SIMULATIONS OF ATTIC VENTILATION AND MOISTURE

T.W. Forest and K. Berg

Department of Mechanical Engineering
University of Alberta
Edmonton, Alberta, CANADA, T6G 2G8

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ABSTRACT

The ventilation of flat ceiling attics is the accepted method for controlling moisture levels. This ventilation is usually provided by roof and soffit vents located on the attic envelope. The accepted vent-to-attic floor area ratio of 1:300 is used as a guide for providing the required ventilation. The question of how much ventilation is provided by this vent area and how it affects attic moisture levels remains unclear.

This study was carried out to simulate the performance of attics with various leakage configurations and different Canadian climatic zones. The model used is a combined ventilation, thermal, and moisture model that was recently developed for CMHC. Seasonal simulations were carried out for a wide range of vent area ratios, various ceiling leakage areas, and a high (42°) and low (19°) roof pitch. Several different climatic zones were investigated including Winnipeg (prairie region), Halifax (east coast maritime region), and Vancouver (west coast maritime region).

The principle conclusions from these simulations were as follows. In extreme climatic zones (prairie region) attic ventilation is required and the code specification of 1:300 is generally satisfactory. In more moderate climates, the code requirement of 1:300 tends to over-ventilate attics resulting in elevated moisture levels. Moisture levels can be substantially reduced by eliminating most of the roof vents and providing only a minimal amount of ventilation. Simulations on the effect of roof pitch indicated that high pitched roofs tend to have higher ventilation rates than low pitched roofs; in maritime climates, the results showed that moisture levels in these attics were higher than in low pitched roofs.

1.0 INTRODUCTION

Moisture in building envelopes, subjected to extreme climates continues to be one of the most persistent problems associated with the long-term viability of a building. This partly stems from the fact that very often moisture accumulates in areas that are not directly visible and the harmful effects of moisture may not be apparent for several heating seasons. One part of the building envelope that is particularly prone to moisture accumulation is the attic space in flat ceiling houses. The range of problems that have been noted in field surveys include, mould growth on roof sheathing and/or framing, wet insulation, corroded truss plates, and water stained or damaged ceiling. In many cases, the source of moisture is the warm, humid air inside the conditioned part of the house that finds its way into the attic. This "leakage" air flow results from unintentional leaks that provide a pathway such as, attic hatches, plumbing stacks, or ceiling light fixtures; in some cases, air may be directed into the attic such as, bathroom fans that are vented into the attic.

The accepted approach in dealing with attic moisture is to ventilate attics with outdoor air. To achieve some level of ventilation, most building codes require that attic vents be installed having a combined vent area equal to 1/300th the attic floor area with some fraction of the vents at ceiling level and the remainder installed near the roof peak. The important question that the code does not answer is "How much ventilation is provided and what level of ventilation will prevent moisture problems?".

In a recently completed study by CMHC (1993), these particular questions were addressed. The two year study consisted of a) developing an attic model which would predict attic ventilation rates and the effect on temperature and moisture distribution within an attic, and b) verifying model predictions with field measurements taken in two full-size attics with different leakage configurations; comparisons between measured and predicted ventilation rates, temperatures, and moisture contents showed very good agreement. The only inputs to the model were the leakage configuration of the attic and house, and the meteorological data for the test site. The report also presents some seasonal simulations of moisture accumulation in attics for a few geographic locations in Canada. The present study has been carried out to extend these simulations for different climatic zones of Canada and a wider range of attic configurations in order to delineate the effect of ventilation on moisture accumulation in attics.

2.0 SIMULATION MODELS

The simulations were carried out for a single storey house which had a gable-end roof. In its present form the model is only capable of handling this basic attic shape. The parameters describing the house and attic that are common to all simulations were based on the Charlottetown house M-4 which was described in Appendix B of the CMHC (1991) survey report on attic moisture survey. The configuration of the house and attic are shown in Fig.1 and the pertinent dimensions are given in Table 1. In all simulations, the house was oriented with the roof ridge perpendicular to the north direction as shown in Fig.1. In addition, it was assumed that the house was one of a row of houses oriented along an east-west direction; the row of houses provide shelter which alters the house and attic ventilation rates significantly.

Table 1. House and Attic Characteristics

House Characteristics	Value
Plan dimensions	12.5 m x 8.4 m
Floor height[1]	0.6 m
Ceiling height	3.0 m
House volume	252 m^3
House leakage area[2]	140 cm^2
House leakage exponent	0.67
Flue	none
Attic Characteristics	
Roof peak height	4.5 m
Roof pitch	19.7°
Attic volume	78.8 m^3
Attic leakage area[3]	1764 cm^2
Attic leakage exponent	0.7
Fraction of leakage area in soffits[4]	67%
Fraction of leakage area in attic envelope	33%

[1] All heights are measured from grade level

[2] Leakage areas are based on 4 Pa pressure difference

[3] Only includes the soffits and background leakage area of the attic envelope

[4] Soffits are located only along the length of the house

The simulations were carried out for a wide cross-section of Canadian climatic zones. The cities that were selected for these simulations were Vancouver, Whitehorse, Winnipeg, Toronto, Halifax, and St. John's and the meteorological data for these sites was obtained from computer data files that had been compiled by CMHC for the WALLDRY program. These meteorological data included wind speed, wind direction (in increments of 10°), outdoor temperature and relative humidity, cloud cover, cloud ceiling (this value is not used in the calculation procedure), solar gains on north, south, east, and west vertical surfaces. The simulations were carried out for one complete year commencing on mid-night of July 1 (hour 1) and ending with June 30 (hour 8760). Since the model is based on the transient response of the attic to changing meteorological inputs, initial conditions had to specified for the simulations. The intial attic relative humidity was set at 35% while the moisture content of all wood components in the attic including roof sheathing and wood framing was set at 8% MC; these initial wood moisture contents, of course implied that the initial amount of condensed mass was zero. Throughout the entire simlulation period, it was assumed that the interior conditions were constant at 20°C and 35% relative humidity.

2.1 Varying Attic Vent Area

The first set of simulations was designed to investigate the effects of installing different attic vent areas on the moisture distribution within the attic. For these simulations, the house leakage area (140 cm^2) was apportioned between the ceiling, floor, and four walls with the following distribution: ceiling - 40%, floor - 20%, and walls - 40%. The wall and floor leakage fraction was assumed to be divided equally between walls 1 (north face), 2 (south face), 3 (east), and 4 (west); the wall number designation is shown in Fig.1.

The base case used for comparison purposes in the simulations was an attic with the code-required vent area of 1:300. For the dimensions quoted in Table 1, the total vent area required was 3500 cm^2; the soffits were taken to be part of this required area and the total soffit vent area corresponding to the eave overhang dimension of 0.3 m was calculated to be 1160 cm^2. The remaining area was supplied by roof vents that were distributed equally on the roof sections above walls 1 and 2 at a height of 4 m above grade level. Each roof vent was assumed to be a standard size vent providing 384 cm^2. Thus a total of 6 vents were placed on the roof, 3 on roof section 1 and 3 on section 2, for a total vent area of 2300 cm^2. For the other simulations, it was assumed that the soffit area was constant and that only the vent area was altered. The number of vents, vent area and location are given in Table 2 for the various simulations. The last simulation in this set was the sealed attic where no vents or soffits were placed in the attic envelope. In this case, the only leakage area was the background leakage associated with construction of the attic and a value of 5 cm^2/m^2 of surface was used to calculate this area. The practice of sealing attics is quite common in various regions of Canada to prevent drifting snow from accumulating iside the attic.

Table 2. Area and Location of Roof Vents used in the Simulations

Simulation Number	Vent Area Ratio	Total vent area cm²	Number of vents	Height above grade m
1	1 : 300	2300	6	4
2	1 : 75	13,060	34	4
3	1 : 150	6140	16	4
4	1 : 600	770	2	4
5	1 : 1200[2]	0	0	-
6	Sealed[3]	-	-	-

[1] This model is used as the **standard** attic configuration
[2] Includes soffit area
[3] Includes only the background leakage of the attic (no soffits)

2.2 Varying Ceiling Leakage Area

In this set of simulations, the fraction of the house leakage area in the ceiling was varied with the total house leakage area fixed at 140 cm^2. The remaining leakage area of the house was divided between the floor and walls in the ratio of 1:2. The leakage fractions chosen for the simulations are shown in Table 3. The attic vent area was kept constant at the standard 1:300 configuration. The variation in ceiling leakage fraction from 30% to 85% was based on the range of values noted in the CMHC (1991) attic survey.

Table 3. Ceiling Leakage Fractions used in the Simulations

Simulation number	Attic Vent Area	% Leakage in:		
		Ceiling	Floor	Walls
8	1 : 300	30	23	47
9	1 : 300	50	17	33
10	1 : 300	65	12	23
11	1 : 300	85	5	10

2.3 Varying Roof Pitch

The final simulation, designated as 7, was carried out for an attic with a roof pitch of 42°. Based on the plan dimensions given in Table 1, the new attic volume was 198 m^3 and the attic leakage area was increased from 1764 cm^2 to 1926 cm^2 to account for the fact that the surface area of the attic envelope was increased; this area included the soffits. The change in roof pitch will alter the pressure coefficients on the roof surface and thus alter the ventilation rates for a given wind speed and wind direction, particularly the north and south directions. For north winds, the upwind roof section 1 will have a positive pressure coefficient for a high roof pitch while for a low roof pitch, the pressure coefficient will be negative. At low pitch angles, the roof is essentially in a region of separated flow producing negative pressure coefficients. The threshold roof pitch is approximately 30° (CMHC, 1993).

3 RESULTS AND DISCUSSION

In order to provide some insight on the effects of ventilation, the first set of results was a parametric calculation of attic ventilation rates and indoor-attic exchange rates as functions of wind speed, wind direction, and outdoor temperature. These values are important for attic moisture since ventilation is intended to remove moisture while the indoor-attic exchange rate is generally, the dominant moisture source. The parametric calculations were carried out for the standard model (#1) with a house leakage distribution of 40% in the ceiling, 20% at floor level, and 40% in the walls.

The effect of wind speed on attic ventilation rates is shown in Figs.2a and 2b for various wind directions between 90° (east - maximum shelter) and 180° (south - no shelter) and outdoor temperatures of 20 and -40°C. For south winds, the attic is completely unsheltered and the large increase in ventilation rates result from the large difference in pressure coefficients, particularly the windward soffit (that has a positive pressure coefficient) and the leeward soffit (that has a negative pressure coefficient). Contrasting with these results is the relatively constant ventilation rate for east winds. For this direction, the attic is completely sheltered by the other houses in the row resulting in equal pressure coefficients on all attic vents including the soffits. Thus, ventilation rates can be expected to be low and relatively constant with wind speed. Interestingly, as soon as the wind direction shifts away from the east, attic ventilation rates increase substantially since the pressure coefficient on the windward soffit changes from negative to positive while the remaining vents have negative values. The effect is quite dramatic and is the main reason why field measurements exhibit so much scatter. For low outdoor temperatures, as shown in Fig.1b attic ventilation rates increase slightly. This results from the attic-outdoor temperature difference that generates a "stack" pressure difference although these pressure differences are much smaller than the wind-generated values. Wind is the dominant driving "force" for attic ventilation.

The indoor-attic exchange rates are shown in Figs.3a as a function of the indoor-outdoor temperature difference for low wind speed (1 m/s) and two wind directions of 90 and 180°. For the house-attic configuration considered, outdoor temperatures below +15°C produce positive exchange rates indicating that the direction of air flow is from the house into the attic. The magnitude of these leakage air flows correspond to a maximum of approximately 0.2 ac/h (air changes per hour based on the house volume) at a temperature difference of 60 C°. The effect of wind speed can be seen in Fig.3b where wind speed is 10 m/s. For this high wind speed, the effect of wind direction is very large. The unsheltered direction (180°) has a large flow rate into the attic for all indoor-outdoor temperature differences indicating that thw wind tends to depressurize the attic relative to the interior of the house. For the sheltered direction (90°), the indoor-attic exchange rates are insensitive to wind speed as can be seen by comparing the lower curve in Fig.3b and the curves in Fig.3a.

Results for the simulations are presented in the following sections of the report. Simulations were carried out for all the cities noted above; however, only results for Winnipeg, Halifax, and Vancouver are presented, those being representative of the prairie, east coast and west coast climates. Results for the standard configuration (model 1) are organised in the following manner:

a) attic ventilation rates
b) surface moisture content of the roof sheathing
c) condensed mass on sheathing.

In order to highlight the effect of a particular variable on moisture accumulation in the attic, only the sheathing moisture content and differences between the condensed mass for model 1 and a different model are presented.

3.1 Effect of Vent Area

a) Winnipeg - Standard Model 1:300 The results for model 1 (standard house-attic configuration) are presented first and used as a reference. Figure 4a gives the correlation of attic ventilation rates with wind speed for north and south directions including a wind angle bin of ±10° about the nominal directions. These data represent the maximum ventilation rates for the unsheltered directions; for other wind angles, ventilation rates will be lower. Figure 4b shows the daily variation in the surface moisture content of the roof sheathing throughout the year. It should be noted that the moisture contents of both the north and south roof surfaces have been plotted; however, the difference between these two values is small for the entire period and the difference is not apparent in this figure. The corresponding variation in the daily averaged condensed mass is shown in Fig.4c. Again, the curves show the mass accumulation on the north and south sheathing separately, although the difference between these two values is small; thus, at hour 4700 (approximately mid-January) for example, the total amount of accumulated moisture is approximately 26 kg. This condensed mass persists through much of the winter period but quickly dissipates as the outdoor temperatures increase. It is interesting to note that, even though moisture accumulated on the sheathing during the middle of winter, the peak sheathing moisture contents reached 25% MC around September (hours 1500 to 2000) and mid-April to end of May (hours 7000 to 8000).

1:75 Using model 3 as the base case, the vent areas were altered to examine the effect of varying ventilation rates on moisture in attics. Figures 5a,5b, and 5c summarise the results for model 2 (vent area ratio of 1:75) where the difference in condensed mass in Fig.5c is defined as the condensed mass for model 1 minus the mass for model 2; thus, positive differences mean that the altered configuration has resulted in a decrease in condensed mass, while negative values imply an increase. A comparison of Figs.5a and 4a shows the increase in ventilation rates with the addition of more vents in the roof. Figure 5b shows that increasing the ventilation rates by adding more vents has reduced the amount of condensed mass during the winter months which on the surface would be desireable; however, a closer examination of Fig.5b shows that during the "shoulder" period, September and mid-April to May, the surface moisture contents of the sheathing actually increased to peak values over 30% MC with increased ventilation. This is probably due to the added moisture that is convected through the attic from outdoors when ventilation rates are increased.

1:150 Results for model 3 are shown in Figs.6a, 6b, and 6c. Much the same pattern can be seen in these results as with the previos model, except that the reduction in condensed moisture in mid-winter is not as large as model 2; on the other hand, sheathing moisture contents during the shoulder periods are reduced slightly below those of model 2.

1:600 Results for model 4 are shown in Figs.7a, 7b, and 7c. With a reduction in the vent area, the ventilation rates decrease slightly below that for the standard model. Reduction in the ventilation rates produces an increase in condensed moisture during the mid-winter period; however, over all the sheathing moisture contents continue to show a reduction particularly during the shoulder periods.

1:1200 Results for model 5 are not presented here. When the computer program was executed with this model the iteration procedure for calculating moisture distribution within the attic failed to converge; this usually occurs when conditions are such that the wood is close to saturation.

Sealed The final simulation was carried out for model 6, the sealed attic (no vents or soffits but a small background leakage of 590 cm^2 distributed uniformly over the entire attic exterior envelope); results are shown in Figs.8a, 8b, and 8c. For this case, ventilation rates are over an order of magnitude less than the standard model and reflect the small leakage area. In this case, the condensed mass accumulates over much of the winter resulting in a substantial amount of moisture in the attic. This mass of moisture slowly dries out in the spring but the sheathing moisture contents remain at or near saturation for a prolonged period; such a situation would probably produce degradation of the roof sheathing. The large accumulation of moisture is a direct result of moisture being convected from inside the house. Sealing attics is not recommended unless all leakage flow from inside the house can be eliminated.

b) Halifax - Standard Model 1:300 Results of the standard model for Halifax are presented in Figs.9a, 9b, and 9c. The ventilation rates shown in Fig.9a are for north - south wind directions and show a similar correlation with wind speed to that for Winnipeg; the somewhat lower ventilation rates can be attributed to the lower indoor-outdoor temperatures that prevail for the east coast as compared to the prairie region. Seasonal variation in the surface moisture content of the roof sheathing is shown in Fig.9b. The most striking feature of these results is the high moisture contents (near saturation) for much of the fall and spring periods. These high moisture contents reflect the fact that the east coast climate has high relative humidity throughout much of the year. The condensed moisture is shown in Fig.9c. The actual mass of moisture condensed at any time is not large but there are several periods throughout the year when condensation does occur. This contrasts with the prairie climate where moisture condensation generally occurs in winter.

1:75 Results for the high ventilation rate case (model 2) are shown in Figs.10a, 10b, and 10c. Although there is a slight reduction in condensed mass accumualtion during the winter period, the higher ventilation rates tend to increase the sheathing moisture content during the rest of the year; in fact, in Fig.10c, increased ventilation actually produces periods of condensation where none existed for the 1:300 case. These results would suggest that increased ventilation is not the correct strategy for this type of climate.

1:150 Model 3 results are given in Figs.11a, 11b, and 11c. The pattern here is much the same as for model 2, except that the sheathing moisture contents are not as high and the incidence of condensation is reduced but still greater than for the base case. Reducing ventilation rates below that of the 1:300 case may have some advantages in reducing sheathing moisture contents.

