Shelterbelt Influences[1]

II. The Value of Shelterbelts in House-Heating

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A good belt of trees protecting the farm home was estimated by farm owners in eastern South Dakota to reduce the fuel bill about 25 percent, according to a survey conducted by the Shelterbelt administrative force in 1935. That this is well within the limits of a belt giving substantial protection only from northerly winds, is shown by the experimental data here presented and analyzed; while protection from both north and west winds may increase this substantially, and all-around protection in the center of a grove or forest might effect a saving of 40 percent. The experimental data have been adjusted to actual heating conditions of the typical farm home, and calculations made for wind and temperature conditions which prevail at four different latitudes in the Plains region. These facts should discourage the removal or too severe thinning of farmstead groves in the present emergency, with a view to effecting savings in coal. Total fuel consumed may be much greater if the protective belt is weakened, and only dead wood could profitably be employed to replace coal.

THE householder who has had to heat an isolated home, or one not well sheltered by natural features or by other buildings, need hardly be told that much more fuel is required to maintain ordinary indoor temperatures on a windy day than on a calm day of comparable outside temperature. While the extent of such increase depends much on the type and quality of house construction (the "snugness" of the house), there remains an inevitable relationship between amount of wind, or of wind exposure of the individual house, and fuel requirements. There are also certain associated effects of wind upon the immediate environment of the house which have made it seem desirable to approach the subject not from the standpoint of the architect or heating engineer but from that of modifying the environment. The results which are here described must be considered as somewhat specific for the given climatic conditions of the Plains as expressed mainly by wind velocities, winter temperatures, and sunshine duration and intensity.

Background of the Study

Nearly all the early settlers on the Plains were faced with an extreme shortage of fuel and, at the same time, with almost complete lack of protection from winds which roamed the plains "without let or hindrance" and were often of great velocity and persistence during the most severe storm periods. Those with foresight and understanding of the conditions built thick-walled, flat-roofed sod houses, houses with similar walls of logs, where obtainable, or dugouts where the protection of a south-facing bank could be had. The improvident or latecomers, attempting to pass a first winter in a tiny shack of boards and tar paper, hovered on the lee side of the stove and wished that the shack had only half as much space to be heated.

A natural reaction to these conditions was to plant windbreaks of trees. Some settlers did this almost as soon as any ground could be broken; others were encouraged to do so by the "Timber Culture Act" (1873-91), which made the planting of a given acreage of trees (in lieu of longer residence under the Homestead Act) a prerequisite to obtaining title to the land. The settlers who were foresighted enough to make this provision found themselves in possession of better building sites by the time their own first battles had been won and railroads had sufficiently opened the country so that grain crops could be sold for cash.

This time coincided with the free flow of white pine and other good building lumber from the Lake States into the northern and central Plains regions and, a little later, with the similar flow of southern pine lumber into the central and southern Plains. For their more permanent homes, therefore, the settlers had incomparable building material; and, as a general rule, large and roomy, 2-story "square houses" were built. A striking feature of the northern Plains is the fact that not only are the houses often built on

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the most exposed hilltops, but also they are extremely tall, the less pretentious emulating the more expensive in this respect if in no other. That in an undulating glaciated region the lower ground offering some protection from wind is swampy, and hence unsuitable, is of course apparent. But nothing could have justified this particular type of architecture, which under the circumstances is out of place, foreign, and "outlandish."

Without much question farm buildings, especially in the early days when travel and intercourse were much more difficult, have not generally made the best possible use of the materials available, because of the actual scarcity of skilled building mechanics and because of the need to economize in cash outlay. This is said in no spirit of criticism, for the resourcefulness of the farmer in all fields is an admirable character. It is meant to imply, rather, that the farm homes with which we are dealing are not, as a general rule, of high-quality construction. If this suggests to architects and insulating concerns that there is a very great field for the improvement of farmhouses, so much the better. Insulation is undoubtedly desirable; however, before that phase is considered, the architect should have an opportunity to revamp radically the exterior design of thousands of houses in the Plains region which are "wind traps" of the worst possible kind.

The points to which this "background" discussion leads are simply these:

1. Although tree planting in the earlier years developed protection about the original farm home, or the later building often was placed where there was such protection, this was by no means universally true. In the northern Plains, especially, the custom of erecting houses on hilltops has placed many where trees grow but poorly, and where it is most difficult to obtain protection in any case. In other cases, the groves have died out because of actual senility or lack of care.

2. In referring to the possible benefits from wind protection it should be kept in mind that, broadly speaking, the most exposed farmhouses are often very loosely constructed. It will be made plain what this means in a discussion of the possibilities of heat losses being abetted by wind.

A survey of farms in eastern South Dakota, conducted as an administrative phase of the Prairie States Forestry Project, showed that there is a general appreciation of the value of wind protection. Even in this fairly favorable territory, however, not all groves were successful nor are more than half of the farmsteads receiving the protection they might well have. The survey aimed to get an over-all estimate of the value of a good shelterbelt or grove as a fuel saver, through opinions both of the farmers who have them and those who have none, or less than they would like. The concensus of both groups was that such exterior protection would reduce by about 25 percent the winter fuel bill, which without the grove would average approximately $80 per year. Those whose belts or groves permitted some cutting for fuel were, in some cases, making a further cash saving of the cost of coal; in other cases this wood fuel seemed to be a luxury item added to the purchased fuel.

Considering that farm homes are rarely heated throughout to the degree that city dwellers consider normal, and that bedrooms often are heated very little, a fuel cost of $80 per year may seem a little high, but probably reflects the fact that any isolated dwelling has a good deal more exposure to cope with than the houses in even an uncongested village. Also, the average size of farm dwellings probably exceeds the average size of dwellings in cities and towns today, where new construction is at all advanced.

Test Houses

The original plan of this experiment called for a "spot" or empiric test of the heat use of two or more identical house units differently exposed to wind. One house was to receive the full force of the Plains wind through the winter; another would be so placed as to receive the maximum possible protection by a typical windbreak; while a third would represent an intermediate degree of protection. If the actual wind which occurred in each position were recorded, such a test would not only tell its own story directly for the climatic conditions of the Plains, and for the specific local protection, but also the results could be extended to other situations represented by known wind velocities.

Since the character of the results would depend not only on the velocity of the winds which occurred, and the severity of the cold or degree of difference in temperature between the houses and the outside air,[2] but also even more directly on the wind direction (provided only one-sided protection were given), an obvious requirement of such a test was that it should be continued long enough to give a typical "sample" of all the weather conditions likely to occur in a winter; in fact, it must cover all, or equal proportions of all parts, of the heating season of 7 to 9 months on the Plains. From this standpoint no one locality would be quite satisfactory, but a middle latitude seemed preferable, and because of other work going on at Holdrege, Nebraska, that point was selected.

An item not considered in planning this direct approach was that very small house units—desirable from the standpoint of accurate heat control and recording of temperatures, as well as for economy of operation—could hardly be so constructed as to "represent" larger houses in every respect. The critical consideration is that the ratio between heat losses which occur through the walls and wall materials of the house and those which occur by reason of air movement through cracks should be average, or typical of a certain standard of construction which, as already implied, is not a high standard with farmhouses if general "tightness" be considered. For the first of these items, principally conduction, referred to as "transmission loss," is only very slightly influenced by wind, while the second, or "infiltration loss," may be more than directly proportionate to wind velocity. In addition, flue losses seem to be influenced in about the same way by wind, although this is not an item in house construction, and has to be considered in this experiment largely as a matter of over-all fuel efficiency.

To make clear why very small test houses distort the results as to the degree of wind effect, and thus necessitate a more analytical approach than was first contemplated, it is only necessary to use a simple example. If the test houses had been so designed as to be miniatures of, for instance, 2-story square houses, with a typical proportion of glazing to total wall area, then the transmission loss through glass, which is high relative to that through wall materials, would have been typical also, and the heating value of sunlight a considerable item in saving fuel, would have played its normal part, in so far as light through glass is more effective than light applied to exterior wall surfaces. However, due to the simple geometric fact that as rectangles are increased in size their areas increase much more rapidly than their primeters, the miniature house would in this case have a much greater footage of window cracks relative to either wall or glass area than the house of normal dimensions. With the 12-inch by 18-inch glass used in the test houses (omitting sash width) there is 5 feet of perimeter or crack for 1.5 square feet of glass, or 3.33 to 1. With windows using 30-inch by 30-inch glass, the ratio is $\frac{10}{6.25}$, or 1.6 to 1 for each sash separately, but only $\frac{17.5}{12.5}$, or 1.4 to 1 for double-sash windows. Thus the miniature house would be certain to have from 2 to 2.5 times as much infiltration loss as the house of usual dimensions, in relation to transmission loss, if its area of glazing were exactly proportioned.

Since a proper balance was not brought about, as regards the two types of heat losses, and it would have been impossible with such adjustment to have sunlight heating in proper proportion, we are faced with essentially the situation used as an illustration, for the test houses, which were 4-foot cubes in inside dimensions. Adding half of the wall thickness, i.e., calling the squares 4.33 feet, since it is such an important item with so small a cube, the wall-and-ceiling area is 93.75 square feet. Three windows of the size mentioned, with 2-inch sash allowance all around, plus one door 24 by 44 inches, gives a total crack footage of 28⅔, which may be rounded off to about 31 feet with allowance for a ½-inch pipe through the ceiling. Upon examining the plans for two types of farmhouses, a Cape Cod cottage is found to have about 2.1 times the ratio of wall area to crack footage which is indicated above; 26-foot by 26-foot two-story square house about 2.5 times.

Although these facts indicate that the infiltration losses of the test houses should be reduced

[2]To save space, the outdoor temperature will hereafter be referred to as *To*, the house or interior temperature as *Ti*, and the difference in temperatures, which is the critical value in heat loss rates, as *Ti-To*. Generally speaking, mean temperatures for each unit period of operation are referred to and extremes are ignored, the means being determined from thermograph traces checked at least once each day by maximum and minimum thermometers. In addition to the above, we have reason to refer later to *Tu*, the temperature of the house heated only by the sun, or otherwise the "unheated house."

by somewhat more than one-half, in order that infiltration and transmission losses shall be in proper balance and the effect of wind not be exaggerated, there are circumstances which make a reduction of just one-half seem, in the opinion of the writer, entirely fair. This basis has been adhered to despite the opinion of a prominent heating engineer that the resultant ratio of infiltration to transmission—for example at 15 m.p.h. wind and 25° *To*, about ½/1—is "high." As already pointed out, it is intended to represent houses of relatively poor and loose construction. Actual infiltration was that to be expected if windows had been weather-stripped. In addition, the transmission loss of the test houses should be high, relative to wall area, because sheathing was omitted: and while there are actually many farmhouses without sheathing, that is certainly too low a standard of wall construction to be considered typical.

