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MATHEMATICAL MODELLING APPROACHES TO AIR INFILTRATION AND VENTILATION APPLICATIONS

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The objective of this paper is to highlight the range of air infiltration and ventilation models that are available to the designer and to indicate the appropriate level of associated computer hardware that is necessary to support these modelling methods.

The paper concludes with a description of some currently available algorithms, guidelines on selecting an appropriate technique for specific applications and an analysis of the reliability and uncertainties of present calculation methods.

INTRODUCTION

Air infiltration and ventilation has a profound influence on the internal environment and the energy needs of buildings. Inadequate attention to ventilation may result in an unacceptable indoor climate which, under extreme conditions, can be harmful to occupants. On the other hand, unnecessarily high air change rates will present an excessive burden on a building's heating (or cooling) system, resulting either in an unnecessary waste of energy or in the inability of the heating or airconditioning system to satisfy thermal requirements. Problems relating to moisture migration, cold draughts and a generally uncomfortable living or working environment may also be experienced. This subject has therefore become a key factor in both energy conservation and indoor air quality studies.

Ventilation requirements are frequently satisfied by means of natural air infiltration, coupled with the use of openable windows, vents and stacks. However, problems associated with widely varying air change rates, poor control and uncertain air distribution have become important considerations in the design of modern energy efficient ventilation systems. Although mechanical ventilation can overcome these problems, the benefits provided by such an approach may easily be destroyed by inadequate attention to the interaction of intentional ventilation with air infiltration. Thus a poorly implemented strategy, combined with an inappropriately designed building shell, may adversely affect energy needs and indoor climate. Poor design may also be expected to affect the reactions of occupants, especially in relation to window opening behaviour.

Despite the importance of the process of air infiltration, it is still an aspect of building physics about which there is considerable uncertainty. In part, this problem has been made difficult by the diverse range of buildings, each constructed according to widely varying specifications and site practices. In the past, progress has also been hampered by the inherent difficulty of actually making measurements which, in turn, has resulted in a wholly inadequate database for use in the development of predictive techniques. Furthermore, the complexities of the flow mechanisms themselves have added to the difficulty of quantifying infiltration rates. It is this lack of understanding which has frequently resulted in deficiencies in design. Often airtightness measures are misunderstood and are applied without due consideration to ventilation needs or ventilation approach. The outcome may be reflected in moisture problems, severe contamination of the indoor air and possibly backdraughting from flues and exhaust vents. Clearly, good design will minimise the problem, yet without explicit guidance there is little that can be accomplished to improve design methods.

Recently, advances in both experimental techniques and mathematical modelling methods have resulted in a considerable improvement in the understanding of air infiltration. The use of tracer gas as a direct measure of air infiltration has been developed to the point where measurements are relatively straightforward to perform. By combining the results of many measurements, a general pattern of air change relationships is emerging. Additionally, by using the data to verify the performance of numerical models, it has become possible to develop very powerful predictive methods. As a consequence, mathematical models are now capable of playing a fundamental role in the design and evaluation of energy efficient ventilation strategies. By combining the design air leakage and ventilation parameters of a building with local terrain and climatic data, mathematical models can provide a reliable route to the estimation of air change rates.

It is the objective of this paper to outline some of the calculation techniques available for air infiltration and ventilation rate design calculations and to provide an indication of the most appropriate methods for specific applications. Data and computer needs are also summarised. This presentation stems from the production of a Calculation Techniqes Applications Guide in which comprehensive details of calculation techniques, algorithms and data sets have been compiled (1).

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. In the following, a brief description of these methods and the applications appropriate to each technique are outlined.

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. Two methods are outlined in the CIBSE Guide. In the first, infiltration is calculated by graphical means using local wind speed, building height and window quality data. A basic infiltration rate is calculated based on design wind speed. Adjustments are then made to individual room rates according to window distribution and room level. The second approach makes use of a table of expected values for buildings of typical construction.

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 on how infiltration will be affected by wind, temperature, terrain and shielding. However, numerous experimental tests have shown that the approximate air infiltration rate will be of the order of 1/20th of the measured air change rate at 50 Pa, i.e.

