A study of the controllability of air movements in predominantly naturally ventilated houses.

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A STUDY OF THE CONTROLLABILITY OF AIR MOVEMENTS IN PREDOMINANTLY NATURALLY VENTILATED HOUSES

by

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Abstract

Ian Lee Jennett; A study of the Controllability of Air Movements in Predominantly Naturally Ventilated Houses

The aim of this study is to measure interzonal airflows through different doorway openings, due to the effects of temperature difference and combined temperature and pressure difference.

The method of measurement uses tracer gases which are injected into spaces and their growths and decays are monitored. These concentration histories, when suitably analysed, reveal the interzonal airflow rate.

Empirical formulae describing the interzonal airflow rate as a function of temperature difference are derived for different door opening positions.

The test measurements are split between controlled laboratory conditions and site conditions, which are subjected to the influence of the weather. Comparison is made between the two separate conditions, the parametric effects of the weather being investigated.

The control of interzonal airflow rates in houses is investigated.

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Chapter 1 Introduction

The advent of increased costs for primary fuels, especially since the 1973 oil crisis, has resulted in a growing awareness by society of the need to conserve energy. If one considers that approximately 30% of the primary energy used is in the domestic sector (18), then a relatively modest reduction in energy consumption would create significant savings. Consequently, a great deal of research effort has been undertaken to achieve practicable energy conservation in dwellings.

These energy conservation techniques may have one of two forms. First to increase the thermal resistance of the building envelope, and secondly to control the rate of ventilation and air movement inside the building envelope. Increasing the thermal resistance can be achieved by cavity wall insulation, loft insulation and insulated batts between the joists of suspended ground floors.

The second problem of reducing the natural ventilation and internal air movement is more complicated in practice. The two physical mechanisms of dwelling ventilation are wind and internal to external temperature differences. The driving mechanism of air leakage is the pressure differences caused by these two parameters.

Infiltration of cold air, and the exfiltration of warm air occurs through openings in the building envelope. Such openings are of two distinct types; adventitious and purpose provided. Adventitious openings generally occur in the form of cracks around doors and windows, purpose provided openings are incorporated into the building at the design stage, and may comprise of airbricks, window ventilators and chimneys.

The development of predictive techniques for calculating air infiltration rates have been reported (2,3,6). Success has been shown to be limited due to the complex nature of the way in which wind speed, direction, internal/external temperature differences, building shape and local terrain effects all contribute to the overall ventilation rates.

Of increasing interest is the movement of air between the internal spaces of dwellings (5,7,14,18). These are of interest to building designers, since air movements can affect the temperature in living areas, and can cause condensation where moist air is carried to a cold surface. An illustrative example of this is when the airflow is from moisture producing areas such as the kitchen, and unheated bedrooms or roofspaces. Bedroom condensation can cause mould growth, creating an unhealthy environment. The migration of water vapour to the roofspace can also create mould growth, and in extreme cases, rot. The thermal resistivity of any insulating material can also be detrimentally affected.

Work such as (37,44,45) have attempted to derive, theoretically, the dependence of the airflow rate on temperature difference across the doorway. Limited data is available in defining this airflow as a function of temperature difference. There appears to be gap in the knowledge for experimentally derived formulae for this dependence; this project attempts to close the gap by deriving empirical formulae, under both laboratory and site conditions. Site tests are performed under a wide range of prevailing weather conditions.

These measurements are made specifically using either the single or multiple tracer gas technique. Emphasis is made on the portability of the measuring equipment, as this can be seen to be an aid to the building designer in providing quick and easy airflow measurements, and not simply a research tool. Whilst accuracy in determining the airflow rates is seen to be important, of equal importance is the realisation that any derived formulae will only be of the most general in nature, due to the unpredictable influences of the weather. These empirical formulae may be of interest to the building designer, since they may also be used to predict the heat transfer between zones.

The degree of controllability of interzonal airflows for different door positions may also be gauged from these equations.

The use of mechanical extract fans in controlling interzonal airflows is also investigated. These are seen as perhaps the most powerful method of controlling interzonal airflows.

The following gives a brief summary of all the chapters in this thesis;

Chapter 2 describes the fundamental theory and practice of measuring air change rates and interzonal airflows. It proceeds to describe, in greater detail, the theory and practice of the chosen method of analysis used in this project.

Chapter 3 describes the fundamental theory and practice of evaluating building and individual building component airtightness.

Chapter 4 describes the testing facilities which were available for the duration of the Project. These were split between laboratory and site conditions. Under site conditions, the effects of the weather could be investigated.

Chapter 5 describes a simple theoretical analysis of the airflow through a doorway due to the effects of a temperature difference on either side of the door.

Chapter 6 describes the experimental measurements of temperature driven airflows through doorways under laboratory conditions, for 2 zones. These measurements were performed for 3 different door opening positions, for which empirical formulae are derived.

Chapter 7 describes the experimental measurements of temperature driven airflows under site conditions, for 2 zones. These measurements were performed for 2 different door positions, for which empirical formulae are derived.

Chapter 8 describes the theory of airflows through doorways due to the combined effects of temperature and pressure difference. The practice of measurements under laboratory conditions are described for a single door position, for which an empirical equation is derived.

Chapter 9 describes the experimental measurements of combined temperature and pressure difference driven flows through doorways, under site conditions. A single door position is investigated, for which an empirical formula is derived.

Chapter 10 describes the experimental measurements of temperature driven flows through doorways, extended to three zones.

Chapter 11 describes the conclusions of the project, and recommendations for future work.

CHAPTER 2 MEASUREMENT OF AIR EXCHANGE RATES

LIST OF SYMBOLS

Cb	Background concentration of tracer gas.
Ci	Concentration of tracer gas in cell i
Co	Concentration of tracer gas at time zero
Ct	Concentration of tracer gas at any time t
CA1	Concentration of tracer gas A in Zone 1
CA2	Concentration of tracer gas A in Zone 2
$\widetilde{CA}1$	Mean concentration of tracer gas A in Zone 1
$\widetilde{CA}2$	Mean concentration of tracer gas A in Zone 2
CB1	Concentration of tracer gas B in Zone 1
CB2	Concentration of tracer gas B in Zone 2
$\widetilde{CB}1$	Mean concentration of tracer gas B in Zone 1
$\widetilde{CB}2$	Mean concentration of tracer gas B in Zone 2
COA1	Initial concentration of tracer gas A in Zone 1
COA2	Initial concentration of tracer gas A in Zone 2
COB1	Initial concentration of tracer gas B in Zone 1
COB2	Initial concentration of tracer gas B in Zone 2
δij	Kronecker delta function (simple either/or operation)
K	No. of time periods in two zone analysis
N	Air change rate (ac/s)
N1	Air change rate in Zone 1 (ac/s)
N2	Air change rate in Zone 2 (ac/s)
N1'	First approximation of air change rate in Zone 1 (ac/s)
N2'	First approximation of air change rate in Zone 2 (ac/s)
Si	Net flow from ith Zone to outside (m3/S)
Sj	Net flow from jth Zone to outside (m3/S)
Q	Airflow rate through test space (m3/S)
Q12	Airflow from Zone 1 to Zone 2 (m3/S)
Q21	Airflow from Zone 2 to Zone 1 (m3/S)
Qij	Airflow from Zone i to Zone j (m3/S)
Qji	Airflow from Zone j to Zone i (m3/S)
Qio	Airflow from Zone i to outside (m3/S)
Qoi	Airflow from outside to Zone i (m3/S)
Qp	Production rate of tracer gas in test space (m3/S)
Qpi	Production rate of tracer gas in Zone i (m3/S)
V	Effective volume of Test Space (m3)
Vi	Effective volume of Zone i (m3)
V1	Effective volume of Zone 1 (m3)
V2	Effective volume of Zone 2 (m3)

Chapter 2 Measurement of Air Exchange Rates

Introduction

This chapter examines the fundamental theory and practice of measuring air change rates and interzonal airflows. It proceeds to describe, in greater detail, the theory and practice of the chosen method of analysis used in this particular project.

2.1 Measurement of Air Change Rates

A method of measuring the bulk movement of air into and out of a test space involves the injection and monitoring of a tracer gas within the test space. The concentration of tracer gas in the test space may be expressed by a fundamental tracer gas equation, as described below;

$$V \frac{dc}{dt} = Q\ (\ Cb - Ct\ ) + Qp \qquad 2.1$$

where the symbols have the following meaning;

V = Effective volume of test space (m^3)

Q = Air flow rate through test space (m^3/s)

Cb = Background concentration of tracer gas

Ct = Concentration of tracer gas at time t

Qp = Production rate of tracer gas within test space (m^3/s)

This fundamental continuity equation forms the basis of all tracer gas measurements. There are three approaches to the solution of equation (2.1) namely concentration decay, constant emission and constant concentration.

2.1.1 Measurement of Air Change Rates using the Concentration Decay method

This method is that which is most commonly used, since it is the least demanding in terms of equipment and expertise.

A small quantity of tracer gas is injected into the test space, sufficient to enable it to be measured by a suitable tracer gas analyser. When the concentration has become uniform throughout the test space, usually promoted by small electric fans, measurements are made of how the concentration of tracer gas decreases with time.

After the initial injection of tracer gas stops, also assuming that the concentration of tracer gas in the outside air is negligible or nil, and that there are no sources of tracer gas production within the test space, then equation (2.1) will reduce to;

$$V \frac{dc}{dt} = - Q \, Ct \qquad 2.2$$

separating the variables gives

$$\frac{dc}{Ct} = - \frac{Q}{V} dt \qquad 2.3$$

Assuming a steady state flow rate Q then integrating -

between the appropriate limits;

$$\int_{c_t}^{c_o} \frac{dc}{Ct} = - \frac{Q}{V} \int_{t_t}^{t_o} dt \qquad 2.4$$

where Co is the initial concentration at the beginning of the test period gives;

$$\ln Ct - \ln Co = - Q\, t \qquad 2.5$$

solving for Ct gives;

$$Ct = Co \exp\left(- \frac{Q}{V} t \right) \qquad 2.6$$

or

$$Ct = Co \exp(- N\, t) \qquad 2.7$$

where

$$N = \frac{Q}{V} \qquad 2.8$$

and N is the air change rate.

If N remains constant over the measurement over the measurement period, the tracer gas concentration will decay exponentially. If the natural logarithms of the tracer gas concentrations are plotted graphically against time, the gradient of the line of best fit is a measure of the air change rate as shown in Figure 2.1 , over the page.

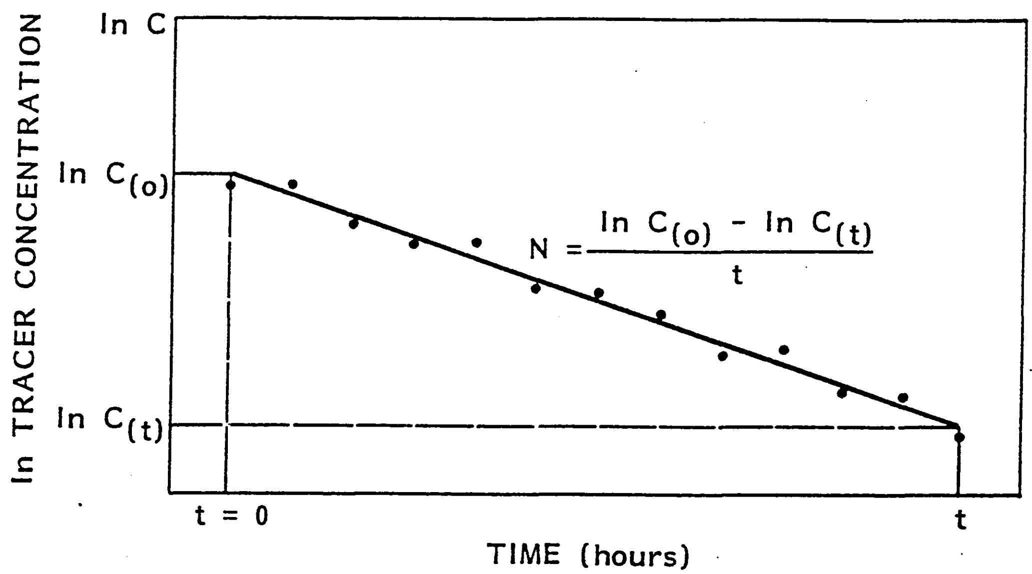

Figure 2.1 Graph of log concentration versus time

Measuring Equipment and Procedure

In its simplest form, the technique for concentration decay measurements requires the following test equipment:

A suitable tracer gas and method of injecting into the test space,
A means of mixing the tracer gas to produce an initial homogeneous concentration within the test space,
An analyser which can detect the tracer gas in the very low concentrations used for the test,
A manifold system whereby tracer gas maybe sampled from different locations within the test space,
Some means of measuring time.

A schematic of the decay method is shown in Fig. 2.2

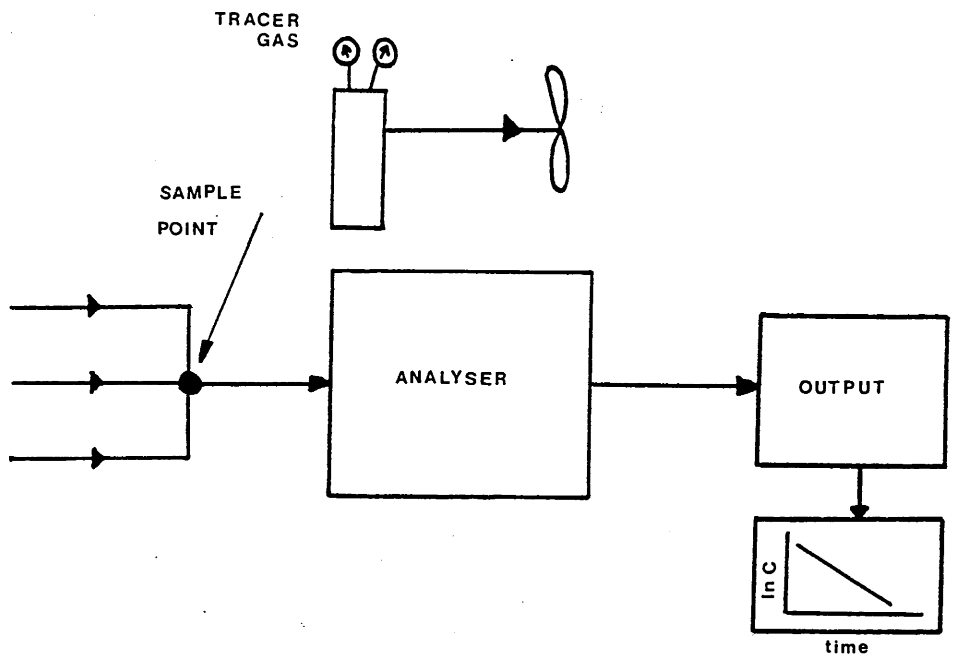

Figure 2.2 Schematic of concentration decay method

Tracer gas maybe injected into the test space directly from the nozzle of the gas bottle. This is unlikely to produce a uniform concentration, and the quantity is difficult to control.

Tracer gas maybe fed through a manifold system (1) which discharges the gas at many points throughout the test space simultaneously. Tracer gas maybe injected by gas tight syringe, filled via a septum port fitted to a gas bottle.

The air is then artificially mixed by small electric fans. Care must be taken, since this may upset the natural conditions which are to be measured. It is common practice to stop mixing and allow a short time for these conditions to return, before measurements of tracer concentration begin.

The gas analyser can be located within the test space, or removed to a semi remote location to be connected to the test space by tubing. By connecting the analyser to tubing, samples maybe taken at any location within the test space.

Adantages of the Concentration Decay Method

It is relatively easy to perform the measurements and analyse the results.

Expertise and equipment are the least demanding of the three methods.

Disadvantages of the Concentration Decay Method

If a significant volume of tracer gas is enclosed within furniture, such as cupboards or soft furnishings, then the gas decay does not decrease exponentially, making it difficult to analyse the results.

The initial preparation in creating a uniform concentration distribution within the test space, usually by electric fans, may to a certain extent, upset the natural equilibrium conditions.

2.1.2 Measurement of Air Change Rate using the Constant Emission Method

Another approach to the solution of equation 2.1 is to supply tracer gas to the test space at a uniform rate, Qp, during measurements.

This can be achieved in practice by allowing a gas cylinder to emit tracer gas at a uniform rate. Assuming that the initial concentration Co is zero and that the background concentration Cb is negligible or zero, then equation 2.1 reduces to;

$$V \frac{dc}{dt} = - Q\ Ct + Qp \qquad 2.9$$

solving for Ct gives;

$$Ct = \frac{Qp}{Q} - \frac{Qp}{Q} \exp(-Q\ t) \qquad 2.10$$

$$Ct = \frac{Qp}{Q} (1 - \exp(- N\ t) \qquad 2.11$$

Assuming that the ventilation rate N, remains constant from the time that the gas is first discharged, a finite time is needed for the tracer gas concentration to reach equilibrium. This time is determined by the transient term in equation 2.11 . When the concentration has reached equilibrium, i.e. when (1 - exp (- N t)) = 1, then equation 2.11 reduces to;

$$Ct = \frac{Qp}{Q} = \frac{Qp}{N\ V} \qquad 2.12$$

or

$$N = \frac{Qp}{Ct\ V} \qquad 2.13$$

Thus by setting the tracer gas flow to a desired value and measuring the concentration within the test space, the ventilation rate may be determined. The variation of the ventilation rate may also be measured throughout the test, since if this varies, the concentration of tracer gas will not be constant.

Measuring Equipment and Procedure

The technique of constant gas emission requires tracer gas to be injected into the test space at a known and constant rate. The essentials of the measurement technique are the same as for concentration decay, but this time some way of controlling the emission of tracer gas is required. This is usually done with fully automated equipment, controlled by a microcomputer. A schematic of the constant emission method is shown in Fig. 2.3

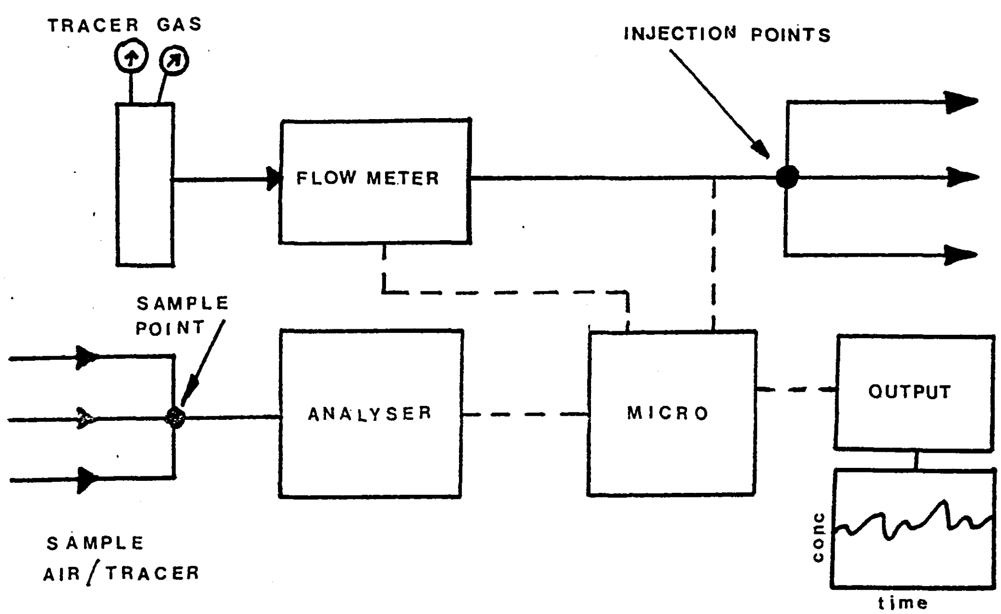

Figure 2.3 Schematic of constant emission method

In order to aid mixing, the tracer gas may be injected by tube, the mouth of which is placed near a small electric fan. Prior to measurement, it may be necessary to inject tracer gas into the test space to achieve approximate equilibrium conditions.

The tracer gas concentration is measured either continuously or at short intervals, thus essentially allowing continuous measurement of the air change rate to be made. As with concentration decay, samples are usually taken at several locations within the test space. One of the penalties of the constant emission technique is the use of large amounts of tracer gas. A careful choice of tracer gas and minimum concentration levels can reduce the problem of gas consumption and costs to a minimum (2).

Advantages of the Constant Emission Method

This method permits the continuous measurement of air change rate.
The instrumentation is simpler than for the constant concentration method.

Disadvantages of the Constant Emission Method

Considerable variations in the gas concentration can arise due to changing weather conditions effecting the building. Quite a long stabilisation period is necessary before the measurements can begin, i.e. when equilibrium concentration has been achieved. Tracer gas is consumed during this period, and this method is the most wasteful of the three techniques.

It is not always easy to achieve an absolutely constant rate of tracer gas emission.

2.1.3 Measurement of Air Change Rates using the Constant Concentration Method

In this case the concentration is held at a constant level by adjusting the input of tracer gas Qp. Since in this case the rate of change of concentration is zero, and the background concentration, Qb, is again assumed to be negligible or zero, then equation 2.1 reduces immediately to;

$$Q\ Ct = Qp \qquad 2.14$$

Hence

$$Q = \frac{Qp}{Ct} \qquad 2.15$$

If

$$N = \frac{Q}{V} \qquad 2.16$$

Then

$$N = \frac{Qp}{V\ Ct} \qquad 2.17$$

As can be seen from equation 2.17 the air change rate is directly proportional to the tracer gas injection rate required to maintain constant concentration.

Measurement Equipment and Procedure

The practical realisation of this method is probably the most demanding in terms of equipment and expertise of all the three methods. The aim is to maintain a constant level of tracer gas concentration throughout the whole of the test space. By sampling the concentration at regular intervals throughout the test, it is possible to determine the amount of tracer gas which must be injected to maintain a constant concentration. Etheridge (3) proposes continuous mixing of the air throughout the test. Since the amount of tracer gas injected is directly proportional to the air change rate, the higher the injection rate, the higher the air change rate. Because of this constant feedback between injection and concentration, this method requires a sophisticated control system (4).

A schematic of this method is shown in Fig. 2.4

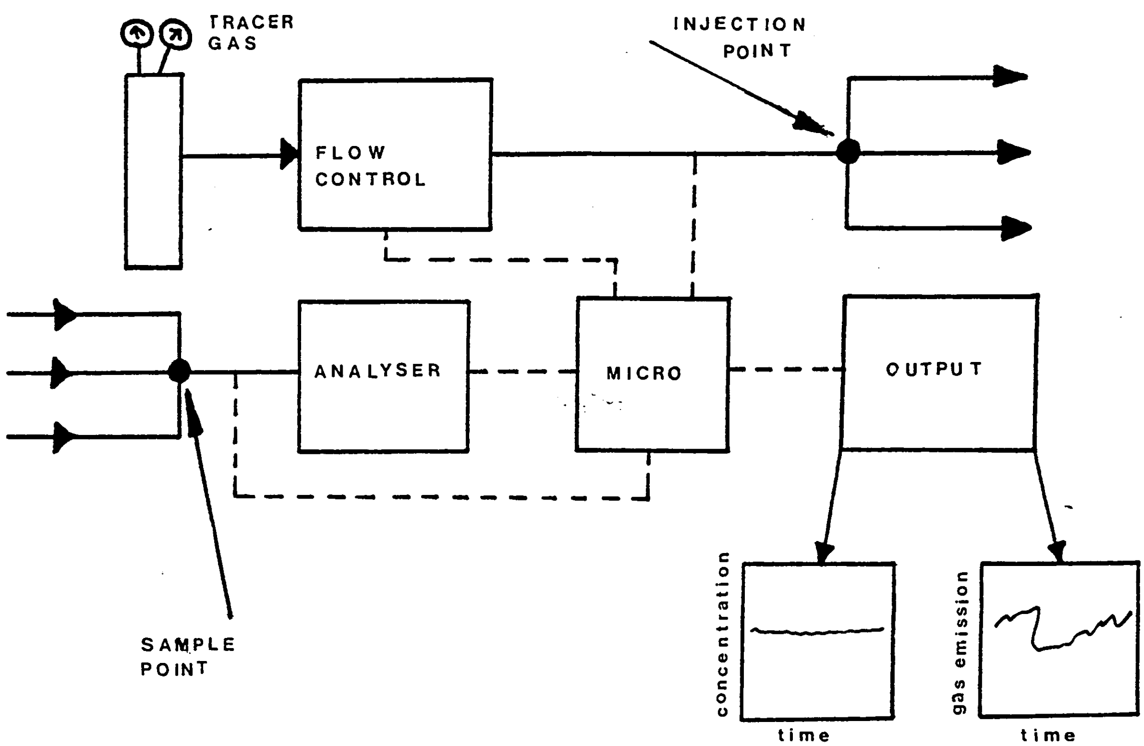

Figure 2.4 Schematic of constant concentration method

Advantages of the Constant Concentration Method

The method allows continuous measurement of the air change rate to be performed.

Disadvantages of the Constant Concentration Method

The test equipment is more complicated than in other tracer gas measurement techniques.
There is always a time lag between the gas release and reaction of the gas analyser, which can introduce errors into the analysis.
Achieving constant concentration implies continuous mixing within the test space, this may upset equilibrium conditions.

2.2 Measurement of Internal Air Flow Rates

The fundamental continuity equation assumes that the test space under investigation is a single, well mixed enclosure. This is adequate in many cases to enable the air flow rate into a space to be measured using the tracer gas techniques. Recently air flows between internal spaces and air flows between individual internal spaces and the outside environment have been the subject of much interest and research (5,6,7,8). Interzonal air movement is important when considering the migration of pollutants from one part of a building to another. For example, if water vapour is transported from producing areas such as the kitchen or bathroom to cooler areas such as the roof space or bedrooms, then condensation problems may occur.

2.2.1 Theory of Interzonal Air Flows

Measurement of these interzonal air flows may also be performed by the use of the tracer gas techniques. Again the analysis has as its starting points the fundamental continuity equation. The building of interest is assumed to consist of a number of physical cells each of which contain air and tracer gas which are perfectly mixed. The flows of air and tracer gas into and from other cells are also assumed to be well mixed and instantaneous.

For these purposes the number of cells required to describe the building will depend on how the internal doors are set. If for example all doors are fully open, then the number of cells, n, may be as low as two (upstairs and downstairs) or if some doors are closed, n may be higher. This problem is made more complex by the possibility of doors only being partially open.

Tracer Gas Continuity Equation

The following analysis uses a similar approach to that adopted by Sinden and Perera (9,10). If there are n cells, then these may be called cell 1, cell 2, ... cell n and for i = 1 to n the volume of the i'th cell is Vi. A tracer mass balance equation can be developed for each cell.

In this instance as well as the exchange with the outside air, the tracer gas lost to and gained from each of the other cells must be taken into account. If the background tracer concentration is assumed to be negligible, then the continuity equation for the i'th cell is given by;

$$Vi\,\frac{dCi}{dt}=Qpi+\ Qji\ Cj(1-\delta ij)\ -\ Qio\ Ci+\ Qij\ Ci(1-\delta ij) \qquad 2.18$$

where Vi = Tracer gas concentration in cell i at time t

Qpi = Production rate of tracer gas in cell i (m^3/s)

Qij = Flow rate of air between cell i & j (m^3/s)

Qji = Flow rate of air between cell i & j (m^3/s)

Qio = Flow rate of air between cell i & outside (m^3/h)

The Kronecker delta function is defined as;

$\delta ij = 0$ when $i \neq j$

$\delta ij = 1$ when $i = j$

Since there is no net build up of air in the building as a whole, the total flow into a cell must be equal to the total flow out. Therefore a second set of n equations can be obtained by considering the mass conservation of air described below;

$$Qoi+\ Qji(1-\delta ij)=Qio+\ Qij(1-\delta ij) \qquad 2.19$$

Where Qoi = airflow from outside to the i'th cell (m^3/s)

Qio = airflow from the i'th cell to outside (m^3/s)

The problem here is to evaluate the interzonal airflows

Qij and Qji. This is achieved by making site measurements of the variation of concentration with time in the cells. There are (n^2 - n) unknown interzonal airflows plus the 2n unknown values Qio and Qoi, giving a total of (n^2+n) unknowns. There are n equations from equation 2.18 plus n equations from equation 2.19. If the n equations of equation 2.18 are used then there are still a total of n^2 unknown airflows with only the n equations from equation 2.19 available to solve them. Therefore (n-1) independent sets of equations similar to equation 2.18 have to be generated.

Methods of Solving the Tracer Gas Continuity Equation

There are three methods of generating the (n-1) independent sets of equations;

1. Using continuous tracer gas injection, the injection rate being varied n times.
2. Observing Ct and $\frac{dc}{dt}$ at n different time points.
3. Using n different tracer gases.

Option 1 requires the use of sophisticated microprocessor controlled tracer gas injection. This method creates problems of maintaining constant tracer gas concentration without disturbing existing air flow patterns. Assuming these difficulties can be overcome, n cell air flow measurements using a single tracer gas greatly increases the duration of a test run. The assumption of Qij's remaining constant over such extended periods is doubtful. Grimsrud (11) has carried out measurements using this technique.

Option 2 suggests the use of a single tracer gas released in one cell and monitored in all n cells. The variation in tracer concentration with time, Ct, can then be subdivided into K time periods. If K > n then the unknown Qij's can be solved by the method of least squares. The derivation of n^2 equations from a single tracer gas is discussed in great detail by Sinden (9) and Penman (12).

Option 3 using n tracer gases removes the difficulties associated with extended time periods encountered using only a single tracer gas. The consequent increase in analysis equipment needed to accommodate multiple tracer gas monitoring can be greatly eased by using decay methods of multiple tracer gas injection. This option has been adopted by Irwin (18) and Perera (10), and is used in this project.

Practice of Interzonal Air Flow Measurements

Essentially the practice of measuring interzonal air flows is an extention of the methods used in evaluating air change rates using single tracer gases as described in Section 2.1 .

2.2.2 Multiple Tracer Gas Decay Method

Multiple tracer gas decay requires the same number of tracer gases as there are zones. A different tracer gas is injected into each zone, the concentrations of each of the gases are then measured against time. It is usual practice to use a family of tracer gases, in this way it is possible to use only a single detector, thus reducing both the physical size and cost of the system. It is advisable to reduce the measurement time to as short as possible whilst gathering sufficient data, since the environmental conditions which may effect the flows are apt to change rapidly and uncontrollably. Irwin et al (8) have attempted to gather as much data in as short a space of time the detector will allow, with the development of a rapid sampling technique.

2.2.3 Multiple Tracer Gas Constant Emission Method

Measurements of the interzonal air flows in a building may only be made by the constant emission method using an extention of the passive sampling technique (13). As a technique, it is very complex, requiring a great deal of expertise, and the cost of equipment and microprocessor control, along with high consumption of tracer gas makes other methods more attractive.

2.2.4 Multiple Tracer Gas Constant Concentration Method

Interzonal air flows may be made by the constant concentration method. Here a different gas is injected into each zone of the building. Tracer gas injection and monitoring equipment is used to maintain a constant concentration of the tracer gases in the zone of initial injection. It is not possible to maintain constant concentration of tracer gas in the zone which they were not injected, therefore, the concentrations of each tracer gas are monitored in each zone of the building. This data is then used to evaluate the interzonal air flow rate.

2.3 Choice of Multiple Tracer Gas Method

The most widely used analysis technique for interzonal air flows is the multiple tracer gas decay method. This was the method of measurement and analysis used in this work, partly due to the relative simplicity as compared to other techniques and partly because of the available expertise. Extensive collaboration had already been undertaken between the Departments of Building at Sheffield City Polytechnic and UMIST (14) .

2.4 Multiple Tracer Gas System

This section describes the important elements that comrise a multiple tracer gas system, suitable for the concentration decay method. Modifications to this system are described which enable rapid sampling of the tracer gas concentrations.

Gas Analyser

The type of analyser used was an Analytical Instruments A I 505 gas chromatograph with electron capture detector

Detector Cell

The electron capture detector comprises two oppositely charged plates and a radioactive beta particle source (Ni63)
This source causes an excess of negative ions in the detector which are collected at the positively charged plate creating a standing current. When an electron absorbing gas, such as oxygen or tracer passes through the detector cell, a quantity of electrons are captured. The standing current therefore decreases, and this drop in current is monitored, amplified and fed to an X-T chart recorder. Decreases in standing current are proportional to the concentration of detected tracer gas. The machine, as supplied by the manufacturer, is primarily designed to detect sulphur hexafluoride (SF_6) tracer gas. However, there are no similar gases to SF_6 which would comprise a family of tracer gases. This could mean that for each separate tracer gas used, a different chromatograph column is needed. This would introduce problems of calaibration between the different tracer gases used, and also incur extra costs. Because of this, the original instrument was modified by using a single chromatographic column, and a family of Fluorocarbon (Freon) tracer gases (5).

Chromatographic Columns

Air samples are carried through the column by inert Argon carrier gas. The role of the column is to separate the tracer gases and the atmospheric Oxygen before the air sample reaches the detetor cell. Each gas is absorbed and desorbed at different rates by the material in the column, thus the component gases arrive at the detector at different times.

Column Specifications

Material : Stainless steel

Length : 3m (coiled to approximately 8cm diameter)

Internal diameter : 6mm

Packing : 10% squalane

Support : 90% C.N.A.W. diatomaceous earth
(inert packing material)

At room temperatures, small fluctuations in temperature can have significant effects on the performance of a column. During operation, the column was placed in a themostatically controlled water bath, capable of holding the temperature to ± 0.5 c of a chosen temperature.

Tracer Gases

A number of tracer gas characteristics have been defined by various workers, such as Bargetzi (16) and Honma (17).

Some of these are defined below;

The gas concentration must be measurable with good accuracy even when highly diluted. The gases present in ordinary air should not affect the tracer gas analysis.

The tracer gas should be cheap and readily available. Adsorption and absorption of the tracer gas in the walls and furniture should be insignificant.

The tracer gas should have good chemical stability, and not react chemically with the air or surroundings.

The gas should not be a health hazard when breathed in the concentrations used for measuring.

The gas must not be radioactive, flammable, or explosive.

The density of the gas should be as close to that of air as possible.

As far as is known, no tracer gas fulfils all of these requirements. A family of tracer gases in widespread use,is the Freon group. These are particularly suitable since they are highly electron capturing, have a claimed low toxicity in the recommended dilutions, and are easily separable using gas chromatographic techniques. A list of suitable Freon gases are described in Table 2.1

Gas	Formula	Boiling point	Relative sensitivity to electron capture
BCF	CBrCLF2	-3	most sensitive
Freon 11	CCL3F	+24	
Freon C318	CF2CF2CF2CF2	-6	
Freon 13Bl	CBrF3	-58	
Freon 12	CF2Cl2	-30	
Freon 114	CCLF2CCFL2	+4	
Freon 115	CCLF2CF3	-38	
Freon 22	CHF2CL	-41	
Freon 13	CCLF3	-82	least sensitive

Table 2.1 Freons suitable for electron capture detection

Previous work by Irwin (18) has suggested the use of three suitable Freons for multiple tracer gas measurements; BCF, Freon 12 and Freon 114. These were deemed suitable after measurement trials using all of the readily available Freons in Table 2.1. The reasons for this choice were due to the relative insensitivity of three of the gases; Freon 115, Freon 22 and Freon 13. Freon C318 was no longer manufactured. Separation of atmospheric Oxygen and Freon 13Bl was impossible at the carrier gas pressures used for testing. The throughput time for Freon 11 was too slow at 158 seconds.

The minimum detectable and safety limits for Freon 12, Freon 114 and BCF are described below;

Freon 12

The minimum concentration of Freon 12 which can be detected by the gas analyser is 60 parts per billion. The recommended exposure limit to this gas is 8 hours at a concentration of 1000 parts per million (19).

Freon 114

The minimum concentration of Freon 114 which can be detected by the gas analyser is 135 parts per billion. The recommended exposure limit to this gas is 8 hours at a concentration of 1000 parts per million.

BCF

The minimum concentration of BCF which can be detected by the gas analyser is 0.5 parts per billion. There is no recommended safety limit as to the exposure time or concentration. Indeed the labeling on the gas bottle states that the toxological properties of this gas are not fully known. However, only very small concentrations are needed for testing purposes; a further safety aspect was to remove the gas bottle from the test space.

Chart Output of Freon Tracer Gases

A typical chart output of Freon tracer gas concentrations is shown in Fig. 2.5 . The common practice in gas chromatography is to relate the area under a peak to the concentration of tracer gas being measured. However the assessment of peak areas in field measurements is time consuming; an alternative approach is to measure the peak heights. The electron capture device has a different sensitivity for each tracer gas, in determining interzonal airflows from such measurements, it is the relative values of tracer gas concentrations which are important, and not the absolute values.

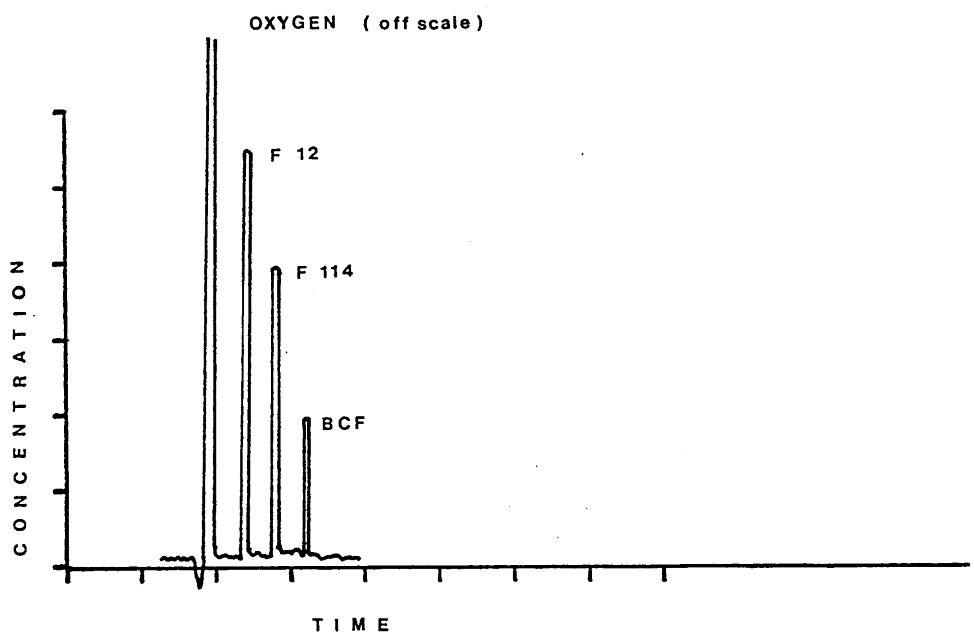

Figure 2.5 Typical chart output of Freon gases

Future Legislation on Fluorocarbon Use

At the time of writing, concern had been raised by many scientists about the claimed destructive effects of fluorocarbons on the Earth's ozone layer. Several Western industrial nations, including the UK, have signed the Montreal protocol which is hoping for a reduction of 50%

in the production and use of fluorocarbons by the year 2000. It would seem that because of political lobbying, the Government of the UK may in fact reduce this by up to 80 % or even totally ban the use of these gases before this date. The future use of fluorocarbons as tracer gases, therefore, appears to be in some doubt.

Further Modifications to Multiple Tracer Gas System

This section describes modifications to the basic multiple tracer gas system as previously described. These were done in accordance with those modifications prescribed by Irwin. In order to meet the criterion of gathering as many site data points within 20 minutes, thus reducing the possibility of the recirculation of tracer gas between the zones of interest, two chromatograph columns were in parallel. By switching between the two in a set sequence, the ECD would always be on-line, ready to receive samples. In this way the dead time associated with waiting for a sample to pass through a single column would be reduced. This dead time, is the time that it takes for detectable freons within the atmosphere, possibly by contamination, to pass through the chromatograph column. A schematic of the rapid sampling system is shown in Fig. 2.6 .

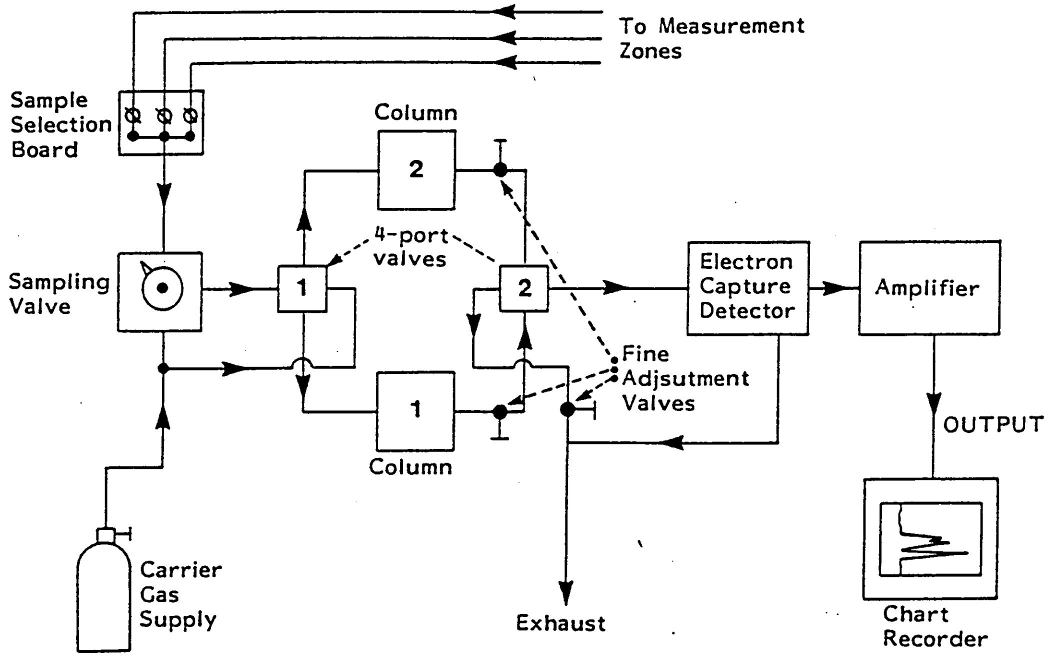

Figure 2.6 Schematic of rapid sampling system

Chromatograph Columns

The chromatograph columns were supplied in accordance with Irwin, namely;

Columns were bought from the same manufacturer and packed during the same production run from the same batch of packing material. Before use, both columns were baked in parallel in an oven at 100 c for 12 hours, with the purging gas (Argon) being drawn from the same cylinder. When not in use, both columns were kept under a blanket of argon (5 psi), with the purging gas being drawn from the same cylinder.

Four Port Valves

Two dead volume valves are used in the rapid sampling system. Each valve has four ports, and by a single turning action, two inputs can be directed to either of two outlets, as shown in Fig. 2.7 .

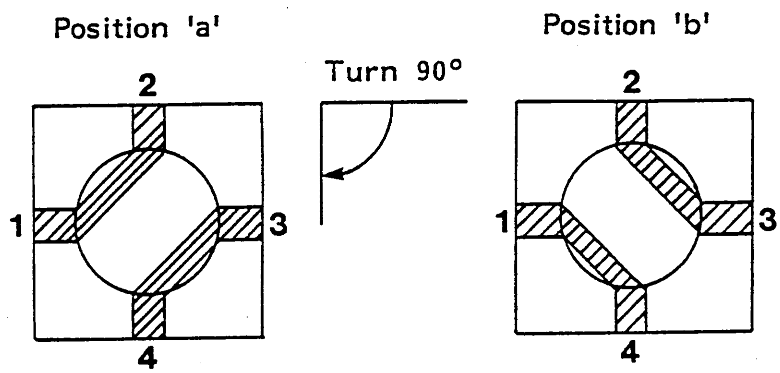

Figure 2.7 Direction of flow through four port valves

Zone Selection Board

This simple arrangement of three on/off valves allows air samples to be taken from up to four measurement zones. The suction is provided by a small pump within the gas analyser. The original pump was found to be inadequate at creating this suction over the long lengths of tubing used for sampling tracer gas concentrations. This was replaced by a small electric pump with a capacity of 90 litres per hour.

Sample Valve

The manually operated six-port sample valve isolates a fixed volume, (0.5 ml), of the tracer/air mixture from the sampling tubes. The sample is then carried towards the columns by the argon carrier gas.

Valve 1

This valve determines to which column the sample is directed, the other column being automatically kept under a trickle of argon from the gas supply bottle. Switching the valve through 90 degrees reverses the roles of the columns.

Valve 2

Gas flows, from the two columns, are the inputs to the second four port valve. The position of this valve determines whether the flow from a column is sent to the detector cell, or to exhaust.

Switching Sequence for Four Port Valves

The switching sequence for the four port valves is shown in Fig. 2.8 , over the page.

TIME (s)	ACTION	POSITION OF VALVE 1*	POSITION OF VALVE 2*	SYSTEM STATUS
0–3	Inject sample	a	b	Sample directed to column 1
12	Switch 1	b	b	Sample going through column 1: column 2 on line ready for next sample
23	Switch 2	b	a	ECD on line to column 1. Ready to receive sample
30–33	Inject sample	b	a	First sample shows an ECD output: second sample column 2
42	Switch 1	a	a	First sample still being output: second sample going through column 2: column 1 on line ready for next sample
52	Switch 2	a	b	First sample finished with: ECD on line ready to receive second sample
60–63	Inject sample	a	b	Second sample shows as ECD output: third sample directed to column 1

Figure 2.8 Switching sequence for four port valves

2.5 Validation of Multiple Tracer Gas Rapid Sampling System

To evaluate the effects of systematic measurement errors using the multiple tracer gas rapid sampling technique, air movement tests were carried out using the double chamber facility (section 4.1), by Irwin et al (14).
Air movement between the two chambers took place through two 100 mm diameter holes in a partition wall which separates them. Controlling the mechanical supply and extract rates to each chamber enabled a steady airflow from one side to the other. Air velocities through the holes in the partition wall were measured by hot wire

anemometer. By releasing tracer gas into the chamber which received the supply air, the airflow through the hole could be calculated by simple logarithmic decay methods (section 2.1.1).

Comparison between measured airflow rates and those calculated from tracer gas measurements suggested systematic errors of between 2% to 6% for this one way flow between the chambers. Further tests involving two way flows between the chambers suggest systematic errors of between 1% to 8% for calculated and measured airflow rates.

Problems of Measuring Airflow Rates Using the Multiple Tracer Gas Rapid Sampling Technique

Problems were encountered with column output mismatch. It was never possible to obtain equal Oxygen peak heights. The best that could ever be realised was within 10%, which ironically was with a pair of columns which were considered old and past their best condition; low output and slow response, possibly due to contamination with water. The purchase of new columns, meeting Irwin's criterion exactly, gave a mismatch of between 20% to 25%. It was impossible to cure this solution, even after a thorough overhaul of the gas analyser, needle valves, flushing valves and internal pipework.

The gas analyser runs off rechargeable batteries inside the machine, which are constantly trickle charged by connection to the mains supply. These were once accidentally exhausted by leaving the instrument operational whilst being disconnected from the mains supply. It was subsequentally found to be impossible to recharge the batteries enough to provide the necessary standing current to perform tests. Since it was concluded that although in principle, battery power was ideal, all the associated test equipment was mains powered. Therefore a mains powered 12V dc supply was substituted for the batteries, this also appeared to improve the baseline stability of the analyser.

The occurence of atmospheric freons was never conclusively proved during testing. Under laboratory conditions, described in section 4.1, it was occassionally the case that an electron capturing gas would be detected. However, due to the nature of the establishment, containing workshops directly adjacent to the laboratory, and a photographic darkroom directly above on the next floor, it was probably due to contamination of the environment, possibly from aerosol propellants. During site testing, described in section 4.2, atmospheric freons were never detected.

