SUMMERTIME INFILTRATION RATES IN MOBILE HOMES

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INTRODUCTION

An earlier publication, Goldschmidt et al. [1] presented comparative data for wintertime infiltration rates in two mobile homes and described the test set-up and procedure. For completeness, Fig. 1-4 of that preceeding publication and descriptions of the measurement procedure of the homes are presented in the Appendix.

The major objectives of the study were two: 1) to determine through a comprehensive set of tools, the dependence of infiltration rate on weather and 2) to quantify the benefits of using a continuous* sheathing board in the roof and walls to reduce infiltration, hence energy consumption for HVAC.

Published data on infiltration rates in mobile homes (see, for instance, Ref. 1-3) are extremely limited. For that matter, references of measurement of infiltration rates in residences, in general, is in itself also limited (see, for instance, Ref. 4-9) and most unfortunately a consistent formulation on the dependence of infiltration on wind does not result.

In this particular study the residences tested were unoccupied, free from obstructions to wind by terrain or other buildings, and had windows on all sides. As a result, the dependence on wind direction was small compared to that on wind magnitude. The wind was measured locally and simultaneously to measure the infiltration rate. Wind was recorded every 5 min. except for high velocities which were recorded every 2 min. Average values of wind were taken over intervals of no less than 20 min. and usually no greater than 60 min. This is an important consideration as the response time of infiltration to level of wind is extremely short and the relationship between them is definitely not linear.

The homes were tested under different configurations. The North home was assembled with caulking used as a sealant at all joints. It was alternatively tested with or without skirting (obtained and installed by a local mobile home dealer). The South home was assembled with continuous sheathing board and no caulking. In this manner the comparative benefit of continuous sheathing board on reducing infiltration rate could be estimated. (Skirting was also added to the South home).

RESULTS OF MEASUREMENTS

The measurement procedure is outlined in Ref. 1 and 10. An error analysis is included in Ref. 11. (The primary source of error is zero drifting of the CO meters. For most readings an uncertainty of less than ±20% is expected.) The effects of skirting on reduced infiltration were also tested but were noted to be within the scatter and hence not substantial. The scatter is inherent

*Rather than using individual panels, a continuous sheath is wrapped around the sides and a separate one over the roof.

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and primarily attributed to variations in the weather and drift in the concentration sampler. To overcome that scatter substantial data had to be taken. A semi-automated injection and read-out was used in this work permitting storage of all the data in a computer.

Data were generally sampled at 5 min. intervals. Recorded were: concentration in both homes (CO was used as a tracer to determine infiltration by the decay gas method; see Appendix for discussion), inside temperature of both homes (dry and wet bulb), outside wind (magnitude and direction), outside temperatures (dry and wet bulb), and solar radiation. A typical computer plot of concentration as a function of time is noted in Fig. 1. The values of wind are noted below the corresponding data points clearly exhibiting the dependence on wind. For those sections where a consistent slope is noted, a measure of infiltration rate can be made and related to the corresponding average weather conditions during that time. As an example, in Fig. 1, five different values of infiltration rates, I, (in changes per hr.) would have resulted for each home. A total of 390 sets of data points were obtained during the summer test. The range of temperature differences (inside minus outside) noted was from 9°C to -19°C. The plus value corresponds to summer data defined by that for which air conditioning was called for. (Due to solar loads, air conditioning can be required even when the inside temperature is less than the outside temperature.) The range of wind noted was from essentially no wind to 13 m/sec, with most of the data at winds from 2 to 7 m/sec.

Table 1 shows representative summer data. The major dependence is on wind magnitude and temperature differences. A correlation of the data suggests a general dependence of the form

$$I = \text{function } (W, \Delta T) \qquad (1)$$

In order to establish that dependence, data at limited temperature ranges is selectively plotted in Fig. 2-7. Two immediate observations apply: 1) A parabola fits the data satisfactorily. (The least square fit is noted in the figures.) 2) The sheathed home has consistently lower values of infiltration rate (in the order of half at 6.7 m/sec).

A similar parabolic dependence was noted for the winter data suggesting (Ref. 1) that

$$I = A(\Delta T) + B(\Delta T)W^2 \qquad (2)$$

where $A(\Delta T)$ means A, a function of ΔT.

The dependence of infiltration on ΔT can be explored by selectively choosing and plotting only that data at a certain wind level. Fig. 8 and 9 plot those values for extremely calm cases (winds under 1.3 m/sec) for both the summer and winter data (from Ref. 1). The obvious linear relationship with $|\Delta T|$ (the absolute value of ΔT, irrespective of algebraic sign) suggests then that

$$A(\Delta T) = I_o + C_1|\Delta T| \qquad (3)$$

A similar set of plots at a design wind of 6.7 m/sec (15 mph) is shown in Fig. 10. The winter data is again included. The surprising result is that a straightforward dependence on $|\Delta T|$ is not there, neither is there a clean cut dependence on ΔT itself. However, a plot of $I - A(\Delta T) = B(\Delta T)W^2$ vs ΔT (see Fig. 11 derived from data for various wind speeds near 15 mph) exhibits a convincing (but so far unexplained) relationship for

$$B(\Delta T) = C_2 + C_3\Delta T \qquad (4)$$

DISCUSSION OF RESULTS

Combining Eq. 1-4 gives a relationship defining the dependence of I on W and ΔT of the form

$$I = I_o + C_1 |\Delta T| + C_2W^2 + C_3\Delta TW^2 \qquad (5)$$

The quadratic dependence of I on W is as would be expected due to the pressure on the envelope caused by the wind. The mobile home is a bluff body and that pressure will be proportional to the square of the wind. The flow through small openings in the walls, windows, etc. would most expectedly be laminar. A laminar (Poiseuille) type flow will have a flow rate linearly proportional to the pressure difference (or the square of the velocity).

