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# A Review of European Research into Airtightness and Air Infiltration Measurement Techniques

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**ABSTRACT:** An important function of the Air Infiltration Centre, Bracknell, Berkshire, Great Britain, is to keep research organizations informed of on-going research into air infiltration in buildings. To fulfill this need, the Centre regularly undertakes a worldwide survey of current research. In this report, the results of the Centre's most recent survey, completed in 1983, are used to provide a background to present European airtightness and air infiltration measurement practices. A wide range of research activities are summarized involving the use of both pressurization and tracer gas techniques. In addition, the increasing effort being devoted to the measurement of air infiltration in nondomestic buildings is emphasized. Other topics covered include ventilation efficiency measurements and multitracer air movement studies.

**KEY WORDS:** review, airtightness, air infiltration, measurement methods, dwellings, nondomestic buildings

An important function of the Air Infiltration Centre (AIC) is to maintain a current awareness of air infiltration research. The Centre endeavors to fulfill this commitment in a number of ways, the most important of which is to undertake a regular worldwide survey of on-going research into air infiltration in buildings [*1*]. Since the inception of the AIC in June 1979, the results of three such surveys have been published. The first, in Oct. 1980, contained an analysis of 65 projects based on information received from organizations in 14 countries. This was followed in Dec. 1981 by an analysis of 126 new projects. The results of the most recent survey were published in Nov. 1983 and were based on an analysis of 187 projects in 22 countries. In recognition of the

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growing importance being attached to the influence of fresh air exchange rates on indoor air quality, the scope of this latest survey was specifically extended to include this topic.

Approximately one third of the respondents to the survey cited indoor air quality as a specific objective, with measurement techniques taking second place with a 25% response. The remaining most widely cited objectives included mathematical modeling, airtightness construction and retrofit methods, studies into the cost-effectiveness of airtightness measures, and investigations into the performance of heating, ventilation, and heat recovery systems.

Almost 50% of the projects reported were based on research summaries received from Europe; these projects include a number of entries from the Eastern European countries of Czechoslovakia, Hungary, Poland, and Yugoslavia. Of the remaining entries, 25% came from the United States, 20% from Canada, and 5% from other countries. A full list of countries is given in Table 1. It is the purpose of this report to focus on the European aspects of this survey, with particular emphasis on measurement methods. In preparing this report, other sources of research information also were used, including the International Council for Building Research (CIB) "Heating and Climiti-

TABLE 1—*Survey of research—contributing countries.*

| Country | Number of Replies |
|---|---|
| Australia | 1 |
| Belgium | 2 |
| Canada | 37 |
| Czechoslovakia | 1 |
| Denmark | 4 |
| Finland | 4 |
| France | 1 |
| Germany | 8 |
| Hungary | 1 |
| Italy | 2 |
| Japan | 6 |
| Netherlands | 18 |
| New Zealand | 1 |
| Norway | 2 |
| Papua New Guinea | 1 |
| Poland | 2 |
| South Africa | 1 |
| Sweden | 10 |
| Switzerland | 6 |
| United Kingdom | 31 |
| United States of America | 47 |
| Yugoslavia | 1 |

zation Review of Research" [2] and details of the Commission of the European Communities research program into building energy conservation [3].

## Basis for European Research

The significance of air infiltration research cannot be overemphasized; on the one hand, air infiltration can account for a substantial proportion of the heat loss from a building, while, on the other hand, excessive levels of airtightness can result in a serious deterioration in indoor air quality. These apparently conflicting needs have formed the basis behind much of the research effort in Europe over several decades. In the United Kingdom, as early as 1942, for example, the Egerton Committee on Heating and Ventilation [4] recommended minimum standards for ventilation in dwellings based on the need to keep occupied spaces free from noticeable odors. It was further stated that ". . . . the standards recommended, which are minimal for winter conditions, should not be much exceeded in winter otherwise the cost of heating will be significantly increased." During the intervening period, energy resources became more plentiful with the result that reduced consideration was given to the need for energy conservation. More recently, however, the unreliability of imported energy supplies has been vividly demonstrated, thus providing renewed impetus for further research. This is particularly true of Sweden, where indigenous energy resources are limited and the winter climate is severe. Consequently, the Swedish government is placing substantial emphasis on the conservation of energy in buildings, with the intention of reducing energy consumption in the existing building stock by 30% [5]. In pursuance of this aim, much effort has been concentrated on the reduction of air infiltration and on the introduction of ventilation heat recovery systems. Stringent airtightness regulations for new buildings also have been introduced [6]. To support these actions, a substantial research program is in progress. In other parts of Europe, the oil crisis of 1973 also resulted in the initiation of energy conservation research.

