Air Infiltration and Ventilation Calculation Techniques

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Introduction

A range of calculation techniques is available for the calculation of air infiltration and ventilation in buildings. The choice is largely dependent on intended application, while the level of complexity ranges from straightforward empirical techniques to detailed multi-zone numerical methods. The objective of this article is to outline some of the techniques currently available and to indicate the purposes for which they are most suited. More detailed information is presented in the AIVC's Air Infiltration Calculation Techniques Guide.[1] The prime function of these techniques if to provide basic data for ventilation design and associated parameters (Figure 1).

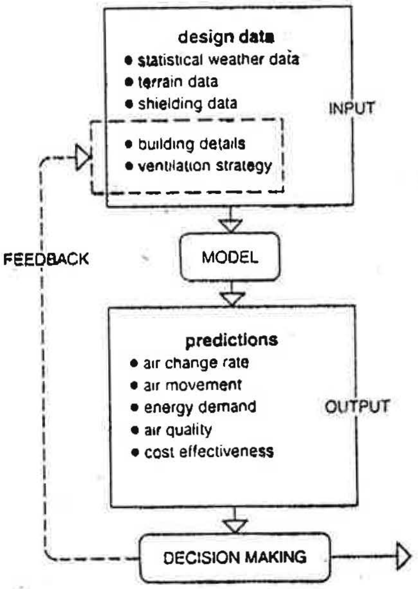


Figure 1: Role of mathematical modelling in design

Calculation techniques

In practice, the choice of calculation technique varies according to the required level of accuracy, the availability of data and the type of building under investigation. Consequently, a wide variety of methods have been developed to cope with the problems of estimating the rates of air infiltration in buildings, with no single method being universally appropriate.

Despite the many methods, prediction techniques can be grouped into five generic forms. These are:

(i) 'air change' methods.

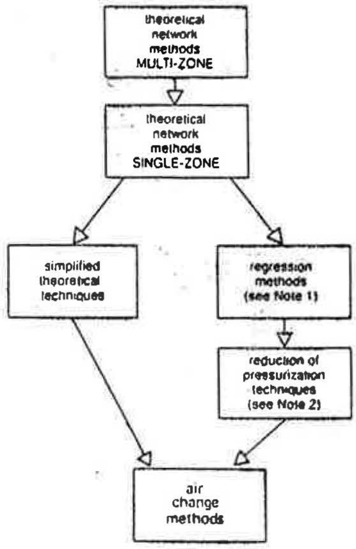
(ii) 'reduction' of pressurization test data.

(iii) regression methods.

(iv) theoretical flow network models.

(v) 'simplified' theoretical techniques.

Methods (i) - (iii) are essentially empirical techniques in which the calculation of air infiltration is only loosely based on the theoretical principles of air flow. While these methods tend to be fairly straightforward to apply, they usually have a rather limited range of applicability. The remaining methods are based on a much more fundamental approach involving the solution of the equations of flow for air movement through openings in the fabric of the building. These methods have a potentially unrestricted range of applicability but can be very demanding in terms of computer execution time and data needs. The final choice of method is largely dependent on the intended application for which the air infiltration prediction is required. It should also be noted that the various forms of calculation technique have a hierarchical order representing both their range of applicability and their level of complexity (Figure 2). As a general rule, alternative methods for specific applications can only be selected by moving up the hierarchy. In the following, a brief description of these methods and the applications appropriate to each technique are outlined.



Notes:

1 Assumes that air infiltration rates can be measured in the building.

2 Assumes that airtightness measurements (pressurization testing) may be made or estimated.

Figure 2: Hierarchical order of techniques

Air change methods

These are the 'classical' methods to be found in Section A4 of the CIBSE Guide (2) and in Chapter 22 of the ASHRAE Fundamentals (3) for the sizing of heating appliances. The purpose of this approach is to estimate an air change rate for specific design conditions for use in estimating the total heating or cooling load on the system. For such a task, intricate detail of the flow process is not required; instead the utmost simplicity is sought.