The calculated transmission of the test houses, on the basis of inside dimensions, is 26.239 B.t.u. per hour-degree in still air. It apparently must be less than this in order that total heat losses may not exceed the actual as obtained by extending the measured heat losses from the lowest point on the curve at about 1.6 m.p.h. wind, and it has been necessary to assume this starting point for transmission as being 23.0 B.t.u. per hour. Transmission losses calculated for 5, 10 and 15 m.p.h. have then been reduced in this same proportion. The increase in transmission to 20 m.p.h. is only 8.7 percent of the basic rate, and 7/10 of this increase occurs below 5 m.p.h.

In order that any statements made herein may be subjected to checks, a few points regarding the test-house construction should be recorded. Figure 1 shows the design clearly enough, especially as to the type of roof and roof-ceiling space. The roof itself was of ¾-inch by 2-inch slats, covered by a layer of prepared roofing paper out to and over ends of slats, but there may have been fine cracks for infiltration on the underside of the 2-inch projection of the slats. The ceiling was wallboard only, while the roof arches had a central height of 9½ inches. The walls were 3½-inch studding, covered, on the outside, by glazed building paper and lap siding, on the inside by ½-inch Celotex (somewhat porous) wallboard. Lap siding covered the ends of the 2-inch by 4-

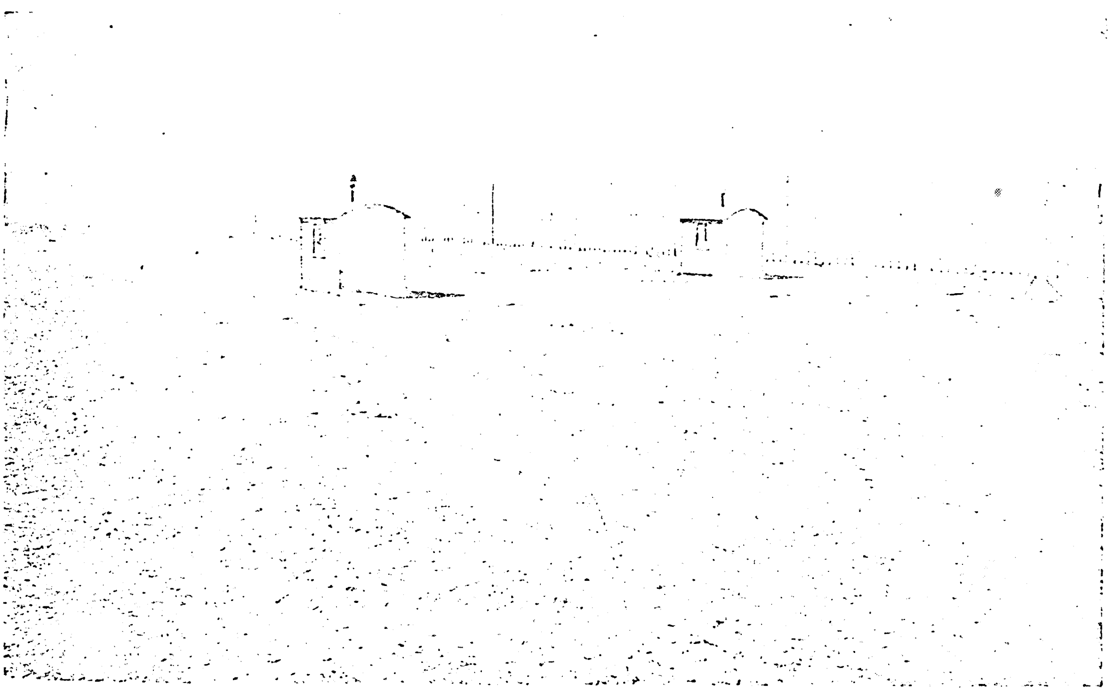

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Fig. 1.—Test houses as set up at Holdrege in March, 1936, looking northwest toward the "60-percent" solid barrier. Doors open to the east. Anemometer stands are shown at right, while stakes visible at left represent line through center of long barrier, on which evaporimeters were placed.

180

inch floor joists, resting on 2 by 4's laid flat as runners, thus putting the floor of $\frac{3}{4}$-inch fir about $5\frac{1}{4}$ inches above the ground. The houses were kept banked with soil or snow so that wind could not sweep under. The door was two layers of Celotex over a $\frac{3}{4}$-inch frame, and was rather loose fitting, especially at the bottom, while the windows were tightly stopped all around and held snugly against the outside casings. The houses were constructed identically (as far as could be seen), and in very workmanlike manner. They were first used when new, and between the first and second winters received a coat of paint which prevented any warping.

Results of Tests

Two sets of tests were made, near the beginning of 1936 and 1937 respectively. In the first, the original idea was carried out, but for so brief a period that the direct comparison of protected and unprotected houses has very little significance as a seasonal relationship. It then being apparent that data on heat-loss rates of a more fundamental character would have greater value, and that the number of variables should be held to a minimum, a considerably different plan was followed in the second season. The primary deficiency of the results in the second season is the lack of any flue-loss element and the fact that, with heating by electrical energy, "fuel efficiency" must at all times be taken as 100 percent. To some extent the first-year results give the basis for estimating this element.

Since the primary purpose of this article is not to discuss the physics of house heating, but to show how established physical facts "work out" under Plains conditions, and the extent to which fuel use may be reduced by exterior protection, the treatment of the measurements made is as brief as possible. This treatment, which may not interest the casual reader, is designed to place the measured results on record for any possible use or interpretation, and to show the steps taken to put them in usable and convenient form, as in Table 4. However, in order that even Table 4 may be used safely by others, it is necessary to mention certain precautions, necessitated by the fundamental physics of the problem.

First Test, 1936

The setup for this test was that illustrated in Figure 1. The 12-foot slat barrier, 496 feet long, appearing behind the houses, is the east-west barrier of the so-called "orientation" pair. The houses are located 2-H (24 feet) and 5-H south of the barrier, to benefit under prevailingly north winds, while a third house was in the open, without obstruction for hundreds of feet. Of the two locations used, the 5-H position is likely to show the lower wind velocity with north winds or those within, possibly, 45 degrees of north, while the 2-H position will show lower velocities with winds from nearly all other directions. With somewhat more than average preponderance of north winds during the observation periods in 1936, however, the 2-H position had a slight advantage.

The test houses had been ready for some time before actual "runs" were made near the end of March. It had been found impossible to control the only available oil-burning (brooder) stoves at a low enough rate of fuel consumption to avoid excessive interior temperatures earlier, but colder days at the end of March kept temperatures within the limits of recording thermometers. At this time six periods, totaling 69 hours, were considered to have acceptable records, although interior temperatures could not be held to 70° F. and went to an extreme of 114° F. By combining all six periods, there are obtained interior averages which are not too variable between the three houses.

As is probably well known, brooder stoves are rather hoods than stoves, and the amount of "draft" cannot be closely limited. Consequently, as excessive draft is a primary cause of heat loss through the flue, it is found that for the entire period, in the control house requiring the hottest fire, the fuel use was somewhat excessive, although the efficiency is calculated, from later results, as having been about 61 percent. The actual flue-loss rates which may be derived from the present data are, therefore, greater than might be considered normal for these houses and the conditions prevailing, and must be modified as described later.

The results of Test 1, treated as a single period, are shown in Table 1 and Figure 2. The effect of wind is very pronounced, and as between the two houses which varied only slightly in average wind velocity, the results show only slight inconsistency when the relationship is covered by the straight line "A" (Fig. 2). However, it is obvious these two lower points are too close together to determine the nature of the curve "B," although this happens to fit to the two points more closely

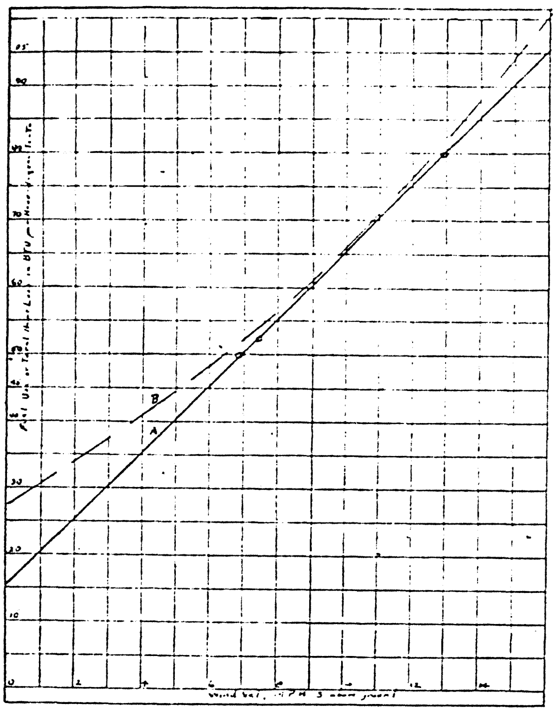

Fig. 2.—Effect of wind velocity on fuel use and heat loss.

For ease of reference to the over-all effect of wind protection during the short period of the test, the two lower sets of values are averaged, and it is found that on the south side of the 60-percent solid barrier there was wind reduction from 12.93 m.p.h. average, to 7.18 m.p.h. average, or nearly 45 percent, while heat use was reduced from 79.97 to 51.10 B.t.u. per hour-degree, or 36.1 percent. In short, there was about 0.81 percent reduction in fuel use for each 1 percent reduction in wind.

