A Study of Weather Related Space Heating Fuel Use in the University Houses, University of Wisconsin - Madison

by

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I. Introduction

The energy crisis and increased price of fuel oil used for space heating have made us acutely aware of the need to efficiently utilize this non-replenishable resource. Allocation measures have been set up within the State of Wisconsin to ensure an equitable distribution of fuel oil throughout the state. The Wisconsin Office of Emergency Energy Assistance relies heavily on a single climatic indicator, heating degree days, as a basis for allocation decisions. In this report we examine the correlation between fuel use and heating degree days and explore the possibility that space heating fuel requirements may be correlated with weather variables other than air temperature. We have made use of fuel consumption data supplied to us by Mr. Fritz Lutze, manager of the University Houses complex administered by the University of Wisconsin.

The University Houses consist of 150 apartment units in 31 buildings heated by five boilers. Each boiler serves several buildings. Fig. 1 displays a plan view of the Houses and indicates the location of each boiler and buildings heated by that boiler. Each boiler is subject to a different heat load which is determined by the distribution of apartment size in each building. Table 2 gives a break-down of the heat load which is theoretically placed on each of the boilers according to the original 1948 engineering data for the convectors used in the Houses.

The data set on which we applied our statistical and regression analysis is given in Table 1. Fuel oil consumption in gallons per month is shown for each of the boilers and combined for the entire group. These values are obtained through monthly dip-stick oil level measurements of the oil remaining in each storage tank. Monthly heating degree day data, base 65, for the heating season 1 Sept. through 30 April, are from the National Weather Service records for Truax Field, Madison, Wi. The additional climatic variables we considered to be of importance in determining the heat loss are sunshine and wind speed. The average wind speed for the month is given in miles per hour. Sunshine data gives the number of hours of sunshine received for the month indicated.

II. Temperature

Home owners and fuel distributors have long realized that air temperature plays an important role in determining the fuel requirements for space heating. Heat loss is found to be proportional to the difference in temperature between the inside and outside walls of a building. In order to standardize this temperature difference so that heating requirements can be uniformly expressed, an inside temperature of 65 degrees has been chosen. By subtracting this value from the average temperature for a given day an index called heating degree day is obtained which should correlate closely with the amount of fuel used to keep a building at a comfortable temperature.

Table 1: Climatic and fuel consumption data for University Houses boilers.

Date	HDD	Wind	Sun	#5	#10	#21	#30	#39	All Boilers
Sep 66	252			951	1517	1195	1155	901	5719
Oct 66	533			2345	3863	3053	3524	3229	16014
Nov 66	862			3534	5032	3829	4572	3523	20490
Dec 66	1369			5224	7011	5560	6563	4326	28684
Jan 67	1242			4567	6035	4722	5521	3854	24699
Feb 67	1407			5029	6426	5035	6264	3774	26528
Mar 67	978			4300	5638	4297	5082	3861	23168
Apr 67	620			2972	3969	3161	3769	3333	17204
Sep 67	239			1475	1667	1662	1745	1390	7939
Oct 67	535			2660	3440	2758	3605	3182	15645
Nov 67	955			3939	5044	3912	5309	3628	21832
Dec 67	1295			5104	6495	5001	6402	4136	27138
Jan 68	1335			5041	8684	3632	6377	4662	28396
Feb 68	1327			5781	7465	4912	6433	4843	29434
Mar 68	792			4055	6461	3864	5307	4462	24149
Apr 68	510			2513	4516	2348	3618	3208	16203
Sep 68	151			--	2003	1703	1741	1344	--
Oct 68	460			--	3830	2752	2447	2820	--
Nov 68	873			3903	5256	3576	4573	3000	20308
Dec 68	1234			5131	6398	4484	6084	3675	25772
Jan 69	1619			6042	10472	5516	7256	4462	33748
Feb 69	1152			4827	6052	4216	5611	3530	24236
Mar 69	1143			4748	6269	4295	5823	3850	24985
Apr 69	542			2865	4821	3174	4072	3070	18002
Sep 69	197			1000	1544	1036	1588	1190	6358
Oct 69	579			3086	4268	3343	4048	2830	17575
Nov 69	951			3744	4643	3705	4481	3429	20002
Dec 69	1302			4693	5537	4375	5268	3798	23671
Jan 70	1749	8.7	139.8	6162	6926	5231	6601	4909	29829
Feb 70	1286	10.3	172.0	5488	6253	4752	6116	4259	26868
Mar 70	1010	9.4	236.5	4350	5195	3850	4926	3667	21988
Apr 70	521	12.1	230.9	3126	4475	2792	3474	2850	16717
Sep 70	196	8.3	215.6	1563	2471	1512	1899	1416	8861
Oct 70	431	9.9	157.6	3085	4881	3104	4070	3086	18226
Nov 70	853	11.3	86.1	4245	5178	4211	4795	2749	21178
Dec 70	1310	10.9	120.1	6308	7374	4875	7334	4070	29961
Jan 71	1860	11.1	156.9	7374	8800	5445	8063	4595	34277
Feb 71	1116	11.6	112.4	4936	5574	4066	6277	3500	24353
Mar 71	1124	11.3	191.3	5734	6756	4299	6749	3717	27256
Apr 71	582	10.7	254.4	3810	5581	2789	5456	3132	20768