## Buildings Investigated

The majority of buildings referenced in the Centre's survey of research are dwellings, although, increasingly, other varieties of building are being considered. In the 1980 survey, for example, the ratio of dwellings to other buildings was approximately 3:1, whereas in the 1983 analysis this ratio had reduced to 2:1. The remaining buildings include commercial premises, industrial buildings, schools, and hospitals. Measurements in both occupied and unoccupied buildings are being performed, with simulated occupancy also being a fairly popular approach. Unlike North America, very few buildings (especially dwellings) are air-conditioned, thus energy conservation studies tend to concentrate on space heating needs rather than cooling loads.

## Measurement Methods

### *Air Leakage Measurements (Pressurization Testing)*

*Dwellings*—Airtightness standards for new dwellings were introduced in Sweden in 1980 [*6*]. The statutory maximum leakages of 3 ACH at 50 Pa for single-family dwellings, 2 ACH for other two-story dwellings, and 1 ACH for high-rise apartment buildings put an obligation on builders and the local building inspectorate to ensure that new housing conformed to these standards. Whole building pressurization test measurements are, therefore, a common procedure in Sweden, and suitable instrumentation for measurements in dwellings is available from several manufacturers. Test conditions are very precise [*7*] and it is important to recognize that it is the "fabric" leakage that is measured; all purpose-provided openings and slot air vents, etc., are sealed for the duration of the test. Norway has proposed similar but slightly less stringent airtightness requirements [*8*], with the result that pressurization testing is becoming a common practice in this country. Elsewhere in Europe, whole-house, air-leakage testing is restricted very much to the research sector, and commercially produced instrumentation such as the "blower door" is not available.

*Industrial Buildings*—The maximum volume of enclosure that may be pressurized is governed by the overall airtightness of the building and the size of the available fan. In the past, these conditions have restricted the size of the building in which pressurization measurements could be made. More recently, however, tests have been made in large industrial-type premises. Lundin [*9*] describes such a technique used by the Swedish National Testing Institute, where air leakage measurements have been made in buildings with gross volumes in excess of 60 000 m$^3$.

*Component Leakage*—Component pressurization leakage testing appears to be much more widely reported in Europe than elsewhere. Many of these investigations are being performed to improve the theoretical understanding of air leakage sites in buildings and to quantify component leakage values. Components of interest include windows, doors, facades, and party walls. This technique also is being used in the United Kingdom by Ward [*10*] to assess the potential and performance of retrofit measures. European countries reporting component pressurization testing in the AIC survey include Belgium, Finland, France, Italy, Poland, Sweden, Switzerland, and the United Kingdom.

### *Tracer Gas Measurements*

The tracer gas technique is well established, and basic concentration decay measurements are commonplace throughout Europe. The most significant difference between European and American tracer gas testing is the widespread use in Europe of nitrous oxide, which now appears to be little used in the United States and Canada. Recent tracer gas developments have concentrated on automatic methods for multizone monitoring and on multitracer air movement studies. Other important studies are focusing on ventilation efficiency measurements and on the measurement of air infiltration in large enclosed spaces. Each of these aspects is covered in further detail in paragraphs that follow.