Aside from the fact that the temperatures during the brief period of these measurements cannot be considered typical of the heating season as a whole, there are two reasons why such an expression overrates the value of the protection, as well as the average effect of wind. Regarding the first, for the entire heating season of 1936 the position at 5-H south of the barrier showed only 25.1 percent reduction of the wind in the open,[3] although these continuous measurements were made at a level of 16 inches, in comparison with 36 inches at each house during the heating tests. It is thus evident that the test period was not typical of average wind directions. Further-

TABLE 1.—HEAT USE WITH PROTECTION OF BARRIER ON THE NORTH; 1936 TESTS WITH OIL-BURNING HEATERS, LARGE FLUE LOSSES

Condition	Total length of observation periods[1]	Mean temperature	Excess over outside temperature Ave.	Excess over outside temperature Hour-Degs.	Volume of fuel used	Theoretical heat generated[3] Total	Theoretical heat generated[3] Per Hour-Deg.	Mean wind velocity
	Hrs.	*°F.*	*°F.*		*(C.c.)*	*(B.t.u.)*	*(B.t.u.)*	*(M.p.h.)*
Open-air[2]	69.19	24.67	....	....	....	....	....	16.45
Control house, heated	68.83	97.10	72.38	4,981.86	10,850	398,412	79.97	12.93
House 2 hts. S. of barrier	68.68	94.09	69.35	4,762.90	6,480	237,946	49.96	6.83
House 5 hts. S. of barrier	68.72	95.66	70.94	4,874.77	6,935	254,653	52.24	7.48

[1]Since component periods are not of the same length for different houses or even for each item measured, several items in the table which are obtained by summing the short-period components will be found not to check exactly, such as the average excess of house temperature over outside temperature. Discrepancies are insignificant, however.

[2]Wind velocity shown opposite is for 16 feet from ground at control station, or more nearly as velocities are commonly indicated, and about ⅓ higher than at the 3-foot level at same point. All test velocities are at 3 feet above ground, and all are corrected for instrumental error for the shorter periods.

[3]At full value 139,000 B.t.u. per gallon, or 36.72 B.t.u. per c.c.

than the straight line. Even after "fixing" the lower end of curve "B" as a result of some rough tests showing that flue loss could hardly be reduced below 3 B.t.u. per hour-degree, the shape of the curve was found to be difficult to fix by graphic methods alone. Consequently, the curve as drawn is based on certain relations between flue loss and other losses, established later, and described in connection with Table 3.

more, the velocity of 12.93 m.p.h. at an elevation of 36 inches is considerably above average, and is partly responsible for the reduction of 42

[3]It is worthy of note that at the same distance north of the barrier, the average reduction was 17 percent, showing plainly that even a windbreak to the south of a house would not be without value in the winter. However, the further point is probably apparent, that while there would then be some protection from north winds, it would be primarily in the period of milder, south winds that the protection would be given.

TABLE 2.—BASIC DATA FROM THE 71 DAYS OF OBSERVATION ON TWO HOUSES (ADJUSTED FOR APPARENT DIFFERENCE IN METERING) AND PRIMARY 25-DEGREE CURVES BASED ON ALL OF THE DATA

Original data for groups in same whole-mile class (e.g. 2.01-3.00 m.p.h.)											Smoothed values for *To* 25° F.		
No. days in class		Average wind velocity	Average temperatures		Rates per hour in b.t.u.			Average of hour-deg. heat-loss rates[2]	Correction per hour-deg. *To*[3]	Corrected hour-deg. heat loss at 25 °F.	Wind velocity	Per hour-deg.	
House No. 1	No. 2		*To*	*Ti-To*	Fuel use	Sun heat	Total heat loss					Fuel use	Heat loss
		M.p.h.	*°F.*	*°F.*				*B.t.u.*	*B.t.u.*	*B.t.u.*	*M.p.h.*	*B.t.u.*	*B.t.u.*
..	..	....	....	....	....	....	....	....	....	....	0	20.002	21.000
..	..	....	....	....	....	....	....	....	....	....	1	21.362	25.467
7	12	1.654	24.66	46.11	1003.02	209.34	1212.36	26.457	.0084	26.454	2	22.762	26.961
12	11	2.504	21.93	48.01	1136.63	200.05	1336.68	27.696	.0125	27.658	3	24.205	28.191
6	11	3.448	28.08	42.20	1081.39	154.48	1235.87	29.238	.0184	29.295	4	25.698	30.918
5	7	4.486	25.46	44.79	1180.68	203.22	1383.90	30.678	.0278	30.691	5	27.245	31.612
5	3	5.394	25.83	44.10	1259.99	220.86	1480.85	32.350	.0384	32.382	6	28.850	33.275
6	3	6.453	28.89	40.96	1202.49	201.74	1404.23	33.819	.0556	34.035	7	30.513	34.917
4	4	7.541	23.42	46.81	1507.38	171.35	1678.73	35.431	.0768	35.310	8	32.247	36.661
5	2	8.607	23.36	46.92	1574.45	223.92	1798.37	38.279	.1003	38.104	9	34.067	38.428
1	8	9.530	15.67	55.11	2041.15	199.20	2240.35	40.412	.1228	39.266	10	35.964	40.252
4	1	10.536	31.27	38.67	1419.48	127.49	1546.97	39.825	.1500	40.764	11	37.937	42.147
6	1	11.597	28.62	40.85	1561.28	180.96	1742.24	42.414	.1794	43.062	12	40.006	44.117
2	2	12.330	25.06	44.47	1962.04	131.40	2093.44	45.860	.2000	45.871	13	42.165	46.181
2	3	13.482	24.61	46.12	2082.34	138.25	2220.59	47.332	.2322	47.242	14	44.430	48.404
..	..	....	....	....	....	....	....	....	....	....	15	46.782	50.835
5	3	15.029[1]	28.54	41.92	1866.94	209.13	2076.07	49.767	.2804	50.759	16	49.251	53.536
..	..	....	....	....	....	....	....	....	....	....	17	51.861	56.521
..	..	....	....	....	....	....	....	....	....	....	18	......	59.802
..	..	....	....	....	....	....	....	....	....	....	19	....	63.387
1	0	21.25	24.77	45.00	3000.35	272.73	3273.08	72.736	.470	72.628	20	......	67.280

[1]Because of great variability and few observations at this level, includes velocities from 14 to 16.22 m.p.h.

[2]Since periods with higher *Ti-To* and lower *To* generally run at higher rates, it follows that the average obtained by dividing the preceding column by average *Ti-To* will give a higher rate than the average of the individual rates shown here. However, in most cases the difference does not exceed 0.25 B.t.u. per hr.-deg., exceptions being in 12-13 and 13-14 m.p.h. groups, where temperature effects are very pronounced, and in 1-2 and 14-16 m.p.h. groups where temperature effects are reversed—probably accidental variation. These variations make it clear why it is difficult to assign true values to the temperature correction curve, and its irregular form.

[3]Corrections are given in this form, rather than actual amounts of correction, because similar values are used to develop curves for *To* 0° F. and *To* 50° F. Here, when *To* is above 25° F. the correction is plus; when below, minus.

percent at this station, since the percentage reduction invariably rises as the velocity rises, at least in so far as the position of maximum reduction is concerned.

This statement does not make sufficiently clear, however, why it is important, for the accurate determination of probable heating benefits, to deal with true wind velocity as it actually impinges on the house, rather than with an approximate or assumed average velocity. Even if we were dealing with so simple a relationship of fuel use to wind velocity as is illustrated by curve "A" of Figure 2, a little thought would show that the percentage relationship arrived at depends not alone on the above varying values of protection, but also on the point from which calculation is started. This is because the curve (such as "A") does not strike zero heat use at zero wind velocity, but is always held up at low velocities by the continuing transmission loss. Roughly, curve "A" has a "dead weight" item of 15 B.t.u. which is not influenced by wind at all. Taking the rate of rise as 5 B.t.u. for each mile of wind, calculations are made very simple. Thus, if the initial wind velocity be 13 m.p.h., it is found that the ratio of 0.81 between fuel-use reduction and wind reduction, when both are expressed as percentages of the initial rates, is actually the ratio $\frac{80—15}{80}$ (derived from $\frac{5}{80} :: \frac{1}{13} = \frac{65}{80}$); likewise, starting from 10 m.p.h. the ratio is expressed by $\frac{65—15}{65}$, or 0.77, and at 5 m.p.h. by $\frac{40—15}{40}$, or .625. These varied results are all from points on the same straight line, making it clear that the result depends very much on the

Table 3.—Skeleton Data Showing the Steps by Which Basic Results Are Transformed into Final "Curves" for Three Temperatures; All Units, Except Col. 1, Are in B.t.u. Per Hour-Degree

Wind velocity m.p.h.	Total heat-loss rates[1] 0°F.	25°F.	50°F.	Transmission rate	Infiltration rates (residual) 0°F.	25°F.	50°F.	Basic flue-loss rates (1936)[2] As used	Alternate (see text)
0	24.131	24.000	23.881	23.000	1.131	1.000	0.881	3.400	3.400
5	32.527	31.642	30.842	24.401	8.126	7.241	6.441	12.685	12.532
10	43.798	40.252	37.043	24.791	19.007	15.461	12.252	25.673	25.809
15	58.167	50.835	44.202	24.928	33.239	25.907	19.274	43.158	43.189
20	79.457	67.280	56.263	24.998	54.459	42.282	31.265	62.762	69.971

Wind velocity (m.p.h.)	Flue-losses to combine for efficiency of[3] 67% at 0°F.	70% at 25°F.	73% at 50°F.	Alternate 25°F.	Sums, Tr., half of Infiltr. and flue loss, with deduction for sun heat[4] At 0°F.	At 25°F.	At 50°F.
0	2.202	1.813	1.496	3.400	22.268	20.813	16.936
5	8.215	6.764	5.580	6.671	33.179	30.285	25.201
10	16.629	13.692	11.296	13.738	47.424	41.713	34.213
15	27.954	23.017	18.989	22.990	66.002	56.399	45.554
20	40.652	33.473	27.615	37.246	89.380	75.112	60.245

[1]Values for 0°F. and 50°F. derived from basic curve for 25°F., using 105 percent of the standard correction per degree shown in Table 2 (at even m.p.h.) for 0°F., and 95 percent of the standard for 50°F.

[2]Amounts by which total loss rates in 1936 exceeded those shown in Col. 3. Several points as to derivation and use of these figures are discussed in text.

[3]Sampling to obtain about average wind effect there are used 4 times the rates at 6 m.p.h., 4 times those at 8 m.p.h., 3.5 times those at 10, 3 times those at 12, 2.5 times those at 14, and once the rates at 16 m.p.h. These "samples" result in sums of 471.252 for Col. 9 values, and of 619.729, 586.411, and 560.607 when Col. 5 is combined with one-half of the infiltration in Cols. 6, 7, and 8 respectively. To give 70 percent fuel efficiency there are needed flue losses (for 25°F.) which will total, for a similar sample, 3/7 as much as 586.414, or 251.333, and this in turn is 53.33 percent of the sample sum for the basic flue losses; therefore, this percentage is taken at all velocities. Likewise, 0°F. and 50°F. require respectively 61.77 percent and 44.0 percent of the base to attain the efficiencies indicated for them.