Table 1: Climatic and fuel consumption data for University Houses boilers. (Continued)

DATE	HDD	Wind	Sun	#5	#10	#21	#30	#39	All Boilers
Sep 71	--	--	--	--	--	--	--	--	--
Oct 71	290	9.5	182.7	2258	3592	2195	3339	2063	13447
Nov 71	885	11.8	112.3	3936	4746	3436	4989	3295	20402
Dec 71	--	--	--	--	--	--	--	--	--
Jan 72	--	--	--	--	--	--	--	--	--
Feb 72	1401	10.2	125.2	5997	7579	4926	7253	4707	30462
Mar 72	1079	12.3	199.6	5098	6783	4300	6578	4233	26992
Apr 72	745	10.2	178.2	3927	5911	3620	5200	3660	22318
Sep 72	--	--	--	--	--	--	--	--	--
Oct 72	580	9.9	157.8	3273	4982	3178	4362	3170	18965
Nov 72	--	--	--	--	--	--	--	--	--
Dec 72	1523	9.9	69.8	5843	7792	5099	7656	4873	31263
Jan 73	1231	11.1	143.2	4791	6490	4290	6788	4218	26577
Feb 73	1170	11.2	134.8	4769	7175	4570	6756	4243	27513
Mar 73	714	10.4	144.2	3531	6831	4051	5666	3916	23995
Apr 73	529	12.3	166.5	2577	4962	3121	4532	2863	18055

HDD = Base 65 monthly heating degree day total.
WIND = Average monthly wind speed in miles per hour.
SUN = Monthly total hours of sunshine.
FUEL = Gallons fuel oil used per month.

We applied a linear regression to the fuel consumption and heating degree day data for each boiler separately and for all boilers combined. The results of this analysis are shown in Table 3. Three parameters are given that describe the regression. At the top of each block is given the slope of the linear regression line. This slope gives the gallons of fuel oil consumed for each heating degree day accumulated. Small values of slope indicate efficient use of fuel or a small heat load on the boiler. The second parameter is the Y-intercept of the regression line. This parameter has little significance though it may be related to fuel consumption for purposes other than space heating, i.e., hot water. The final parameter is the linear correlation coefficient. This parameter can be interpreted as a measure of the goodness of fit of the regression line and indicates the extent to which the regression explains the variation of fuel consumption. These parameters are given in the same sequence in other tables.

It is strikingly apparent that the slopes show a great variation from year to year and one boiler compared to another. We also find that the correlation coefficients on a yearly basis are highly significant indicating that temperature expressed in heating degree day format is able to explain much of the variation in fuel consumption. Most impressive is the range of values obtained for the slope of the regression line from the five boilers. We compared the slopes obtained for the seven heating seasons combined and found the differences in slope to be much greater than could be expected for a random variable. Table 4 gives the probability that the slope differences observed for the five boilers are not a random occurrance. From this table it is clear that boiler #39 is significantly different from all the others.

Table 2 : Theoretical heat load on University Houses boilers based on convector design.

