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Measured Air Flows Across the Ceiling in Typical Residential Assemblies.

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Synopsis

A laboratory for the study of residential attic performance under natural conditions has been constructed. In one of the test cells, with a flat ceiling, white shingles, and venting devices at the soffit and ridge, measurements were taken of air flow through the plane of the ceiling. A ceiling "hole" was constructed in the otherwise tight ceiling, consisting of a PVC tube, an anemometer and a direction sensor. Data were collected for a six-month period. The velocity data have been compared to the recorded values taken at the site for outdoor air temperature and wind (resolved to a north/south wind component).

The results show that up to half of the variance in the air velocity measurements can be accounted for using these two variables. Of the two variables, outdoor air temperature is the more important. The air flow through the ceiling into the attic is considerably greater during the winter than during the summer months. There is a strong correlation between air pressure differences and air velocities through the ceiling hole.

Aim

The intent of this paper is to present measured values for air flow between an indoor space and the attic in a typical residential assembly. The data results from a research project, the Attic Performance Project, which has the larger aim of describing overall attic performance in residential assemblies typical of North American construction under natural conditions.

There are several factors which affect attic performance, including wind, temperature, humidity, construction detailing, and building use. Two construction details appear to be particularly important for attic performance: ceiling airtightness and attic ventilation. Of these two, ceiling airtightness appears to be the more critical. Ceiling airtightness is also the attic performance parameter which has a significant impact on overall building performance.

Measured values for air flow are important in that they will assist any estimation of moisture flow and heat flow across the ceiling plane. Recent work has highlighted the moisture impact of air flows through building cavities (TenWolde 1992).

Test Setup

In 1989, a laboratory building was constructed for the field study of the performance of typical residential attic assemblies under natural conditions. The building is situated on a slight rise, 150m from the nearest tree line. The building contains eight test cells. Each of the test cells has similar construction, and each is maintained at similar temperature and humidity.

The attics are of varied construction. Five of the bays are framed of wood trusses forming a flat ceiling, as shown in **Figure 1**. Three of the bays are framed with dimension lumber, forming a "cathedral ceiling".

The principal data from this paper is data from Bay 1. This test cell has a flat ceiling, fiberglass batt insulation, truss framing, sheathing of oriented strand board, felt roofing underlayment and white-colored asphalt shingles. The bay has ventilation devices, as shown in **Figure 1**, namely, perforated vinyl panels at the soffits and a ridge vent device at the ridge. Above the top wall plate, a polystyrene air chute is used to ensure that air can flow between the soffit area and the attic volume.

A "hole" was placed in the ceiling of each of the study bays, as shown in **Figures 1** and **2**. The hole is actually a length of PVC plumbing pipe, 1 1/2" (38mm) diameter, that extends through the ceiling gypsum board and through the ceiling insulation. The hole can be capped or opened. An anemometer is used to measure air speed through the hole. The interior of each test bay was designed to be tight. Using air pressurization testing and tracer gas testing, the entire indoor enclosure was found to have a leakage area of less than 2 sq. in. (129 mm^2) (CMHC 1990). A port was provided through the wall on the north side to provide makeup air for air flowing through the ceiling.

Instrumentation

Ceiling air flows are measured using a heated thermistor anemometer, shown in **Figure 2**. The anemometer contains an excitation circuit, a heated thermistor in the air stream, a temperature compensating thermistor protected from the air stream, and a voltage output circuit. The anemometers were calibrated in a wind tunnel down to approximately 0.1 m/s. The anemometers are practically omnidirectional--a plastic framework shields the thermistors on two sides.

Thermometry was used to determine air flow direction through the pipe opening in the ceiling. A thermocouple was installed in the pipe opening at the midpoint of the insulation. The data acquisition equipment permits the temperature at that point to be compared to the attic temperature and the indoor temperature. If the pipe temperature was found to be closer to the indoor temperature than to the attic temperature, then a positive value was assigned to the air flow magnitude, indicating flow upward through the ceiling. Conversely, if the pipe temperature was found to be closer to the attic temperature, a negative value was assigned to the air flow, indicating flow downward. This technique was found to be very reliable.

Pressure difference measurements were made across the ceiling plane using a sensitive electronic manometer. The manometer was calibrated to a 0.25 Pa pressure difference against a Wahlen Gauge (ASHRAE 1985, Willard 1921).