1:600 Model 4 results are given in Figs.12a, 12b, and 12c. A comparison of Figs.12a and 9a shows a slight decrease in ventilation rates for reduced vent area. This produces a slight reduction in the sheathing moisture content as can be seen by comparing Figs.12b and 9b, although the moisture content values are still quite high. The occurrence of condensed mass is reduced as is shown in Fig.12c particularly for the fall period. During winter, there is actually more mass condensed but this moisture is quickly dissipated when the temperature increases in the spring. Overall, this configuration has lower sheathing moisture contents than the standard model.

1:1200 Model 5 results are given in Figs.13a, 13b, and 13c. In this case, ventilation is provided by soffits only and still produces ventilation rates that are only approximately 20% less than the standard model. Reducing ventilation rates further, produces an overall reduction in sheathing moisture content, although the model 4 and model 5 results are not that much different.

Sealed Results for model 6 are presented in Figs.14a, 14b, and 14c. With the attic sealed (no vents or soffits and background leakage only) there is a dramatic reduction in sheathing moisture contents particularly during the fall and spring. The incidence of condensation is restricted to the winter period where the sheathing moisture content actually increases; however, these higher moisture contents do not last for a long period of time. This is actually the same pattern that was observed in Winnipeg, except that the amount of condensed mass is much less. Unlike the prairie climate, this condensed mass does not appear to produce much of a problem. In this case, the ventilation rates (shown in Fig.14a) are an order of magnitude less than the standard case shown in Fig.9a. The reduced ventilation rate tends to keep the attic warm and the minimal ventilation provided by the background leakage is enough to keep the attic relatively dry. It should be noted that the same pattern of results was obtained in the simulations performed for St. John's. For the east coast maritime climate, attic sheathing moisture content can be reduced by sealing the attic or at least substantially reducing the vent area.

c) Vancouver - Standard Model 1:300 Results for the standard case are presented in Figs.15a, 15b, and 15c. Given that the west coast climate is relatively wet but mild, one would expect relatively high sheathing moisture contents. The simulation in Fig.15b shows sheathing moisture contents that are relatively high throughout the entire year and few periods of condensation (Fig.15c). Based on the results presented for the east coast climate, one may anticipate a similar conclusion for the west coast climate; therefore, results are presented only for models 2 (1:75), 5 (1:1200), and 6 (sealed).

1:75 Results for the high ventilation case are shown in Figs.16a, 16b, and 16c. Sheathing moisture contents increase with the higher ventilation rates and there is a more frequent occurrence of condensation periods throughout the entire year, as can be seen by comparing Fig.16c and 15c. Clearly, increasing ventilation is not going to alleviate moisture problems.

1:1200 Results in this case are shown in Figs.17a and 17b; a figure for condensed moisture is not shown since there was no condensed mass for the entire year. The 20% reduction in ventilation rates produces a decrease in the seasonal average sheathing moisture content and a reduction in peak values. These results follow the same trends as were noted in the Halifax simulations.

Sealed Results for the sealed attic case are shown in Figs.18a and 18b (no condensed mass). With the low ventilation rates (under 1 ac/h for most of the time), the attic remains much warmer than the standard case and this helps to keep the sheathing moisture contents at a seasonal average of approximately 15% MC with a slight increase during the winter period. A conclusion similar to that for the east coast can be made for the west coast climate: a substantial reduction in ventilation rates will tend to keep attics drier than attics with code-required vents.

3.2 Effect of Ceiling Leakage Area

In these sets of results, the ceiling leakage area fraction (for a given total house leakage area of 140 cm^2) is varied over a wide range of values - 30% to 85% with the balance of the house leakage distributed between the floor and walls in the ratio of 1:2. The ceiling leakage area changes the indoor-attic exchange rate which alters the amount of moisture entering the attic. The effect of this change on attic moisture levels will be more pronounced in cold, dry climates like the prairie region where the only moisture source is from the interior of the house. In maritime climates, this effect will be superimposed on the outdoor moisture that is convected through the attic with the ventilation flow. Thus, results in this section are limited to Winnipeg and Halifax.

a) Winnipeg - Standard Model: 40% Results for the standard model were presented in Figs.4a, 4b, and 4c. The indoor-attic exchange rates for this model are shown in Fig.19 correlated with indoor-outdoor temperature difference where data has been selected for wind speeds less than 2 m/s; the small amount of scatter is mainly due to variation in wind speed and direction.

30% Results for this case are shown in Figs.20a, 20b, and 20c. Reduction in the ceiling leakage area reduces the exchange rates as can be seen by comparing Figs.20a and 19. The net effect is a reduction in condensed mass accumulation during the winter period as seen in Fig.20c. However, the sheathing moisture content over the entire year remains unchanged. In particular, the elevated moisture contents during the fall and spring are completely unaffected by the reduction in exchange rates, suggesting that during these periods sheathing moisture contents are dictated by the outdoor moisture convected into the attic with the ventilation flow.

50% Results for this simulation are presented in Figs.21a, 21b, and 21c. Increasing the ceiling leakage area results in a slight increase in exchange rates (Fig.21a) which in turn produces more condensed mass during the winter period as shown in Fig.21c; however, the increased condensed mass during the winter does not change the sheathing moisture content.

65% Results for this case are shown in Figs.22a, 22b, and 22c. Comparing Figs.22a and 19, shows that the exchange rates are almost identical to the standard model. This is reflected in Fig.22c which shows that the amount of condensed mass during the winter period is virtually identical to the base case. When more of the house leakage area is shifted to the ceiling, this tends to raise, on average the neutral pressure level towards the ceiling. The results in a reduction in the ceiling attic pressure difference and hence, a reduction in the exchange rate.

85% Results for this model are not shown since the program failed to converge for these conditons.

b) Halifax - Standard Model 40% For the standard model, the exchange rates are shown in Fig.23 correlated with indoor-outdoor temperature difference. As mentioned previously, for a maritime climate with high outdoor humidity levels, it is not expected that indoor-attic exchange rates provide very much moisture load on an attic; thus, only the 30% and 85% scenarios are presented below.

30% Results for this case are shown in Figs.24a, 24b, and 24c. A reduction in ceiling leakage area produces the expected decrease in exchange rates. However, sheathing moisture contents over the entire year are unaffected by this change as can be seen by comparing Figs.24b and 9b. The amount of condensed mass is virtually unaffected by the decrease in exchange rates, particularly during the winter period. These results confirm the fact that for this climate, the dominant moisture source for the attic is the outdoor air.

85% Results for this simulation are presented in Figs.25a, 25b, and 25c. As mentioned previously, shifting most of the house leakage area to the ceiling, on average, reduces the pressure difference resulting in smaller exchange rates, as can be seen by comparing Figs.25a and 23. However, the sheathing moisture contents are unaffected by this change and the amount of condensed mass is virtually the same as for the standard model.

Simulations where the ceiling leakage fraction was varied, were also carried out for Vancouver. The results followed the same pattern as observed in the Halifax simulations; there was virtually no difference in sheathing moisture content and condensed mass accumulation between the different ceiling leakage fractions.

3.3 Effect of Roof Pitch

Simulations were carried out for an attic with a roof pitch of 42° and the code-required vent area of 1:300. Results for Winnipeg are shown in Figs.26a, 26b, and 26c. Comparing the ventilation rates in this attic and the standard model (Figs.26a and 4a), shows that the peak ventilation rates (corresponding to winds from exactly the north and south directions) are higher for the high pitched roof than the low pitched roof. The roof vents facing upwind on the high pitched roof have postive pressure coefficients, while those on the low pitched roof have negative pressure coefficients. Pressure coefficients on the upwind surface of the roof however are very sensitive to wind direction and as the wind direction changes slightly, these pressure coefficients decrease rapidly resulting in a reduction in the ventilation rate; the grouping of data into separate curves below the peak curve, as shown in Fig.26a, is a result of wind directions other than 0° and 180°. The net effect for this climatic zone is a very marginal increase in sheathing moisture content during the fall and spring and decreased condensed mass during the winter period.

Results for a high pitched roof in Halifax are shown in Figs.27a, 27b, and 27c. The same pattern can be seen in the ventilation rates where the high pitched roof has higher peak ventilation rates than the standard model. For this maratime climate, the net effect of these ventilation rates is a slight increase in sheathing moisture content and a more frequent occurrence of condensed moisture throughout the entire year. The conclusion from these results is that high pitched roofs are somewhat more susceptible to moisture problems than low pitched roofs, particularly if the one of the roof high pitched roof surfaces faces the prevailing wind direction.

4 CONCLUSIONS

Simulations of the seasonal variations in attic moisture levels were carried out for a number different Canadian climatic zones and different house-attic configurations, including varying vet areas, ceiling leakage, and roof pitch. The conclusions that were reached are summarised below:

Roof Vent Area

1. In climatic zones that exhibit extremes in outdoor temperature (prairie regions), ventilation of attics will reduce sheathing moisture content and reduce the amount of condensed moisture that results from indoor air escaping into the attic. The code requirement of roof vent area being 1/300th the attic floor area is adequate unless the indoor-attic exchange rates are high.

2. In maritime climatic zones characterized by cool and wet outdoor conditions, attics should not be over-ventilated. Generally, the 1:300 code requirement for vent area provides too much ventilation. Attic moisture levels can be substantially reduced by providing a very small attic leakage area. This may be achieved by <u>not</u> installing any vents (roof or soffit) and relying only on the background leakage of the attic envelope.

Ceiling Leakage

3. For a fixed house leakage area, as the ceiling leakage fraction increases, the indoor-attic exchange rate first increases (resulting in more moisture being transported into the attic) and then decreases as the fraction becomes larger than 65%. Thus, concentrating all house leakage in the ceiling will not produce excessive moisture load on the attic.

Roof Pitch

4. High pitched roofs (greater than 30°) tend to have somewhat higher ventilation rates than low pitched roofs. In prairie climates, the increased ventilation will be beneficial in reducing moisture levels. In maritime climates, high pitched roofs will tend to have more moisture problems than low pitched roofs.

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CMHC (1993), "Attic Ventilation and Moisture", Report prepared by T.W. Forest and I.S. Walker, University of Alberta for Canada Mortgage and Housing Corporation, Ottawa, Ontario.

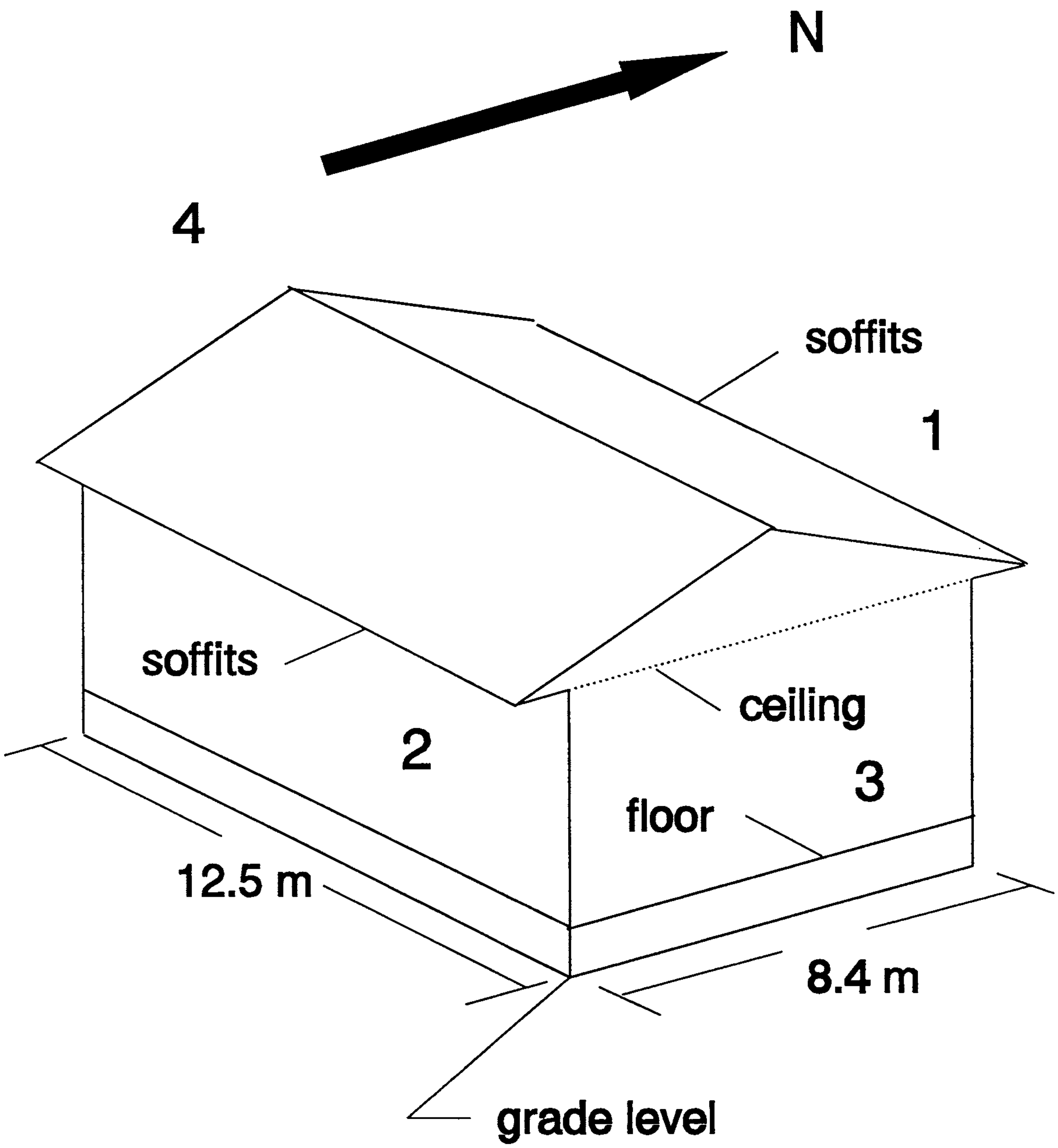

Figure 1 Schematic of the house used in the simulation

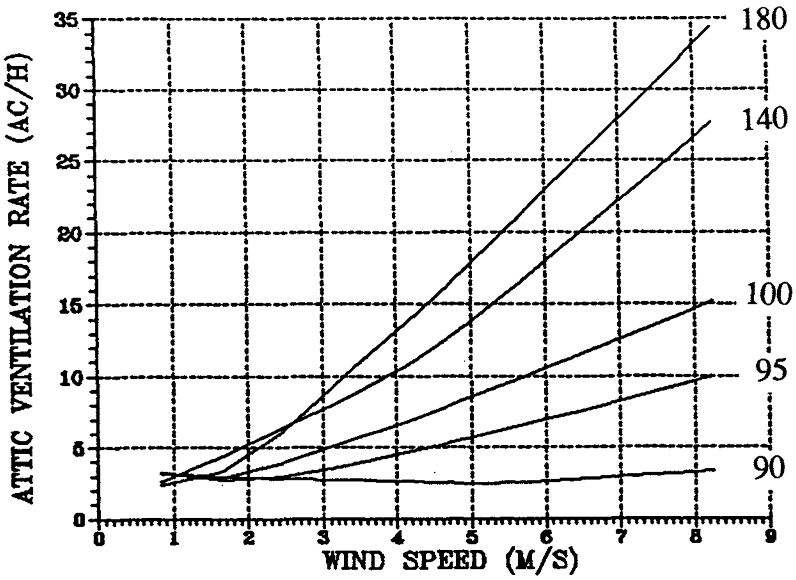

Figure 2a Attic ventilation rates versus wind speed for various wind angles (90° is east and 180° is south). Outdoor temperature is 20°C.

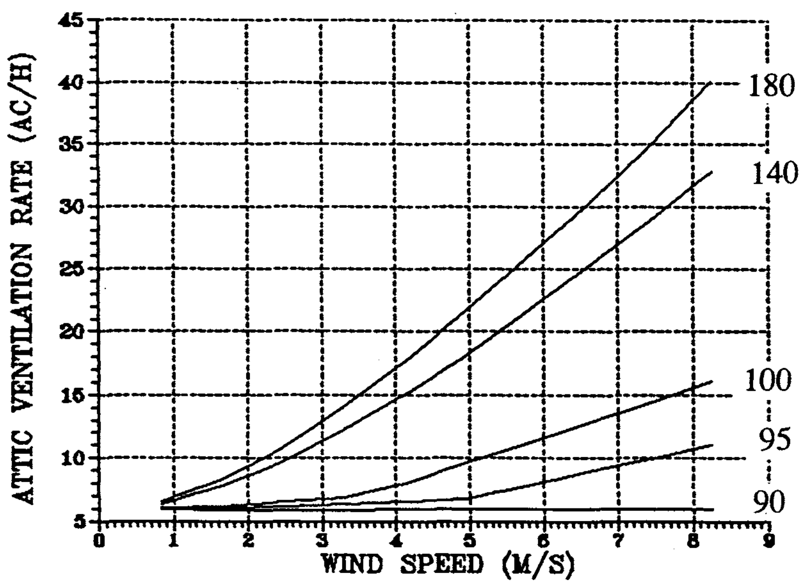

Figure 2b Attic ventilation rates versus wind speed for various wind angles (90° is east and 180° is south). Outdoor temperature is -40°C.

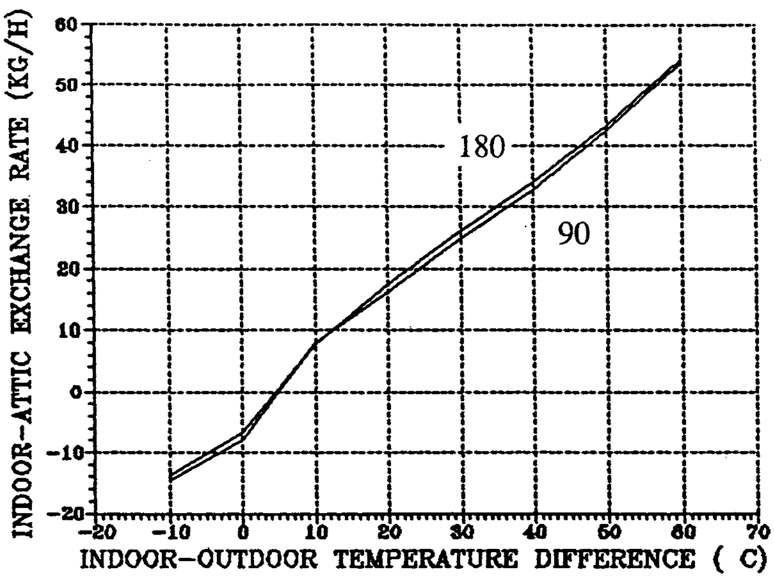

Figure 3a Indoor-attic exchange rates versus indoor-outdoor temperature difference for a wind speed of 1 m/s. Upper curve is for a wind direction of 180°.