The timing and switching sequence of the valves on the selection board were rather impractical in continuous use. It was very easy indeed to get out of sequence, perhaps due to a variation in column throughput time of only a few seconds, or perhaps because of a momentary lapse in concentration by the operator. The throughput time saving between using a single column and two parallel columns was only of the order of about 5 seconds.

Because of the problems encountered above, it was decided that all measurments would be taken with only a single chromatograph column.

2.6 Practice of Airflow Measurements using Multiple Tracer Gas System

Initial Preparation

The test equipment, including the Argon carrier gas supply, was designed to be as compact and portable as possible. It was easily transported to a site in the back of a small family hatchback car. A general view of the test equipment is shown in Plate 1.

If starting the system from cold, it was necessary to allow a stabilisation period of about 20 minutes. During this time baseline drift of the column output reduced from unacceptable limits (> 1cm per minute, but it was variable from test to test, even though operating conditions may have been identical), to more acceptable limits. If excessive baseline drift occured through the test period, it was a simple operation to re-zero the baseline using the chart recorder X facility.

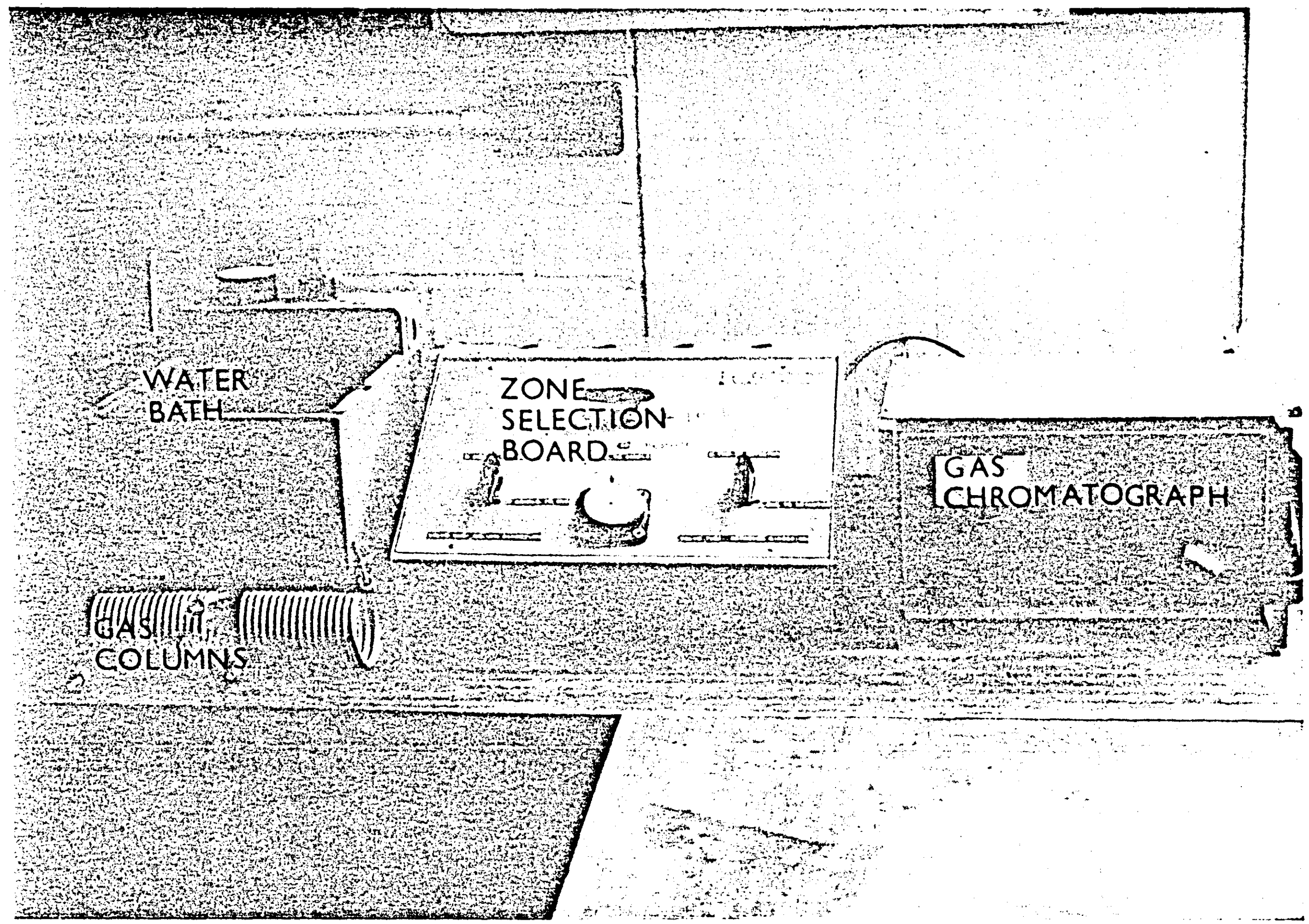

Plate 1 View of test equipment

WATER
BATH

GAS
COLUMNS

ZONE
SELECTION
BOARD

GAS
CHROMATOGRAPH

GAS
CHROMATOGRAPH

ZONE
SELECTION
BOARD

WATER
BATH

GAS
COLUMNS

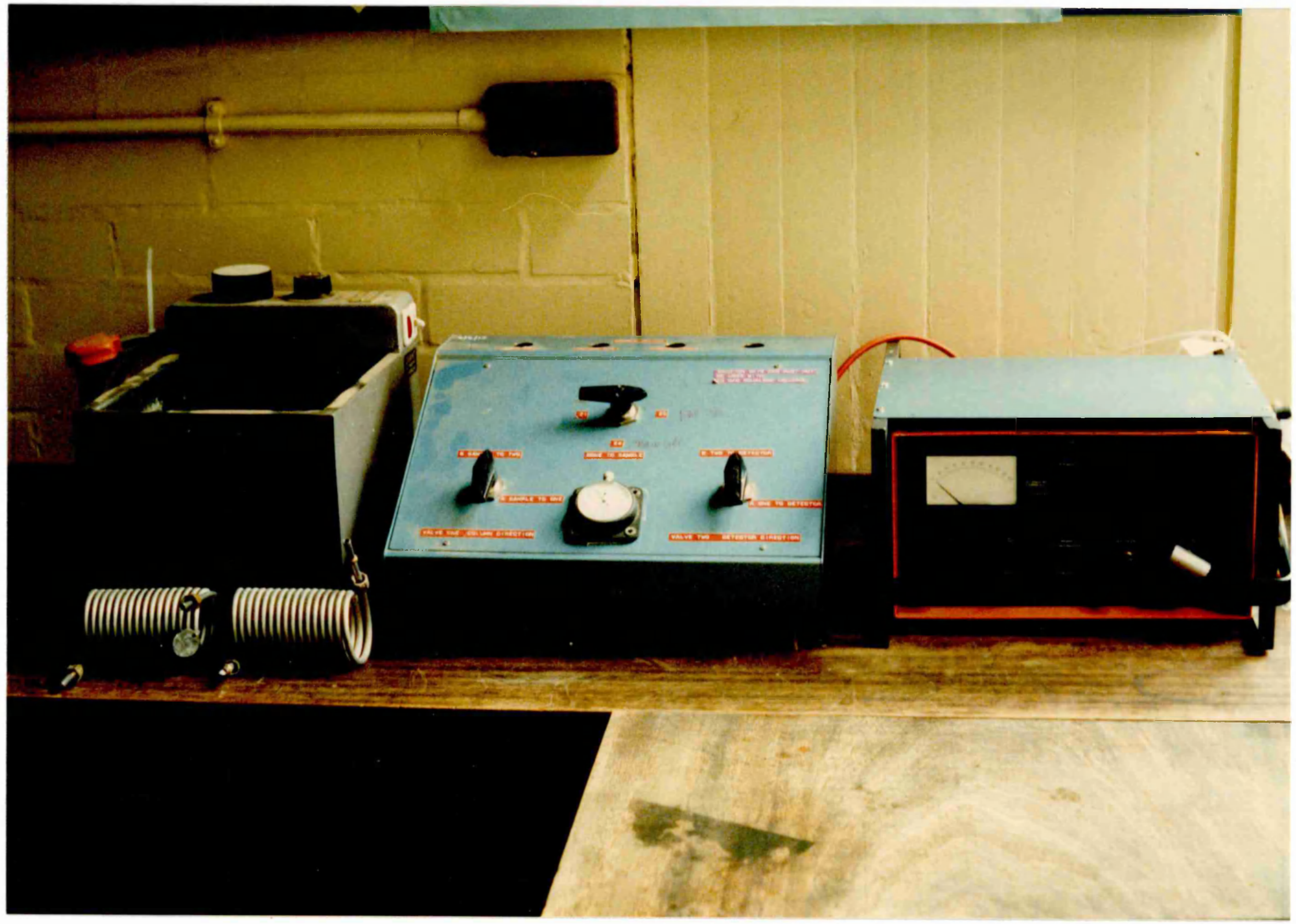

Plate 1 View of test equipment

System Optimisation

A column temperature of 35 c and an Argon pressure of 2.5 bar was found to be the optimum balance of column operating conditions. This gave good resolution of all the chosen tracer gases, with a throughput time of 50 seconds for the Oxygen. The response times for the tracer gases were, Freon 12; 55 seconds, Freon 114; 60 seconds and BCF; 90 seconds. These conditions differ slightly from other workers' optimum settings (18), perhaps because of differences in the inter connecting pipework of the modified chromotagraph. At these quoted figures i.e. column temperature of 30 c and carrier pressure of 3 bar, it was found to be impossible to separate the output of Freon 12 from Freon 144.

It was a deliberate policy to reduce the levels of tracer gas released to as low as possible, because of the possible toxic and environmental effects described in section 2.4 . Therefore the maximum allowable scale setting of the gas analyser was used; this was not the absolute maximum scale possible, since at these extreme limits, the analyser showed signs of instability (excessive baseline drift). At this setting the Oxygen peak height went off the chart recorder scale. The optimum gas analyser setting was 5 units, the chart recorder setting was 200 mV.

Injection Strategy

The injection strategy was to release two of the tracer gases used, Freon 12 and Freon 114, by inflating toy balloons with the gases. The amount of tracer gas released could be gauged with good accuracy by inflating to a known diameter, which by previous calculations, corresponded to a known tracer gas concentration. This was typically 18 cm and 25 cm for freon 12 and 114 respectively, for a room volume of 60 m^3. The balloons could be exploded remotely by the use of an electrically operated hot filament. The balloons were placed in as central a location as possible. Because of the extremely low volume of BCF gas needed, (typically 10 ml for a room volume of 60 m^3), it was impractical to inflate the balloons to a usable diameter. Attempts to further inflate the balloon with Argon proved impossible, since during this operation BCF, would leak from the balloon's mouth. Hence BCF was released by manual injection into the test space, using a gas tight syringe, filled via a septum port fitted to the top of the gas bottle.

Mixing Strategy

To provide a uniform tracer gas concentration within the test space, small, 30 cm diameter, oscillating electric desk fans were used to promote mixing. After injection the mixing fans were switched on, with the doors to the test space fully closed. One fan (20) was found to be sufficient for each zone (between 30 m^3 and 56 m^3) with the exception of the hallway on site (section 4.2). Two fans were necessary in this case, one upstairs, and one downstairs. This was because of the complex geometry of the zone, as compared to the others.

Different researchers allow different lengths of time to allow for sufficient mixing. For comparable zone volumes, Littler (5) allows up to 30 minutes, whilst Irwin (18) deduced that 5 minutes was adequate. For very large volumes, such as industrial warehouses (21) or aircraft hangars (22), the mixing period may be very long; up to several hours.
It was found during meaurements that 5 minutes was entirely sufficient to provide good mixing; any longer than this and it was noticed that tracer gas was leaking between zones, through cracks around the door, perhaps being exacerbated by the action of the mixing fans. If longer periods should be needed, it may be wise to seal up all the cracks around the door with adhesive tape, prior to mixing.

After the mixing period was over, the mixing fans were switched off, and a further 3 minutes were allowed to enable pre-mixing equilibrium conditions to return. Then the interconnecting doors between the zones were opened, and measurements began. Irwin deduced that the errors in calculating the airflows between two zones due to non uniform mixing within the zones were approximately + 7%.

Problems of Mixing

If a tracer gas is released into a test space, there are three main types of mixing problem which can occur. These are mixing with fresh air entering the test space, mixing of air and tracer gas in the space and circulation of gas within the space. Each of these mixing problems may affect the measured tracer concentrations differently (23).

Firstly, fresh air entering a space may not be uniformly distributed, consequently the concentration of the air and tracer gas mixture will vary for different locations.

Secondly, air infiltrating into a space and then exfiltrating out again without mixing, can occur. This does not effect tracer gas concentration and can generally be ignored.

The final mixing problem occurs if the physical volume of the space is not the same as the effective volume of the space. Effective volume is defined as the volume of the space participating in the air exchange process. The presence of cupboards or soft furnishings can lead to the effective volume being smaller than the physical volume. Conversely the presence of a suspended ceiling in the space of interest, having a significant air leakage will cause the effective volume of the space to be larger than the physical volume.

Sampling Strategy

As the mixing between the tracer gas and air can never be perfect, measurements made at a single point within the test space may not be a totally reliable indicator. This problem can be dealt with in practice by several means;

Air is sampled at several points and then mixed together. This concentration of the mixture is then used in calculating the air flow rate.

The rate of decrease of concentration is measured at several points and the measurement point which shows a rate of decrease nearest to the average rate from all points is used.

The decrease in concentration is measured at several points and the average value of this decrease is used when calculating the airflow rate.

The first option, as described, is the method most widely used. To realise this in practice, sampling tubes were fed from the analyser to the required location. The ends of each individual tube was connected to a three way manifold, which in turn was connected to three sampling tubes of equal length (in this way, the pump suction is equalised between the three tubes, allowing equal airflows through each). The sampling tubes were positioned in a central position within the test zone, this was considered to be the most representative condition of the room as a whole (24). The ends of the tubes from the manifold were positioned vertically within the test space, thus allowing for any tracer gas concentration gradients; either due to imperfect mixing, or to stratification with time.

2.7 Solution of Multiple Tracer Gas Continuity Equation

It was not within the scope of this work to propose new, or to refine, existing analytical solutions to the tracer gas continuity equation. Rather, the policy was to use any appropriate existing solutions, simply as a tool in the evaluation of airflow rates. There are many workers who have proposed their own method of solution to the tracer continuity equation, these include Sinden, Perera, I'Anson, Irwin, Littler and Waters (9,10,15,18,12&24). Some of the pertinent points about each of these solutions are given below;

Sinden Method

Sinden presents a very detailed mathematical analysis of airflows between n zones. However, the way in which this could be solved using site concentration data was not elaborated upon. Therefore, this method was not considered suitable.

Perera Method

The method of analysis of equation 2.18 and 2.19 adopted by Perera can be applied to n cells, the limiting factor being the number of suitable tracer gases.

By consideration of equation 2.18 and 2.19 for n = 2 zones, the solution for the unknown airflows requires determination of the concentration gradients $\frac{dCi}{dt} \ldots \frac{dCn}{dt}$.

This requires integrals of equation 2.18 and 2.19; unfortunately the time dependency of the tracer gases are not known. Therefore Perera uses numerical integration of the concentration gradients at a specific time, obtained by drawing a straight line between two points on the tracer concentration curves. Perera suggests that this should bne done from the earliest parts of the concentration curve, between 5 and 10 minutes.

It has been shown (18), that by imposing a ± 5% random error onto the site data (this assumed to be the probable mean measurement error), Perera's method shows calculation errors of between 1.5% and 43.5% in the evaluated airflows when compared to the actual measured airflows. These errors were considered to be large when compared to Irwin's method, which was adopted in preference.

I'Anson Method

The analysis of I'Anson is only applicable for a two cell case. This method requires the solution of linear equations, the coefficients of which are expressed as the roots of a quadratic equation. It has been shown (18) that by imposing a random ± 5% error on the site data points, the roots of this quadratic equation are complex. This leads to a failure of the equation. Therefore, small random errors commonly experienced during tracer gas measurements, could lead to a significant failure rate with this analysis.

Irwin Method

Irwin's method of analysis can be extended to n cells, the limiting factor being the number of suitable tracer gases. This method is fully explained in section 2.8, as it was the chosen method of analysis. By imposing ± 5% random errors on to the site data, this leads to errors of ± 10% in the calculated airflows.

Littler Method

The method of analysis used by Littler and the Building in Research group at the Polytechnic of Central London, is basically modelled upon the analysis of Sinden. The concentration data is automatically fed into a microcomputer from the gas analyser, for which algorithms have been developed. Problems of noise in the data, which in some cases are great enough to disallow use of the algorithm, have claimed to been surmounted by the use of the iterative parameter extractor. The parameter extractor creates a flow matrix from measured concentration data, and then recreates a set of concentrations to fit the (unknown) airflows. Each

element is peturbed in turn as the search for the flow matrix which corresponds best to the measured data. Further constraints are imposed to enable a best match.
The tracer measurements of Littler et al , therefore require the use of sophisticated data gathering and manipulation equipment. This method was not considered because of the complex method of analysis, and some reservations about the iterative parameter extractor.

Waters Method

Although Waters' work is primarily concerned with airflows within large, single cell buildings, a multi chamber theory is adopted. This is done by delineating imaginary zones within the real single zone; Waters uses up to six such imaginary zones. However, the physical realisation of this solution, requires six independent gas analysers, each one sampling a zone.
This method was not considered because of the lack of portability, calibration problems and excessive cost of six gas analysers.

Chosen Method of Analytical Solution

Irwin's method of analysis was chosen as it was the best compromise between the other methods. This was because it is relatively simplistic in nature, gives stable solutions and has acceptable error limits. Irwin states that these solutions have been used to measure interzonal airflows for two and three zones (18). These solutions have been validated by comparing the calculated airflow rates with those measured by pitot-static tubes, as described in section 2.5 .

Irwin's Analytical Solutions for Two Cell Case

The fundamental tracer gas continuity for two cells is expressed as;

$$Vi \frac{dCi}{dt} = Qpi + \quad Qji\ Cj\ (\ 1 - \delta ij\ ) \quad - Si\ Ci \qquad 2.20$$

Where the symbols have their previous meanings, and Si is the net outflow from cell i to the environment, and are shown in Fig. 2.9 .

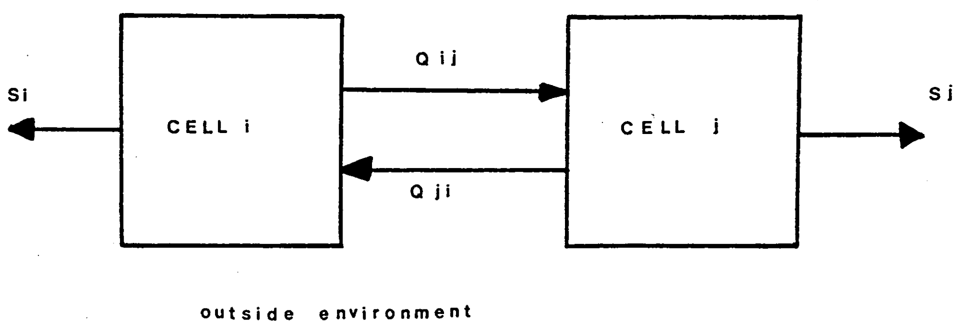

Figure 2.9 Airflows between two cells

The full mathematical analysis is very lengthy and laborious. It is sufficient here to simply write down the solutions for the determination of airflows and air change rates. The full mathematical solution is given in detail in Irwin's thesis (18).

The following discussion assumes that the effects of recirculation of tracer gas are time dependent. Provided sufficient site data (minimum of 10 ci(t) points) are collected before recirculation of tracer gas is greater than 15% of Ci(t), then the following solutions are valid.

$$Q12 = \frac{[CA2+COA2 \cdot (DN2-1)] \cdot (V2(N2'-N1'))}{COA1 \cdot (\exp(-N1't) - \exp(-N2't))} \qquad 2.21$$

$$Q21 = \frac{[CB1+COB1 \cdot (AN1-1)] \cdot (V1(N1'-N2'))}{COB2 \cdot (\exp(-N2't) - \exp(-N1't))} \qquad 2.22$$

$$N1 = \frac{-}{A} \frac{1-CA1}{A \cdot COA1} + \frac{Q21 \cdot COA2 \cdot (\exp(-N2't)-\exp(-N1't))}{V1 \cdot COA1 \cdot A \cdot (N1'- N2')} \qquad 2.23$$

$$N2 = \frac{-}{B} \frac{1-CB2}{B \cdot COB2} + \frac{Q12 \cdot COB1 \cdot (\exp(-N1't)-\exp(-N2't))}{V2 \cdot COB2 \cdot B \cdot (N2'- N1')} \qquad 2.24$$

Where; $$A = -t + \frac{N1't\hat{}2}{2!} - \frac{N1'\hat{}2t\hat{}3}{3!} + \frac{N1'\hat{}3t\hat{}4}{4!} + \ldots \qquad 2.25$$

and $$B = -t + \frac{N2't\hat{}2}{2!} - \frac{N1'\hat{}2t\hat{}3}{3!} + \frac{N1'\hat{}3t\hat{}4}{4!} + \ldots \qquad 2.26$$

since (1 - AN1) is a Maclaurin expansion of exp(-N1t)

and (1 - BN1) is a Maclaurin expansion of exp(-N2t)

The use of the Maclaurin expansion is to simplify the exponential terms within the analytical solutions. To calculate airflows and airchange rates Q12, Q21, N1 and N2, a first order estimate of N1 is required, denoted N1'. This is achieved by taking the first six data points of CA1 versus time in cell 1. Similarly an estimate of N2 is obtained from six data points of CB2 versus time in cell 2, denoted N2'. The result of a least squares fit on such data points will provide this first order estimate. The initial tracer gas concentrations COA1, COA2, COB1 and COB2 are taken from data measurements. The mean concentrations of tracer gas CA1, CA2, CB1 and CB2 are found by numerical integration of all the data points taken during measurements. If this time period is from t=0 to time t=t, then the mean concentration is expressed as;

$$\tilde{Ct} = \frac{\int_{t=t}^{t=0} Ct \, dt}{\Delta t} \qquad 2.27$$

In practical terms, an arithmetic average of all the concentration points divided by the length of time of the test period is sufficient. These mean concentrations are denoted $\tilde{CA1}$, $\tilde{CA2}$, $\tilde{CB1}$ and $\tilde{CB2}$. The volume terms V1 and V2 should be taken as the effective volumes (section 2.6).

Boundary Conditions Imposed For Test Measurements

Throughout the Project, it was a deliberate policy to ensure a methodology whereby the initial concentrations of tracer gas B in zone 1, and of tracer gas A in zone 2 where always zero for each test. This was done by ensuring that zones 1 and 2 were effectively sealed from one another during the injection and mixing periods. These enforced boundary condititions enable Irwin's equations to reduce still further, to the following solutions;

$$Q12 = \frac{V2 \cdot CA2 \cdot (\ N2'-N1'\ )}{COA1 \cdot (\ \exp(-N1't)-\exp(-N2't)\ )} \qquad 2.28$$

$$Q21 = \frac{V1 \cdot CB1 \cdot (\ N1'-N2'\ )}{COB2 \cdot (\ \exp(-N2't)-\exp(-N1't)\ )} \qquad 2.29$$

$$N1 = \frac{1}{A} - \frac{CA1}{A \cdot COA1} \qquad 2.30$$

$$N2 = \frac{1}{B} - \frac{CB2}{B \cdot COB2} \qquad 2.31$$

These are the solutions which were used to determine the airflow and airchange rates throughout the Project. The computer program used was implemented on an Apple 11e microcomputer, and is shown in Appendix A. The computer program was verified by manual calculations of the air flow and air change rates.

Conclusions of Chapter 2

It is possible to measure air change rates and interzonal airflows by the use of tracer gas techniques.

The solution of a tracer gas continuity equation can be realised in practice by three methods; concentration decay, constant emission and constant concentration. The concentration decay method is considered here to be the most suitable, because of its relative simplicity as compared to the others.

Of the many proposed analytical solutions to the tracer gas continuity equation, Irwin's method is considered here to be the best compromise , because of its relative simplicity; by imposing initial boundary conditions to this solution, a simpler version is proposed.

The tracer gas measuring and analysis equipment is described, for which the optimum operating conditions are stated.

CHAPTER 3 AIRTIGHTNESS OF BUILDINGS

LIST OF SYMBOLS

K	Flow coefficient (m3/s at 1 Pa)
n	Flow exponent
N50	Air change rate at 50 Pa (ac/h)
dP	Pressure difference (Pa)
Q	Airflow rate (m3/s)

CHAPTER 3 AIR TIGHTNESS OF BUILDINGS

Introduction

This chapter examines the fundamental theory and practice of evaluating building envelope and individual building component airtightness (or leakiness).
The main reason for conducting airtightness measurements, is to characterise the building fabric without climatic parameters influencing the result.

3.1 Measurement of Building Envelope Airtightness

There are two basic approaches to the evaluation of building airtightness; D.C. pressurisation and A.C. pressurisation. The former technique has been in use for many years (26), and is the subject of several national standards (27,28,29).

The second technique, A.C. pressurisation, has been developed only more recently (30), and has not been in such widespread use.

Therefore only the D.C. pressurisation method will be discussed here.

3.2 D.C. Pressurisation

This technique involves replacing an external door with a panel containing a variable speed fan, known as a blower door. A correctly designed panel will not require the existing door to be removed from its hinges.

Airflow through the fan creates an artificial, uniform, static pressure throughout the building. Internal and external pressure tappings are made and a manometer is used to measure the induced pressure differential across the building envelope. It has become common practice to test buildings up to 50 Pa.

Some means must be provided to enable the volumetric flow rate through the fan to be evaluated. The aim of this type of measurement is to relate the pressure differential across the building envelope to the airflow required to produce it.

In general, the higher the flow rate required to produce a given pressure difference, the less airtight the building.

The general configuration for a D.C. pressurisation test is shown in Fig. 3.1 .

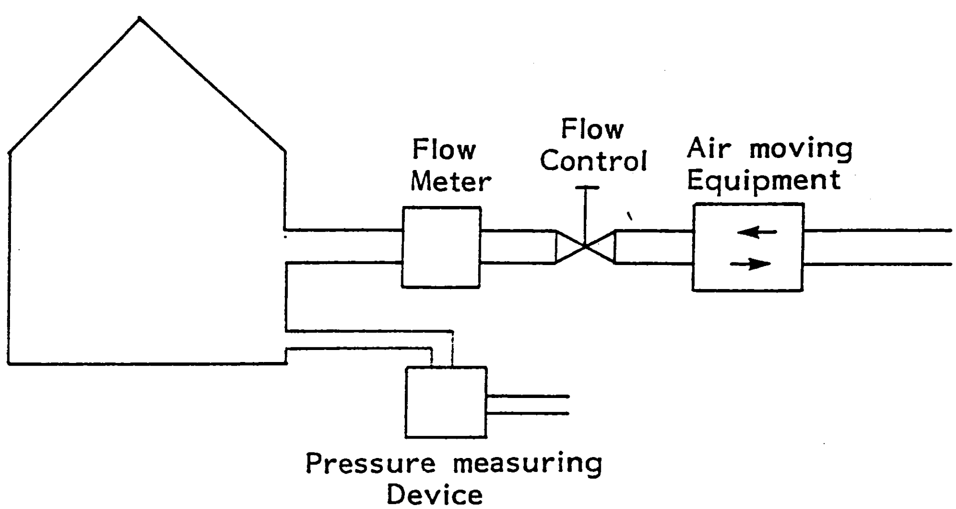

Figure 3.1 Configuration of D.C. pressurisation system

By selectively sealing different potential leakage paths with, for example, adhesive tape it is possible to determine the fraction of the total air leakage through different components of the building envelope, such as windows and doors. This technique is often known as reductive sealing.

3.3 Theory of Airtightness Measurements

Flow Coefficient and Flow Exponent

This method of expressing the results of airtightness measurements is applicable to both the building envelope and the individual components. By making pressure difference and flow rate measurements, the following generalised leakage function can be determined;

$$Q = K\, dP^{n} \quad (m^3/s) \qquad 3.1$$

Where Q = Airflow rate (m^3/s)

dP = Pressure Difference Pa

K = Flow coefficient $(m^3/s$ at 1 Pa$)$

n = Flow exponent

Values of K and n describe the air leakage characteristics of the envelope or component over the range of pressure differentials examined.

Air Change Rate at 50 Pa

The air change rate at 50 Pa is a single number which in some cases may be adequate to describe the air leakage characteristics of the building envelope. Often referred to as the N50 value, it may be evaluated by substitution into equation 3.1. In several countries, it has been adopted as a standard when assessing buildings in terms of airtightness.

Conclusions of Chapter 3

The airtightness of a building or component may be quantified by the use of the D.C. pressurisation technique.

Values of flow coefficient and exponent may be derived, which characterise the building or component. It is thus possible to compare these values with "standard" buildings and components, and thereby assess their degree of leakiness.

CHAPTER 4 TESTING FACILITIES

LIST OF SYMBOLS

S	Sealed (condition of component)
US	Unsealed (condition of component)

CHAPTER 4 TESTING FACILITIES

Introduction

This chapter describes the testing facilities which were available for the duration of the Project. These were split into two sections; laboratory and site facilities. In this way, airflows could be measured with and without the extraneous effects of the weather.

4.1 Laboratory Facilities

Double Chambers

The laboratory facilities were located in the Department of Building, Sheffield City Polytechnic. These consisted of a double chamber facility, comprising two airtight rooms each of internal dimensions 2.6m x 3.0m x 3.89m (height x length x width). The chambers are shown in Fig. 4.1 , over the page.

The two rooms were separated by a partition wall, into which was fitted a door of dimensions 1.98m x 0.76m (height x width), together with its door frame and architrave. The door was fitted by a qualified tradesman, and was deemed to be a good fit.

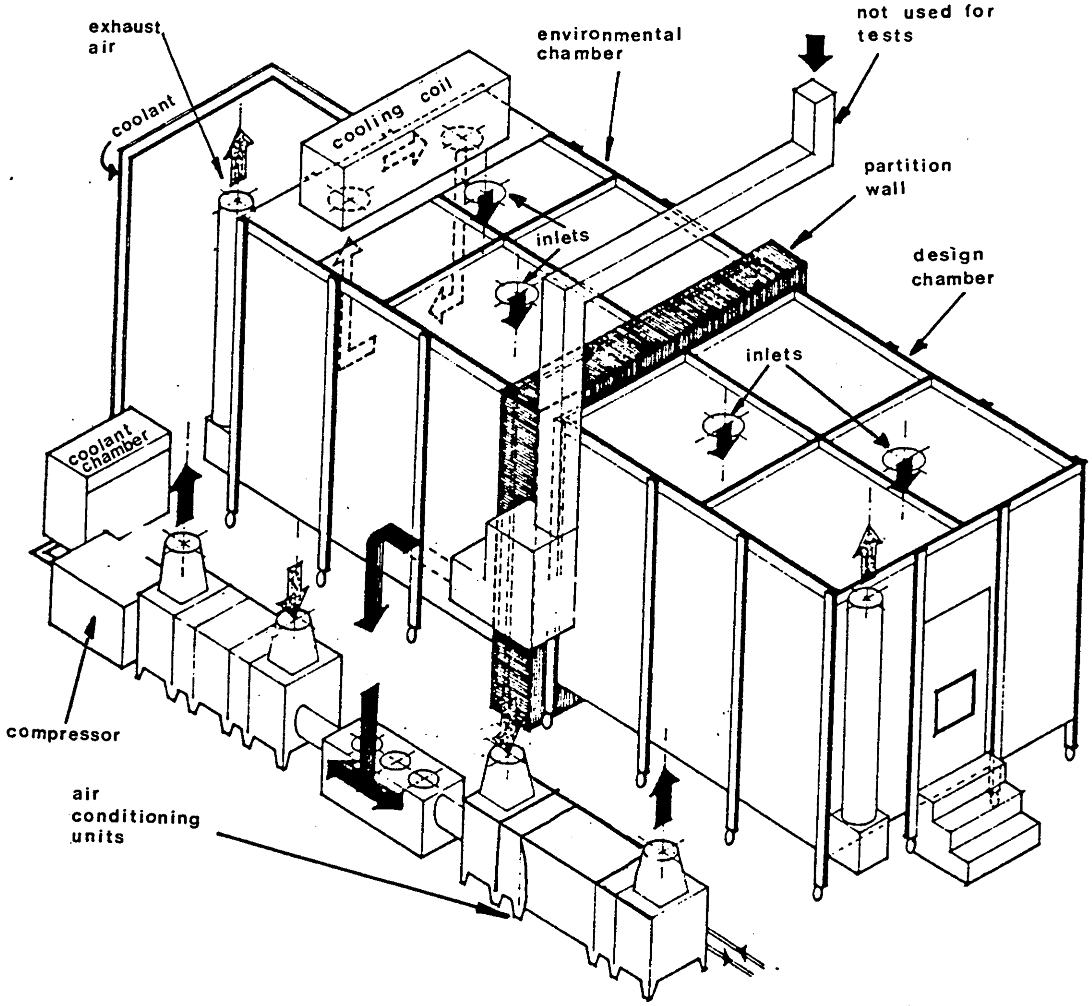

Figure 4.1 View of double chamber facility

Air Supply and Extract

Each side of the double chamber had an independent, air supply and exhaust system. Air was supplied to each chamber via two ceiling diffusers; operated by electrically controlled fan. The rates of supply was controlled by an iris damper within the connecting ductwork; measurement was provided by pressure tappings from a pitot-static tube. The maximum rate of supply to each room was 390 m^3/h (12.9 ach). Air was extracted via a grille at floor level within both rooms and was operated by electric fan, the air being exhausted to the outside environment. The rate of extract was controlled by a butterfly valve within the ductwork. Flow measurements were made by pressure tappings from a pitot static tube; the maximum rate of extract in both rooms was 505 m^3/h (16.7 ach).

Temperature Control; Environmental Side

One side of the double chambers, dubbed the environmental side, contained a recirculatory air handler unit. This was located outside, on top of the chamber roof. The closed loop ductwork consisted of an inlet and outlet, located in the ceiling of the chamber. The air handler unit was controlled by an IBM microcomputer, which could hold the temperature within the room to ± 20 c, with an accuracy of ± 0.5 c.

Temperature Measurement; Environmental Side

Temperature was measured in the environmental side using copper/constantan thermocouples fed to a Farnell model FCO 11, 10 channel digital thermometer. Two were used, both placed in the centre of the room, at 60cm and 120cm above the floor. The quoted manufacturer's accuracy was to within 0.1 c, for temperatures of between 0 c and 100 c.

Temperature Control Design Side

The other side of the double chamber, dubbed the design side, contained a single thermostatically controlled 2 kw convector heater placed on the wall furthest from the door. This was because most domestic radiators are wall mounted; it was also thought that this position would create the most representative artificial airflow pattern, possibly imposing itself upon the natural airflow patterns through the door. Temperatures of up to + 35 c could be generated and held; initial tests indicated that this could be held to an accuracy of ± 2 c.

Temperature Measurement Design Side

The remaining eight channels of the digital thermometer were fed to thermocouples in the design side. These were again placed in the centre of the room, and arranged in a vertical fashion, at 30 cm intervals from floor level. In this way, the effects of temperature gradients with height could be measured.

Leakiness of Double Chamber Facility

To assess the leakiness of the double chamber facility, a single tracer gas decay (section 2.1.1) test was done, this enabled a room airchange rate to be determined. All the possible leakage routes were sealed up, these included the service inlet holes, and the air supply and extract grilles. The data from this series of tests are shown in

Appendix B.

Leakiness of Environmental Side

The background leakage for the environmental side was found to be between 0.035 and 0.046 air changes per hour. With the air handler ducting open to the chamber, the air change rate was found to be 0.76 air changes per hour. This apparently closed loop ducting thus proved to be very leaky.

Leakiness of Design Side

The background leakiness for the design side was found to be 0.026 air changes per hour

4.2 Site Facilities

Choice of Site

The site chosen for the duration of the Project, was a single dwelling house. It was a deliberate policy to concentrate on just one house. In this way, the possible parametric effects of different house types i.e. whether it was terraced or semi-detatched etc, individual building components i.e. different window or door types, location, terrain and shielding, would be reduced to single set, particular to the chosen site. Work of this kind has been undertaken by several workers, including Warren, who has measured the effect of house type on airchange rates (31), and McGrath, who has measured the effect of different individual building components on the air change rate (32).

Location of Site

The site location was Norfolk Park, Sheffield, England. The house stands within its own grounds, the front facade facing South East. Mature trees, reaching above eaves height, surround the front and left-hand side of the house. The general location is however, within a built up residential area. The site was within 5 minutes drive from Sheffield City Polytechnic, and so logistical problems were reduced to a minimum.

Type of House

The chosen building was a detatched dwelling house, built circa 1895. This was constructed of stone, with walls 0.36m thick. The roof was slate with a pitch of approximately 35 degrees, ventilation being purposely provided by an eaves gap of 10 mm. A general view of the house is shown in Plate 2.

House Layout

The house was built on four levels, basement cellar, ground floor, first floor and second floor attic. The general layout of the ground floor and first floor are shown in plan view in Figs 4.2 and 4.3 , over the page.

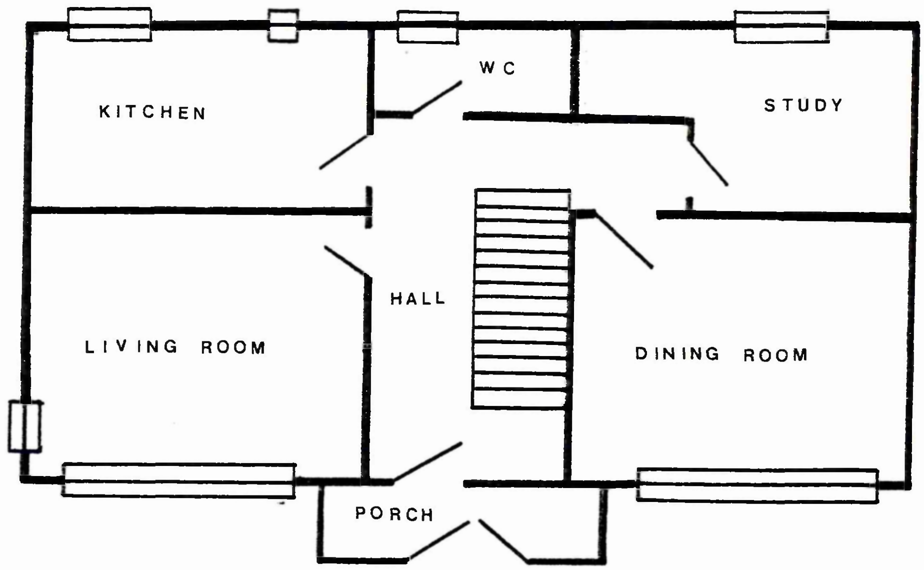

Fig 4.2 Plan view of ground floor

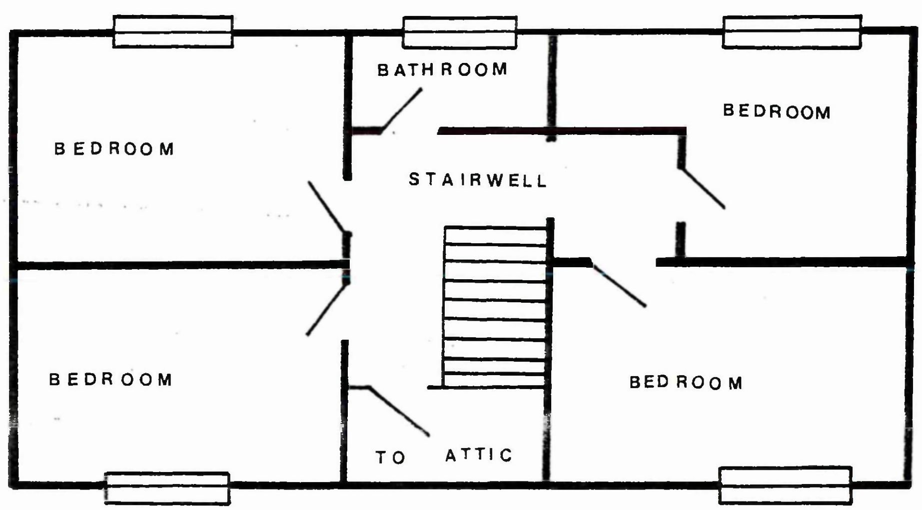

Fig.4.3 Plan view of first floor

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Plate 2 View of test house (Rear)

It was decided that the house was rather unrepresentative of most of the current housing stock in the UK; there were too many rooms, the individual rooms being large with very high ceilings.

Modifications to the House

The house was made smaller by sealing off nearly one half of the total volume. These modifications are shown on the plan views of the ground floor and first floor, in Figs. 4.4 and 4.5 .

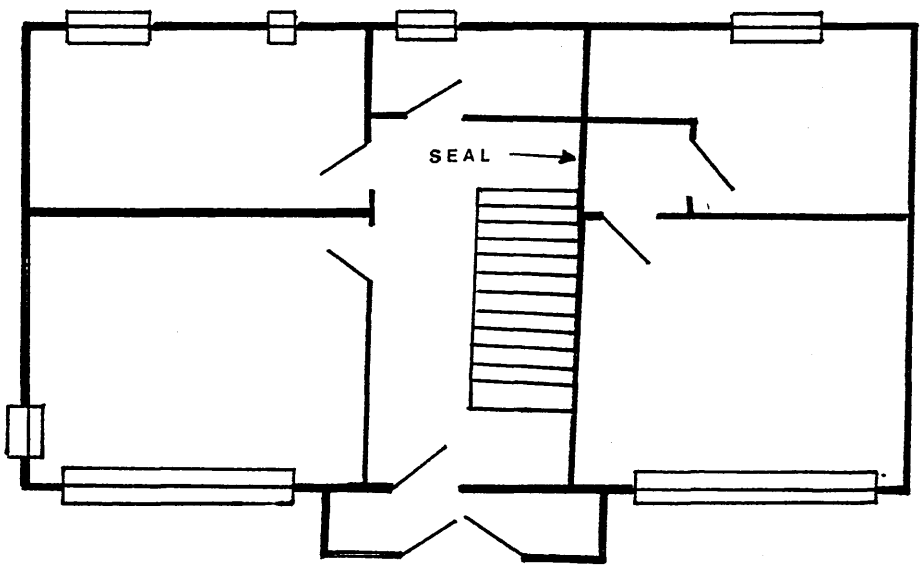

Figure 4.4 Modifications to house; ground floor

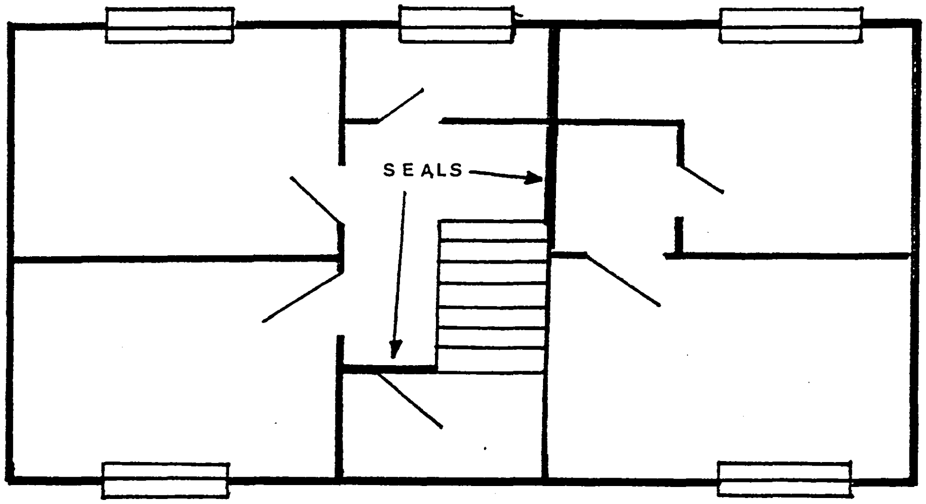

Figure 4.5 Modifications to house; first floor

At ground floor level, the dining room, study and bathroom were connected to the rest of the house by an archway which was connected to the hallway. Also connected by this route was the basement cellar. All these rooms were sealed off from the rest of the house, by fixing polythene sheeting to the archway frame with adhesive tape. Bedrooms 3, 4 and the attic were sealed off in a similar manner. Each of the sealed off rooms contained air-bricks, which were left open to the environment; also the heating to these rooms was switched off. The conditions of temperature and pressure were therefore similar to those of the outside environment.

Effective Volume of Rooms

The effective volumes of the remaining rooms are shown in Table 4.1

Room	Effective Volume m^3
Living Room	56
Kitchen	50
Hallway	65
Bedroom 1	56
Bedroom 2	52
Bathroom	27

Table 4.1 ; Effective Volumes of Rooms

Commissioning of Test House

The house was made continuously available for the duration of the Project; approximately two years. As many tests were envisaged, all the tracer gas sampling tubes and thermocouples were fitted into permanent position. This allowed very rapid dismantling and re-assembly of the test equipment, between laboratory and site work; approximately half a man day. All the testing equipment was located in the kitchen, and all operations, with the exception of door opening and BCF injection could be done from here.

Room Temperature Control

Room temperature was provided by central heating radiators already installed in the house. All the rooms were heated in this way, with the exception of the hallway, which was unheated. It was not feasible to pre-determine a given temperature and adjust the radiator valves to achieve this, rather, the valves were varied, and the temperature that resulted was taken. If very high temperatures were needed, then variable output (1 to 3 kw) fan heaters were used. To reduce the possible effect of superimposing artificial airflows upon the natural ones, the fan heater was pointed at the wall. It was hoped, that in this way, the airflow pattern might be similar to the convective plume from a central heating radiator (33).

Room Temperature Measurement

All the rooms were fitted with two thermocouples, placed in the centre of the room, at vertical distances of 0.1 m and 0.2 m from the floor. These were then fed to a digital thermometer, the values being taken manually every five minutes.

Wind Measurement

Initial wind measurement trials were done using a Midas wind speed and direction indicator, principally designed designed for marine use. This was placed on the top of a telescopic mast at eaves height (34), the direction and speed being logged manually. Unfortunately, the nature of the wind was so variable in both respects, that little of any use could be made of the data. However, even if these problems had been overcome, to convert the data into usable wind pressure data (section 7.3), would have required detailed knowledge of how the wind affected the building envelope. This would be impossible from just one single wind measurement, all that would be gained of any use is the general regime of house pressurisation i.e. which face of the house is windward or leeward.

An attempt to measure the pressure difference directly across the building envelope was done by placing pressure tappings across the the window of bedroom , these were fed to a micromanometer which in turn fed output to the chart recorder. It must be stated however, that this pressure difference was only characteristic of that between the bedroom and the air mass at the front of the house, other rooms would undoubtably show different pressure differences (due to the different locations with respect to the prevailing direction of the wind, or internal resistances of interconnecting doors). This pressure difference was however, of primary importance, since it was thought to be a driving mechanism of airflow between the bedroom (through all the possible leakage paths therein), and the environment.

4.3 Qualitative Assessment of House Leakiness

Windows

All of the windows were of the sash type. After many years' usage, all of these windows had worn away the surrounding window frames, creating many large gaps (up to 5mm wide). The slots within the surrounding frame, provided for the sash pulleys, were particularly leaky, as it was possible to feel strong draughts through them. Some windows had been nailed shut for security purposes, in these instances layers of paint had effectively sealed up all the gaps.