*Automatic Instrumentation for Multizone Monitoring*—Instrumentation for multizone monitoring has been developed in Denmark [*11*], Sweden [*12*], and the United Kingdom [*13*] and also is currently in the course of development at the Federal Institute of Technology in Lausanne, Switzerland. The Danish instrumentation has been used to continuously monitor air change rates within an occupied dwelling over a period of many months. The system comprises a microcomputer, which is used to monitor the rate of tracer gas injection and to sample tracer gas in up to 10 rooms. The tracer gas is sampled in each room sequentially, and any drift in concentration from a nominal value of 50 ppm is restored by adjustments to the tracer gas injection rate. The fresh air exchange rate in each room is therefore directly proportional to the tracer gas injection rate. In its original form, the instrumentation was designed to operate using nitrous oxide tracer gas but subsequently has been modified to use sulfur hexafluoride.

Similar operating principles are used in the instrumentation developed at the National Testing Institute in Sweden [*12*] and at British Gas in the United Kingdom [*13*]. The British Gas system also has been designed to accommodate a secondary tracer gas for use in air movement studies.

The main problem with these methods is that instability in tracer gas concentrations tends to arise as a result of a step change in conditions, as occurs, for example, when windows or external doors are opened or closed. Thus, when developing the software to operate multizone constant concentration systems, it is essential to ensure that step changes do not give rise to excessive or harmful increases in tracer gas concentration. The principal advantage of the multizone method is that it enables individual room air change rates to be quickly measured. This has proved invaluable in assessing the influence of various design features on both individual room and whole house air change rates. In particular, such problems as insufficient ventilation rates can be rapidly identified.

*Measurements of Air Movement*—Air movement studies have become an important aspect of air infiltration research and a number of measurement systems recently have been developed for this purpose. One such system, based on a multitracer concentration decay technique, has been developed at the Polytechnic of Central London in the United Kingdom [*14*]. The system can accommodate up to four perfluoro tracer compound gases, which may be released at various points in the building. The mixture of gases may be sampled at any number of positions in the building as a function of time since release. The samples are collected using adsorption tubes and subsequently are analyzed in the laboratory. From the analysis, the concentration of each gas at discrete time intervals and at each location can be determined. The entire sampling process is controlled by means of a microcomputer.

A variation of this technique has been developed at Sheffield University, also in the United Kingdom [*15*]. This system is capable of measuring the concentrations of up to three fluoro tracer gases simultaneously, using a directly linked gas chromatograph with electron capture. Each gas may be released into one of three distinct zones within the building and, by measuring the variations in concentration of the gases over a period of 2 to 3 h, the ventilation rate and interzone air movement may be determined. A similar approach for determining interzone air movement within a large office building (with a gross volume of 1860 $m^3$) has been developed at the U.K. Building Research Establishment [*16*]. The building is subdivided into three zones, each of which is seeded with either carbon dioxide, sulfur hexafluoride, or nitrous oxide. An automatic sampling system is used to monitor the concentrations of each of these gases in each zone. As with the previous methods, the resultant gas concentrations are used to determine the interzone airflow patterns.

*Ventilation Efficiency*—Measurements into the efficiency of ventilation strategies have had important significance in Sweden, where the implementation of airtightness regulations for dwellings has resulted in the widespread introduction of mechanical ventilation systems in domestic buildings. The fundamental aim of current investigations is to develop design guidelines for establishing efficient ventilation in multiroom applications [*17*]. Of particular concern is the optimum location of inlet and exhaust terminals to ensure adequate ventilation. Measurements are being made in an indoor full-scale test house with one facade exposed to the outdoor environment. The performance of both mechanical extract and combined supply/extract systems are being assessed. Ventilation efficiency is being measured using both the concentration decay and constant emission tracer gas techniques. In both instances, the tracer gas concentration is continuously recorded at different locations within the building, from which the local ventilation rate and hence the ventilation efficiency is determined.

*Tracer Gas Measurements in Industrial Buildings*—The success of the tracer gas method is dependent on the perfect mixing of the gas. Adequate mixing normally can be achieved in dwellings by placing small mixing fans at each internal doorway or by injecting the gas directly into the air distribution plenum of warm air heating systems. Furthermore, small deficiencies in mixing often can be overcome by paying careful attention to the sampling method. Very often multipoint sampling is used, in which each location is either linked via an equal length tube to a manifold or is sampled sequentially and averaged. Other detection methods rely on single-point sampling from a central location or on sampling the tracer gas concentration in the return air duct of warm air systems. Unfortunately, the tendency for internal air circulation and stratification to resist mixing tends to place an upper limit on the size of enclosure in which conventional tracer gas measurements may be made. It is partly for this reason that so much effort has been devoted to dwellings and very little to other varieties of buildings. Recently, however, consideration has been given to the excessive air infiltration heat loss from large single cell industrial structures, with particular emphasis on warehouses. These buildings are frequently very leaky and, unlike factories, have no waste process heat available to satisfy space heating requirements.