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

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, i.e.

$$I = A + B\Delta T + CV \tag{1}$$

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. The latter approach is normally also necessary for air movement and indoor air quality design predictions in dwellings.

The decision chart presented in Figure 1 is intended to assist the user in deciding between a multi- or single-zone approach. There are two possible starting positions depending on the type of building under consideration. The alternatives are the ostensibly single zone and the ostensibly multi-zone building. Whenever possible it is preferable to 'coerce' the building into a single zone structure, since this considerably simplifies the calculation. Indeed, if a single zone approximation is not possible, then none of the empirical methods will normally be suitable. Furthermore, if computational resources are limited or if insufficient data are available, then the single zone approximation may prove to be the only option available to the user.

The most commonly used equation to present flow through an opening (2) is given by

$$Q = k(\Delta p)^n \qquad m^3/sec \tag{2}$$

where, k = flow coefficient
n = flow exponent ($0.5 \leqslant n \leqslant 1$)
Δp = pressure difference across opening (Pa)

An alternative formulation which is sometimes regarded as being more theoretically accurate (5) is

$$\Delta p = A'Q + B'Q^2 \tag{3}$$

where, A' and B' are constants

In both cases the pressure difference, Δp, is generated by the actions of wind, temperature ('stack effect') and mechanical ventilation. The principal wind and temperature pressure equations are given by

$$p_w = \frac{\rho}{2} C_p \bar{V}^2 \qquad (Pa) \tag{4}$$

where, p_w = pressure due to wind with respect to free stream (Pa)

C_p = pressure coefficient (reference 1 provides sample data)

$\bar{V}$ = mean wind velocity at a specified datum level (usually building height) (m/s)

ρ = air density,

and

$$p_s = -\rho_0 g \; 273 \left[\frac{1}{T_{ext}} - \frac{1}{T_{int}}\right] (h_2 - h_1) \qquad \textbf{(Pa)} \qquad \textbf{(5)}$$

where, p_s = stack induced pressure at level h_2 with respect to an opening at level h_1 (Pa)

g = acceleration due to gravity (m/s^2)

ρ_0 = density of air at 273K

T_{ext} = external temperature (K)

T_{int} = internal temperature (K)

The derivation of these equations and sufficient data to implement them are presented in reference 1.

In the single zone formulation any number of flow paths, terminating within the internal zone, can be selected to represent leakage openings in each face of the building.

For j such flow paths, a mass flow balance is given by

$$\sum_{i=1}^{j} \rho_i Q_i = 0 \quad (Kg/s) \qquad \textbf{(6)}$$

where, ρ_i = density of air flowing through i'th flow path (Kg/m^3)

Q_i = volumetric flow rate (m^3/s)

By substitution of the above in the power law form of the flow equation (Equation 2), the condition of mass balance becomes

$$\sum_{i=1}^{j} \underset{\substack{\uparrow \\ \textit{Term 1}}}{\rho_i} \; \underset{\substack{\uparrow \\ \textit{Term 2}}}{\underbrace{k_i |p_i - p_{int}|^{n_i}}} \; \underset{\substack{\uparrow \\ \textit{Term 3}}}{\left(\frac{p_i - p_{int}}{|p_i - p_{int}|}\right)} = 0 \qquad \textbf{(7)}$$

where, k_i = flow coefficient of the i'th flow path

n_i = flow exponent of the i'th flow path

p_i = external pressure acting on the i'th flow path

p_{int} = internal pressure

ρ_i = density of air mass in the i'th flow path

For infiltrating air the density, ρ_i, is given by that of the outside air while for the exfiltrating air it is given by that of the internal air mass. If the density differences between the internal and external air masses are negligible in comparison to the magnitude of the overall density of air, i.e. when the internal/external temperature difference is less than approximately 20°C, then Term 1 of Equation 7 may be ignored. The problem then becomes one of balancing the volume flow rate rather than the mass flow rate. Term 2 expresses the absolute value of the internal/external presure differences across each opening and is applied to avoid exponentiating a negative number when $p_i < p_{int}$. Term 3 restores the sign of the flow direction which was lost in the previous term.