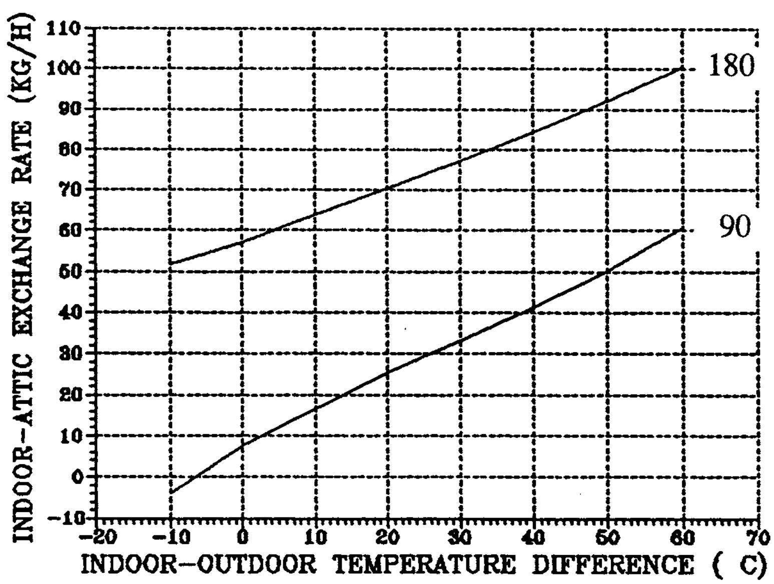

Figure 3b Indoor-attic exchange rates versus indoor-outdoor temperature difference for a wind speed of 10 m/s. Upper curve is for a wind direction of 180°.

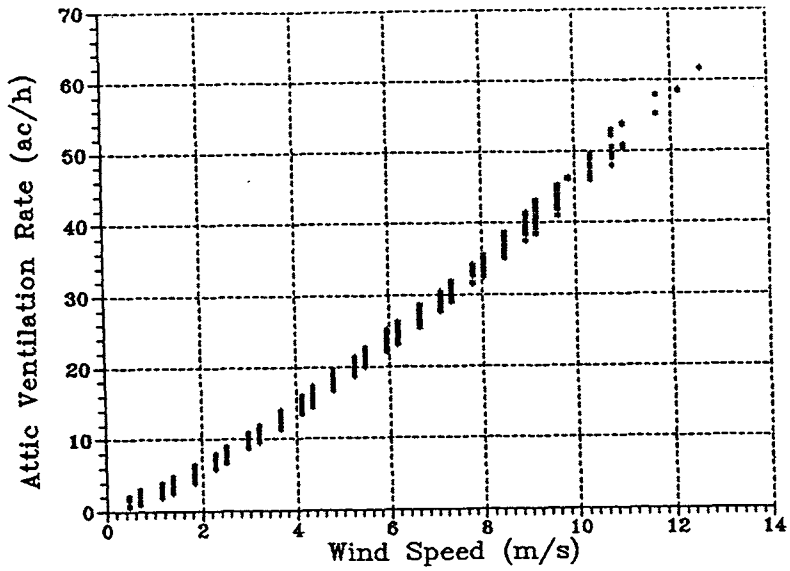

Figure 4a Attic ventilation rates versus wind speed for north and south winds (±10°). Results for Winnipeg - model 1 (1:300).

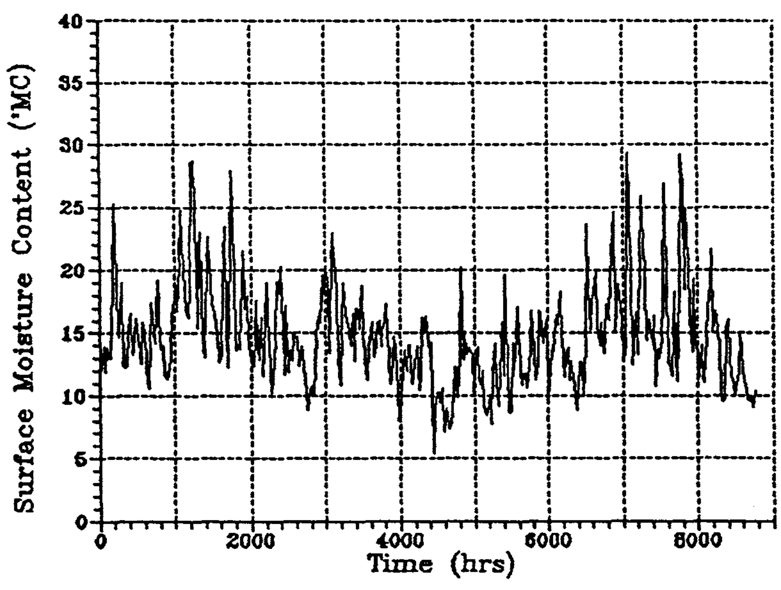

Figure 4b Moisture content of north and south sheathing for one year commencing July, 1. Results for Winnipeg - model 1 (1:300).

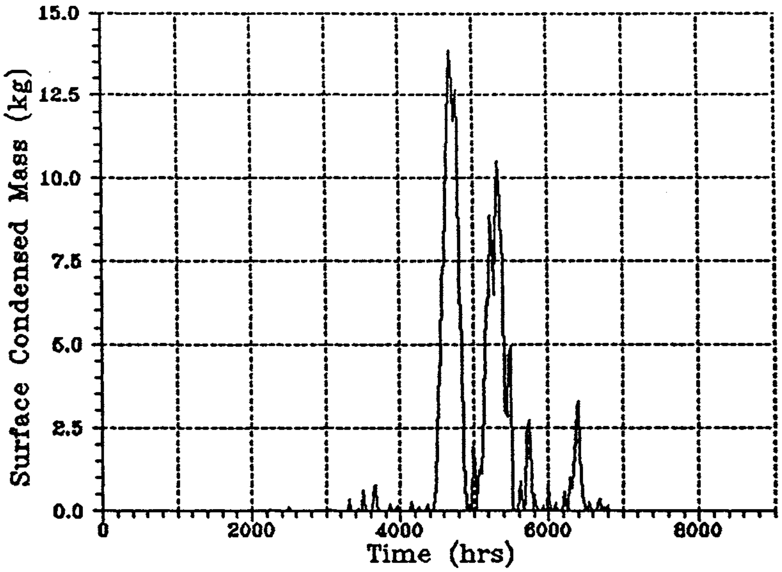

Figure 4c Variation in condensed moisture on north and south sheathing over one year commencing July 1. Curves for north and south sheathing are the same. Results for Winnipeg - model 1 (1:300).

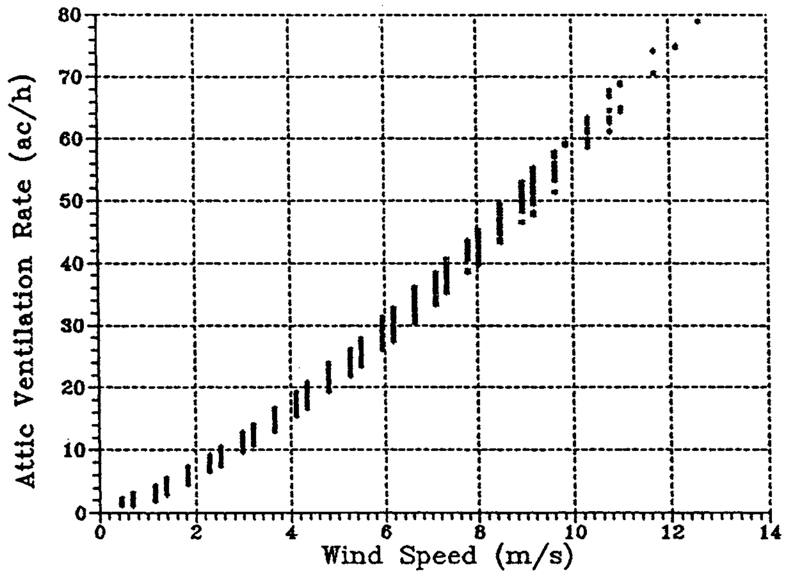

Figure 5a Attic ventilation rates versus wind speed for north and south winds (±10°). Results for Winnipeg - model 2 (1:75).

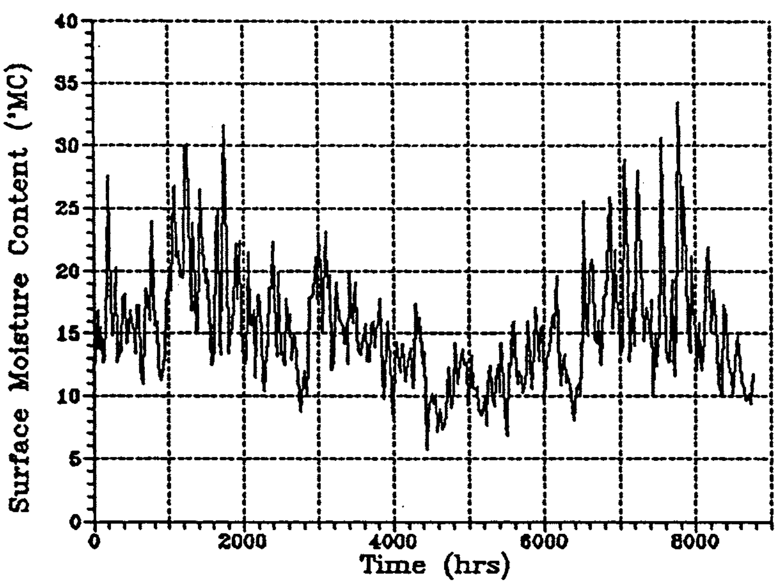

Figure 5b Moisture content of north and south sheathing for one year commencing July, 1. Results for Winnipeg - model 2 (1:75).

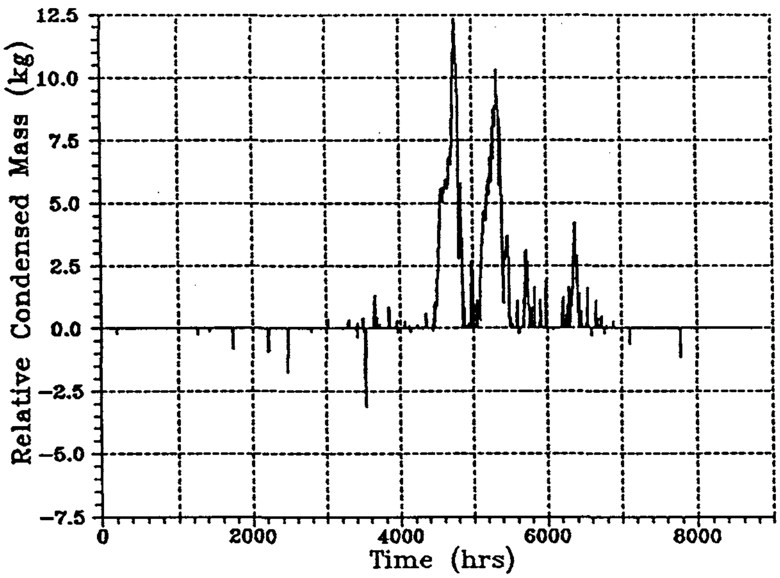

Figure 5c Difference in condensed moisture between model 1 and model 2 (model 1 - model 2) over one year. Results for Winnipeg.

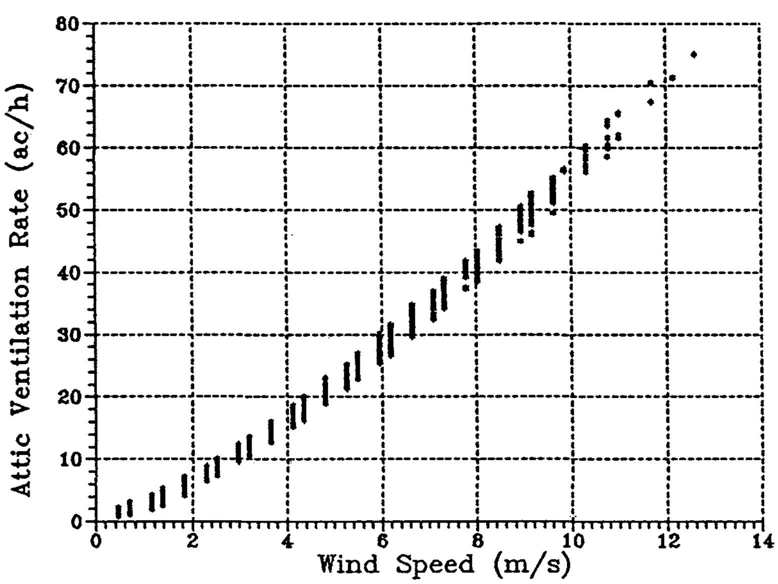

Figure 6a Attic ventilation rates versus wind speed for north and south winds (±10°). Results for Winnipeg - model 3 (1:150).

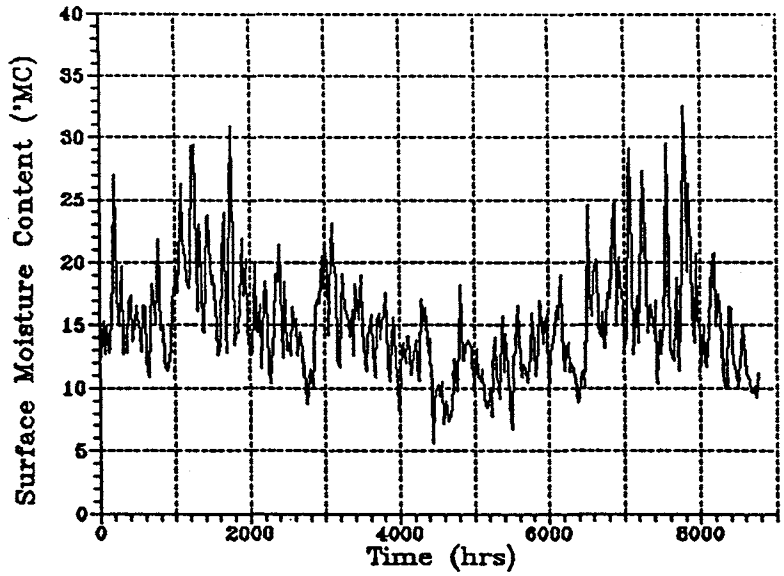

Figure 6b Moisture content of north and south sheathing for one year commencing July, 1. Results for Winnipeg - model 3 (1:150).

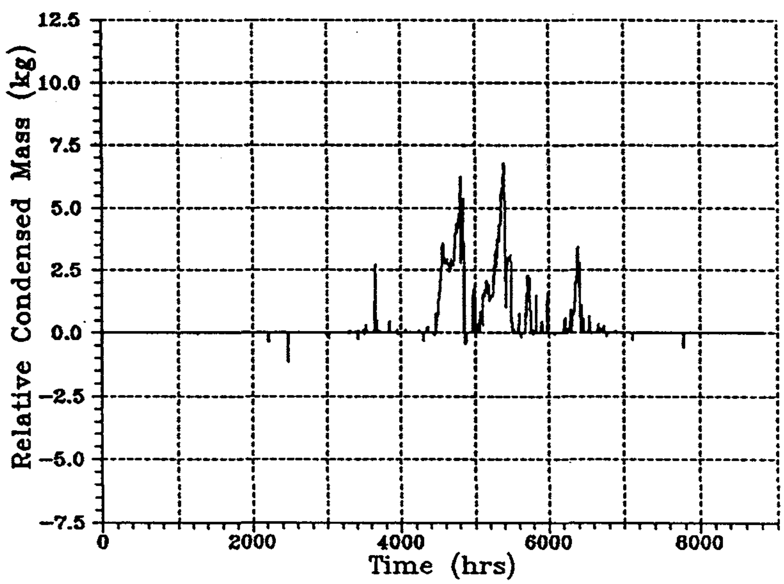

Figure 6c Difference in condensed moisture between model 1 and model 3 (model 1 - model 3) over one year. Results for Winnipeg.

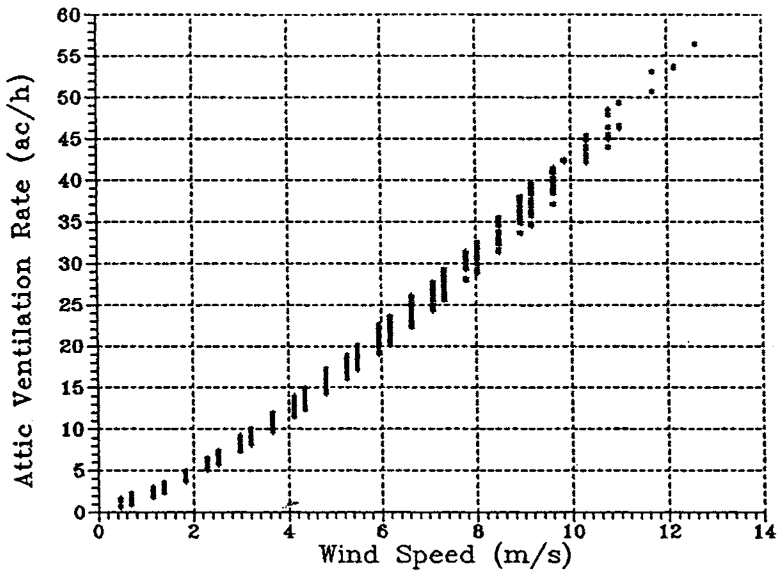

Figure 7a Attic ventilation rates versus wind speed for north and south winds (±10°). Results for Winnipeg - model 4 (1:600).