Doors

The main entrance door to the house was enclosed within a glass storm porch, which in itself had double doors. All of these doors appeared to be very leaky, mainly around the bottom of the door. The internal doors within the house also appeared to be leaky, mainly due to warpage of the door within the frame. There appeared to be a tight fit between the bottom of the door and the corresponding room carpet.

Other Leakage Routes

Additional leakage routes appeared to be the gaps around skirting boards on external walls. This was especially noticable in the living room. Further routes seemed to be the gaps around central heating pipes, electrical service points and ceiling roses. All the walls were sound with a layer of wallpaper and several layers of paint.
Purpose provided air-bricks were present in all the rooms, except the hallway. These were sealed up for testing

purposes.

4.4 Quantitative Assessment of House Leakiness

To gain a quantitative assessment of the leakiness of the test house, a series of tests were done using the D.C. pressurisation method as described in section 3.2. The series were split into two sections; whole house leakage test and individual component leakage tests. The system used is described below;

D.C. Pressurisation System

Fan

The pressure differential was provided by a Myson GA 400 axial flow fan, of variable speed, capable of producing an airflow of 7 1 M^3/s at 50 Pa.
The fan was bolted directly to a sheet of wood, with a hole cut into it the same size as the internal diameter of the fan housing. The external dimensions of the wood were cut to the internal dimensions of the door frame, and fixed to it with adhesive tape, thus providing an airtight fit. The airflow rate through the fan could be varied either by an iris damper within the ducting or by electric potentiometer.

Fan Airflow Rate Measurement

Airflow through the fan was measured by a 30cm Wilson Flow Grid. This is essentially a calibrated pitot-static tube, the configuration being shown in Fig. 4.6

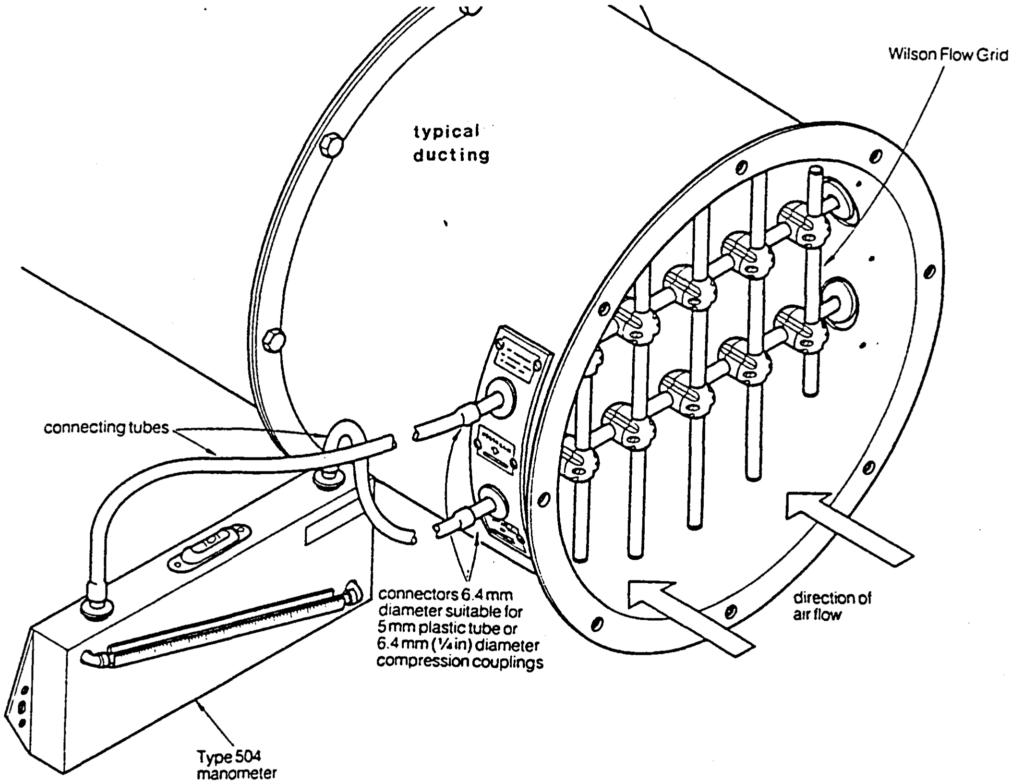

Figure 4.6 Configuration of Wilson flowgrid

The flowgrid was mounted within a length of ducting 100cm long and internal diameter 30cm, 60 cm downstream of the fan, as per manufacturer's instructions. The accuracy of the flowgrid is quoted as ± 5% . Pressure tappings from the flowgrid were fed to a micromanometer, the flow rates being calculated by reference to the manufacturer's calibration curve of airflow versus pressure difference, across the flow grid.

Pressure Difference across the Building Envelope

The pressure difference across the building envelope was determined by leading one of the two pressure tappings from a micromanometer, by polythene tubing, through the blower door, to the outside environment. Care must be taken to avoid the draught created dy the fan in the door, which would create false readings. The other pressure tapping is left open to the conditions within the house.

Pressure Difference Measurement

Pressure difference measurement was provided by a digital micromanometer, model Furness instruments FCP 011 capable of measuring pressure differences up to ±200 Pa, in increments of 0.1 Pa. The instrument has a variable damping control; in this way rapidly fluctuating pressure differences are time averaged, giving a more steady mean pressure reading.

4.5 Practice of Leakage Measurements

This section describes the practice of leakage testing. The data for the series of tests are shown in Appendix C.

Whole House Leakage Measurements

To assess the leakiness of the whole house, the blower door was fitted to the main entrance door, the storm porch doors were fully open. All the internal doors were fully open. Unfortunately, the fan was incapable of generating the full standard 50 Pa, the maximum pressure difference that could be obtained was 25 Pa. Thus the flow equation, as derived in section 3.2, is only valid up to this pressure. The flow equation for the whole house is shown in Table 4.2 over the page.

Individual Room Pressure Tests

Individual room pressure test were done for the hallway, living room, kitchen and bedroom 1. To measure the leakiness of components such as windows, doors and service inlets, a series of tests were done with the cracks around them progressively sealed up with adhesive tape. A series of flow equations could then be derived; by subtracting the flow equation for the sealed component from the flow equation for it unsealed, a characteristic flow equation for the component itself could be calculated. The practice of testing is similar to that described for the whole house except, that to assess the leakiness of the room door, the fan was placed in the window.

The flow equations for the individual rooms and their components are shown in Table 4.2 , over the page.

4.5.1 Presentation of Results

As can be seen from Table 4.2, the flow equations can become very awkward, with dissimilar flow exponents. To ease this problem, dummy pressure difference data was fed into the flow equations, and a least squares analysis on this gave an equivalent flow equation. To allow direct comparison of rooms and components, the flow at 50 Pa is tabulated.

Component	Flow Equation (m^3/s)	Equivalent Flow Equation (m^3/s)	Flow at 50 Pa (m^3/s)
Whole house	Q=0.079dp^0.69	Q=0.079dp^0.69	1.18
Hallway	Q=0.011dp^0.78	Q=0.011dp^0.78	0.23
Living room	Q=0.030dp^0.64	Q=0.030dp^0.64	0.37
Window	Q=0.030dp^0.64 -0.017dp^0.67	Q=0.013dp^0.60	0.14
Room Door	Q=0.020dp^0.67 -0.005dp^0.81	Q=0.015dp^0.60	0.16
Skirting	Q=0.017dp^0.67 -0.005dp^0.81	Q=0.013dp^0.56	0.12
Background	Q=0.005dp^0.81	Q=0.005dp^0.81	0.12
Kitchen	Q=0.032dp^0.66	Q=0.032dp^0.66	0.42
Window	Q=0.032dp^0.66 -0.035dp^0.58	Q=0.0006dp^1.32	0.10
Outside Door	Q=0.035dp^0.58 -0.028dp^0.55	Q=0.020dp^0.45	0.12
Room Door	Q=0.049dp^0.51 -0.028dp^0.55	Q=0.007dp^0.66	0.09
Background	Q=0.028dp^0.55	Q=0.028dp^0.55	0.24
Bedroom	Q=0.016dp^0.72	Q=0.016dp^0.72	0.27
Window	Q=0.016dp^0.72 -0.009dp^0.72	Q=0.007dp^0.72	0.12
Room Door	Q=0.012dp^0.72 -0.009dp^0.72	Q=0.003dp^0.72	0.05
Background	Q=0.009dp^0.72	Q=0.009dp^0.72	0.15

Table 4.2 Summary of Room and Component Flow Equations

4.5.2 Discussion of Site House Leakiness

In calculating an equivalent whole house air change rate at 50 Pa, it was necessary to extrapolate beyond 25 Pa, since this was the maximum pressure generated by the test fan. Using the total volume of the whole house from Table 4.1, the air change rate at 50 Pa is equal to 14 air changes per hour. Warren (31) calculated the air change rate for a similar type of house as 11 air changes per hour. It can be seen that the test house is leakier than average.

For values of the flow exponent, Liddament (35) gives the following generalised values, for a variety of different leakage types, as shown in Table 4.3

Type of opening	n
Large opening	0.5
Cracks (doors & windows)	0.66
Porous materials with joints	0.75
Porous materials alone	1.0

Table 4.3 Values of n for different crack type (after Liddament)

The pressurisation tests indicated values of 0.60 to 0.72 for the windows in the house, (a value of 1.32 was obtained, but n is meaningless if n>1. This may be as a result of deriving the equivalent flow equation.)

The internal doors fall within the range 0.60 to 0.72. The external door to the kitchen showed an exponent of 0.45, indicating an excessively leaky door.

The background leakages showed exponents within the range 0.55 to 0.81. The value of 0.81 was for the living room. This could indicate that the majority of these routes were the walls and the cracks between them and the ceiling.

The value of 0.55 for the kitchen background could indicate that large opening areas had been unidentified as leakage routes, and not been sealed for the pressure tests.

The flow coefficient for the various components are usually described as the flow per metre length of crack. The figures obtained for the tests were the total leakage over the whole length of crack. For comparison purposes, these are divided by the length of crack, and are shown in Tables 4.4 and 4.5, along with "standard" flow coefficients for similar types of component.

Flow coefficient K (dm^3/s/m Pa^2/3)					
Door; single side hung timber unweatherstripped	Standard max	Standard min	Kitchen	Bedroom	Living room
internal	3.38	0.49	1.26	0.54	2.69
external	3.52	0.79	3.59	n/a	n/a
N.B. The length of the door perimeters are taken as 5.56 m					

Table 4.4 Flow coefficients for doors; "standard" and site measured. ("standard" values after Liddament)

Flow coefficient K (dm^3/s/m Pa^2/3)				
Window; Vertical sliding double unweatherstripped	Standard	Kitchen	Bedroom	Living room
	mean 0.17	no result n>1	1.1	1.6
N.B. Length of bedroom window crack taken as 6.2 m Length of living room window crack taken as 8.3 m				

Table 4.5 Flow coefficients for windows; "standard" and site measured. ("standard" values after Liddament).

It can be seen from Table 4.4, that the leakiness of all the internal doors fall within the range of the standard doors.

The external door to the kitchen falls at the most leakiest range of those described.

For comparison purposes, the nearest standard window to that in the site house is double, vertical sliding, timber and unweatherstripped; the test windows would appear to be up to ten times as leaky as this type.

4.6 Leakiness of Bedroom 1

To gain a quantitative assessment of the leakiness of the leakage routes within the bedroom, a series of single tracer gas tests, as described in section 2.1.1 were performed.

The assumed leakage paths were progressively sealed up using polythene sheeting and adhesive tape, and the ventilation rate was then determined.

Unlike the pressurisation tests performed in section 4.5, these tests were designed to measure actual room airchange rates under a range of different weather conditions. Additionally, the possibility of the floor as a potential leakage route was investigated.

4.6.1 Presentation of Results

The data for this series of tests are shown in Appendix D. The airchange rates and relevant environmental data are shown in Table 4.6 , over the page.

Key: sealed=S unsealed=US

Door	Window	Floor	ach	Wind press	Temp diff Int/Ext	Temp diff Bed/Hall
S	US	US	0.3	0.3	23	1
S	US	US	0.3	0.4	22	2
S	US	S	0.3	0.1	23	4
S	US	S	0.2	0.3	25	3
US	US	S	0.5	0.5	19	3
US	US	S	0.5	0.3	20	3
S	S	S	0.04	0.7	24	1
S	S	S	0	0.2	23	1

Table 4.6 The effect of sealing different combinations of leakage routes on the room air change rate.

4.6.2 Discussion of Bedroom Leakiness

It can be deduced from Table 4.6, that the leakiness of the door and window are produces approximately the same room airchange rates under the conditions of weather tested. The floor contributes very little to the room air change rate

Conclusions of Chapter 4

The available testing facilities are split into two sections; laboratory and site.

The laboratory facilities enable airflows to be measured without the influences of air infiltration and exfiltration and the effects of the weather (

section 7.3), since the leakiness has been determined to be very low.

The site facilities enable airflows to be measured with the above influences acting, since the house has been shown to have many possible leakage paths.

The house has been shown to be excessively leaky when compared to other similar house types.

It has been shown that there are other leakage routes within the house, other than well definable routes such as windows and doors. The background leakiness has been shown to be appreciable.

The floor does not appear to be a leakage route between the zones.

CHAPTER 5 THEORY OF TEMPERATURE DRIVEN AIRFLOWS THROUGH DOORWAYS

LIST OF SYMBOLS

A	Area of Slot	(m2)
A1	Area of Slot at top of opening	(m2)
A2	Area of Slot at bottom of opening	(m2)
Cd	Coefficient of discharge	
E	Ratio A1/A2	
G	Gravitational constant (m/S2)	
H	Height of partition (m)	
ha	Height of equivalent column of air (m)	
P1	Air Pressure in Zone 1	(Pa)
P2	Air Pressure in Zone 2	(Pa)
$\rho 1$	Air Density in Zone 1	(kg/m3)
$\rho 2$	Air Density in Zone 2	(kg/m3)
Po	Pressure at neutral glare	(kg/m3)
Q	Airflow between Zones	(m3/S)
t	Thickness of partition	(m)
T1	Temperature in Zone 1	(k)
T2	Temperature in Zone 2	(k)
W	Width of partition in room	(m)
Z	Height of distance Z	(m)

Chapter 5 Theory of Temperature Driven Airflows Through Doorways

Introduction

This chapter describes a simple theoretical analysis of the airflow through doorways, due to the effects of a temperature difference on either side of the door.

5.1 Simple Theory of Temperature Driven Airflows Through a Rectangular Vertical Opening in a Partition (after Brown and Solvason (36))

This type of opening is taken by many workers, such as Shaw (37), to be the area of airflow through a doorway. Shaw used a sheet of wood across a doorframe, which could be slid along to create different areas of opening. This area of flow then, is rather different to that met around most " real " doors which are hinged at one side. The analysis is given below;

Consider a large sealed enclosure consisting of rooms 1 & 2 , as shown in Fig 5.1 , over the page.

The rooms are separated by a vertical partition with a rectangular opening of height H and width W. The temperatures in the rooms are T1 and T2 respectively. Since the total enclosure is sealed, there is no net flow of air across the opening.

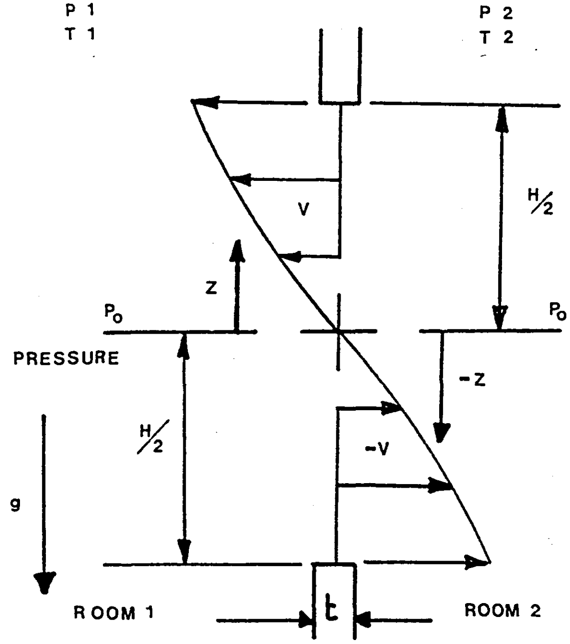

Figure 5.1 Theoretical airflow rate through a doorway due to temperature difference.

The absolute pressure Po at the elevation of the centre line is everywhere equal. In room 1, the pressure P at level z below the centre line will be;

$$P1 = Po + \rho_1 gz \qquad 5.1$$

Also the pressure at the same level in room 2 will be;

$$P2 = Po + \rho_2 gz \qquad 5.2$$

g being the acceleration due to gravity, and and being the densities of air in room 1 and 2 respectively. The pressure difference in the two rooms at the same level is;

$$P2 - P1 = (\rho_2 - \rho_1) g z \qquad 5.3$$

This pressure can be expressed as the height of a column of air, ha, where;

$$ha = \frac{(\rho_2 - \rho_1)\, z}{\bar{\rho}} = \frac{\Delta\rho\, z}{\bar{\rho}} \qquad 5.4$$

where $\bar{\rho}$ is the mean density, and;

$$\bar{\rho} = \frac{\rho_1 + \rho_2}{2}$$

Assuming that flow is ideal, Bernoulli's equation can be assumed i.e.

$$V = (2\, g\, ha)\hat{\ }0.5$$

or $$V = \left(2\, g \frac{\Delta\rho}{\bar{\rho}} z \right)\hat{\ }0.5 \qquad 5.5$$

where V = air velocity

now Q = C A V

where Q = rate of volumetric discharge

Cd = coefficient of discharge

A = area of opening of slot

The total volumetric discharge through one half of the opening can be written as;

$$Q = Cd \int_0^{H/2} W \left(2\, g \frac{\Delta\rho}{\bar{\rho}} z \right)\hat{\ }0.5\, dz \qquad 5.6$$

On integrating equation 5.6, the total volumetric discharge through one half of the opening will be;

$$Q = Cd \frac{W}{3} \left(g \frac{\Delta\rho}{\bar{\rho}} \right)\hat{\ }0.5\ h\hat{\ }1.5 \qquad 5.7$$

As an approximation, $\Delta\rho \approx \Delta T$, where T is the mean absolute temperature difference. Substituting this approximation into equation 5.7 gives;

$$Q = Cd \frac{W}{3} \left(g \frac{\Delta T}{T} \right)^{0.5} H^{1.5} \qquad 5.8$$

5.2 Modified Analysis; Airflow through Doorways

This analysis attempts to take into account the difference between the simple slot doorway, as used by Shaw, and the openings around a "real" doorway. These differences are shown in Figure 5.2

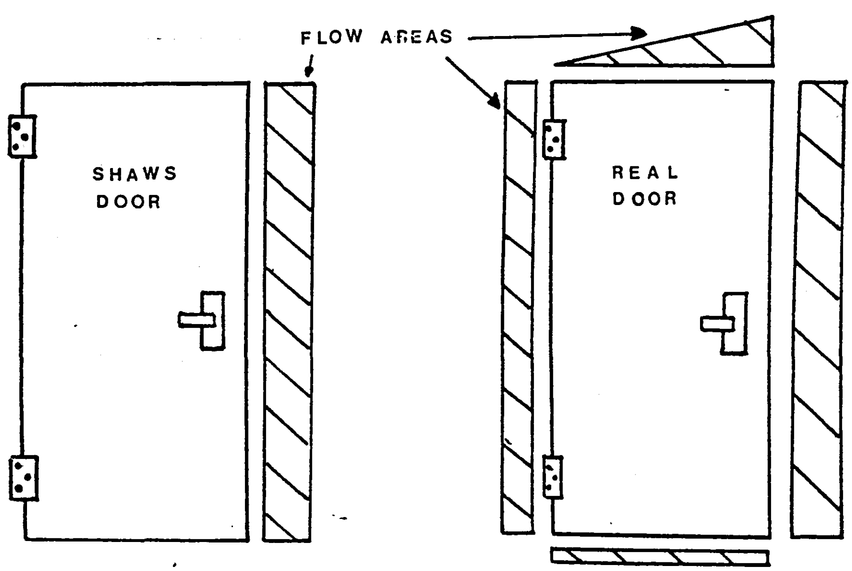

Figure 5.2 Visualisation of flow areas around "Shaws" door and a "real" door. (not to scale)

In the continuing discussion the fluid will be taken to be air, which when assumed to be a perfect gas gives;

$$\frac{\Delta \rho}{\rho} = \frac{\Delta T}{T}$$

By dimensional analysis, this general equation may be written as;

$$\frac{Q}{\rho\, b\, h}\left\{\frac{T}{g\ h\Delta T}\right\}\hat{}0.5 = \text{function}\left\{\frac{\Delta T\ g\ h\hat{}3}{T\quad \hat{}2}\ ,\ \frac{h}{b}\right\}$$

The first independent dimensionless group is the Grashof number, and the second is the aspect ratio of the opening. If the temperature differences are small in comparison with the absolute temperatures, then the volume flow rate may be given by;

$$Q = \text{Area.function (Grashof No ,Aspect ratio)}.\frac{(g\Delta Th)\hat{}2}{T}$$

If the viscous forces are small in comparison with those due to buoyancy, ie the Grashof No is large, then it has been shown by Brown & Solvason that function is given by;

$$\text{function (Grashof No, aspect ratio)} = \frac{1\ Cd}{3}$$

where Cd is the coefficient of discharge. Hence for a single opening

The basic starting point is that described for vertical openings in partitions. However, for this modified analysis, the openings at the top, bottom and hinge sides of the door are taken into account. This is because at small door openings, these may contribute a relatively large amount to the total flow as envisaged around a real door.

At larger door openings the flow through the top of the door is considerable, and disregarding it can only be seen as a serious omission to the total area of flow.

The flow through the top and bottom of the door is described by Warren (38), and is shown below;

Simple Theory of Temperature Driven Airflow Through Horizontal Rectangular Openings in a Partition

Consider an enclosed space containing fluid at a density of $\Delta\rho$ above the fluid density outside the space, at a density ρ. The space is connected to the outside by a single rectangular opening of height h, and breadth b. The difference in weights of air will cause a flow into the enclosed space at the lower part of the opening and out at the upper part. The mass flow rate, Q, is given by the following general expression;

$$Q = \text{function}\ (b, h, \Delta\rho, \rho, \nu, g)$$

$$Q = \frac{A\ Cd}{3} \frac{(g \Delta T\ h)^{2}}{T}$$

Brown and Solvason have noted (36) that this analysis can be extended to multiple openings, separated by various distances. It has been shown that for the simplest of arrangements, of interest here because it has relevance for the openings around a door, which consists of two openings of areas, A1 and A2, with their centres a distance H apart, that the flow rate Q is given by;

$$Q = (2\ A\ Cd)^{0.5} \frac{E}{(1 + E)(1 + E^{2})^{0.5}} \left\{ g \Delta T\ H \right\}^{0.5}$$

Where E is the ratio of the areas, A1/A2.

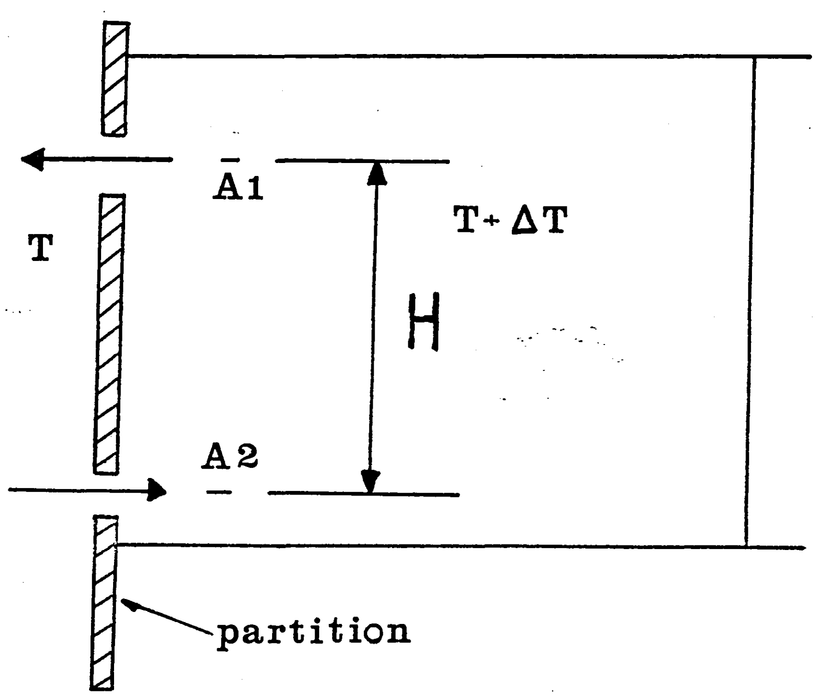

Figure 5.3 Airflow through horizontal openings in a partition (not to scale)

The present modified analysis proposes that for a real doorway, the combined effects of the vertical and horizontal openings can be superposed. The total volumetric flow through the door will therefore be given by;

$$Q = \left[\frac{C_d W}{3}\,\frac{g\Delta T}{T}\right]^{0.5} H^{3/2} + \frac{2AC_d \qquad E\,(\,g\;T\;H\,)^{0.5}}{(\,1+E\,)(\,1+E^{2}\,)^{0.5}} \qquad .9$$

For this situation, the following points are assumed;

The type of crack opening around the door is the same for the sneck, hinge, top and bottom of the door. As has been pointed out by Etheridge (39), rather complex relationships exist for describing the flow through cracks, depending upon whether the flow is turbulent or laminar, and on the details of the crack (straight through, how many bends etc.). The openings are all therefore assumed to be sharp edged orifices, for which the coefficient of discharge is taken to be 0.61 (section 5.2.2)

The airflow through the top and bottom of the door is assumed not affect the airflow through the sneck and hinge, and vice-versa.

The areas of flow through the sneck and hinge can be added together to form an equivalent area equal to the sum of the two areas.

The total airflow is the additive sum of the airflows through the vertical and horizontal areas which make up the doorways.

Factors which may influence the theoretical analysis include the background turbulence of the air, and the coefficient of discharge, which are described below;

5.2.1 Background Turbulence of the Air

The air inside a dwelling is always moving, and there is no need for a temperature difference between rooms to induce airflows through a connecting doorway. Warm and cold surfaces create convective flows which make the whole air move.

The main criticism of the simple theory as described here is that it takes no account of this influence. At small temperature differences, this flow may be of significant importance, whilst at larger temperature differences, the temperature difference between the two rooms would be the dominant driving mechanism.

Lidwell (40), Bruce (41) and Siren (42) have all attempted to make modifications to the simple theory to take turbulence into account. These are all different in their approach however, and there appears to be no concensus of opinion between the workers.

The introduction of turbulence terms into the simple theory of temperature driven airflows through doorways was outside the scope of this project.

However, it will be seen later in Chapters 6, 7 and 10, that the experimental work reveals background flows which may be attributable to turbulence in the main body of the rooms.

5.2.2 Coefficient of Discharge

The aim of the coefficient of discharge is to take account of the real frictional flow compared with the ideal flow. Lidwell states that there is difficulty in practice in deciding on the appropriate value of temperature difference. Use of the difference between the temperature at the top of the doorway for temperature differences between 3 c to 10 c gave a Cd approximately equal to 0.65. If however the temperature difference was taken as the measured value at mid height in the two rooms at the side of the opening uninfluenced by the air flowing through it, then the calculations gave a Cd of 0.80

Riffat (43) claims that the coefficient of discharge decrease from 0.61 to 0.22 as the temperature decreases from 0.5 c to 13 c. He claims that this decrease in the coefficient of discharge may be due to an increase in the interfacial mixing as a result of the direct transfer of cold air through the doorway meeting the warm air from the other zone.

Riffat defines the coefficient of discharge in the usual way as;

$$Cd = \frac{\text{measured airflow rate}}{\text{ideal airflow rate}}$$

However, this raises a question as to his determined values of Cd. In determining the interzonal airflow rates through the doorway, Riffat subtracted the effects of the wind and stack (section 7.3) directly from the measured airflow rates. This may be dubious, since the complex way in which these weather parameters affect interzonal airflows are not really known with any great degree of certainty.

Shaw (37) claims that the coefficient of discharge was found to be primarily a function of temperature differential and not dependent on the door opening. Shaw therefore effectively renamed the coefficient of discharge, the coefficient of temperature. This was found to decrease from a value of 1.8 to 0.65 as the temperature increased from 0.25 c to 4.0 c, at which the coefficient remained constant until 10 c, then rose slowly again to 1.0 as the temperature difference rose to 50 c.

Since the way in which the coefficient of discharge varies with temperature is open to debate, and is not known with any certainty, it has been assumed, for this project, to take a constant value of 0.61, consistent with orifice flow.

Conclusions of Chapter 5

It is possible to theoretically describe the temperature driven flow of air through a doorway.

The type of doorways used by most researchers, are in fact simple slots. A slight modification to the simple analysis of temperature driven flows has been made to take into account the differences between a simple slot and a "real" doorway.

The omission of turbulent terms within the simple analysis may be significant at low temperature differences.

The variation of the coefficient of discharge at different temperature differences is open to debate amongst researchers. In light of this, a constant coefficient of discharge, equal to 0.61, has been assumed, consistent with a sharp edged orifice.

CHAPTER 6 LABORATORY MEASUREMENT OF TEMPERATURE DRIVEN AIRFLOWS THROUGH DOORWAYS; 2 ZONE

LIST OF SYMBOLS

Q	Airflow through doorway (m3/h)
ΔT	Mean Temperature difference between room (C)
W	Width of door opening (m)

Chapter 6 Laboratory Measurement of Temperature Driven Airflows Through Doorways; 2 zone

Introduction

This chapter describes the experimental measurements of temperature driven airflows through doorways, under laboratory conditions, as described in Section 4.1 . Under these conditions it is possible to reduce air infiltration and exfiltration to the outside environment, and also reduce the possible effects of the weather, such as wind and stack (Section 7.3).
These measurements were performed for three different door opening positions, for which theoretical and empirical convective flow equations will be derived.
These theoretical and empirical equations will be compared with each other.

6.1 Choice of Door Position

As there are an infinite number of door opening positions between fully closed and fully open, an attempt was made to choose appropriate door positions which would have relevant applications.
Of immediate interest was the closed door and those positions of the door resting near to its doorframe. These could be related to user practice, since very often, when a door is left to close of its own devices, it comes to rest at or near to these positions.

Because of time limitations, only three door positions were investigated, these were designated Positions 1, 2 and 3. The door opening was formed by fixing wooden spacers, of different lengths, between the door and doorframe as shown in Figure 6.1

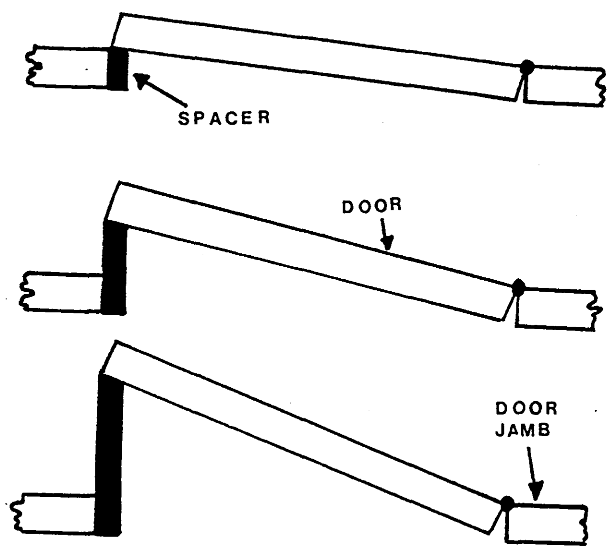

Figure 6.1 Plan view of door showing spacers

Measurements of the larger gaps around the door were done with a steel ruler. It was necessary to take measurements every 10 cm around the perimeter of the door because of warpage along its longest lengths, the gap between it and the doorframe not being constant. A mean gap width was therefore determined. The hinge side of the door necessitated the use of feeler gauges because of the very small gap widths. Again, a mean gap width was determined because of the variation of width over the hinge side. The gap area around the top of the door was taken to be an approximate triangle, as shown in Figure 6.2, with the addition of a small slot at the intersection of the door and doorframe.

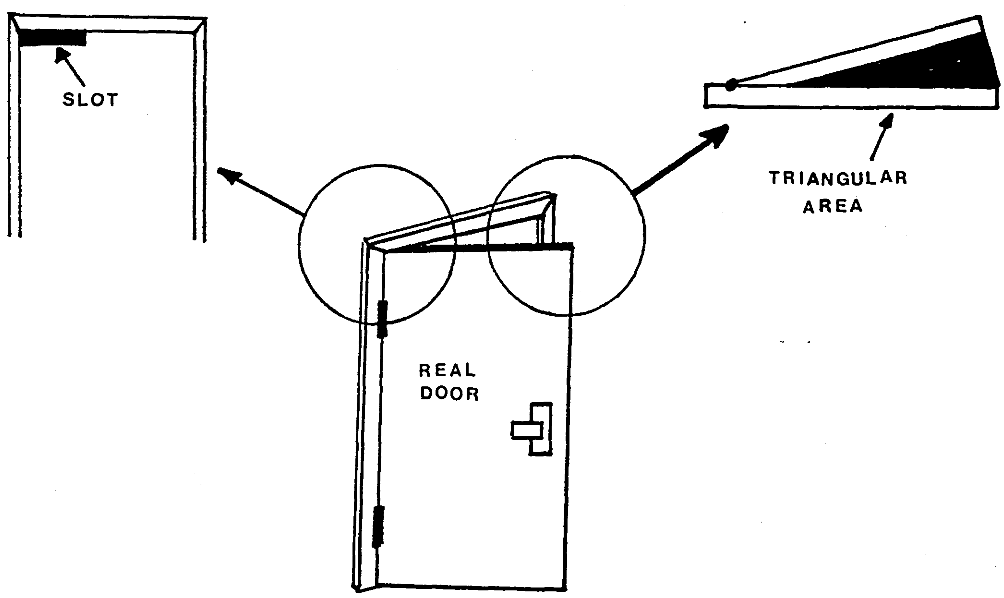

Figure 6.2 View of area through top of door

The characteristics of all the gaps around the door were assumed to be sharp edged orifices, with a coefficient of discharge of 0.61, for the reasons outlined in section 5.2.2

The measured areas of the gaps around the three door positions are shown in Table 6.1, with the individual component areas again defined in Figure 6.3, over the page.

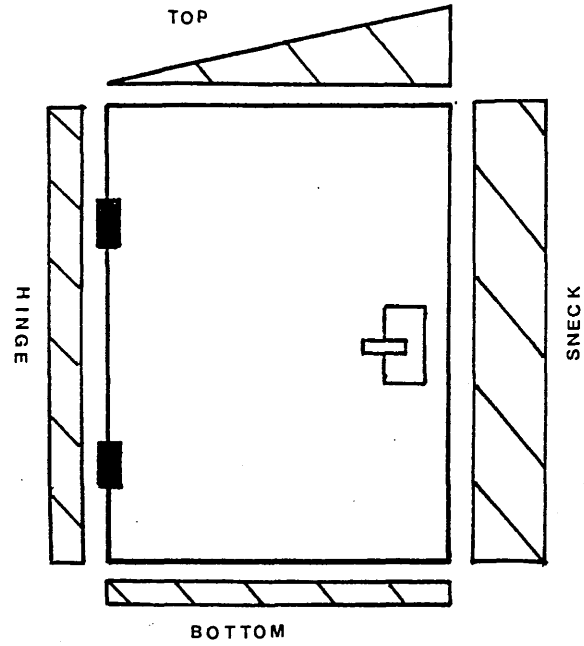

Figure 6.3 Definition of door component areas

AREA OF GAPS AROUND DOORS (m^2)			
	POS 1	POS 2	POS 3
Sneck	0.0048	0.0126	0.0490
Hinge	0.0045	0.0055	0.0059
Top	0.0022	0.0023	0.0195
Bottom	0.0055	0.0055	0.0055
TOTAL	0.0170	0.0259	0.0799

Table 6.1 Area of gaps around door Pos.1, 2 & 3

6.2 Theoretical Temperature Driven Flow Equations

To obtain the theoretical flow equations for the different door positions, the measured door gap areas (Table 6.1) were inserted into the equations 5.8 & 5.9 for the simple and simple modified analysis of temperature driven flow.

Comparison of Theoretical Temperature Driven Flow Equations

Comparison between the two analyses is not straightforward because of the different approach in defining the gap areas around the door. As mentioned in section 5.2, the simple theory, as used by Shaw (37), is only applicable for vertical slots, whereas the modified analysis attempts to include other definable gap areas around the door. For comparison purposes here, the total area is taken as being identical for both analyses. For this to be so, however, the implication is that the doorway width is not the same in both cases (since the height dimension of the door does not change).

The theoretical flow equations are shown in Table 6.2

Door Pos'n	Simple Theory Flow Equation (m^3/h)	Modified Simple Theory Flow Equation (m^3/h)
Pos'n 1	$Q = 3.2 \Delta T^{0.5}$	$Q = 3.5 \Delta T^{0.5}$
Pos'n 2	$Q = 4.9 \Delta T^{0.5}$	$Q = 5.4 \Delta T^{0.5}$
Pos'n 3	$Q = 15.1 \Delta T^{0.5}$	$Q = 19.6 \Delta T^{0.5}$

Table 6.2 Theoretical Temperature Driven Flow Equations

At the smaller door openings, Position 1 and 2, there seems to be little difference in the two analyses.

However at the larger door opening, Position 3, there is an appreciable difference between the two analyses, with the modified theory indicating an approximately larger flow of 25%. This may be due to the fact that at this position, the opening at the top of the door becomes appreciable and should not be neglected as described by the simple theory.

The theoretical flow equations will be compared to the empirical equations in Section 6.6

6.3 Experimental Procedure

The experimental procedure for assessing the airflow through doorways was to release a single tracer gas in the design side of the double chamber facility (section 4.1). By monitoring the decay of the tracer gas concentration within this room, with time, it was possible to determine a room airchange rate, by performing a logarithmic decay analysis on the data points (section 2.1.1). Since the leakiness of the double chambers as a whole was known to be very low (section 4.1), it was assumed that air infiltration and exfiltration with the outside environment was negligible. Hence, the airflows between the design and environmental sides, were equal to the opposite flows between the environmental and design side. The airflow was obtained by multiplying the room airchange rate by the room volume.

A typical chart recorder output for a single tracer gas test is shown in Figure 6.4

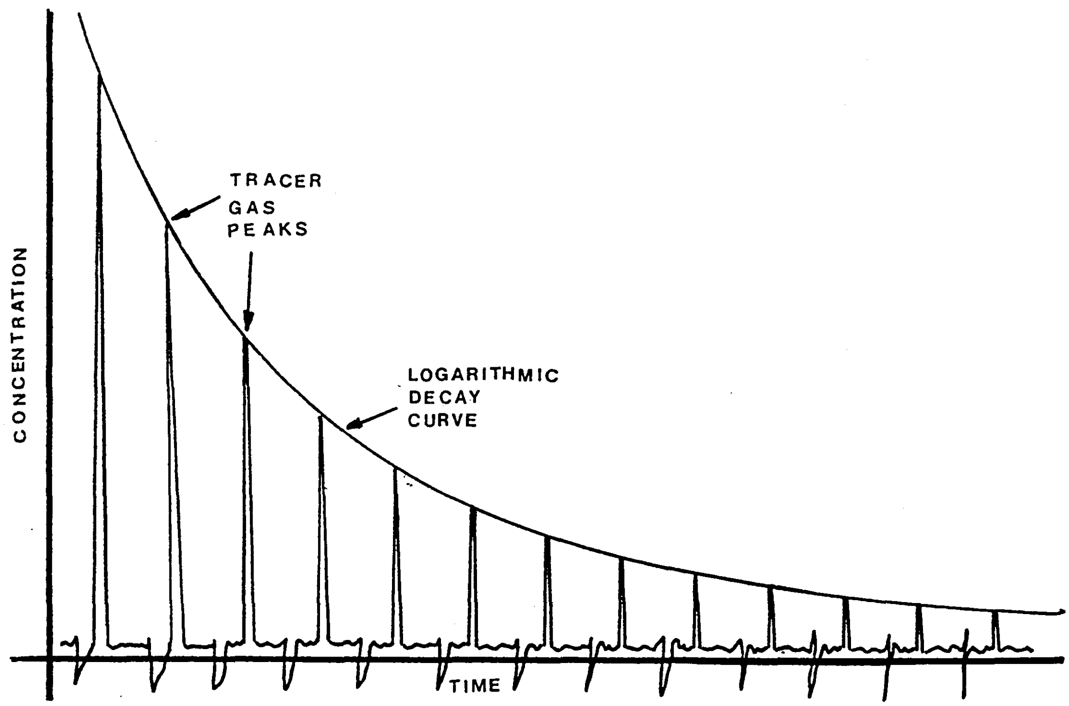

Figure 6.4 Typical chart recorder output for single tracer gas

Problems of Laboratory Measurements

Pumping Action of the Chamber Door

After the tracer gas had been injected into the design side, mixed and equilibrium conditions had returned, it was necessary to physically enter the double chambers, via the environmental side main door, and open the connecting door to the required position. When leaving the chamber after doing this, care was taken to close the main chamber door slowly, thus reducing the possible "pumping action" of the door. Under these conditions, it may be possible that air could be forcefully pumped between the two zones, creating initial tracer gas concentration anomalies.

Variation of Temperature Difference with Time

The environmental side was always chosen to be the cooler of the two sides. Once the connecting door was opened, warm air flowed from the design to the environmental side, and cool air flowed from the opposite direction. Thus from time zero of the measurement period, there was a tendency for any initial temperature difference between the two sides to lessen with time. The rate at which this occured was not constant, since it depended upon the temperature conditions pertaining at the time, and also the setting of the door. At larger temperature differences, for example, the rate would be greater than at lower temperature differences. At these highest temperature differences (30 c), this could be in the region of a 5 c lowering of the initial temperature difference, over a typical 20 minute period.

However, without recourse to very complicated feedback heating systems, this situation would be difficult to overcome, it being an inherent part of interzonal airflow conditions.

Vertical Temperature Stratification with Height

After the initial tracer gas mixing had stopped, the air temperature within the two sides showed signs of vertical temperature stratification as the test proceeded.

Figures 6.5 and 6.6 shows the degree of temperature stratification in the design side for door positions 2 and 3, dependent on the temperature difference between the two rooms.

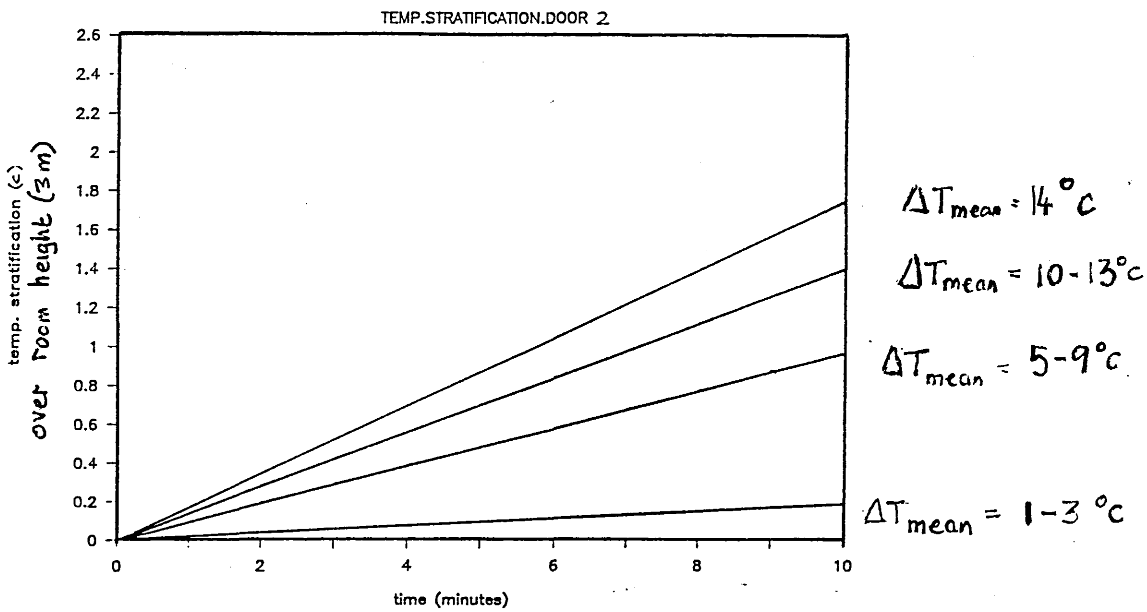

Fig 6.5

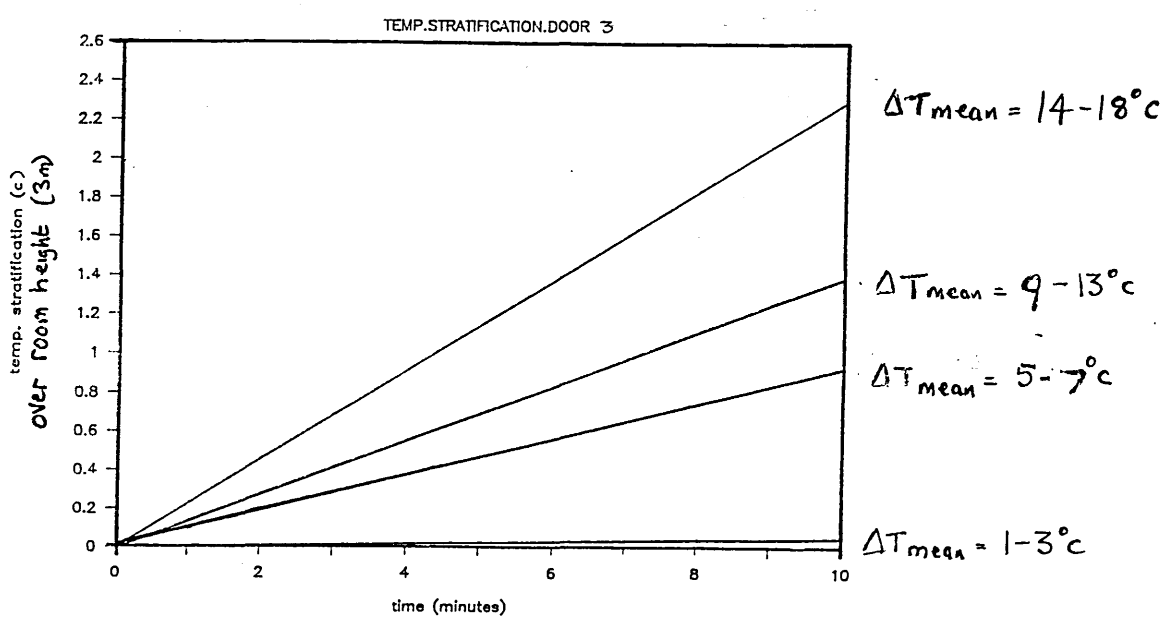

Fig 6.6

As can be seen, there is little difference in temperature stratification for the different door positions. However at higher room temperature differences, there is a greater degree of stratification. At the higher room temperature differences, this may be up to 2.2°C between the top and bottom of the room.

The theoretical effects of a vertical temperature stratification on the flow of air through doorways has been presented by Bouman (44,45). The case in question is for two rooms which show identical temperature stratification, but a net zero temperature difference between the rooms. Under these conditions it is shown that there is, theoretically, a temperature driven flow as a consequence of this stratification. The way in which this effect would change with a time dependent variation of the temperature stratification, as encountered for experimental tests is not stated. The contributory effect of the temperature stratification on the measured airflow rates is not known; however these values must be assumed to be combination in some way of both the temperature stratification within the rooms, and the temperature difference between the rooms.