Building Type	1 (down) 29,900	1 (up) 33,600	2 (inside) 35,900	2 (outside) 41,900	3 37,700	Total heat load for Building
A	2	2	0	0	2	202,400
B	2	2	2	0	0	198,800
C	0	0	2	2	0	155,600

Boiler	Number of Buildings of Each Type A 202,400	B 198,800	C 155,600	Total Heat Load
5	1	2	2	911,200
10	1	2	5	1,378,000
21	0	1	5	976,800
30	1	3	3	1,265,600
39	1	1	3	868,000
All	4	9	18	5,399,600

Heat load in BTU/hr/90F° temperature differential.

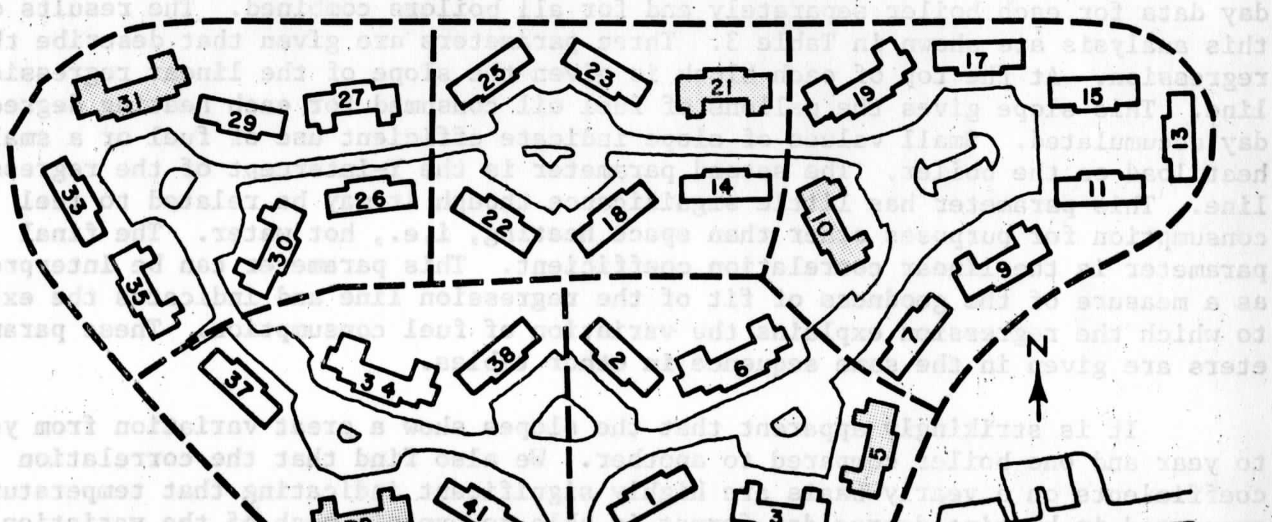

Figure 1: Plan view of University Houses complex divided into sectors heated by boilers located in shaded buildings.

Table 3: Climatic and fuel use data for heating seasons from 1966 to 1973.

Season	Boiler 5	Boiler 10	Boiler 21	Boiler 30	Boiler 39	Houses Combined
66-67	3.57 364 .98	4.14 1145 .96	3.26 863 .97	4.14 736 .97	2.20 1263 .84	17.27 4368 .96
67-68	3.43 836 .98	5.19 801 .92	2.43 1429 .89	3.98 1346 .97	2.44 1503 .87	17.46 5917 .96
68-69	2.85† 1498 .99	5.02 1002 .96	2.50 1422 .99	4.01 988 .99	1.92 1425 .96	18.15† 3957 .99
69-70	3.25 793 .97	3.26 1619 .95	2.53 1201 .95	3.07 1614 .95	2.25 1164 .97	13.60 6476 .93
70-71	3.49 1317 .98	3.28 2759 .93	2.17 1791 .94	3.69 1967 .96	1.70 1635 .91	14.53 9146 .97
71-72††	3.43 1191 .99	3.72 2274 .95	2.51 1421 .99	3.66 2197 .98	2.46 1325 .99	15.78 8408 .98
72-73†††	2.68 1644 .99	2.15 4414 .79	1.68 2481 .92	3.15 2954 .97	1.49 2526 .94	11.16 14018 .95
All Seasons Combined	3.25 1034 .96	3.80 1946 .88	2.48 1453 .94	3.60 1674 .92	1.95 1641 .87	14.84 8223 .94

† Sept. & Oct. data missing; 6 months only.
†† Sept., Dec., & Jan. data missing; 5 months only.
††† Sept., & Nov. data missing; 6 months only.