There is a non-zero infiltration at no wind and no temperature gradient. That value may be attributable to the blower in the evaporator section of the split air conditioners used. (The blowers were kept on continuously except for a few runs to validate the above statements.)

The dependence on ΔT is harder to explain. The stack effects, by themselves, are not sufficient to explain the values noted nor the different temperature dependence (on $|\Delta T|$ or on ΔT) of the A and B coefficients.

Correlating the entire set of data, for both wintertime (some 320 points, Ref. 1 and 10) and summertime (some 390 points) to fit Equation 5 gives the following:

$$I = I_o + C_1 |\Delta T| + C_2 W^2 + C_3 \Delta T W^2$$

where the coefficients become

	I_o	C_1	C_2	C_3
North home	0.0635	0.0103	0.018	1.53×10^{-4}
South home	0.0503	0.0065	0.0086	0.89×10^{-4}

when W is in m/sec, ΔT in ^oC and I in h^{-1}. The corresponding correlation coefficients are 0.942 and 0.948, showing an amazingly good fit to the data (a value of 1.0 would be perfect correlation).

CONCLUSIONS

The extensive data taken in the two test mobile homes for both winter and summertime (with the wintertime values reported elsewhere) show a dependence on velocity squared and linearly to temperature. At typical design conditions for these particular homes, the following are noted:

wintertime (T_o = 3°F, W = 15 mph) (-16°C, 6.7 m/sec)

for the home with sheathing board: 0.83 h^{-1}

for the home with caulking only: 1.53 h^{-1}

summertime (T_o = 91°F, W = 15 mph) (32.8°C, 6.7 m/sec)

for the home with sheathing board: 0.46 h^{-1}

for the home with caulking: 0.91 h^{-1}

The corresponding (maximum allowed) infiltration levels, based on ANSI A119.1 would be around 0.9. (The infiltration level at design conditions in ANSI A119.1 is that not exceeding that leading to a heat loss,* in Btu/h, given by the perimeter (in feet) times 0.7 times the temperature difference (in degrees fahrenheit).)

The above confirm that the home with continuous sheathing board just satisfied the ANSI A119.1 criteria, whereas the alternative with caulking, fails to do so.

The summary of data taken to date suggests that:

1. Further data, for different types of residences, are necessary to confirm and formalize the dependence of I on ΔT. (In addition, the effects of window and door fits should be tested.)
2. A scheme for measuring a parameter descriptive of infiltration rates in mobile homes just off the assembly line is desirable. This scheme should be "calibrated" against field data and could lend itself as a quality control device.
3. There is a strong probability that the typical mobile home, unless receiving a treatment better than merely caulking, will not comply with the infiltration criteria of ANSI A119.1.

*The reference document is in English units and is now quoted in that manner.

REFERENCES

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The authors were uniquely assisted by Mike Holtsclaw and Mehran Golbabai. The first designed and instrumented the semi-automatic injection and sampling technique as a sophomore student in Engineering Technology. The latter patiently assisted in the data retrieval while pedaling his bicycle a seemingly infinite number of times under all sorts of Indiana weather to and from the test site.