[4]To attain about average sun heat as in tests, 202 B.t.u. per hour, distributed as it is likely to be with max. in midwinter with snow on ground and clear skies, the rate used for 0° F. is $\frac{245}{70\ (Ti\text{-}To)}$ = 3.5 B.t.u. per hr.-deg.; for 25°F., $\frac{202.5}{45}$ = 4.5 B.t.u. per hr.-deg.; and for 50°F., $\frac{160}{20}$ = 8 B.t.u. per hr.-deg. The last group is probably more typical of cloudy spring days than of autumn days of same temperature.

[illegible] caused by the item of 15 B.t.u. of transmission loss.

Then, the curve "B," which is much nearer to a true representation of the relations, shows that the transmission loss is much greater than 15 B.t.u., and also that the form of curvature would tend further to minimize the fuel-use reductions in passing from high toward low wind velocities. Thus, it is by no means as important or as effective in fuel saving, even on a percentage basis, to reduce the wind by a given proportion where and when it is 10 m.p.h., as when it is likely to average 12 to 14 m.p.h. This item becomes important not only in arriving at a true average for the locality and season, but also in considering the height above ground at which the wind strikes the house.[4] The average level of the windows in a house is probably as safe a one to choose as any.

It should be stated that the above values have no significance as actual ratios and are taken from the first-year results for illustration only.

SECOND TEST, JANUARY-MARCH, 1937

For the second test the primary consideration was to obtain full control of heat use in order that both the exposed and protected house might be kept uniformly at 70° F. and, both for control and ready availability, electrical energy was obviously superior to any other form. There is, of course, no necessary flue loss with electric stoves, and the 3-inch openings in ceilings and roofs of houses were closed except for a ½-inch pipe, which might more wisely have been omitted. In order to eliminate one additional variable, it was decided to enclose the protected house by a circular—actually 11-sided—barrier of the same construction as the barrier referred to, and of such diameter that the house in the center of the circle would be at 2-H from the barrier regardless of wind direction. No claim is made that this resembled ordinary shelterbelt protection, although it might resemble the type of protection of a house set down in an opening of less than one acre in the midst of a grove or forest, where the height of the trees exceeded that of the house in a ratio of 3 to 1 or thereabouts. More usable, and perhaps more exact, results might have been obtained by employing a barrier of half the density used, which was 60-percent "solids"; for a more open barrier is less likely to produce eddies or vertical currents within the small enclosure.

Velocities which would affect the protected house in this case were calculated from those determined when the house was not present, because there was no place at the *side* of the house at which the true impact could be measured. The predetermined ratios to wind in the open, in all cases at a height of 2.5 feet, varied from .274 at 4 miles per hour to .299 at 16 miles per hour, and while absolute constancy could not be expected, any variation from the given ratios would be so small as to have negligible effect on the results. There having been one day in which a portion of the "corral" was down, the averages show about 71 percent reduction in wind velocity during the entire test.

House No. 2 was operated in the open for 29 days, covering the colder part of the entire period which began January 17, 1937, while house No. 1 was in the closure. The positions of the two houses were then reversed for a period of 42 days, mostly of milder weather. The same electrical meters remained with each house throughout, so that, if there was any difference in their rates of heat use, it could not be determined certainly whether it arose from the houses themselves or from variation in the meters.

House No. 3 was employed throughout to determine the effect of sun heat. Recording of maximum, minimum, and current temperatures, and of anemometer and electric-meter dials, were made daily, as near as possible to 9 A.M., and all calculations are for such daily units of time, but put on an hourly basis to eliminate variation in length of days.

[4]Since there are several references in this text to transpositions between velocities at different levels, it is well to make clear the basis used. The available Forest Service data cover exhaustively comparative velocities at 16 feet and 16 inches above ground, with numerous measurements up to 40 feet. At no point near the ground are the decreases in velocity constant with lowering level, being more rapid with higher wind velocity and with increasing roughness of ground or vegetation surface. However, it has been deemed sufficiently close to assume that when the velocity at 16 feet is between 10 and 15 m.p.h. it will be 91 percent of that at 30 feet. We may then plot or spline a 3-point curve from two known velocities, which will show with considerable accuracy, for example, the velocity at 12 feet, and this averages about 96 percent of that at 16 feet. The ratio between 16 inches and 16 feet varies from about .62 to .80, but averages about .72 with low grass cover. Below 16 inches the decline may be abrupt, of course, although velocity a fraction of an inch above the ground may be appreciable unless the cover is very dense. Attempt to explore down to the 6-inch level has not been satisfactory, since available zero-level velocities pertain only to sm[illegible]th, hard ground and cannot be correctly measured by the Robinson anemometer.

Since the temperatures of the two periods were quite different, it might be expected the results would be not quite the same. In the first period the average *To* was 14.9° F., in the second 31.9° F., and for the 71 days very slightly under 25° F. Sun-heating effects were actually greater in the first period, apparently because of reflection from the snow cover.

Thus, in the first 29 days the house in the open was exposed to average wind of 9.74 m.p.h., 442.6 k.w.-hrs. were required to heat it, and the average use per hour-degree (this measure accounts for slight differences in house temperatures and for time lost) was 44.501 B.t.u.; while the sheltered house was exposed to average wind of 2.81 m.p.h., required 270.4 k.w.-hrs., and used fuel at the average rate of 27.216 B.t.u. per hour-degree. In the second period, of 42 days, the wind velocities were 9.88 and 2.91 respectively, the exposed house used only 380.3 k.w.-hrs., or 39.587 B.t.u., per hour-degree; while the protected house used 272.0 k.w.-hrs., or at a rate of 28.102 B.t.u. per hour-degree. Thus, wind reductions which, by use of such averages, amounted to 71.0 percent and 70.5 percent respectively, caused a reduction of 38.84 percent in average rate of fuel use during the colder period, but a reduction of only 29.01 percent in the milder weather after February 15. As almost the same number of hour-degrees was involved in each period, the lump-sum reduction for the entire 71 days is very close to the mean of the two values, 34.1 percent. This includes no flue loss, but does include the excessive infiltration, which is nevertheless a smaller item.

However, as to the effect of different temperatures in the two periods, when allowance is made for an apparently constant difference of about 5 percent in the heat-loss rates of the two houses involved, it is found that the fuel-use reductions should be more nearly of the order of 32 percent for the milder period and 36 percent for the colder weather, without changing the average from 34 percent.

The discrepancy between the two houses[5] was investigated through the same processes as were used to determine rate of change in heat loss with change in *To*. House No. 1 always showed lower heat losses than house No. 2 under similar circumstances. Its exposure to higher winds was generally at the higher levels of *To*, and consequently its heat losses were of a lower order. However, the effect of increasing *To* was found to be much greater as between houses 1 and 2, than when only the data for either house were used separately.

Although, in neither aspect does this analysis show good consistency at different wind levels, due in the main to additional variables of which wind direction is most outstanding in effect, it was decided first, that a correction of −5 percent must be applied to all fuel-use amounts for house No. 1, to put it on approximate parity with house No. 2. Differences due to *To* were then reworked on this basis of parity. However, for final levels, the combined and average quantities for both houses were lowered by 3 percent, so that the results as used are not in measurable degree different from the actually recorded results except for "smoothing" processes.

The first step in the analytical approach which would permit separation of the several elements that comprise the total fuel use, the reduction of the infiltration losses, and the addition of appropriate amounts for flue loss, was to obtain a smooth curve for total heat-loss rates. The basic data, together with the first curves corrected to a basis of 25° *To*, are given for record in Table 2.

Sun-heat calculations.—It is evident that fuel-use and heat-loss rates are not synonymous expressions, and that if the former rates result in a smooth curve it is accidental, since the "help" given by the sun from day to day may vary through a wide range. It was therefore necessary to use the records of house No. 3 in an attempt to determine the daily magnitude of this addition to fuel. Unfortunately, not only was the temperature of house No. 3 (*Tu*) determined only by maximum and minimum thermometers, but also the light from the south window at noon fell at varying distances from the thermometers in the center of the room, and

[5]No evidence exists that house No. 1 could actually have lost heat at a lower rate than house No. 2, and in fact there is some slight evidence to the contrary in notes relative to door cracks. It is for this reason that a metering difference (and a constant percentage difference) of approximately 5 percent is assumed to exist. Although it had been requested meters be checked before installation, this apparently was not done, and it is believed variations of as much as 5 percent are not unusual after long use. It should be recorded here that both houses lost heat perhaps 10 percent more rapidly under north than under south winds, with doors facing east.

after about 20 days it was considered desirable to curtain this window with light gauze. This, together with the variation in actual sun-heating effects which apparently arose from the snow cover existing until about March 1, introduces several variables, and very substantial adjustments of the original calculations have been made, the exact nature of which cannot be described in a reasonable space. In making these adjustments solar-radiation data of the Weather Bureau at Lincoln have been the base, although when weather is changeable the relations between the two points, 200 miles apart, is necessarily variable.

The method for originally computing the value of sun heat has been to compare the average of maximum and minimum temperatures of house No. 3 with outdoor maxima and minima. If on this basis, for example, it is shown that the "unheated" house was heated 10 degrees by the sun, whereas on the same day the exposed house was heated 50 degrees by *sun and fuel,* then the sun heat is assumed to have been one-fourth as great as the fuel use. This assumption is, at best, a very rough approximation, and probably underrates sun heating.[6]

Having drawn the curve for total heat losses at 25 degrees, employing all of the data, the next step is to obtain similar curves for zero and 50-degree levels of *To,* or any other levels such that intermediate values for relatively small differences in *To* may be interpolated. These two other primary curves are shown in Table 3 in skeleton form only, since the purpose is merely to illustrate the method. Actually, the computations were made for each mile of wind, and the differences from mile to mile very carefully smoothed. To create these curves the "standard differences" per degree of *To,* as given in Table 2, have been used, modified up and down by 5 percent, so that the changes are a little sharper from 0° F. to 25° F. than from 25° F. to 50° F., since they may be assumed proportionate to the percentage change in absolute temperatures. Figure 3 shows the three primary curves, and the 25-degree curve in the last two stages of development.

Curves for the three temperatures are carried through the processes of separating transmission from infiltration, reducing the latter by one half, and adding what seem to be appropriate flue losses. The resultant rates are then reduced by amounts which correspond in a very general way with the sun-heat values as originally found, so that the final curves are again fuel-use curves. It is these which are, as a final step, interpolated for Table 4, to give results by 10-degree stages from —10° F. to +50° F.