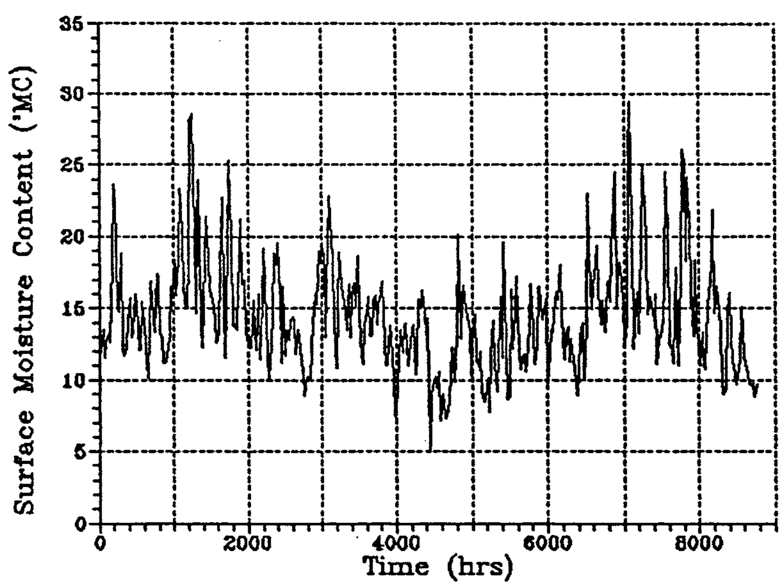

Figure 7b Moisture content of north and south sheathing for one year commencing July, 1. Results for Winnipeg - model 4 (1:600).

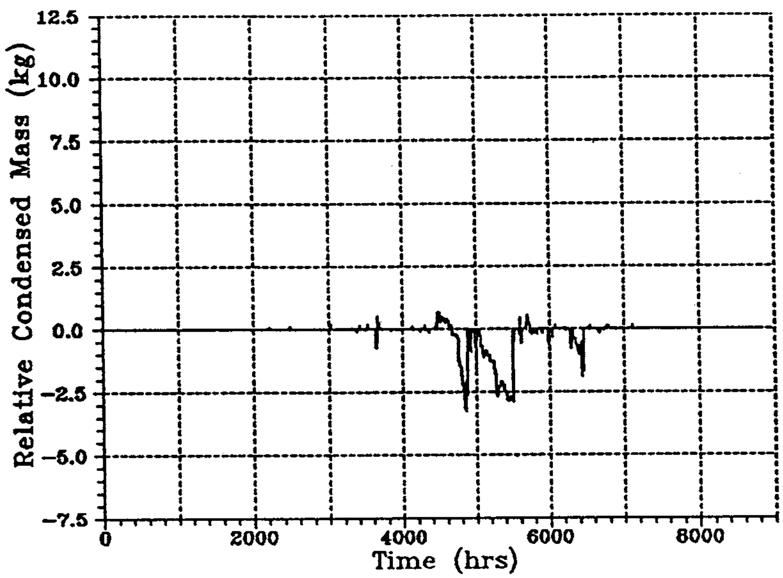

Figure 7c Difference in condensed moisture between model 1 and model 4 (model 1 - model 4) over one year. Results for Winnipeg.

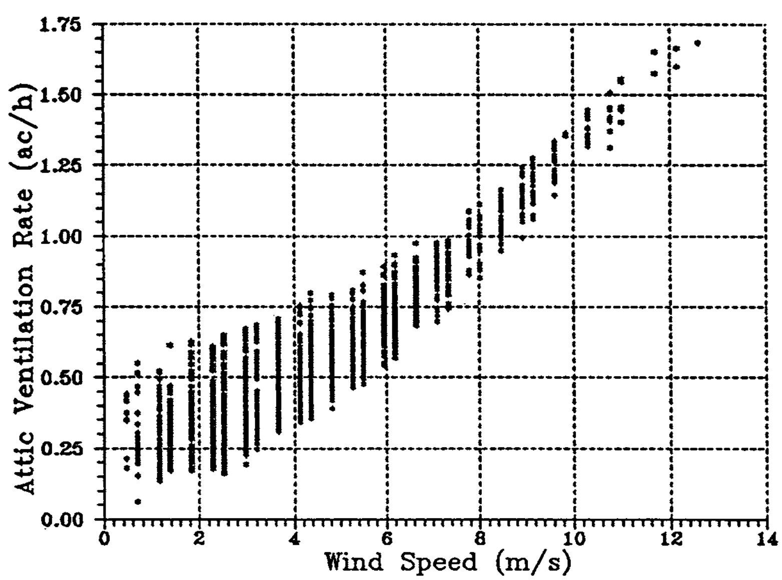

Figure 8a Attic ventilation rates versus wind speed for north and south winds (±10°). Results for Winnipeg - model 6 (Sealed).

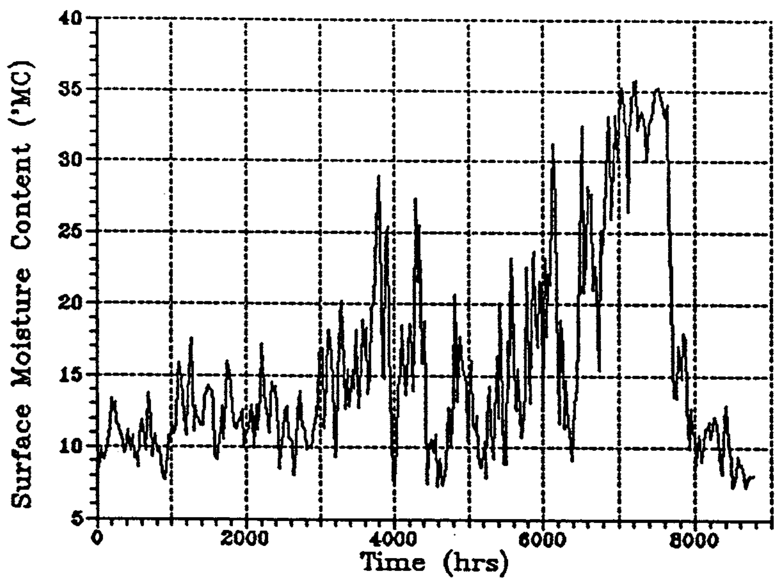

Figure 8b Moisture content of north and south sheathing for one year commencing July, 1. Results for Winnipeg - model 6 (Sealed).

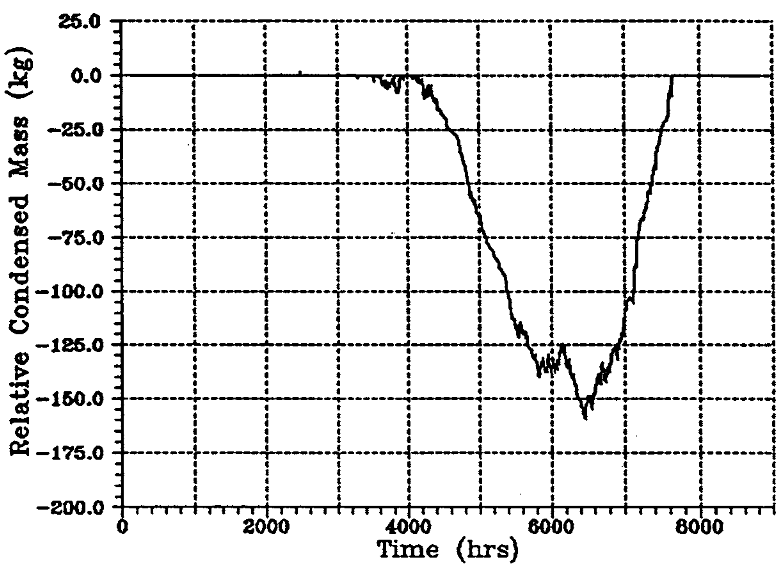

Figure 8c Difference in condensed moisture between model 1 and model 6 (model 1 - model 6) over one year. Results for Winnipeg.

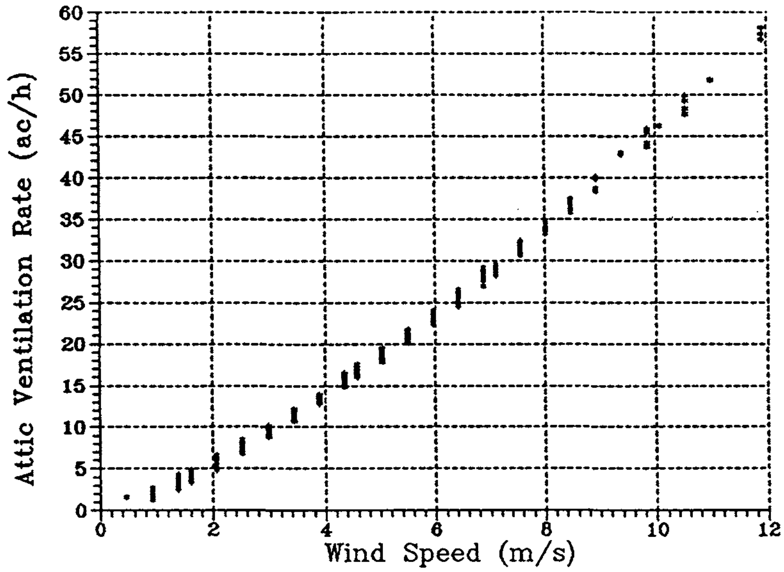

Figure 9a Attic ventilation rates versus wind speed for north and south winds (±10°). Results for Halifax - model 1 (1:300).

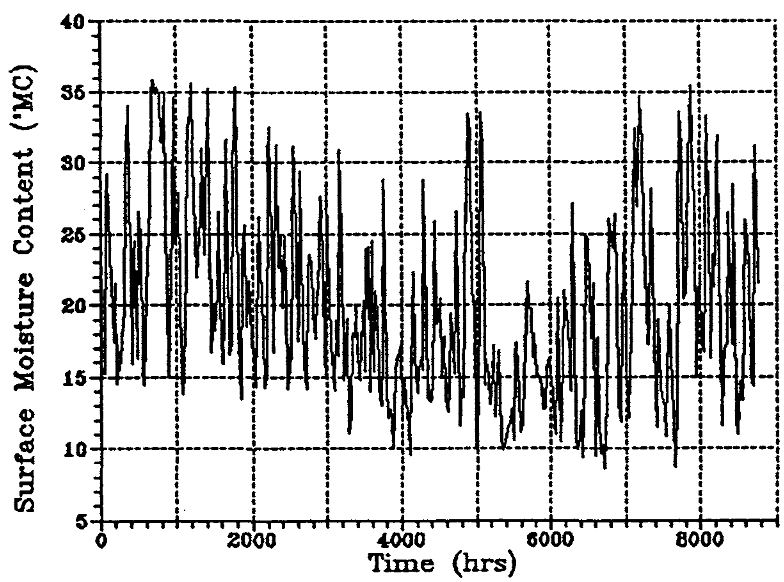

Figure 9b Moisture content of north and south sheathing for one year commencing July, 1. Results for Halifax - model 1 (1:300).

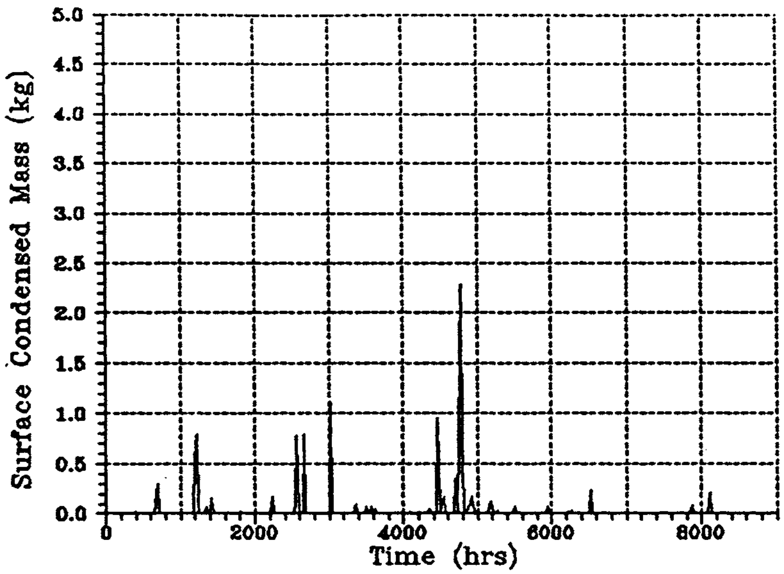

Figure 9c Variation in condensed moisture on north and south sheathing over one year commencing July 1. Curves for north and south sheathing are the same. Results for Halifax - model 1 (1:300).

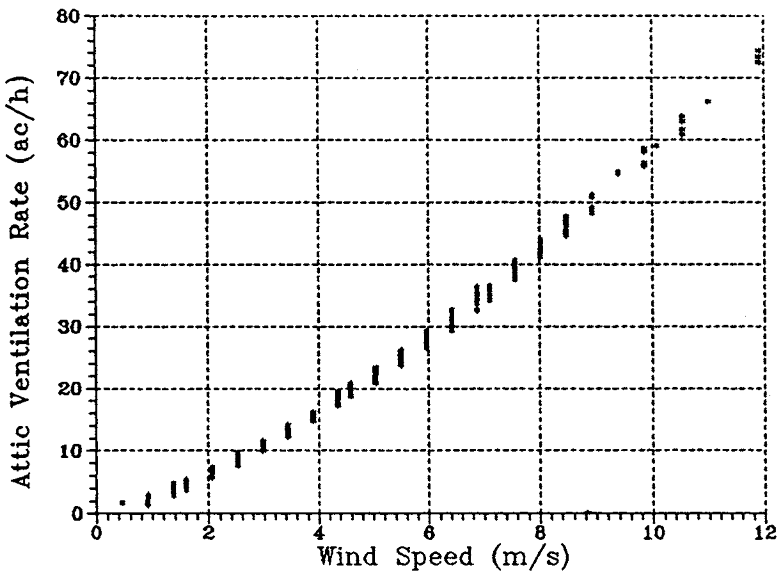

Figure 10a Attic ventilation rates versus wind speed for north and south winds (±10°). Results for Halifax - model 2 (1:75).

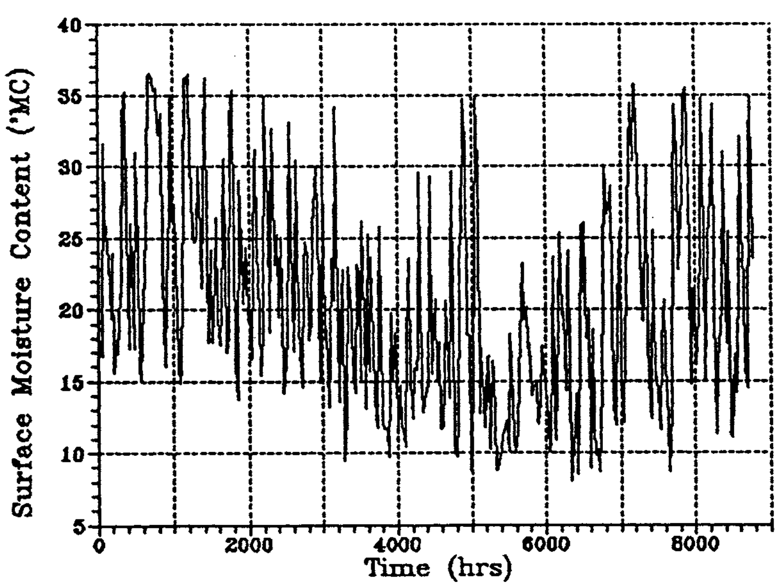

Figure 10b Moisture content of north and south sheathing for one year commencing July, 1. Results for Halifax - model 2 (1:75).

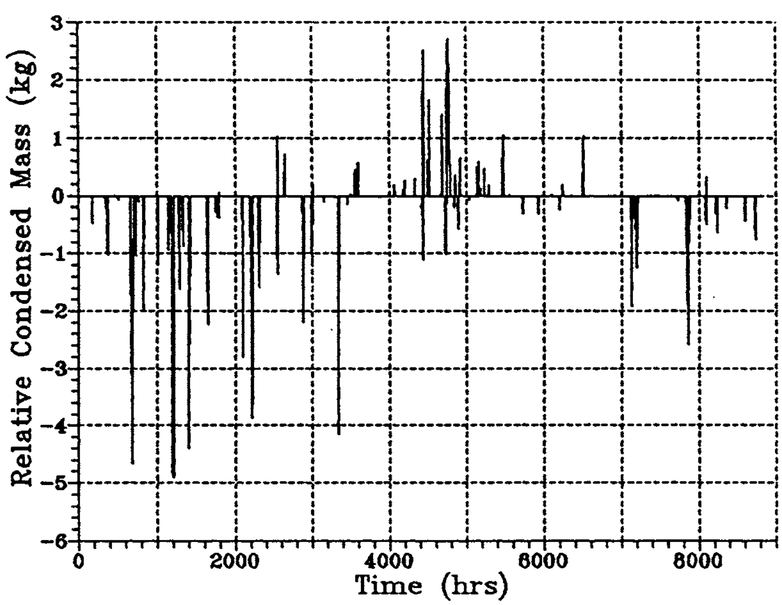

Figure 10c Difference in condensed moisture between model 1 and model 2 (model 1 - model 2) over one year. Results for Halifax.

