Summary

The session on measured air infiltration rates in residences showed that the situation has changed drastically since the first symposium on air infiltration in 1978. Whereas in 1978 little measured data existed on air infiltration in residential buildings, today there are probably more than a thousand dwellings on which air infiltration data or pressurization data, or both, exist. This session contained excellent papers that summarized the state of the existing data on air infiltration.

Lagus and King discussed air infiltration and induced pressurization in duplexes and row apartments at two naval bases. Data were collected in both the winter and summer. They calculated the leakage areas in these dwellings using both air infiltration data and fan pressurization data. The directional nature of the dependence of air infiltration on wind speed is shown in some of the data.

The paper by Shaw gives a detailed study of the seasonal variation of air leakage in two Canadian houses. The data show as much as a 20% seasonal variation in the airtightness of the houses and that there is a good correlation of this variation to the relative humidity.

Nagda et al. presented the results of a 2-year detailed study of air infiltration and indoor air quality in two houses, one of which was retrofitted to reduce its air infiltration. The effect of installing an air-to-air heat exchanger also was studied. Though the retrofitting reduced the air leakage by 40%, the reduction in air infiltration due to the retrofit was overwhelmed by the reduction in infiltration rates due to the changes in weather conditions, the absolute differences between the two houses remaining surprisingly identical before and after retrofit. The air-to-air heat exchanger increased the ventilation rate of the house by about 0.3 to 0.4 air changes per hour.

Persily presented the results of air infiltration and pressurization measurements on about 70 passive solar buildings. Though it has been believed that houses of passive solar design were tighter than typical construction, the data in this paper show that passive solar buildings are no tighter than typical new construction. The paper also presents several models to relate the measured air infiltration as a function of temperature and wind speed to the building tightness.

Gammage et al. presented data on air infiltration and airtightness in 31 East Tennessee homes. In these homes the duct system was a major source of air leakage and added about 0.3 air changes per house to the air infiltration rate. Some of these houses have return air ducts that run through the garage, and this was a source of infusion of contaminants into the houses.

Goldschmidt presented an extensive review of the existing data on air infiltration worldwide with the purpose of trying to determine the effectiveness of the operation of gas furnaces on the air infiltration in homes. He concludes that the existing data support an 0.1 to 0.2 additional air exchange per hour due to the existence of gas furnaces. This paper is a good source for reference to the data on air infiltration.

The purpose of the commercial and industrial session was to present the state of the art of air leakage measurement techniques as they relate to nonresidential buildings. For the past several years many researchers have been working on residential infiltration, specifically single-family structures. Since the largest number of residential buildings in North America are single-family, this effort has been properly placed. In the last few years, however, much has been learned in these structures, and many researchers are beginning to turn their attention to nonresidential structures.

The Lundin paper discussed pressurization tests of nine moderately sized industrial buildings by fan pressurization. The buildings ranged in floor area from 1025 to 6524 m^2, with envelope areas (walls and roofs) from 2100 to 9876 m^2. The buildings included both steel frames with attached sheet metal wall elements and precast concrete frames with light-weight concrete wall elements. Because of the high airflow rate, conventional means for its measurement were not appropriate, and tracer gas was used for determining actual flow rates. This method proved effective and accurate. Airflow rates per square meter of building envelope, measured at a pressure difference of 50 Pa, ranged from 2.0 to 8.0 m^3/h. There was no obvious and significant difference between the steel and concrete buildings.

The paper by Waters and Simons and the paper by Ashley and Lagus dealt with the problems of making tracer gas measurements in large, single-cell, industrial-type buildings. The problem of mixing was deemed paramount; problems related to mixing included injection, sampling, and control. The paper by Waters and Simons described how multipoint sampling may be helpful in understanding the mixing problems and internal flows. The paper by Ashley and Lagus described many of the practical problems associated with making measurements in structures as large as airplane hangers.

The papers by Hunt, Grot and Persily, and Persily and Grot dealt with making fan pressurization and tracer gas measurements on mid- to high-rise office buildings. The paper by Hunt was concerned with making differential measurements on subsections of these buildings. As it turned out, the fan used for the zone measurements was relatively undersized, and Hunt went into detail about how one can extract useful information from such results and what kind of accuracies one can expect.

The Grot and Persily papers concerned almost the same set of buildings; Grot described the results of tracer gas measurements made in these buildings with the HVAC system both on and off, while Persily discussed the pressurization measurements made with the buildings' HVAC system. The tracer measurements indicated that it is important to consider a large building's infiltration rate (that is, ventilation when the mechanical system is off) and ventilation when operating the outside-air intakes; the results suggest that in many cases the building can get sufficient outside air with the outside-air damper fully closed. The leakage studies used the HVAC system to pressurize or depressurize the building and to determine the tightness characteristics. Interesting comparisons were made between these buildings and typical residential ones. Since large buildings have a much smaller surface-to-volume ratio, it was concluded that air changes per hour at a specified pressure difference was not a good method for comparing buildings of different sizes. Preliminary results using the Shaw model for correlating the pressurization results to the tracer gas results were disappointing, but Grot and Persily indicated that more work would be done in this area.

