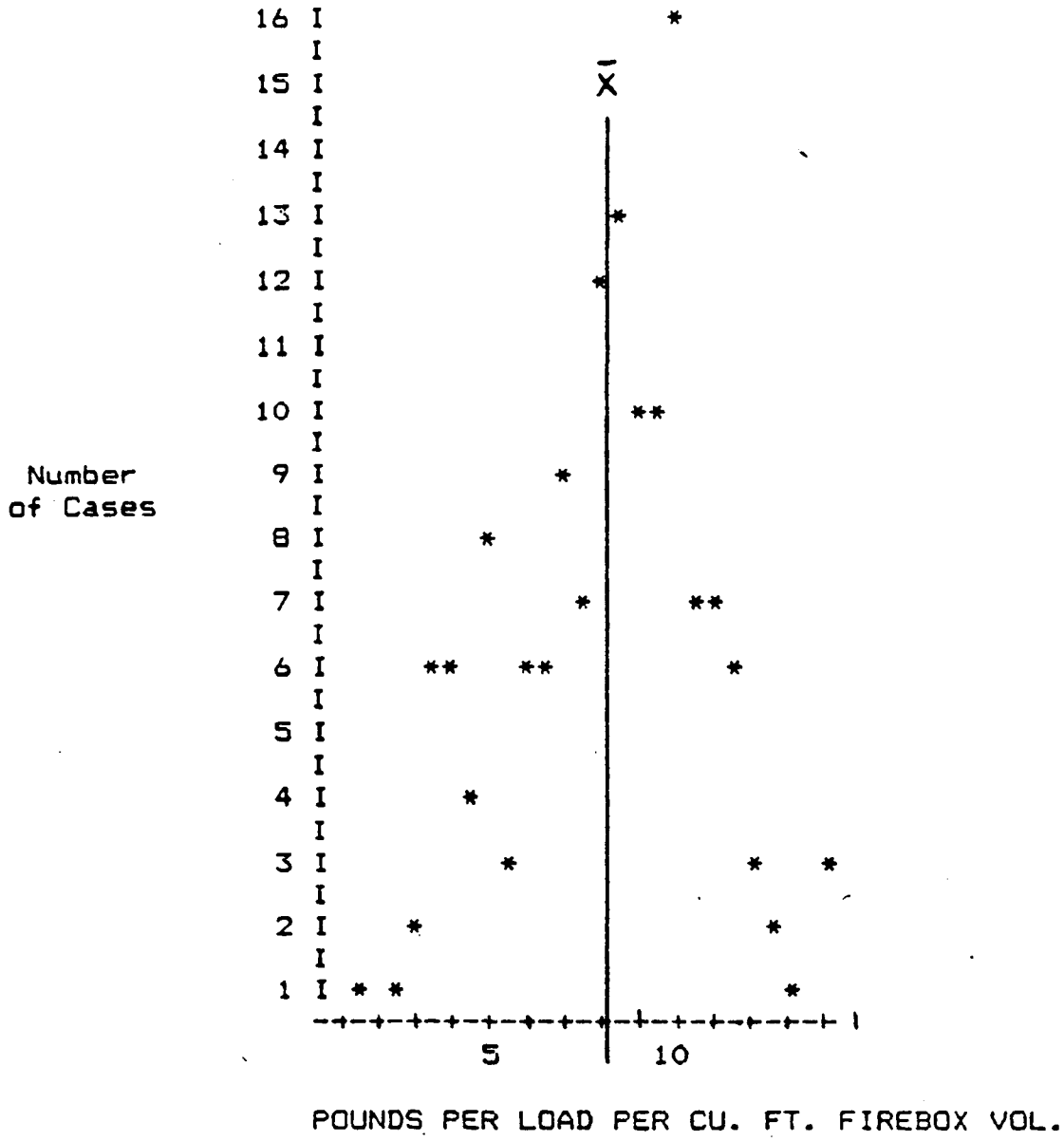
* Data distribution coefficients *

Skewness	=	-0.232
Kurtosis	=	2.523

Valid cases = 149
Missing cases = 0
Response percent = 100.0 %

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 2,1980, HORIZ. BAFFLE STOVE,2.6 CU.FT.,26% MC



HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 2,1980,NITE LOADS, HORIZ. BAFFLE STOVE

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	5.52
Maximum	=	14.05
Range	=	8.53
Sum	=	421.74
Mean	=	9.585
Median	=	9.6
Mode	=	Multi-Modal
Variance	=	3.342
Standard deviation	=	1.828

Standard error of the mean = 0.279

95 Percent confidence interval around the mean = 9.039 - 10.131

99 Percent confidence interval around the mean = 8.867 - 10.303

* Unbiased estimates of population *

Variance	=	3.419
Standard deviation	=	1.849

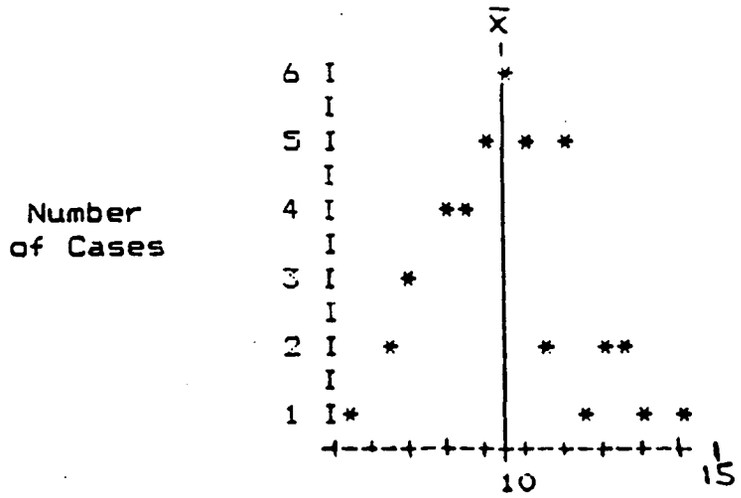
* Data distribution coefficients *

Skewness	=	0.090
Kurtosis	=	2.776

Valid cases = 44
Missing cases = 0
Response percent = 100.0 %

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 2,1980,NITE LOADS, HORIZ. BAFFLE STOVE



POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 3,1984, CONDAR CATALYTIC STOVE,2.8 CU.FT.29% MOIST

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	.95
Maximum	=	9.8
Range	=	8.85
Sum	=	268.77
Mean	=	4.799
Median	=	4.74
Mode	=	4.74
Variance	=	2.654
Standard deviation	=	1.629