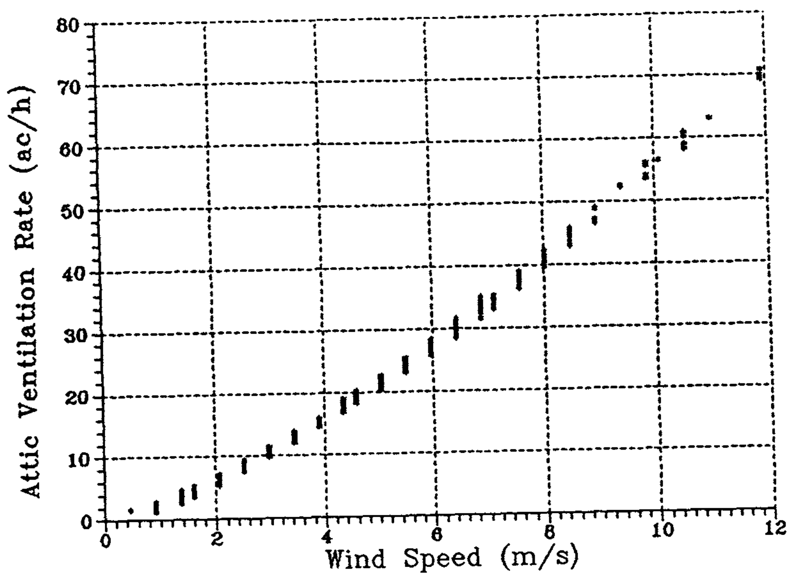

Figure 11a Attic ventilation rates versus wind speed for north and south winds (±10°). Results for Halifax - model 3 (1:150).

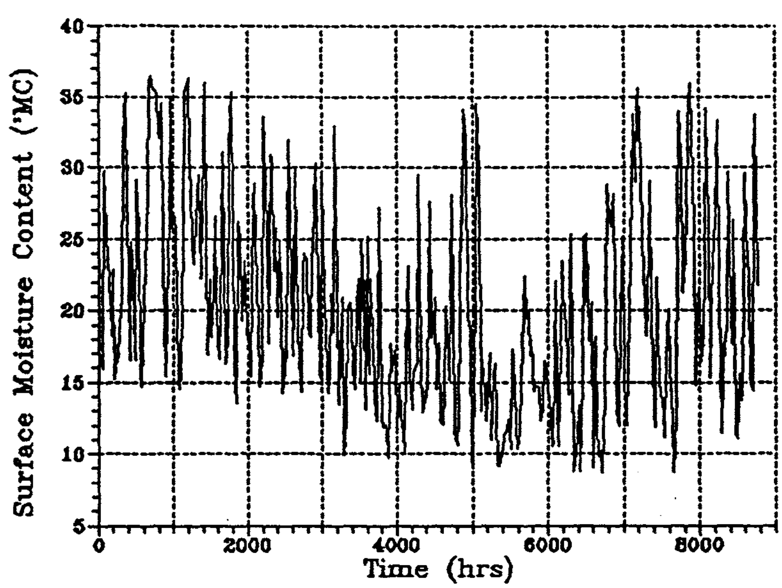

Figure 11b Moisture content of north and south sheathing for one year commencing July, 1. Results for Halifax - model 3 (1:150).

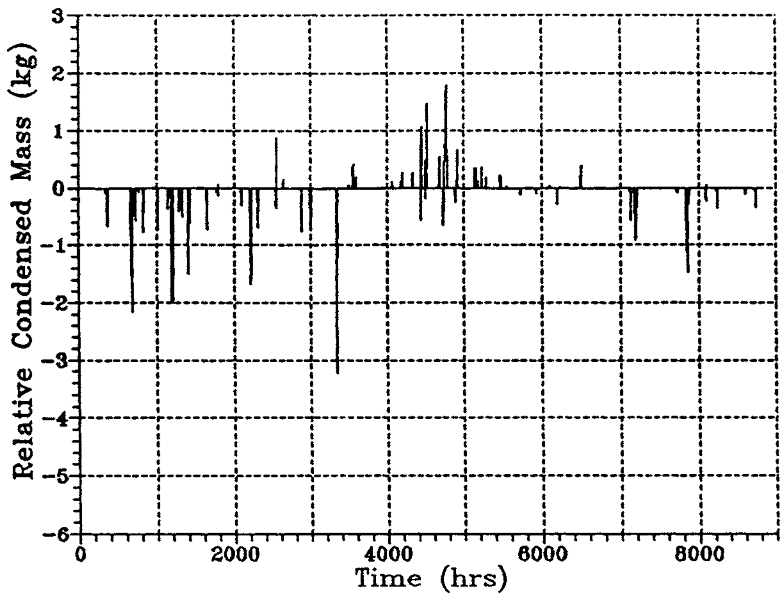

Figure 11c Difference in condensed moisture between model 1 and model 3 (model 1 - model 3) over one year. Results for Halifax.

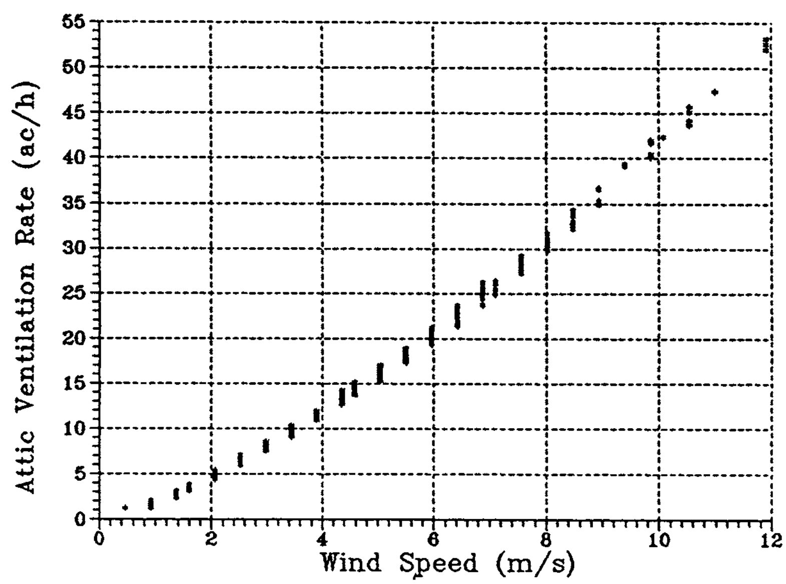

Figure 12a Attic ventilation rates versus wind speed for north and south winds (±10°). Results for Halifax - model 4 (1:600).

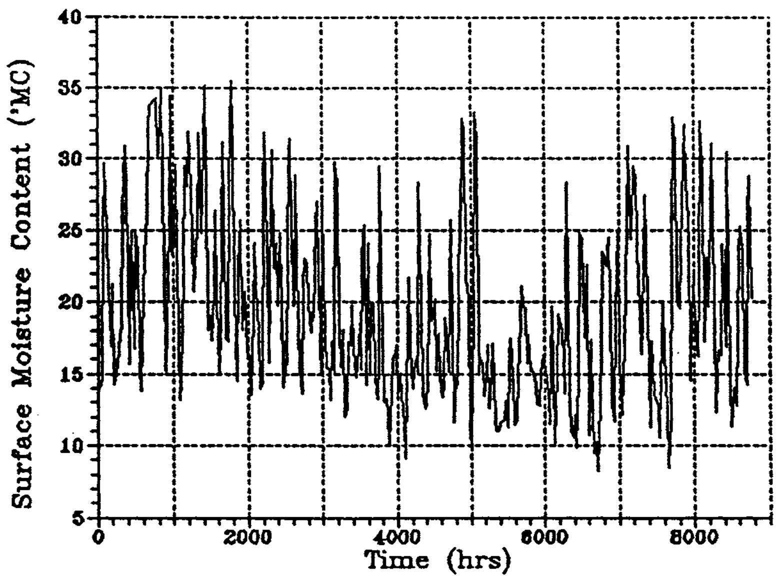

Figure 12b Moisture content of north and south sheathing for one year commencing July, 1. Results for Halifax - model 4 (1:600).

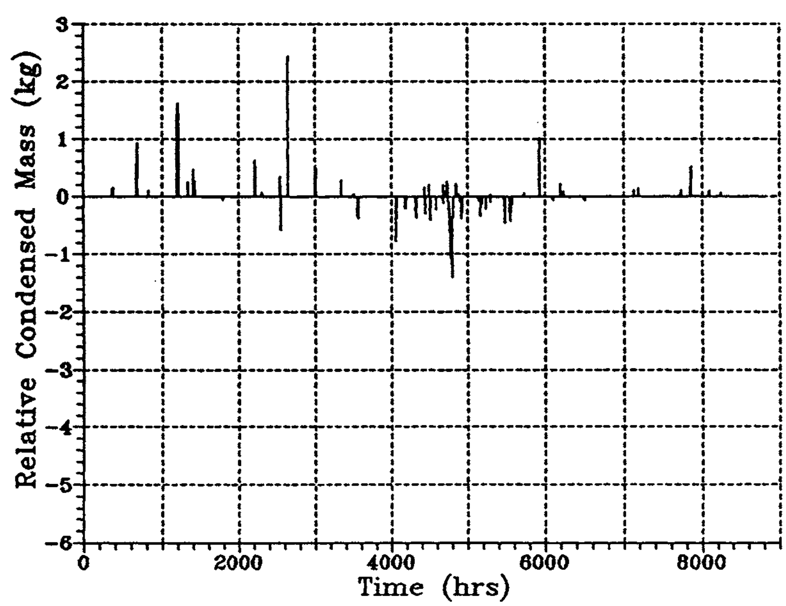

Figure 12c Difference in condensed moisture between model 1 and model 4 (model 1 - model 4) over one year. Results for Halifax.

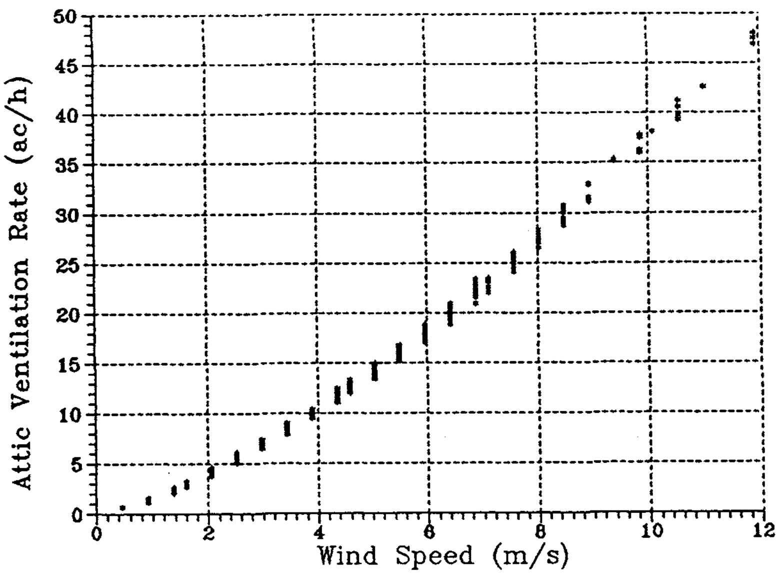

Figure 13a Attic ventilation rates versus wind speed for north and south winds (±10°). Results for Halifax - model 5 (1:1200).

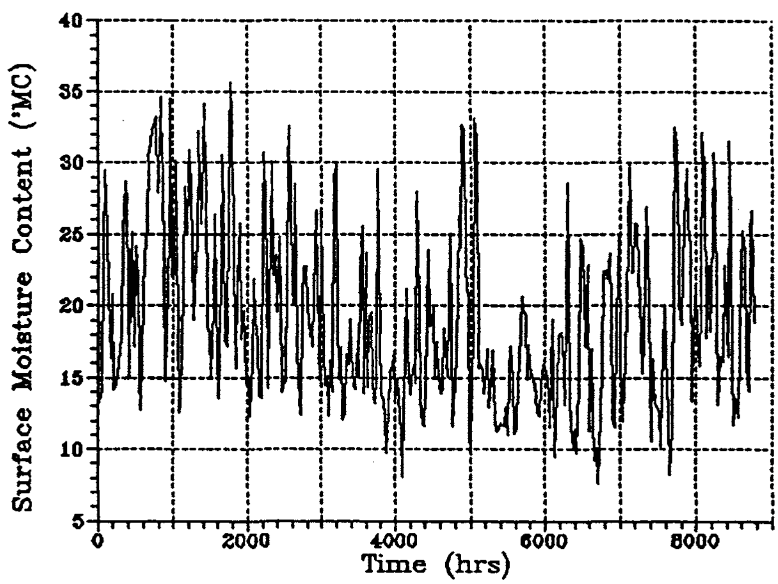

Figure 13b Moisture content of north and south sheathing for one year commencing July, 1. Results for Halifax - model 5 (1:1200).

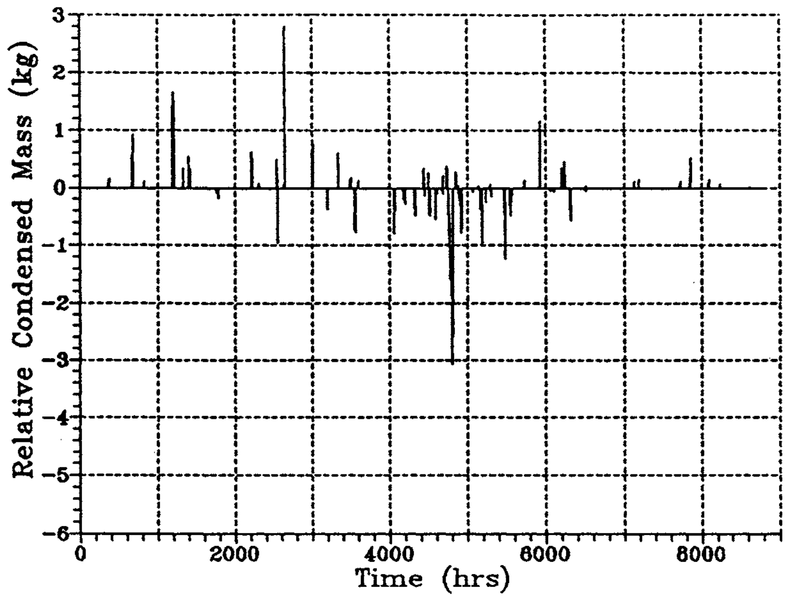

Figure 13c Difference in condensed moisture between model 1 and model 5 (model 1 - model 5) over one year. Results for Halifax.

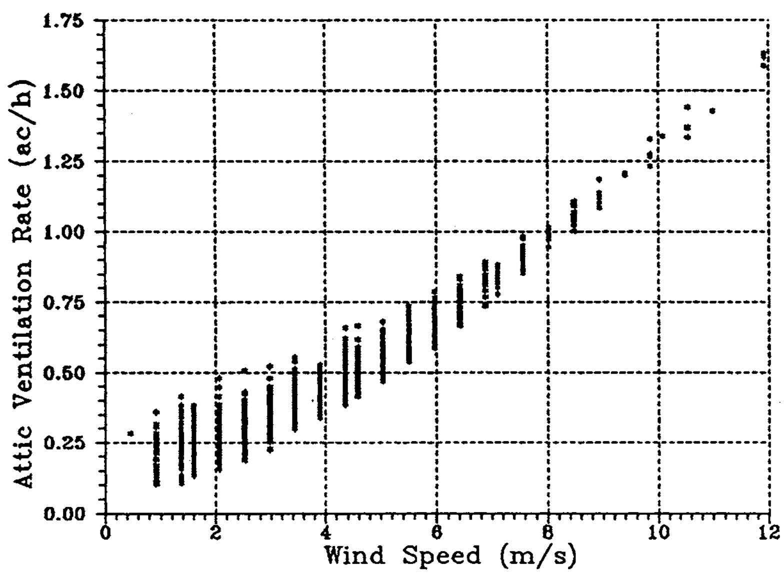

Figure 14a Attic ventilation rates versus wind speed for north and south winds (±10°). Results for Halifax - model 6 (Sealed).

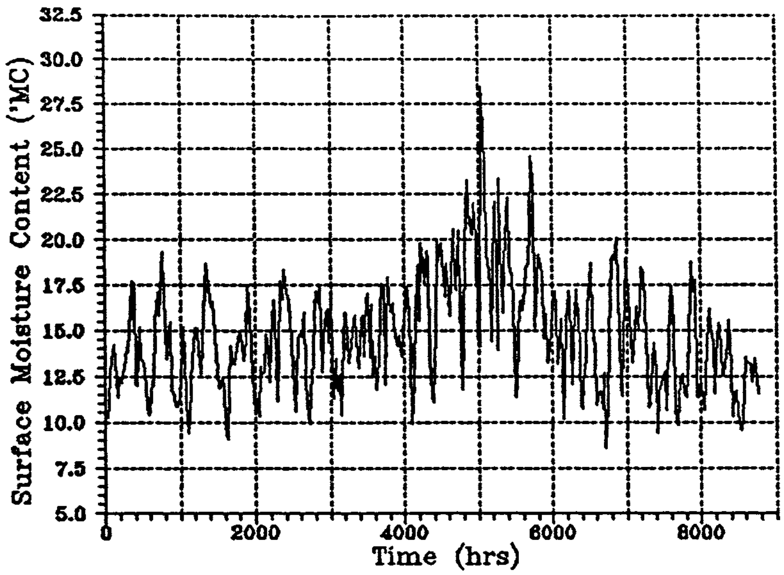

Figure 14b Moisture content of north and south sheathing for one year commencing July, 1. Results for Halifax - model 6 (Sealed).

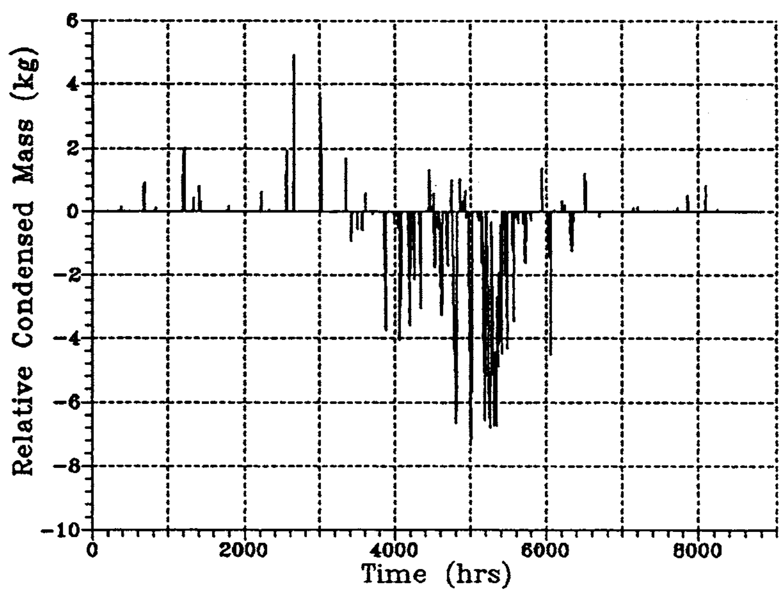

Figure 14c Difference in condensed moisture between model 1 and model 6 (model 1 - model 6) over one year. Results for Halifax.