Flue-loss calculations.—In these processes only one element seems to deserve further explanation, as implied by earlier commitments. This is the allowance for flue loss. In Table 3, two sets of figures are given, although only one of them has been used. Frankly, they represent different possible interpretations of the same data. The writer does not know which is best. Briefly, the situation is this: The 1936 results, which include excessive flue loss, when compared with the 1937 curve for total losses at 25 degrees, show that the presumed flue losses stand in constant relation to infiltration losses at 7.18 and 12.93 m.p.h., the actual ratios at these levels being 1.673 and 1.677 respectively. Since, however, the ratio at the minimum, in still air, is much higher (3.4 as assumed) it is evident that the literal employmen of these two established ratios will result in a reverse curve, having a downward trend to 7 m.p.h., and even dipping slightly lower around 10 m.p.h., before rising to 1.677 at 13. In addition, there has been caused a second reversal from 14 to 20 m.p.h., for conservatism, hoping thereby to counteract any possibility that the meager data for velocities above 15 m.p.h., in 1937, might not be safe averages. Thus the ratio on the curve as used, at 20 m.p.h., has dropped to 1.481.

The alternative proposition implies that this ratio of flue loss to infiltration loss should decline sharply from 0 to about 5 m.p.h., to only 1.69 at 7 m.p.h., and from that velocity to 1.631 at 20 m.p.h. In addition, however, it implies

[6]Expressed as formula, sun-heat per day or hour = $\frac{\text{Fuel Use}}{Ti\text{-}Tu} \times (Tu\text{-}To)$. For a few days in March the character of the sun heating was apparent in the other houses, as it was sufficient to cut out the electrical heaters for several hours. It appeared, at least with these cubical houses, that a rate very close to the maximum was sustained for at least 5 to 6 hours after 10 to 11 A.M. Actually, however, the effect on clear days does not appear to exceed the effect of normal sun rays on 2.5 square feet of surface. It apparently is not dependent on glazed area, but fully as much on the character of the walls. Thus the writer found his windowless, thin-walled garage being heated fully as much, and perhaps more quickly in the morning, as these test houses on the best days.

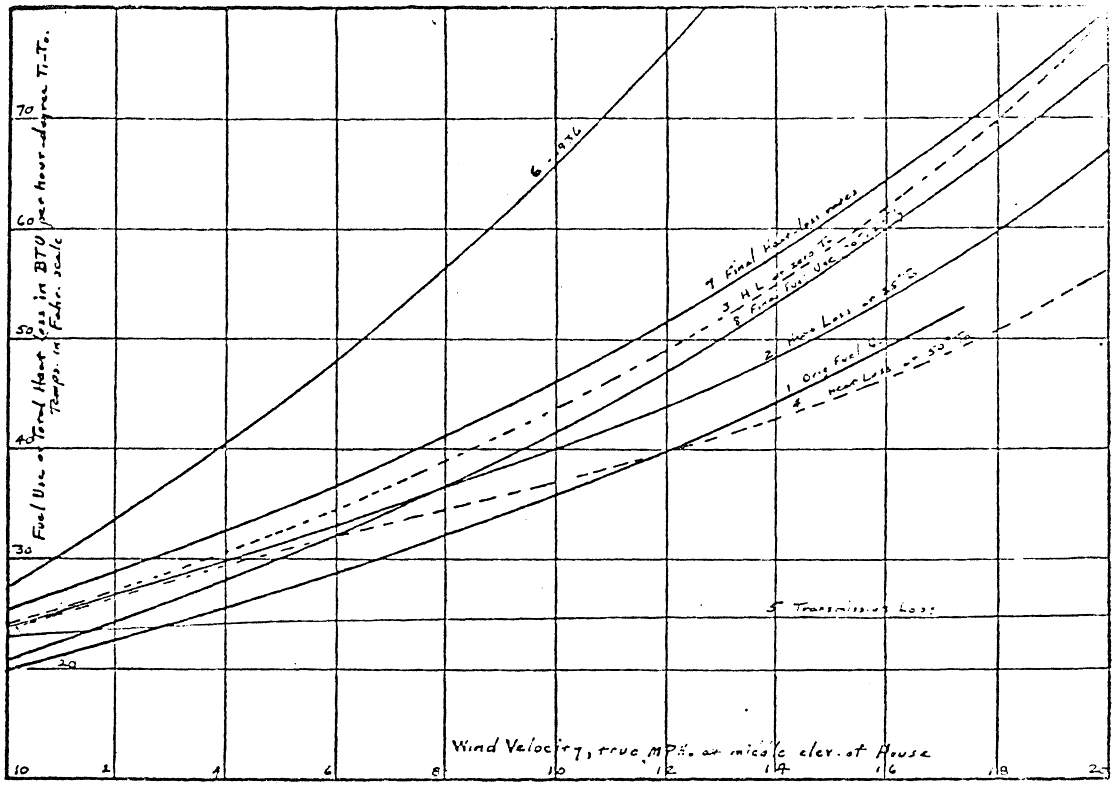

Fig. 3.—Progressive steps in finding fuel-use rates applicable to house of normal proportions.

that when these "standard" flue-loss rates are reduced on a straight percentage basis throughout, it shall be recognized that the minimum rate of 3.4 applies at 0 velocity, regardless of the "efficiency" attained in *actual* winds of 4 m.p.h. and over. There being no such thing as a day without wind in the Plains, this seems academic, and interests us only because this minimum cannot be connected with the curve representing, say, only 53 percent of the standard flue losses, without affecting values up to 4 m.p.h. Thus, at least the lowest line of values in Table 4 would show a greater "flattening off" of the ratios, which is logical.[7]

However, both of the "alternate" columns which are inserted in Table 3 are based on a combination of flue losses computed in this manner and also by comparing the 1936 rates with *total* losses from the house. The logic of this is that, while flue losses may tend to "behave" like infiltration losses, actually the probability of their being large or small depends on what the total rate of loss from the house is, and on how hot the fire must be. The curve of ratios in this case is quite a different thing, and the combination of the two calculations may tend to eliminate any error in either method.

If these "alternate" values are preferable, the data actually employed will be found to be insignificantly affected through the velocities of 8 to 14 m.p.h. which will ordinarily be used in any calculations. Here the ratios given in Table 4 may be too low by from 2 to 4 points in the third integer. At the ends, however, opposing errors of somewhat the same magnitude, possibly as much as 3 to 4 points in the second integer, may be involved. This would affect the integrated result hereafter referred to, which actually employs the entire gamut of velocities, but as nearly as can be seen without a complete check the integrated result found and used is well on the conservative side.

[7]This is meant in a practical sense. Except with oil-burning plants thermostatically controlled, a stove or furnace which is adequate for the more severe weather simply cannot be "held down" to the lowest demands upon it.

Table 4.—Summarization of Test Data in Form for General Use, Showing for Test Houses at 70°F. Adjusted Fuel-Use Rates in B.t.u. Per Hour for Each Wind Velocity and Temperature, Corresponding Use Rate (in Italics) if Wind Is Reduced 35 Percent, and the Ratio Between the Two Which Is Complementary to the Fuel-Saving Ratio

	—10°F.		0°F.		10°F.		20°F.		30°F.		40°F.		50°F.	
Wind velocity	Fuel use per hour	Ratio	Fuel use per hour	Ratio	Fuel use per hour	Ratio	Fuel use per hour	Ratio	Fuel use per hour	Ratio	Fuel use per hour	Ratio	Fuel use per hour	Ratio
M.p.h.	*B.t.u.*	*B.t.u.*	*B.t.u.*		*B.t.u.*		*B.t.u.*		*B.t.u.*		*B.t.u.*		*B.t.u.*	
2	2164	.....	1847	.....	1546	.....	1251	.....	954	.....	672	.....	404.7	
3	2353	.....	1999	.....	1669	.....	1348	.....	1028	.....	723	.....	437.6	
4	2550	.....	2157	.....	1797	.....	1449	.....	1104	.....	775	.....	470.6	
2.60	*2278*	.893	*1936*	.898	*1618*	*.900*	*1308*	.903	*997*	.903	*703*	.907	*424.4*	.902
5	2757	.....	2323	.877	1700	.....	1553	.....	1181	.....	828	.....	504.0	
3.25	*2401*	.871	*2037*	.877	*1700*	*.881*	*1373*	.884	*1046*	.886	*736*	.889	*445.8*	.885
6	2976	.....	2499	.....	2070	.....	1661	.....	1261	.....	883	.....	538.0	
3.90	*2529*	.850	*2141*	.857	*1783*	*.861*	*1439*	.866	*1096*	.869	*770*	.872	*467.2*	.868
7	3209	.....	2686	.....	2218	.....	1774	.....	1345	.....	941	.....	572.5	
4.55	*2661*	.829	*2246*	.836	*1869*	*.843*	*1506*	.849	*1146*	.852	*804*	.854	*488.8*	.854
8	3456	.....	2885	.....	2375	.....	1892	.....	1432	.....	1001	.....	608.3	
5.20	*2800*	.810	*2357*	.817	*1957*	*.824*	*1574*	.832	*1197*	.836	*839*	.838	*510.7*	.840
9	3718	.....	3096	.....	2541	.....	2017	.....	1523	.....	1064	.....	615.5	
5.85	*2942*	.791	*2471*	.798	*2049*	*.808*	*1644*	.815	*1249*	.820	*875*	.822	*532.9*	.826
10	3996	.....	3320	.....	2717	.....	2148	.....	1619	.....	1130	.....	681.3	.....
6.50	*3090*	.773	*2588*	.780	*2143*	*.789*	*1716*	.799	*1302*	.804	*912*	.807	*555.2*	.811
11	4289	.....	3556	.....	2902	.....	2286	.....	1720	.....	1199	.....	724.8	.....
7.15	*3244*	.756	*2715*	.764	*2240*	*.772*	*1790*	.783	*1357*	.789	*950*	.792	*577.8*	.797
12	4596	.....	3803	.....	3096	.....	2432	.....	1826	.....	1272	.....	767.7	.....
7.80	*3405*	.741	*2845*	.748	*2341*	*.756*	*1867*	.768	*1413*	.774	*989*	.778	*600.8*	.783
13	4919	.....	4063	.....	3300	.....	2585	.....	1938	.....	1349	.....	813.1	
8.45	*3570*	.726	*2978*	.733	*2448*	*.742*	*1947*	.753	*1471*	.759	*1029*	.763	*624.9*	.769
14	5257	.....	4335	.....	3514	.....	2745		2055	.....	1430	.....	860.9	.....
9.10	*3743*	.712	*3118*	.719	*2558*	*.728*	*2030*	.740	*1531*	.745	*1070*	.748	*649.4*	.754
15	5611	.....	4620	.....	3738	.....	2914	.....	2178	.....	1515	.....	911.1	
9.75	*3923*	.699	*3263*	.706	*2672*	*.715*	*2115*	.726	*1594*	.732	*1113*	.734	*674.6*	.740
16	5983	.....	4919	.....	3972	.....	3091		2308	.....	1604	.....	964.0	
10.40	*4110*	.687	*3413*	.694	*2790*	*.702*	*2202*	.712	*1659*	.719	*1157*	.721	*700.3*	.726
17	6371	.....	5231	.....	4216	.....	3276	.....	2444	.....	1698	.....	1019.6	
11.05	*4303*	.675	*3563*	.682	*2912*	*.691*	*2293*	.700	*1726*	.706	*1203*	.708	*726.9*	.713
18	6777	.....	5558	.....	4471	.....	3470	.....	2587	.....	1797	.....	1078.3	
11.70	*4501*	.664	*3728*	.671	*3038*	*.679*	*2387*	.688	*1795*	.694	*1250*	.696	*754.4*	.700
19	7201	.....	5899	.....	4737	.....	3674	.....	2737	.....	1901	.....	1140.0	
12.35	*4706*	.653	*3893*	.660	*3167*	*.669*	*2484*	.676	*1866*	.682	*1299*	.683	*783.3*	.687
20	7646	.....	6257	.....	5014	.....	3888	.....	2895		2010	.....	1204.9	
13.00	*4919*	.643	*4063*	.649	*3300*	*.658*	*2585*	.665	*1938*	.669	*1349*	.671	*813.1*	.675