Outdoor air temperature was taken using a resistance temperature detector in a standard weather station enclosure. Wind direction and wind speed were taken at 5m using standard weather station anemometry. The wind vector was resolved into its north/south and east/west components. The north/south wind component was used in this analysis in that it is the component acting perpendicular to the length of the building, the soffit vents and the ridge vent. This component was selected as a variable, after a preliminary analysis showed very little correlation of ceiling air velocity with scalar (directionless) wind speed.

Data were sampled at 4 minute intervals and hourly averages were kept. The data for this study are for the period from January 1992 to June 1992.

Findings

Six months of data were compiled to illustrate performance during 1) January and February 1992 ("winter" data), 2) March and April 1992 ("spring" data) and 3) May and June 1992 ("summer" data). Measurements of air velocity through the hole in the ceiling were compared to the outdoor air temperature, and to the north/south wind component. The results are shown in **Figure 3** through **Figure 8**. These charts include plots of the hourly data points, together with interval means and standard deviations within the interval. A simple multivariate regression were performed and the results are shown in **Table 1**.

An air velocity of 1 m/s through the pipe can be seen during periods of cold temperature or during periods of high winds. The section area of the pipe is 11.3 cm^2. If the flow were uniform through the pipe, this velocity would indicate a volume flow rate of 4 m^3/hr.

The results show considerable scatter, which is common in any measurement of convective effects. The correlation coefficient (R^2) is less than .5, indicating that less than half of the total variance of the data points is explained by these two variables.

The comparison of the ceiling air velocity with the outdoor air temperatures indicates a clear trend for increased air flows at lower temperatures. This is a simple illustration of bouyancy. With the coming of spring, high outdoor (and attic) temperatures instigated downward air flows, which appear as negative velocity values in the accompanying figures. Flows at temperatures above 20 degC indicate downward flow during spring and relatively strong upward flow in the summer data set. Both of these effects should be attributed to unexplained variation. If the data sets are combined, the effects are seen to cancel one another, and the trend toward zero net flow at that temperature is evident.

The first line of **Table 1** shows that the mean velocity for the entire data period is considerably higher in the winter (0.85 m/s) than in the summer months (0.36 m/s).

There is a slight trend for greater air flows at higher outdoor wind speeds (north/south component). The correlation of ceiling air flows with north/south wind component is clearly seen in **Figures 4, 6,** and **8**. **Table 1** shows the weakness of wind as an explanatory variable. The t-value is the ratio of the regression coefficient to the standard error for that coefficient. In this case, given the lack of cross-correlation between outdoor air temperature and north/south wind speed, the relative size of these numbers may serve as an indicator of their relative importance as explanatory variables.

Results from pressure difference testing were compared to the ceiling air velocity during a two week period in January 1992. Those results are shown in **Figure 9**. In this case the correlation coefficient (R^2) is 0.79, indicating rather close agreement. Thus, close estimates of rates of air flow could be deduced from measurement of pressure differences across the ceiling plane.

Conclusions

Measurements of air velocity through a ceiling hole were taken for three seasons in a laboratory containing test cells under natural conditions. The velocities during the winter are considerably higher than they are during the summer months. The effects of outdoor air temperature and wind speed on ceiling air velocities can be seen, though these variables together explain no more than half of the total variance in the velocity data. Of the two variables, outdoor air temperature is more important. In this test cell, ceiling air velocity correlated closely with measured values for air pressure difference across the ceiling.

Acknowledgement

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Table 1

statistic	Jan/Feb	Mar/April	May/June
mean air velocity (m/s)	0.85	0.73	0.36
R^2_{ns}	.06	.03	.09
R^2_{ato}	.12	.42	.12
$R^2_{ns,ato}$	.18	.47	.21
t-value$_{ns}$	9.2	9.6	11.7
t-value$_{ato}$	12.8	29.0	13.4

Note: R^2 is the correlation coefficient computed for the individual variables: ns for north/south wind component, and ato for outdoor air temperature. The statistic t-value is the ratio of the regression coefficient to the standard error for that coefficient in multivariate regression. Higher values of R^2 and t-value indicate relative importance of that variable.