All papers in this session were excellent contributions to the literature and opened a new field of infiltration research. For those who wish to extend their knowledge of the work that has been done in this area, I recommend that they review the proceedings of the 4th Air Infiltration Centre (AIC) conference that took place in Elm, Switzerland in September 1983. The proceedings and other infiltration research is available directly from the AIC in Bracknell, Great Britain.

The coming of age of the perfluorocarbon tracer (PFT) methods, developed at Brookhaven National Labs, was apparent in the opening presentation (Dietz et al.) in the session on Techniques for Measurements and Infiltration Reduction. Not only has the method proved to be successful in relatively long-term average ventilation measurement, but short-term and multizone measurements have been achieved also using the PFT approach. In multizone measurements, three distinct perfluorocarbon tracers allow the research team to quantify interzone airflows in a three-zone structure. A fourth tracer is currently under investigation.

The paper presented by Jacobson et al. compared air leakage reduction from house retrofits as measured by pressurization and tracer gas measurements. The lack of a strong correlation between these two quantities indicates the difficulty of using pressurization data in estimating air infiltration energy savings.

On-site measurements in family housing using a streamlined testing procedure, which included fan depressurization only, was described by Verschoor and Collins of Manville Research and Development Center. Key to the testing was the extremes in tightness encountered in the housing, clearly pointing out that certain housing needs no further tightening.

Treating all of the outer wall surfaces, other than windows, Luebs and Weimar from NAHB Research Foundation and DuPont reported on the success using an air barrier just under the exterior sheathing. This approach eliminates air penetration but allows trapped moisture to escape. The heating season savings measured in a test house were greater than 25%, of which about half could be attributed to the reduction of air infiltration.

Throughout the session it was very evident that our field measurements of house airtightness have greatly increased over the past few years. The techniques for measurement have continued to be refined, but that technique directly interpreting air infiltration from pressurization measurements alone comes with a sizeable error band. Component leakage values fulfill a useful purpose in placing tightening goals in perspective, but testing the building as completed is the final proof that the desired airtightness level has been achieved. Such airtightness quantification allows one to point out where mechanical ventilation is desirable or necessary or both. Standards for the testing methods must be well-specified, and calibration methods for test equipment must not be overlooked.

The paper by Giesbrecht and Proskiw discussed a field study on the effectiveness of air leakage sealing techniques on 82 houses located in Winnipeg and Southern Manitoba, Canada. Air leaks were detected using negative pressure and smoke pencils. Air sealing measures included the weather-stripping of windows and doors and the caulking of other leakages as indicated. Before and after retrofit, fan pressurization tests (negative pressure only) indicated median equivalent leakage area reductions of 31.6% at 10 Pa. The greatest reduction was in single story houses with 36.9%. In two-story houses, the reduction averaged only 24.4%.

During a panel discussion at the 1978 symposium "Building Air Change Rate and Infiltration Measurements" hosted by ASTM Committee E-06, one gentleman asked a detailed question about the prediction of infiltration rates under a wide variety of meteorological and building conditions. There was, at that time, a lot of interest and pressure from, for instance, various regulatory agencies at the local, state, and (to a somewhat lesser degree) federal levels. At that time, the committee was being asked to run a four-minute mile while, in fact, we were just at the stage where we were learning to crawl. In the intervening 6 years, it appears that we have learned to walk—and, occasionally, to run. However, listening to papers presented in the Analysis Session, as well as the ensuing discussion, the situation can be likened to Friday rush hour in Manhattan's Penn Station.

The paper by Sherman and Modera basically outlined the continuing work at Lawrence Berkeley Laboratory on an infiltration model designed to predict natural air infiltration from fan pressurization measurements. The model, itself, deals with two parts: the first, with the weather and local environment; the second, with the leakage distribution of an individual structure. In order to arrive at a physically tractable model, a large number of assumptions regarding uniformity of leakage, wind profile, shielding, temperature profile, wind directions, and a linear flow envelope have been made. In addition, linear superposition of thermal and wind effects has been posited. Four key assumptions regarding the model are: (1) orifice flow, (2) flow superposition, (3) averaging over aspect ratio, and (4) averaging over wind directions. Extensive calculational analysis shows that errors due to wind-direction averaging could be as much as 60% for some cases. Errors due to aspect-ratio averaging could be as much as 20%. The model itself, however, seems to predict average behavior of a large number of structures under diverse meteorological conditions. As such, it provides a powerful analytical constraint on measured data, as well as on other calculational models.