Table 4: Likelihood (%) that differences in slopes are not random.

Boiler	#10	#21	#30	#39
#5	76	89	67	99
#10	--	96	60	99
#21	--	--	95	82
#30	--	--	--	99

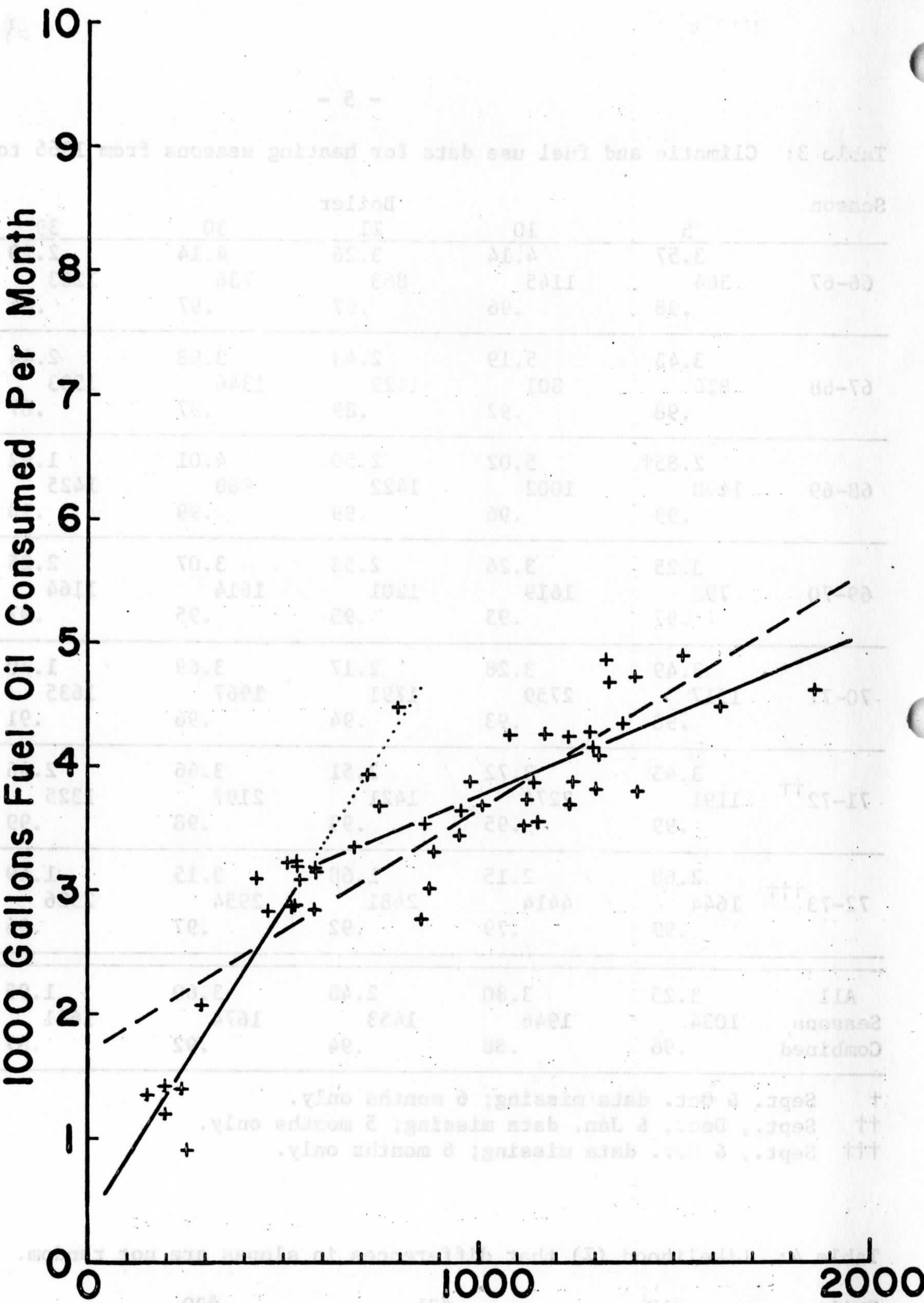

Figure 2: Fuel consumption by Boiler #39. Solid lines give regression lines based on stratification by degree days. Broken line gives regression line based on all data.