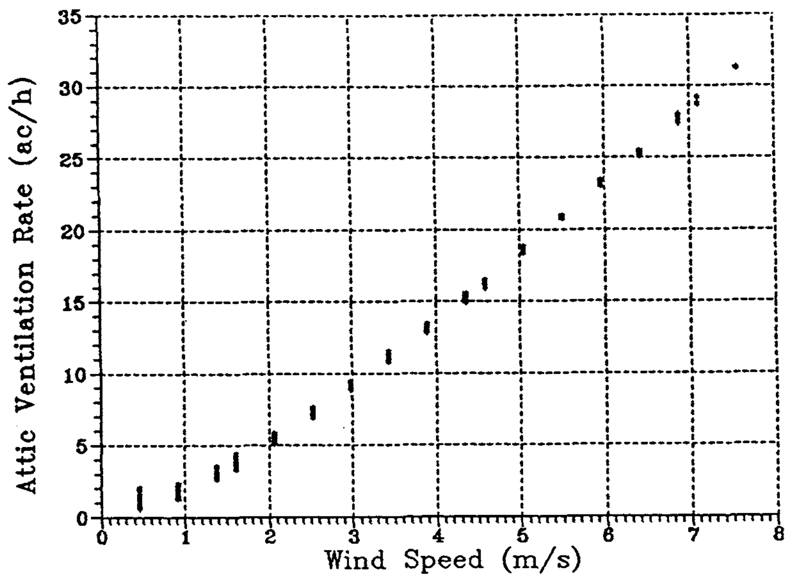

Figure 15a Attic ventilation rates versus wind speed for north and south winds (±10°). Results for Vancouver - model 1 (1:300).

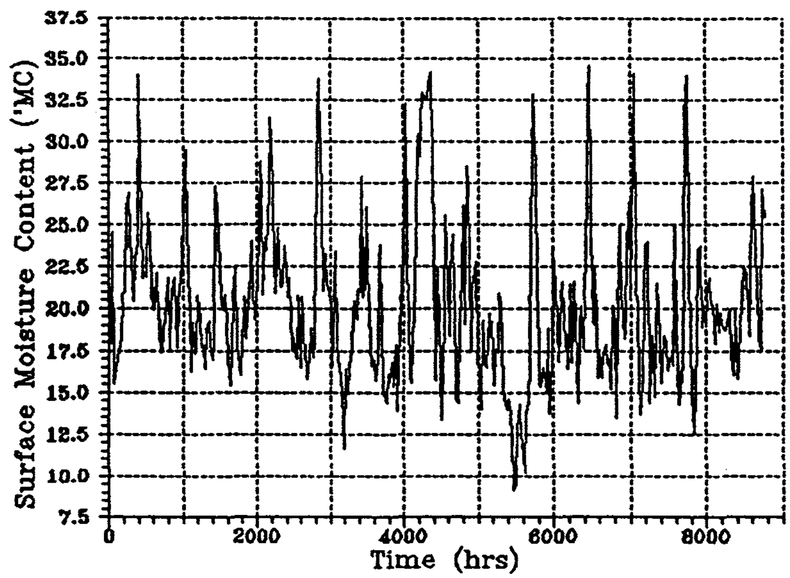

Figure 15b Moisture content of north and south sheathing for one year commencing July, 1. Results for Vancouver - model 1 (1:300).

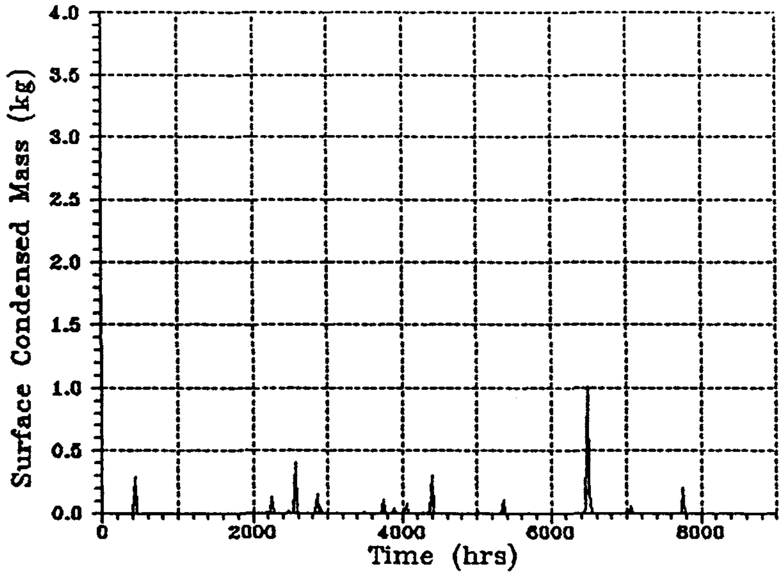

Figure 15c Variation in condensed moisture on north and south sheathing over one year commencing July 1. Curves for north and south sheathing are the same. Results for Vancouver - model 1 (1:300).

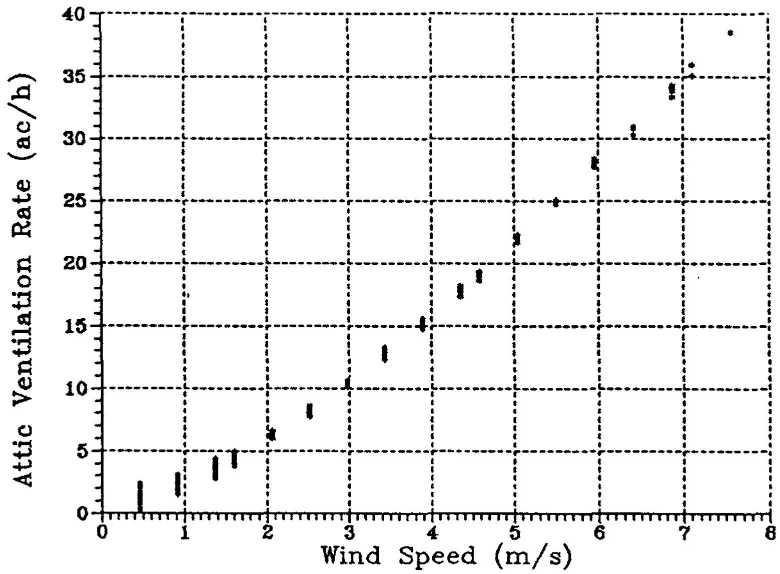

Figure 16a Attic ventilation rates versus wind speed for north and south winds (±10°). Results for Vancouver - model 2 (1:75).

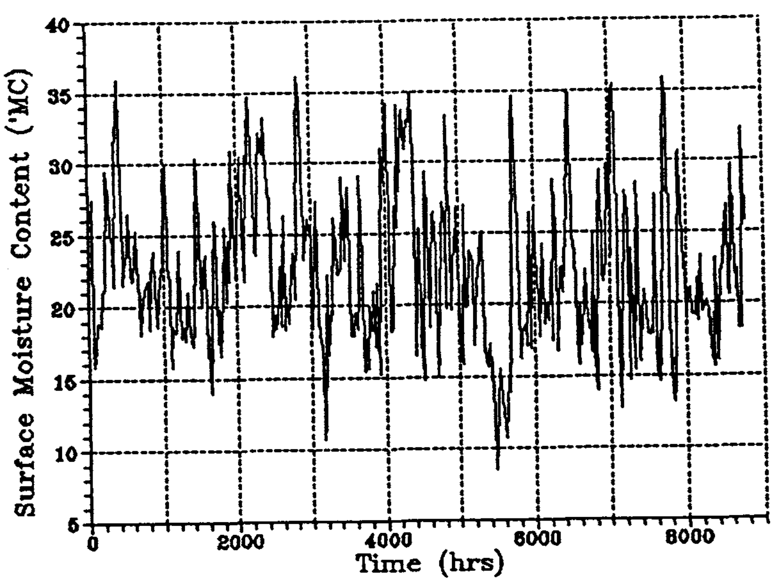

Figure 16b Moisture content of north and south sheathing for one year commencing July, 1. Results for Vancouver - model 2 (1:75).

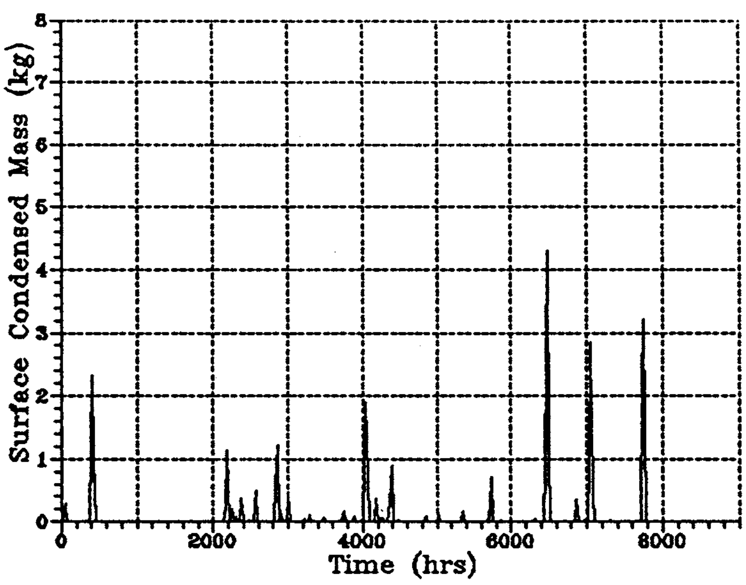

Figure 16c Variation in condensed moisture on north and south sheathing over one year commencing July 1. Curves for north and south sheathing are the same. Results for Vancouver - model 2 (1:75).

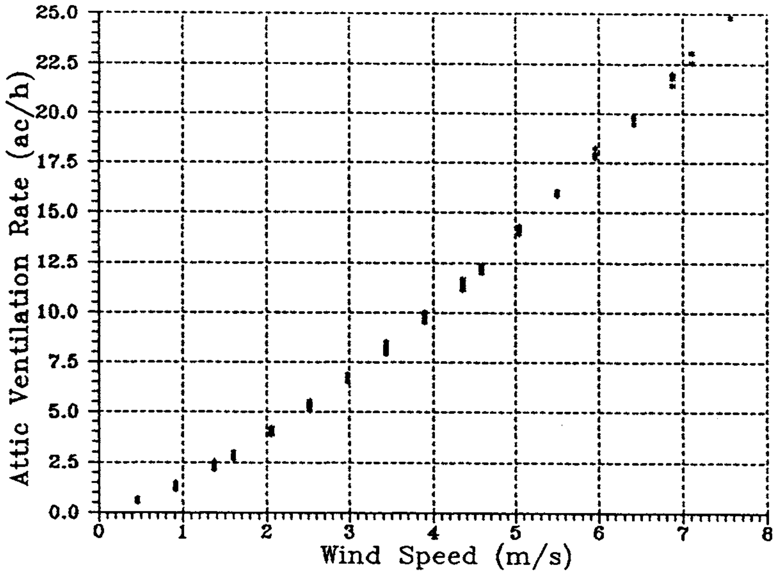

Figure 17a Attic ventilation rates versus wind speed for north and south winds (±10°). Results for Vancouver - model 5 (1:1200).

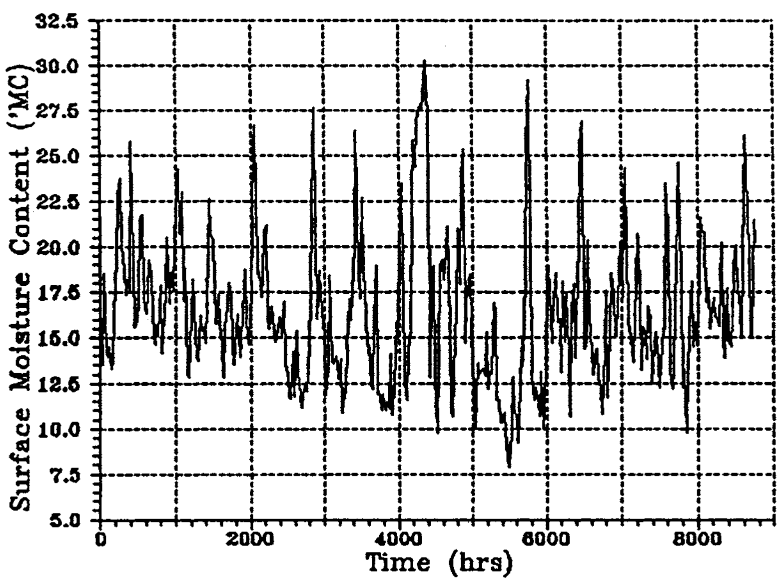

Figure 17b Moisture content of north and south sheathing for one year commencing July, 1. Results for Vancouver - model 5 (1:1200).

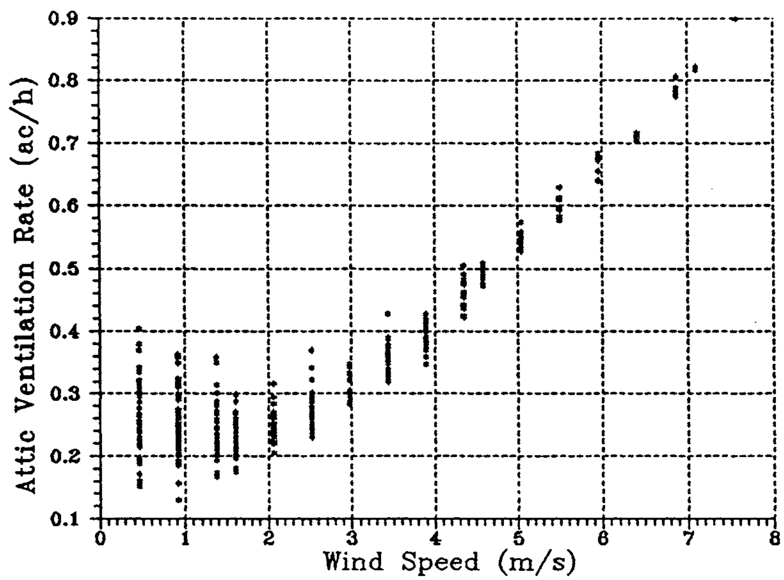

Figure 18a Attic ventilation rates versus wind speed for north and south winds (±10°). Results for Vancouver - model 6 (Sealed).

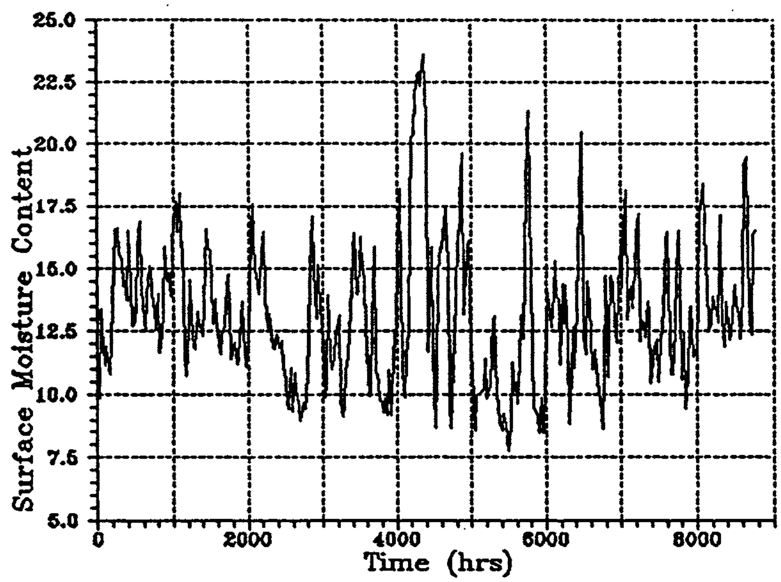

Figure 18b Moisture content of north and south sheathing for one year commencing July, 1. Results for Vancouver - model 6 (Sealed).

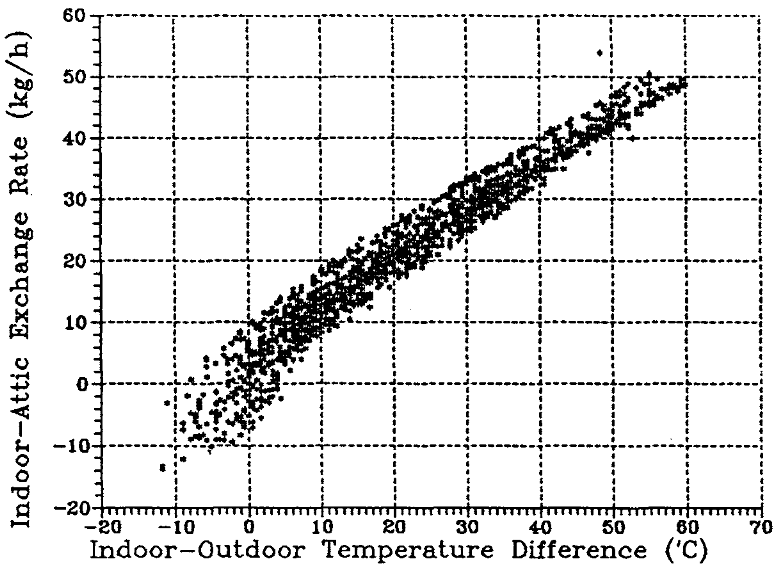

Figure 19 Indoor-attic exchange rates versus indoor-outdoor temperature difference for wind speed less than 2 m/s. Positive values imply flow <u>into</u> the attic. Results for Winnipeg - model 1 (40% ceiling leakage fraction).