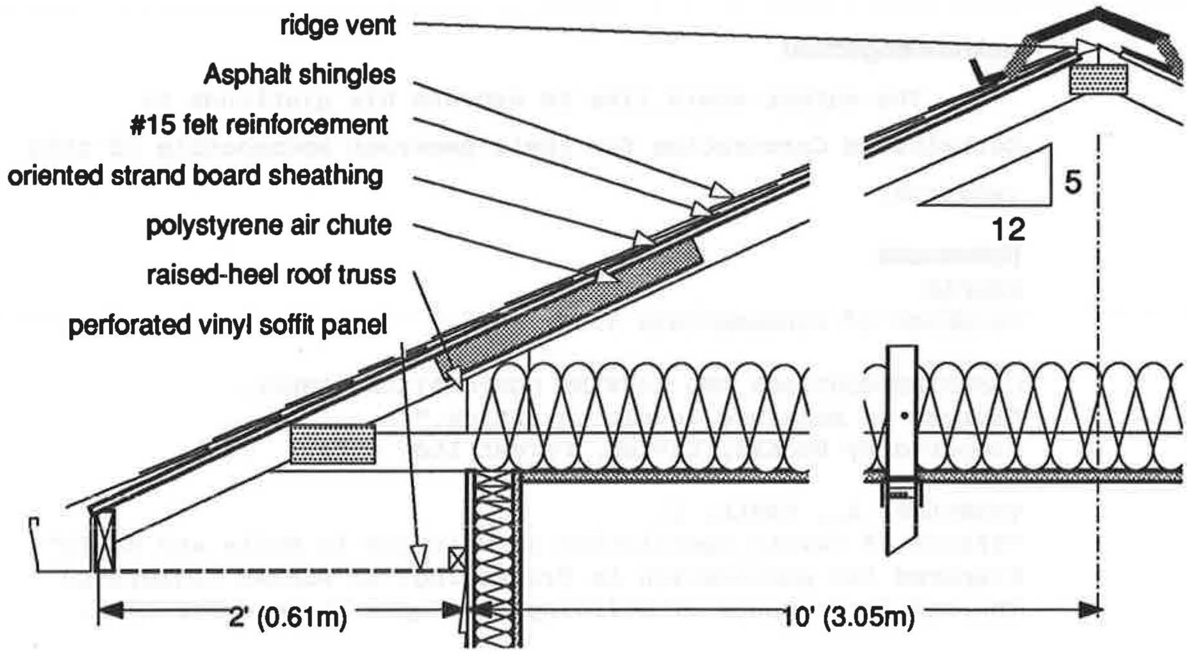

Figure 1. Detail section of the research laboratory attic. The assembly shown is a flat-ceilinged, vented attic, with perforated vinyl soffit panels and a ridge vent.