Note. Figures for wind velocity printed in italics are in each case 35 percent less than the immediately preceding figures; the corresponding fuel use per hour is also shown in italics. The "ratio" in each case is determined by dividing the fuel use per hour on the same line in the preceding column by the fuel use per hour in the line above.

SUMMATION

As has been implied, besides showing fuel-use rates for seven temperature levels, the results are put in the most usable form in Table 4. The assumption is that reductions of wind by windbreaks are more likely to be of the general order of 35 percent than any other, and that if they do not vary too widely from this standard, or say within the limits of 25 to 45 percent, it will be sufficiently accurate to assume that the reduction in fuel use (the complement of the ratio given) will be proportionate to that computed for the 35-percent wind reduction, at the proper initial wind and temperature level. If there is any doubt of this, it will be quite simple to calculate the fuel-use reduction ratio for any initial velocity and percentage of wind reduction. Straight-line interpolations between even miles per hour cannot create any serious error, although in preparing Table 4 interpolations on the curve have been made.

All of this permits ready calculation of the percentage of fuel that can be saved, without having to think in terms more technical than the present amount of fuel used per season, or its cost. However, it should not be inferred from this that sound predictions can be made without (1) at least a qualitative knowledge of the present heat losses of the house and whether they are high or low because of the character of wall construction (and insulation) or because of losses around windows and doors and through other cracks such as those which all too often occur at eaves and foundations; and (2) a fairly exact knowledge of the wind velocities to which the house is exposed,[8] and the temperatures of the heating season, although some error in the latter item will have no important effect.

[8]It is very unfortunate in this connection that, although all first-order Weather Bureau stations have for years obtained wind velocity and direction records, these are not comparable for different stations because of variations in exposure, nor can they be said to represent the wind velocities of the open country nearby. It is to be hoped that, as a result of present observations on flying fields, it may be possible to build up a framework of data to show actual velocities at various elevations above open ground. Even these better readings, however, are not to be taken as representing velocities at the stated elevations above ground; anemometers are, as before, generally 12 feet above the building roof, and the effect of the building cannot be ignored.

Integration of Results to Seasonal Basis

It has already been emphasized that fuel-reduction rates or ratios are specific for certain winds and temperatures and combinations thereof, and the ratios shown in Table 4 clearly illustrate this. On one day, with a 20-m.p.h. wind and zero temperature there might be saved 35 percent of the fuel, while with the same 35-percent reduction in wind, for a temperature of 30° F. and a wind of 10 m.p.h. the saving would be only 19.6 percent of the fuel which otherwise would have been consumed on such a day. Moreover, that basic fuel use would have been slightly more than one-fourth as much (1,619 against 6,257 heat units per hour) on the milder of the two days. While, then, the table may be used for direct estimation of savings for short periods representing specific weather conditions, it is evident that only by adding together the amounts of heat that would be used in all of the different kinds of days that occur in a heating season, and each of these in its normal proportion, can it be ascertained what the fuel saving is in terms of the winter's fuel bill.

No attempt has been made to do this except for certain combinations of conditions which are fairly typical of the Plains region as a whole. The integrated results to which reference will be made will not be at all applicable if the correlation between temperature and wind velocity which occurs in the Plains does not exist in the local climate. For example, a locality in which the winds of higher velocity occur in the coldest months would reverse the Plains correlation, and hence would produce a different integrated result for the heating season.

Primarily to determine the frequency of occurrence of winds of different velocities, but also to bring out any existing correlation between wind velocity and temperature, wind records from the airport at Huron, South Dakota, for the heating seasons falling within the calendar years 1940, 1941, and 1942, a total of 838 days, have been classified to the nearest mile (24-hour averages, only, used) and the days on which each occurred classified as to temperature in 10-degree groups.[9] The mean velocity for all days was 13.038 m.p.h., the extreme velocity 37.0 and

[9]The unpublished data necessary for these computations have been furnished through the courtesy of Mr. B. R. Laskowski, section director of the Weather Bureau at Huron.

Table 5.—Relative Frequency of Days Having Mean Wind Velocities of Different Levels, Expressed as Percentage of the Seasonal Average.

Frequency	Percent of ave. wind velocity
6	43
18	61
22	80
19	100
15	120
10	140
5	160.8
5	196

3.5 m.p.h., and the mean temperature for the heating season is 35.70 degrees, but during these years averaged about 2 degrees above this normal. Velocities are expressed as percentages of this average, as it is believed the same relative scale may be applied where the mean velocity is either higher or lower.

Since the writer knows of no such data being published, and it may be helpful in other relations, wind frequencies are shown in Table 5. Only at the extremes where the groups are not well filled out have exact averages been computed.

While these calculations are for the heating season of 279 days in this particular case, it may be assumed that the relative frequencies would not be changed appreciably were the heating season shorter, or were the entire year employed, although the average velocity for such season might be higher or lower.

As to correlation between wind and temperature, this is mainly due to a marked rise of wind with increase of temperature in March and April, with only a slight wind recession in May, this being typical of the Plains as a whole. This seasonal relation is not obscured by a contrary trend in the fall.

Thus, with adjustments necessary to put temperatures on a normal basis, and to reduce the Huron airport velocities to those which are likely to prevail at 12 feet above ground, or approximately at the middle of a 2-story house, the 838 heating-season days have been divided into four periods showing the following characteristics:

No. of days	Ave. temp., °F.	Ave. vel. 12 ft. above ground, m.p.h.
122	1.8	9.76
267	21	10.45
244	42	11.09
137	61.25	11.34
68	70.63 (requiring no fuel use)	

This implies that, to obtain an integrated heat-use ratio, the amounts of heat use with and without a given wind reduction should be worked out for the four temperature levels, and within these, for each of the eight velocity levels shown in Table 5. Having performed these calculations for each temperature, the four will be combined in the proportions shown by the number of days for each.

The integrated result in this case, for a wind reduction throughout of 35 percent, is a ratio of .7791. This ratio is found, by Table 4, and at the mean heating-season temperature of 36°F., to apply at a wind velocity of 11.80 m.p.h., whereas the mean 12-foot velocity is 10.795 m.p.h.

In short, then, due to the far greater importance in the season's total fuel use of the minority of days having appreciably more than average wind velocity, we are justified in assuming that to read the fuel saving somewhat directly from Table 4, one mile per hour may be added to the true mean velocity which is applicable in the circumstances. Withal, the effect of temperature on the ratios is small, yet it is obvious that in a climate in which the highest wind velocities were associated with the lowest temperatures, the significance of high-wind periods would be still further augmented.

A separate calculation has been made from the assembled data to show what effect will result from the tendency with nearly all windbreaks to give an increasing percentage wind reduction with higher velocities.[10] If it be assumed the 35-percent reduction of wind is obtained at average velocity, and that this increases or decreases 0.5 percent with each m.p.h., the effect of this added factor is to change the average ratio of .7791 only to .7757. However, as this ratio applies at a velocity of 12.05 m.p.h., it more firmly establishes the fact that the full m.p.h. may be added to the mean, where long periods and a great variety of winds and temperatures are involved.

[10]A windbreak of a given type does not reduce the wind by a given number of miles per hour, but more nearly by a given percentage at all times. Actually, this percentage, at most positions, increases as the wind velocity increases, so that, for example, if a 5-m.p.h. wind were decreased 20 percent, or 1 m.p.h., a 15-m.p.h. wind might be decreased 25 percent, or 3.75 m.p.h. Since calculations here show that this change may be disregarded, if we determine the *percentage* by which the wind is reduced at any medium velocity, this percentage may be applied to the true mean velocity for a season, with insignificant error.

Degree of Wind Reduction to be Expected From Tree Belts

Tree belts placed about farm buildings may give much or little protection, and in the northern Plains may complicate or simplify the problem of snow drifting about buildings, according to their placement, composition, and density, and, of course, their height. While even the protection near the ground line given by a thick hedge may be helpful, obviously the trees should be taller than the house to be protected to obtain the kind of results which the test houses have brought out. Very close to the windward side of a belt, air currents produced by strong winds are being "shot" upward, but they quickly turn down again, and over the top of a wide grove should be thought of as horizontal, with a tendency to dip as soon as the edge is reached .Height is not so important therefore, if the house may be placed quite closely in the lee of a narrow belt. But again, this may be an area of considerable snow settling.