The values of ρ_i, k_i, n_i and p_i must be specified for each flow path, leaving the internal pressure, p_{int}, as the only unknown.

The infiltration rate is given by

$$Q_{inf} = \sum_{i=1}^{j} Q_i \text{ (for } Q_i > 0) \quad (m^3/sec) \tag{8}$$

and the hourly air change rate is given by

$$ACR = \frac{Q_{inf} x\ 3600}{Vol} \quad (ach) \tag{9}$$

where, Vol = internal volume of zone (m^3)

Mechanical extract or supply ventilation is most easily incorporated by expanding the mass balance Equation (6) to give

$$\rho Q_{mv} + \sum_{i=1}^{j} \rho_i Q_i = 0 \tag{10}$$

where, Q_{mv} is the mechanical ventilation rate.

In the multi-zone formulation, flow paths terminating within each internal zone are again selected to represent leakage openings in the building envelope. Additionally, paths are selected to represent leakage openings across internal zones. For the m'th such zone with a total of j_m flow paths, the mass flow balance is given by

$$\sum_{i_m = 1}^{j_m} \rho_{im} Q_{im} = 0 \quad (Kg/s) \tag{11}$$

where, Q_{im} = volumetric flow rate through the i'th flow path of the m'th node.

ρ_{im} = density of air flow through the i'th flow path of the m'th node (Kg/m^3)

Analogous to the single cell version (Equation 7), substitution of the above in the power law form of the flow equation (Equation 2) gives

$$\sum_{i_m = 1}^{j_m} \rho_{im}\, k_{im} \left|p_{im} - p_m\right|^{n_{im}} \left(\frac{p_{im} - p_m}{\left|p_{im} - p_m\right|} \right) = 0 \tag{12}$$

where, k_{im} = flow coefficient of the i'th flow path of the m'th zone.

n_{im} = flow exponent of the i'th flow path of the m'th zone.

p_{im} = pressure of zone adjacent to the m'th node across which the i'th flow path connects.

p_m = internal pressure of m'th node.

The mass balance equation must apply to each zone. Therefore, assuming a total of ℓ zones, total mass balance is given by

$$\sum_{m=1}^{\ell} \sum_{i_m=1}^{j_m} \rho_{im} k_{im} \left| p_{im} - p_m \right|^{n_{im}} \left(\frac{p_{im} - p_m}{|p_{im} - p_m|} \right) = 0 \qquad (13)$$

Unlike the 'single cell' approach, where there was only one internal pressure to determine, there are now ℓ such values. This adds considerably to the complexity of the numerical solution method.

An important advantage of the multi-zone network method is that not only can it be used to calculate air infiltration rates but it also enables flow rates between rooms to be determined. This can be a very useful application in indoor air quality studies.

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 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).

The purpose of the BRE method is to provide a technique for relating the air infiltration rate for any given set of conditions to the leakage characteristics of the building as determined by a pressurization test. Air movement under ambient conditions is described by the power law equation

$$Q_V = Q_T \left[\frac{\rho_0 V^2}{\Delta P_T} \right]^n F_V(A_r, \emptyset) \qquad (m^3/s) \qquad (14)$$

where, Q_V = ambient flow rate (m³/s)

Q_T = flow rate at an arbitrarily chosen reference pressure (m³/s)

ρ_0 = air density (Kg/m^{-3})

V = wind speed at roof ridge height (m/s)

ΔP_T = internal/external pressure difference (Pa)

F_V = infiltration rate function (see text)

A_r = Archimedes number

$\emptyset$ = surface pressure function

For wind action alone, this equation reduces to

$$Q_W = Q_T \left[\frac{\rho_0 V^2}{\Delta P_T} \right]^n F_W(\emptyset) \qquad (m^3/s) \qquad (15)$$

where, F_W = wind infiltration function

While, for stack effect only, the flow equation becomes

$$Q_B = Q_T \left[\frac{\Delta T \rho g h}{T_I \Delta P_T}\right]^n F_B \qquad (m^3/s) \tag{16}$$

where, F_B = stack infiltration function
ΔT = internal/external temperature difference (K)
T_I = internal temperature difference (K)
g = acceleration due to gravity (m/s^{-2})
h = height of building (m)

The infiltration function F_B is determined by the building shape and the distribution of leakage; F_W in addition depends upon the surface pressure coefficients, while F_V includes the effects of the major weather dependent parameters V and ΔT.