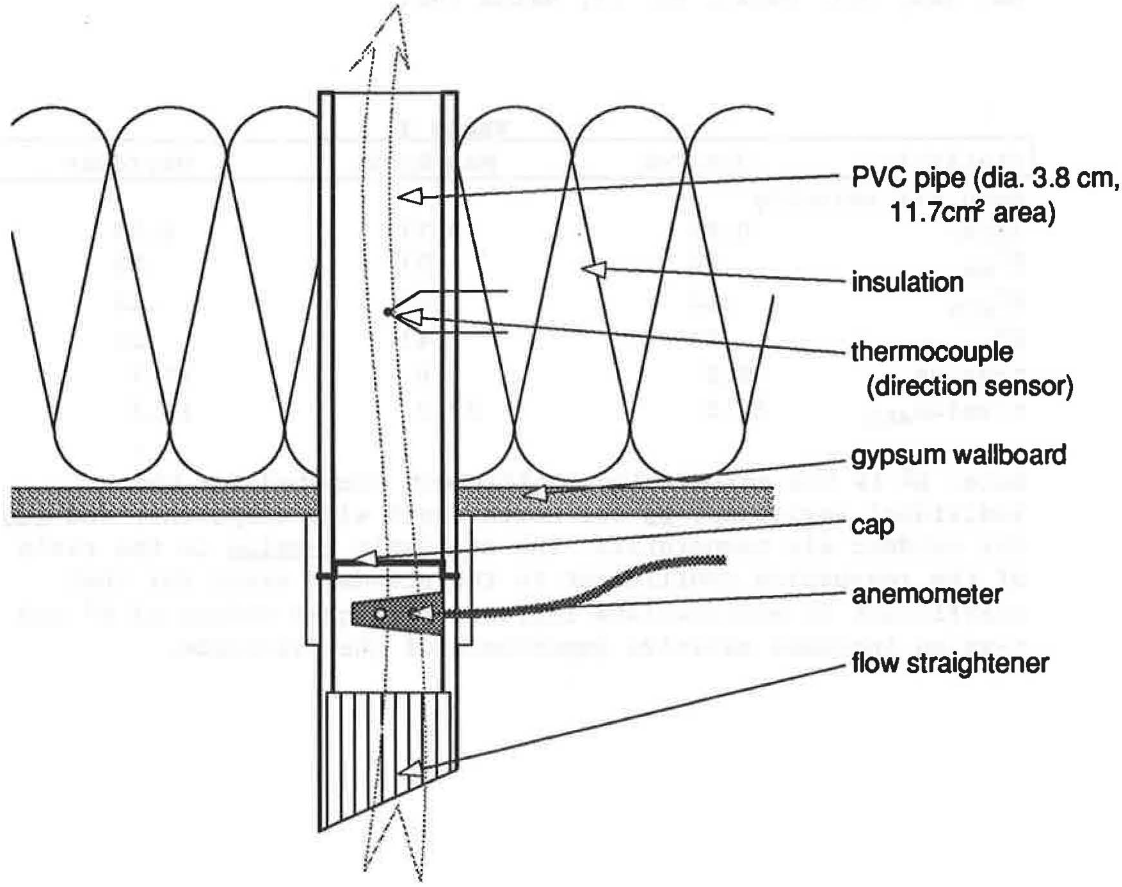

Figure 2. Schematic drawing of PVC pipe used as ceiling hole, showing placement of heated thermistor anemometer, cap (which can be opened for measurement) and thermocouple used as a direction sensor.

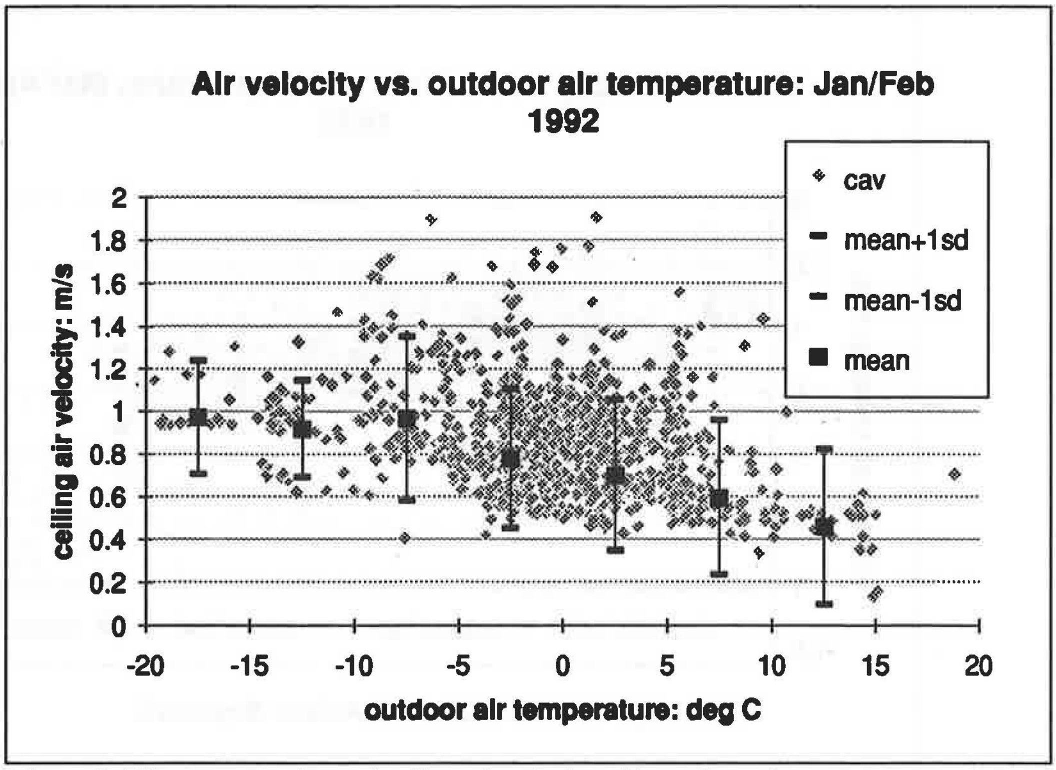

Figure 3. Winter comparison of ceiling air velocity with outdoor air temperature. Confidence band of 1 standard deviation is shown. Trend toward reduced ceiling flow at lower temperatures is evident.