Although gasketing options are normally available, occupiers are very often unwilling to pay the additional premium because there is no reliable information on payback periods. As a consequence, a number of researchers have begun to devote their attention to this problem. The position regarding airtightness measurements in warehouses already has been touched upon [*9*], but new techniques involving the use of tracer gas are being introduced. Two such approaches were described at the Air Infiltration Centre's 4th Annual Conference, held in Elm, Switzerland [*18,19*]. While in some respects the methods adopted are contrasting, the underlying philosophy of each is very similar. Firstly, it was agreed that it is unwise to attempt to overcome, by means of artificial mixing, the naturally occurring stratification and air movement patterns in these buildings. Apart from the extreme difficulty of implementing such a measure, it is argued that the conditions under which air infiltration ordinarily occurs would be destroyed and that, therefore, such an approach would yield a meaningless result. Both methods therefore are based on the assumption that imperfect mixing is likely, and that the measurement of air infiltration rates should take account of this. The approaches also are similar in that multipoint injection and sampling techniques are used.

The method developed by Dewsbury [*2,18*] incorporates three infrared gas analyzers, each linked to ten sampling tubes via computer-operated valves. The network has been designed to automatically sample the tracer gas concentration at 30 locations within a 5-min period. Nitrous oxide tracer gas is initially injected throughout the building, and the local concentration decay rate at each measurement site is recorded over a period of several hours. The apparatus is currently being verified by comparing results against a known induced air change rate in a warehouse having an approximate volume of 7 000 $m^3$. The system also is being verified against various patterns of imperfect internal mixing.

Freeman [*19*] uses discrete injection and sampling units, each of identical design and comprising a sealed gas bag and a peristaltic pump. The injection units are initially filled with sulfur hexafluoride, while the sample units are empty. Tracer gas is released at a constant rate of emission and locally mixed using small fans to ensure no layering of the tracer gas due to density differences. Samples are taken some distance from the injection points by drawing air into the sampling units. The flow rate can be adjusted to collect samples over periods ranging from 0.5 to 14 days. Many samples can be collected simultaneously at different heights and positions in the zone being investigated. The performance of this technique has been compared with conventional decay and constant concentration techniques in test volumes of up to 630 $m^3$, this being the volume limit for the conventional approaches.

Further studies on tracer gas measurements in naturally ventilated large enclosures are being carried out in France at the Centre Technique des Industries and in the United Kingdom at Coventry Polytechnic.

## Discussion

From the viewpoints of both energy conservation and indoor air quality considerations, there is an urgent need to ensure that design and retrofit approaches are well planned and are conducted in conjunction with a coordinated program of measurements. It is, therefore, encouraging to note that a diverse range of air infiltration and airtightness measurement techniques are being developed and used, not only in Europe but also throughout the world. In addition to the widespread use of basic pressurization and tracer gas measurement methods, a move towards air infiltration studies in nondomestic buildings has resulted in a strengthening of research into multicell applications and air movement measurements. In particular, an understanding of air flow patterns in tight buildings is vital in order to maximize ventilation efficiency at low air exchange rates. Many of these new areas of study still require further development, especially in the interpretation of results.

Measurement methods still are confined largely to the research sector, with no complete tracer gas system being commercially available in Europe. This tends to hamper progress and limits the number of buildings in which air infiltration measurements are being made. It is hoped that future developments, perhaps in the field of passive tracer gas techniques, will overcome this problem.

It is thought that a continuing need to conserve energy, especially in the industrial and commercial sectors where individual space heating demands can be large, will provide a foundation for further development in measurement techniques.

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