Standard error of the mean = 0.220

95 Percent confidence interval around the mean = 4.369 - 5.230

99 Percent confidence interval around the mean = 4.234 - 5.365

* Unbiased estimates of population *

Variance	=	2.702
Standard deviation	=	1.644

* Data distribution coefficients *

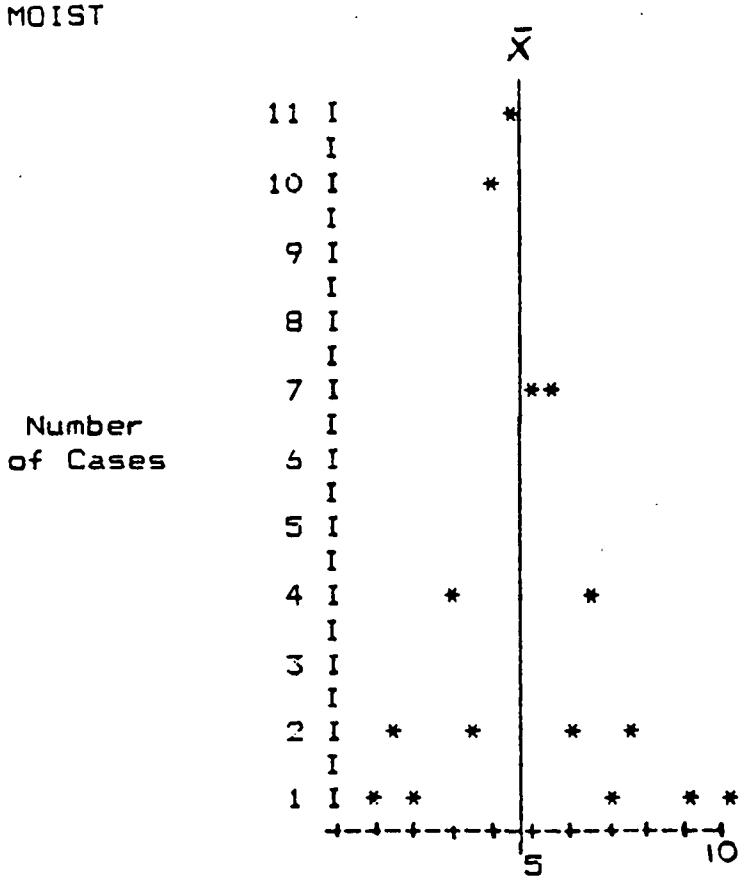
Skewness	=	0.401
Kurtosis	=	4.120

Valid cases = 56
Missing cases = 0
Response percent = 100.0 %

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 3,1984, CONDAR CATALYTIC STOVE,2.8 CU.F

MOIST



POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 3,1984,NITE LOADS,CONDAR CATALYTIC STOVE

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	3.79
Maximum	=	9.8
Range	=	6.01
Sum	=	68.73
Mean	=	5.728
Median	=	4.74
Mode	=	4.74
Variance	=	3.595
Standard deviation	=	1.896

Standard error of the mean = 0.572

95 Percent confidence interval around the mean = 4.607 - 6.848

99 Percent confidence interval around the mean = 4.255 - 7.200

* Unbiased estimates of population *

Variance	=	3.922
Standard deviation	=	1.980

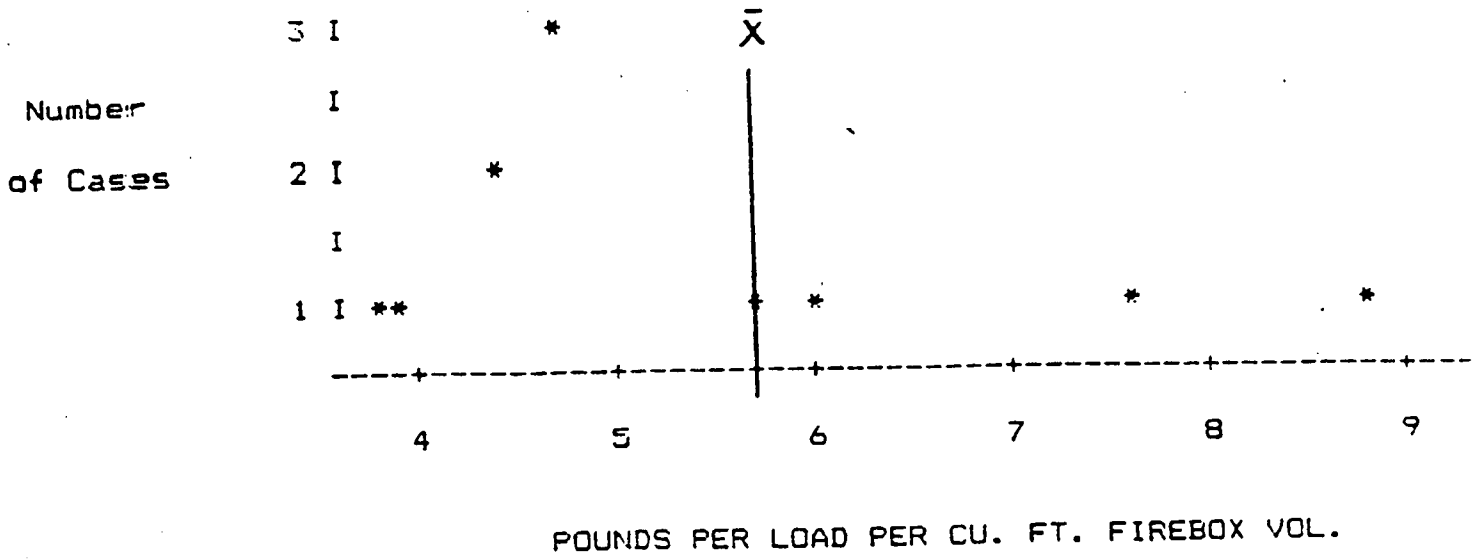
* Data distribution coefficients *

Skewness	=	1.030
Kurtosis	=	2.676

Valid cases = 12
Missing cases = 0
Response percent = 100.0 %

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 3,1984,NITE LOADS,CONDAR CATALYTIC STO



HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 4,1984,STEP STOVE,3.7 CU.FT,23% MOIST

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	1.61
Maximum	=	10.98
Range	=	9.37000000000001
Sum	=	234.34
Mean	=	5.716
Median	=	5.62
Mode	=	5.11
Variance	=	4.075
Standard deviation	=	2.019