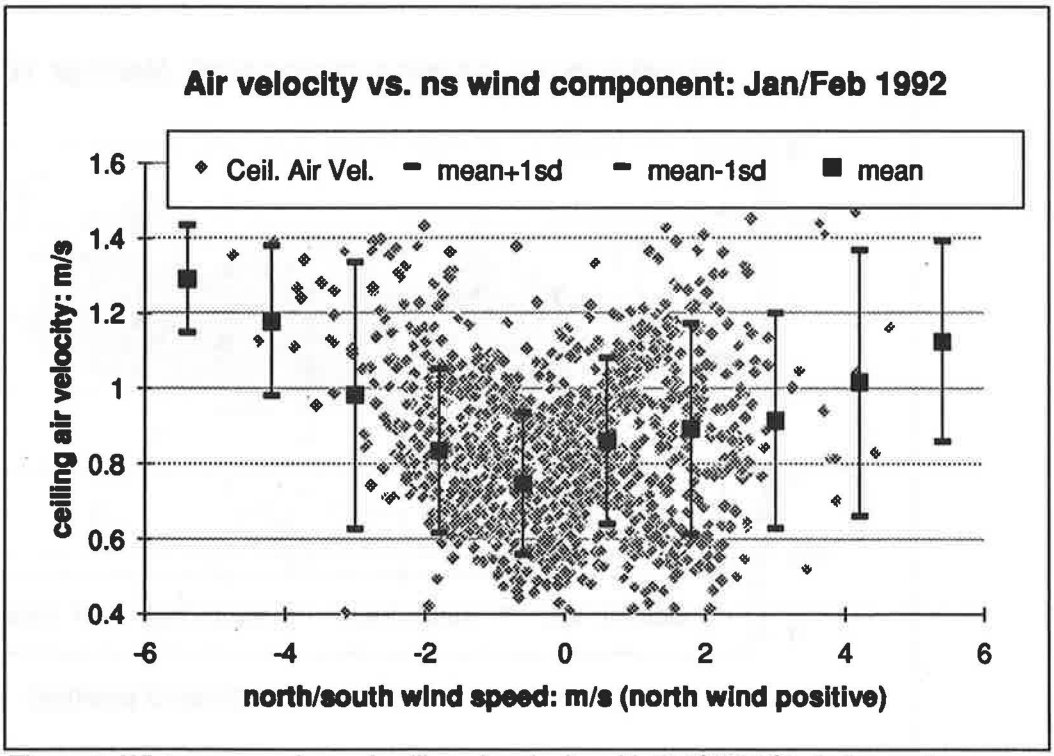

Figure 4. Winter comparison of ceiling air velocity with north/south wind speed. Effect of both north and south winds on ceiling air flows is evident.