TABLE 1

Representative Summer Data*

DAY NO.	START TIME	NORTH HOME INFLT HR-1	SOUTH HOME INFLT HR-1	RATIO IN/IS	WIND SPEED MPH	OUT DRY BULB (C)	OUT WET BULB (C)	SOUTH DRY BULB (C)	SOUTH WET BULB (C)	SOLAR RAD. WATTS/SQMT	NORTH DRY BULB (C)	NORTH WET BULB (C)	WIND DIR. DEG.
123	15.83	.672	.294	2.28	10.74	25.0	25.1	27.3	27.4	255	26.1	26.1	303
123	16.92	.528	.185	2.85	11.07	23.8	23.9	27.2	27.3	196	26.4	26.4	313
123	18.08	.694	.270	2.57	11.68	21.9	22.0	26.8	26.9	70	26.5	26.5	308
123	20.25	.738	.421	1.75	9.13	18.4	18.5	26.7	26.7	-0	25.7	25.7	267
123	21.33	.904	.443	2.04	12.77	17.5	17.7	26.0	26.1	-0	25.1	25.1	257
123	22.75	.968	.451	2.15	12.49	18.0	18.2	26.1	26.2	-0	25.4	25.4	256
123	23.75	.557	.177	3.14	9.98	18.2	18.4	26.2	26.1	-0	25.7	25.7	257
129	16.33	.370	.281	1.32	9.99	15.4	15.8	27.2	27.2	554	26.6	26.5	153
129	17.50	.437	.191	2.29	9.93	13.8	14.1	27.3	27.3	329	26.5	26.5	170
129	18.50	.463	.211	2.19	13.32	12.4	12.8	27.6	27.6	159	26.5	26.4	166
129	18.92	.420	.145	2.90	11.50	11.8	12.1	27.2	27.2	92	26.0	25.9	157
129	19.75	.398	.152	2.62	6.57	9.8	10.2	26.2	26.2	2	25.3	25.3	174
129	20.92	.313	.153	2.04	4.03	8.3	8.9	26.1	26.1	0	25.2	25.2	167
129	22.00	.251	.139	1.81	1.60	7.3	8.1	26.2	26.3	0	25.7	25.6	177
129	23.08	.096	.113	.84	2.26	6.5	7.4	26.5	26.4	-0	25.5	25.5	185
129	23.50	.215	.099	2.18	1.22	6.7	7.6	26.4	26.4	0	25.6	25.6	189
138	17.75	1.030	.549	1.88	18.06	22.6	23.2	23.6	23.6	3	23.4	23.3	151
138	18.08	.711	.436	1.63	8.78	20.8	19.1	23.6	23.6	1	23.4	23.3	118
138	18.42	.301	.234	1.29	5.11	23.1	20.7	23.5	23.6	2	23.9	23.8	3
138	18.92	.247	.171	1.45	4.49	22.9	21.3	23.6	23.7	3	23.6	23.5	25
138	19.83	.552	.378	1.46	8.52	22.9	21.1	23.5	23.6	2	23.4	23.4	55
138	20.08	.397	.252	1.58	7.11	22.2	22.0	23.9	24.0	-0	24.1	24.0	67
138	20.92	.321	.132	2.43	4.95	21.8	21.9	23.9	24.0	-0	24.6	24.5	71
138	21.83	.160	.063	2.53	2.75	20.8	21.0	23.8	23.8	-1	24.0	24.1	226
138	22.83	.149	.073	2.03	2.46	20.0	20.1	24.1	24.2	-1	24.2	24.2	202
138	23.75	.136	.061	2.23	2.79	18.3	18.5	24.0	24.1	-1	24.0	24.0	134
138	24.17	.079	.068	1.16	1.55	18.1	18.2	24.0	24.0	-1	23.9	23.9	54
139	17.92	.388	.261	1.49	6.81	26.5	26.6	23.9	24.0	80	23.4	23.3	74
139	18.33	.532	.321	1.66	8.00	25.9	26.0	23.4	23.5	76	23.0	23.0	63
139	18.58	.216	.165	1.31	4.50	25.7	25.8	23.9	24.0	52	23.6	23.5	12
139	19.17	.491	.317	1.55	9.01	26.5	26.4	23.8	23.8	17	23.8	23.8	261
139	19.50	.891	.476	1.87	9.12	25.9	26.0	23.8	23.8	1	23.6	23.5	300
139	19.92	.222	.189	1.18	3.66	23.9	24.3	23.7	23.7	-0	23.6	23.6	357
139	20.50	.229	.160	1.42	3.68	22.9	23.0	23.7	23.8	-0	24.2	24.1	152
140	15.50	.255	.160	1.59	11.11	32.8	21.2	23.8	16.8	657	23.6	17.8	355

* The data are only a part of the total data collected.