Representative Temperature

Because of the problems of temperature variation and stratification throughout the test period, the question is posed as to what is the most representative temperature difference between the two rooms. Shaw performed a series of tests which attempted to solve this problem, and concluded that the most easily measured representative value was that of the centre of the room at mid-height. This position was chosen for testing purposes here , with the addition of multiple point thermocouple temperature monitoring (Section 4.1). A representative temperature taking vertical stratification into account was obtained by taking a mean of all the separate values. A further mean of these single values was taken, to take the variation with time into account.

6.4 Presentation of Results

The results of the exprimental tests are shown in Tables 6.4, 6.5 and 6.6 . The data for this series of tests are shown in Appendix B. Note that because of temperature variation throughout the test period, these are mean values.

Position 1 mean ΔT °c	Experimentally measured airflows m^3/h
0	1
2	15
7	3
8	14
9	10
14	8
16	14
34	10

Table 6.4 Experimental results for door Position 1

Position 2 mean ΔT °c	Experimentally measured airflows m^3/h
1	18
2	10
2	18
2	24
2	24
3	15
3	15
5	30
9	21
10	15
13	30
13	39
14	21
14	21
14	30

Table 6.5 Experimental results for door Position 2

Position 3 mean ΔT °c	Experimentally measured airflows m^3/h
1	18
3	39
3	39
3	45
5	69
7	54
9	78
9	69
10	78
12	60
13	69
14	75
18	90

Table 6.6 Experimental results for door Position 3

A linear fit regression of the data points revealed the following empirical equations, as shown in Table 6.6 . These equations are presented in graphical form in Figures

6.7, 6.8 and 6.9 and show the spread of data points about the line of best fit.

Door position	Empirical flow equation m^3/h	Correlation coefficient
Pos'n 1	$Q = 1\,\Delta T^{0.5} + 6$	0.365
Pos'n 2	$Q = 4\,\Delta T^{0.5} + 11$	0.505
Pos'n 3	$Q = 19\,\Delta T^{0.5} + 10$	0.901

Table 6.6 Empirical equations for door Positions 1, 2 & 3

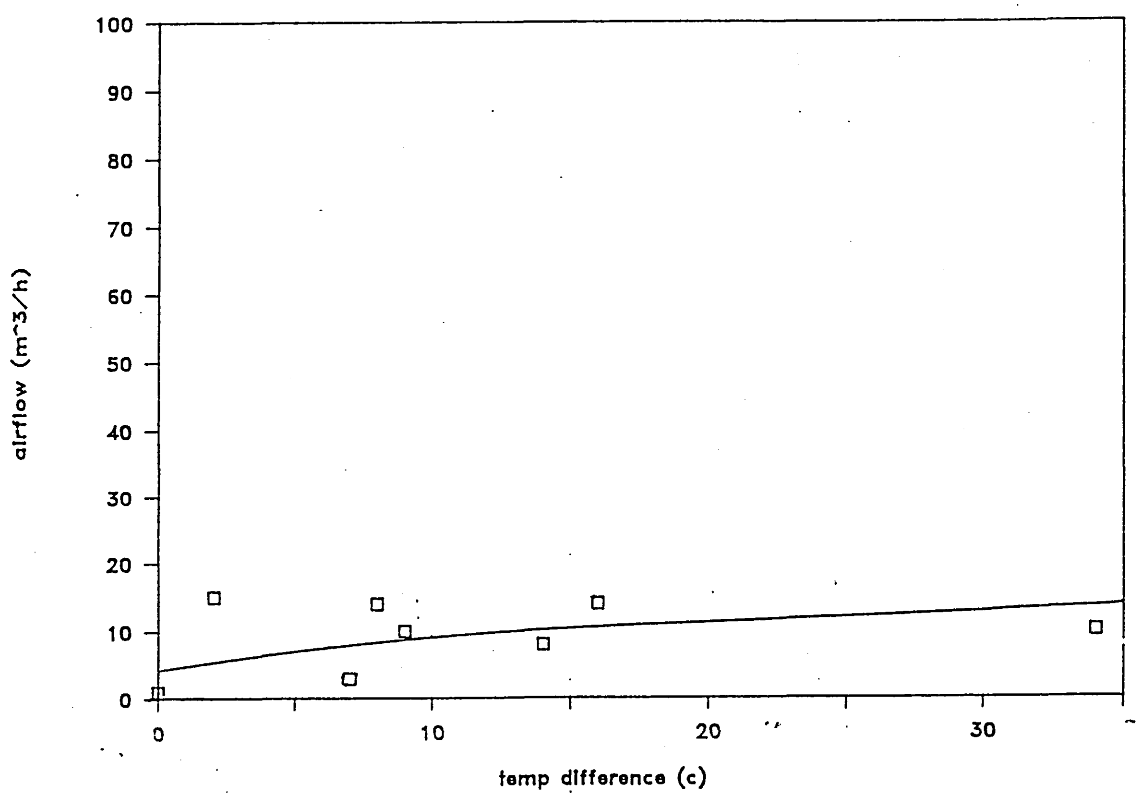

Figure 6.7 Graph of empirical equation door Pos 1

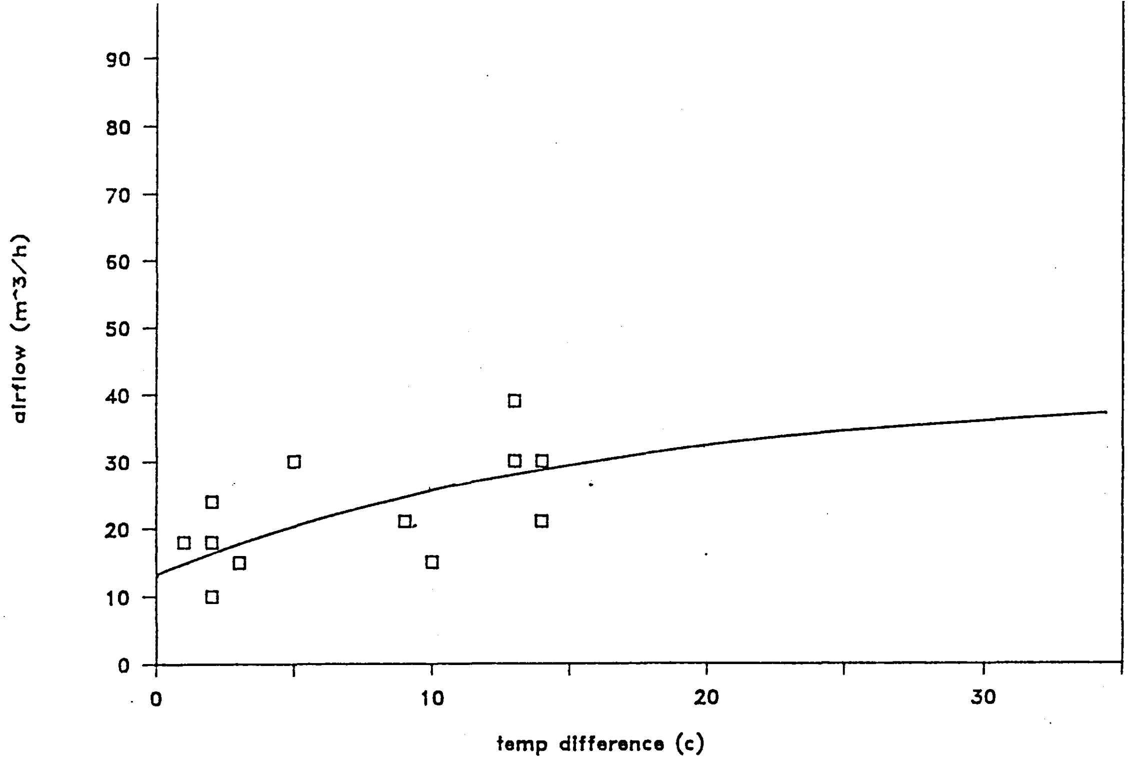

Figure 6.8 Graph of empirical equation for door Pos 2

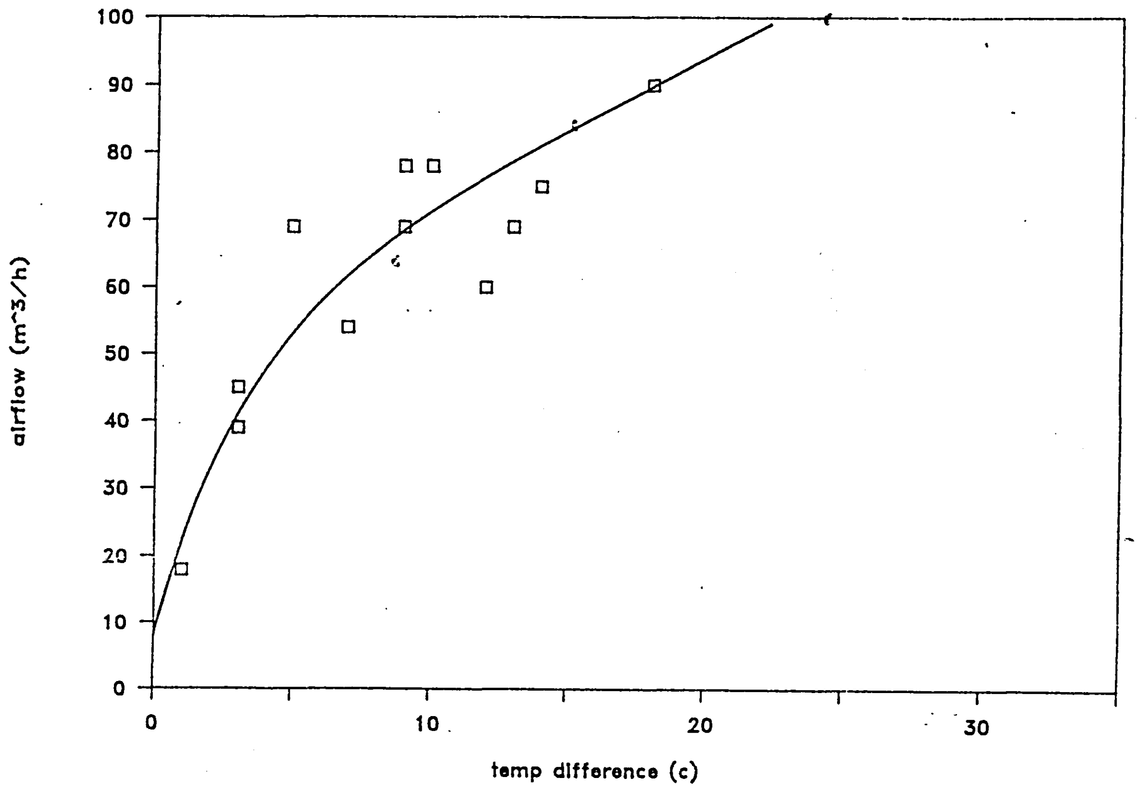

Figure 6.9 Graph of empirical equation for door Pos 3

The correlation between the two variables is seen to become progressively poorer for smaller door openings. It may be that this is a consequence of poor mixing of the "parent" tracer gas within the "receiving" zone.

The opening of the door itself, in effect, creates mixing within the zones, due to the temperature driven airflows through the doorway. As the door is progressively closed, this effect is reduced. At these smaller door openings, relatively smaller amounts of tracer gas have to mix with a constant volume of air in the "receiving" zone. It may be that due to a reduction in the mixing mechanism, the mixing of the tracer gas within the air is not homogeneous, and that instead, "clumps" of tracer gas migrate around the zone, incapable of being sampled from only two locations within the zone.

This would imply that it is the analysis , which requires instantaneous, homogeneous mixing, that is in error, progressively more so at smaller openings, and not necessarily that there is a lack of correlation between the airflow and temperature difference.

6.5 Comparison of Experimentally Measured Airflows Through Doorways With Other Research Workers

There is in fact very little available data with which to compare the experimentally measured airflows.

Lidwell (40), Bruce (41) and Siren (42) were primarily

concerned with the theoretical analyses of temperature driven flow, and no data was presented with these.
Shaw (37), Bouman (44,45) and Riffat (43) have published papers on the experimental measurements of temperature driven airflows through doorways.

Of these, Riffat does not elaborate on the configuration or opening sizes of the doorway used in his tests. Further, the airflows were assumed to be ideal, since the effects of the weather had somehow been subtracted from the actual measured airflow rates. Quoted figures are 194 m^3/h and 276 m^3/h for temperature differences of 0.5 °c and 3.5 °c respectively, for unknown door opening areas.

Bouman only sites one example, for which there was a temperature difference of 1 °c between two rooms and a single doorway opening of 1.6 m^2. This led to an airflow rate of 219 m^2/h. These tests were conducted within the confines of a hospital; the general location of the test rooms with respect to other rooms and the outside environment was unknown. The inclusion of this case in this section, assumes therefore that the conditions were ideal, or laboratory conditions.

Shaw also conducted a series of tests within a hospital, between an operating theatre and connecting rooms. Again, whether or not these conditions can be considered to be subject to the effects of environmental influences is not known. They are included here on the assumption that they are not.

The data for Shaw's work are presented in graphical form in Figure 6.10 . This has been taken from the paper by Lidwell, who in turn took the data from Shaw's papers ((37) Fig 4.10 and (24) Fig 9)

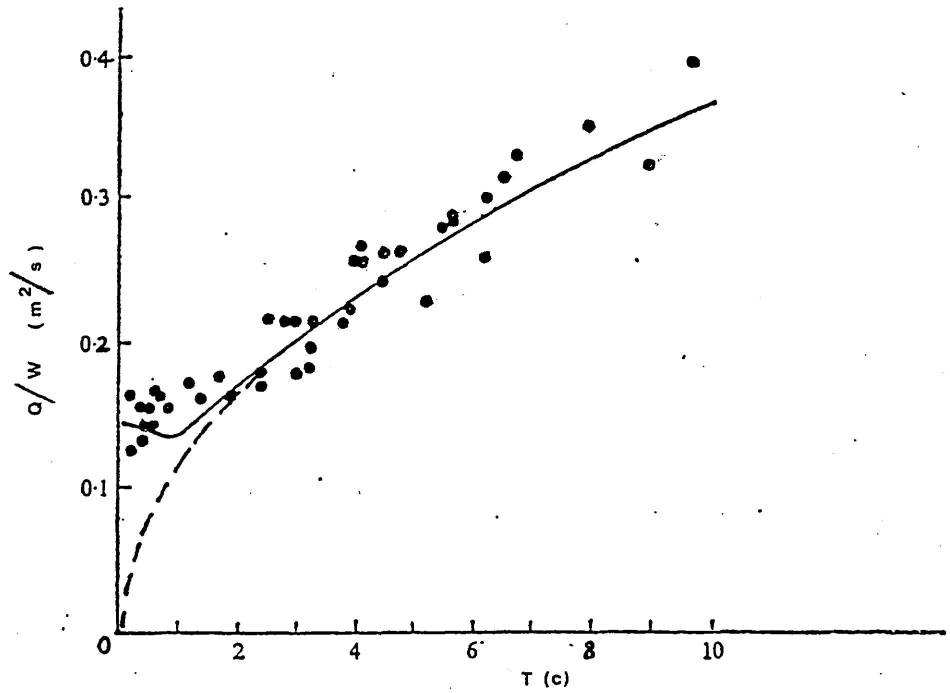

Figure 6.10 Data for Shaws work

Shaw's measured airflows are presented in the form of the airflow per unit width of door opening, Q/w, and a line of best fit constructed for all of the data irrespective of door opening. By so doing, the airflows are mean values for all different door openings. As can be seen from Figure 6.10, there is a spread of data points about the line of best fit. If therefore, lines of best fit had been constructed for each different door opening, there would in fact have been a line for each.

For comparison purposes, between Shaw and those experimentally derived in this project, the data for each has been converted to the airflow per unit area. These are shown in Table 6.7 . This shows the airflow for each of the individual door positions 1, 2 and 3 , and also shows the mean value for all three positions, thus enabling a more valid comparison with Shaw's results. The single result for Bouman is also shown.

AIRFLOW RATE PER UNIT AREA OF DOOR OPENING m^3/h/m^2						
Temp diff °c	Shaw area=1.025 to 1.845m^2	Bouman area=1.6m^2	Laboratory tests pos1	pos2	pos3	mean1,2&3
0	243 to 317	-	352	424	125	300
1	243 to 317	219	411	576	362	449
2	341	-	436	640	460	512
4	395	-	470	730	600	600
6	482	-	497	800	706	668
8	570	-	519	859	796	725
10	632	-	539	910	876	775

Table 6.7 Comparison of experimental airflow rates

N.B. the figures quoted for Shaw's experimental results are gained by reading off from a graph printed in his paper. These can therefore only be expected to be approximate numbers . There is slight difficulty in defining an airflow rate at zero temperature differential, the limits of upper and lower values are therefore included.

The mean values of experimental airflow rates appear to be consistently higher than those measured by Shaw, which may be due to the following reasons;
The rooms within Shaw's tests were heated by a combination of radiators and supply heating via ceiling grilles. This was said to break up any convective plumes generated by the radiators, and create a situation where there was no temperature stratification. As described in section 6.3, this was not the case within the Project. It is possible therefore that the different methods of heating the rooms created dissimilar airflow regimes within the different rooms.

The method of airflow measurement is different for both cases. Shaw used hot wire anemometers to measure the velocity of the air through the doorway, from which the airflow was calculated. The errors associated with the use of this type of instrument on the calculation of airflow rate were not stated.

The orders of magnitude of door openings are different for both cases. Shaws smallest door opening was fifty times larger than the smallest door opening used in the Project It may be that under these circumstances, the airflow regimes through the openings may not be of the same type, and direct comparison cannot be made.

As stated earlier in this section, the location of the test rooms within the general layout of the hospital is not known. It may be that these rooms were influenced in some way by the effects of the weather, thus affecting the measured airflow rates.

No mention is made of temperature variation with time by Shaw. As no specialist heating system was mentioned which could prevent this, it must be assumed that none existed. Temperature variation with time, especially at higher temperature differences, is inevitable. How this was included in Shaw's representative temperature difference is not stated.

6.6 Comparison of Theoretical and Empirical Temperature Driven Airflows Through Doorways

This section compares the theoretical and empirically derived flow equations from sections 6.2 and 6.4, and are summarised in Table 6.8

FLOW EQUATIONS m^3/h			
Door pos'n	Simple theory	Simple modified	Empirical
Pos 1	$Q=3.2\,\Delta T^{0.5}$	$Q=3.5\,\Delta T^{0.5}$	$Q=1\,\Delta T^{0.5} + 6$
Pos 2	$Q=4.9\,\Delta T^{0.5}$	$Q=5.4\,\Delta T^{0.5}$	$Q=4\,\Delta T^{0.5} + 11$
Pos 3	$Q=15.1\,\Delta T^{0.5}$	$Q=19.6\,\Delta T^{0.5}$	$Q=19\,\Delta T^{0.5} + 10$

Table 6.8 Summary of Flow equations

The first noticable difference between the theoretical and empirical equations is the inclusion of a constant term, independent of temperature, in the empirical equations. This could be a measure of the amount of background air turbulence (section 5.2.1), ever present, even when there is no net temperature difference between rooms. The use of radiators has been shown to be a source of turbulent flow within rooms (33). If this is the case, then the amount of turbulent flow measured is between 6 m^3/h to 11 m^3/h.

Perera (46) has shown that the equations as described by Lidwell indicate a turbulent flow of 430 m^3/h, eachway through a doorway of dimensions 1.9 m x 0.8 m (height x width). The indications are therefore, that the amount of turbulent flow also depends on the door opening. This is only partly borne out by the empirical equations. Positions 2 and 3 indicate larger turbulent flows than Position 1, which is to be expected, but Position 2 shows greater flow than Position 3, even though 3 is larger than 2. By converting the empirical turbulent flows to the flow per unit area, these are 352, 423 and 125 m^3/h for Positions 1, 2 and 3 respectively. Conversion of Perera's figure now indicate specific turbulent flows of 282 m^3/h. In arriving at this figure, the assumption made by Perera is that of a constant turbulent air velocity through the doorway. This can only be assumed to be an approximate value however, since there are so many possible permutations of conditions which can exist to create these turbulent velocities (the thermal properties of walls, floors and ceilings of the enclosing rooms, dimensions and geometry of the rooms, method of heating of the rooms).

The temperature dependent terms for both the simple and simple modified theory show poor correlation at the smallest of the door openings. This may be because of the incorrect assumption of the door gap flow characteristics, such as the value of coefficient of discharge.

The correlation between the temperature dependent terms of both the empirical and theoretical equations appears to be good for Position 2. This agreement also appears to be good for the simple modified equations for Position 3. The agreement at this position for the simple equation is less good, showing an approximately 25% lower figure.

A contributory factor to the poor agreement between the theoretical and empirical equations, may be errors in determining the area terms within the theoretical equations, which are unknown. It is probable that because the method of measurement was the same for all three door positions, the errors in measurement will be proportionately greater at the smaller door openings than at the larger ones.

Conclusions of Chapter 6

It is possible to derive empirical equations for convective airflows through doorways. The correlation between these and simple theories of convective flow is good for Positions 2 and 3. For the closed door, the correlation is poor. The simple modified analysis gives better agreement with experimental results, especially at larger door openings.

Of concern is the lack of knowledge of the behaviour of the coefficient of discharge at different temperature differences, especially for the closed door position. The airflow measurements for this position would indicate better agreement with the theoretical equations had a coefficient of discharge equal to 0.19 had been used.

A better knowledge of the coefficient of discharge could enable more accurate theoretical solutions to be determined.

The omission of turbulent airflows is a criticism of both simple theories. At lower temperature differences this appears to be a significant contributory factor to the total flow through doorways.

CHAPTER 7 SITE MEASUREMENTS OF TEMPERATURE DRIVEN AIRFLOWS THROUGH DOORWAYS; 2 ZONE

LIST OF SYMBOLS

Cp	Surface pressure coefficient	
g	Gravitational constant	(m/S2)
h1	Height at position 1	(m)
h2	Height at position 2	(m)
N1	Air change rate of Bedroom	(ac/h)
N2	Air change rate of Stairwell	(ac/h)
P	Pressure (Pa)	
Pw	Pressure due to the wind	(Pa)
	Air Density at 0 C	(kg/m3)
Q	Airflow through doorway	(m3/h)
Q12	Airflow from Bedroom to Stairwell	(m3/h)
Q21	Airflow from Stairwell to Bedroom	(m3/h)
S	Stack dominant pressure	
Tc	Temperature at bottom of Stairwell	(C)
Th	Temperature at top of Stairwell	(C)
Tc	Absolute external temperature	(K)
Ti	Absolute internal temperature	(K)
V	Mean wind velocity at building Height	(m/S)
W	Wind dominated pressure	

Chapter 7 Site Measurements of Temperature Driven Airflows Through Doorways; 2 zones

Introduction

This chapter describes the experimental measurements of convective airflows through doorways, for two zones, under site conditions, as described in section 4.2 . Under these conditions, the possible effects of the weather on these airflows may be investigated.
These measurements were performed with different door positions, for which theoretical and empirical flow equations will be derived.
The empirically derived equations will be compared to the theoretical equations.
Further, the empirically derived site equations will be compared to the laboratory empirical equations of chapter 6

7.1 Door Positions

Because of the different door and doorframe configurations between those in the laboratory and those on site, the original door spacers as used in chapter 6, did not reproduce the same gap dimensions in both cases. Further door spacers were therefore made so that the door position numbers, in both cases, gave approximately the same mean sneck gap width; however the total door gap areas were different due to different sizes. To differentiate between the laboratory and the site, the chosen door positions were designated 2a and 4a. The comparable position to 4a was not fully investigated for laboratory work.

The definition of door gap areas, method of measurement, and assumptions of gap characteristics are the same as described in chapter 6. The gap areas around the door are shown in Table 7.1

AREA OF GAPS AROUND DOORS FOR LAB & SITE m^2			
	Position 2	Position 2a	Position 4a
Sneck	0.0126	0.0143	0.1010
Hinge	0.0055	0.0076	0.0078
Top	0.0023	0.00054	0.0203
Bottom	0.0055	0.00070	0.0014
Totals	0.0170	0.0231	0.1305

Table 7.1 Gap areas around door for lab & site

N.B. position 4 was not investigated for laboratory work

7.2 Theoretical Temperature Driven Airflow Equations

If the gap areas around Positions 2a and 4a are inserted into equations 5.8 and 5. , as outlined in chapter 5, then the following theoretical equations are derived, as shown in Table 7.2 , over the page.

Door Pos'n	Simple theory flow equation m3/h	Modified theory flow equation m^3/h
Pos'n 2a	$Q = 4.4 \Delta T^{0.5}$	$Q = 4.5 \Delta T^{0.5}$
Pos'n 4a	$Q = 24.7 \Delta T^{0.5}$	$Q = 21.8 \Delta T^{0.5}$

Table 7.2 Theoretical Temperature Driven Flow Equations

At the smaller door opening, Position 2a, there seems to be little to choose between the two methods of analysis.

However, at the wider door opening position, there is slight disagreement between the two methods of analysis, with the modified version showing the lower of the two values. This may be due to the very small gap width at the bottom of the door, which brushes against the carpet within the room. This only contributes a relatively small part to the total airflow rate.

The theoretical equations will be compared to the empirically derived equations in sections 7.7.2 and 7.7.2

7.3 Parametric Effects of the Weather Influencing Interzonal Airflows

The theoretical airflows through the site room doorways, or interzonal airflows, have been assumed to be isolated from any environmental factors which may affect them. For laboratory work as described in chapter 6, this was valid, since the test chambers were not affected by the environment. However, for sitework, the rooms within the house are connected to the environment by the many leakage routes, through cracks and crevices (sections 4.5.2 and 4.6.2)

Weather Effects

The driving forces of natural ventilation, are the pressures generated by temperature induced buoyancy and wind, which act on the openings distributed about the dwelling. These are usually described as the stack and wind effects respectively.

Stack Effect

The stack effect arises as a result of differences in temperature, and hence air density between the interior and exterior of a building. This produces an imbalance in the pressure gradients of the internal and external air masses, thus creating a vertical pressure difference.

When the internal air temperature is higher than that of the outside air temperature, air enters through openings in the lower part of the building and escapes through openings at higher levels. Liddament (35) has shown that for a building with a uniform temperature distribution throughout all the rooms, the stack induced pressure between two points at vertical distances of h1 and h2, as shown in Figure 7.1, is;

$$P = -\rho_o\, g\, 273\, (h2 - h1) \left(\frac{1}{Te} - \frac{1}{Ti} \right) \quad (Pa) \qquad 7.1$$

Where ρ_o = air density at 0 c (kg/m^3)

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

Te = absolute external temperature (K)

Ti = absolute internal temperature (K)

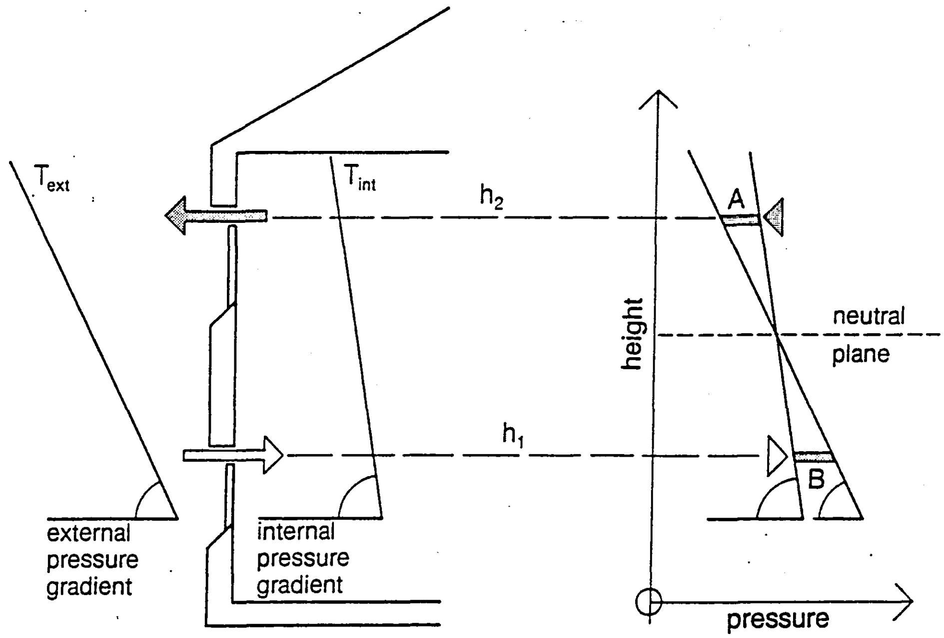

Figure 7.1 Stack induced pressure between two vertically placed openings

By inserting the values for the air density and gravitational acceleration, and assuming that the range of temperatures encountered falls within ± 35 °c, then as stated in the CIBSE guide (34), equation 7.1 reduces to

$$P = 0.043\ (h2 - h1)\ (Ti - Te) \qquad 7.2$$

where the symbols have the same meaning as before.

Further equations have been shown by Liddament to describe the stack effects in buildings which are not of a uniform temperature. These consider the independent cases of a vertical temperature difference, and a horizontal temperature difference within a building. Unfortunately, the case most likely to be encountered, which is a combination of the two , is not described. As these additional equations go no further in describing the stack regime than does the simple case, these are not considered here.

The effects of any stack induced pressure, assuming that the primary flow paths are from leakage routes at lower to higher levels within the building, would be subject to the effects of internal resistances. The overall stack effect would therefore be a function of how many resistances lie in the paths of the airflows, such as the number and settings of doors and windows.

Wind Effects

Wind effects are far more difficult to predict than stack effects. This is due to the nature of the wind; it is constantly changing both in speed and direction. These effects are complicated by building shape, distribution of cracks within the building envelope, surrounding terrain and shielding conditions. The mathematical representation of wind induced airflows through and within the building is extremely complex. In order to develop relationships for the flow process, considerable simplifications have to be made. Algorithms have been developed (6) whereby wind induced flow is integrated within airflow models. However, the data required for even these simple models is quite formidable, requiring detailed pressure distributions about the building envelope, meteorological data as to the statistical occurence of weather for a particular site, local shielding and terrain effects.

A simple assessment of the pressures induced by the wind is given in the CIBSE guide (34). This states that provided the building has relatively sharp corners, the time averaged pressure acting at any point on the surface of a building may be expressed as;

$$Pw = \frac{Cp}{2} V^2 \qquad 7.3$$

Where Pw = surface pressure due to the wind (Pa)

Cp = surface pressure coefficient

V = mean wind velocity, usually at building height (m/s)

Few data exist on surface pressure coefficients for buildings of diffrent shape and shielding. For buildings of simple form which stand alone, BS 5925 (47) gives average surface pressure coefficients. More complicated buildings are considered in the Air Infiltration

Calculation Guide (35).

Combined Effects of Wind and Stack

Usually, the weather induced effects do not act independently. Rather, they act in a complex way that depends on the pattern in which cracks and crevices happen to be distributed over the surface of the house (48). For some patterns the effects of wind and temperature tend to cancel, for other patterns they add.

A solution to this problem (47) is to make a first approximation of the independent effects of wind and stack. The larger of the two effects are taken as the dominant regime, calculations are then based on this effect, the values that are obtained being the lowest that can be expected.

7.4 Experimental Procedure

Interzonal airflows were measured through the doorway connecting bedroom 1 to the hallway of the site house as described in section (4.2).

A two tracer gas technique was used as described in section 2.2.2 . This was because the two zones were connected to the outside environment, and airflows between this and the two zones were possible because of the many possible leakage routes. The experimental technique is fully described in section 2.5

Tests were performed for door positions 2a and 4a with the bedroom window both open and closed to the environment. This was done by sealing the cracks around the bedroom window with adhesive tape; the window being the single most definable leaky component, apart from the door, in this room (sections 4.5.2 and 4.6.2)

The window was sealed so as to impose the following two conditions upon the bedroom;

With the window open, the room could be assumed to be ventilated by both wind and stack effects,

With the window sealed, the leakage paths for wind and stack induced flows could be reduced.

It might thus be possible to determine the effects of wind and stack upon the interzonal airflows through the bedroom door.

Problems of Measurement

Mixing

Tracer gas was injected at two locations within the hallway. Equal amounts were dispensed upstairs and downstairs. After mixing, the concentration of tracer gas upstairs an downstairs matched to within 5%. However, as the measurement proceeded, concentration variations were evident throughout the hallway, primarily between upstairs and downstairs, in some cases up to 20%.

No mixing problems were encountered within the bedroom.

Temperature Variation with Time

As well as creating a uniform tracer gas concentration, mixing also created a uniform temperature distribution within the hallway. After mixing had stopped, the temperature within the hallway always showed signs of temperature stratification between upstairs and downstairs, in some instances it was up to 5 c warmer upstairs.

Stairwell Flows

The reasons for the variations in the upstairs to downstairs temperature and tracer gas concentrations can only be the subject of conjecture, as the actual flow paths of the air within the stairwell were not studied. These effects may be the result of warm air rising within the stairwell, the temperature difference being exacerbated by the ingress of cold air through the leaky front door.

To the Author's knowledge, there are only two previous works investigating the flow of air within a stairwell, namely by Reynolds et al (50) and Riffat (43).

Reynolds presents a very detailed mathematical study of the recirculation of airflows within a stairwell. In this work, the stairwell is assumed to consist of two chambers separated by an area of flow, as shown in Figure 7.2 .

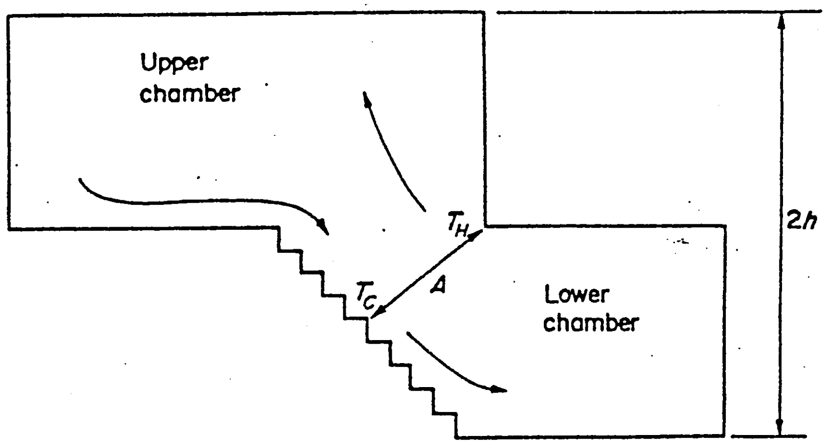

Figure 7.2 Geometry of stairwell, after Reynolds

These chambers are assumed to be very simple in geometry and to be totally sealed from any other rooms or the outside environment. Scale model tests were performed which concluded that the recirculatory airflows depended upon very complicated functions of characteristic temperature difference (Th-Tc), absolute chamber temperatures, Reynolds, Froude and Stanton numbers. In practical terms, the analysis has limited applications because of the complicated geometries of most stairwells, and the fact that it is intimately linked to its surroundings. The modelling of stairwell flows, in fact, goes no further than to state that the general flow pattern of air is that shown in Figure 7.2

Riffat discusses the experimental measurements of airflows through a doorway between the upper and lower floors of a house. The layout of the test house is shown in side view in Figure 7.3 .

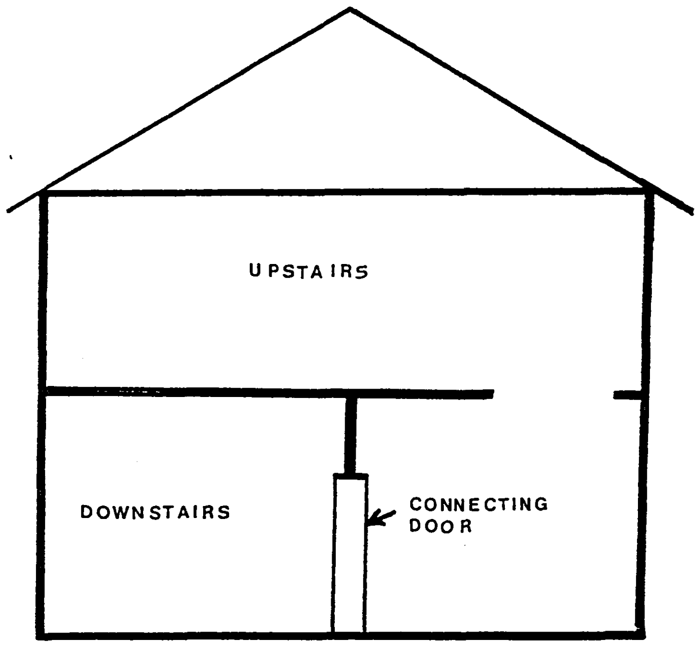

Figure 7.3 Side view of test house, after Riffat

The distinction of the stairwell as a separate zone from all the other rooms on the upper floor is not made.
The general flow regime seems to be a movement of air from lower to upper floors, and a flow in the opposite direction.

For site tests, the stairwell was assumed to be a single distinct zone, connecting rooms on the lower floors to those on the upper floors.

7.5 Analysis of Results

The site concentration data was analysed using Irwin's equations, as described in section 2.8 . The data was fed into an Apple IIe microcomputer, the program of which is given in Appendix A.

A typical chart output for a two zone test is shown in Figure 7.4

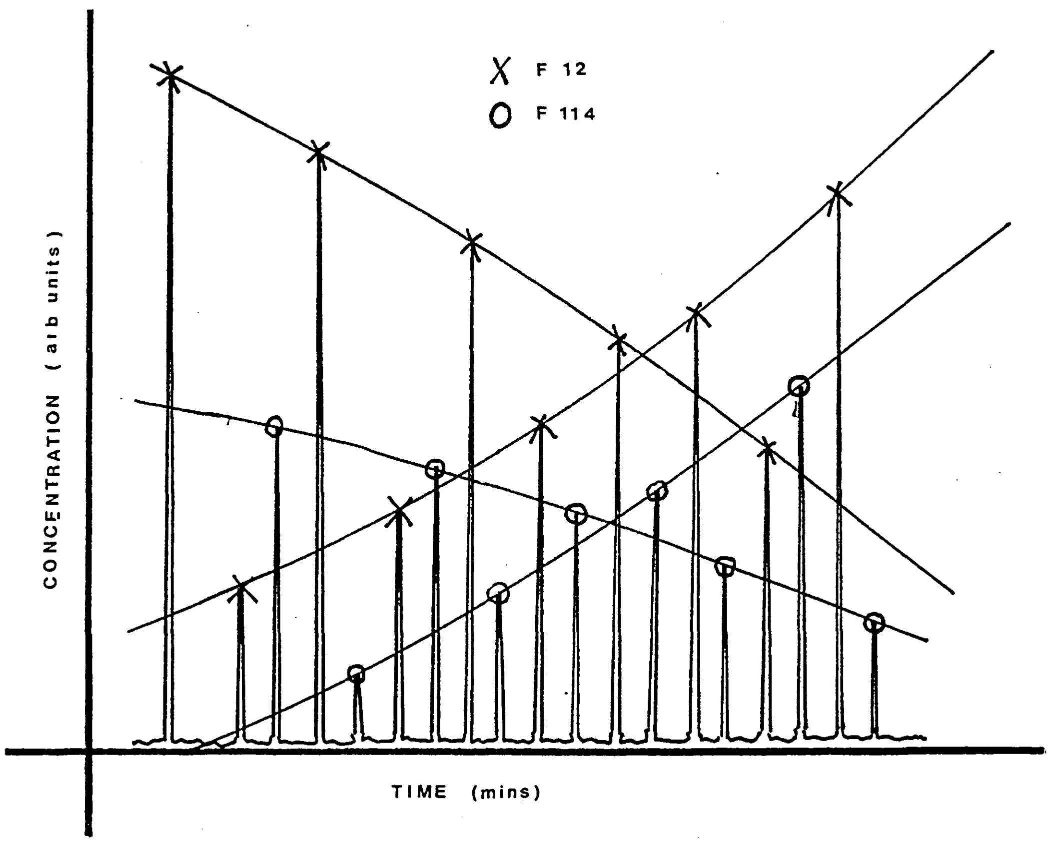

Fig 7.4 Typical chart output for two zone test

Extended Test Period

Irwin (18) states that the length of the test should be made as short as possible, within 20 minutes, to reduce the possible effects of recirculating tracer gas between zones. This period of time was measured by examining the shape of tracer gas decay curves for a series of tests, which should theoretically be exponential in shape. However, by examining the deviation from this true exponential decay, said by Irwin to be caused by the recirculation of tracer gas, the measurement period could be determined.

The recirculation of tracer gas, however, may be a function of several factors, including temperature difference between the rooms, room size, and degree of connection between the rooms. Since the rooms encountered on site were nearly twice as large as those in the laboratory, it would seem probable that any such effects might take longer to happen. The physical measurement of recirculated tracer gas is impossible using these particular tracer gases, since the distinction between "new" tracer gas within the room, and "old" recirculated gas cannot be made.

Due to the necessity to gather sufficient data, the duration of the tests were extended up to a maximum of 40 minutes.

Weather Effects

Positive Pressure Within the Bedroom

As stated in Section 4.2, the pressure difference between the bedroom and the outside air mass was measured across the bedroom window by using a micromanometer. For definition purposes, the bedroom is said to be at a positive pressure when the bedroom is at a higher pressure than the outside air mass. With this regime of wind and stack effects, the general flow of air within the house is assumed to act as shown in Figure 7.5. As can be seen, in this case the effects of the weather are assumed to act together across the bedroom leakage routes.

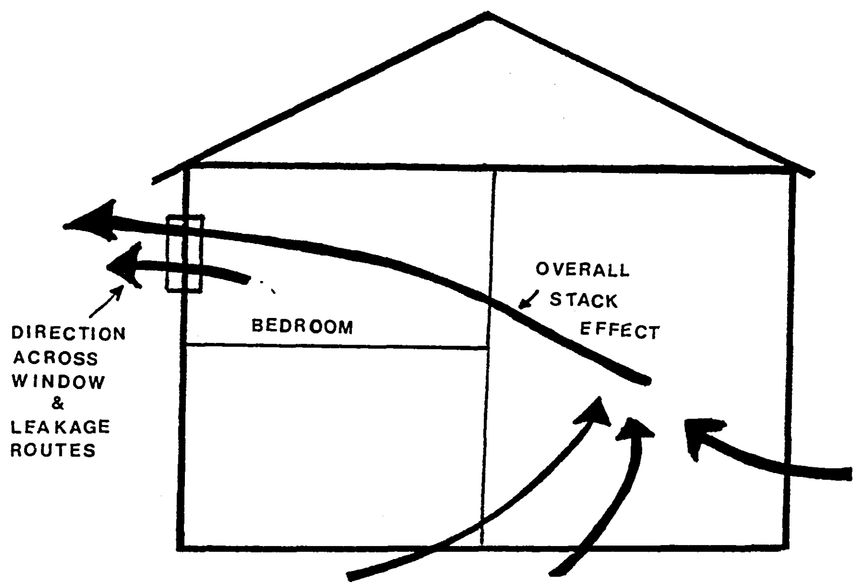

Figure 7.5 Assumed general flow of air within the house; positive pressure within the bedroom

Negative Pressure Within the Bedroom

With the bedroom at a negative pressure, the pressure within this room is defined as being at a lower pressure than the outside air mass. With this regime, the general flow of air within the house is assumed to be as shown in Figure 7.6 As can be seen, in this case the effects of the weather are assumed to act against each other, across the bedroom leakage routes.

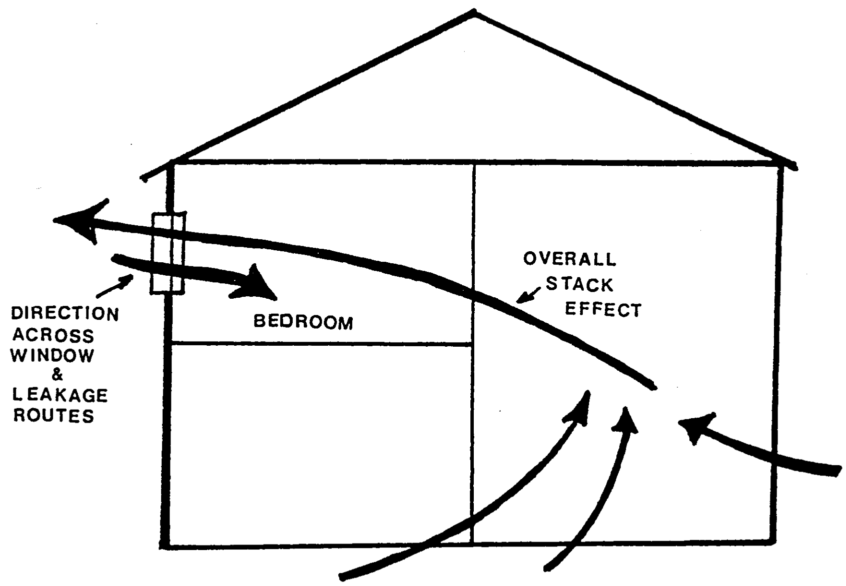

Figure 7.6 Assumed general flow of air within the house; negative pressure within the bedroom

Dominant Effects of the Weather

The interaction between wind and stack induced flows is complex, for both signs of pressure differential, with respect to the outside air mass, this relationship being unknown.

However, as a first approximation, as mentioned in section 7.3, for calculation purposes the follwing assumptions are made;

If the bedroom is at a positive pressure, the wind and stack act together,

If the bedroom is at a negative pressure, wind and stack act against each other.

In this case, the largest of the two forces, with respect to pressures generated, is assumed to be the dominant force.

7.6 Presentation of Results

The results of the experimental tests are shown in Tables 7.3, 7.5, 7.8 and 7.10. For the sealed window tests, the simple parametric effects of the weather are presented alongside, as is the deduced dominant acting force.
The data for this series of tests are presented in Appendix F.

Door Position 2a Window Unsealed								
Bed/hall ΔT °c	Q12 m^3/h	Q21	N1 ach	N2	Int/ext ΔT °c	Stack Pa	Wind	Dominant
3	22	9	0.1	1.4	9	1.2	+0.6	stk+wind
2	85	1	0.5	2.1	16	2.1	-3.0	wind
2	56	12	0.3	3.4	17	2.3	-3.0	wind
2	57	8	1.0	1.3	12	1.6	-8.0	wind
12	130	30	2.8	3.8	15	2.0	+2.0	stk+wind
9	5	41	0.9	0.8	22	2.9	+3.0	stk+wind
14	11	36	0.8	0.5	23	3.1	-0.4	stack
12	16	19	0.9	0.6	13	1.7	+2.0	stk+wind
12	7	28	0.8	0.6	14	1.9	-1.0	stack
6	7	29	0.9	0.5	9	1.2	-3.0	wind
6	20	8	1.1	0.7	8	1.1	-25.0	wind
3	21	12	0.9	0.8	9	1.2	-3.0	wind
5	8	29	0.6	0.2	13	1.7	+1.0	stk+wind

Table 7.3 Results for door Pos 2a; window unsealed

N.B. The height over which the stack effect is assumed to act is 3.1 m. This is the vertical height between the hydraulic centres of the house front door and the bedroom window.

A linear fit regression analysis of Q12, Q21 and N1 against the hall/bedroom temperature difference reveals the following empirical formulas, as shown in Table 7.4 , over the page.

Empirical formulae	Correlation coefficient
$Q12 = -8\Delta T^{0.5} + 52$ m^3/h	-0.17
$Q21 = 11\Delta T^{0.5} - 7$ m^3/h	0.76
$N1 = 0.4\Delta T^{0.5} + 0.03$ ach	0.48

Table 7.4 Empirical formulae for Pos 2a; window unsealed

The graphs of these empirical formulae are shown in Figures 7.7, 7.8 and 7.9 . Along side the data points are the dominant weather effects during the time of measurement.