Standard error of the mean = 0.319

95 Percent confidence interval around the mean = 5.090 - 6.341

99 Percent confidence interval around the mean = 4.894 - 6.537

* Unbiased estimates of population *

Variance	=	4.176
Standard deviation	=	2.044

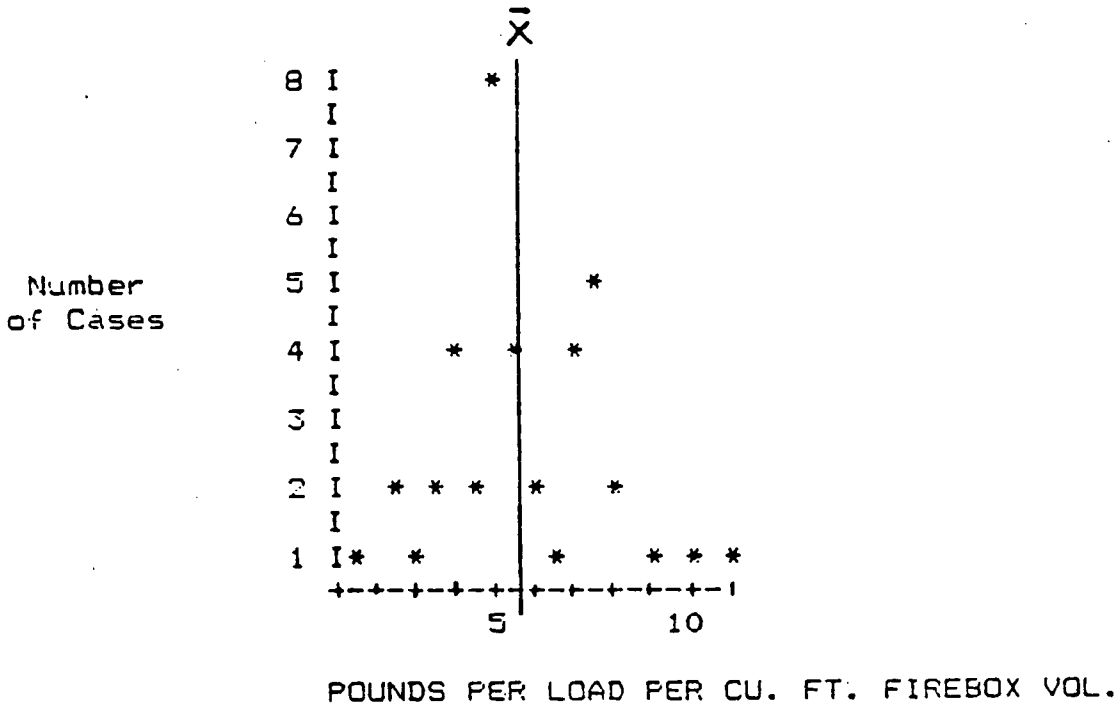
* Data distribution coefficients *

Skewness	=	0.335
Kurtosis	=	2.956

Valid cases = 41
Missing cases = 0
Response percent = 100.0 %

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 4,1984,STEP STOVE,3.7 CU.FT,20% MOIST



HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 4,1984, NIGHT LOADS , STEP STOVE

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	2.3
Maximum	=	10.98
Range	=	8.680000000000001
Sum	=	62.57
Mean	=	6.257
Median	=	5.745
Modes (Bimodal)	=	5.11 & 5.62
Variance	=	4.720
Standard deviation	=	2.173

Standard error of the mean = 0.724

95 Percent confidence interval around the mean = 4.838 - 7.676

99 Percent confidence interval around the mean = 4.392 - 8.122

* Unbiased estimates of population *

Variance	=	5.245
Standard deviation	=	2.290

* Data distribution coefficients *

Skewness	=	0.483
Kurtosis	=	3.428

Valid cases = 10
Missing cases = 0
Response percent = 100.0 %

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 4,1984, NIGHT LOADS , STEP STOVE

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POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 5,1984,CONDAR CATALYTIC STOVE,2.85 CU.FT,27%MOIST

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	3.84
Maximum	=	11.85
Range	=	8.010000000000001
Sum	=	314.93
Mean	=	7.324
Median	=	7.68
Mode	=	9.6
Variance	=	4.632
Standard deviation	=	2.152

Standard error of the mean = 0.332

95 Percent confidence interval around the mean = 6.673 - 7.975

99 Percent confidence interval around the mean = 6.469 - 8.179

* Unbiased estimates of population *

Variance	=	4.742
Standard deviation	=	2.178

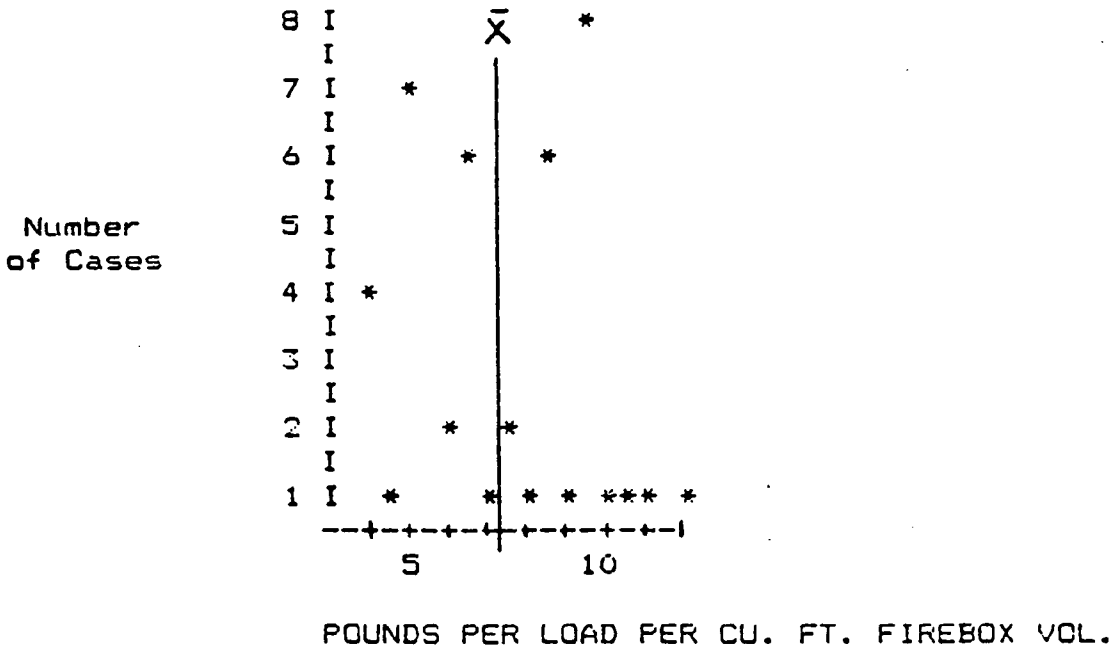
* Data distribution coefficients *

Skewness	=	-0.038
Kurtosis	=	1.925

Valid cases	=	43
Missing cases	=	0
Response percent	=	100.0 %

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 5,1984,CONDAR CATALYTIC STOVE,2.85 CU.FT,27%M(



HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 5,1984,NITE LOADS, CONDAR CATALYTIC STOVE

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	3.84
Maximum	=	11.85
Range	=	8.010000000000001
Sum	=	91.53
Mean	=	7.628
Median	=	6.88
Mode	=	Multi-Modal
Variance	=	5.739
Standard deviation	=	2.396

Standard error of the mean = 0.722

95 Percent confidence interval around the mean = 6.212 - 9.043

99 Percent confidence interval around the mean = 5.768 - 9.487

* Unbiased estimates of population *

Variance	=	6.260
Standard deviation	=	2.502

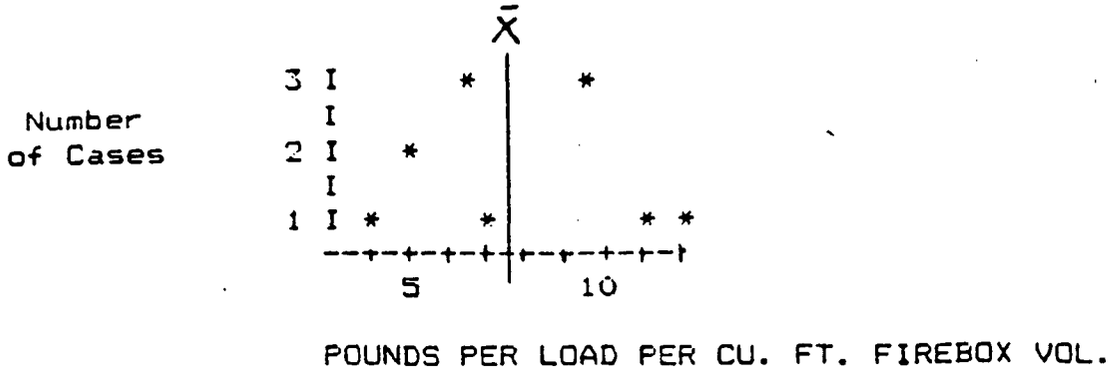
* Data distribution coefficients *

Skewness	=	0.217
Kurtosis	=	1.898

Valid cases = 12
Missing cases = 0
Response percent = 100.0 %

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 5,1984,NITE LOADS, CONDAR CATALYTIC STOVE



HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX VOLUME, TO 20% MOIST

* HOUSE 6,1984,EAST CROSSDRAFT STOVE,3.6 CU.FT.36%MOIST

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	1.98
Maximum	=	9.23
Range	=	7.250000000000001
Sum	=	337.78
Mean	=	5.926
Median	=	6.37
Mode	=	Multi-Modal
Variance	=	4.018
Standard deviation	=	2.005

Standard error of the mean = 0.268

95 Percent confidence interval around the mean = 5.401 - 6.451

99 Percent confidence interval around the mean = 5.236 - 6.616

* Unbiased estimates of population *

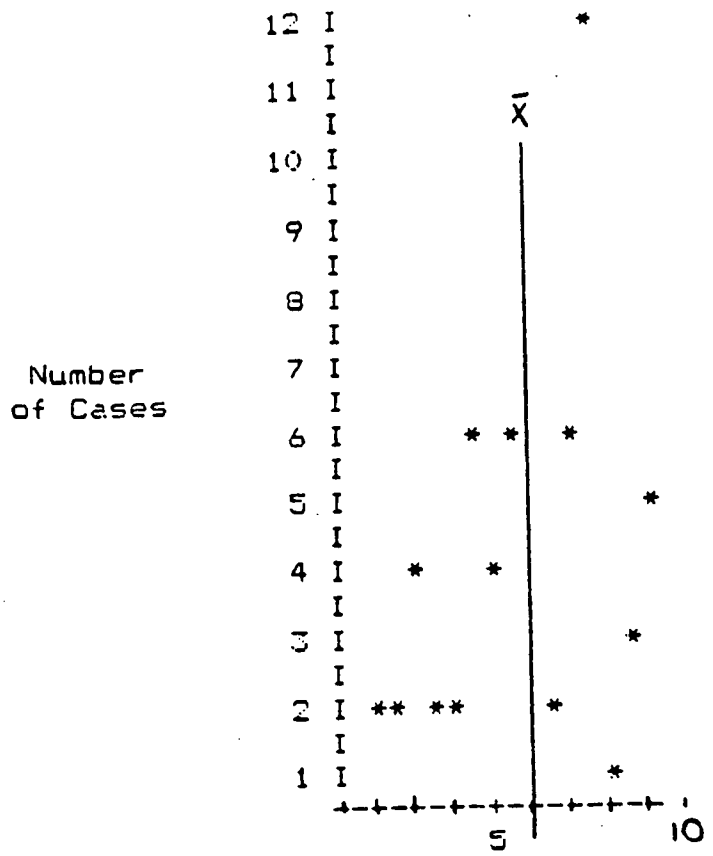
Variance	=	4.090
Standard deviation	=	2.022

* Data distribution coefficients *

Skewness	=	-0.254
Kurtosis	=	1.900

Valid cases = 57
Missing cases = 0
Response percent = 100.0 %

FISCHER HOUSE 6,1984,CAST CROSSDRAFT STOVE,3.6 CU.FT.36%MC(ST



POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX [illegible]

HOUSE 6,1984,NITE LOADS, CAST CROSSDRAFT STOVE

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	4.4
Maximum	=	9.23
Range	=	4.83
Sum	=	70.54
Mean	=	7.054
Median	=	7.47
Mode	=	8.35
Variance	=	2.936
Standard deviation	=	1.714
Standard error of the mean	=	0.571
95 Percent confidence interval around the mean	=	5.934 - 8.174
99 Percent confidence interval around the mean	=	5.583 - 8.525

* Unbiased estimates of population *

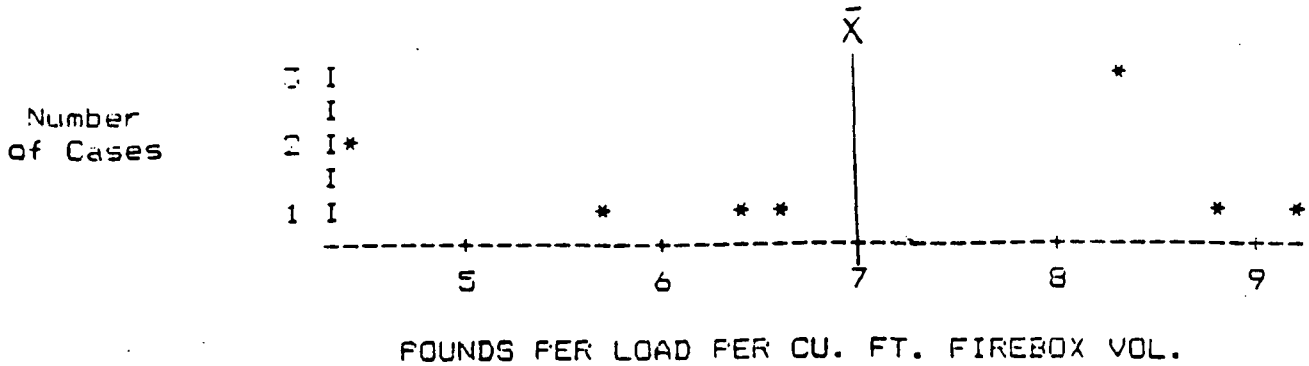
Variance	=	3.263
Standard deviation	=	1.806

* Data distribution coefficients *

Skewness	=	-0.361
Kurtosis	=	1.655

Valid cases	=	10
Missing cases	=	0
Response percent	=	100.0 %

HOUSE 6,1984,NITE LOADS, CAST CROSSDRAFT STOVE



HOUSE 7,1984,CONDAR CATALYTIC STOVE,2.8 CU.FT.36%MOIST

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	1.14
Maximum	=	9.71
Range	=	8.57
Sum	=	190.3
Mean	=	5.597
Median	=	5.715
Mode	=	4.29
Variance	=	4.773
Standard deviation	=	2.185
Standard error of the mean	=	0.380
95 Percent confidence interval around the mean	=	4.852 - 6.342
99 Percent confidence interval around the mean	=	4.618 - 6.576

* Unbiased estimates of population *

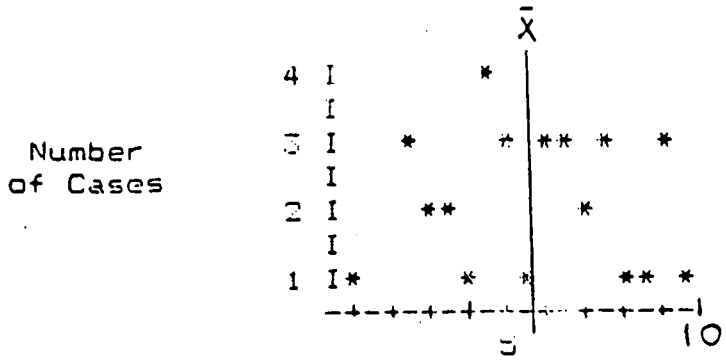
Variance	=	4.918
Standard deviation	=	2.218