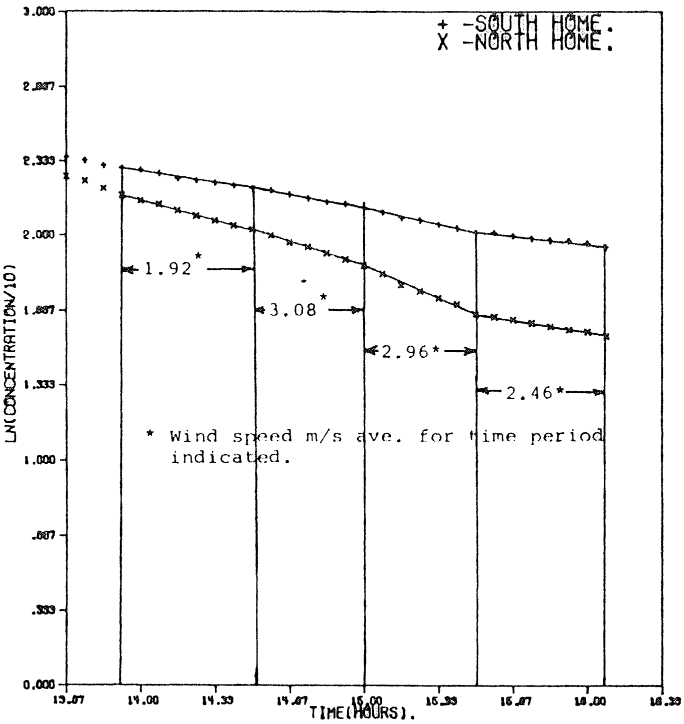

Fig. 1 Typical concentration plots

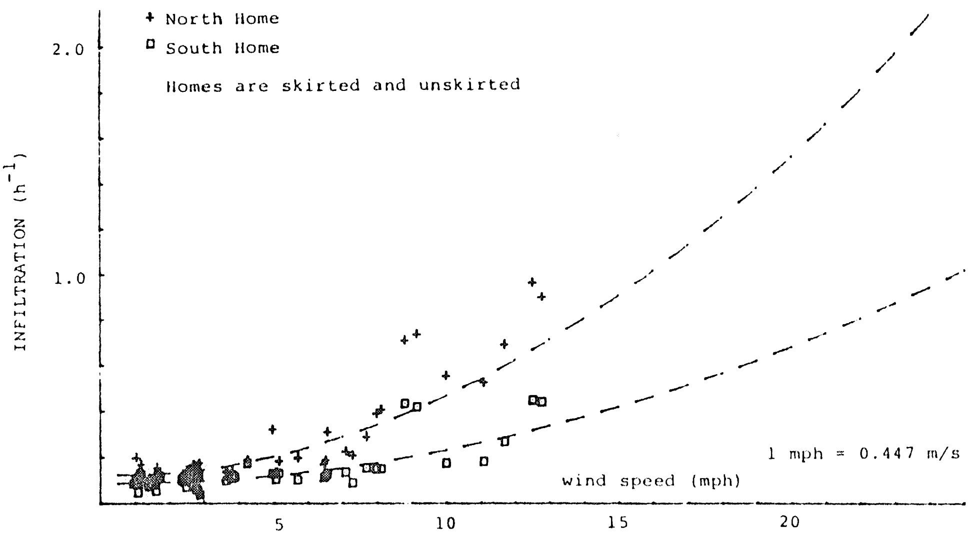

Fig. 2 Infiltration vs wind speed for $2^{o}C < \Delta T < 9^{o}C$

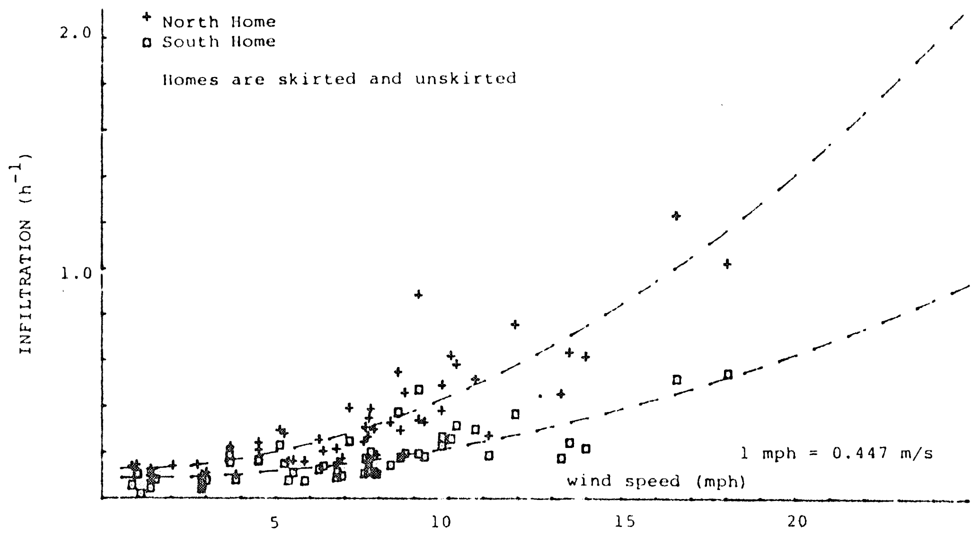

Fig. 3 Infiltration vs wind speed for $-2.5^{o}C < \Delta T < 2^{o}C$

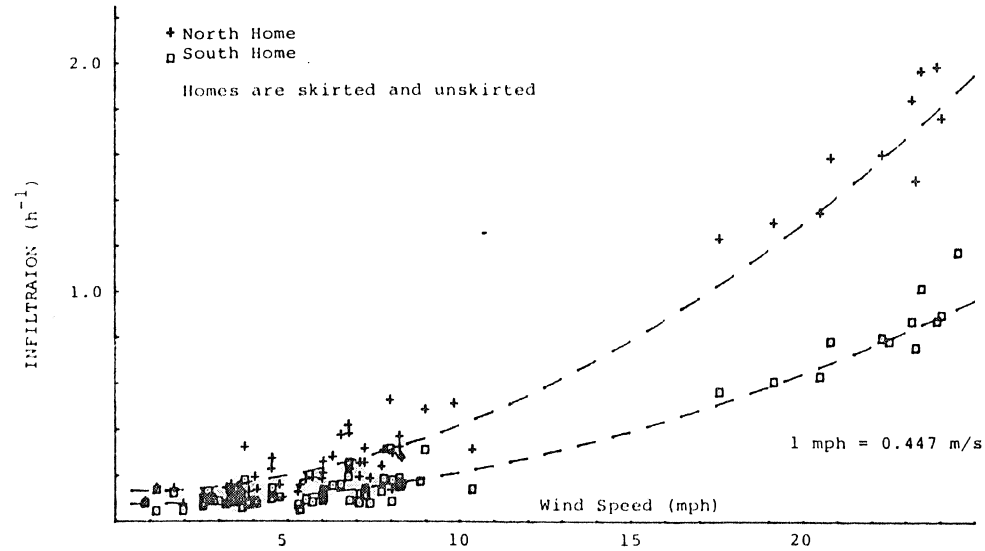

Fig. 4 Infiltration vs wind speed for $-5^{O}C < \Delta T < -2.5^{O}C$

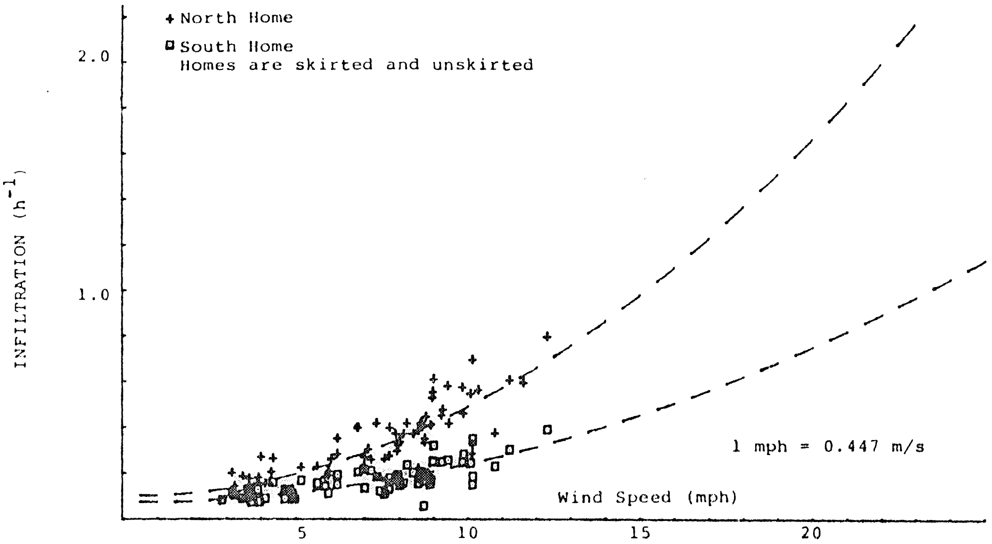

Fig. 5 Infiltration vs wind speed for $-7^{O}C < \Delta T < -5^{O}C$

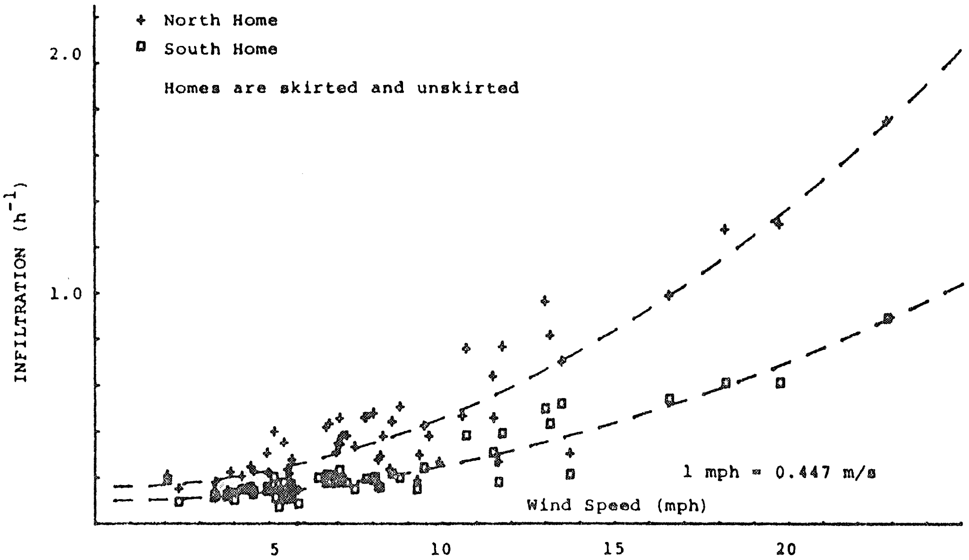

Fig. 6 Infiltration vs wind speed for $-9^{O}C < \Delta T < -7^{O}C$

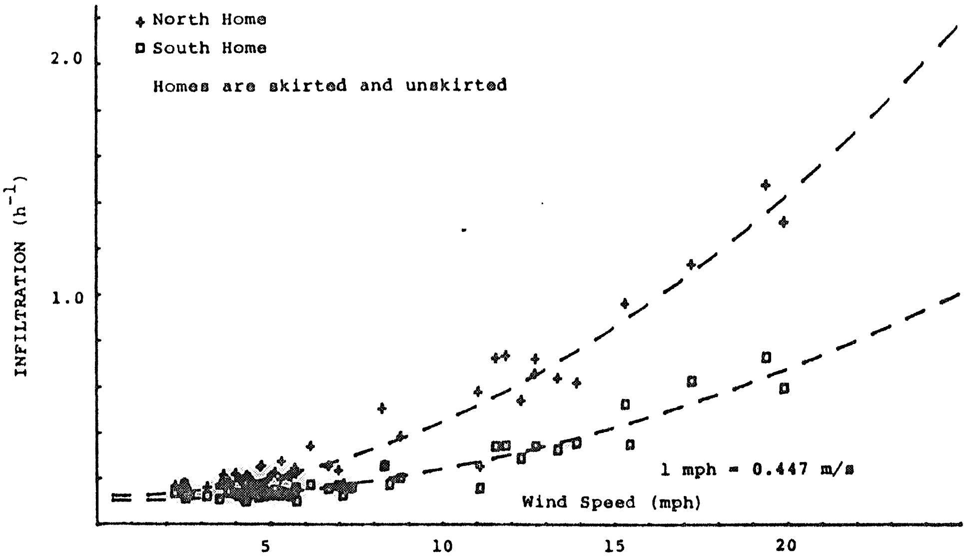

Fig. 7 Infiltration vs wind speed for $-18^{\circ}C < \Delta T < -9^{\circ}C$

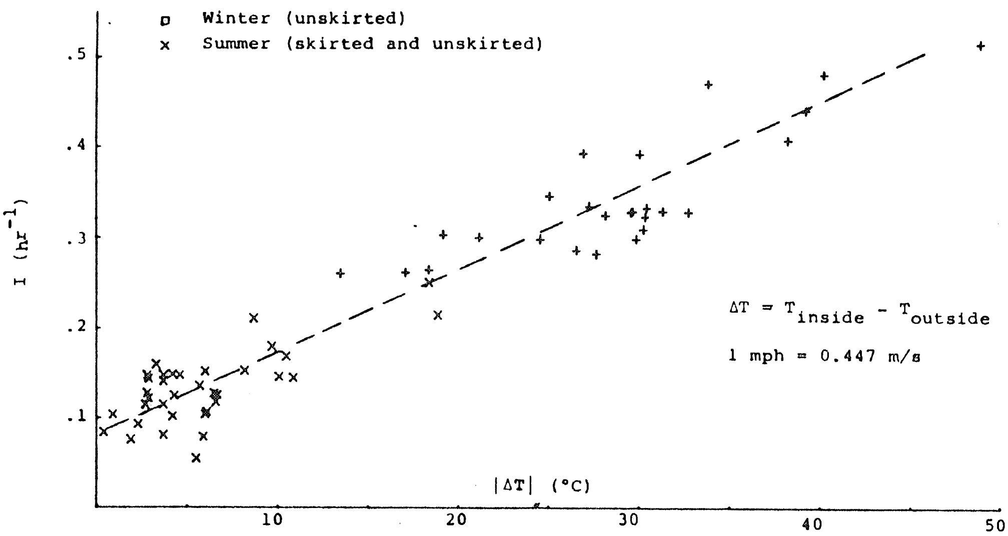

Fig. 8 Infiltration vs $|\Delta T|$ for winds less than 3.0 mph - North home

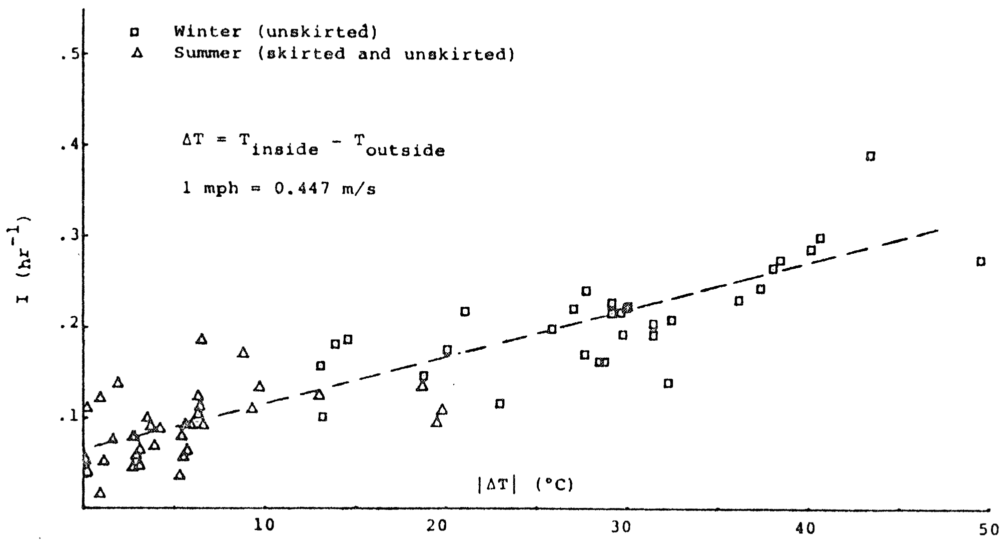

Fig. 9 Infiltration vs $|\Delta T|$ for winds less than 3.0 mph - South home

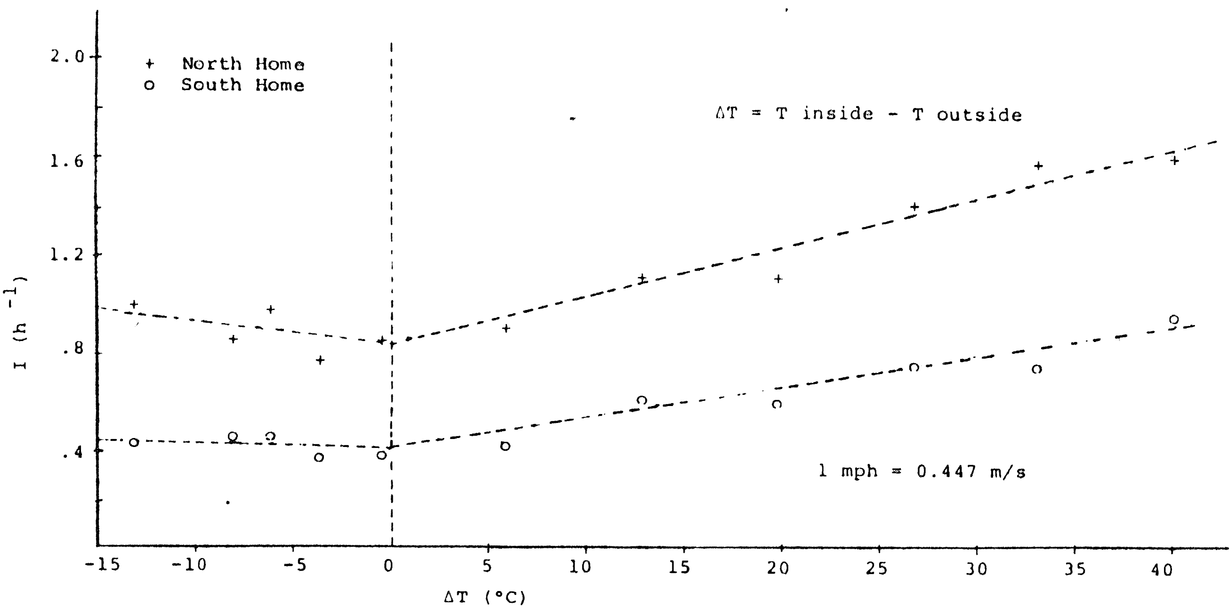

Fig. 10 Infiltration vs temperature difference for W=15 mph