The LBL model was developed to predict the impact on air infiltration rates of retrofit and other changes in the building envelope using the minimum number of model parameters. The model was specifically designed for simplicity and therefore precise detail was sacrificed for ease of application.

The building is approximated by a single rectangular structure of 'single zone' construction through which air flow is described by the equation

$$Q = A \left[\frac{2}{\rho} \Delta P\right]^{\frac{1}{2}} \qquad (m^3/s) \tag{17}$$

where, A = effective leakage area (m^2)
ρ = air density (Kg/m^3)
ΔP = internal/external pressure difference (Pa)

The effective leakage area, A, is determined by means of a building pressurization test or may be taken from data presented in Chapter 22 of the ASHRAE Fundamentals (3).

The rates of air infiltration due to wind and stack driven pressure differences are calculated independently and are combined by summing the results in quadrature. The influence of mechanical ventilation systems is similarly included in the quadrature equation to yield a total ventilation rate of

$$Q_{total} = (Q^2_{stack} + Q^2_{wind} + Q^2_{vent})^{\frac{1}{2}} \qquad (m^3/s) \tag{18}$$

where, Q_{stack} = $A\, f_s \Delta T^{\frac{1}{2}}$ = stack infiltration (m^3/s)
Q_{wind} = $f_w V_c$ = wind infiltration (m^3/s)
Q_{vent} = flow rate of mechanical ventilation system (m^3/s)
ΔT = internal/external temperature difference (k)
V_c = wind speed at ceiling height (m/s)
and f_s and f_w are stack and wind parameters respectively (see Ref.9)

Operational details of each of these categories of calculation methods are summarised in Table 1 and a guide to the most appropriate calculation technique for some specific applications is presented in Figure 2.

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. Regression methods can be successfully executed using the statistical functions of a pocket calculator to evaluate the regression coefficients.

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 7 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). 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. Despite this improvement of software availability, many users may still require the relative calculation simplicity of the 'simplified' theoretical techniques. Although sufficient calculation information can be obtained from the source papers to produce the necessary algorithms, there are no published algorithms as such. In an attempt to alleviate this problem, a step-by-step example of the application of the LBL method (8) has been included as a worked example in the Air Infiltration Centre's guide to calculation techniques (1).

DISCUSSION AND CONCLUSIONS

The prediction of air infiltration and ventilation rates in buildings has always been uncertain. In many instances accurate estimates are not needed but in others, especially in indoor air quality and energy conservation applications, reliable estimates are essential. To suit these various needs, a wide choice of calculation techniques is available. However, it must be noted that there is always a trade-off between accuracy, ease of use and data requirements. While, for example, a theoretical network method may be used for almost any application, it requires extensive flow path information and also a greater level of computer sophistication than any of the empirical methods. Since the level of effort the user has available may be an important consideration, guidance in this paper has concentrated on directing the user to the simplest technique for a given application (see Figure 2).

As regards current level of accuracy, the Air Infiltration Centre's programme of model validation (6) showed that for buildings up to approximately 500 m^3, many theoretical network methods gave predictions within ±25% of measured infiltration rates. The key to good results is the accurate interpretation of input data.

An area in which the performance of infiltration calculation methods is less well known is in estimating air change rates in large commercial and industrial buildings. This is a very important application and, while network models may be used to calculate infiltration rates in such buildings, validation results are sparse.

One of the principal aims of the Centre's Application Guide (1) has been to summarise published data for use in air infiltration calculations and to provide step-by-step guidance on the application of numerical techniques.