* Data distribution coefficients *

Skewness	=	0.034
Kurtosis	=	2.119

Valid cases = 34
Missing cases = 0
Response percent = 100.0 %

HOUSE 7,1984,CONDAR CATALYTIC STOVE,2.8 CU.FT.36%MOIST



POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

HOUSE 7,1984,NITE LOADS, CONDAR CATALYTIC STOVE

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	3.14
Maximum	=	9.14
Range	=	6.00000000000001
Sum	=	69.72
Mean	=	6.972
Median	=	7.57
Mode	=	6.29
Variance	=	3.544
Standard deviation	=	1.882

Standard error of the mean = 0.627

95 Percent confidence interval around the mean = 5.742 - 8.202

99 Percent confidence interval around the mean = 5.356 - 8.588

* Unbiased estimates of population *

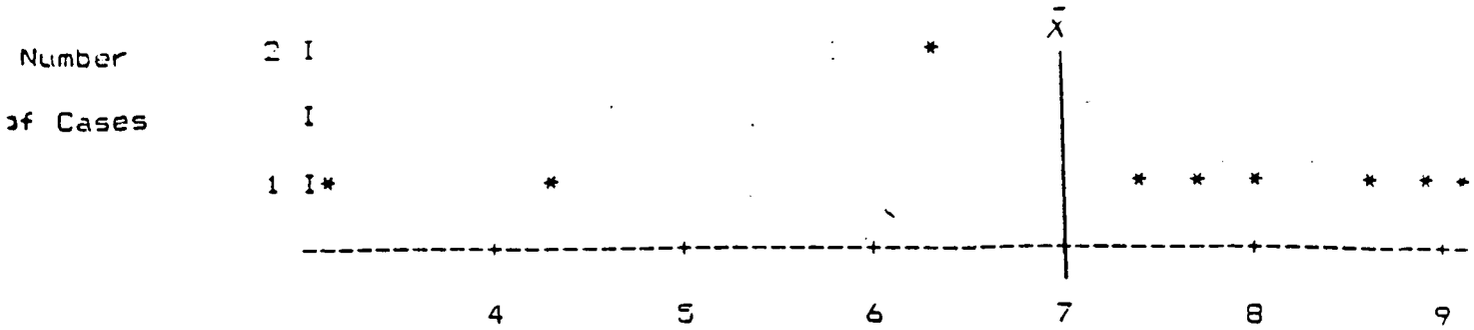
Variance	=	3.937
Standard deviation	=	1.984

* Data distribution coefficients *

Skewness	=	-0.804
Kurtosis	=	2.473

Valid cases	=	10
Missing cases	=	0
Response percent	=	100.0 %

HOUSE 7,1984,NITE LOADS, CONDAR CATALYTIC STOVE



POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 8,1984, CONDAR CATALYTIC PROTOTYPE,4.8 CU.FT.20% MOIST

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	1.34
Maximum	=	6.63
Range	=	5.29
Sum	=	149.08
Mean	=	3.313
Median	=	3.05
Mode	=	2.69
Variance	=	1.940
Standard deviation	=	1.393
Standard error of the mean	=	0.210
95 Percent confidence interval around the mean	=	2.901 - 3.724
99 Percent confidence interval around the mean	=	2.772 - 3.854

* Unbiased estimates of population *

Variance	=	1.984
Standard deviation	=	1.409

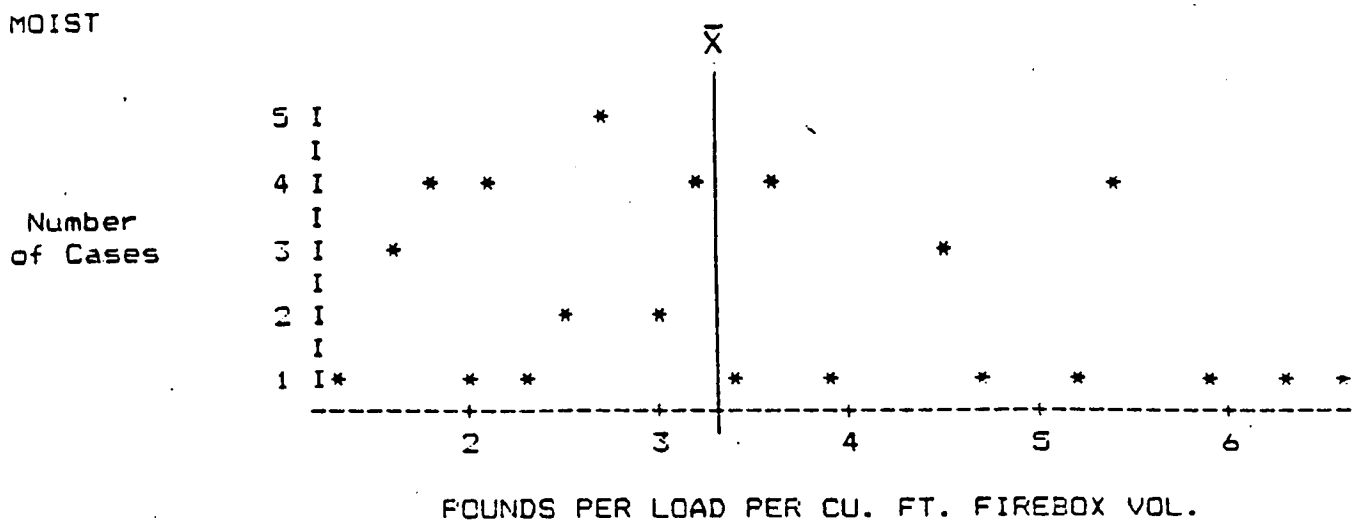
* Data distribution coefficients *

Skewness	=	0.669
Kurtosis	=	2.447

Valid cases = 45
Missing cases = 0
Response percent = 100.0 %

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 8,1984, CONDAR CATALYTIC PROTOTYPE,4.8 CU.FT.



HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 8,1984,NITE LOADS, CONDAR CATALYTIC PROTOTYPE

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	2.69
Maximum	=	6.63
Range	=	3.94
Sum	=	49.13
Mean	=	4.913
Median	=	5.29
Mode	=	5.38
Variance	=	1.177
Standard deviation	=	1.085
Standard error of the mean	=	0.362
95 Percent confidence interval around the mean	=	4.204 - 5.622
99 Percent confidence interval around the mean	=	3.982 - 5.844

* Unbiased estimates of population *

Variance	=	1.307
Standard deviation	=	1.143

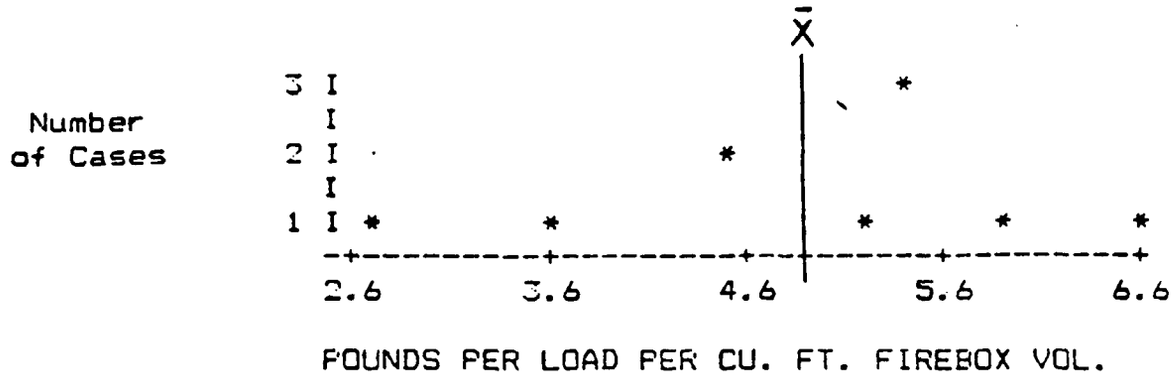
* Data distribution coefficients *

Skewness	=	-0.553
Kurtosis	=	2.703

Valid cases	=	10
Missing cases	=	0
Response percent	=	100.0 %

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 8,1984,NITE LOADS, CONDAR CATALYTIC PROTO



HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 9,1984, STEP STOVE,4.0 CU.FT.34% MOISTURE

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	1.87
Maximum	=	9.54
Range	=	7.67
Sum	=	236.84
Mean	=	4.833
Median	=	4.56
Mode	=	Multi-Modal
Variance	=	3.336
Standard deviation	=	1.827

Standard error of the mean = 0.264

95 Percent confidence interval around the mean = 4.317 - 5.350

99 Percent confidence interval around the mean = 4.155 - 5.512

* Unbiased estimates of population *

Variance	=	3.406
Standard deviation	=	1.845

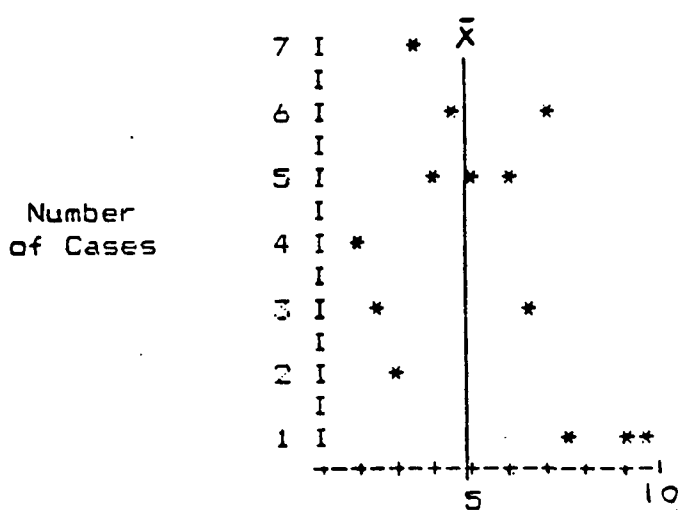
* Data distribution coefficients *

Skewness	=	0.444
Kurtosis	=	2.682

Valid cases = 49
Missing cases = 0
Response percent = 100.0 %

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 9,1984, STEP STOVE,4.0 CU.FT.34% MOISTURE



POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

HOUSE 9,1984,NITE LOADS, STEP STOVE

POUNDS PER LOAD PER CU. FT. FIREBOX VOL.

Minimum	=	2.07
Maximum	=	7.05
Range	=	4.98
Sum	=	50.34
Mean	=	4.576
Median	=	4.52
Mode	=	3.73
Variance	=	2.179
Standard deviation	=	1.476

Standard error of the mean = 0.467

95 Percent confidence interval around the mean = 3.661 - 5.491

99 Percent confidence interval around the mean = 3.374 - 5.778

* Unbiased estimates of population *

Variance	=	2.397
Standard deviation	=	1.548

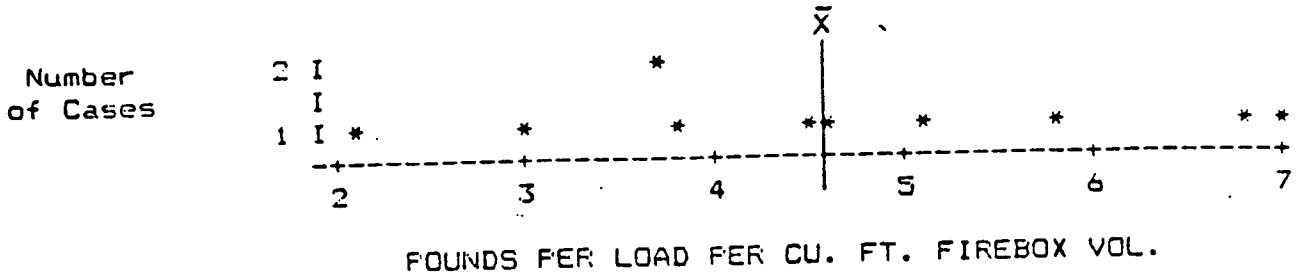
* Data distribution coefficients *

Skewness	=	0.210
Kurtosis	=	2.183

Valid cases = 11
Missing cases = 0
Response percent = 100.0 %

HOMEOWNER WOOD LOADS PER CU. FT. OF FIREBOX (CORR. TO 20% MOIST

SCHELLER HOUSE 9,1984,NITE LOADS, STEP STOVE



OAR Box 1806

Prepped by Charmelle Mathews

Document Number:

181) II-I-34

Docket Number:

A-84-49

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II-I-34

Analysis of Wood Loading Data from a Study of Indoor/Outdoor Residential Wood Combustion Particulate Relationships

The Tennessee Valley Authority conducted a study during the first quarter of 1984 on indoor particulates and their sources in two homes in areas where the use of wood stoves for heating is common. The study gathered data on indoor and outdoor particulate concentrations (fine and coarse), the elemental concentrations of the particulates, occupant activities, and in one home the wood stove exit temperature, wind speed and direction, and air exchange rates. In addition, data on the amount of wood loaded in the study home with the wood stove and in a neighboring home was collected. The results of an analysis of the wood loading data are presented here. The remainder of the data will be analyzed for a paper to be presented at the 1985 APCA Annual Meeting.

The wood loading data was recorded in a log book in the two neighboring homes which were heated entirely by wood stoves during a 22-day period from January 20 through February 10, 1984. Both homes were owned by TVA employees who work from 0730 to 1615, Monday through Friday. Both homes are about 1,600 square feet, have R30 insulation in the ceiling, and storm windows. The stoves are both similar, being of the convection type and having a maximum wood load of about 50 pounds. The wood was weighed before each load, and the weight and the time of the loading were recorded in the log book along with information on the state of the burn at the time of loading.

Home 1, the study home, burned 1,994 pounds of wood during the 22-day period, and home 2 burned 1,955 pounds. Figure 1 is a plot of the daily pounds of wood loaded for the two homes. The maximum amount of wood loaded on any one day was 145 pounds. Assuming that all of the wood were consumed in 24 hours, this yields a maximum burn rate of 6 pounds per hour. The average number of heating degree days during the 22-day period was 27, and the average wood burn rate was 3.7 pounds per hour.