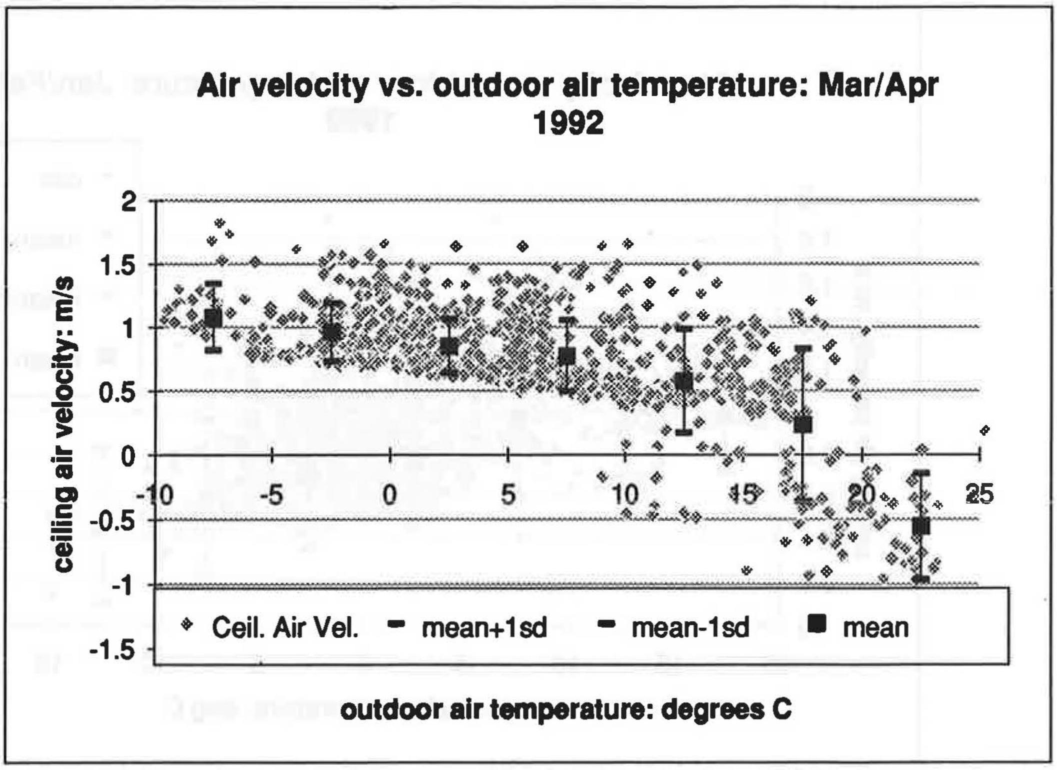

Figure 5. Spring comparison of ceiling air velocity with outdoor air temperature. Results above 20 degC conflict with findings from following months.

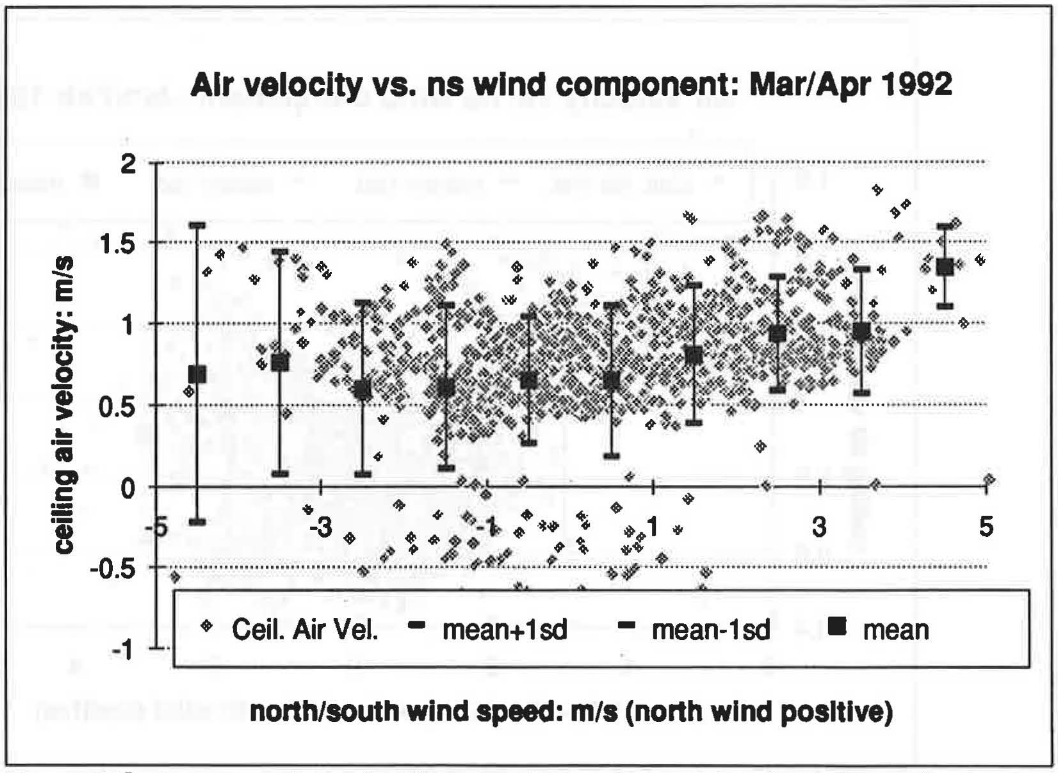

Figure 6. Spring comparison of ceiling air velocity with north/south wind speed. Effect of wind speed is less visible than during winter.