Of all the items which affect the *degree of wind reduction*, it is safe to say that none is so important as the *area* which may be devoted to trees. While two rows of trees do not have double the effectiveness of one, and the value added is less with each row, it is only through mass effects that very complete stilling of the air can be obtained. It has been pointed out that the 70-percent reduction in wind caused by the circular barrier used in this experiment could hardly be duplicated for winds from all directions, or for the average, anywhere except in an opening more or less in the center of an extensive grove or forest; and that if this is to be an opening of an acre, so that the yard is not encumbered by trees at all, the grove must be, let us say, 70 feet high. Even in such an opening one would naturally seek the north side to obtain best protection for a house, and in this opening there would be little or no problem of drifting snow. With such protection, the data of Table 4 show that where the mean heating-season temperature is 20° F. a saving of 42.1 percent in fuel might be made (using the 12-m.p.h. line), or for 40° temperature, 39.9 percent, these values being roughly 1.8 times the saving to be had with wind reduction of only 35 percent.

With many farmsteads, it is feasible to have a substantial belt only on one side of the house, or at most two. Almost invariably the north side will be first choice. If, possibly, the house is too close to a road on that side, or to other buildings, the west will be second choice in the northern Plains, but of considerably less importance or value farther south. In the northern Plains not only are north and northwest winds somewhat the more persistent through the heating season, and likely to show the most extreme velocities, but also temperatures are 4 to 5 degrees lower when the winds are in that quarter than when southerly. Since snow drifts in mainly from the north or north-westerly direction, there is added reason for having the belt on the north, but only if it is of sufficient width to form a snow trap may best advantage be taken of a position close to it.[11] With narrower belts, both snow movement and actual wind protection at the higher velocities dictate that the distance shall be more nearly five times than twice the height of the trees.

Such being the facts, it is desirable to observe just how good is "one-way protection." Unfortunately, there is available but one set of readings, on a hardwood belt, covering a sufficiently long period in the winter (with the trees leafless) to give representation to winds of all directions which must be taken into account. Even these observations are deficient, in that there are no comparative readings except at an elevation 16 inches above ground. These, however, show less effect of ground friction than usual, as a good, somewhat wavy blanket of snow covered the ground during most of the period. This east-west belt at Huron, S. Dak., was studied during February, 1937, and is believed to be fairly typical of the better farmstead protection commonly obtained from the hardwoods which were almost exclusively used in early plantings. It was 200 feet wide, with the cottonwoods, which occupied the north half, 70 feet high. Green ash trees about 40 feet high, in the south half, kept the belt as a whole from being as open, below, as it would otherwise have been. All of the trees were old, however, and there was scant undergrowth (Fig. 4).

[11] Mechanically, there is less difference between the different sides of belts, in protection given, than might be supposed, if season-long velocities be considered. The north side of a compact belt (this is quite untrue if the wind can sweep under) may give, say, four-fifths as much protection as the south side. The very conditions which make possible such wind reduction at 2 heights north, however, cause this to be the worst possible place for snow drifts.

For the entire period of 27 days measurements on this field showed average wind equivalent to 12.03 m.p.h. at an elevation of 12 feet, while the "ground control" at 16 inches above the snow level averaged 9.62 m.p.h. According to Huron Weather Bureau records, all northerly winds accounted for 55.8 percent of the mileage, while the normal for winter is only 44.3 percent from northerly quarters. Average temperature was 16° F. Under these circumstances, a point 3-H, or 210 feet, south of the edge of the belt showed the lowest average velocity near the ground, 60.2 percent of that at the controls. At 2-H it was 62.2 percent. As with many other belts of such open character, and with slat barriers, higher velocity was shown at the leeward edge of the belt—75.9 percent in this case. Based on the showing at 3-H, assuming the percentage reduction in wind to be the same at 12 feet as at 16 inches, but reading Table 4 at 12.5 m.p.h. (for a partially generalized situation) it is found a 40-percent reduction at 16° temperature should reduce fuel use to 2,017 B.t.u. from 2,783, or by 766 B.t.u. per hour, or 27.5 percent.

For a total of 150 hours it is possible to segregate unmixed northwest winds covered mostly by short intervals between observations. For this time the average 12-foot velocity is 12.35 m.p.h., that near the ground 10.64 m.p.h., and at the "low" point, 3-H south of the trees, 5.01 m.p.h. or 47.1 percent of the control. Temperatures with such winds averaged about 13° F. Again using 12.5 m.p.h. as the base, and 5.9 for the reduced velocity, the heat quantities involved become 2,990 for full wind, and 1,933 for the reduced wind, a saving of 1,057 B.t.u. per hour, or 35.4 percent.

For two consecutive days wind at the control, for 12-foot elevation, averaged 18.93 m.p.h. from the northwest, the ground wind 15.24 m.p.h., and that at 3-H south of the belt 6.66 m.p.h., or 43.7 percent of the control, while temperature was about 15° F. Assuming that the 12-foot velocity with protection was 8.25 m.p.h., the heat values involved are 4,189 B.t.u. for full wind and 2,233 for reduced wind, a reduction of 1,956 B.t.u. and 46.7 percent.

These latter values, of course, represent short periods. The purpose in discussing them in detail is, in part, to show the method to be employed in use of the tabular data, but more particularly to emphasize the point that the greater savings of fuel, as expressed by percentages, come at the times when the fuel use is high.

The question remains as to whether the measurements made on this belt may be considered as representative of the heating season as a whole, with application to the climatic conditions where made, or to others. In attempting to answer this question, the fact that the south side of this belt, during the measurements, received more than normal protection from north winds may be pitted against the fact that the reduction in wind velocity, in this case as in all similar cases, undoubtedly would have been greater at the level of 12 feet, than at the level of only 16 inches above the snow blanket. This applies usually out to a distance of 7-H to 8-H, and is particularly true of stations close to the belt or barrier. We may take it as an assured fact, whenever the structure of the barrier is such as to permit marked currents of wind to "blow under," and to show higher ground velocity immediately to leeward than at points somewhat farther away. This characteristic has been noted with the slat

Fig. 4. Old cottonwood and ash belt SD-5, as seen from the north approximately along the line on which wind velocities were measured; 200 feet wide, cottonwoods on near side 70 feet high. Younger trees offer more resistance through greater limbiness, at least along margins.

barriers which are of the same "density" from top to bottom, and is even more likely to be noted with old trees which offer little resistance near the ground.

Although data for this belt were not taken, a setup on an ash grove, 40 feet high, with measurements made in September, 1935, after the leaves had dried and were partly fallen, gives a clear indication of the nature of the phenomenon. Velocities above ground were not, in this case, taken at a control station (except at 16 inches and 16 feet), but rather at 5-foot intervals on "towers" erected at a distance of 2-H both on the windward and leeward sides. However, the windward station velocities may be adjusted to control-station values, at least up to a height of 16 feet, by very simple relations.

With or without this adjustment, it is found that at all wind velocities above 10 m.p.h., the leeward station shows the lowest ratio to windward velocities at the elevation of 15 feet, while with a wind of about 5.4 m.p.h. the 25-foot level showed the greatest reduction. Selecting a NNW wind of 11.73 m.p.h. as nearest to the means that are of interest, *with* the adjustments, these ratios read .544 at 16 inches, .447 at 5 feet above ground, .396 at 10 feet, and .378 at 15 feet. From this level they increase to approximately .600 at the level of the tree tops. Thus, interpolating for 12 feet in elevation, we have a ratio of .389 to compare with the "ground" ratio of .544 in this case. Certainly we may count on a fifth greater reduction of wind 12 feet above ground than where the observations were habitually made for close-in leeward positions. The same effect occurs in lesser degree when the same station becomes a windward one. For this grove there was, at 2-H on the south side, a general wind reduction percentage at 12-foot elevation at least one-eighth greater than that indicated by the anemometers at 16 inches elevation. It is our judgment—going back to the grove measured under winter conditions—that the same effect would prevail there to the extent of about one-tenth, and that this would just about counterbalance the lesser frequency of north winds in a full, normal winter.

A fully integrated, normal "benefit" from this cottonwood and ash grove would, therefore, be obtained by assuming that the normal wind for Huron, which is about 10.8 m.p.h. at 12-foot elevation, would apply, and that the reduction at this elevation (probably more certainly obtained at 2-H than at 3-H) would be 40 percent as first stated, and that the mean heating season temperature would be 36° F. As already pointed out, the integrated result is that which applies at a velocity of 11.8 m.p.h.; the ratio is .779, the fuel saving is 22.1 percent for 35-percent reduction in wind, and when extended one-seventh for the 40-percent reduction becomes 25.2 percent.

It is surprising to note that no data are available giving a sound basis for a substantially higher estimate of fuel saving than was obtained in the case just cited, for a single belt or what may be termed "one-way protection from north winds." The only conclusions that can logically be drawn from the data studied in this connection are that slightly better results are obtainable with a more compact type of windbreak, *if* the position is the very best possible; but that actually the open, screen-like type of belt is far more effective than its appearance indicates.

Particularly effective hardwood belts in the Plains region have shown summer wind reduction on the leeward side, with direction essentially normal to the axis, to be as great as 70 percent within a limited area. Such reductions are obtained only where there is good support by underplanted or flanking trees, so that relatively little wind can move *under* the main body of trees. This is the type of protection one would expect also with conifers, and they should have the advantage of giving the same degree of protection in winter as in summer. DenUyl[12] has given the results of a number of measurements on coniferous belts in Indiana. Using his data for "density class 3" and for wind of 15 m.p.h. in the open, his reduction figure of 73 percent seems possibly applicable to the type of growth that is attainable in the Plains. This applies at a distance of 2-H leeward, under the same limited conditions as to wind direction.

However, observations on barriers at Miller, S. Dak., over a period of about three months in the late winter of 1937-38, show that, when winds of all directions are considered, there may be expected at a point 2-H south of the barrier only about 65 percent (for safety, say 63 percent) of the wind reduction that accrues when such point is definitely on the leeward side. It, therefore, follows that with the best or most compact type of windbreak the general reduction on the south

[12] DenUyl, Daniel. Zone of effective windbreak influence. Jour. Forestry 34:689-695, 1936.

side, for Plains conditions, will not exceed 45 percent. This, plainly, is no great gain over the cottonwood belt.