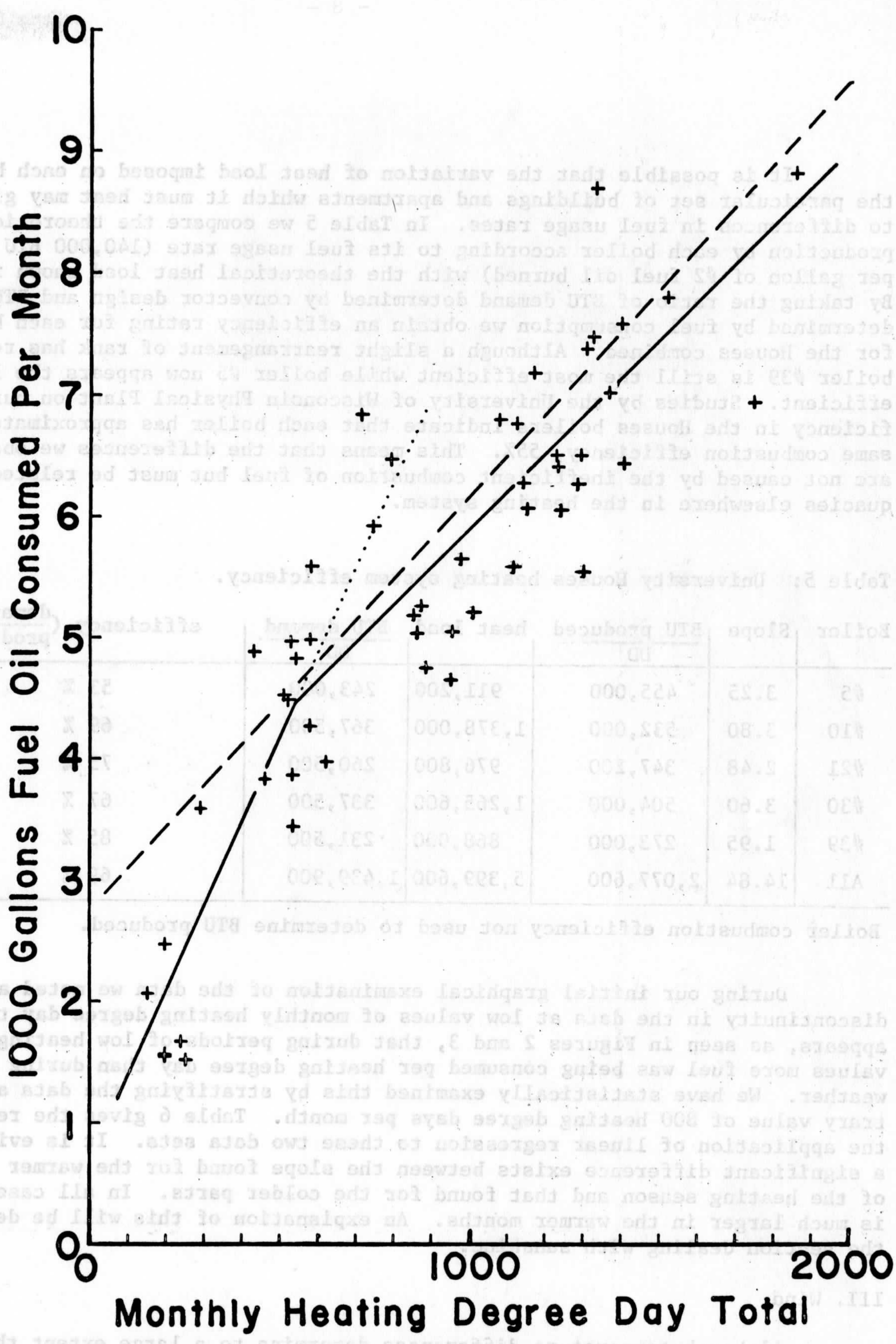

Figure 3: Fuel consumption by Boiler #10. Solid lines give regression lines based on stratification by degree days. Broken line gives regression based on all data.