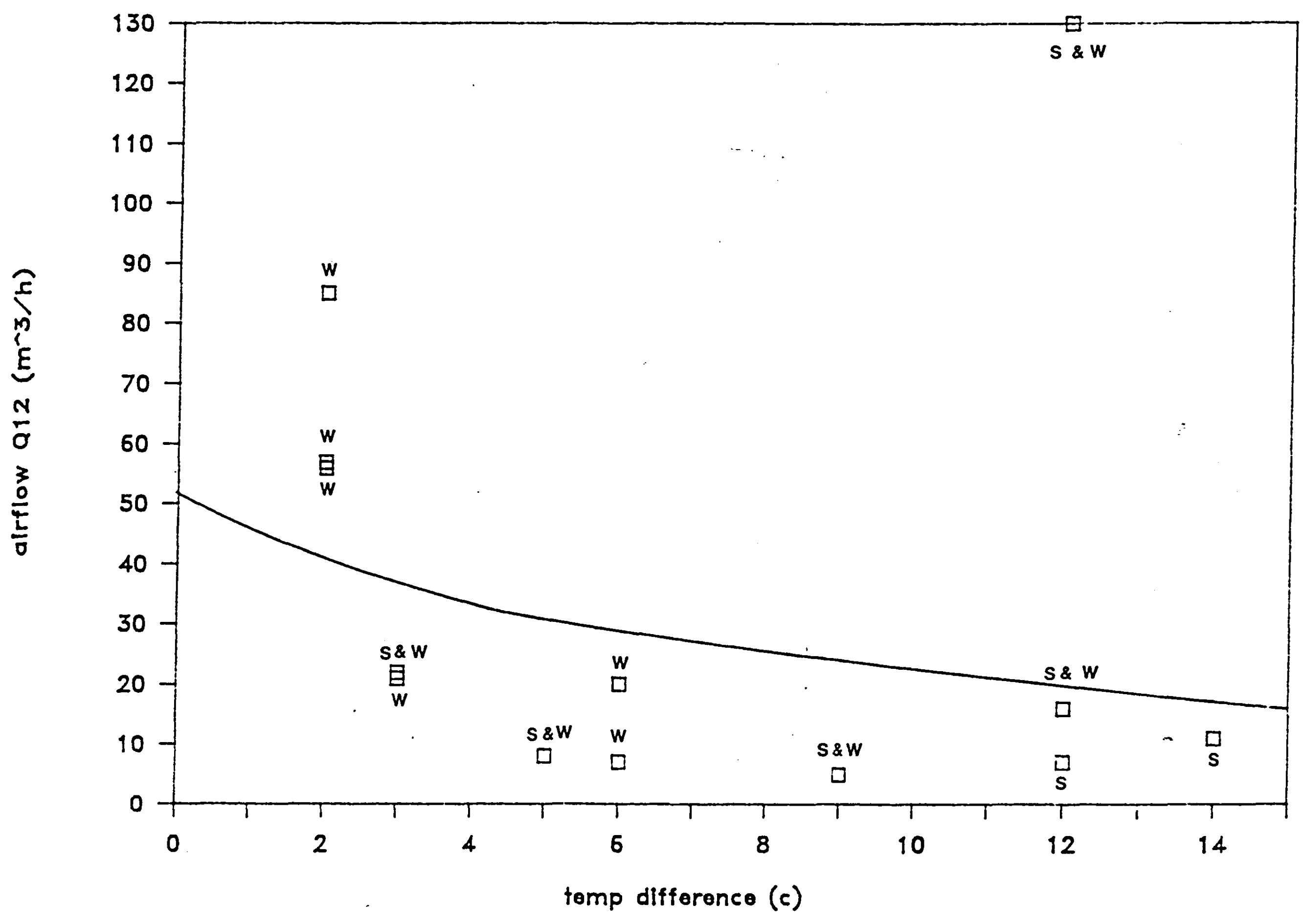

Figure 7.7 Graph of empirical formula Q12

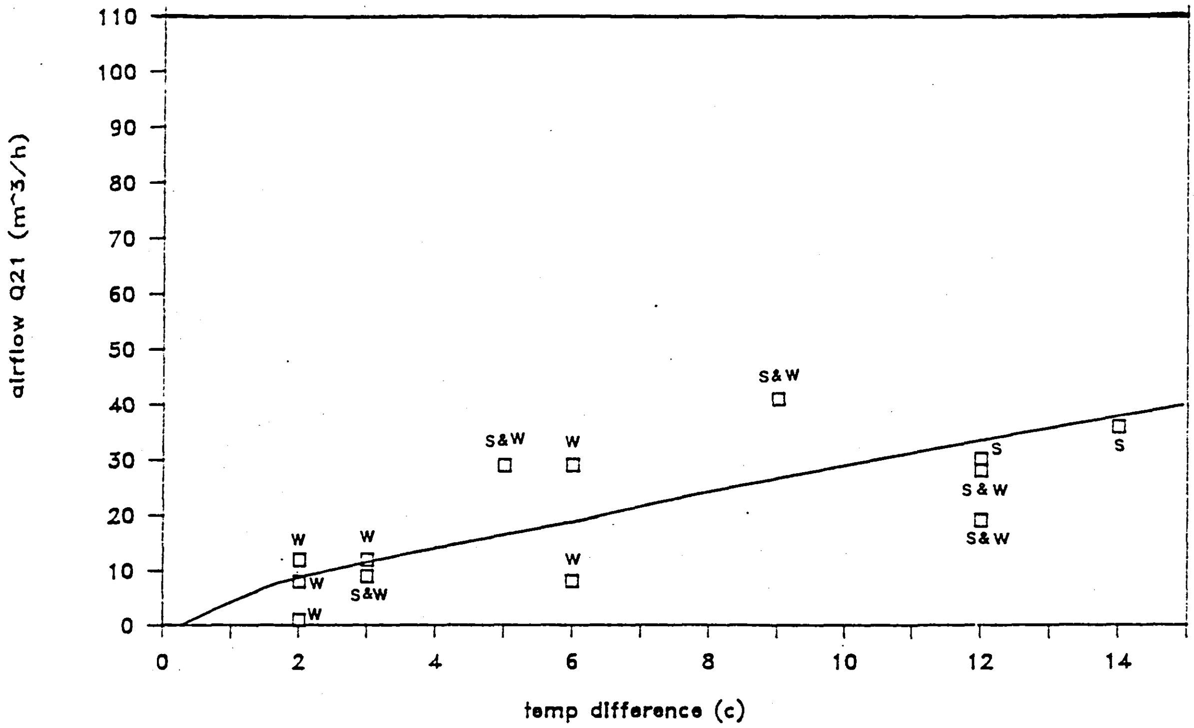

Figure 7.8 Graph of empirical formula Q21

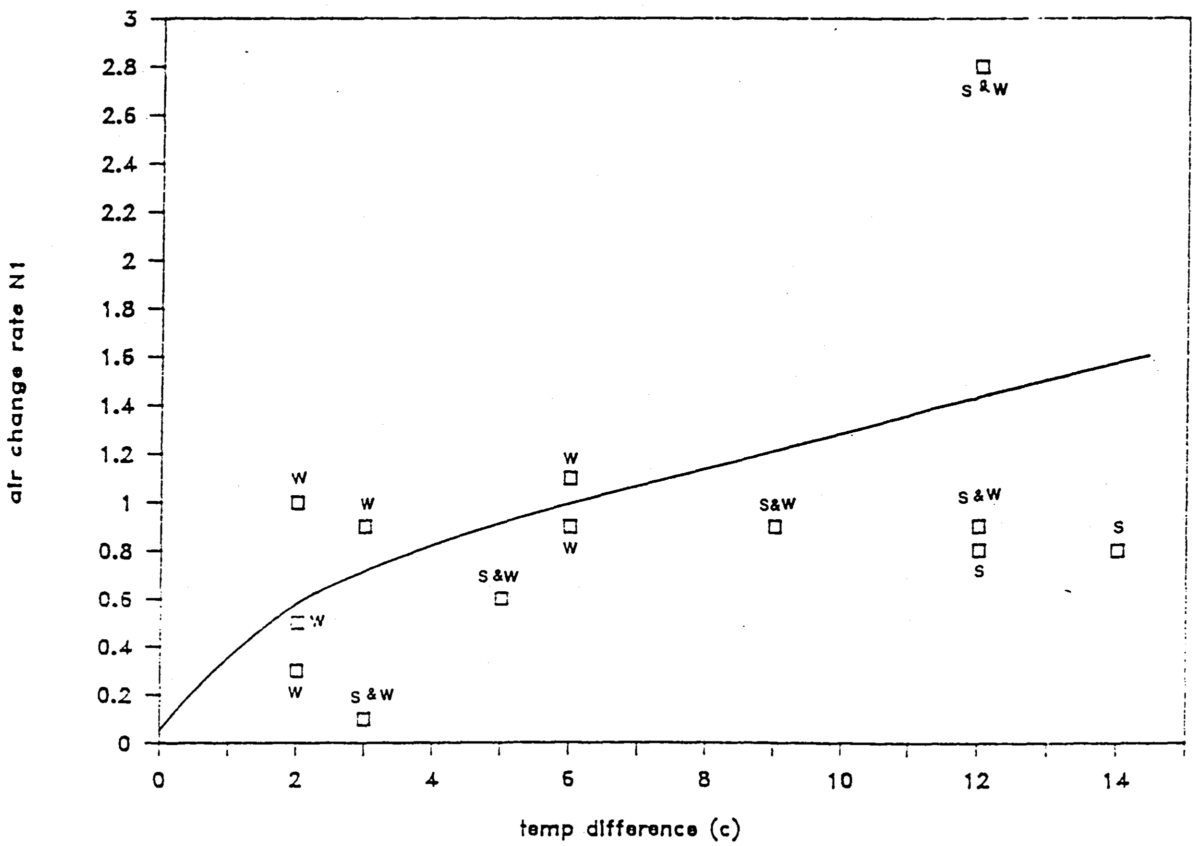

Figure 7.9 Graph of empirical formula N1

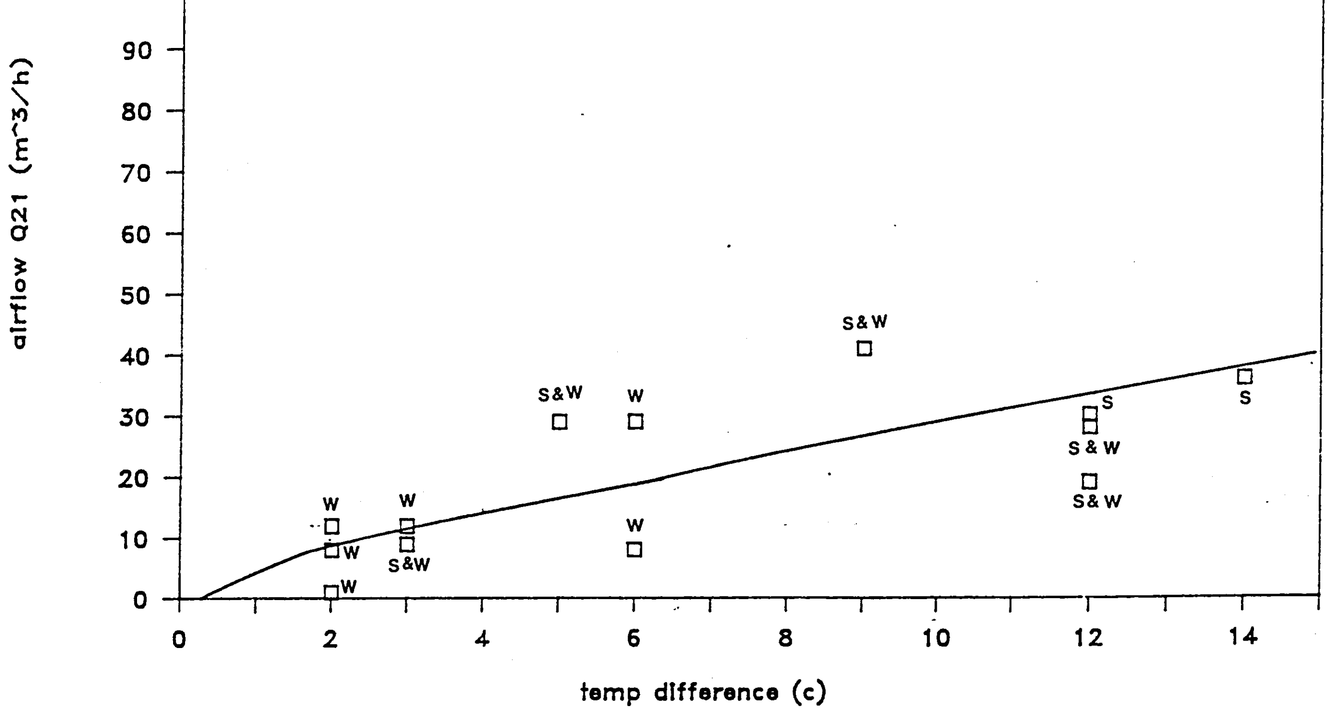

Figure 7.8 Graph of empirical formula Q21

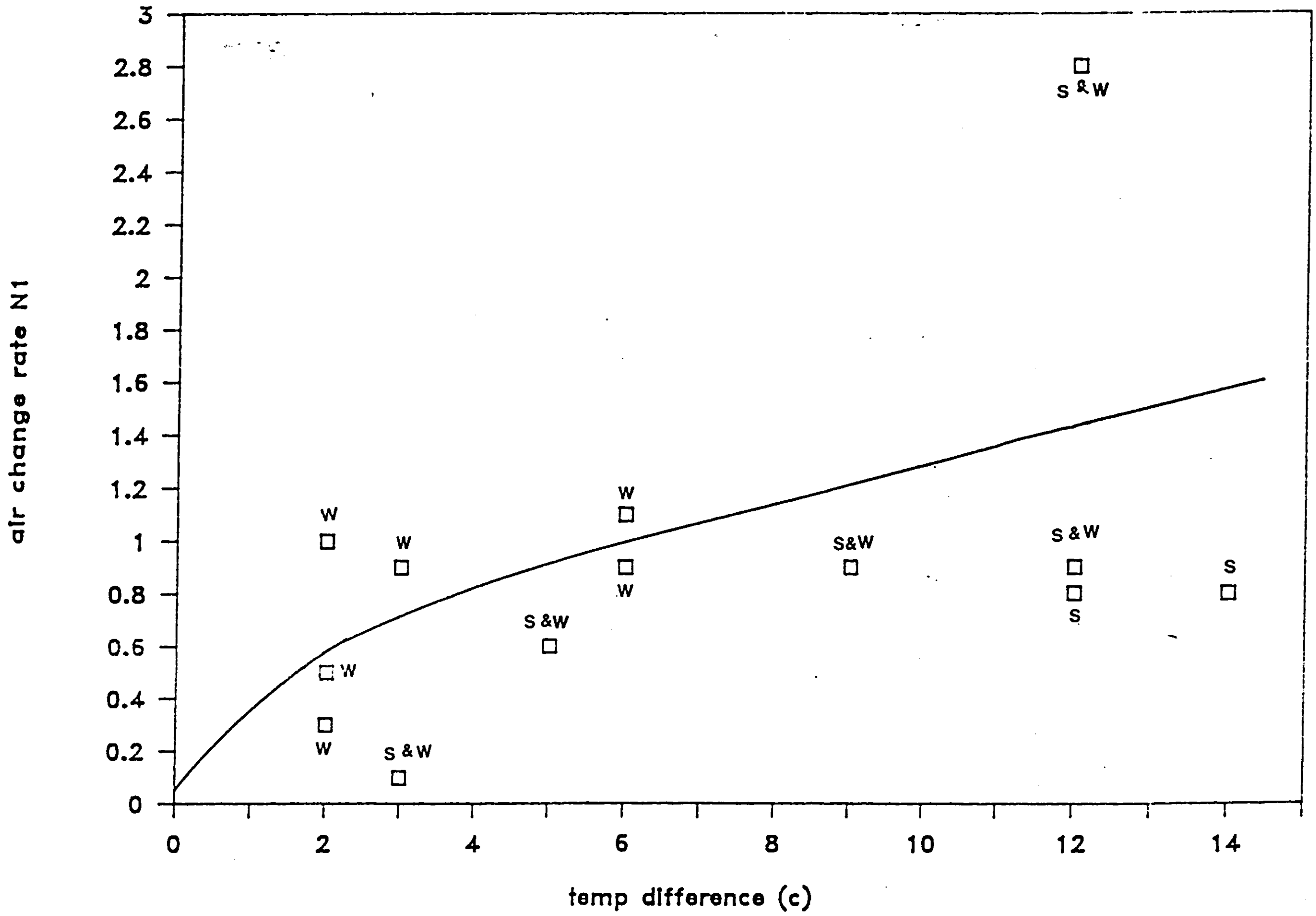

Figure 7.9 Graph of empirical formula N1

Door Position 2a Window Sealed				
Bed/hall ΔT °c	Q12	Q21	N1	N2
	m^3/h		ach	
6	9	29	0.3	1.8
5	0	25	0.2	1.9
15	24	22	0.3	1.2
5	1	28	0.1	1.3
4	44	14	0.4	1.5
3	0	19	0.4	0.4
2	12	11	0.3	0.6
4	0	23	0.3	0.5
2	10	15	0.2	1.5

Table 7.5 Results for door Pos 2a; window sealed

N.B. The window to the bedroom is sealed, therefore there is no definite air leakage route through which the wind and stack can have effect. However the room is not totally sealed to the environment due to other leakage routes through skirting boards, walls and service inlets. Since it is difficult to define the exact location and dimension of these, the pressures exerted by wind and stack are not known.

A linear fit regression analysis of Q12, Q21 and N1 aginst the bedroom/hall temperature difference reveals the following empirical formulae, as shown in Table 7.6, over the page.

Empirical formulae	Correlation coefficient
$Q12 = 5\,\Delta T^{0.5} + 1$ m^3/h	0.25
$Q21 = 4\,\Delta T^{0.5} + 12$ m^3/h	0.49
$N1 = -\,0.002\,\Delta T^{0.5} + 0.3$ ach	-0.016

Table 7.6 Empirical formulae Pos 2a; window sealed

Graphs of these empirical formulae, along with the data points are shown in figures 7.10, 7.11 and 7.12

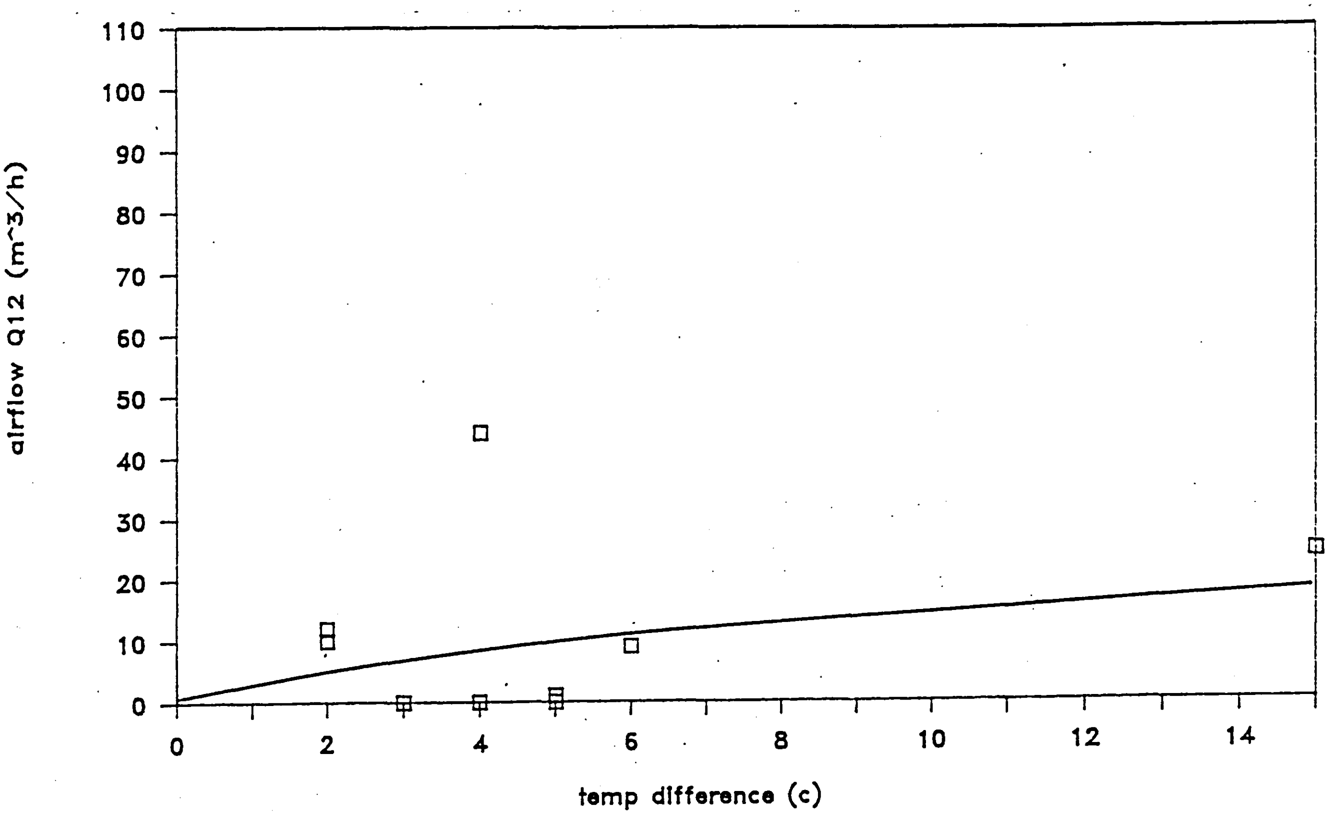

Figure 7.10 Graph of empirical equation Q12

Empirical formulae	Correlation coefficient
Q12 = 5 $\Delta T^{0.5} + 1$ m^3/h	0.25
Q21 = 4 $\Delta T^{0.5} + 12$ m^3/h	0.49
N1 = - 0.002 $\Delta T^{0.5} + 0.3$ ach	-0.016

Table 7.6 Empirical formulae Pos 2a; window sealed

Graphs of these empirical formulae, along with the data points are shown in figures 7.10, 7.11 and 7.12

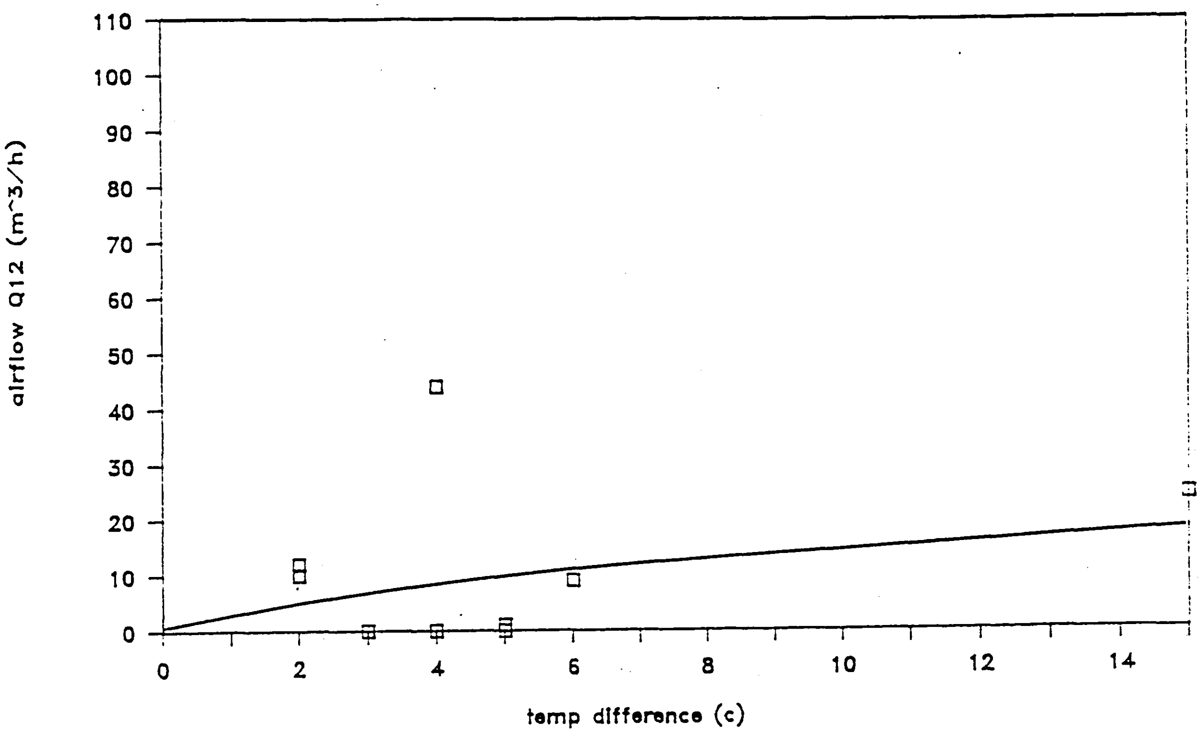

Figure 7.10 Graph of empirical equation Q12

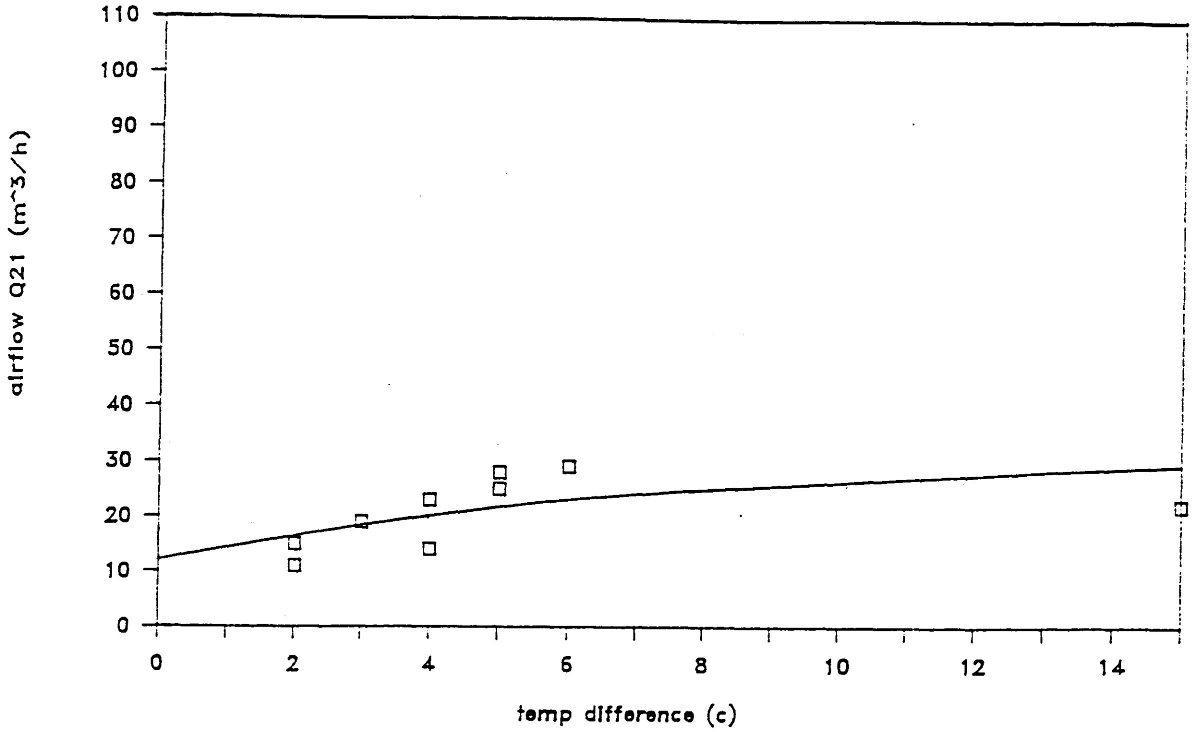

Figure 7.11 Graph of empirical equation Q21

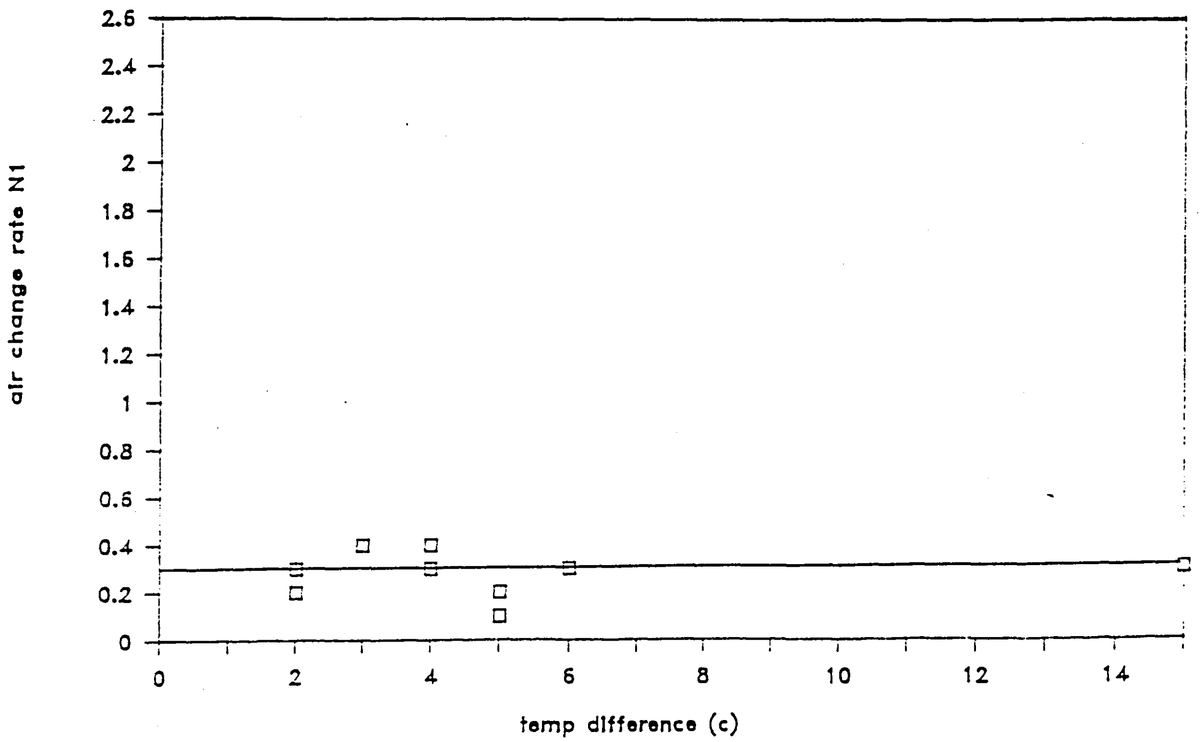

Figure 7.12 Graph of empirical formula N1

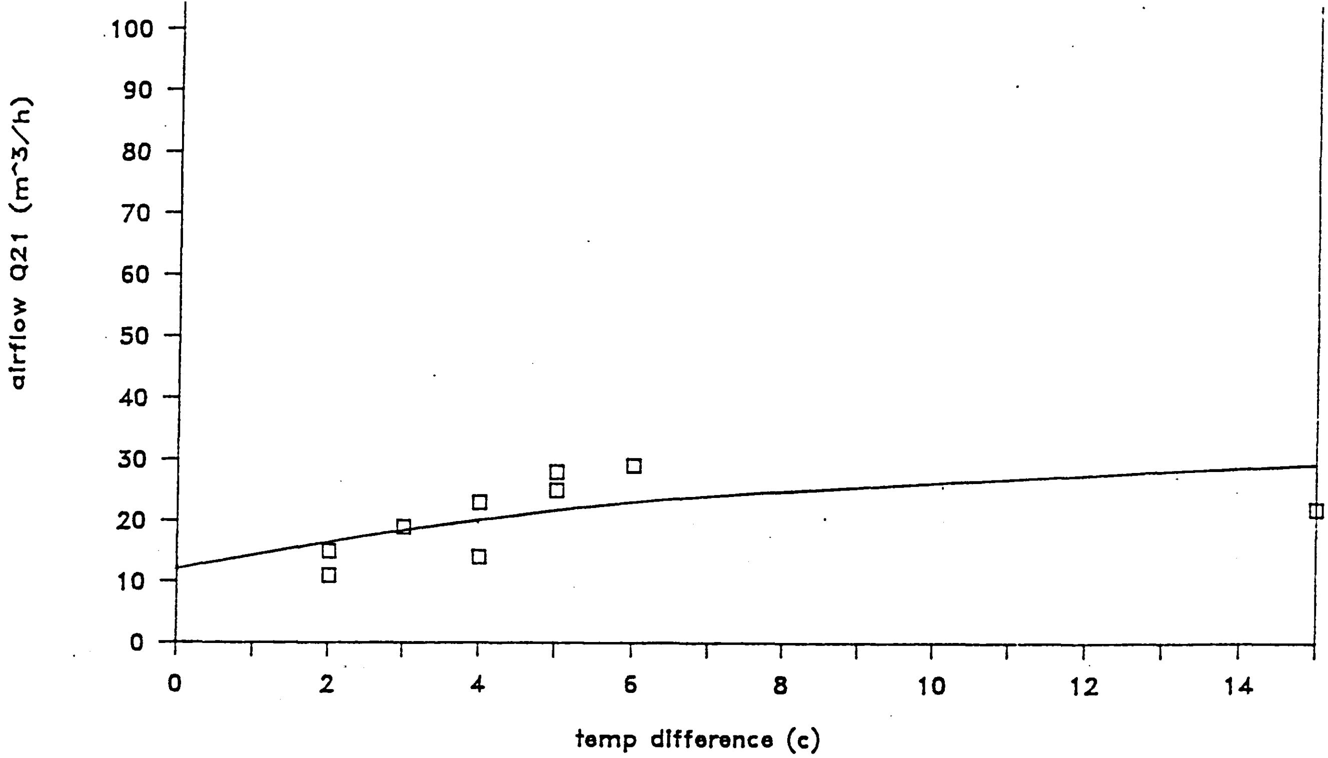

Figure 7.11 Graph of empirical equation Q21

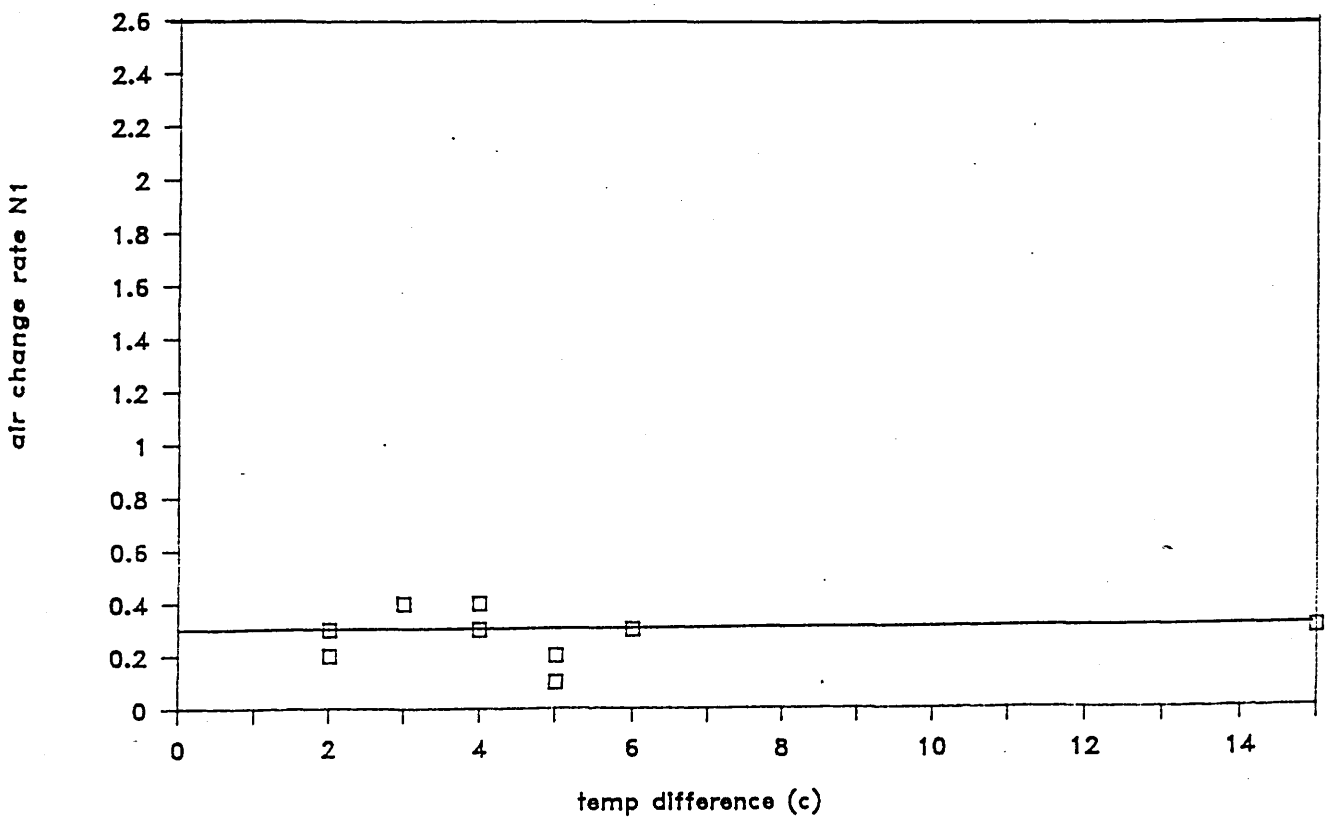

Figure 7.12 Graph of empirical formula N1

7.7 Discussion of Door Position 2a

The first thing to notice about the results, as plotted on the graphs, is the wide spread of data about the lines of best fit. This may be partly explained by the very variable way in which airflows seem to behave.

With this door position, and the bedroom window sealed,the two flows, Q12 and Q21, indicate similar temperature dependent terms (within 20% of each other), with the difference being in the constant terms. These constant terms are assumed here (section 5.2.1) to be a measure of the background turbulence flow of air through the doorway. The background flow of air being that which cannot be classed as dependent upon the temperature difference between the bedroom and hallway. This flow may partly be due to the effects of weather; wind and stack.

It is significant, that with the window sealed, this independent term is larger for Q21 than for Q12, this being a measure of the turbulent and background flows in the hallway (zone 2), which has been assumed to be subject to various air movement processes (creating temperature and tracer gas stratification).

With the window sealed, the bedroom was assumed to be less under the influence of air intraction across the bedroom window, which could otherwise possibly promote mixing of the air within this room; thus the background turbulence term would in this case be low.

Both equations in this case would appear to be predominantly temperature difference dominated, with the background turbulence term being significant at low temperature differences for Q21.

With the situation reversed, and the bedroom window unsealed and open to the environment, both flow equations include negative terms. The physical meaning of this is not known; it does not for example imply a flow "in the opposite direction" to that indicated, since the terms are scalar quantities.

What is significant about the flow Q12 is the very large turbulent and background flow. With the window open, the room is subject to air interaction across the window, the effect of which could promote mixing of the air within this room, thus increasing the turbulence.

The equation would indicate that the flow Q12 is independent of the temperature difference between the bedroom and the hallway, the majority being turbulence induced flows.

The equation for Q21 contains a negative constant term. This implies failure of the equation at temperature differences of less than 0.8 $^{\circ}$c, which would seem to be insignificant when compared to the majority of tested temperature differences. This flow equation would appear to be mainly temperature dominated.

7.7.1 Comparison of Bedroom Window Sealed and Unsealed

The effect of unsealing the bedroom window was to alter the pattern and magnitude of the flow through the doorway. By reference to Figures 7.7 and 7.8, it can be seen that this effect generally increases the flow rate through the doorway. The effect of unsealing the window on the room air change rate is much more dramatic, as can be seen in Figure 7.9 .

How the individual effects of the weather, wind and stack, manifest themselves upon the airflow and air change rate are not known, since the way in which they are spread about the line of best fit of the flow equations appears to be totally random, as shown previously in Figures 7.7, 7.8 and 7.9 .

7.7.2 Comparison of Site Empirical with Theoretical and Laboratory Empirical Equations; Pos 2a

For comparison, the relevant flow equations are summarised in Table 7.7

Position 2a		Flow Equations m^3/h
Modified Theory		$Q=4.5\Delta T^{0.5}$
Simple Theory		$Q=4.4\Delta T^{0.5}$
Lab. Empirical		$Q=4\Delta T^{0.5}$
Site Empirical	sealed	$Q12=5\Delta T^{0.5}+1$
		$Q21=4\Delta T^{0.5}+12$
	unsealed	$Q12=-8\Delta T^{0.5}+5$
		$Q21=11\Delta T^{0.5}-7$

Table 7.7 Comparison of Flow Equations Door Position 2a

The agreement between airflows Q12 and Q21 for the window sealed appears to be good with both the theoretical and laboratory empirical equations. The theoretical equations do not of course contain constant terms, but the temperature dependent terms of all the equations show very good agreement.

With the window unsealed, there is very little to compare with those of either the theoretical or laboratory empirical equations. It is assumed, therefore, that the effects of the weather alter the flow regime through the doorway.

Door Position 4a Window Unsealed								
Bed/hall ΔT °c	Q12 m^3/h	Q21	N1 ach	N2	Int/ext ΔT °c	Stack Pa	Wind	Dominant
6	27	60	0.8	2.0	10	1.3	0	stack
10	69	98	1.8	2.1	23	3.1	+0.4	stk+wind
7	42	109	2.3	1.4	20	2.7	+0.4	stk+wind
8	72	107	1.6	1.9	20	2.7	+1.0	stk+wind
2	127	35	1.9	0.4	15	2.0	-5.0	wind
12	111	31	2.4	3.2	15	2.0	+2.0	stk+wind
4	60	31	1.9	1.2	7	0.9	-3.0	wind
5	56	26	2.4	1.6	9	1.2	-25.0	wind
4	53	89	0.7	1.3	9	1.2	+0.4	stk+wind
0	128	26	1.2	1.7	10	1.3	-4.0	wind
3	39	57	0.5	1.2	9	1.2	0	stack

Table 7.8 Results door Pos 4a; window unsealed

N.B. The height over which the stack effect is assumed to act is 3.1 m. This is the vertical height between the hydraulic centres of the house front door and the bedroom window.

A linear fit regression analysis of Q12, Q21 and N1 against the hall/bedroom temoerature difference reveals the following empirical formulae, as shown in Table 7.9 over the page.

Empirical formulae	Correlation coefficient
Q12 = - 14 ΔT^0.5 + 101 m^3/h	-0.37
Q21 = 16 ΔT^0.5 + 25 m^3/h	0.46
N1 = 0.3 ΔT^0.5 + 1.0 ach	0.40

Table 7.9 Empirical formulae Pos 4a; window unsealed

Graphs of these empirical formulae are shown in Figures 7.13, 7.14 and 7.15 . Alongside the data points are the dominant weather forces acting throughout the test period.