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(a) Empirical methods

Technique	Data requirements	Availability of algorithms	Advantages	Disadvantages
Air change methods	Basic building design details (size, height, etc)	CIBSE and ASHRAE guides provide sufficient operational guidance	- Ease of use - No computing facilities required	- Does not provide detailed infiltration predictions
Reduction of pressurization test data	Pressurization test data	None required	- Ease of use - No computing facilities required	- Applies only to existing buildings in which pressurization test data is available. - Does not indicate the effects of weather, shielding and terrain conditions.
Regression methods	Infiltration measurement data with corresponding wind and temperature records.	ASHRAE Fundamentals	- Fairly easy to use. Regression coefficients may be calculated using the statistical functions on a pocket calculator. - Gives weather dependent infiltration predictions. - Can give reasonable results if care is taken to calculate regression coefficients.	- Only really applies to existing building in which tracer gas measurements have been made. - Typical regression data are available but they can give very unreliable results.

(b) Theoretical methods

Network models	- Building description (size, dimensions, orientation, number of cells) - Surrounding shielding data. - Terrain roughness. - Flow path data. (location and description of leaks)	NBS Algorithms, also commercial algorithms are available.	- Predicts air distribution patterns. - Determines internal pressure distribution. - Responsive to weather, terrain and shielding parameters. - Moderately sizeable networks can be run on small computers. - May be used for combined air infiltration and mechanical ventilation calculations.	- Substantial data may be required to describe flow network. - Considerable computational effort.
Simplified theoretical models	- Air leakage characteristics of building, e.g. pressurization test data. - Shielding data. - Terrain roughness.	No specific algorithm has been published although sufficient details can be obtained from source papers.	Offers a compromise between the complexity of network models and the inaccuracy of empirical techniques.	- Only applicable to single zone structures. - Provides no information on the direction of air movement.