It is possible that the variation of heat load imposed on each boiler by the particular set of buildings and apartments which it must heat may give rise to differences in fuel usage rates. In Table 5 we compare the theoretical heat production by each boiler according to its fuel usage rate (140,000 BTU generated per gallon of #2 fuel oil burned) with the theoretical heat load shown in Table 1. By taking the ratio of BTU demand determined by convector design and BTU produced determined by fuel consumption we obtain an efficiency rating for each boiler and for the Houses combined. Although a slight rearrangement of rank has resulted boiler #39 is still the most efficient while boiler #5 now appears the least efficient. Studies by the University of Wisconsin Physical Plant on burner efficiency in the Houses boilers indicate that each boiler has approximately the same combustion efficiency, 55%. This means that the differences we observe here are not caused by the inefficient combustion of fuel but must be related to inadequacies elsewhere in the heating system.

Table 5: University Houses heating system efficiency.

Boiler	Slope	BTU produced / DD	heat load	BTU demand / DD	efficiency $(\frac{\text{demand}}{\text{produced}})$ %
#5	3.25	455,000	911,200	243,000	53 %
#10	3.80	532,000	1,378,000	367,500	69 %
#21	2.48	347,200	976,800	260,500	75 %
#30	3.60	504,000	1,265,600	337,500	67 %
#39	1.95	273,000	868,000	231,500	85 %
All	14.84	2,077,600	5,399,600	1,439,900	69 %

Boiler combustion efficiency not used to determine BTU produced.

During our initial graphical examination of the data we noted an apparent discontinuity in the data at low values of monthly heating degree day totals. It appears, as seen in Figures 2 and 3, that during periods of low heating degree day values more fuel was being consumed per heating degree day than during colder weather. We have statistically examined this by stratifying the data at an arbitrary value of 800 heating degree days per month. Table 6 gives the results of the application of linear regression to these two data sets. It is evident that a significant difference exists between the slope found for the warmer portions of the heating season and that found for the colder parts. In all cases the slope is much larger in the warmer months. An explanation of this will be deferred to the section dealing with sunshine.

III. Wind

Although temperature differences determine to a large extent the rate of heat loss by buildings we also recognize that buildings also experience a "wind chill". The effect of the wind is to increase the rate at which heat is carried away from the outside walls of a building and also to increase the rate of air

Table 6: Stratification by heating degree days.

Heating Degree Days	Boiler 5	10	21	30	39	Houses Combined
<800	4.64 394 .91	7.26 598 .89	4.17 685 .92	6.44 489 .88	4.81 414 .95	27.65 2366 .93
>800	3.02 1331 .88	4.11 1484 .79	1.94 2108 .83	3.11 2283 .81	1.74 1849 .80	13.93 9053 .90
Significance(%) of Slope Difference	79	86	95	93	98	93
Regression Break point	578 46°F	282 56°F	638 44°F	539 47°F	467 50°F	487 49°F

exchange through the building. Both of these factors result in a greater heat loss as the wind speed increases. To see if this effect is noticeable in the University Houses we stratify the climatic data into two sets according to wind speed; the boundary between the sets is set at 9.9 miles per hour. Linear regressions are applied to each of these sets for each boiler individually and for the Houses combined; the results are presented in Table 7. Three of the five boilers demonstrate that higher winds lead to increased fuel consumption; the remaining two boilers show little change or even small decreases. In this case, however, we can not demonstrate that the difference in slopes is not related to a random sampling of the data.

Table 7: Stratification by wind speed.

Wind	Boiler 5	10	21	30	39	Houses Combined
≤ 9.9	2.75 1500 .98	2.34 3016 .90	2.12 1669 .96	2.51 2422 .93	1.96 1660 .94	11.70 10258 .95
> 9.9	3.12 1673 .96	3.08 2903 .90	2.11 1855 .95	3.07 2729 .89	1.55 2037 .87	12.93 11197 .95

With this tentative success in demonstrating the wind chill effect we sought to identify more precisely the contribution wind gives to fuel consumption. In order to isolate the wind's effect we subtract from the actual fuel use data of Table 2 hypothetical values derived from the linear regression equations found with heating degree day data. Linear regressions are then applied to the residuals as a function of the actual monthly average wind speed. Our results are that no significant correlation between the residuals and wind speed exist. The additional variance explained by our correlation with the wind results in less than one percent.