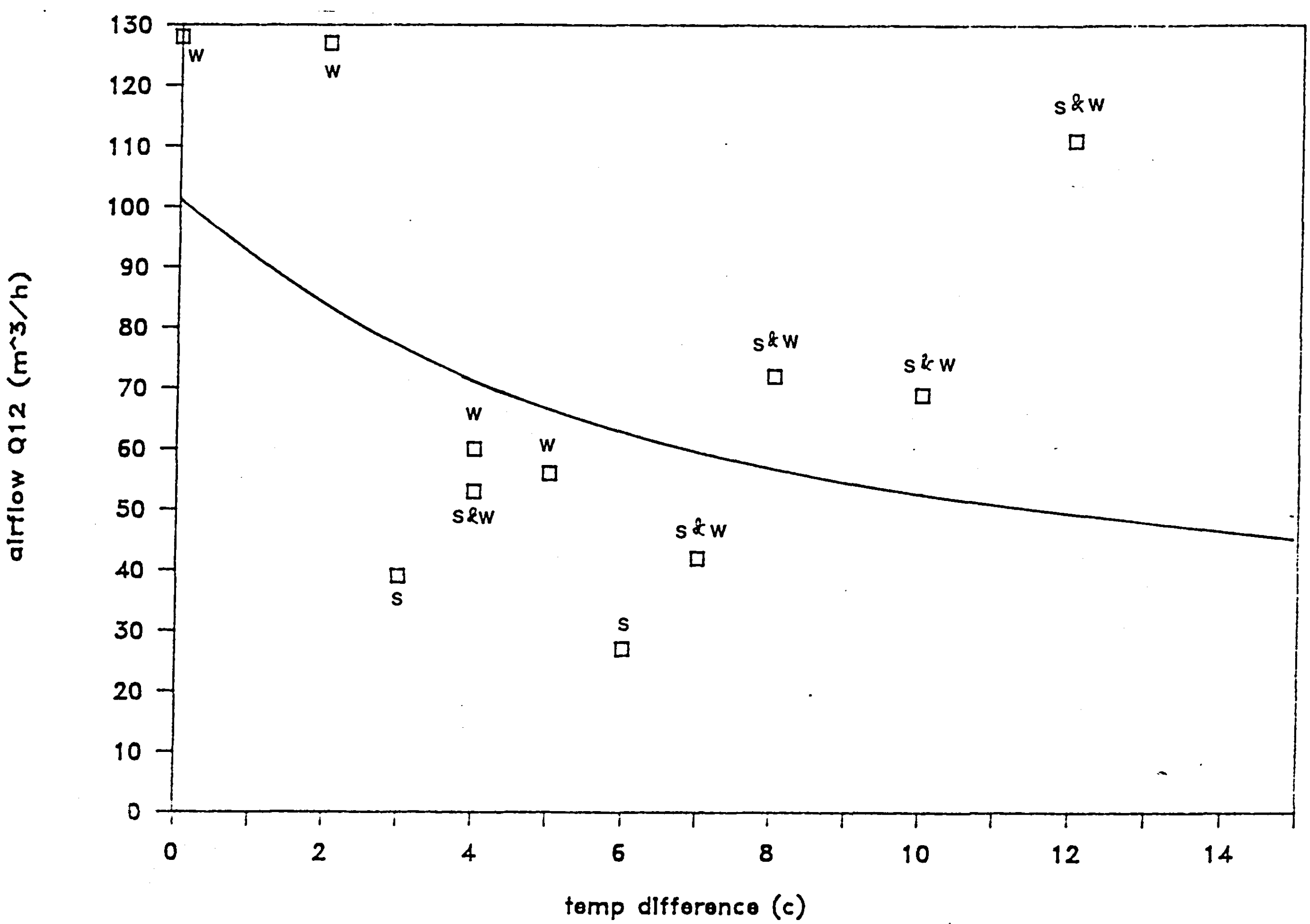

Figure 7.13 Graph of empirical formula Q12

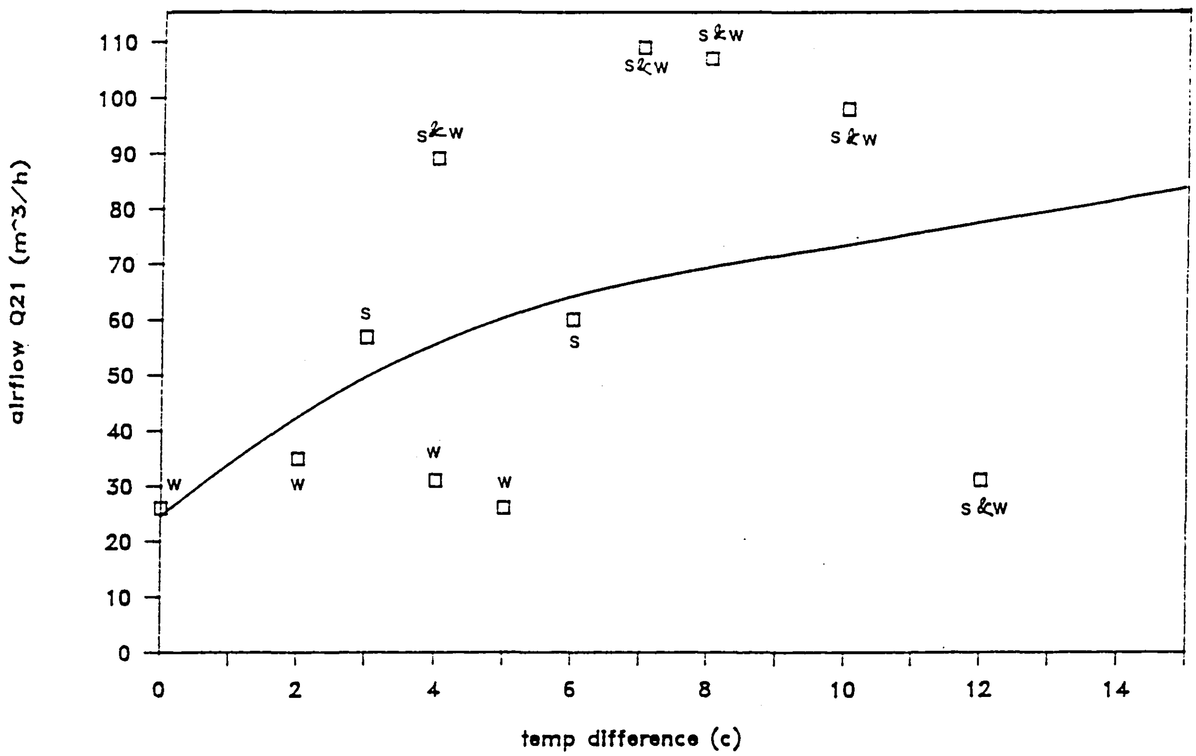

Figure 7.14 Graph of empirical formula Q21

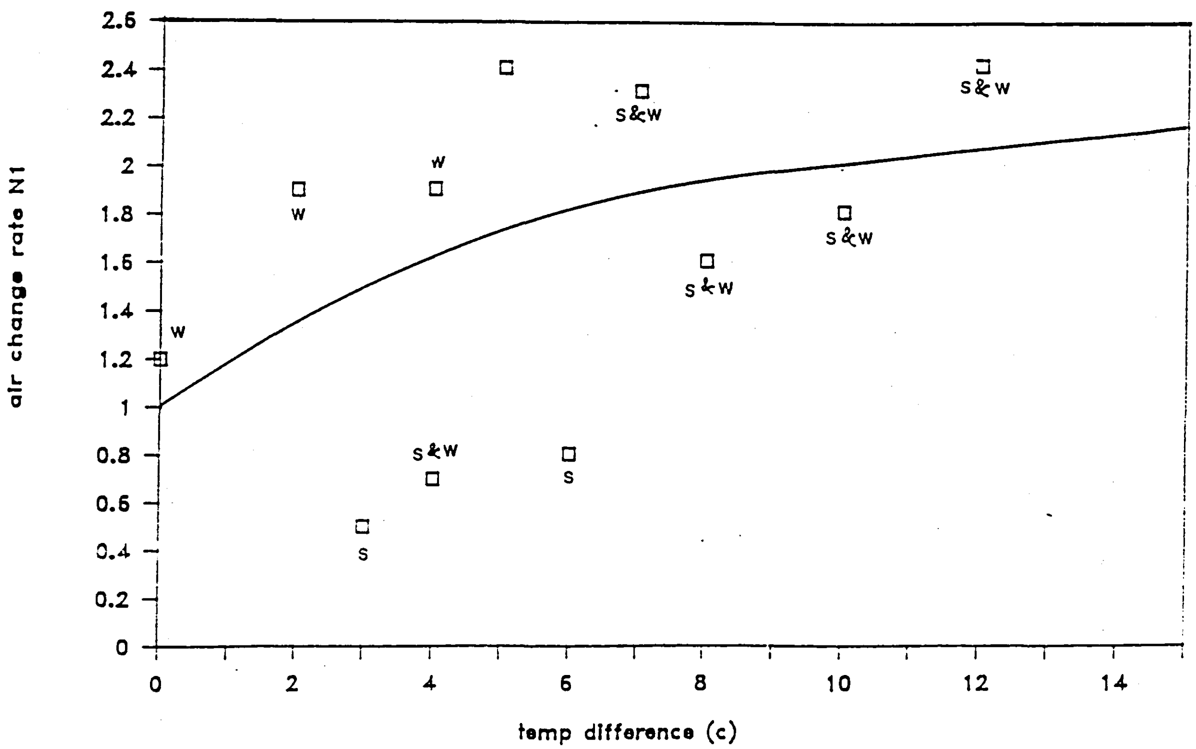

Figure 7.15 Graph of empirical formula N1

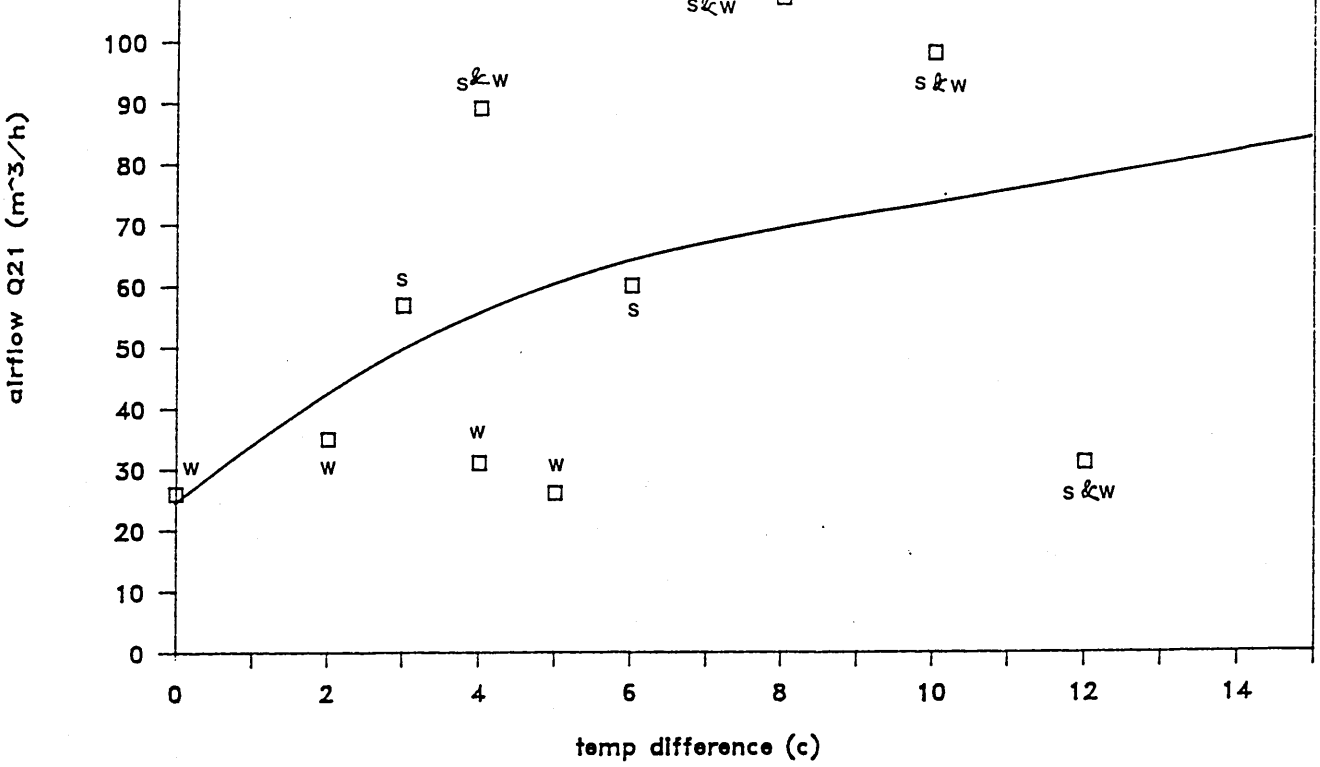

Figure 7.14 Graph of empirical formula Q21

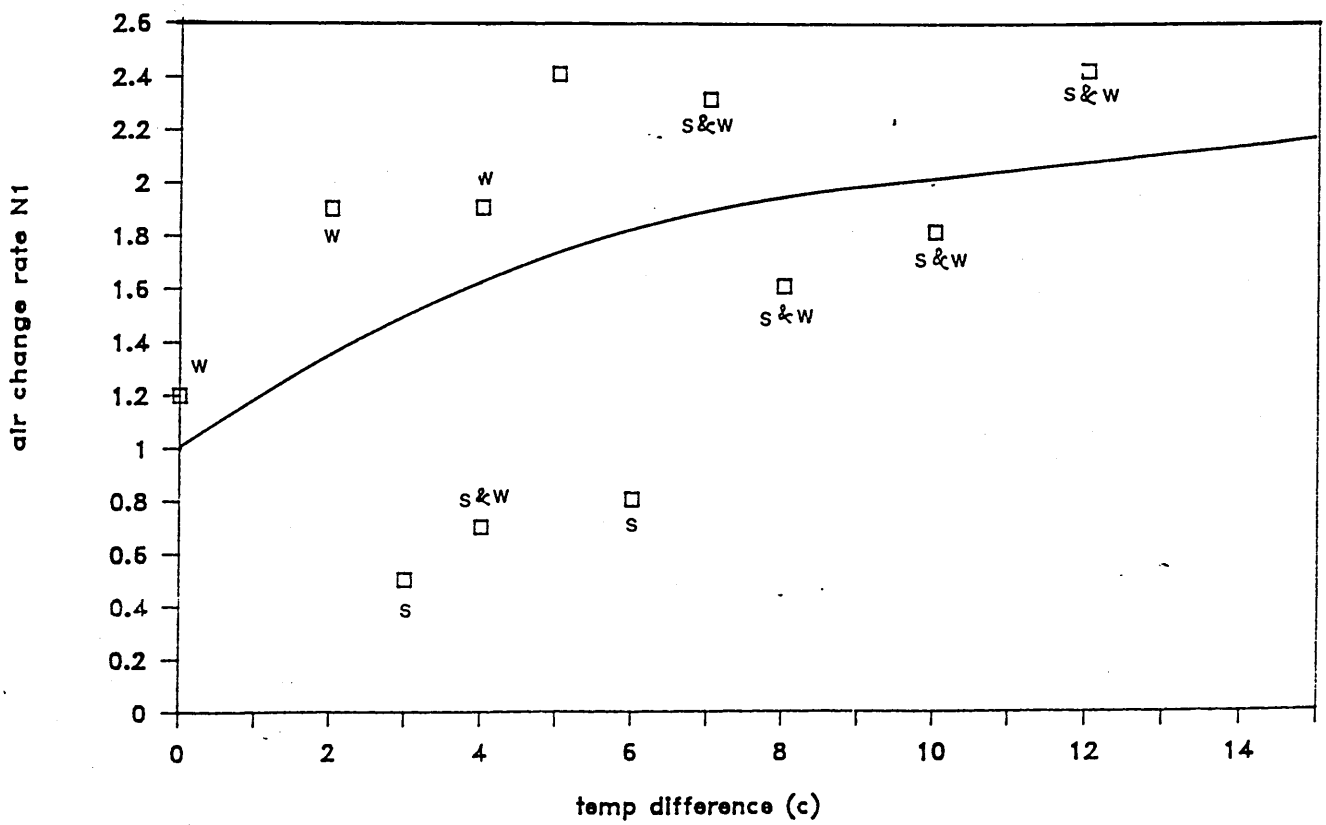

Figure 7.15 Graph of empirical formula N1

Door Position 4a Window Sealed				
Bed/hall ΔT °c	Q12	Q21	N1	N2
	m^3/h		ach	
7	64	65	0.8	1.8
4	50	35	0.4	1.1
9	74	83	1.7	0.8
8	80	66	1.1	0.9
4	40	48	0.7	0.5
4	39	56	0.6	1.3
3	32	64	0.9	0.5
2	43	38	0.6	1.0
4	62	76	0.6	2.0

Table 7.10 Results door Pos 4a; window sealed

N.B. since the bedroom window is sealed, the comments regarding Position 2a window sealed are applicable here also.

A linear fit regression analysis of Q12, Q21 and N1 reveal the following empirical formulae, as shown in Table 7.11

Empirical formulae	Correlation coefficient
Q12 = 27 ΔT^0.5 - 6 m^3/h	0.85
Q21 = 20 ΔT^0.5 + 15 m^3/h	0.65
N1 = 0.5 ΔT^0.5 - 0.4 ach	0.74

Table 7.11 Empirical formulae Pos 4a; window sealed

The graphs of the empirical formulae are shown in Figures 7.16, 7.17 and 7.18, along with the data points.

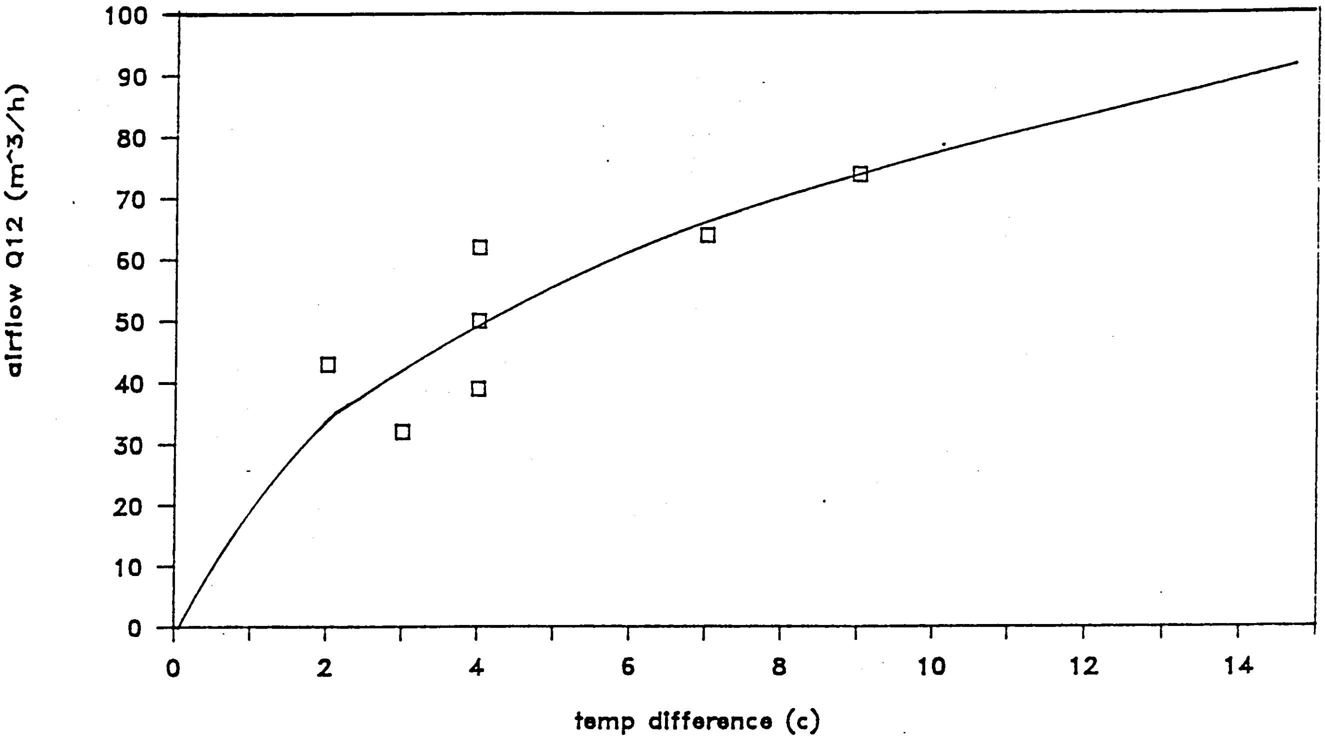

Figure 7.16 Graph of empirical formula Q12

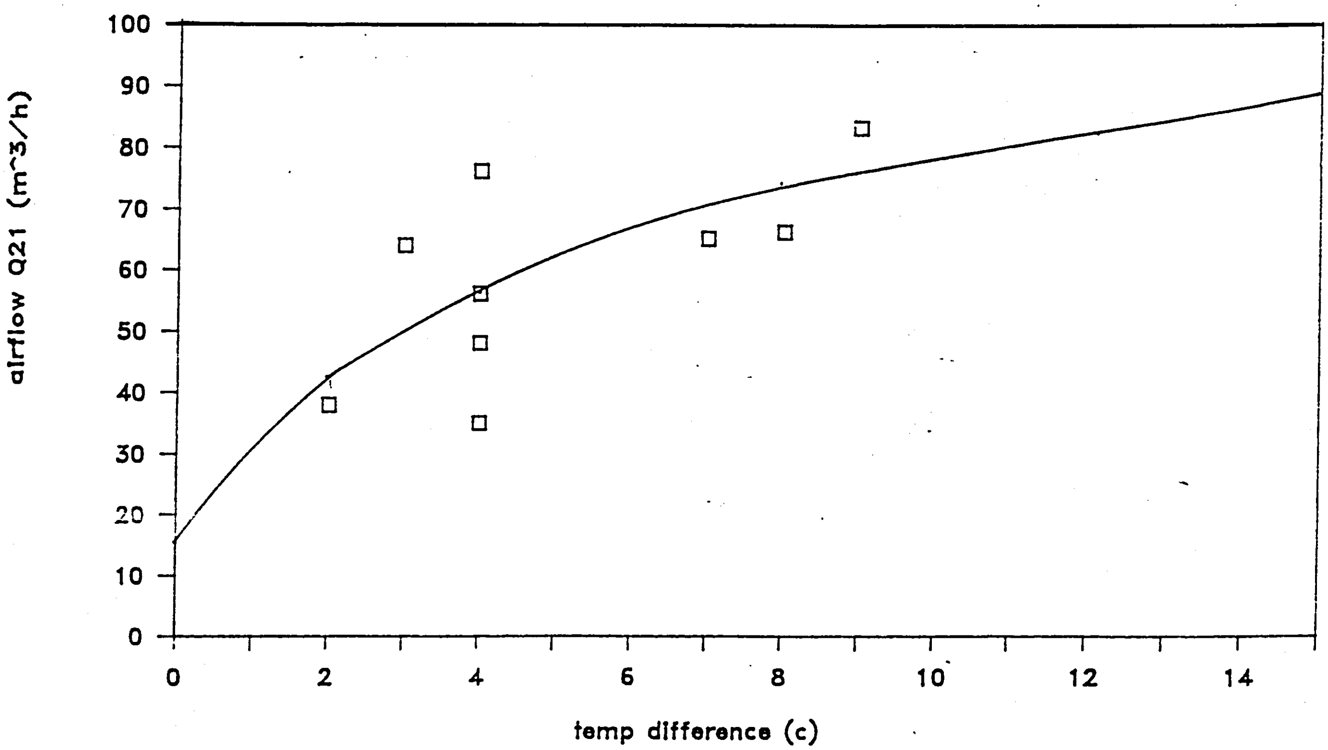

Figure 7.17 Graph of empirical formula Q21

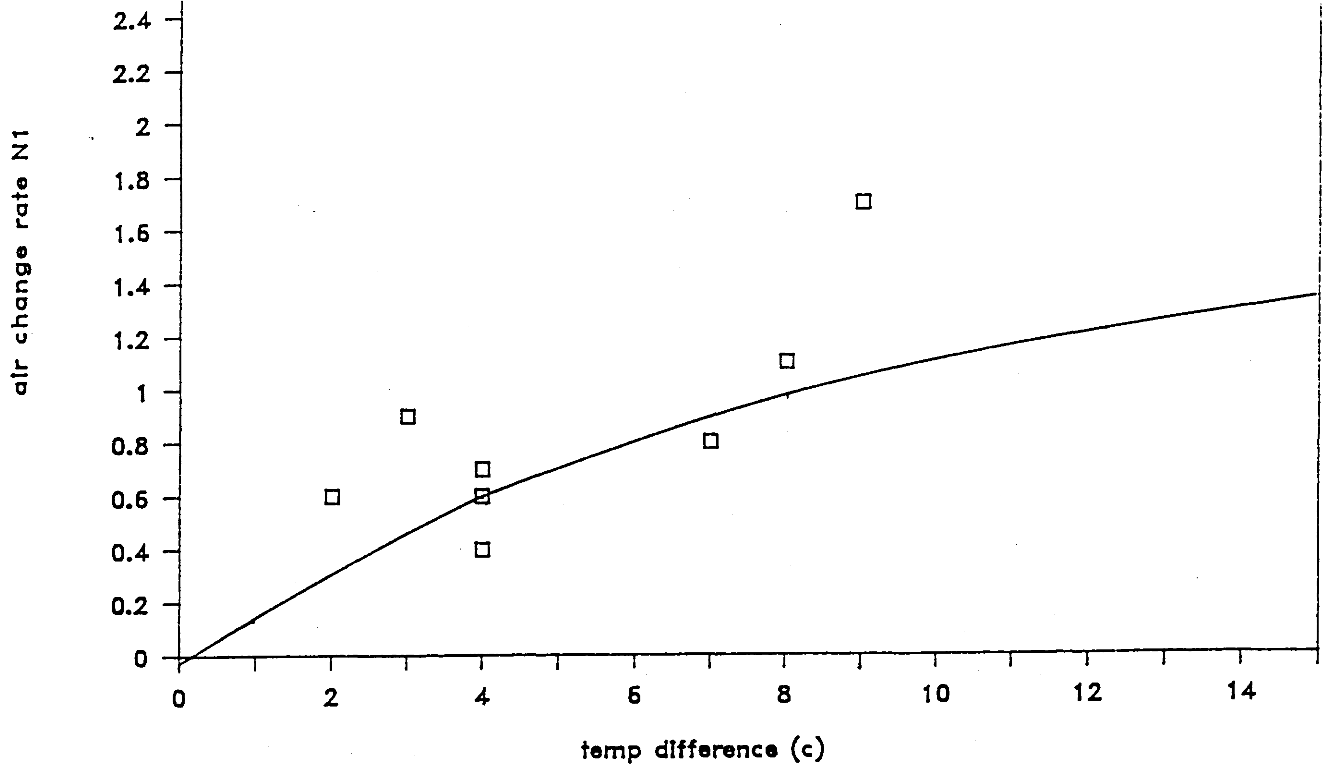

Figure 7.18 Graph of empirical formula N1

7.8 Discussion of Door Position 4a

As with door Position 2a, a wide spread of data about the lines of best fit can be seen in Figures 7.16, 7.17 and 7.18 . With the bedroom window sealed, there are approximate differences of 25% between the temperature dependent terms, with the constant term showing large differences. Both flow equations appear to indicate a temperature difference dependency of the airflow through the doorway.

With the window unsealed, the flow, Q12, appears to be independent of temperature difference, with the background turbulence term being dominant for all temperature differences likely to be encountered (< 30°c).

The flow, Q21, indicates a more temperature difference dependency; however, at low temperature differences, the background turbulence flow is significant.

7.8.1 Comparison of Bedroom Window Sealed and Unsealed

The effect of unsealing the bedroom window is, like Position 2a, to alter the pattern and magnitude of the flow through the doorway.

With the window unsealed, the effects of temperature difference dependency, are less than those with the window sealed.

The effect of opening the window generally increases the total airflow through the doorway, as shown in Figures 7.16 and 7.17 . However, like Position 2a, the effect is more dramatic in the increase of the room air change rate, as shown in Figure 7.18

As with Position 2a, the individual effects of the weather appear to effect the flow through the doorway. How this is done is not clear, since there appears to be a random spread of these effects about the line of best fit of the flow equations, as shown previously in Figures 7.13, 7.14 and 7.15 .

7.8.2 Comparison of Site Empirical with Theoretical and Laboratory Empirical Equations

No comparison can be made with the laboratory equations, since this door position was not investigated.

For comparison purposes, the relevant flow equations are summarised in Table 7.12

	Flow Equations m^3/h
Modified	Q=21.8ΔT^0.5
Simple	Q=24.7ΔT^0.5
Site Empirical sealed	Q12=27ΔT^0.5-6 Q21=20ΔT^0.5+15
unsealed	Q12=-14ΔT^0.5+101 Q21=16ΔT^0.5+25

Table 7.12 Comparison of Flow Equations Door Position 4a

The correlation between equations for site and laboratory was closer with the window sealed. The equations with the window sealed showed poorer correlation. It is assumed, therefore, that this difference between the site and laboratory could be as a consequence of the effects of the weather.

Conclusions of Chapter 7

It is possible to derive general two-way equations for the airflow, dependent upon temperature difference, between the bedroom and hallway of a house, under a wide range of weather conditions.

The graphical plots of airflow and room air change rate against temperature difference shows a wide spread of data about the lines of best fit. This shows the variable nature of airflow measurements.

The comparison of site empirical and theoretical equations indicate reasonable agreement (25%) for the temperature dependent terms, with the bedroom window sealed to the environment. With the window unsealed, the agreement is poorer, (35% to 50%), for the same temperature dependent terms.

With the bedroom window unsealed, the flow between the bedroom and hallway appears to be independent of temperature difference, the majority of flow being assumed to be background turbulence. For the flow between the hallway and the bedroom, there appears to be a dependency on temperature difference, although at low values of this, background turbulence flows are increasingly significant.

With the bedroom window sealed, the flow in both directions, between the hallway and bedroom, is dominated by temperature difference, with the increasing significance of background turbulence flows at lower temperature differences.

The effect of unsealing the window tends to generally increase the flow through the doorway, when compared to those with the window sealed.

The effect of unsealing the window is to dramatically increase the room air change rate, when compared to the window sealed.

The effects of the weather are seen to alter the airflows through the doorway, when the bedroom window is unsealed. The individual way in which this assumed dominant force affects the airflow rate cannot be determined, since there appears to be a random spread of these effects about the line of best fit of the flow equations.

CHAPTER 8 AIRFLOWS THROUGH DOORWAYS DUE TO THE COMBINED EFFECTS OF TEMPERATURE DIFFERENCE AND PRESSURE DIFFERENCE; LABORATORY

LIST OF SYMBOLS

g	Gravitational constant	(m/S2)
H	Height of opening in partition	(m)
Pe	Excess pressure	(Pa)
Po	Pressure at neutral plane	(Pa)
Pt	Pressure due to temperature difference	(Pa)
P1	Pressure in Zone 1	(Pa)
P2	Pressure in Zone 2	(Pa)
QL	Airflow into room	(m3/h)
Qo	Airflow out of room	(m3/h)
Qx	Excess air supply	(m3/h)
Q12	Airflow from Zone 1 to Zone 2	(m3/h)
Q21	Airflow from Zone 2 to Zone 1	(m3/h)
R	Ratio of pressures Pt/Pe	
T	Absolute temperature	(K)
T1	Temperature Zone 1	(C)
T2	Temperature Zone 2	(C)
ΔT	Temperature difference between Zone 1 and Zone 2	(C)
t	Thickness of partition	(m)
Vx	Air Velocity due to excess Supply	(m/S)
W	Width of opening in partition	(m)

Chapter 8 Airflows Through Doorways due to the Combined Effects of Temperature Difference and Pressure Difference Laboratory

Introduction

The simple theory as proposed by Brown and Solvason (36), in Chapter 5, was developed on the basis that airflows due to temperature difference took place through the doorway, in an other wise closed room, so that no net flow took place through the doorway. If, however, the room is subject to a forced volumetric flow, by mechanical means, such as air exhaust or supply, a net flow will occur through the doorway. The result is that the exchange rates across the doorway are not equal. If the forced flow is great enough, the exchange rate, or backflow, in one direction can theoretically be reduced to zero.

This chapter is concerned with the measurement of backflows between zones, through doorways, under laboratory conditions. The conditions necessary for the possible elimination of these backflows will be investigated.

An empirical equation, involving a ratio of the temperature and excess supply pressures, versus the backflow rate will be derived.

8.1 Theory of Airflows due to Combined Temperature and Pressure Difference

Shaw's Formula

Attention was drawn by Shaw (37) to the effectiveness of an excess air supply to a room at a higher temperature than the space outside the doorway in reducing or eliminating inflow from this space into the room. Shaw's formulas are, however, symmetrical witht respect to both the direction of any unbalanced air supply and the sign of the temperature difference across the doorway, so that they are equally applicable to all the possible permutations of these factors.

It is shown by Shaw, that the result of this excess supply is to shift the position of the neutral axis of the door, from the mid-door height for temperature difference only, to a position where it is outside the physical dimensions of the door. Under these conditions, theoretically, there is no backflow. This is shown in Figure 8.1 , over the page.

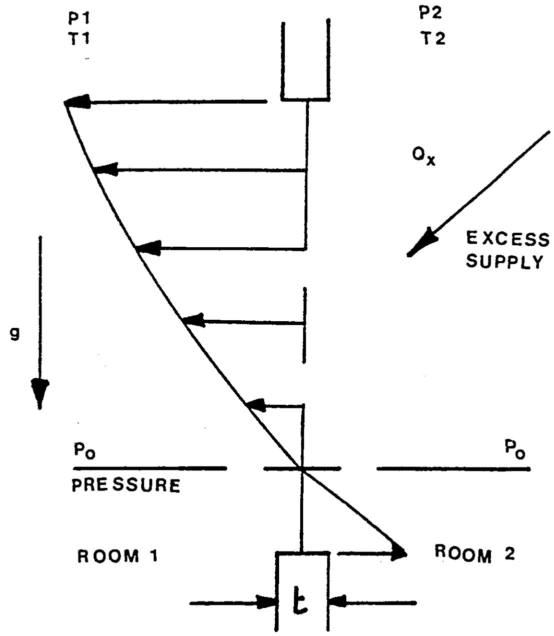

Figure 8.1 Theoretical movement of neutral axis

By equating the excess pressure, Px, within the room required to produce a given net outflow, with the velocity head corresponding to the mean outflow velocity, Vx, over the whole of the doorway opening, Shaw obtained the following expression for the flows into the room;

$$Q_L = \frac{Cd\ W\ T}{3\ \Delta T}\left(\frac{g\,\Delta T\ H}{T} - Vx^2\right)^{3/2} \qquad 8.1$$

And for the flow out of the room;

$$Qo = \frac{Cd\ W\ T}{3\ \Delta T}\left(\frac{g\,\Delta T\ H}{T} + Vx^2\right)^{3/2} \qquad 8.2$$

where the symbols have the meaning as defined in the text, and previously in Chapter 5.

8.2 Experimental procedure

The tests were conducted within the double chamber facility, as described in Section 4.1, the series concentrating on the door position 3.

Airflow rates through the doorway were determined by using a multiple tracer gas technique, as described in Section 2.5. The data was analysed using Irwin's 2 zone method as described in Section 2.8 .

Pressure Difference Control

The pressure difference between the two zones was provided by mechanically exhausting air from the environmental side of the double chambers, as shown in Figure 8.2

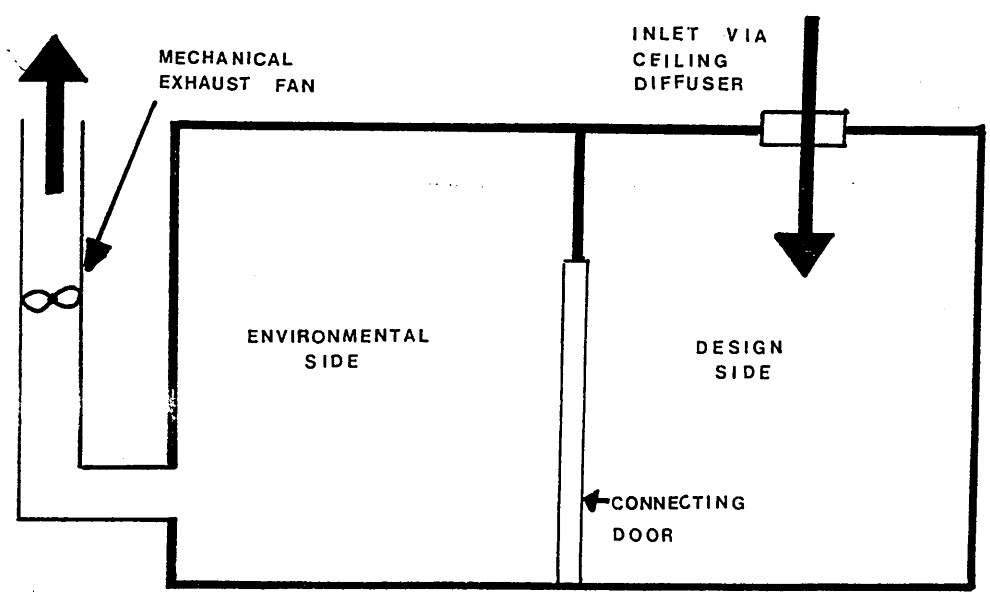

Figure 8.2 Pressure difference between double chambers

The circuit was completed by opening the ceiling diffusers in the design side to the atmosphere. This in effect created a greater pressure difference within the design side with respect to the environmental side. This pressure difference was controlled by a butterfly valve within the exhaust ductwork.

The pressure difference between the two rooms was measured by feeding lengths of polythene tubing from each room to a micromanometer, the sampling location being the centres of the room outside the influence of the airflows.

The rate of extract was measured by feeding further lenghts of polythene tubing from pressure tappings within the extract ductwork to a micromanometer.

Temperature Control

The temperature difference was created by the use of a convector heater within the design side, and the air handler unit in the environmental side, as described in section 4.1 . After the required temperature difference was reached, the air handler unit grilles were sealed with plastic sheeting to eliminate the leakage of air (section 4.1).

Experimental Strategy

The experimental strategy was to create a set temperature difference between the two zones for a particular series of tests, and gradually change the pressure difference. A further series would then be performed at a different temperature difference, again altering the pressure difference. This strategy was chosen to eliminate the possibility of creating the net same effects of temperature and pressure, on the airflow through the doorway.

Problems of Measurement

There were problems of temperature variation with time. This problem was greater at higher extract rates, when this temperature difference at the start of the test could be 10 c greater than at the end. Under these conditions the extract rate could be up to 13.2 air changes per hour. As a practical solution to this problem, the test was reduced to as short as possible, usually up to 20 minutes. The representative temperature was taken as a mean of all the measured temperature differences.
Because of the high extract rate in some instances, the seals covering the air handler unit grilles were prone to fail during the measurement period. This would lead to incorrect values being obtained for the supply rate, since the rates of supply and exhaust would not then necessarily be equal due to leakage of air into the environmental side. Under these circumstances, the tests were abandoned.

Pressure Measurement

The resolution of the micromanometer was 0.1 Pa. At the lower extract rates, the pressure difference generated between the two zones, could be as low as 0.2 Pa. It was therefore possible that the error in reading the instrument could, in these instances be up to 100%.

8.3 Presentation of Results

The results of this series of tests are presented in Table 8.1, the data are shown in Appendix G.

Pressure diff Pa	Temp diff °c	Q12 m^3/h	Q21 m^3/h
0.5	9	149	10
0.35	10	177	18
0.75	11	137	6
1.3	11	275	3
0.2	14	154	6
0.2	15	150	11
0.2	16	210	12
0.75	16	204	12
1.15	20	218	14
0.95	21	206	11
0.5	22	130	13
0.85	23	243	10
0.45	26	195	27
0.55	27	158	36
0.45	28	167	39

Table 8.1 Results of experimental tests

Backflow Rate Q21

Of specific interest is the backflow rate due to the combination of temperature and pressure difference.

Direct comparison between the different rates is difficult, because of all the many different ways in which the causitive effects of temperature and pressure can combine.

As an attempt to solve this problem of backflow depending on two parameters, it is proposed that these parameters are combined together to form a ratio of the pressures which act across the door opening.

8.3.1 Ratio of Pressures Across the Doorway

The pressure difference acting across the top and bottom of a doorway of height H, with different temperature on either side (section 7.3) can be approximated to;

$$Pt = 0.041\ H \Delta T \qquad 8.1$$

assuming that the mean pressure difference acts at the height of the neutral axis of the door (H=1 m), then this is given by;

$$Pt = 0.041 \Delta T \qquad 8.2$$

The pressure difference across the doorway due to the excess supply, is a direct measurement, and may be denoted Pe. Thus the ratio of pressures, defined as R, is given by;

$$R = \frac{Pt}{Pe} = \frac{0.041\Delta T}{Pe} \qquad 8.3$$

The calculated values of R, using the experimental results of Table 8.1, are tabulated with the measured backflow rates in Table 8.2

R	Backflow Q21 m^3/h
0.78	10
1.23	18
0.63	6
0.36	3
3.01	6
3.23	11
3.44	12
0.92	12
0.75	14
0.95	11
1.89	13
1.16	10
2.48	27
2.11	36
2.67	39

Table 8.2 Calculated values of R and Backflow

A power curve regression analysis of the data gives the line of best fit as;

$$Q21 = 10.25\ R^{0.53} \qquad 8.4$$

This is shown in Figure 8.3, along with the data points.

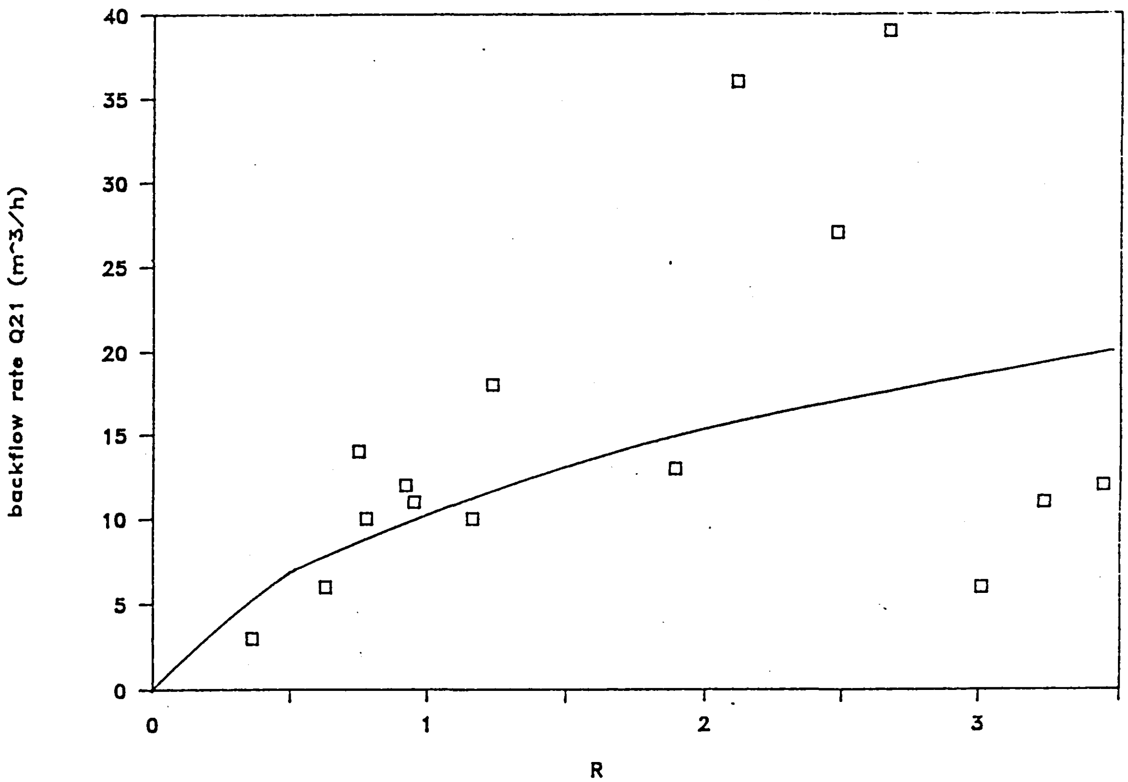

Figure 8.3 Empirical power curve combined temperature and pressure difference

8.4 Discussion of Results

It was never possible to eliminate the backflow completely, although there was a definite trend of reducing it with increased excess supply. By inspection of the empirical formula, it can be seen that if R=1, at which point the balance of pressures due to temperature and excess pressure are equal so that there should be no backflow, there remains a residual term of 10.25 m^3/h.

This term may be a measure of the background turbulence flows of air between the rooms. This value, when converted to flow per unit area, is approximately 128 $m^3/h/m^2$. This compares very well indeed with the identical door position for temperature difference only, as described in Section 6.6

Other Workers' Measured Values

Lidwell, in his paper (40) publishes a table in which the excess supply required for the total elimination of backflow is shown against various temperature differences. Lidwell himself did not perform any field tests, but instead used data from Shaw's papers. This was done to show the effects of Lidwell's modifications to Shaw's basic theory. This modification was to take the effects of turbulence into account. The various different methods of analysis required to do this are tabulated, the values thus calculated are shown alongside the results of Shaw's observed values. The conclusion of this comparison, was that the simple theory of Shaw most closely matched the observed data, the only problem being that this fails at zero temperature difference, when turbulent flows can still be measured.

Unfortunately, direct comparison with this set of data cannot be made, because the total elimination of backflow was never measured in the Project.

However, Shaw (37) also quotes a figure requiring a flow of 0.25 m^3/s excess supply for every square metre of doorway for a temperature difference of 1°c.

Bouman (44,45) indicates that an excess supply of 0.17 m^3/h is required to stop the backflow for the same conditions.

Calculations using the empirical flow equation 8.4, indicate that an excess supply of 0.45 m^3/s would be required to reduce the backflow to 1 m^3/h (the equation fails if Q21=0) for 1°c temperature difference.

The difference between the experimental results and those of other workers could be due to a number of factors which could include;

variation of temperature throughout the test period, leakage of air through ineffective seals in the chamber at high extract rates; thus giving inaccurate supply rate values,

Different measurement techniques; Shaw used hot wire anemometers which could not differentiate between the direction of airflow, thus posing difficulties in actually assessing which flows were in fact backflows.

Conclusions of Chapter 8

The total elimination of backflows due to the effect of excess air supply (pressure difference between rooms) to one room was never realised in practice.

The effect of increasing the pressure difference between the two rooms, was to decrease the backflow to very low values.

An empirical formula could be derived which relates the combined effects of temperature and pressure difference on the backflow rate. Knowing only one of the parameters, it is thus possible to determine the magnitude of the other in specifying a certain backflow rate.

CHAPTER 9 AIRFLOWS THROUGH DOORWAYS DUE TO THE COMBINED EFFECTS OF TEMPERATURE DIFFERENCE AND PRESSURE DIFFERENCE; SITE

LIST OF SYMBOLS

R	Ratio of pressures	Pt/Pe
Qback	Air backflow rate	(m3/h)

Chapter 9 Airflows Through Doorways due to the Combined Effects of Temperature Difference and Pressure Difference; Site

Introduction

This chapter describes the experimental measurements of combined temperature and pressure difference driven flows through doorways, under site conditions (section 4.2). The series of tests are an extension of those performed under laboratory condititions in Chapter 8.
Thesde tests have significance with respect to the use of extract fans, perhaps within the kitchen. Their influence in preventing the movement of moist air to other zones in the house are of interest in reducing condensation.

9.1 Experimental Procedure

The tests were conducted within the living room of the site house (section 4.2). The fan used for leakage measurements of the test house (section 4.5) was used as an extract fan, the fan being fitted into an open window, rather like a blower door.

The extract rate of the fan was measured using a Wilson flowgrid and micromanometer (section 4.5). The pressure difference between the living room and the hallway was measured by attatching lengths of polythene tubing to a micromanometer, the ends of which were placed in the respective rooms.

Airflows through the living room doorway were determined by using a multiple tracer gas technique, as described in section 2.5 . The data was analysed using Irwin's two zone method, as described in section 2.8 .

A single door postion, 4a, was chosen because of time limitations.

Experimental Strategy

The experimental straregy was to create a set temperature difference between the two zones, and vary the pressure difference as described in section 8.2 .

Problems of Measurement

The main measurement problem was the determination of a representative pressure difference between the two zones.

The pressure difference varied dramatically, depending upon the sampling location, specifically within the hallway. Therefore, the same location, of approximately the centre of the downstairs hallway, was used throughout the tests.

Problems of temperature variation with time were also evident, especially at the higher extract rates. The temperature differences are therefore expressed as mean temperature differences, prevalent during the measurement period.

9.2 Presentation of Results

The results of this series of tests are presented in Table 9.1, the data are shown in Appendix H.

Pressure diff Pa	Temperature diff C	Backflow rate m^3/h	Presence of 114 in bedroom 1
1.0	5	6	NO
1.1	4	51	YES
0.9	5	74	YES
0.4	4	101	YES
0.5	4	45	NO
1.3	4	0	NO
1.3	5	0	NO

Table 9.1 Experimental results

Of interest is the backflow rate due to the combined influence of temperature and pressure difference, and the presence of Freon 114 (released in the living room) in the bedroom 1.

As described in section 8.3, a ratio of the pressure differences due to the combined effects of temperature abd extract rate, R, is assumed to be dependent on the backflow rate. These values of R are shown in Table 9.2 , over the page.

R	Backflow rate m^3/h
0.22	6
0.16	51
0.24	74
0.43	101
0.34	45
0.13	0
0.17	0

Table 9.2 Calculated values of R and backflow rate

A power curve regression analysis of the data gives the line of best fit as;

$$Q_{back} = 172\ R^{1.1} \qquad (m^3/h) \qquad 9.1$$

This is shown in Figure 9.1, along with the data points.

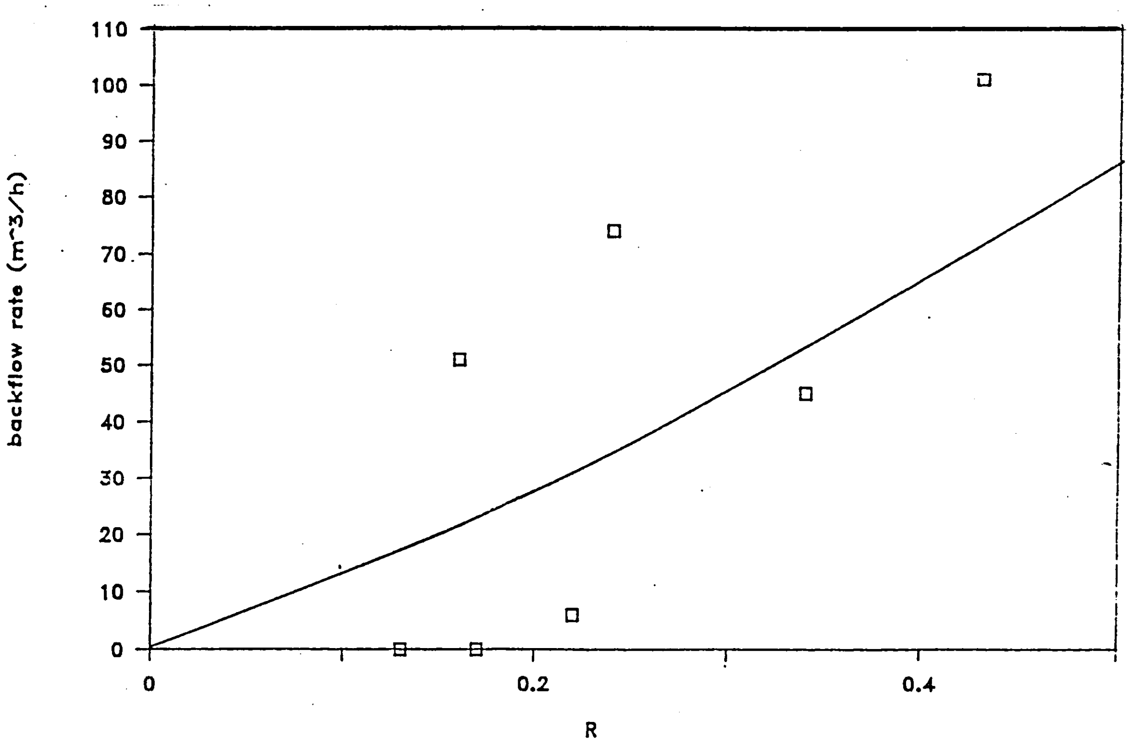

Figure 9.1 Graph of empirical power curve

Discussion of Results

Unlike the tests performed in the laboratory (Chapter 8), it was possible to eliminate totally the flow of air from one zone to another by the use of a mechanical extract fan. However, by comparison of data from Tables 8.1 and 9.1, there was no comparable temperature difference; those of the laboratory were consistently higher (thus generally promoting larger backflow rates).