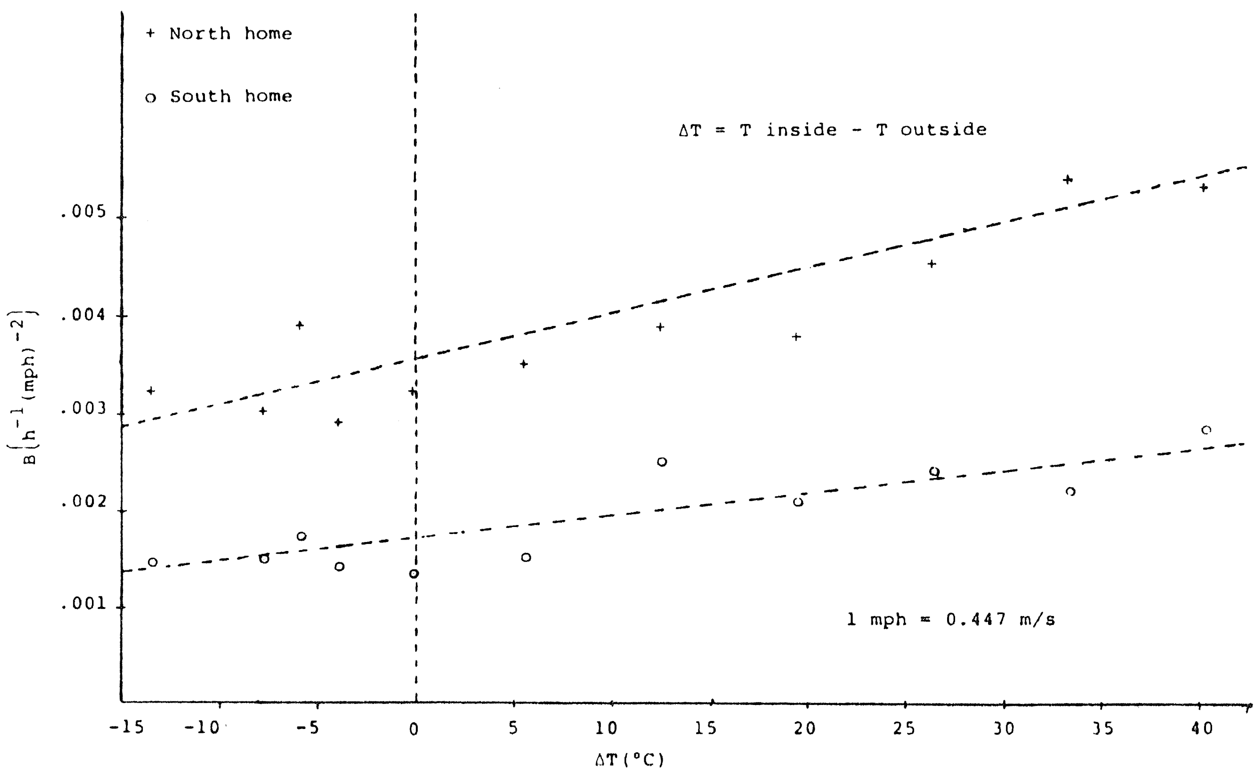

Fig. 11 I - A(ΔT) vs ΔT for W=15 mph

APPENDIX

Description of the Homes and Measurement Procedure

Two mobile homes whose floor plan is shown in Fig. A.1 were selected for this study. The homes were identical except for the treatment used to reduce air infiltration. One of the homes used a sheathing material in the side walls and under the roof as an infiltration barrier while the other home used caulked joints at floor, wall, and roof intersections as an alternative method to reduce infiltration*. Typical wall cross-sections are shown in Fig. A.2. The floors of both homes were of similar construction, with impregnated paper stretched and stapled on the underside. The small effect of skirting on infiltration suggests that there was a good seal on the floors.

The test site at Purdue University Airport provided an unobstructed exposure to the prevailing southwest wind and to solar radiation. Fig. A.3 shows the arrangement of the two homes and the building which housed the instrumentation and recording equipment.