This is not to say that wind speed has no effect on the rate of fuel use in space heating. Rather it says that if a relationship exists it is likely to be very non-linear. This is to be expected considering the complexities of convective heat transfer. The initial stratification study does demonstrate that wind has an effect on fuel consumption that is in addition to the effects of air temperature.

IV. Sunshine

The interception of solar energy by a structure should play an important role in the over all energy balance and should be a factor in the consumption of fuel for space heating. As a first step in correlating fuel use with sunshine we determine the degree of correlation of the hours of sunshine per month with the number of heating degree days accumulated in a given month. The resulting linear regression has a correlation coefficient of -0.45; that is, the number of hours of sunshine increase as the monthly heating degree days decrease. The correlation is quite weak but never-the-less in the direction to be expected since we experience the greatest total of degree days during months when the hours of daylight are at a minimum.

However, when we stratify the data into two classes with the boundary at 160 hours of sunshine, which is the median sunshine amount for the data sample, we obtain the very unexpected results seen in Table 8. Our linear regressions indicate the rate of fuel use is higher by 40% for the Houses combined in the group with monthly sunshine totals exceeding 160 hours.

Table 8: Stratification by hours of sunshine.

Sunshine Hours	Boiler 5	10	21	30	39	Houses Combined
<160	2.90 1635 .96	2.43 3713 .82	1.66 2451 .94	2.69 3132 .90	1.42 2334 .85	11.10 13265 .94
>160	3.66 1101 .97	3.26 2800 .88	2.69 1339 .98	1.94 3594 .49	2.32 1480 .94	15.60 8844 .95
Significance of Difference	67%	68%	80%	65%	79%	73%

This is a quite unexpected result. From a heat balance point of view one would expect that increased sunshine would mean that more solar energy is available to heat the exterior of the building and thereby reduce the heat loss through the walls. This reduced heat loss should mean that the amount of energy needed to maintain a comfortable temperature within the dwelling is also reduced and overall fuel consumption should decrease.

The key to this arguement is, however, the assumption that some means of controlling the energy expended to heat the building is at the disposal of the residents of that building. In the University Houses, individual thermostatic controls are not present in each apartment. Rather, an attempt is made to vary the heat supplied to each building by changing the temperature of the water provided to the heating system by each boiler according to the outside air temperature. The unexpected inverted response of fuel consumption to sunshine demonstrates the inadequacy of such a system to properly respond to a combination of weather conditions. The extent to which this problem exists is also seen in the increased slope of the regression lines for the warmer months. Large values of the regression line slope are associated with small heating degree day values and high sunshine values because the only mechanism available to a resident of the Houses for reducing the temperature within his apartment is to open windows or doors to let the hot air out. When this hot air leaves, the heating system responds by sending more hot water. Under such circumstances one can not but expect to find the correlations we have observed.

In Table 6 the intersection of the two regression expressions is given as the regression break point expressed as a monthly heating degree value and as an equivalent average daily temperature. At temperatures below this value it would appear that the useage of fuel follows the regression found for the colder months. The sunshine data however indicates fuel useage is increased even during the cold months whenever it is very sunny.

V. Conclusions

This study of the correlation of fuel consumption for space heating in the University Houses with weather and climatic parameters has reiterated the usefulness of heating degree days as an indicator of fuel use. This single climatic factor can be used to explain 91% of the variance in fuel consumption. The relationship between heating degree days and fuel use is highly linear making the application of the regression to predict fuel useage a simple task.

Wind was not found to be linearly correlated with fuel useage but was shown to affect the rate of fuel consumption in a sense consistant with physical reasoning. No attempt was made to isolate a non-linear "wind chill" effect.

Our study of the relationship between sunshine and fuel use produced unexpected results that complimented the study of fuel use in warm months. The lack of temperature control within individual apartment units places an additional burden on the heating system whenever outside air temperature, sunshine, and even wind permit the inside temperature to become uncomfortably warm.