Further, the pressure differences generated in the site house were greater than was possible in the laboratory; this would generally tend to eliminate the backflow rate.

The empirical formulae for the site work reveals a greater backflow than those of the laboratory for a given value of R. This can simply be explained by the fact that the door opening was larger for the site work. However, it impossible to discern any correlation between the laboratory and site work, and/or door positions from the limited data sets.

Conclusions of Chapter 9

It is possible to eliminate totally the flow of air from one zone to another by the use of an extract fan.

It is also possible to eliminate totally the movement of air from rooms on the lower floors of a house to rooms on the upper floor by the use of an extract fan. The rate of extract does not need to be as large, in this case, as

CHAPTER 10 SITE MEASUREMENTS OF TEMPERATURE DRIVEN FLOWS THROUGH DOORWAYS; 3 ZONE

LIST OF SYMBOLS

Q12	Airflow between Bedroom and Stairwell	(m3/h)
Q21	Airflow between Stairwell and Bedroom	(m3/h)
Q23	Airflow between Stairwell and Living Room	(m3/h)
Q32	Airflow between Living Room and Stairwell	(m3/h)
Q13	Airflow between Bedroom and Living Room	(m3/h)
Q31	Airflow between Livig Room and Bedroom	(m3/h)
ΔT	Temperature difference between Zones	(C)

Chapter 10 Site Measurements of Temperature Driven Flows Through Doorways; 3 Zone

Introduction

This chapter describes the experimental measurements of temperature driven flows through doorways under site conditions (section 4.2).
The measurements are extended from 2 zones (Chapter 7) to 3 zones simultaneously.
Of primary interest was the air movement from rooms on the lower floors of the site house, to rooms on the upper floors; these have relevence to the possible migration of odours or moisture between these levels.

10.1 Choice of Rooms, Door Positions and Window Condition

Rooms

The three rooms chosen were bedroom 1, the stairwell and the living room.
With reference to Figure 10.1, it can be seen that the bedroom and living room were both located at the front of the house, as indeed was part of the hallway. These rooms were chosen because the influence of the wind upon the front of the house would be common to each, in a way that a room at the back of the house would not.

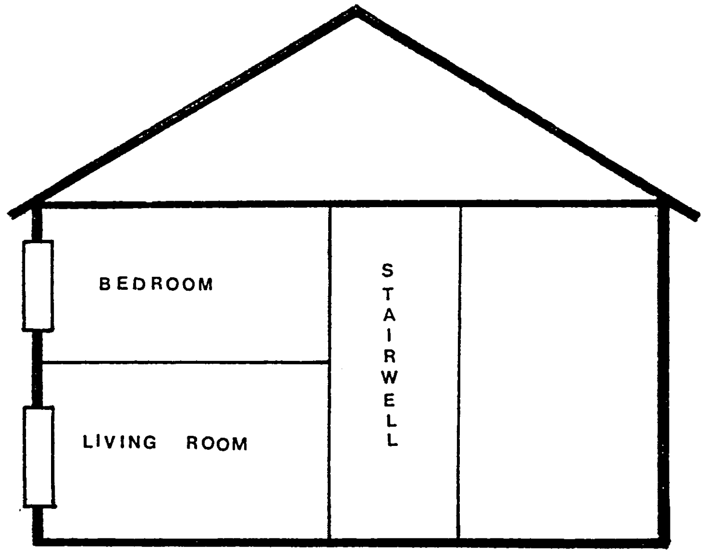

Figure 10.1 Side view of test house

Rooms were chosen at different levels, so that the general airflow regime between floors could be investigated. As stated in the introduction to this chapter, this has relevence to the possible migration of odours and water vapour, from sources such as washing, the drying of clothes on radiators and respiration, to cooler zones such as unheated bedrooms and roofspaces, which could create potential condensation problems.

Door Positions

Because of time limitations, a single door position, 4a (section 7.1), was chosen for the evaluation of airflows between 3 zones. This position was chosen, as opposed to

2a, since it was generally easier to measure the airflows, in practical terms, at wider door openings (section 6.4).

Bedroom Window

The bedroom window was sealed for this series of tests, because, as stated in Sections 7.7.1 and 7.8.1, the effects of sealing the window was to produce a predominantly temperature driven flow regime between the bedroom and stairwell.

10.2 Experimental Procedure

For the measurement of 3 zone airflows it was necessary to use three tracer gases (section 2.2.1).
BCF was released in the bedroom, freon 114 in the living room and freon 12 in the stairwell.
The methods of injection, mixing and instrumentation was the same as for 2 zone work as described in Section 7.4 .

Problems of Measurement

Mixing; Tracer Gas Concentration Variation

Problems of mixing were again encountered, these were similar to those described in Section 7.4, only for 3 zone tests, the situation appeared to worsen. Of particular concern was the stairwell, which seemed to suffer from two types of problem;

The first was the problem of concentration stratification between the upstairs and downstairs of the tracer gas initially released in this zone; the upstairs concentration was always higher than that downstairs at the end of the test period. The reason for this, as stated in Section 7.4, is not really known, but could include the general movement of air from lower to higher levels due to a combination of stairwell thermal buoyancy, cool air through the leaky main door and the possible superimposition of stack effects.

The second problem was the movement of tracer gas from the other two zones into the stairwell. By sampling the concentration of all the tracer gases in the upper and lower parts of the stairwell, it was plainly clear that the mixing of the incoming gases was far from instantaneous. The movement of these tracer gases appeared to suffer time lags between the upper and lower floors and also the opposite direction. A visualisation of this is shown in Figure 10.2, over the page, where a typical concentration history of freon 114 in the stairwell is shown at any time;

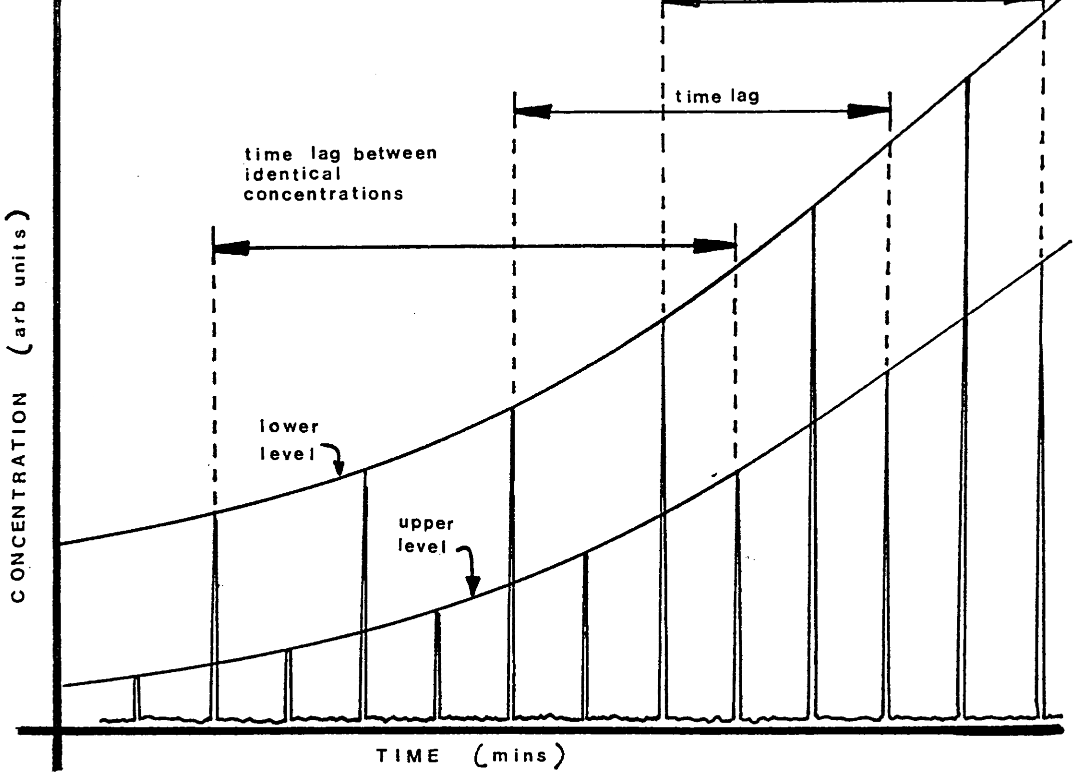

Figure 10.2 Time lag of Freon 114 in the stairwell

Representative Temperature Difference

The temperature difference within the stairwell showed signs of vertical stratification, similar to that described in Section 7.4 For this reason, the representative temperature difference was taken from the mean conditions of the stairwell.

10.3 Analysis of Results

The data from the series of tests was initially analysed using a 3 zone approach, as described by Irwin (18). Unfortunately, this method proved unreliable, because many of the calculated flows were grossly exaggerated, typically between the living room and bedroom.

By reference to a typical 3 zone chart recorder output, as shown in Figure 10.3, this can be explained as follows;

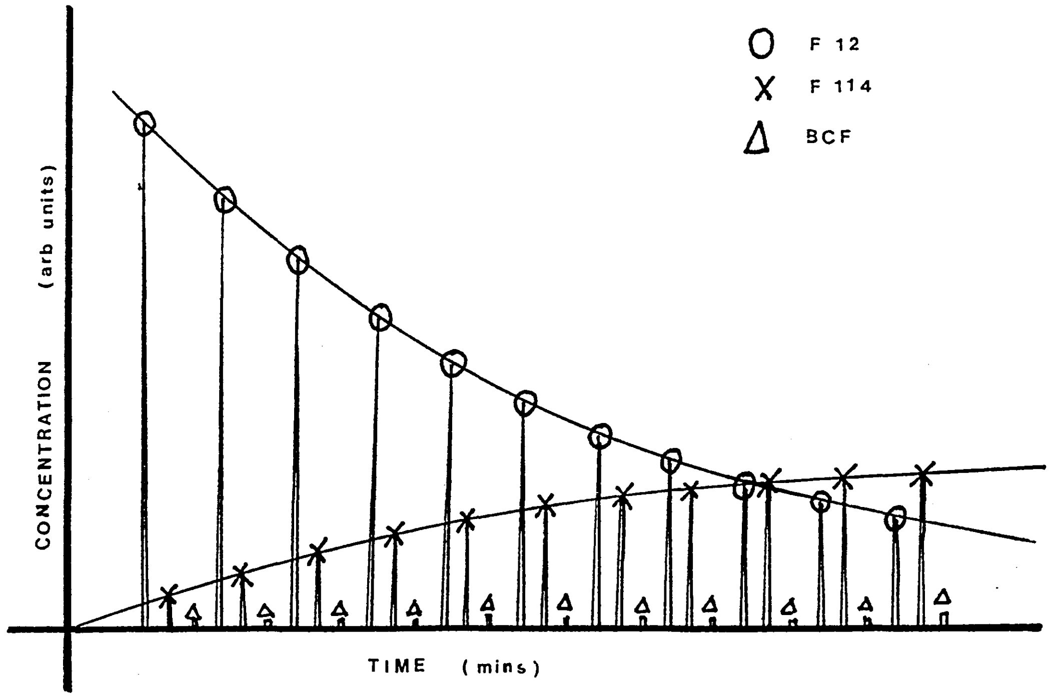

Figure 10.3 Typical 3 zone chart output

The output of BCF tracer gas was very small when compared to the other two tracer gases, when sampled from either the lower stairwell or the living room. Typically this output was between 0.1 and 0.3 units on the scale of the chart recorder paper. There was difficulty in reading off these small concentrations, if for example it was between say, 0.1 and 0.2 . If the "real" value was 0.15, but was read off as 0.2, then this would represent an increase of 25% of the apparent tracer concentration within the room. There was also ambiguity about the baseline of the analyser output, as shown in Figure 10.4 . It was not possible to determine which was the actual zero line for the BCF concentration peaks.

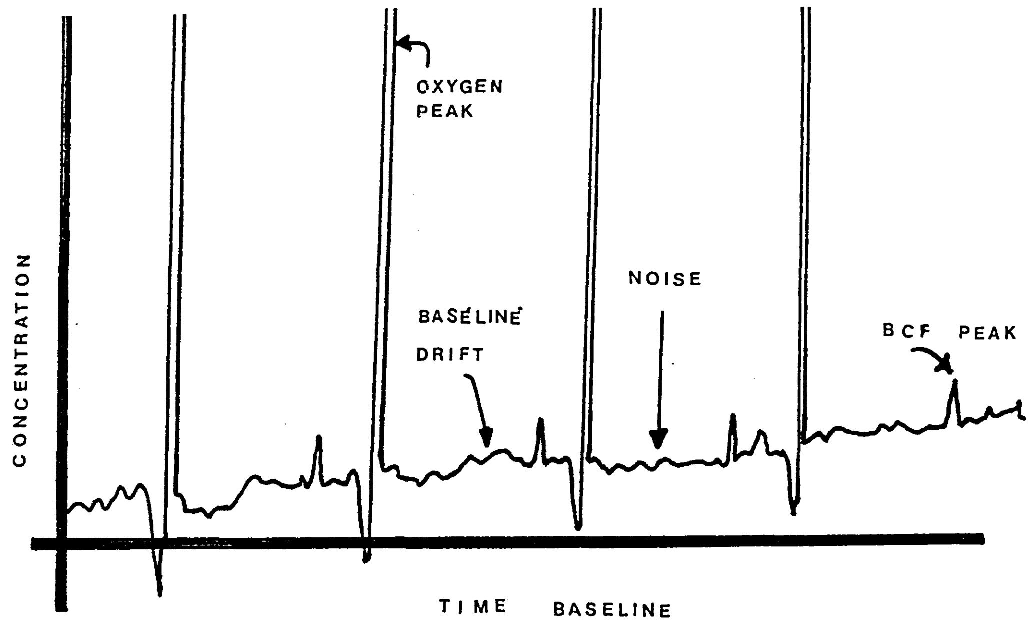

Figure 10.4 Baseline of tracer gas chart output

Therefore, relatively speaking, small errors in reading off the BCF concentrations produced very large errors in the 3 zone analysis.

It was not possible, either, to increase the initial concentration of BCF in the bedroom, thus producing larger concentrations downstairs, since the result of this was to send the chart recorder off-scale.

As a solution to this problem, a 2 zone approach was adopted for the flows between the stairwell and bedroom and stairwell and living room. These were solved using

Irwin's equations as described in Section 2.8, for which the computer program is shown in Appendix A.

The analysis of the flows between the living room and the bedroom assumes a direct flow between the zones. Therefore, there may be uncertainty in the calculated values using the 2 zone approach, since the stairwell acts as a "buffer" zone between these zones.
It is probable though, that for the determination of airflow rates, this buffer effect between the two zones would be the same for each individual calculation. The general trend of calculated rates is therefore assumed to be correct, i.e. is the flow between the living room and bedroom greater or smaller than the flow in the opposite direction ?

10.4 Presentation of Results

The results of the experimental tests are shown in Table 10.1 . The data for the series are shown in Appendix I. The numbering of the zones is shown in Figure 10.5 .

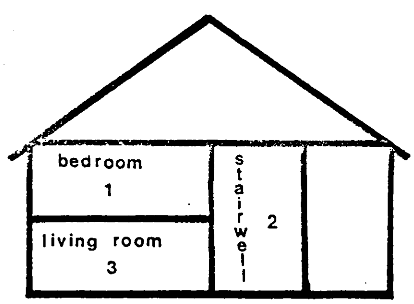

Figure 10.5 Side view of test house showing numbering of zones

Q12 m^3/h	Q21	ΔT °c	Q23 m^3/h	Q32	ΔT °c	Q13 m^3/h	Q31
64	190	17	41	107	12	6	51
73	65	1	61	97	5	18	13
36	96	2	98	124	16	10	27
32	88	2	124	158	16	9	33
22	68	1	102	122	17	7	20
21	69	1	100	121	16	4	17
84	111	8	108	117	15	50	34
78	145	9	111	123	10	7	42
86	131	17	5	29	0	1	5
69	146	17	54	69	5	6	34
53	133	10	34	81	5	4	30
76	74	7	91	72	6	4	6
32	33	1	93	71	9	7	10
80	72	8	81	91	8	4	8
65	82	9	90	87	10	8	11
95	72	3	71	61	3	19	32
75	102	6	14	11	0	2	3
105	75	10	76	87	12	32	20

Table 10.1 Results of 3 zone experimental tests

A linear fit regression analysis of the flowrates versus temperature difference revealed the following empirical flow equations, as shown in Table 10.2, over the page.

Empirical flow equation	correlation coefficient
$Q12 = 14 \Delta T^{0.5} + 29$	0.62
$Q21 = 28 \Delta T^{0.5} + 30$	0.77
$Q23 = 21 \Delta T^{0.5} + 18$	0.62
$Q32 = 28 \Delta T^{0.5} + 12$	0.80

Table 10.2 Empirical equations for 3 zone tests

Where the symbols are defined in Figure 10.5 . Note that there is no empirical equation for the flows Q13 & Q31, since the variables upon which they may be dependent are not known. The graphs of the empirical formulae are shown in Figures 10.6, 10.7, 10.8 and 10.9, along with the data points.

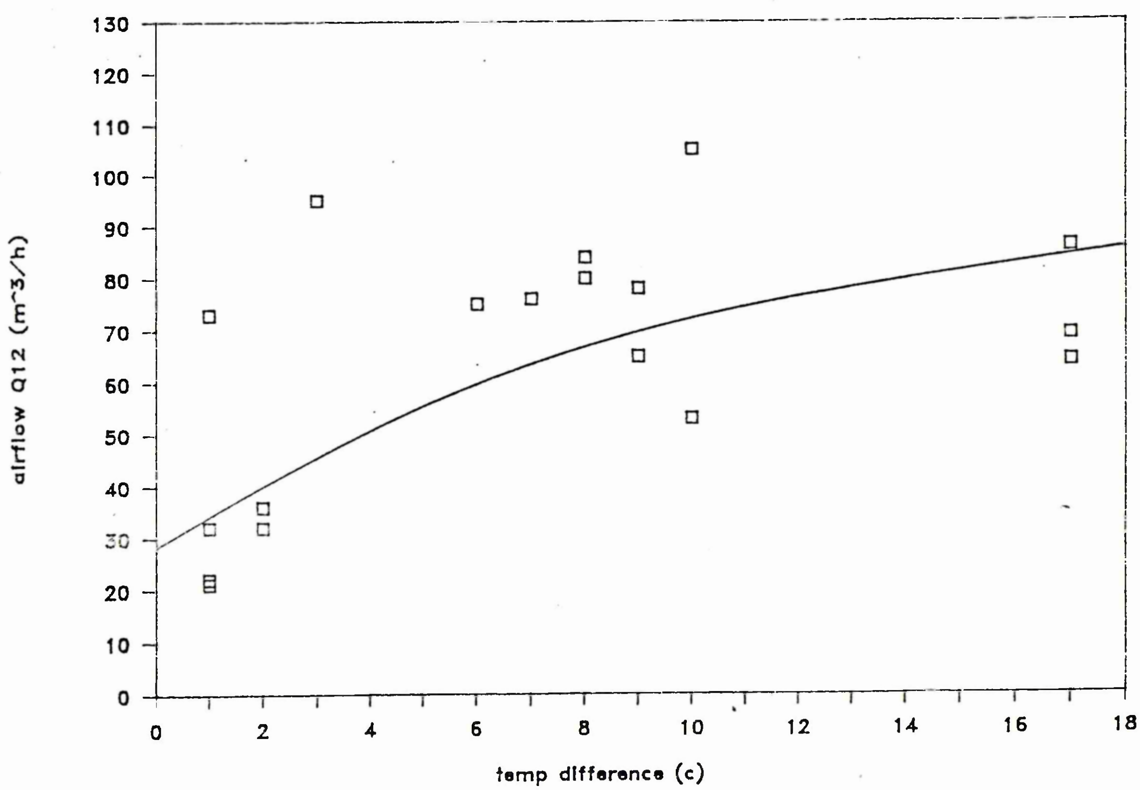

Fig 10.6

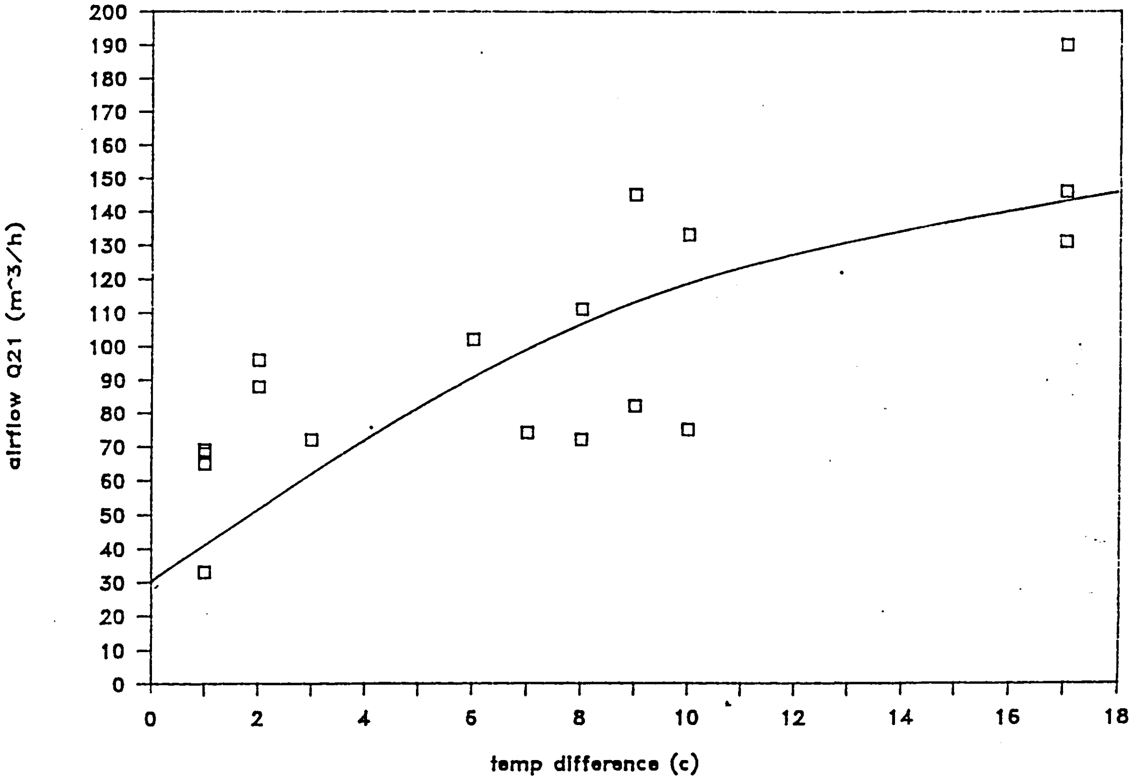

Fig 10.7

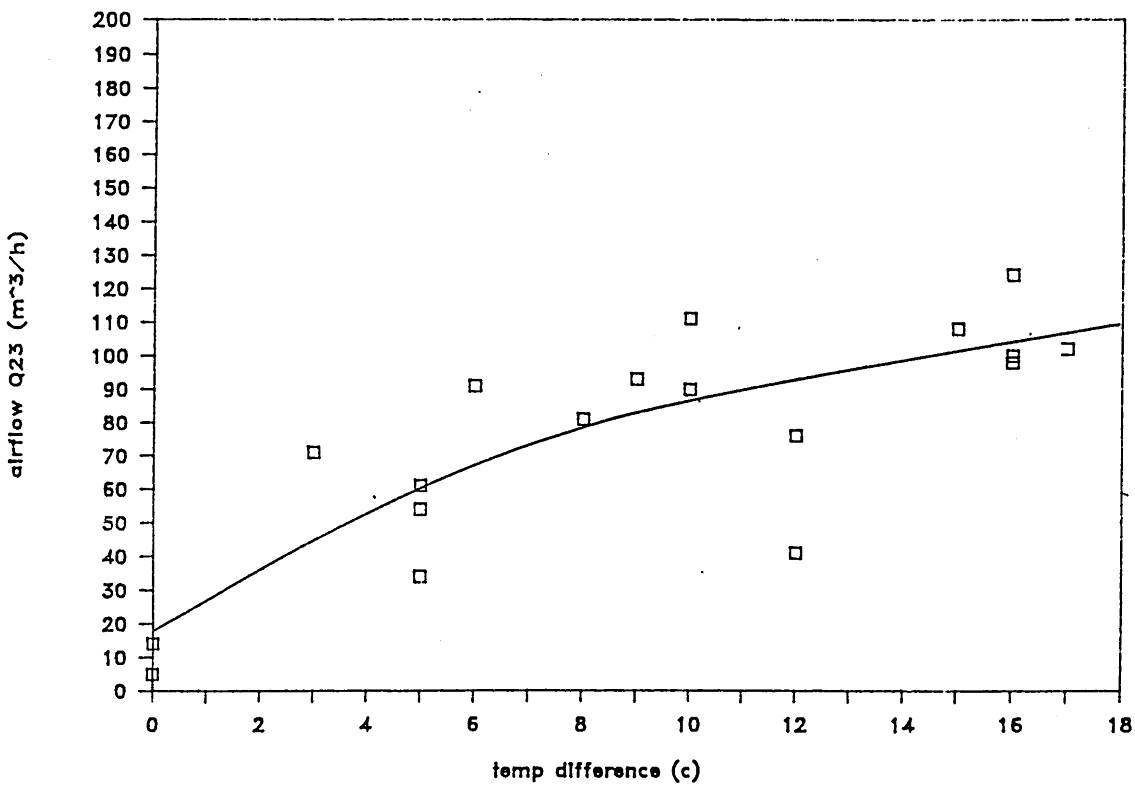

Fig 10.8

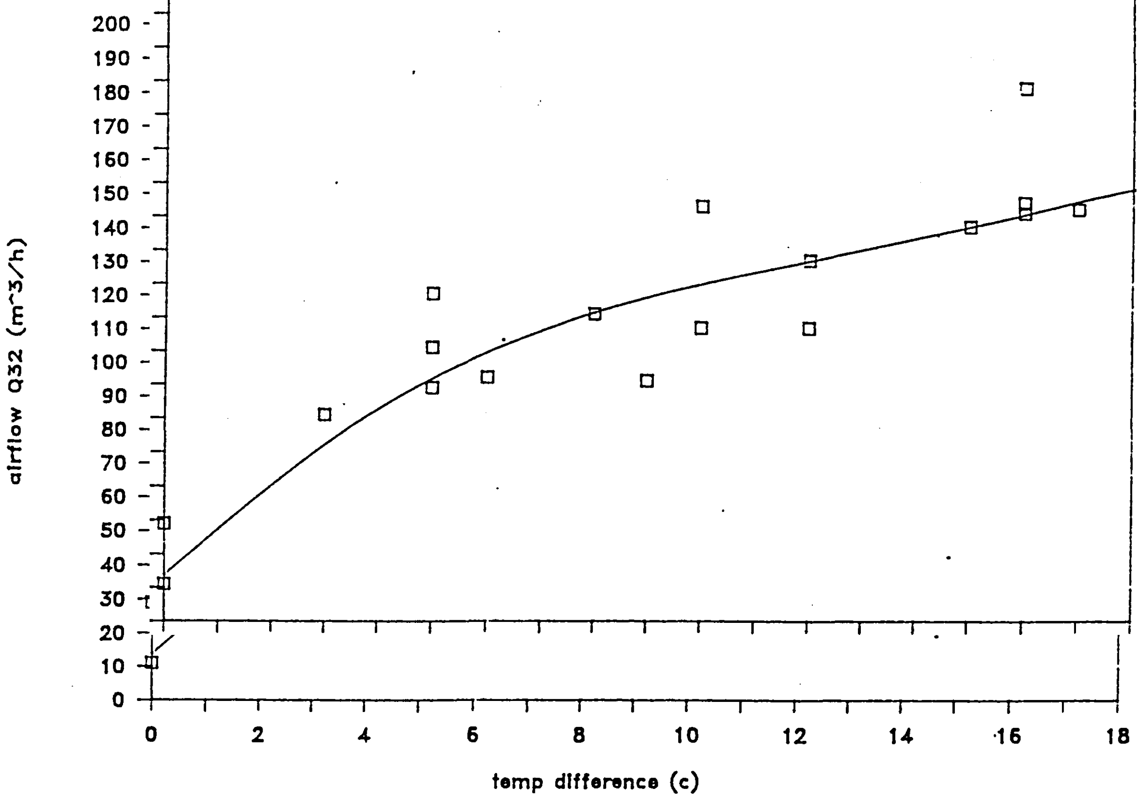

Fig 10.9

10.5 Discussion of 3 Zone Airflows

As can be seen from the empirical equations, the general flowrate Q21 is larger than the flow Q12; similarly the flow Q32 is larger than the flow Q23. For the flows between the bedroom and living room, there are no empirical equations, but by inspection of the values in Table 10.1, it can be seen that there a significantly greater number of flows where Q31 is larger than Q13.

It would seem therefore, that the overall general flow within the house is from lower to upper levels, as shown in Figure 10.10, over the page.

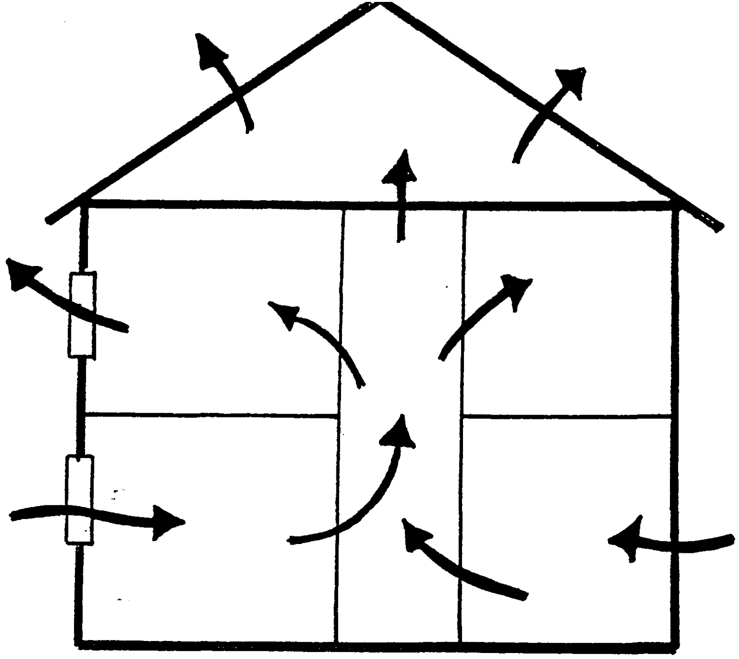

Figure 10.10 General flow of air within the test house

The opening of the door between the living room and the hallway is seen to influence the flow between the bedroom and the hallway. This can be seen by comparing the similar empirical formulas for 2 zone work, as shown in Table 10.3

Door position 4a	
2 zone	3 zone
$Q12 = 27 \Delta T\hat{}0.5 - 6$	$Q12 = 14 \Delta T\hat{}0.5 + 29$
$Q21 = 20 \Delta T\hat{}0.5 + 15$	$Q21 = 28 \Delta T\hat{}0.5 + 30$

Table 10.3 Comparison of 2 and 3 Zone empirical equations for door Pos 4a

This effect upon the total flow Q12 through the doorway (including both terms of the equation) is not clear by inspection of the empirical equations. By inserting data for the temperature difference into these equations it can be seen that the flow Q12 is greater for the 3 zone case until 8 c, when the 2 zone flow is greater.
The flow Q21 is always greater for the 3 zone case.

The flows Q12, Q21, Q23 and Q32 are within +33% of the simple theories for temperature driven flow, these are shown for comparison purposes in Table 10.4

Door position 4a		
Theoretical equations		Empirical equations
Simple	modified	
$Q=24.7\Delta T^{0.5}$	$Q=21.8\Delta T^{0.5}$	$Q12=14\Delta T^{0.5}+29$
		$Q12=28\Delta T^{0.5}+30$
		$Q23=21\Delta T^{0.5}+18$
		$Q32=28\Delta T^{0.5}+12$

Table 10.4 Comparison of theoretical and empirical equations for door position 4a

Conclusions of Chapter 10

The analysis of air flows between three zones simultaneously is not strictly possible, because of practical problems with the test equipment.

The effect of extending test measurements from 2 zone to 3 zone, by including the influence of airflow from the living room to the hallway, is to alter the flow rates between the bedroom and hallway (as tested for 2 zone only).

The overall general flow of air in the house appears to take place within the hallway, from lower levels to higher levels. The exact mechanism of this is not known, but could include a combination of thermal buoyancy of the air inside the hallway, and stack effect.

The role of the stairwell is still not fully clear from these tests. However, it would appear that the stairwell is not simply a static pool of air, but rather a driving mechanism of flows between zones and within itself.

Altering the degree of connection between the stairwell, and any one zone, would appear to influence all the other interzonal flows connected to the stairwell.

To reduce the flow of air between rooms on the lower level of the house into the bedroom, the doors of the downstairs rooms should be closed (obviously). However, this effect also has the secondary influence of reducing the flow between the hallway and the bedroom.

CHAPTER 11 CONCLUSIONS, AND RECOMMENDATIONS FOR FUTURE WORK

In correlating the influences of temperature difference upon the airflow rate through doorways, (when using the tracer gas method as the measurement technique), there is always a wide spread of data about the line of best fit. This is just as evident whether the tests are performed under the controlled conditions of the laboratory, or under prevailing weather conditions encountered on site. This would seem to imply that the tracer gas technique is highly variable in practice, with uncertainties in the determined airflow rates.

This uncertainty may be due to several factors, such as the inability to create an instantaneous homogeneous mixing of the tracer gas and air, necessary for a correct solution of the analytical equations. Another factor is the uncertainty in defining a representative temperature difference between zones, as this varies as the measurement period proceeds, in general, in a non repeatable manner.

Empirical formulae were derived for both laboratory and site tests, which showed good general agreement with theoretical equations (incorporating a coefficient of discharge consistent with orifice flow). The correlation could be improved by a more detailed knowledge of the variation of the coefficient of discharge with both door opening and temperature difference.

The test data analysis, using linear fit regression, reveals a constant term independent of temperature difference. The meaning of this term is open to interpretation; it could be a measure of the background turbulence of the airflow through the doorway at zero temperature difference. However , it could also arise as a consequence of the spread of data about the line of best fit.

The empirical formulae can only be taken to be general in nature, due to the uncertainties of the measurement technique, and the variable nature of influencing parameters such as the weather. However, these empirical formulae could be of use to building designers, as a basis in predicting both the movement of air and the heat transfer between zones within a house.

From site tests, the effect of opening a window within the bedroom was seen to increase the general interzonal airflow rate between the bedroom and the hallway. However, the effect was more dramatic upon the room air change rate. Thus, from this evidence, it is concluded that although the weather influences the interzonal airflow rate, the dominant mechanism of this flow is that of temperature difference. The superimposed effects of the weather are seen to be totally random.

By extending the site work from 2 to 3 zones simultaneously, it is concluded that the general movement of air within the house is from lower to higher levels; this mechanism is concluded to be due to the influences of the weather induced stack effect.

The role of the stairwell in influencing interzonal airflows within houses is seen to be complex. The degree of connection between any one zone and the stairwell also influences interzonal airflows between any other zone and the stairwell. The set position of any door connected to the stairwell is therefore seen to be a controlling factor of all other interzonal airflows.

The use of an extract fan in the site house was seen to alter the flow paths of air within the house, by reducing or eliminating, the movement of air from the room on the lower floor which contained the fan, to rooms on higher floors. Extract fans are thus seen as powerful controlling influences of air movements in houses.

Recommendations for Future Work

A fundamental measurement problem throughout the Project was that of temperature variation with time. There could be two possible solutions to this. One could be the incorporation of a transient term within the fundamental tracer gas equations. The present problem is that of attempting to model non-steady state conditions with steady state equations. The second solution would be to create steadier-state conditions within the zones themselves. This could possibly be done by allowing temperature conditions within the zones to remain at the required temperature for an extended period, creating a large thermal inertia of the rooms. This was impractical to do in the majority of tests described here, because of the necessity to perform as many tests as possible in a limited period of time. The temperature differences themselves could be limited to relatively low values, since the use of large ones is probably only of academic interest, as they are rarely encountered in real situations.

The variation of the coefficient of discharge with door opening and temperature difference should be investigated. This would enable more reliable predictive formulae to be derived. This would imply the use of accurate airflow measurements, necessary to evaluate the value of the coefficient of discharge, which is not the case with present tracer gas measurement techniques.

The airflow patterns within a stairwell could be investigated, to gain a clearer insight into the role of this zone in influencing interzonal airflows within a house. As it is probable that the flow process is complex, and might never be modelled satisfactorally, the use of techniques such as smoke or bubble generation may give visual insights into the airflow regime within this zone.

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APPENDIX A COMPUTER PROGRAM FOR IRWIN'S ANALYTICAL SOLUTION OF 2 ZONE AIRFLOWS

EXPLANATION OF COMPUTER PROGRAM

The following is an explanation of the concept behind the computer program for Irwin's 2 Zone analysis (Section 2.7)

The program prompts for the number of data sets for each zone, which must be equal to each other. Further prompts are for the length of the test and effective volumes of the 2 Zones.

Using linear regression, (Commonly found on pocket statistical calulators.), the program evaluates the initial concentration of tracer gases A in Zone 1 and B in Zone 2, which are uncertain from test data. Also evaluated are the first approximation of the air change rates in Zones 1 and 2, N1' and N2' respectively and the mean tracer gas concentrations $\widetilde{CA1}$, $\widetilde{CA2}$, $\widetilde{CB1}$ and $\widetilde{CB2}$. The latter are simply averages of the respective concentration over the whole test period.

By using the formulae for the 2 Zone analysis, the program gives output for the following:-

Q12	Airflow between Zone 1 and 2	(m3/h)
Q21	Airflow between Zone 2 and 1	(m3/h)
N1	Airchange rate Zone 1	(ac/h)
N2	Airchange rate Zone 2	(ac/h)
N1'	First approximation of air change rate Zone 1	(ac/h)
N2'	First approximation of air change rate Zone 2	(ac/h)
COA1	Initial concentration of Gas A in Zone 1	
COB2	Initial concentration of gas in Zone 2	
$\widetilde{CA1}$	(MEAN CA1) mean concentration of Gas A in Zone 1	
$\widetilde{CA2}$	(MEAN CA2) mean concentration of Gas A in Zone 2	
$\widetilde{CB1}$	(MEAN C1) mean concentration of Gas B in Zone 1	
$\widetilde{CB2}$	(MEAN CB2) mean concentration of Gas B in Zone 2	

A demonstration of the Program, with computer output, is shown over, along with the data set used.

```
10  DIM T1(20),T2(20),A1(20),L1(2
     0),B1(20),A2(20),L2(20),B2(2
     0)
20  HOME
30  PRINT "HOW MANY SETS OF RESUL
     TS PER ZONE;MUST BE EQUAL ?"

40  INPUT NUM
50  PRINT "WHAT IS THE LENGTH OF
     TEST;IN MINUTES ?"
60  INPUT X
70 T = X / 2: REM  MEDIAN TIME
80  PRINT "WHAT ARE VOLUMES OF RO
     OMS 1&2 ?"
90  INPUT V1,V2
100  PRINT "INPUT T1,CA1,CB1,T2,C
     A2,CB2 SEPARATED BY COMMAS"
110  FOR I = 1 TO NUM
120  INPUT T1(I),A1(I),B1(I),T2(I
     ),A2(I),B2(I)
130  NEXT I: REM  DATA NOW IN ARR
     AYS
140  FOR I = 1 TO NUM
150 L1(I) =  LOG (A1(I))
160 L2(I) =  LOG (B2(I))
170  NEXT I: REM  CA1&CB2 NATURAL
      LOGS
180  REM  LINEAR REGRESSION TO FI
     ND COA1&N1'.FIRST 6 DATA POI
     NTS ONLY
190  FOR I = 1 TO 6
200 ZA = ZA + L1(I): REM   SUM OF
      Y
210 ZB = ZB + (T1(I) * T1(I)): REM
                 SUM OF X*X
220 ZC = ZC + T1(I): REM   SUM OF
                  X
230 ZD = ZD + (T1(I) * L1(I)): REM
      SUM OF X*Y
240  NEXT I
250 I1 = ZA:K1 = ZB:H1 = ZC:J1 =
     ZD:L1 = H1 * H1
260 M1 = ((6 * J1) - (H1 * I1)) /
     ((6 * K1) - L1)
270  IF M1 < 0 THEN M1 = M1 * ( -
     1)
280  REM  FIRST APPROX=N1'
290 G1 = ((I1 * K1) - (H1 * J1)) /
     ((6 * K1) - L1)
300  REM  G1=INTERCEPT.EXPONENTIA
     TE
310 F1 =  EXP (G1): REM  COA1
320  REM  LINEAR REGRESSION TO FI
     ND N2'&COB2.FIRST 6 POINTS O
     NLY
330  FOR I = 1 TO 6
340 ZE = ZE + L2(I): REM  SUM Y
350 ZF = ZF + (T2(I) * T2(I)): REM
      SUM X*X
360 ZG = ZG + T2(I): REM  SUM X
370 ZH = ZH + (T2(I) * L2(I)): REM
      SUM X*Y
```

```
ZF:L2 = H2 * H2
400 M2 = ((6 * J2) - (H2 * I2)) /
    ((6 * K2) - L2)
410  IF M2 < 0 THEN M2 = M2 * ( -
    1)
420 G2 = ((I2 * K2) - (H2 * J2)) /
    ((6 * K2) - L2)
430  REM  INTERCEPT =COB2.EXPONEN
    TIATE
440 F2 =  EXP (G2)
450  REM  ARITHMETIC AVERAGES
460  FOR I = 1 TO NUM
470 AV = AV + A1(I)
480  NEXT I
490 AV = AV / NUM: REM  CA1
500  FOR I = 1 TO NUM
510 AW = AW + A2(I)
520  NEXT I
530 AW = AW / NUM: REM  CA2
540  FOR I = 1 TO NUM
550 AX = AX + B1(I)
560  NEXT I
570 AX = AX / NUM: REM  CB1
580  FOR I = 1 TO NUM
590 AY = AY + B2(I)
600  NEXT I
610 AY = AY / NUM: REM  CB2
620  REM  COA2&COB1 ALWAYS=0 EQUA
    TIONS REDUCE
630 A = T - ((M1) * (T ^ 2)) / 2 +
    ((M1 ^ 2) * (T ^ 3)) / 6 - (
    (M1 ^ 3) * (T ^ 4)) / 24 + (
    (M1 ^ 4) * (T ^ 5)) / 120
640 N1 = (1 / A) - (AV / (A * F1)
    ): REM  NEW VALUE OF N1'
650 Q21 = (AX * V1 * (M1 - M2)) /
    (F2 * ( EXP ( - M2 * T) -  EXP
    ( - M1 * T)))
660 B = T - ((M2) * (T ^ 2)) / 2 +
    ((M2 ^ 2) * (T ^ 3)) / 6 - (
    (M2 ^ 3) * (T ^ 4)) / 24 + (
    (M2 ^ 4) * (T ^ 5)) / 120
670 N2 = (1 / B) - (AY / (B * F2)
    ): REM  NEW VALUE OF N2'
680 Q12 = (AW * V2 * (M2 - M1)) /
    (F1 * ( EXP ( - M1 * T) -  EXP
    ( - M2 * T)))
690 N1 =  INT (N1 * 600 + 0.5) /
     INT (10 + 0.5)
700 Q21 =  INT (Q21 * 600 + 0.5) /
     INT (10 + 0.5)
710 N2 =  INT (N2 * 600 + 0.5) /
     INT (10 + 0.5)
720 Q12 =  INT (Q12 * 600 + 0.5) /
     INT (10 + 0.5)
730  PRINT "N1="N1" AIR CHANGES P
    ER HOUR"
740  PRINT : PRINT "N2="N2" AIR C
    HANGES PER HOUR"
750  PRINT : PRINT "Q21="Q21" MET
    RES CUBED PER HOUR"
760  PRINT : PRINT "Q12="Q12" MET
    RES CUBED PER HOUR"
```

T 1	CA1	CB1	T 2	CA2	CB2
6.50	3.30	0.30	7.90	0.20	6.70
9.10	3.30	0.30	10.00	0.40	6.50
11.00	3.30	0.40	12.00	0.50	6.30
13.00	3.00	0.30	14.20	0.80	6.00
15.20	3.00	0.30	16.20	0.90	5.90
18.40	2.80	0.30	19.40	1.00	5.50
20.50	2.70	0.30	21.60	0.90	5.60
22.90	2.70	0.30	24.00	1.00	5.30
25.20	2.60	0.30	26.40	1.00	4.90
27.40	2.50	0.30	28.80	0.90	4.60
30.30	2.40	0.30	31.30	0.90	4.10
33.50	2.20	0.30	34.80	0.90	3.40
36.00	2.10	0.20	37.10	1.00	3.30
40.50	1.90	0.20	41.60	1.00	2.60

N1' = 1.507141E-02
COA1= 3.738331
N2' = 1.702087E-02
COB2= 7.6938
MEAN CA1= 2.7
MEAN CA2= .8142857
MEAN CB1= .2928571
MEAN CB2= 5.05
N1 = .9 AIR CHANGES PER HOUR
N2 = 1.2 AIR CHANGES PER HOUR

Q21 = 8.600001 CU M PER HR

Q12 = 57 CU M PER HR

APPENDIX B DATA FOR LEAKINESS OF DOUBLE CHAMBERS

Schedules of tests

Section 4.1; Leakiness of Test Chambers

Time minutes	Concentration arbitrary units
1.2	6.35
5.6	6.05
14.7	5.35
15.7	5.3
30.6	4.6
31.7	4.5
52.6	4.0
72.3	3.2

Air handler unit ducting open

Air change rate of Environmental side = 0.76 ach

Time minutes	Concentration arbitrary units
1.1	4.9
11.1	4.2
15.5	4.0
17.2	3.8
22.5	3.7
36.5	3.4
37.5	3.35
42.6	3.25
57.4	3.0
69.2	2.85
76.4	2.8
77.4	2.8
102	2.65

All ducting sealed

Air change rate of Environmental side = 0.035 ach

Time minutes	Concentration arbitrary units
6	6.7
22	6.65
46	6.6
102	6.6
125	6.4
192	6.3
256	6.1
258	6.05
302	6.0
353	5.7

All ducting sealed

Air change rate of Design side = 0.026 ach

Time minutes	Concentration arbitrary units
17	7.2
20	7.2
23	7.1
38	6.95
80	6.7
91	6.7
132	6.45
212	6.1
225	6.1
298	5.7
341	5.6

All ducting sealed

Air change rate of Environmental side = 0.046 ach

APPENDIX C DATA FOR SITE LEAKAGE MEASUREMENTS

Schedules of tests

Table 4.2 (Page 75); Room and Flow Equations; Site

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
25.3	3.23	88.1	0.54	-0.63
21.5	3.07	70.3	0.48	-0.74
19.2	2.95	63.0	0.45	-0.79
16.7	2.82	53.5	0.42	-0.87
13.6	2.61	44.6	0.38	-0.97
12.0	2.48	36.9	0.35	-1.06

WHOLE HOUSE .ALL WINDOWS SEALED. ALL DOORS FULLY OPEN
FAN COULD NOT GENERATE 50 Pa.