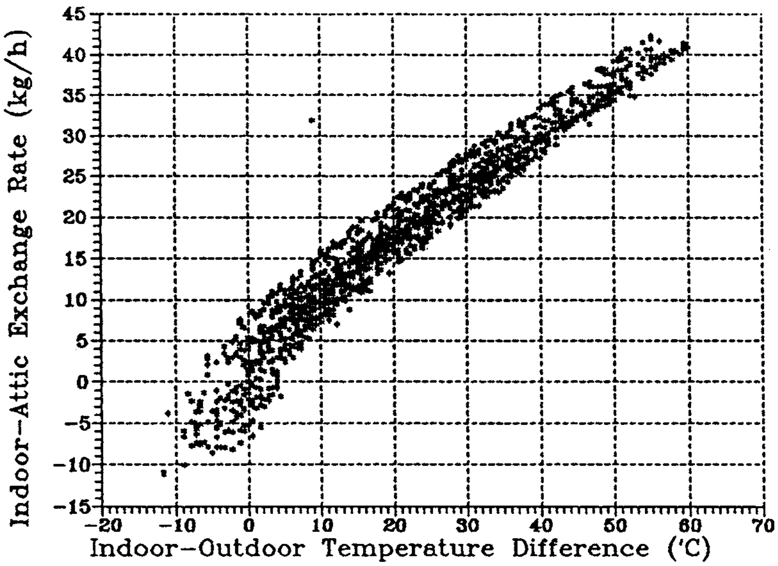

Figure 20a Indoor-attic exchange rates versus indoor-outdoor temperature difference for wind speed less than 2 m/s. Positive values imply flow into the attic. Results for Winnipeg - model 8 (30% ceiling leakage fraction).

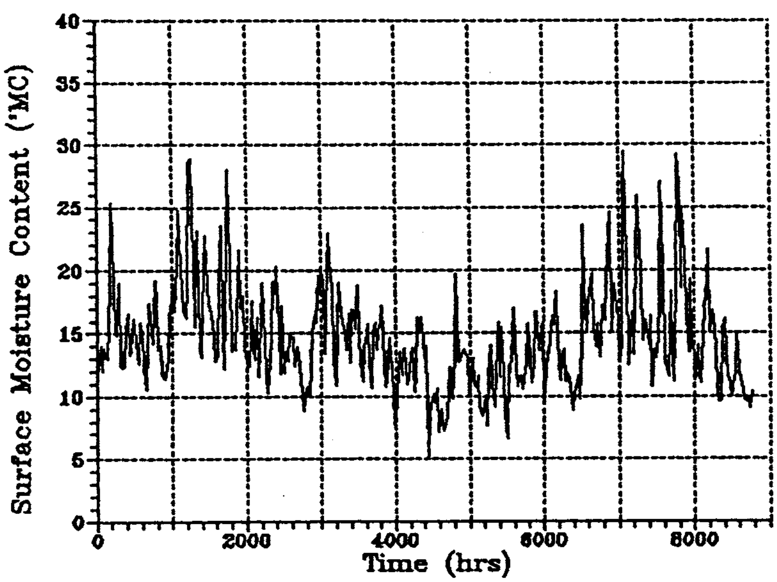

Figure 20b Moisture content of north and south sheathing for one year commencing July, 1. Results for Winnipeg - model 8 (30% ceiling leakage fraction).

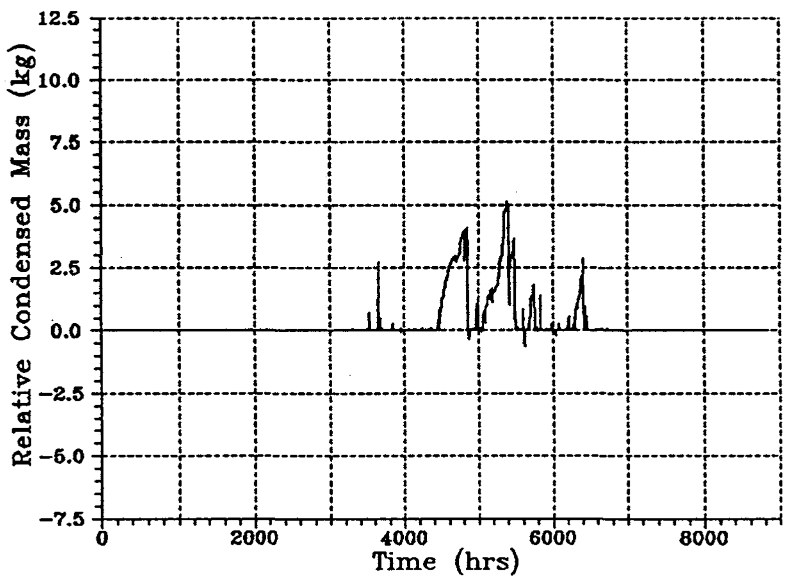

Figure 20c Difference in condensed moisture between model 1 and model 8 (model 1 - model 8) over one year. Results for Winnipeg.

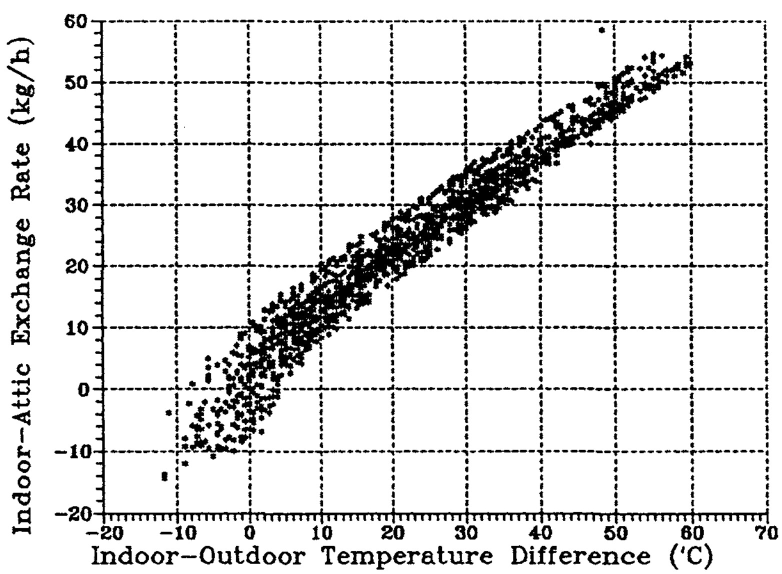

Figure 21a Indoor-attic exchange rates versus indoor-outdoor temperature difference for wind speed less than 2 m/s. Positive values imply flow into the attic. Results for Winnipeg - model 9 (50% ceiling leakage fraction).

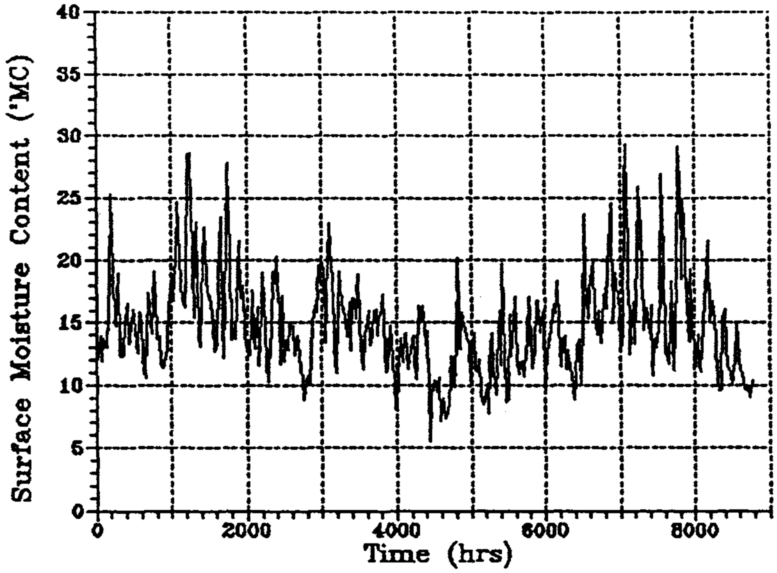

Figure 21b Moisture content of north and south sheathing for one year commencing July, 1. Results for Winnipeg - model 9 (50% ceiling leakage fraction).

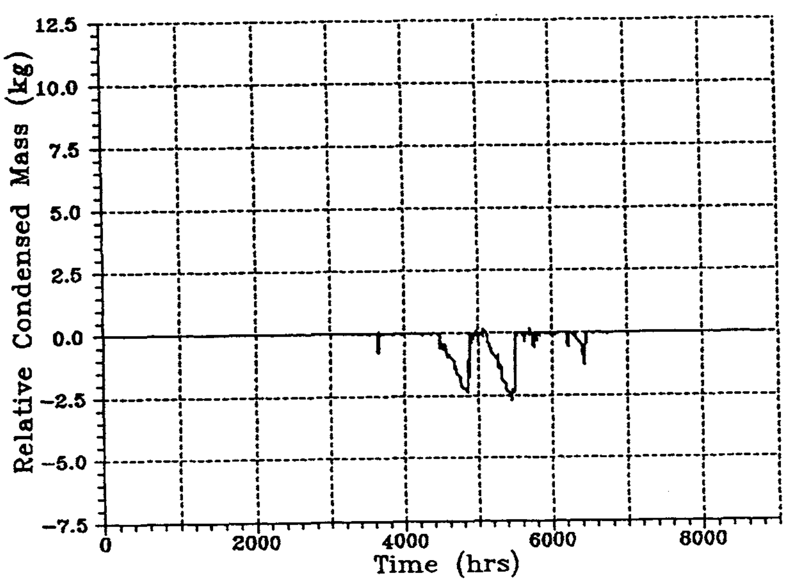

Figure 21c Difference in condensed moisture between model 1 and model 9 (model 1 - model 9) over one year. Results for Winnipeg.

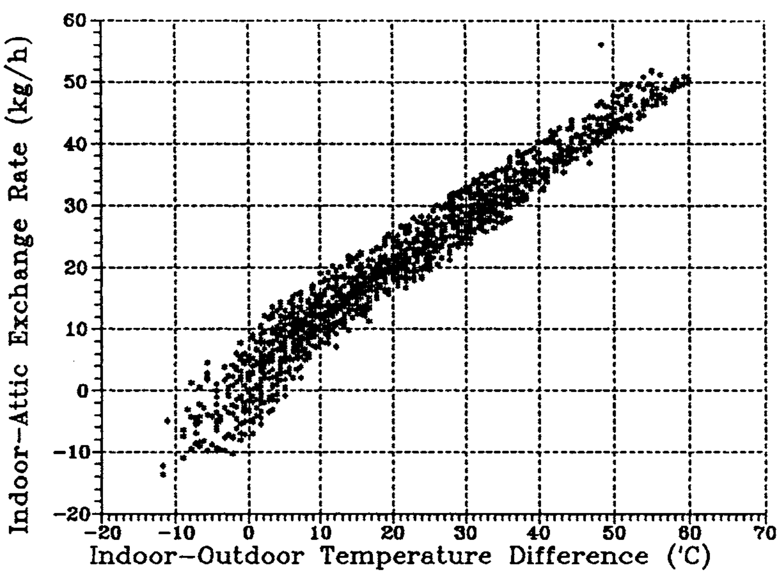

Figure 22a Indoor-attic exchange rates versus indoor-outdoor temperature difference for wind speed less than 2 m/s. Positive values imply flow <u>into</u> the attic. Results for Winnipeg - model 10 (65% ceiling leakage fraction).

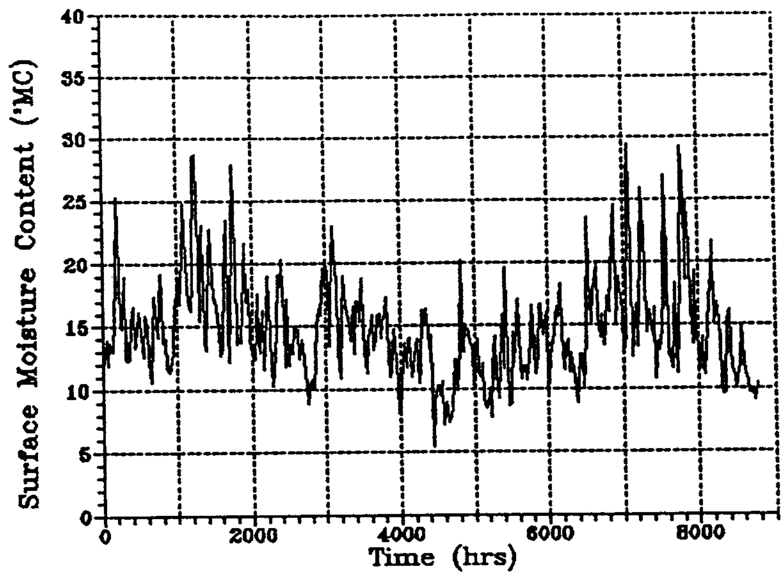

Figure 22b Moisture content of north and south sheathing for one year commencing July, 1. Results for Winnipeg - model 10 (65% ceiling leakage fraction).

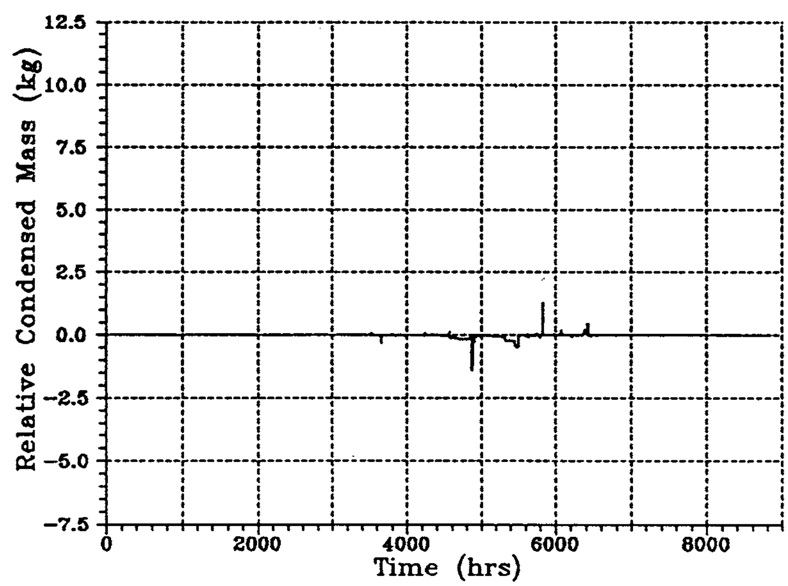

Figure 22c Difference in condensed moisture between model 1 and model 9 (model 1 - model 9) over one year. Results for Winnipeg.

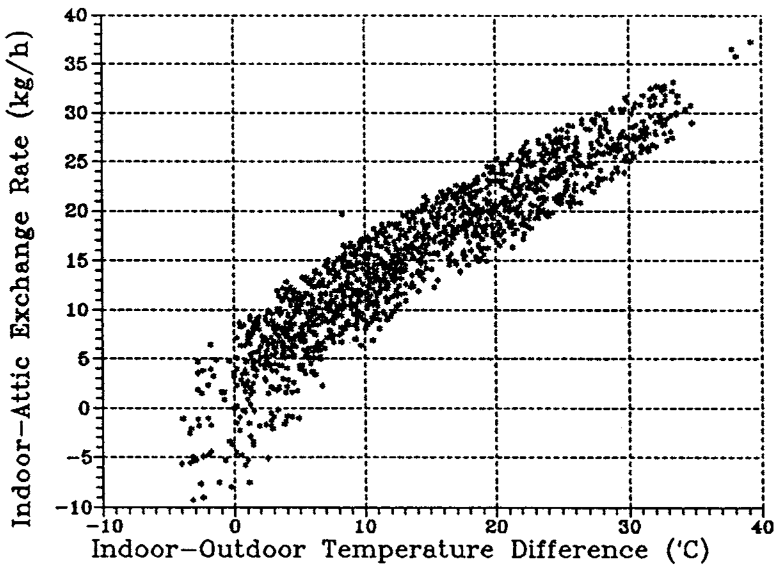

Figure 23 Indoor-attic exchange rates versus indoor-outdoor temperature difference for wind speed less than 2 m/s. Positive values imply flow <u>into</u> the attic. Results for Halifax - model 1 (40% ceiling leakage fraction).

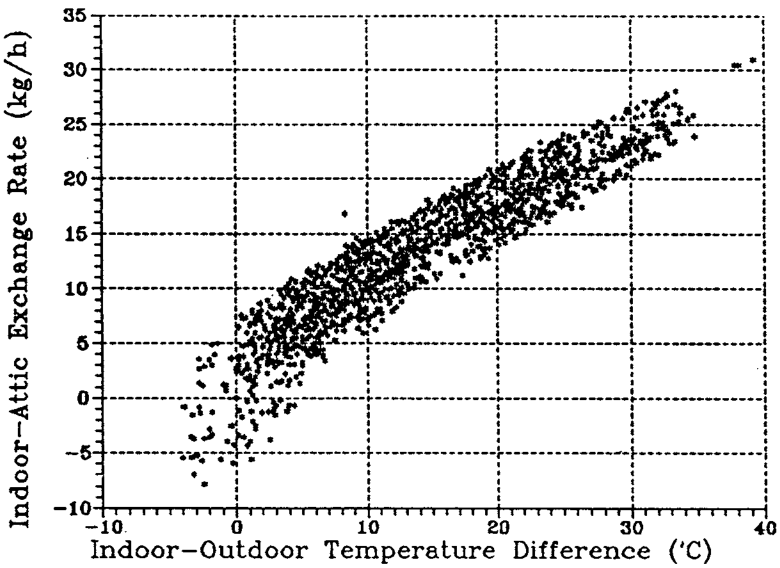

Figure 24a Indoor-attic exchange rates versus indoor-outdoor temperature difference for wind speed less than 2 m/s. Positive values imply flow into the attic. Results for Halifax - model 8 (30% ceiling leakage fraction).