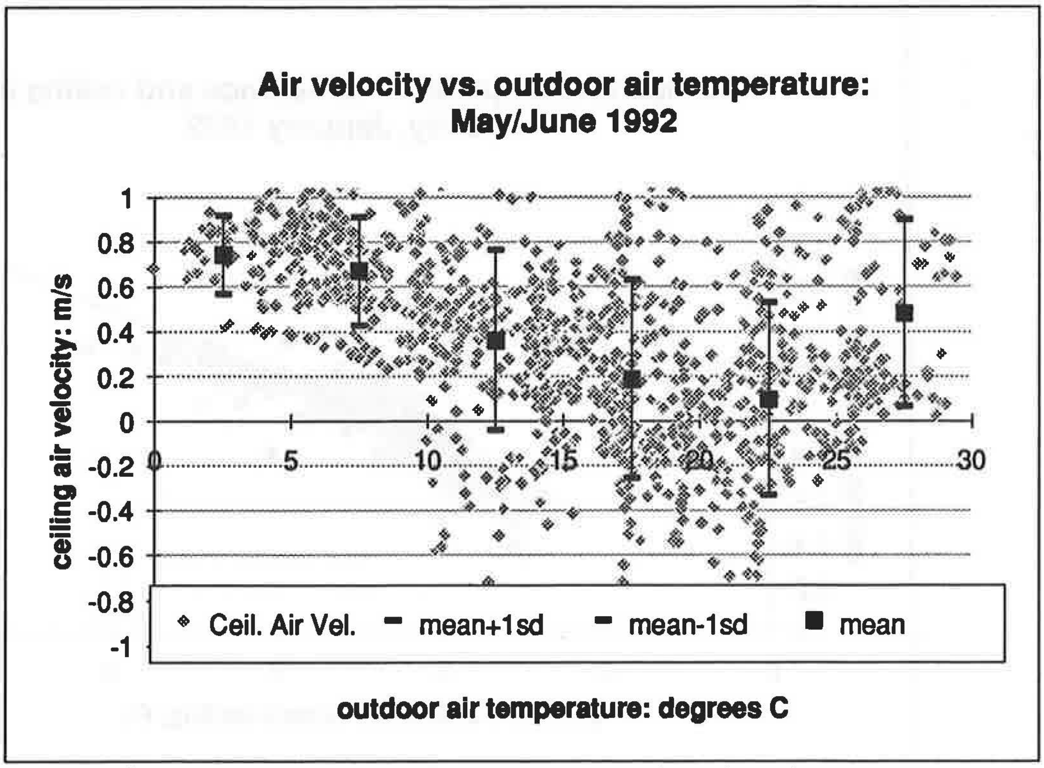

Figure 7. Summer comparison of ceiling air velocity with outdoor air temperature.