Reduction of pressurization test data

This is a very simple technique which nevertheless provides valuable information concerning the average infiltration performance of a building. The artificial pressurization or depressurization of a building as a means of assessing air leakage performance is now a fairly common practice (4). In itself it can only provide data regarding the 'leakiness' of the building (usually expressed in terms of air change rate at a 50 Pa pressure difference, Q_{50}). The result provides no information on the distribution of openings or shielding. However, numerous experimental tests have shown that the approximate mean air infiltration rate will be of the order of one twentieth of the measured air change rate at 50 Pa, ie:

$$\text{Infiltration} = Q_{50}/20$$

This provides a useful 'rule of thumb' estimate should pressurization test data be available. It is of value when considering the implications of building airtightness on the design performance of either natural or mechanical ventilation strategies. For example, a naturally ventilated building intended to meet an average ventilation requirement of 0.5 air changes per hour (ach) would require an overall air leakage rate at 50 Pa of not less than 10 ach. Similarly a mechanically ventilated building would need a considerably greater degree of airtightness if interference by air infiltration is to be avoided. This method is only suitable for small buildings such as dwellings, in which the pressurization test can be made.

Regression techniques

This method is based on the results of statistical fits to long-term time series data of infiltration rate measurements and associated climatic data. In its most basic form, air infiltration is expressed as a linear function of wind and temperature, ie:

$$I = A + B\Delta T + CV \quad (1)$$

where, A, B and C are regression coefficients

ΔT = internal/external temperature difference

V = wind speed

Known combinations of ΔT and V are substituted into the above equation and the regression coefficients are calculated by the method of least squares.

The main value of this approach is in the extrapolation of results beyond a measurement period. Typically, hourly rates of air infiltration are continuously measured over a period of a few days. Appropriate regression coefficients are then evaluated and the performance of the infiltration equation is verified over a further short measurement period. The regression equation may then be used to estimate the air infiltration performance of the building over a wider set of climatic conditions.

The main disadvantage of this method is that the calculated regression coefficients are unique to the building since they reflect not only the airtightness performance of the building but also its orientation with respect to adjacent obstructions. It is therefore not possible to transfer the data to other buildings. Although representative values of regression coefficients have been published for design purposes, they can be very unreliable.

Theoretical network models

The severe limitations imposed by the preceeding techniques render them unsuitable for detailed design calculations. Instead, consideration must be given to a theoretical analysis of the problem. Such methods take the form of a flow network in which nodes representing regions of differing pressure are interconnected by leakage paths. This network is described by a set of simultaneous equations formed by applying an appropriate flow equation to each path. These equations are then solved by determining an internal pressure distribution such that a mass flow balance is preserved between the infiltrating and exfiltrating air masses.

Theoretical models of varying degrees of complexity are available and it is important therefore to make the correct selection according to both building type and intended application. The simplest of all network models approximates the interior of a building as a single zone at uniform pressure. This approximation is generally satisfactory for industrial type buildings such as factories and warehouses and for calculating the overall air change rate in dwellings. However, where partitioning presents an impedence to the general movement of air, it is necessary to divide the interior of the buildings into discrete zones with interconnecting flow paths. Such an approach is almost always necessary in commercial and multi-storey buildings in which floor space is partitioned into office accommodation or in which individual floors are connected by lift shafts and stairways, etc.

Simplified theoretical techniques

A number of 'simplified' methods have been introduced in an effort to minimise the computational effort of theoretical techniques yet enable some of the accuracy of these methods to be retained. As yet they are only applicable to single zone structures and only provide estimates of infiltration. They give no indication of the pattern of air distribution. Two such methods have been analysed by the Air Infiltration and Ventilation Centre and have been found to give satisfactory results for a range of dwellings and climatic conditions (6). These methods have been developed by the Building Research Establishment in the United Kingdom (BRE model) (7) and the Lawrence Berkeley Laboratory in the United States (LBL Model) (8).

Algorithms

Algorithms dealing with empirical type calculation methods may be readily located in the CIBSE Guide (2) and ASHRAE Fundamentals (3). No computing requirements are necessary and it should be possible to perform these calculations with ease. In contrast, the algorithms used to solve network problems are necessarily much more demanding and computing resources are essential. Many of the early methods required main-frame computing facilities and were therefore not generally available. Network type algorithms are available on a commercial or consulting basis from several organisations specialising in building services software. There are also a small number of published routines that can be adapted to suit individual needs. One such algorithm has been published by the National Bureau of Standards in the United States (9). This is a comprehensive multi-zone technique published in FORTRAN IV. It has been used to analyse air infiltration and inter-room air flow rates in commercial buildings. More recently this algorithm has been successfully run on an IBM-AT micro computer for flow networks of up to seven zones for a total of 37 flow paths (10). A multi-zone network model for operating on an IBM PC has also been developed by the Building Research Establishment (11) in the United Kingdom. The increasing availability of network models for the small computer is an important advance and will hopefully lead to the wide use of multi-zone methods in the design of energy efficient ventilation techniques.

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