With respect to two-way protection, data for the barrier setup at Huron give the only available basis for estimating the value of a protected "corner." As has been stated, in the Plains region protection from the north or west or, when possible from both directions, is commonly sought. The barrier position was in reality a west corner, not a northwest corner, and being in fact between two parallel barriers set to meet northwest winds, primarily, was also not entirely free of protection from the south or southeast. However, as the one-way protection at the center of this barrier was affected similarly, we may compare the corner with the center without further correction. Ordinarily, a point only 2-H from the barrier, and the same distance in from its end, will have, by comparison with the center, much less protection. With similar protection on two sides, the end or "corner" position over a period of about 35 days, with better-than-average velocities, showed nearly half again as great a reduction in wind. The actual averages were, at the center of the barrier 33.1-percent reduction, and at 2-H from its end, with the supplemental protection on the southwest, 46.3-percent reduction. A station at the center of the end- or cross-barrier showed only 33-percent reduction, while at the southerly intersection (protection from southeast and southwest) the reduction was 39 percent.

If, then, it be taken that 40 percent reduction represents a fair maximum for one-way protection, it is apparent that a house located in a west or northwest corner, protected by two similar belts, may well expect wind reduction of 55 percent. This is just halfway between one-sided and all-around protection. Based on the normal heating-season conditions for Huron, this implies fuel-use reduction of 33.0 percent.

Value of Fuel Savings in Different Latitudes

In discussions to this point the findings at Holdrege have been applied only to the combination of wind and temperature found at Huron, S. Dak., solely because it was most feasible to combine all of the elements in the problem from data obtained in that vicinity.

It is evident from Table 4, since increasing wind velocity augments the value of wind reduction, while lower temperatures do the same in a less marked degree, that the value of a given amount of protection might either increase or decrease from north to south. It so happens, for the stations for which it is feasible to develop a reliable measure of prevailing wind velocities, for the elevation of 12 feet above ground and representative in all cases of extremely flat terrain, that there is a sufficiently great increase in wind velocities from north to south to compensate for the shorter and milder heating seasons to the south. As shown by Table 6, there seems to be a strong probability that, if the same meridian were adhered to throughout, the percentage of fuel saving would prove to be slightly greater in Kansas than in North Dakota. This, of course, is on the assumed basis of 40-percent wind reduction throughout. If actualities were considered, there probably would be little or no difference in the average case, because it is considerably more difficult to develop tall and dense shelterbelts in the southern portion of the Plains.

Of greater importance than the percentage of fuel saved, of course, is the actual amount for a season. To make clear the magnitude of seasonal amounts, there have been inserted in Table 6 the hourly rates (interpolations of Table 4) both with and without the indicated wind reduction. Multiplying the use per hour in the latter case by the number of days in the heating season gives relative values on total fuel use, found to be roughly 277M B.t.u. in Kansas against 450M B.t.u. on the edge of the very cold Red River Valley in North Dakota. While this is a ratio of about 6 to 10, the larger percentage which it is possible to save in Kansas makes the seasonal saving there worth about 0.67 times as much as in North Dakota. In this respect, the North Dakota and South Dakota stations give almost identical results, as do the Kansas and Nebraska stations. These calculations take no account of differences in heating by sunlight at various latitudes.

Obtaining Wind Protection in the Plains

A reduction of even $15 to $20 annually in the fuel bill, together with the reduced labor of handling, and the greater comfort which may be attained through ability to heat different parts of a house more evenly in the windiest weather, justify not only giving considerable care to the

195

placing of shelterbelts about farm homes,[13] but also devoting considerable space to them. Only by the latter may the *best* results be attained.

Unfortunately, throughout the Plains, protection from wind is inseparable from the problem of drifting snow, and it is for this reason that the planning of protection deserves great care, else the advantages may be largely balanced by the setting up of new difficulties in the way of shoveling paths, confining livestock to their stables, and making the movement of vehicles impossible. Even in the southern Plains, where snow is much less a persistent impediment through the winter than in the north, the occasional snows are often accompanied by high winds, and create as great hazards and inconveniences as elsewhere. All that one can hope to do, by the best use of shelter, is to cause the snow to fall and remain in as even a layer as possible in the farmyard—when it is rarely of sufficient depth to cause great inconvenience—and to prevent the drifting in of snow from great open spaces that may surround it. The latter may be much the more serious item, as this vagrant snow stops only when it finds a sanctuary from wind. However, it rarely drops with the *first* tree it encounters and, if a belt be too narrow, may frequently be found well on the leeward side.

Since the circumstances which will dictate the best form and place for shelters are variable without limit, about all that we may hope to do is to list certain broad groups of possibilities, in order of preference. Plainly, under certain circumstances the least desirable plan or one slightly higher in the scale, is the only one that is at all feasible.

1. Location in center of grove or forest of considerable extent. In an opening up to one acre in extent wind should be the lowest that will be encountered anywhere. House in northwest corner of opening will have maximum protection, while receiving ample sunshine from south and east. There will be no drifting through of snow, but there may be a heavier fall than elsewhere when wind is from north or west, within

[13]The town or village dweller obtains a certain degree of protection through the aggregate effect of all buildings, but locally this protection may be very inadequate. Trees accomplish a great deal in "filling the gaps" between buildings through which tornadic streams of air may otherwise flow. See paragraph 5 on page 186.

TABLE 6.—EXAMPLES OF HEATING-SEASON DATA AND WIND-REDUCTION EFFECTS FOR DIFFERENT LATITUDES IN THE PLAINS

	Length of heating season			Ave. temp.	Weather Bureau data for average wind velocity						Fuel use with (ital.) and without 40-per-cent wind reduction	
	From	To	No. days	(to 1924)	Years	No. of months	Elevation	Heating season average	Correction factor	Velocity 12 ft.[1]	Interpolated hrly. amts.	Reduction
				°F.			Ft.	M.p.h.		M.p.h.	B.t.u.	Percent
Fargo-Moorhead, N. Dak.	Aug. 24	June 16	297	32.97	1941-4	37	43	11.487	.820	9.42	*1171* 1518	22.9
Huron, S. Dak.	Sep. 5	June 10	279	35.70	1940-2	36	41	13.038	.828[3]	10.795	*1120* 1492	24.9
					A-1932-8	84	43	13.250	.832[4]	11.020	*895*	
Holdrege, Neb.	Sep. 22	May 27	248	41.56[2]	B-1918-30	156	....	7.962	1.391	11.074	1193	25.0
Dodge City, Kans.	Sep. 27	May 20	236	43.58	1934-42	96	60[5]	12.001	1.022[4]	12.266	*879* 1174	25.3

[1]Add 1 m.p.h. to obtain the integrated seasonal saving shown in last column. Values used are 10.5, 11.8, 12.0 and 13.25 m.p.h.

[2]Season 23 days shorter, 0.3° F. warmer, than at North Platte, only near-by station given in Monthly Weather Review, Supplement 25, 1925. Holdrege averages 3.4° F. warmer for the year. A is Grand Island airport. B is North Platte regular Weather Bureau station with correction applied to published averages as for 40-ft anemometers. For wind velocities, Holdrege was compared with their 1936 velocities and normal then computed from their averages as shown. Holdrege velocities probably err on the low side.

[3]Determined by 17 months of record at 16-foot elevation on open field near Huron.

[4]Determined from 16-foot velocities on open fields at Holdrege and Dodge City, respectively. From [3] and [4] a similar ratio is assumed for Fargo.

[5]Approximate. Described as 40-foot tower above roof of Federal Building, which is 2-story. Applies after May 21, 1932.

2 to 3 rods of the trees, and this marginal space should be left. Completeness of protection depends, of course, on height of trees relative to that of house.

2. If the grove of trees is of small extent, say not over 1 to 3 acres, a notch cut out of the southeast corner will offer the best protection from north and west winds; and there is also some reduction when wind is from south to east and "banks" against the trees. There may occasionally be drifting of snow when falling, with easterly wind, but this is unlikely to be serious.

3. Creation of widest possible belt to north and west of buildings, or at least to north, with massed outbuildings giving protection on west. Unless width of belt is 4 rods or more, or density is maintained by encouraging all possible undergrowth, snow may occasionally drift through. This can be very largely eliminated by planting a second narrow belt or tall hedge—after original trees begin to lose lower branches—3 to 4 rods outside of the main belt, forming between them what is commonly called a "snow-trap," for snow which may blow in from open fields. Divide this by cross hedges if length from east to west is over 100 feet. The snow trap area often makes an excellent garden tract.

4. Where space permits only a very narrow belt to north or both north and west of dwelling, drifting both during storms and later may be expected; and because of this the house must be set back far enough to make certain the drifts do not encroach on the doorstep. There is a tendency to feel that with only one or two rows of trees possible, evergreens must be used to obtain good protection. The danger in the Plains is that some of the trees will prove short-lived; and, as death causes gaps in the "solid" barrier, through which snow will be readily carried, the drifting problem may be as great as with deciduous trees. This, again, is likely to occur when the conifers lose their early, bushy form. It is strongly recommended that a row of conifers always be flanked by another row of thick-growing hardwoods. Each row should have space enough so that the trees will retain their branches, and also may grow a little taller than trees which are crowded, because of having more ground to draw upon for moisture. In this way the slower growing conifers will not become overtopped and weakened.

5. For the yard already so developed that there is no room for a belt at the more desirable distance, and for hill-top sites where poor tree growth and the slope of the ground, make it next to impossible to obtain protection from trees several rods distant from the house, a "direct screen" of trees is probably the most practical means for obtaining moderate protection. This means placing the trees so close to the house—preferably on the north and west sides—that they at least bear the brunt of the wind's pressure. Obviously this a place where a compact mass of evergreens would be highly effective, while they will not be exposed to breakage as much as though they were standing alone.

In this case we do not attempt to avoid snow drifting, but so confine the scope of the trees that it will be little more than that caused by the house itself, and will consist principally of "streamer" drifts to leeward. Evidently the drive, if any, would be in safest position to the north of such trees. Piling of snow against the house will do no harm where there are no doors; but if it is an impediment near the ends of the L-shaped screen, for example, it can be avoided by keeping the lower branches trimmed off.

If the single row of trees close to north and west walls can be somewhat "supported" on the northwest corner, so as to form a wedge pointing into the strongest winds, the effectiveness will be greatly increased. In this case the outer trees, or point of the wedge, should be of less height than those near the wall, so that the wind is "lifted" as well as being diverted laterally. In short, design this wedge or point like the point of a plow or the pilot of a locomotive.

Addendum

The mean 12-foot wind velocity at Huron, 10.8 m.p.h., which is used as the basis for several earlier calculations and appears in Table 6, has been found to be too low. It is believed that it represents the general latitudinal trends, however, better than the true local figure, and for this reason the calculations made on this basis have not been changed. Retention of the lower figure here tends to keep the implied benefits on a more conservative basis. The true velocity will be shown in the next article of this series.