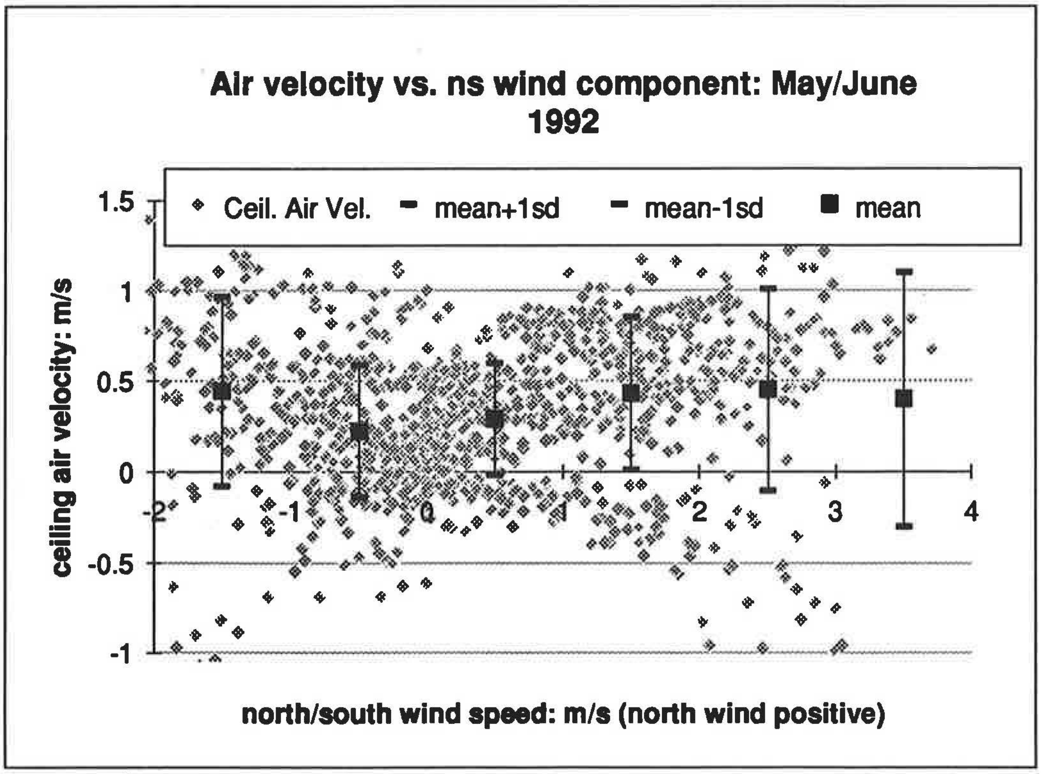

Figure 8. Summer comparison of ceiling air velocity with north/south wind speed.

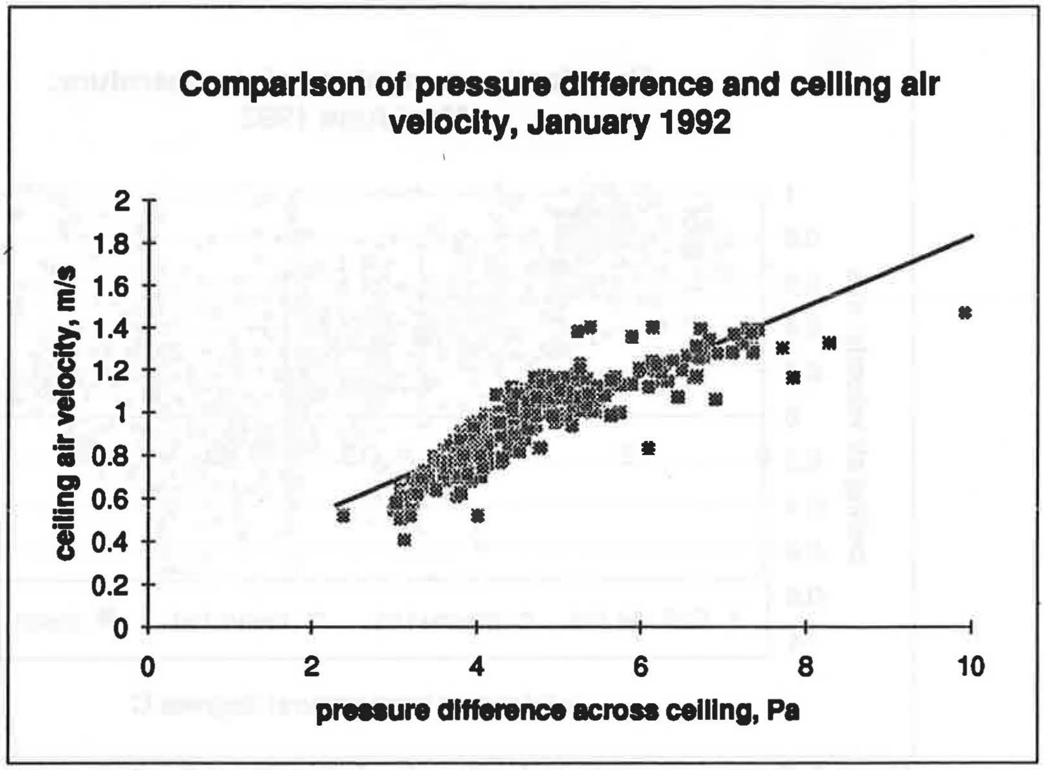

Figure 9. Comparison of ceiling air velocity with air pressure difference. Pressure difference values are hourly averages of 15 samples. Correlation coefficient is 0.79.