The qualification of air infiltration was made through a "decay-gas" method. Carbon Monoxide was used as a tracer gas. The method is explained referring to Fig. A.4. Essentially, a slug of tracer is injected at the instrumentation shed (5) into the concentration sampling loop. Two blowers (3) and (4) in the concentration sampling loop are run continuously. The tracer injected into the sampling loop is introduced at the inlet (3) of the large air distribution blower within the mobile home. The blower is also run continuously. The tracer is introduced right above the filter element. From there it is forced through the supply duct of the mobile home and through all the registers in the distribution system. The mixed tracer is then sampled through the sampling tube (1) and (2) which then takes that sample through the loop and the sampling station at the instrumentation shed itself (5). In this manner, the concentration within the loop a few seconds after the injection of a slug of tracer will be directly proportional to the concentration within the home. The rate of decay of the concentration measured within the loop then at the sampling station will be the same as the rate of decay of the concentration of the tracer within the home itself.

From a mass balance, the change in CO level within the home (C) with a total volume V depends on the volume of air leaking in, V_{in}; volume out, V_{out}; and concentration of the mixture leaving, C_{out}; or, formally,

$$VdC = C_{in}dV_{in} - C_{out}dV_{out} \qquad (A.1)$$

but as the air leaking in does so without any CO in it, provided there is sufficient mixing within the home, then,

$$VdC = -CdV_{out}$$

The subscript may be deleted, and defining infiltration rate as air changes per unit time, or

$$I = \frac{dV}{V}/dt \qquad (A.2)$$

we can solve for concentration as

$$-\ell n\ C = It + \text{constant.}$$

If we let the concentration be C_o at time t_o, then

$$I = \frac{\ell n \frac{C_o}{C}}{t - t_o} \qquad (A.3)$$

Thus, by measuring C_o at some time t_o and C at a later time t the infiltration can be determined.

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* In order to reduce condensation the caulked home had roof vents as well.