Figure 2 is a plot of the average amount of wood loaded during each two-hour period of the day for the homes. The loading patterns are similar as might be expected by the similar work schedules of the employees. The heaviest loading periods were from 0600 to 0800 (on rising) and from 2200 to 2400 (before retiring). Very little wood was loaded before 0600. During the workday the wives of the employees would load the stoves when necessary. The maximum single load recorded was 49 pounds and the minimum was 5 pounds. The average load size for each two-hour period and the number of loads for home 1 were: 0, 0; 0, 0; 0, 0; 28.4, 19; 27.3, 3; 22.5, 6; 20.0, 6; 23.2, 6; 32.7, 6; 29.8, 4; 38.8, 5; and 24.6, 19. The same data for home 2 are: 16, 1; 0, 0; 28, 2; 26.1, 13; 28, 3; 21, 8; 17.5, 6; 15.4, 6; 21.8, 11; 27, 7; 25.8, 12; and 27.2, 13. Thus, home 2 had more frequent wood loads (82 vs. 74) and a slightly smaller average load size (23.8 vs. 26.9 pounds).

	Home 1 (3.5 ft³)	Home 2 3.2
12-2	0	5
2-4	0	0
4-6	0	8.7
6-8	8.1	5.2
8-10	7.8	8.7
10-12	6.4	6.6
12-2	5.7	6.5
2-4	6.6	7.8
4-6	9.3	6.8
6-8	8.5	8.4
8-10	11.1	8.1
10-12	7.0	8.5

7.4 vs 7.7 lb/ft³

The most striking result is the similarity between the wood use patterns in the two homes. The patterns conform to what would be expected knowing the schedules of the two employees. Typically, the stoves would be filled to capacity before retiring. This is not reflected in the average load size since the stoves had wood remaining from earlier loads. The large wood loads, combined with the low burn rates used during the night, can yield large emission rates of particulates and CO during a period when dispersion is often very low. This pattern is probably what accounts for the particulate and CO time-of-day patterns which have been found in TVA and other studies in airsheds which are dominated by woodstove emissions.

An attempt was made to determine the factors which influenced the amount of wood loaded in the two homes. A stepwise multiple linear regression model was used on the wood loading data for each day along with that day's average wind speed squared and heating degree days and the daytime cloud cover. The square of the wind speed is used in infiltration models, and heating degree days has been well associated with heating needs. The daytime cloud cover is intended to give some measure of the solar insolation for the day.

The correlation between the wood loads over the 22 days for the two homes was .557, indicating considerable day-to-day variation in the amount of wood loaded. The stepwise regression was conducted for 22 days for home 1, 22 days for home 2, 22 days for the average of homes 1 and 2, and 53 days for home 2. In all cases, heating degree days was the only independent variable which was statistically significant. Heating degree days explained 48% of the variance for home 1 (22 days), 41% of the variance for home 2 (22 days), 58% of the variance for the average of homes 1 and 2 (22 days), and 58% of the variance for home 2 (53 days). The regression equations were:

$$\text{Wood } (1,22) = 28.9 + 2.16 * \text{HDD}$$

$$\text{Wood } (2,22) = 34.7 + 2.04 * \text{HDD}$$

$$\text{Wood } (1\text{-}2,22) = 31.8 + 2.10 * \text{HDD}$$

$$\text{Wood } (2,53) = -1.4 + 2.82 * \text{HDD}$$

The 22-day period was fairly cold with an average heating degree days of 26.5 and a coefficient of variance of 34%. The 53-day period was somewhat warmer with an average heating degree days of 21.6 and a coefficient of variance of 48%. The 53-day period had days which were so warm that no wood heating was required, while during the 22-day period, wood was burned on each day in both homes. This accounts for the large difference in intercepts for the 22-day and 53-day results for home 2. The behavior suggests that during a cold period habit takes over and the amount of wood loaded is only somewhat dependent on day-to-day variations in the temperature. Apparently there is acceptance of some variation of temperatures within the homes. However, when the temperature rises to the point where heating is no longer needed, then the stove is allowed to go out. The similarity of the fits for homes 1 and 2 for the 22-day period indicates that the responses of the two homeowners during that cold period were consistent.

The poor agreement between heating degree days and the amount of wood loaded relative to previous studies based on electric or oil heat is explainable by the nonlinear relationship between burn rate and heat output. At low burn rates, the efficiency of the stove declines drastically. Another contributing factor may be that expectations are lower for a wood stove's performance and that larger temperature deviations are accepted.

The data base analyzed here is too limited to draw any far-reaching conclusions for wood-burning homes in general. The data do indicate some tendencies which should be investigated on a larger scale: the time-of-day patterns of wood loading; the large amounts loaded at one time; the relatively constant loads during a cold period; and the insensitivity to wind speed and solar insolation.