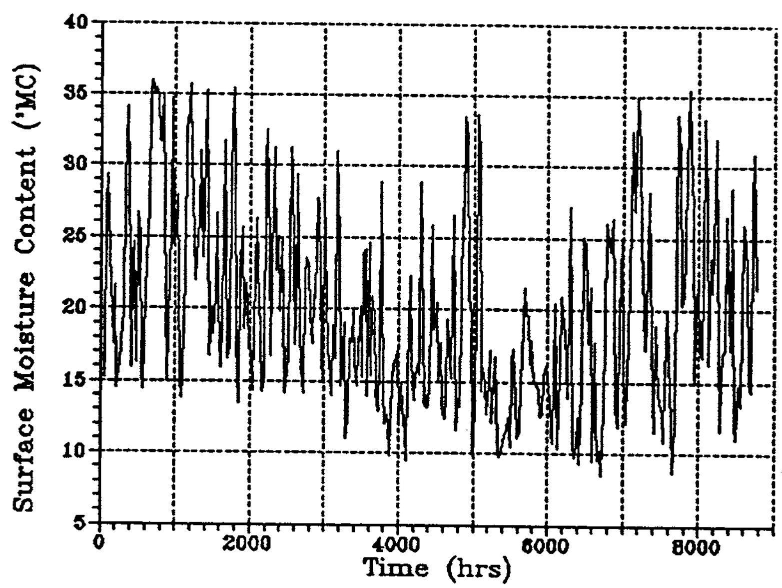

Figure 24b Moisture content of north and south sheathing for one year commencing July, 1. Results for Halifax - model 8 (30% ceiling leakage fraction).

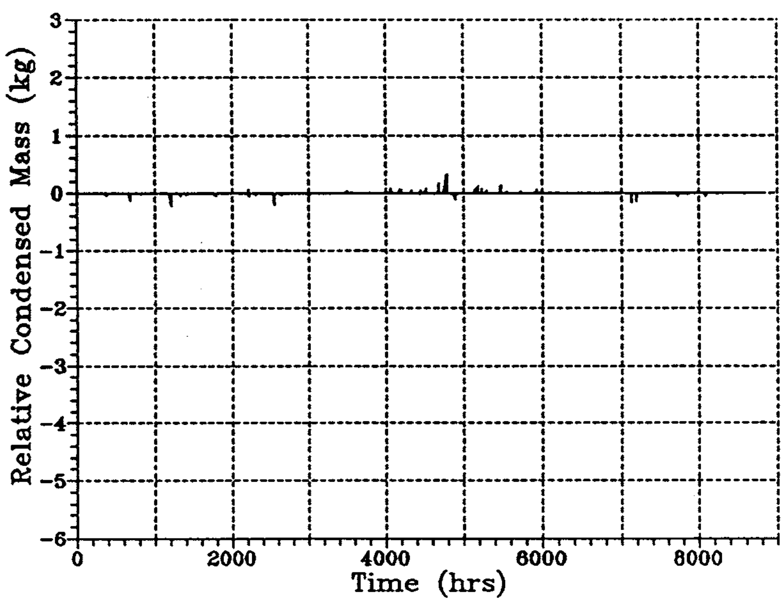

Figure 24c Difference in condensed moisture between model 1 and model 8 (model 1 - model 8) over one year. Results for Halifax.

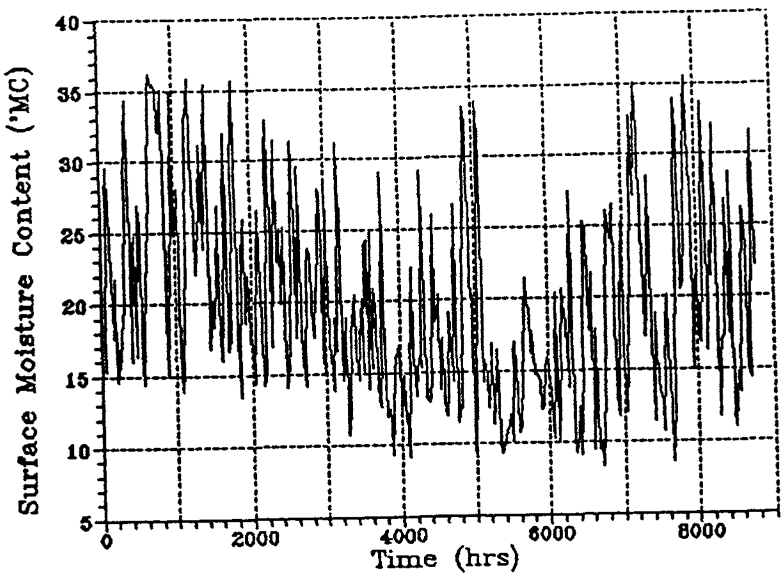

Figure 25b Moisture content of north and south sheathing for one year commencing July, 1. Results for Halifax - model 11 (85% ceiling leakage fraction).

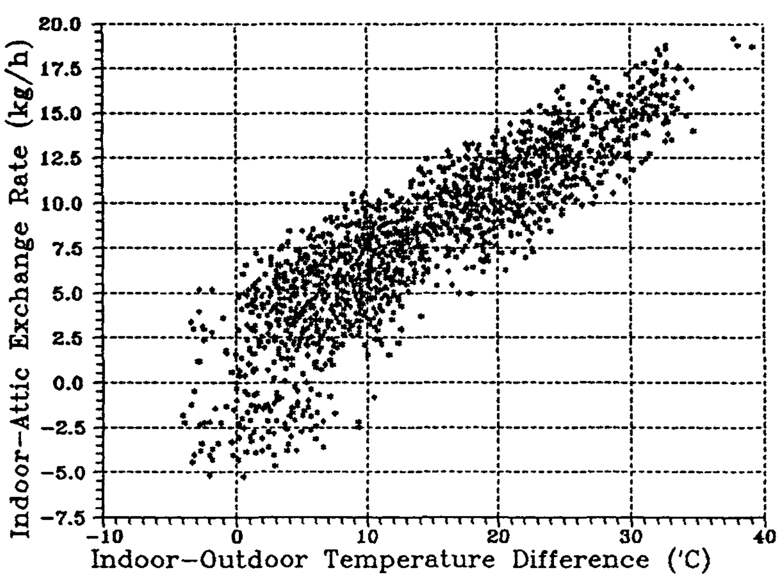

Figure 25a Indoor-attic exchange rates versus indoor-outdoor temperature difference for wind speed less than 2 m/s. Positive values imply flow <u>into</u> the attic. Results for Halifax - model 11 (85% ceiling leakage fraction).

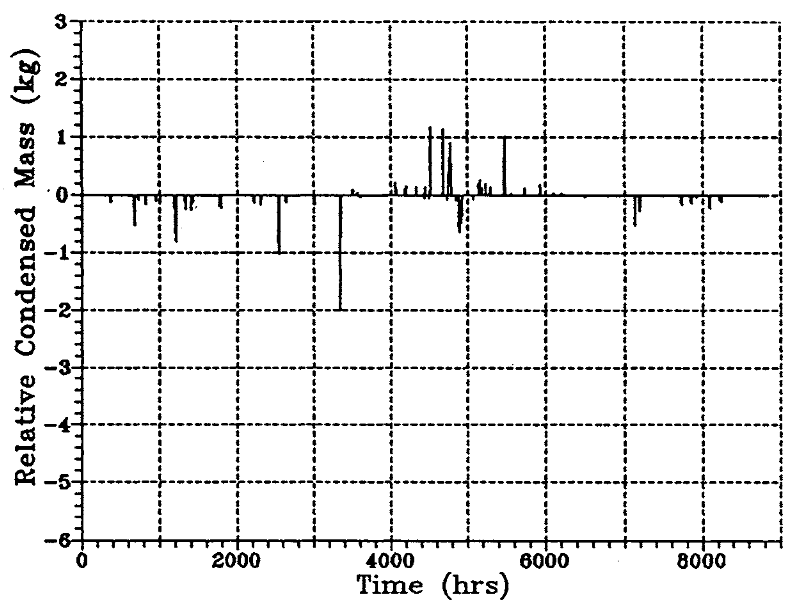

Figure 25c Difference in condensed moisture between model 1 and model 11 (model 1 - model 11) over one year. Results for Halifax.

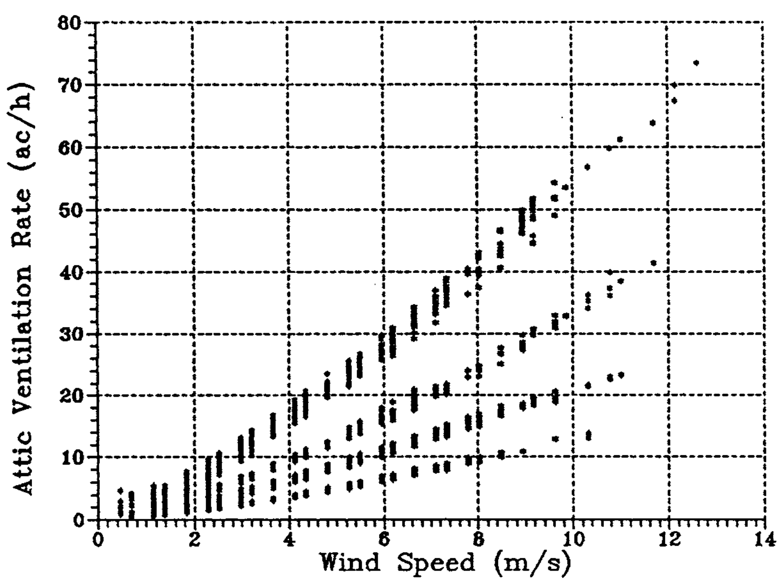

Figure 26a Attic ventilation rates of large pitched roof (42°) versus wind speed for north and south wind directions (±10°). Results for Winnipeg - model 7 (1:300).

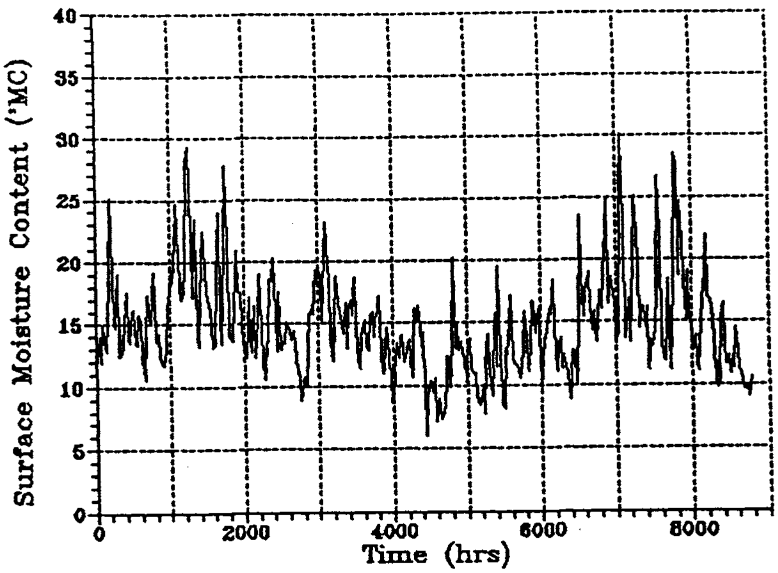

Figure 26b Moisture content of north and south sheathing for one year commencing July, 1. Results for Winnipeg - model 7 (roof pitch of 42°).

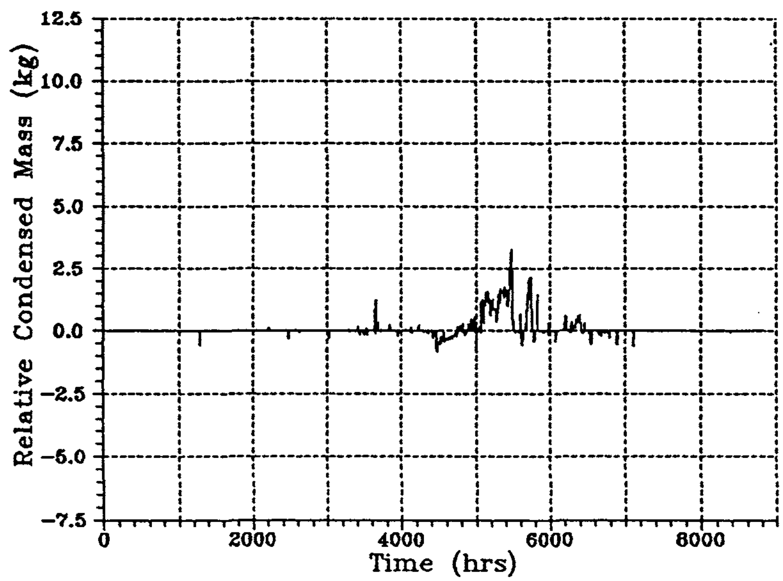

Figure 26c Difference in condensed moisture between model 1 and model 7 (model 1 - model 7) over one year. Results for Winnipeg.

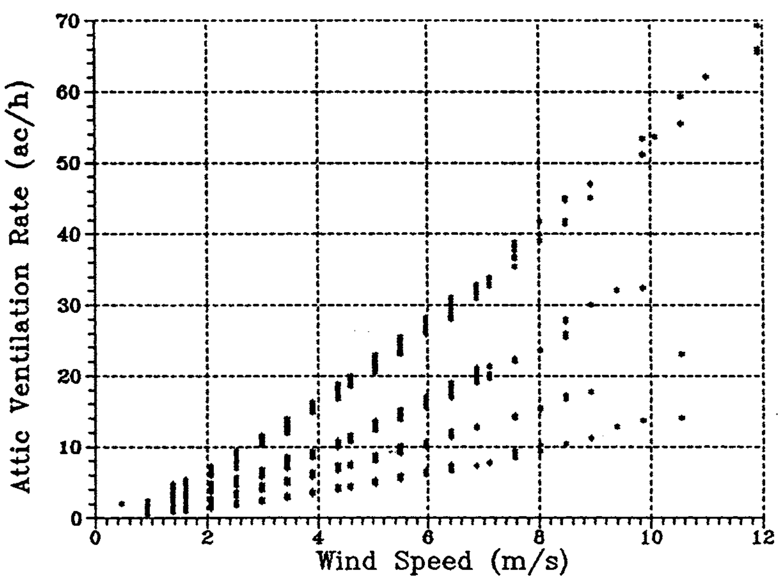

Figure 27a Attic ventilation rates of large pitched roof (42°) versus wind speed for north and south wind directions (±10°). Results for Halifax - model 7 (1:300).

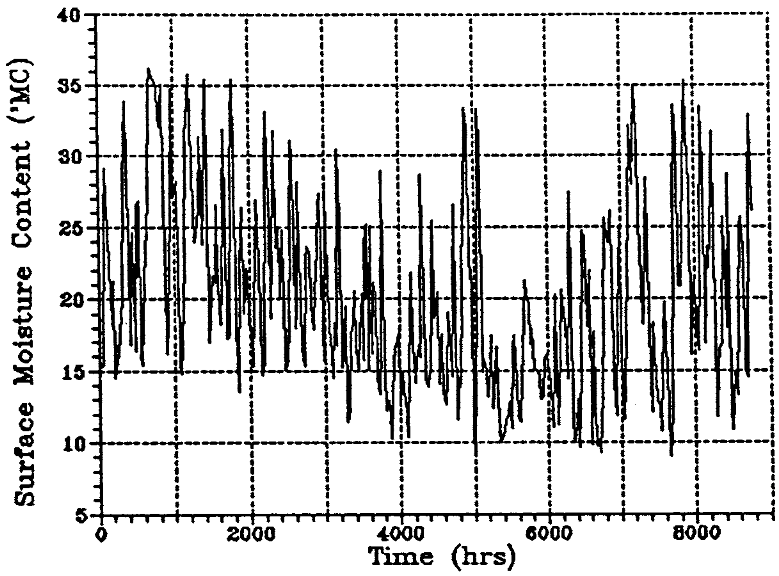

Figure 27b Moisture content of north and south sheathing for one year commencing July, 1. Results for Halifax - model 7 (roof pitch of 42°).

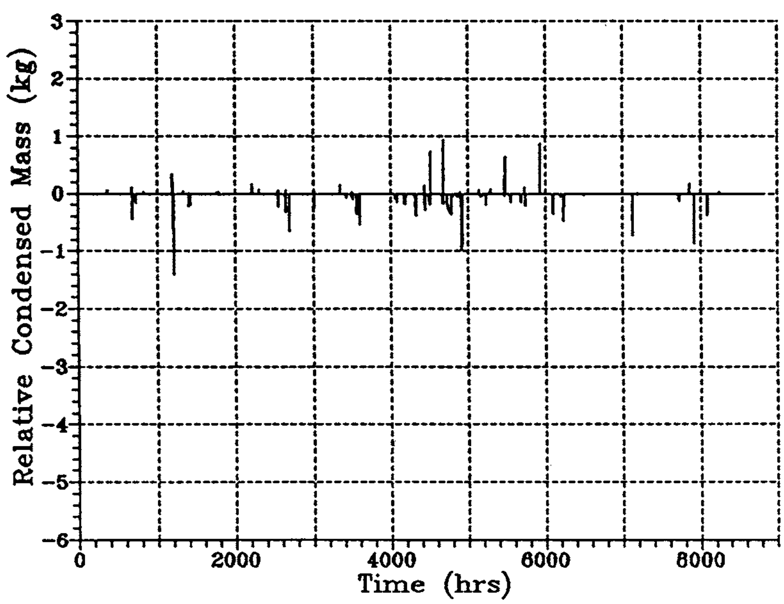

Figure 27c Difference in condensed moisture between model 1 and model 7 (model 1 - model 7) over one year. Results for Halifax.