Table 1: Summary of calculation techniques

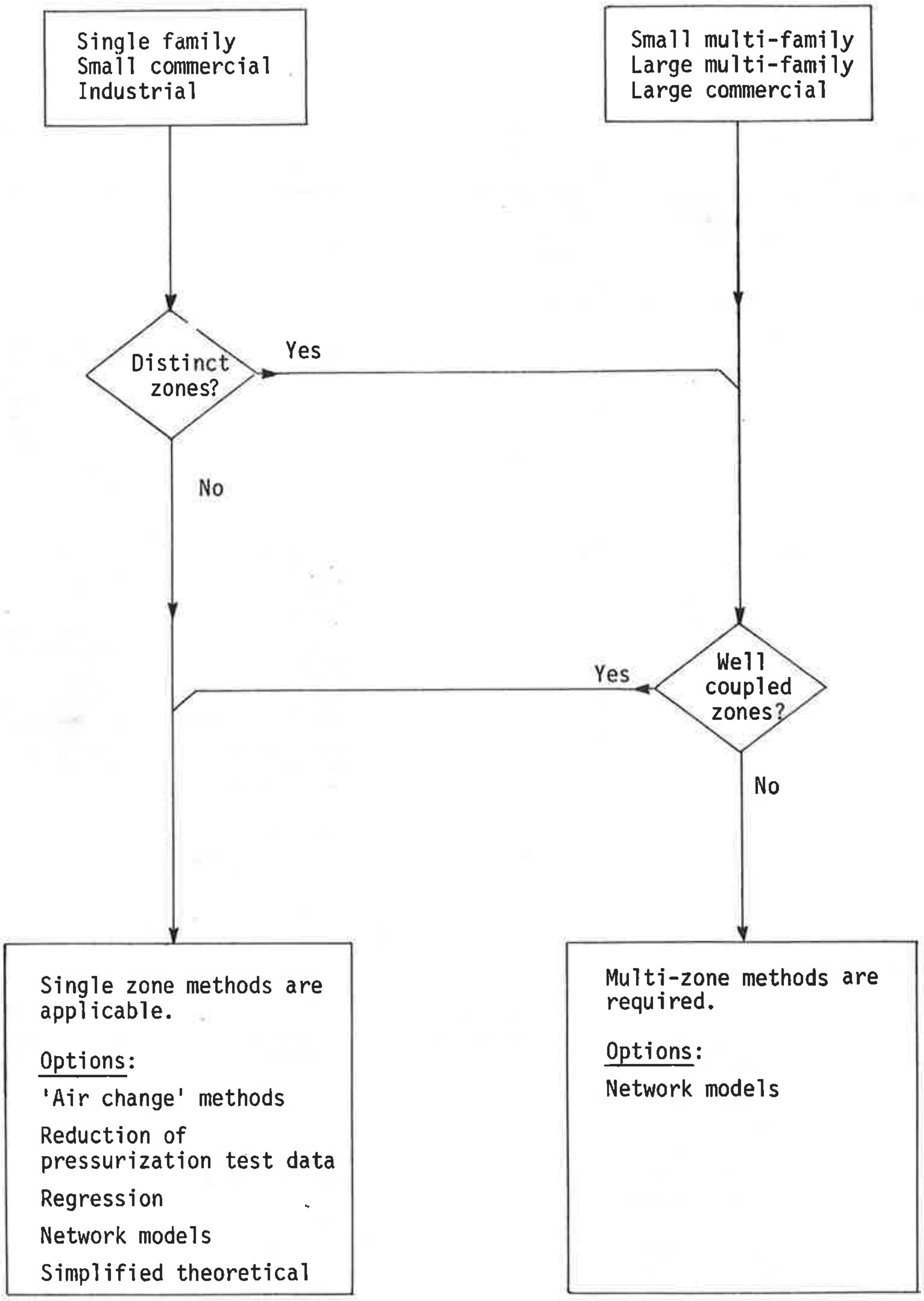

Figure 1: Single zone/multi-zone selection

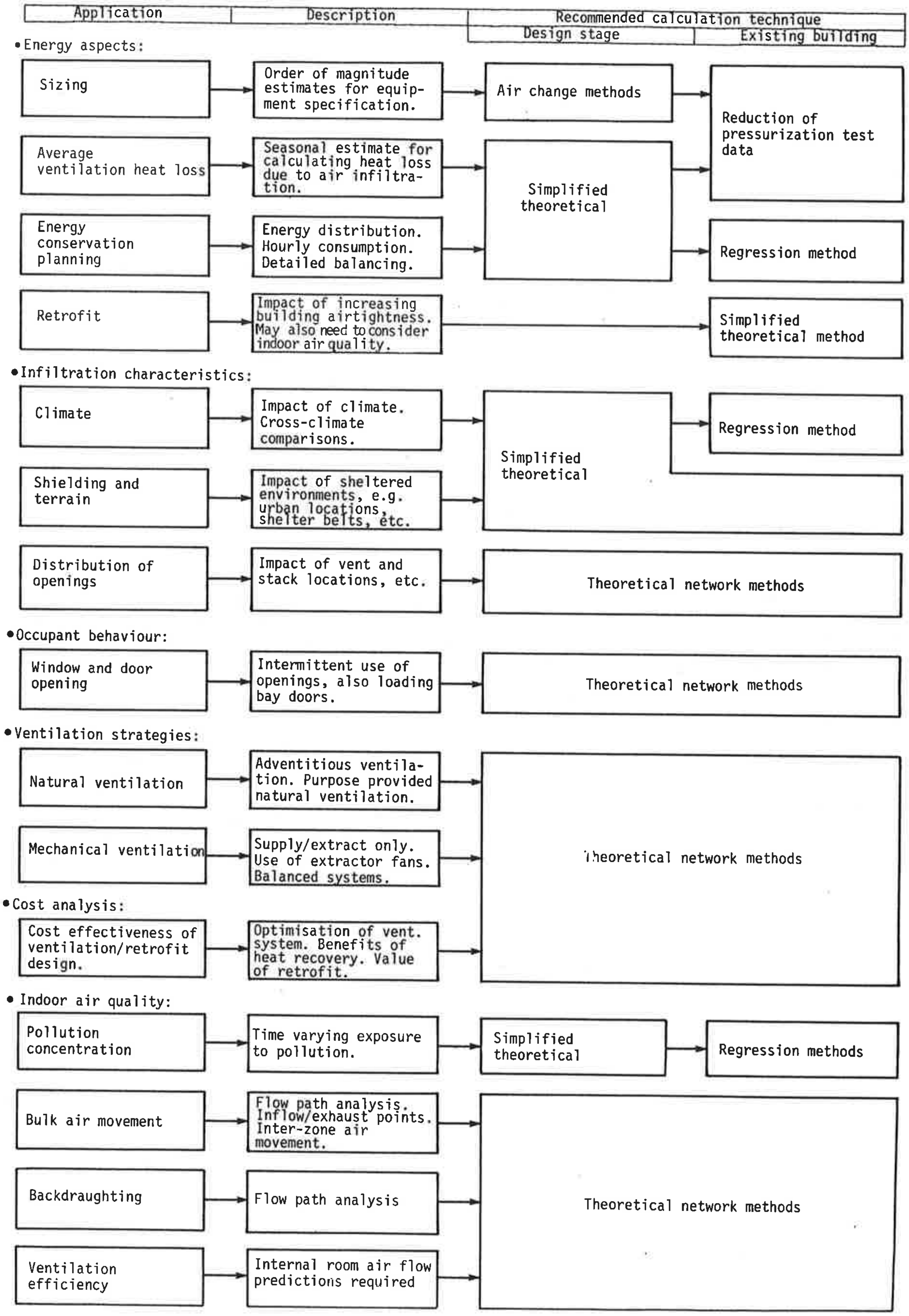

Figure 2: Selection of calculation technique

NUMERICAL SOLUTION OF VENTILATION AIR JET

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The significance of predicting the diffusion characteristics of ventilating air jets in air distribution design is discussed. A finite difference solution of a two-dimensional wall jet using existing numerical methods and standard turbulence models is corroborated by experimental results. The numerical solution is then extended to include wall jets with extensive recirculation zones caused by a wall facing the supply slot or a ceiling-mounted obstacle. It is shown that the effect of a facing wall on the flow of the jet in the vicinity of the wall could be more significant than that specified by diffuser-testing standards (e.g. BS4773). The numerical solution also predicts the separation of a wall jet due to a surface-mounted obstacle accurately.

INTRODUCTION

In most mechanically ventilated buildings a wall jet is used to diffuse the air stream into the required space. A wall jet is used in preference to a free jet so that high velocity regions of the flow may be restricted to the internal surfaces of the building thus freeing the occupied zone of uncomfortable draughts. When the air supply is utilised as an energy distribution medium in the space being cooled or heated, the efficacy of the environmental plant is often determined by the effectiveness of the air distribution system. A theoretical solution of the wall jet equation was first obtained by Glauert/1/ using an integral method by matching the inner boundary layer type of flow with the outer free-mixing layer. The advent of computers has encouraged the development