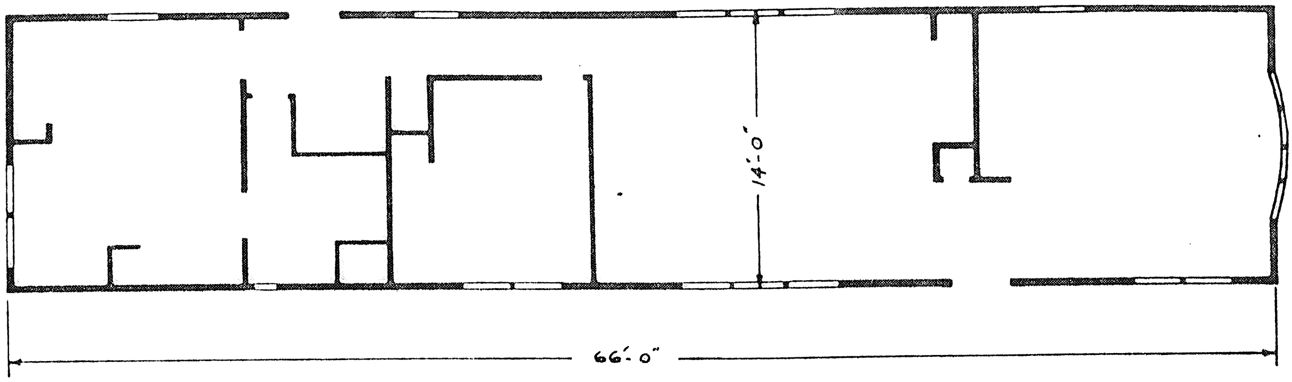

Fig. A.1 Floor plan of mobile homes

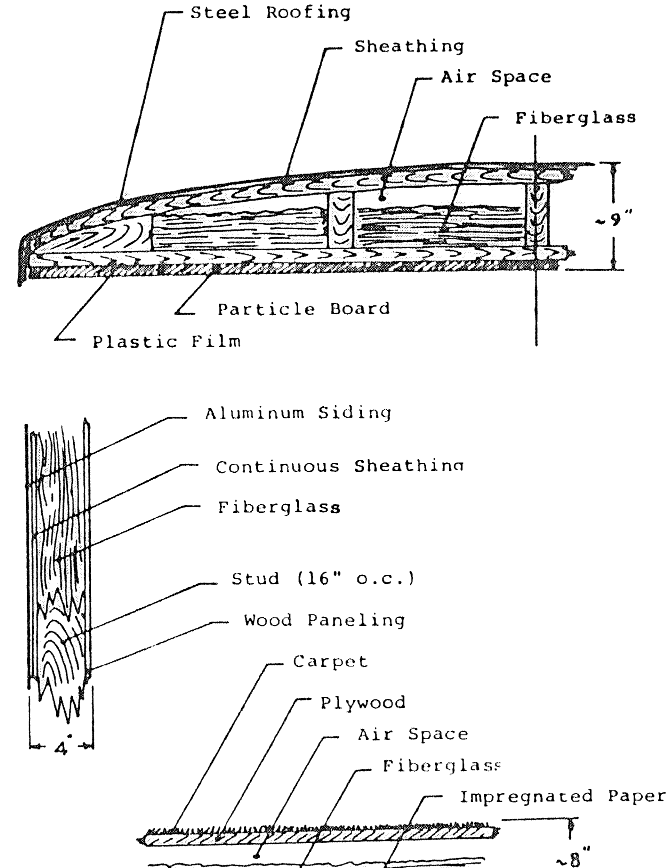

Fig. A.2 Typical sections

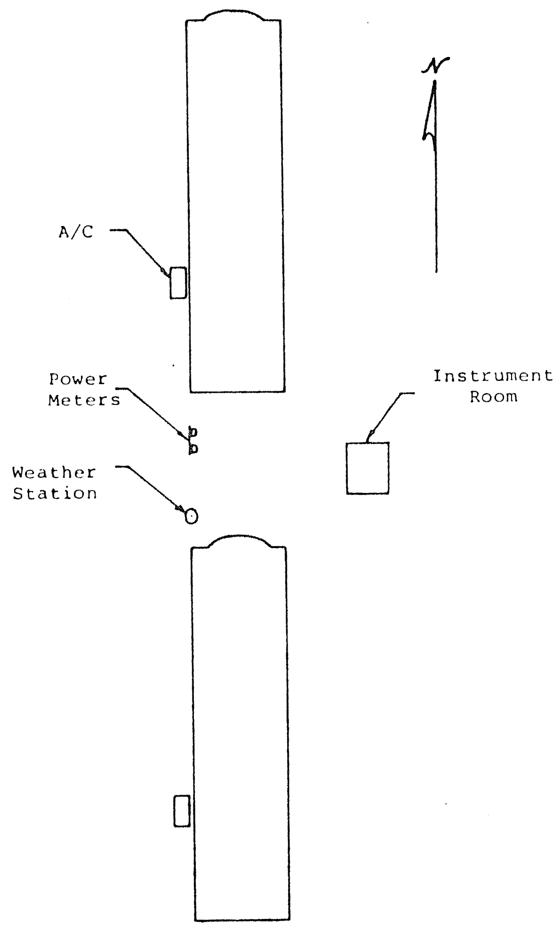

Fig. A.3 Test site

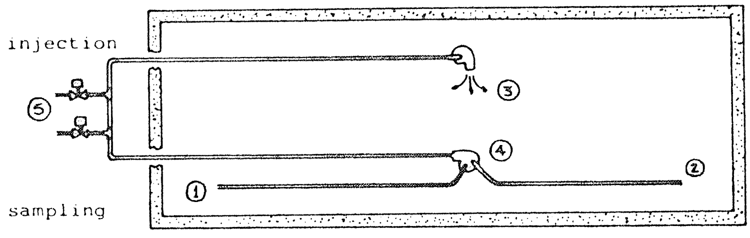

Fig. A.4 Schematic of injection sampling system