The paper by Sherman et al. draws a distinction between air leakage and infiltration. Air leakage is being measured by fan pressurization. However, infiltration is the quantity of interest in, for instance, energy conservation and indoor air pollution studies. The primary thrust of this paper was to study the effects of changes in the value of the leakage constant and the pressure exponent. It is well-demonstrated that if in doubt "n" should be somewhat larger than 0.5, implying that flow is not quite true turbulent flow. A pressure exponent of 0.67 is a good choice in the absence of any other data. One interesting fact that emerged from this study is that for a large sample of houses it doesn't matter whether leakage area is calculated using positive pressurization, negative pressurization, or the average of both. Approximately the same calculated infiltration rates resulted. However, for any one house, the error could be almost 30%. This same magnitude of variability is seen in the leakage area and the exponent "n."

A striking feature of data presented in both of the Sherman papers is the log-normal frequency distribution of infiltration values. This distribution also is seen in Grot's (NBS) community weatherization program data. However, for any given structure or climate, the variability in the pressure exponent and the leakage area precludes simple a priori predictions with great precision.

The paper by Bassett elucidates the adaptation of an infiltration model in a mild climate. In this paper, he points out that it is possible to correlate, in a loose fashion, airtightness data and a wind exposure index determined from site examination. For the New Zealand structures presented, it is apparent that a model appropriate for infiltration calculations in this region is primarily a wind-driven model possessing little sensitivity to temperature.

The papers by Blomsterberg and Lundin and Boman and Lyberg discuss at length various adaptations of the LBL model to Swedish homes. In the Blomsterberg and Lundin paper, extensive discussion is presented for a few homes that are extremely tight by U.S. standards. These houses show 3 ACH at 50 Pa pressurization. The model, itself, is an LBL model that was modified by adding a term for forced ventilation and for an exhaust fan. Mechanical ventilation is necessary since the Swedish homes are generally so tight that an acceptable air quality cannot be maintained by natural infiltration alone. The data presented also show the variations in infiltration from room to room throughout a single structure. These data are notable since they demonstrate graphically that while the *average* air infiltration for a structure may be high enough from an indoor air quality standpoint, several rooms within that same structure may, in fact, fall well below a minimum recommended ventilation rate.

The paper by Boman and Lyberg discusses the results of measurements in 1200 houses in Sweden. The buildings studied include all types of houses within Sweden—including single-family, multi-family, row-housing, one and two-story detached—all of which were built between 1900 and 1982. Natural infiltration was measured using a tracer gas decay technique. A fraction of the homes—approximately 25%—also had air leakage rates determined by a pressurization technique. The data, again, show the importance of the local weather conditions and, particularly, shielding on measured and predicted air infiltration rates.

Both of these Swedish papers demonstrate that it is possible to construct a very tight residential structure. The models used are variants of the Lawrence Berkeley model. This model has permeated the analysis and calculational approaches of the energy—which seems to have permeated the analysis and modeling thinking of the energy conservation community to date.

Liddament discussed a recent survey on air infiltration research. The survey was conducted by the Air Infiltration Centre in Bracknell, Berkshire, United Kingdom. The survey results are used as background for European airtightness and infiltration-measurement practices. Although past and current research emphasizes dwellings, increasing efforts are being devoted to other building types. The survey covered measurement technology, both pressurization and tracer gas (including multitracer air movement studies), airtightness, ventilation efficiency, indoor air quality, and air movement within buildings. The survey included countries in West and East Europe, North America, South Africa, the Far East, Australia, and New Zealand. The results indicate that the conflicting concerns of indoor air quality and of energy conservation through airtightness is being considered worldwide. However, it was noted also that measurements of air infiltration and airtightness still are confined largely to research activities.

It was disappointing that no papers were received discussing other models for infiltration in residences, namely, the Institute for Gas Technology model or the Shaw-Tamura model. While neither of these models has been as widely discussed as the LBL model, they certainly possess validity for at least a limited set of data. At a future symposium, one would hope that a presentation of the rudiments of these models would be presented. Such a presentation would afford a better appreciation and an understanding of the advantages and limitations of the infiltration/air leakage models that have been proposed.

There has been great progress over the last 6 years in the area of air infiltration modelling. However, much of the effort has been devoted strictly to single-cell type models which are appropriate to single-family residential structures. Now that a start has been made for these structures, it is hoped that models appropriate to row housing, apartment buildings, industrial and commercial buildings, and large office buildings will begin to appear. Such models will be required to obtain a detailed understanding of the performance characteristics of these structures, as well as to provide an analytical framework within which to interpret the increasing body of experimental data relative to infiltration, air leakage, and mechanical ventilation.

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