of differential computational techniques for the time - average solution of the turbulent flow equations/2-4/. These calculation procedures require a turbulent model to represent the unsteady nature of the flow by time-average properties. Because of their relative ease of application, the most popular turbulence models are the mixing length hypothesis (a single-equation model) and the k-ε model (a two-equation model)/5/.

Extensive experimental data on isothermal and non-isothermal plane wall jets is available in the literature/6-8/. In practical HVAC applications the flow in a ventilation wall jet is often disturbed by light fittings, ceiling beams, coffers, opposite wall etc. These interference elements could have a major influence on the development of the flow within the jet and ultimately on the distribution of energy within the occupied spaces.

This paper discusses the importance of predicting the diffusion characteristics of ventilating air jets and examines some common practical situations affecting this diffusion. Numerical solutions of these situations are presented and are based on existing turbulent flow, finite difference computational methods. Where available, experimental data are used to corroborate the computational results.

THE WALL JET AND ROOM AIR MOVEMENT

The air supply terminals of a ventilated room are often located on the ceiling or on a side wall close to the ceiling. Slot or linear diffusers producing a plane wall jet are commonly used. For most high level supplies close to the ceiling, the air jet attaches to the ceiling by the Coanda effect producing a flow similar to ceiling-mounted diffusers. The region between the ceiling and the occupied zone serves as an entrainment region for the jet which causes a decay of the velocity in the main jet as a result of the increase in the mass flow. A good