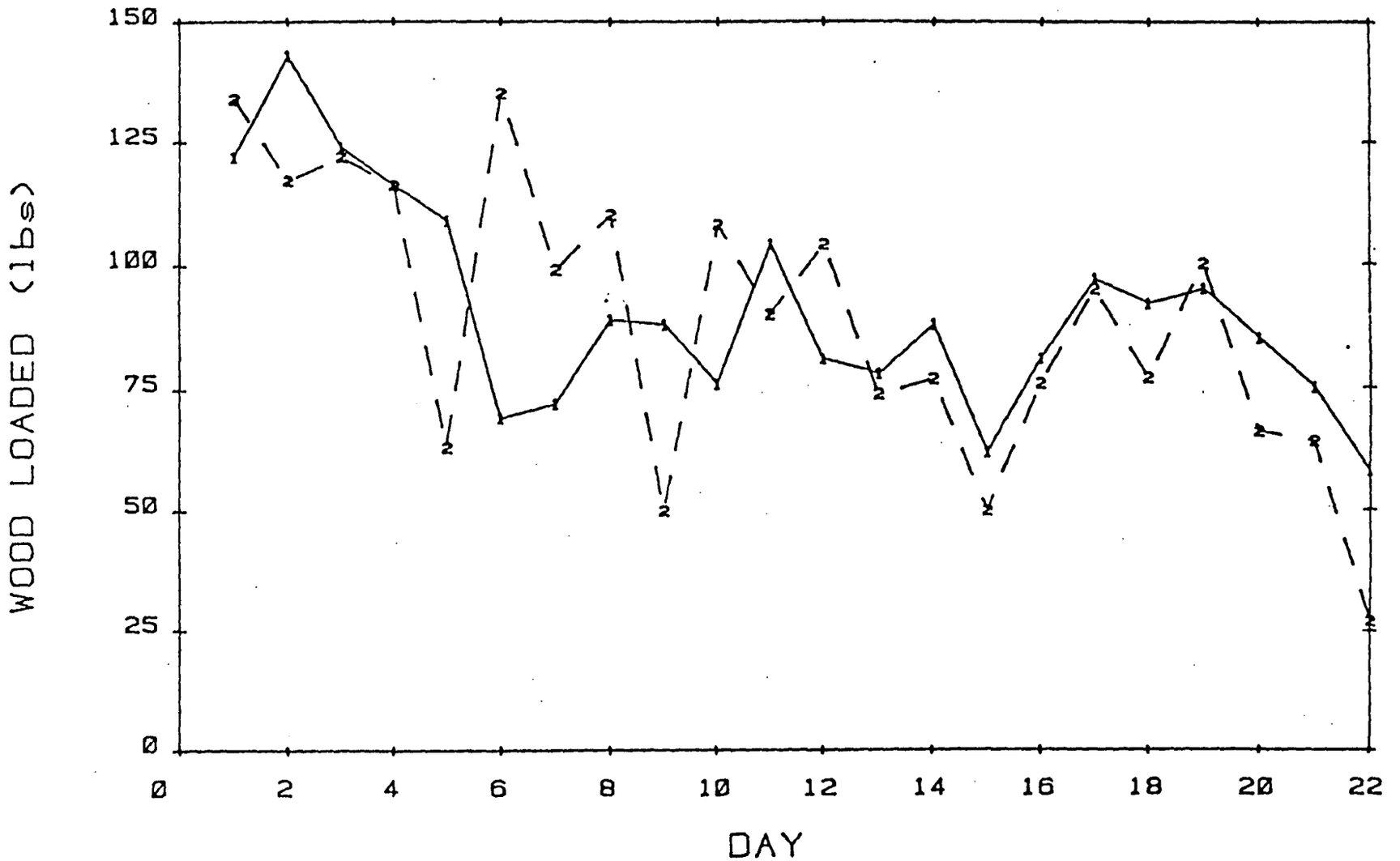

Figure 1. Daily amount of wood loaded for two neighboring homes over a 22 day period.

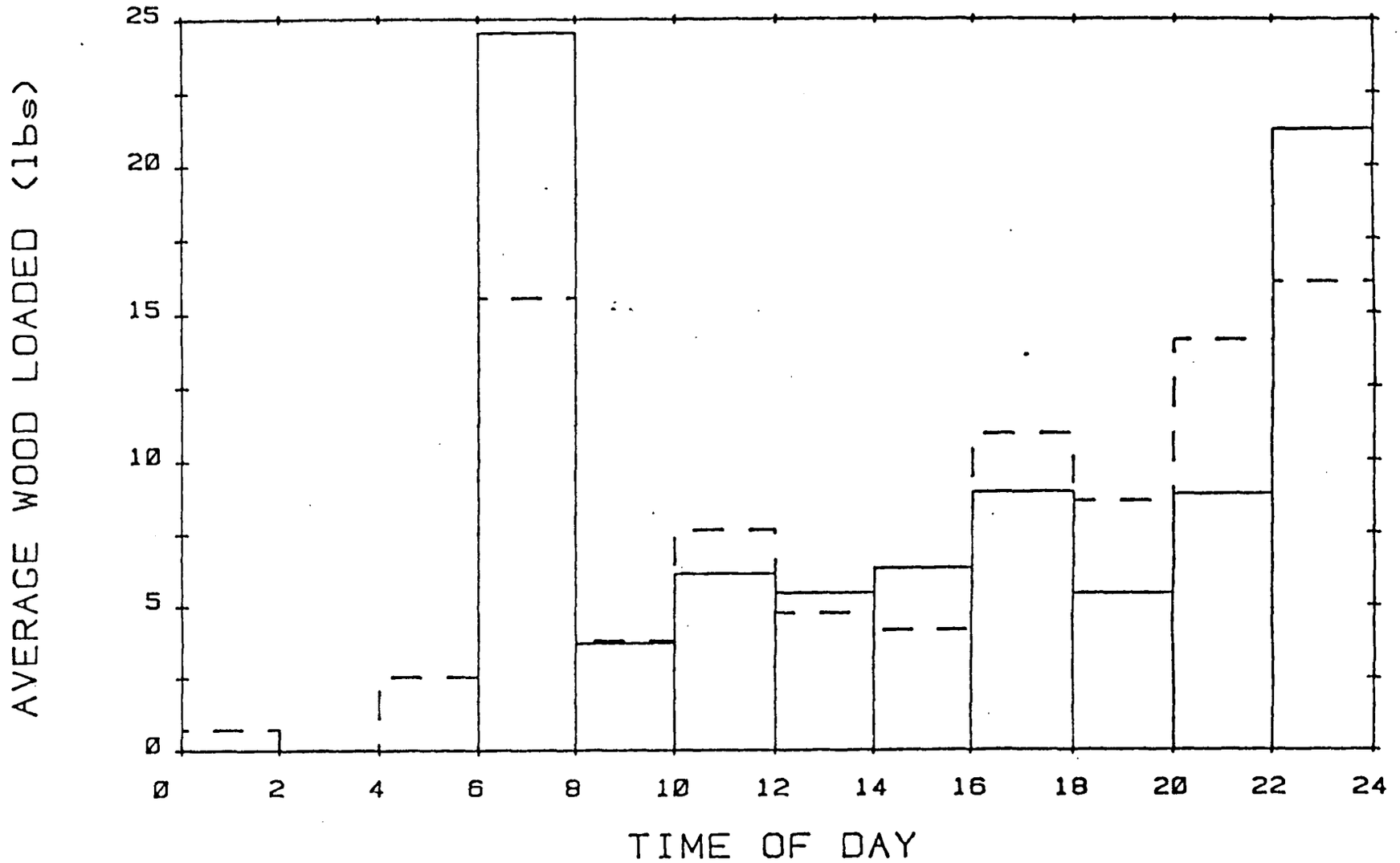

Figure 2. Average weight of wood loaded in each two-hour period for two neighboring homes over a 22 day interval. Solid lines are for home 1, and dashed lines are for home 2.

GDT

TENNESSEE VALLEY AUTHORITY
KNOXVILLE, TENNESSEE 37902

JUL 15 1985

Mr. Peter R. Westlin
Test Support Section
Emission Measurement Branch
Emission Standards and Engineering Division
Office of Air Quality Standards and Planning
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Dear Mr. Westlin:

This letter refers to the June 21 telephone conversation between Jeff Telander and Larry Montgomery of my staff concerning wood loading data in non-test home situations. We do have some information, and the enclosure summarizes TVA data related to wood heater loadings for non-test homes.

Some additional information is required in the present context. The stove in Home 1 was a Sears wood/coal circulating heater with a firebox size of 3.5 cubic feet. The stove in Home 2 was a King circulating heater model 8800-B with a firebox size of 3.2 cubic feet. Both stoves were operated normally by the homeowners, the only requirement was that the wood had to be weighed before charging the stove.

Sincerely,

Martin E. Rivers

Martin E. Rivers, Director
Environmental Quality

Enclosure

217 Chemical Engineering Building

October 19, 1984

Mr. William Greene, Manager
Environmental Assessment Program
Cascade Building, Suite 1120
520 SW Sixth Avenue
Portland, Oregon 97204

Dear Bill:

As I promised, I have taken a look at the wood loading data from our indoor air quality field study. I have enclosed the results of the analysis.

I hope this information will be of use to you in your work for EPA on ambient impacts of Residential Wood Combustion.

Sincerely,

Robert E. Imhoff, Environmental Scientist
Research Section
Air Quality Branch

REI:CD
Enclosure