Q=0.088dP^0.55 m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
16.5	2.80	90.7	0.54	-0.61
14.9	2.70	79.8	0.51	-0.67
13.8	2.62	75.2	0.49	-0.70
12.4	2.52	62.9	0.45	-0.79
11.1	2.41	52.7	0.41	-0.88

WHOLE HOUSE.ALL WINDOWS UNSEALED.ALL DOORS FULLY OPEN.
FAN COULD NOT GENERATE 50Pa

Q=0.079dP^0.69 m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
61.0	4.11	22.6	0.27	-1.31
53.8	3.99	18.7	0.25	-1.39
45.4	3.82	15.2	0.22	-1.51
40.2	3.69	12.7	0.20	-1.61
32.5	3.48	9.3	0.17	-1.77
24.1	3.18	5.5	0.13	-2.04

HALLWAY.ALL DOORS CLOSED AND SEALED

Q=0.011dP^0.78 m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
34.5	3.54	33.5	0.33	-1.11
30.7	3.42	29.8	0.31	-1.17
23.0	3.14	20.0	0.25	-1.39
21.7	3.08	19.6	0.25	-1.39

KITCHEN. ALL CRACKS UNSEALED.

Q=0.032dP^0.66 m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
40.3	3.70	27.3	0.30	-1.20
34.8	3.55	23.5	0.28	-1.27
29.3	3.38	18.5	0.25	-1.39
25.2	3.23	17.4	0.24	-1.43
20.3	3.01	12.5	0.20	-1.61

KITCHEN. WINDOW CRACKS SEALED.

Q=0.035dP^0.58 m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
51.9	3.95	19.8	0.25	-1.39
44.4	3.79	15.5	0.22	-1.51
36.0	3.58	12.5	0.20	-1.61
29.3	3.38	9.5	0.18	-1.71
21.2	3.05	6.7	0.15	-1.90

KITCHEN. WINDOWS AND BACK DOOR SEALED

$Q=0.028dP^{0.55}$ m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
41.8	3.73	31.6	0.32	-1.14
35.9	3.58	27.8	0.30	-1.20
28.1	3.34	22.3	0.27	-1.31
23.0	3.14	17.5	0.24	-1.43
19.8	2.99	14.5	0.22	-1.51

KITCHEN. ALL CRACKS SEALED.FAN IN WINDOW

$Q=0.049dP^{0.51}$ m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
42.5	3.75	32.2	0.32	-1.14
37.4	3.62	28.0	0.30	-1.20
31.1	3.44	23.0	0.27	-1.31
24.8	3.21	16.8	0.23	-1.47
20.0	3.00	12.2	0.20	-1.61

LIVING ROOM. ALL CRACKS UNSEALED.

$Q=0.030dP^{0.64}$ m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
60.6	4.10	21.0	0.26	-1.35
55.6	4.02	19.2	0.25	-1.39
49.9	3.91	16.1	0.23	-1.47
44.2	3.79	14.8	0.22	-1.51
39.1	3.67	12.0	0.20	-1.61
32.5	3.48	9.4	0.17	-1.71
23.3	3.15	6.0	0.14	-1.97

LIVING ROOM. WINDOW CRACKS SEALED

$Q=0.017dP^{0.67}$ m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
43.0	3.76	31.3	0.32	-1.14
38.0	3.63	25.4	0.29	-1.24
31.0	3.43	22.3	0.27	-1.31
22.0	3.09	16.5	0.23	-1.47
20.0	3.00	13.7	0.21	-1.56

FRONT ROOM.WINDOWS,SKIRTING SEALED.DOOR POS 4.FAN IN WINDOW.

Q=0.046dP^0.51 m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
59.7	4.09	6.5	0.15	-1.90
52.2	3.96	5.4	0.13	-2.04
41.3	3.72	4.0	0.11	-2.21
31.0	3.43	2.9	0.10	-2.30
24.2	3.19	1.4	0.07	-2.66
15.9	2.77	0.8	0.05	-3.00

LIVING ROOM. WINDOWS AND SKIRTING SEALED

Q=0.005dP^0.81 m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
51.7	3.95	23.0	0.27	-1.31
41.2	3.72	19.0	0.25	-1.39
34.6	3.54	14.5	0.22	-1.51
29.6	3.39	10.7	0.19	-1.66
20.6	3.03	6.8	0.15	-1.90

LIVING ROOM. DOOR CLOSED. (FAN IN WINDOW)

Q=0.020dP^0.67 m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
54.0	3.99	16.8	0.23	-1.47
47.0	3.85	12.3	0.20	-1.61
37.5	3.62	8.0	0.16	-1.83
30.3	3.41	7.2	0.15	-1.90
24.2	3.19	4.5	0.12	-2.12
2.97	19.5	4.0	0.11	-2.21

BEDROOM.WINDOW SEALED. DOOR CLOSED FAN IN WINDOW

Q=0.012dP^0.72 m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
53.4	3.98	30.4	0.31	-1.17
47.5	3.86	23.6	0.28	-1.27
39.5	3.68	18.7	0.25	-1.39
32.2	3.47	12.7	0.20	-1.61
26.0	3.26	9.0	0.17	-1.77
20.1	3.00	6.9	0.15	-1.90

BEDROOM. WINDOWS SEALED.DOOR POS 4.FAN IN WINDOW

Q=0.014dP^0.77 m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
51.1	3.93	23.0	0.27	-1.31
44.1	3.79	18.9	0.25	-1.39
37.2	3.62	14.8	0.22	-1.51
30.5	3.42	11.8	0.22	-1.61
26.2	3.27	9.4	0.17	-1.77
20.2	3.01	6.3	0.14	-1.97

BEDROOM. ALL CRACKS UNSEALED.

Q=0.016dP^0.72 m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
74.8	4.31	12.8	0.20	-1.61
61.2	4.11	10.5	0.18	-1.71
52.3	3.96	7.9	0.16	-1.83
40.3	3.70	5.5	0.13	-2.04
27.9	3.32	3.0	0.10	-2.30
20.2	3.01	1.9	0.08	-2.53

BEDROOM. WINDOW CRACKS SEALED

Q=0.0091dP^0.72 m^3/s

dP (Pa) rooms	ln dP (Pa) rooms	dP (Pa) flow grid	Q (m^3/s) extract	ln Q (m^3/s) extract
53.4	3.98	30.4	0.31	-1.17
47.5	3.86	23.6	0.28	-1.27
39.5	3.68	18.7	0.25	-1.39
32.2	3.47	12.7	0.20	-1.61
26.0	3.26	9.0	0.17	-1.77
20.1	3.00	6.9	0.15	-1.90

BEDROOM. WINDOWS SEALED.DOOR POS 4.FAN IN WINDOW

Q=0.014dP^0.77 m^3/s

APPENDIX D DATA FOR LEAKINESS OF BEDROOM

Schedules of tests

Table 4.6 (Page 80); **The Effects of Sealing different combinations of leakage routes on the bedroom air-change rate**

TIME mins	CONCENTRATION arbitrary units
0.8	5.5
1.6	5.3
2.5	5.3
4.1	5.2
5.0	5.1
6.5	5.0
7.4	5.0
8.4	4.9
10.0	5.0
11.6	4.9
13.3	4.8
14.2	4.9
15.0	4.7
16.6	4.7
18.4	4.6
19.3	4.6
20.8	4.5
21.7	4.5
23.4	4.5
25.1	4.3
26.8	4.3
28.4	4.2
30.1	4.4
31.8	4.3
33.5	4.1
35.1	3.9

Mean bedroom temperature =24C

Mean stairwell temperature =21C

Mean outside temperature =5 C

Mean wind pressure
predominance(front of house)=-.5Pa

Calculated room ACH =0.5ach

Window =unsealed

Door =unsealed

Floor =sealed

TIME mins	CONCENTRATION arbitrary units
0.8	6.4
1.6	6.4
2.4	6.3
3.3	6.3
5.0	6.3
5.8	6.3
6.6	6.3
7.5	6.3
9.2	6.2
10.8	6.2
12.5	6.1
14.3	6.0
15.2	6.0
16.7	6.0
17.6	6.0
18.5	6.0
19.4	6.0
20.2	5.8
22.7	5.8
23.5	5.8
26.2	5.7
27.8	5.7
29.5	5.5
31.3	5.6
32.2	5.6
34.8	5.5
35.6	5.5

Mean bedroom temperature =26C

Mean stairwell temperature =23C

Mean outside temperature =5 C

Mean wind pressure
predominance(front of house)=+.2Pa

Calculated room ACH =0.3ach

Window =unsealed

Door =sealed

Floor =sealed

TIME mins	CONCENTRATION arbitrary units
1.3	6.6
2.0	6.7
3.7	6.6
4.5	6.6
5.4	6.6
7.2	6.5
8.7	6.4
9.6	6.3
11.4	6.0
12.3	6.2
13.1	6.1
14.0	6.1
14.7	5.8
15.6	5.8
17.5	5.8
18.3	6.0
19.2	6.0
20.0	5.8
21.8	5.9
23.5	5.6
25.2	5.6
26.1	5.6
27.7	5.5
29.4	5.4
31.2	5.1
32.8	5.4
35.3	5.2
37.1	5.0

Mean bedroom temperature =25C

Mean stairwell temperature =22C

Mean outside temperature =5 C

Mean wind pressure
predominance(front of house)=-.3Pa

Calculated room ACH =0.5ach

Window =unsealed

Door =unsealed

Floor =sealed

TIME mins	CONCENTRATION arbitrary units
0.8	7.8
1.8	7.8
4.7	7.7
5.5	7.7
6.5	7.7
8.2	7.6
9.0	7.6
9.9	7.6
10.8	7.6
12.5	7.4
13.3	7.4
14.2	7.5
15.0	7.4
15.8	7.4
16.7	7.4
17.6	7.4
18.5	7.4
19.3	7.5
20.2	7.4
21.0	7.4
21.8	7.3
22.7	7.3
23.5	7.4
24.4	7.3
25.2	7.4
27.0	7.2
28.0	7.3
29.0	7.1
29.7	7.1
30.8	7.2
32.0	7.0

Mean bedroom temperature =27C

Mean stairwell temperature =24C

Mean outside temperature =2 C

Mean wind pressure
predominance(front of house)=-.3Pa

Calculated room ACH =0.2ach

Window =unsealed

Door =sealed

Floor =sealed

TIME mins	CONCENTRATION arbitrary units
1.7	7.2
2.5	7.2
3.4	7.3
5.2	7.1
6.0	6.6
7.0	6.7
7.8	6.8
9.8	6.6
11.5	6.5
12.4	6.2
13.3	6.1
14.2	6.4
16.7	6.2
19.0	5.6
20.0	5.7
22.5	5.7
23.5	5.7
24.3	5.4
27.0	5.3
27.8	5.4
29.6	5.2
30.4	5.3
32.2	5.2
33.0	5.1
34.8	5.0
35.7	4.8

Mean bedroom temperature =26C

Mean stairwell temperature =23C

Mean outside temperature =2 C

Mean wind pressure
predominance(front of house)=-1.4a

Calculated room ACH =0.7ach

Window =sealed

Door =pos 8

Floor =sealed

TIME mins	CONCENTRATION arbitrary units
0.6	6.1
1.5	6.2
2.4	6.1
4.0	6.2
5.0	6.3
5.8	6.2
8.5	6.1
9.4	6.1
10.2	6.1
12.0	6.2
12.8	6.1
15.4	6.1
17.2	6.1
19.8	6.1
21.5	6.1
22.4	6.2
24.2	6.2
25.9	6.1
27.6	6.1
29.3	6.2
31.2	6.1
32.0	6.2
33.7	6.2
34.6	6.1

Mean bedroom temperature =26C

Mean stairwell temperature =24C

Mean outside temperature =3 C

Mean wind pressure
predominance(front of house)=+.2Pa

Calculated room ACH =0 ach

Window =sealed

Door =sealed

Floor =sealed

TIME mins	CONCENTRATION arbitrary units
1.0	6.7
1.8	6.7
2.7	6.7
3.6	6.7
4.6	6.6
5.4	6.6
6.4	6.5
8.2	6.7
10.0	6.6
11.8	6.4
12.6	6.5
13.5	6.4
14.4	6.3
16.3	6.4
17.1	6.4
18.0	6.3
19.8	6.1
20.7	6.2
21.5	6.1
22.5	6.2
23.3	6.2
25.1	6.1
26.0	6.0
27.8	6.1
31.4	5.9
32.3	5.9
33.3	5.8
38.7	5.9

Mean bedroom temperature =27C

Mean stairwell temperature =22C

Mean outside temperature =3 C

Mean wind pressure
predominance(front of house)=0 Pa

Calculated room ACH =+.2ach

Window =sealed

Door =sealed

Floor =sealed

TIME mins	CONCENTRATION arbitrary units
0.8	4.9
1.7	4.9
2.6	4.8
3.5	4.7
5.8	4.7
6.8	4.5
7.7	4.5
8.5	4.6
9.5	4.5
10.4	4.6
11.4	4.5
12.3	4.3
14.0	4.5
15.8	4.4
17.6	4.3
19.5	4.3
21.4	4.3
23.2	4.3
24.0	4.1
25.8	4.2
27.6	4.0
28.5	4.0
29.5	4.1
30.3	3.9
31.3	4.0
32.2	3.9
33.0	3.8
34.0	3.8

Mean bedroom temperature =26C

Mean stairwell temperature =22C

Mean outside temperature =3 C

Mean wind pressure
predominance(front of house)=-.2Pa

Calculated room ACH =0.4ach

Window =unsealed

Door =unsealed

Floor =sealed

TIME mins	CONCENTRATION arbitrary units
1.5	7.3
2.4	7.3
3.3	7.4
4.2	7.4
5.0	7.4
5.9	7.4
6.8	7.3
7.6	7.3
8.5	7.4
9.3	7.3
10.3	7.3
11.2	7.3
12.0	7.3
12.8	7.3
13.7	7.4
14.6	7.4
15.4	7.2
16.4	7.2
17.2	7.2
18.1	7.2
19.0	7.2
19.8	7.2
20.6	7.2
21.5	7.2
22.4	7.3
23.3	7.2
24.2	7.3
25.2	7.2
25.8	7.3
27.0	7.3

Mean bedroom temperature =26C

Mean stairwell temperature =23C

Mean outside temperature =2 C

Mean wind pressure predominance(front of house)=-.7Pa

Calculated room ACH =.05ach

Window =sealed

Door =sealed

Floor =sealed

TIME mins	CONCENTRATION arbitrary units
0.6	7.3
1.5	7.3
2.4	7.3
3.3	7.2
4.2	7.3
5.0	7.3
5.9	7.2
6.8	7.2
7.6	7.3
8.4	7.3
9.3	7.2
10.2	7.3
11.1	7.2
12.0	7.2
12.9	7.4
13.8	7.2
14.6	7.2
15.5	7.2
16.4	7.3
17.3	7.3
18.1	7.2
19.0	7.2
19.9	7.3
20.8	7.2
23.5	7.2
26.2	7.1
27.8	7.2
28.7	7.1
29.6	7.2
30.7	7.1

Mean bedroom temperature =26C

Mean stairwell temperature =23C

Mean outside temperature =2 C

Mean wind pressure predominance(front of house)=-1.2Pa

Calculated room ACH =.03ach

Window =sealed

Door =unsealed

Floor =sealed

TIME mins	CONCENTRATION arbitrary units
1.5	8.4
2.4	8.3
4.0	8.1
5.0	8.1
6.2	8.2
7.2	8.1
8.1	8.1
9.0	8.0
10.7	8.0
11.5	8.0
12.4	7.9
14.2	7.9
15.9	7.8
17.6	7.6
19.4	7.7
21.2	7.5
22.8	7.5
24.6	7.3
26.3	7.5
27.2	7.4
29.0	7.3
30.7	7.3
32.5	7.1
34.2	7.0
35.9	7.2

Mean bedroom temperature =23 C

Mean stairwell temperature =21 C

Mean outside temperature =0 C

Mean wind pressure
predominance(front of house) =-.3Pa

Calculated room ACH =.3 ach

Window =unsealed

Door =sealed

Floor =unsealed

TIME mins	CONCENTRATION arbitrary units
2.1	8.0
3.2	8.0
5.2	7.9
6.0	7.8
7.0	7.8
8.7	7.6
10.4	7.4
11.3	7.6
12.1	7.4
13.0	7.5
14.8	7.5
15.5	7.4
16.5	7.5
17.3	7.4
19.0	7.1
20.6	7.2
21.5	7.3
22.4	7.0
24.0	7.3
25.7	7.1
27.4	7.1
29.2	6.9
30.8	6.9
31.6	6.7
33.5	6.8
35.3	6.7

Mean bedroom temperature =24C

Mean stairwell temperature =22C

Mean outside temperature =3 C

Mean wind pressure
predominance(front of house)=-.4Pa

Calculated room ACH =.3ach

Window =unsealed

Door =sealed

Floor =unsealed

TIME mins	CONCENTRATION arbitrary units
0.8	6.4
1.7	6.2
2.5	6.5
3.4	6.4
5.1	6.5
6.8	6.5
8.5	6.2
9.4	6.1
10.3	6.2
12.0	6.4
12.9	6.4
13.8	5.9
14.6	5.9
15.5	6.1
17.3	6.2
18.9	5.9
19.7	6.1
21.5	6.1
24.0	5.7
24.9	5.8
26.6	5.7
28.4	5.7
30.1	5.4
31.8	5.3
32.7	5.5
34.4	5.5
35.3	5.6

Mean bedroom temperature =26C

Mean stairwell temperature =22C

Mean outside temperature = 3C

Mean wind pressure predominance(front of house)=+.1Pa

Calculated room ACH =.3 ach

Window =unsealed

Door =sealed

Floor =unsealed

APPENDIX E DATA FOR LABORATORY TEMPERATURE DRIVEN FLOW

DOOR POSITIONS 1, 2 AND 3

Schedules of tests

TIME (mins)	CONCENTRATION (arbitrary units)
1.4	2.1
2.7	2.1
3.5	2.1
5.8	2.1
7.0	2.0
8.4	1.95
11.6	1.95
21.3	1.85
26	1.8
37	1.8
51.5	1.55

DOOR POSITION =POS 1

TEMP DIFF =10C

CALCULATED ACH =0.3

CALCULATED FLOW =10 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)		
8	5.2	DOOR POSITION	=POS 1
9.4	5.4		
10.5	5.3	TEMP DIFF	=8 C
11.8	5.2		
13.2	5.1		
14.4	5.0		
15.8	5.0	CALCULATED ACH	=0.46
17.0	5.1		
18.3	4.9	CALCULATED FLOW	=14 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
4.5	3.0
5.8	2.5
7.1	2.6
8.4	3.0
9.7	2.8
10.9	2.7
12.2	2.9
13.5	2.8
14.8	2.8
16	3.1
17.3	2.7
18.5	2.7
19.8	3.0
21.2	2.8
22.4	2.7
23.6	2.7
24.9	2.6
26.2	2.6

DOOR POSITION =POS 1

TEMP DIFF =7 C

CALCULATED ACH =0.11

CALCULATED FLOW =3 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.7	4.4
3.5	3.2
6.0	3.2
7.4	3.2
8.7	3.5
10.1	3.8
11.1	3.9
12.8	3.4
14.5	4.0
17.7	3.8
19.0	3.5
20.4	3.8

DOOR POSITION =POS 1

TEMP DIFF =34 C

CALCULATED ACH =0.33

CALCULATED FLOW =10 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
17	7.2
20	7.2
23	7.1
28.5	7.0
38	7.0
80.5	6.7
84	6.7
90	6.7
131.5	6.5
137	6.5
208	6.2
212	6.1
249	6.0
298	5.7

DOOR POSITION =POS 1

TEMP DIFF =0 C

CALCULATED ACH =0.046

CALCULATED FLOW =1 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.3	6.0
1.2	5.8
2.2	5.7
3.0	5.7
4.0	5.7
5.0	5.7
5.8	5.7
6.8	5.7
7.8	5.7
8.7	5.7
9.6	5.7
10.5	5.6
11.4	5.6
12.3	5.6
13.3	5.5
14.1	5.6
15.0	5.5
16.0	5.5
17.1	5.4
18.0	5.5
18.8	5.4
19.8	5.4
20.6	5.3

DOOR POSITION =1

TEMP DIFF =14.0C

CALCULATED ACH =0.2

CALCULATED FLOW =8 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.9	4.9
1.9	4.8
2.9	4.9
3.8	4.8
5.6	4.8
6.5	4.8
7.4	4.6
8.2	4.6
9.2	4.7
10.2	4.7
11.2	4.7
12.0	4.5
13.1	4.4
14.1	4.7
15.0	4.4
15.9	4.4
16.8	4.3
17.8	4.3
18.6	4.3
19.4	4.3
20.5	4.3

DOOR POSITION =1

TEMP DIFF =16.0C

CALCULATED ACH =0.4

CALCULATED FLOW =14 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)		
0.5	4.3	DOOR POSITION	=POS 2
1.5	4.2		
3.5	4.2	TEMP DIFF	=2.0C
4.8	4.1		
6.1	4.0		
7.6	2.8		
8.8	4.1 mix 20s	CALCULATED ACH	=0.8
10.2	3.3		
11.5	3.2	CALCULATED FLOW	=24 m^3/h
13.0	2.8		
14.3	3.9 mix 20s		
15.6	3.9		
17.0	3.1		
18.4	3.5 mix 20s		

TIME (mins)	CONCENTRATION (arbitrary units)
0.2	3.9
1.4	2.9
2.6	3.3
3.8	3.5
5.0	3.3
6.0	2.9
7.5	3.1
8.8	3.3
11.3	3.1
12.6	2.8
13.7	3.3
15.0	2.9
16.1	2.9
18.4	2.8
19.5	2.8

DOOR POSITION =POS 2

TEMP DIFF =9.0C

CALCULATED ACH =0.7

CALCULATED FLOW =21 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)		
1.5	5.1	DOOR POSITION	=POS 2
2.6	4.9		
4.0	4.7	TEMP DIFF	=2.0C
5.4	4.0		
6.6	4.2		
8.0	4.5		
9.4	3.6	CALCULATED ACH	=0.8
10.6	5.0 mix 20s		
12.0	4.7	CALCULATED FLOW	=24 m^3/h
13.4	3.5		
14.7	4.0		
16.0	4.2		
17.4	3.9		
18.8	3.3		
20.2	4.3 mix 20s		

TIME (mins)	CONCENTRATION (arbitrary units)
0.7	4.4
2.0	4.5
3.5	3.2
6.0	3.2
7.4	3.2
8.8	3.5
10.0	3.9
11.0	3.9
12.8	3.4
14.6	4.0
16.4	4.0
17.7	3.8
19.0	3.5
20.4	3.8

DOOR POSITION =POS 2

TEMP DIFF =2.0C

CALCULATED ACH =0.3

CALCULATED FLOW =10 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.5	5.2
1.8	4.9
3.2	4.4
4.4	4.8
5.7	4.6
7.0	4.5
8.3	4.4
9.6	4.1
12.2	4.0
13.5	4.1
14.8	4.1
16.1	3.8
17.3	3.7
18.6	3.6
20.0	3.6

DOOR POSITION =POS 2

TEMP DIFF =14.0C

CALCULATED ACH =1.0

CALCULATED FLOW =30 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.8	4.9
2.0	4.5
3.4	4.5
4.6	4.6
6.0	4.3
7.3	4.5
8.5	4.1
9.8	4.5
11.1	3.7
12.4	4.1
13.8	4.0
15.0	3.7
16.3	3.6
18.9	4.0
20.3	3.9

DOOR POSITION =POS 2

TEMP DIFF =14.0C

CALCULATED ACH =0.7

CALCULATED FLOW =21 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
1.2	4.1
2.5	3.7
3.9	3.6
5.2	3.2
6.5	3.1
7.8	3.3
9.0	3.2
10.4	3.1
11.6	3.1
13.0	3.0
14.2	3.0
15.5	2.7
16.8	2.6
18.2	2.7
19.5	2.7

DOOR POSITION =POS 2

TEMP DIFF =13.0C

CALCULATED ACH =1.3

CALCULATED FLOW =39 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.5	4.6
1.8	4.4
3.0	4.4
4.2	4.2
5.5	4.2
6.8	3.9
8.0	4.0
9.2	3.9
10.5	3.7
11.8	3.9
13.0	3.9
14.2	3.9
15.5	3.9
16.8	3.6
18.0	3.5
19.3	3.7

DOOR POSITION =POS 2

TEMP DIFF =14.0C

CALCULATED ACH =0.7

CALCULATED FLOW =21 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
1.1	3.5
2.4	3.4
3.7	3.0
5.0	3.3
6.4	3,1
7.7	3.2
9.0	3.3
10.3	2.9
11.6	3.1
13.0	3.1
14.2	2.8
15.5	3.0
16.9	2.9
18.2	2.9
19.5	3.0

DOOR POSITION =POS 2

TEMP DIFF =3.0C

CALCULATED ACH =0.5

CALCULATED FLOW =15 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.8	5.4
1.6	4.9
2.5	5.0
3.5	5.0
4.4	5.0
5.3	4.9
6.3	5.0
7.4	5.0
8.3	4.8
9.3	4.9
10.2	4.8
11.1	4.8
12.0	4.7
13.9	4.8
14.8	4.6
15.8	4.2
16.8	4.2
17.8	4.6
18.6	3.9
19.5	4.5
20.5	4.6

DOOR POSITION =POS 2

TEMP DIFF FOR 10 T/C=2.0C

CALCULATED ACH =0.6

CALCULATED FLOW =18 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.7	4.6
1.6	4.8
2.4	3.7
3.4	4.2
4.2	4.0
5.0	3.9
6.0	4.0
6.8	4.0
7.7	3.8
8.7	3.9
9.6	3.7
10.5	3.7
11.5	3.7
12.4	3.7
13.4	3.7
14.2	3.3
15.1	3.4
16.0	3.3
16.8	3.3
17.8	3.3
18.7	3.5
19.6	3.0
20.5	3.4

DOOR POSITION =POS 2

TEMP DIFF =5.0C

CALCULATED ACH =1.0

CALCULATED FLOW =30 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.7	4.3
1.9	4.6
2.8	4.6
3.8	4.6
4.7	4.4
5.5	4.4
6.5	4.4
7.5	4.2
8.5	4.3
9.3	4.3
10.3	4.0
11.2	4.4
12.2	4.0
13.1	4.1
14.0	4.0
15.1	4.2
16.0	4.0
17.0	4.0
18.0	4.0
18.9	3.9
19.8	4.0

DOOR POSITION =POS 2

TEMP DIFF =3.0C

CALCULATED ACH =0.5

CALCULATED FLOW =15 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
1.1	4.9
2.5	4.5
3.7	4.6
5.0	4.5
6.0	4.2
7.0	4.2
8.2	4.3
10.2	4.1
11.7	3.9
12.7	3.8
13.7	3.9
15.0	3.5
16.0	3.6
17.2	3.5
18.2	3.5
19.3	3.7

DOOR POSITION =POS 2

TEMP DIFF =13.0C

CALCULATED ACH =1.0

CALCULATED FLOW =30 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.9	4.4
1.8	3.4
2.7	3.2
4.0	3.1
5.0	3.0
6.1	3.0
7.0	2.9
9.0	2.7
10.1	2.4
11.0	1.4
11.9	2.5
13.2	2.3
14.1	2.3
15.2	2.1
16.1	2.0
17.0	2.2
17.7	1.9
18.8	1.9
19.8	1.7
20.7	1.7

DOOR POSITION =POS 3

TEMP DIFF =13.0C

CALCULATED ACH =2.3

CALCULATED FLOW =69 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)		
0.3	4.8	DOOR POSITION	=POS 2
1.5	4.3		
2.6	4.3	TEMP DIFF	=1.0C
4.0	4.7 mix 20s		
5.2	3.9		
6.4	4.0		
7.6	4.3	CALCULATED ACH	=0.6
8.9	3.9 mix 20s		
10.2	4.2	CALCULATED FLOW	=18 m^3/h
11.4	3.7		
13.0	4.1		
15.5	3.9		
16.8	4.0		
18.0	3.6		
19.7	3.6 mix 20s		

TIME (mins)	CONCENTRATION (arbitrary units)
1.0	4.9
2.3	4.6
3.3	4.7
4.4	4.7
5.7	4.7
6.8	4.5
8.1	4.3
9.4	4.5
10.5	4.3
11.8	4.2
12.8	4.5
14.0	4.4
15.5	4.3
16.5	4.3
17.6	4.3
18.6	4.0
19.8	4.1

DOOR POSITION =POS 2

TEMP DIFF =10C

CALCULATED ACH =0.5

CALCULATED FLOW =15 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.5	4.4
1.4	4.1
2.3	3.5
3.4	3.3
4.4	3.4
5.5	3.2
6.6	3.2
7.6	3.0
8.7	2.9
9.8	2.8
11.0	2.6
12.0	2.7
13.0	2.6
14.1	2.5
15.3	2.5
16.5	2.3
17.5	2.3
18.7	2.2
19.8	2.0

DOOR POSITION =POS 3

TEMP DIFF =12.0C

CALCULATED ACH =2.0

CALCULATED FLOW =60 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.7	3.6
2.0	3.3
3.3	3.4
4.6	3.3
6.0	3.2
7.2	3.1
8.6	3.0
10.0	2.9
11.3	2.8
12.6	2.7
14.0	2.4
15.3	2.6
16.7	2.5
18.3	2.6
20.6	2.4

DOOR POSITION =POS 3

TEMP DIFF =3.0C

CALCULATED ACH =1.3

CALCULATED FLOW =39 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.7	3.6
2.0	3.3
3.3	3.4
4.6	3.3
6.0	3.2
7.2	3.1
8.6	3.0
10.0	2.9
11.3	2.8
12.6	2.7
14.0	2.4
15.3	2.6
16.7	2.5
18.3	2.6
20.6	2.4

DOOR POSITION =POS 3

TEMP DIFF =3.0C

CALCULATED ACH =1.3

CALCULATED FLOW =39 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.4	5.0
1.6	4.6
3.0	4.4
4.3	4.3
5.5	4.2
6.7	4.0
8.0	3.9
9.4	3.7
10.6	3.6
12.0	3.4
13.4	3.3
16.6	3.0
17.9	2.8
19.3	2.9

DOOR POSITION =POS 3

TEMP DIFF =7.0C

CALCULATED ACH =1.8

CALCULATED FLOW =54 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.7	3.2
2.0	2.7
3.4	2.6
4.8	2.4
6.0	2.2
7.5	2.1
9.0	2.0
10.3	1.9
11.6	1.8
13.0	1.8
14.3	1.6
15.8	1.6
17.0	1.5
18.4	1.4
19.8	1.4

DOOR POSITION =POS 3

TEMP DIFF =10.0C

CALCULATED ACH =2.5

CALCULATED FLOW =78 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.3	4.0
1.7	3.8
3.0	3.5
4.4	3.4
5.7	3.2
7.0	3.2
8.3	3.0
9.7	2.9
11.0	2.9
12.3	2.8
13.6	2.7
15.0	2.7
16.2	2.6
17.6	2.5
18.9	2.4

DOOR POSITION =POS 3

TEMP DIFF =3.0C

CALCULATED ACH =1.5

CALCULATED FLOW =45 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.4	4.5
1.6	3.4
3.0	3.3
4.4	3.2
5.7	2.6
7.1	2.8
8.5	2.7
9.8	2.6
11.2	2.3
12.6	2.3
14.0	2.3
15.4	2.1
16.6	1.9
18.0	2.0
19.4	1.7

DOOR POSITION =POS 3

TEMP DIFF =14.0C

CALCULATED ACH =2.5

CALCULATED FLOW =75 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.6	4.3
2.1	3.4
3.5	3.0
4.8	2.8
6.2	2.6
7.6	2.6
9.0	2.2
10.3	2.4
11.7	2.3
13.0	2.0
14.4	2.0
15.8	1.9
17.1	1.7
18.5	1.8

DOOR POSITION =POS 3

TEMP DIFF =9.0C

CALCULATED ACH =2.6

CALCULATED FLOW =78 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.8	5.2
1.8	4.9
2.7	4.5
3.8	4.1
4.6	4.2
5.5	3.5
6.4	3.7
7.3	3.4
8.2	3.0
9.1	3.3
10.0	3.2
10.8	2.9
11.8	3.0
12.6	2.8
13.6	2.8
14.5	2.7
15.4	2.7
16.3	2.6
17.2	2.5
18.2	2.4
19.0	2.4
20.0	2.3
20.8	2.3

DOOR POSITION =POS 3

TEMP DIFF =5.0C

CALCULATED ACH =2.3

CALCULATED FLOW =69 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.5	5.3
1.5	4.6
2.6	4.7
3.5	5.1
4.4	4.8
5.3	5.0
6.2	4.8
6.2	4.8
7.1	4.7
8.0	4.7
8.9	4.6
10.0	4.3
10.9	4.7
11.8	3.9
12.7	4.3
13.7	4.4
14.7	3.7
15.7	4.5
16.5	4.5
17.5	4.5
18.4	4.2
19.4	3.9
20.3	4.4

DOOR POSITION =POS 3

TEMP DIFF FOR 10 T/C=1.0C

CALCULATED ACH =0.6

CALCULATED FLOW =18 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
1.1	5.0
2.0	5.0
3.6	4.9
4.6	4.6
5.8	4.8
6.8	4.7
7.7	4.6
8.7	4.2
9.5	4.6
10.5	4.5
11.4	4.3
12.4	4.3
13.4	4.3
14.4	4.2
15.4	3.5
16.5	4.0
17.4	3.0
18.5	3.9
19.4	3.0
20.5	3.7

DOOR POSITION =POS 3

TEMP DIFF =3.0C

CALCULATED ACH =1.3

CALCULATED FLOW =39 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
1.2	4.4
2.0	4.0
3.0	3.0
4.0	2.7
5.0	2.7
6.4	2.6
7.3	2.5
8.5	2.4
9.5	2.2
10.4	2.1
11.4	2.1
12.6	1.9
13.6	1.9
14.6	1.8
15.5	1.7
16.5	1.7
17.4	1.5
18.4	1.5
19.4	1.5
20.5	1.4

DOOR POSITION =POS 3

TEMP DIFF =18.0C

CALCULATED ACH =3.0

CALCULATED FLOW =90 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.7	4.9
2.3	4.2
3.6	3.9
5.0	3.6
6.2	3.5
7.5	3.4
8.8	3.3
10.0	3.0
11.4	2.9
12.5	2.7
13.9	2.6
15.2	2.5
16.4	2.3
17.7	2.2
19.0	2.1
20.3	1.9

DOOR POSITION =POS 3

TEMP DIFF =10.0C

CALCULATED ACH =2.6

CALCULATED FLOW =78 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.7	4.9
2.3	4.2
3.6	3.9
5.0	3.6
6.2	3.5
7.5	3.4
8.8	3.3
10.0	3.0
11.4	2.9
12.5	2.7
13.9	2.6
15.2	2.5
16.4	2.3
17.7	2.2
19.0	2.1
20.3	1.9

DOOR POSITION =POS 3

TEMP DIFF =10.0C

CALCULATED ACH =2.6

CALCULATED FLOW =78 m^3/h

TIME (mins)	CONCENTRATION (arbitrary units)
0.8	3.7
1.8	3.4
2.8	3.1
3.9	2.7
4.9	2.7
5.9	2.7
7.1	2.6
8.3	2.4
9.5	2.3
10.4	2.2
11.5	2.1
12.4	2.1
13.8	2.0
14.8	1.9
15.8	1.9
16.8	1.8
19.5	1.8

DOOR POSITION =POS 3

TEMP DIFF =9.0C

CALCULATED ACH =2.3

CALCULATED FLOW =69 m^3/h

APPENDIX F DATA FOR SITE TEMPERATURE DRIVEN FLOWS

DOOR POSITIONS 2a AND 4a

Schedules of tests

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
6.3	0.2	8.0	7.3	7.4	0.1			
8.3	0.3	7.8	9.3	7.5	0.2			
10.3	0.3	7.7	11.1	7.3	0.3			
12.0	0.4	7.6	13.0	7.3	0.3			
14.0	0.4	7.6	15.2	7.4	0.2			
16.2	0.5	7.4	17.3	7.4	0.2			
18.2	0.6	7.4	19.3	7.4	0.3			
21.2	0.6	7.3	22.0	7.0	0.3			
23.0	0.6	7.2	24.0	7.1	0.3			
25.2	0.6	7.3	26.2	6.7	0.3			
27.2	0.7	7.2	28.2	6.8	0.3			
29.3	0.8	7.0	32.3	6.6	0.4			
33.3	0.9	7.1	34.2	6.6	0.3			

Bedroom door =pos 2a
Bedroom window =unsealed

Mean bedroom temp. =18 C
Mean stairwell temp. =23 C
Mean interzonal temperature difference.=5 C
Outside temperature. =8 C
Mean wind pressure predominance. =+1 Pa

FLOW BED TO STAIRS =8 m^3/h
FLOW STAIRS TO BED =29 m^3/h
BEDROOM ACH =0.6ach
STAIRWELL ACH =0.2ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
8.2	0.3	5.2	9.1	8.2	0.2			
10.2	0.4	4.8	11.2	7.9	0.4			
12.0	0.4	4.7	13.0	7.7	0.3			
14.0	0.4	4.6	15.0	7.5	0.3			
18.0	0.4	4.4	18.8	7.2	0.4			
19.8	0.5	4.2	20.7	7.2	0.4			
21.5	0.5	4.7	23.7	7.1	0.4			
24.7	0.5	4.2	26.0	7.2	0.4			
27.9	0.6	4.5	28.7	6.9	0.6			
30.6	0.6	3.9	31.6	6.2	0.7			
32.5	0.5	3.7	33.5	5.9	0.6			
34.5	0.6	3.7	35.9	6.0	0.6			
36.9	0.5	3.5	37.9	5.9	0.6			
38.9	0.6	3.7	40.0	5.9	0.7			

Bedroom door =pos 2a
Bedroom window =unsealed

Mean bedroom temp. =19 C
Mean stairwell temp. =22 C
Mean interzonal temperature difference.=3 C
Outside temperature. =11 C
Mean wind pressure predominance. =-3 Pa

FLOW BED TO STAIRS =21 m^3/h
FLOW STAIRS TO BED =12 m^3/h
BEDROOM ACH =0.9ach
STAIRWELL ACH =0.8ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
5.7	0.2	6.9	6.7	9.9	0.3			
7.7	0.2	6.4	8.7	9.6	0.3			
9.9	0.3	6.2	11.4	9.5	0.5			
12.4	0.3	5.9	13.5	9.2	0.5	15.5	7.1	0.05
16.5	0.3	5.7	17.6	8.8	0.6			
18.9	0.3	5.4	19.9	8.7	0.6			
20.9	0.3	5.0	23.3	8.7	0.7			
24.3	0.4	4.8	25.3	8.1	0.7			
27.4	0.5	4.5	28.4	7.8	0.7			
29.5	0.5	4.5	30.4	7.7	0.7			
31.4	0.5	4.4	32.4	7.5	0.8			
34.0	0.5	3.9	34.9	6.6	0.7			
36.0	0.4	3.7	37.8	6.5	0.6			

Bedroom door =pos 2a
Bedroom window =unsealed

Mean bedroom temp. =15 C
Mean stairwell temp. =21 C
Mean interzonal
temperature difference.=6 C
Outside temperature. =10 C
Mean wind pressure
predominance. =-25Pa Windy day.Winter gales

FLOW BED TO STAIRS =20 m^3/h
FLOW STAIRS TO BED =8 m^3/h
BEDROOM ACH =1.1ach
STAIRWELL ACH =0.7ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
10.0	0.6	4.5	11.0	9.0	0.05			
12.0	0.7	4.2	13.0	8.9	0.05			
14.0	0.9	4.2	15.1	8.8	0.1			
16.2	0.9	4.0	17.2	8.6	0.1			
18.3	1.0	4.0	19.4	8.6	0.1			
20.5	1.0	3.7	21.5	8.2	0.4			
22.7	1.2	3.9	23.7	8.3	0.2			
24.7	1.3	3.7	28.0	8.2	0.1			
27.0	1.4	3.7	28.0	8.2	0.1			
29.2	1.7	3.7	30.3	7.9	0.2			
32.4	2.1	3.9	33.5	8.2	0.1			
34.4	1.8	3.4	35.4	7.7	0.2			
36.5	2.0	3.2	37.6	7.7	0.2			

Bedroom door =pos 2a
Bedroom window =unsealed

Mean bedroom temp. =16 C
Mean stairwell temp. =22 C
Mean interzonal temperature difference.=6 C
Outside temperature. =10 C
Mean wind pressure predominance. =-3 Pa

FLOW BED TO STAIRS =7 m^3/h
FLOW STAIRS TO BED =29 m^3/h
BEDROOM ACH =0.9ach
STAIRWELL ACH =0.5ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
3.0	0.2	6.8	4.2	8.2	0.05			
7.6	0.5	6.3	8.7	8.1	0.1			
9.7	0.5	6.2	10.8	8.0	0.2			
12.0	0.6	6.0	13.0	7.9	0.3			
14.1	0.7	5.8	15.2	7.8	0.3			
16.3	1.0	5.7	17.3	7.7	0.2			
18.5	1.1	5.6	19.7	7.6	0.2			
20.7	1.2	5.5	21.8	7.4	0.2			
22.7	1.3	5.2	23.8	7.1	0.2			
25.0	1.4	5.0	26.0	6.9	0.2			
27.0	1.5	5.0	26.0	6.9	0.2			
29.3	1.6	4.9	30.4	6.2	0.2			
31.5	1.7	4.8	32.6	5.8	0.2			
33.7	1.7	4.6	34.7	5.3	0.2			
35.8	1.7	4.5	36.8	5.0	0.2			
38.0	1.8	4.4	39.1	4.5	0.2			

Bedroom door =pos 2a
Bedroom window =unsealed

Mean bedroom temp. =17 C
Mean stairwell temp. =29 C
Mean interzonal temperature difference. =12 C
Outside temperature. =9 C
Mean wind pressure predominance. =-1 Pa

FLOW BED TO STAIRS =7 m^3/h
FLOW STAIRS TO BED =28 m^3/h
BEDROOM ACH =0.8ach
STAIRWELL ACH =0.6ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
7.0	0.1	5.2	8.2	6.6	0.1			
9.4	0.2	5.1	10.5	6.5	0.2			
11.7	0.2	5.0	12.7	6.5	0.3			
13.9	0.4	4.8	15.0	6.4	0.5			
16.3	0.4	4.7	17.3	6.3	0.6			
18.3	0.4	4.4	19.4	6.1	0.6			
20.4	0.5	4.4	21.7	6.1	0.6			
24.0	0.7	4.3	25.2	6.0	0.5			
27.3	0.8	4.1	28.4	5.7	0.5			
29.5	0.9	3.9	30.6	5.4	0.5			
31.7	1.0	3.8	33.3	5.3	0.4			
34.4	1.1	3.6	35.4	4.7	0.4			
36.7	1.1	3.6	37.7	4.5	0.4			
38.7	1.1	3.4	39.9	4.2	0.4			

Bedroom door =pos 2a
Bedroom window =unsealed

Mean bedroom temp. =16 C
Mean stairwell temp. =28 C
Mean interzonal temperature difference.=12 C
Outside temperature. =9 C
Mean wind pressure predominance. =+2 Pa

FLOW BED TO STAIRS =16 m^3/h
FLOW STAIRS TO BED =19 m^3/h
BEDROOM ACH =0.9ach
STAIRWELL ACH =0.6ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
0.9	0.1	5.7	4.2	7.0	0.7	5.5	8.4	0
6.8	0.4	4.3	7.8	5.5	1.4			
8.8	0.5	3.8	9.9	4.9	1.5			
11.2	0.7	3.7	12.3	4.6	1.6			
13.4	0.7	3.4	14.3	3.3	1.6			
15.5	0.7	2.8	16.6	3.2	1.5			
17.7	0.7	2.3	18.7	3.3	1.4			
19.9	0.8	2.1	21.3	2.7	1.4			
23.5	0.7	1.6	24.6	3.1	1.3	22.3	6.6	0
25.8	0.7	1.4	27.2	1.5	1.2			
28.3	0.7	1.3	29.5	1.5	1.1			

Bedroom door =pos 2a
Bedroom window =unsealed

Mean bedroom temp. =19 C
Mean stairwell temp. =31 C
Mean interzonal temperature difference.=12 C
Outside temperature. =10 C
Mean wind pressure predominance. =+2 Pa

FLOW BED TO STAIRS =130m^3/h
FLOW STAIRS TO BED =30 m^3/h
BEDROOM ACH =2.8ach
STAIRWELL ACH =3.8ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
7.0	0.7	5.2	8.3	6.9	0.1	5.3	7.7	0
9.5	0.9	5.2	10.5	6.8	0.1			
14.0	1.2	4.9	15.4	6.7	0.2			
16.6	1.3	4.7	18.4	6.4	0.2			
19.7	1.5	4.6	21.0	6.4	0.2			
22.0	1.6	4.3	23.0	6.1	0.2			
24.2	1.6	4.0	25.3	5.8	0.1			
26.5	1.7	4.0	28.9	5.6	0.2			
30.0	1.8	3.8	31.2	5.1	0.1			
32.3	1.8	3.6	33.3	4.7	0.1			
34.5	1.8	3.4	35.5	4.4	0.1			
36.5	1.9	3.4	37.4	4.0	0.1			
38.5	1.9	3.139.6		3.7	0.1	40.5	2.8	0

Bedroom door =pos 2a
Bedroom window =unsealed

Mean bedroom temp. =30 C
Mean stairwell temp. =21 C
Mean interzonal temperature difference. =9 C
Outside temperature. =3 C
Mean wind pressure predominance. =+3 Pa

FLOW BED TO STAIRS =5 m^3/h
FLOW STAIRS TO BED =41 m^3/h
BEDROOM ACH =0.9ach
STAIRWELL ACH =0.8ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
5.3	0.2	5.3	6.5	5.9	0.1			
7.6	0.5	5.2	8.7	5.9	0.2			
10.0	0.6	5.0	11.0	5.9	0.2			
12.3	0.8	4.9	13.5	5.9	0.2			
14.5	0.9	4.8	15.6	5.8	0.3			
16.7	1.0	4.6	18.4	5.7	0.3			
19.6	1.1	4.5	20.7	5.5	0.3			
22.0	1.2	4.3	23.5	5.3	0.4			
24.7	1.5	4.2	25.8	5.2	0.4			
27.1	1.6	4.0	28.3	4.8	0.3			
29.5	1.6	3.9	30.6	4.4	0.3			
32.0	1.6	3.6	33.3	4.2	0.3			
34.4	1.6	3.5	35.5	4.0	0.4			

Bedroom door =pos 2a
Bedroom window =unsealed

Mean bedroom temp. =35 C
Mean stairwell temp. =21 C
Mean interzonal temperature difference.=14 C
Outside temperature. =5 C
Mean wind pressure predominance. =-.4Pa

FLOW BED TO STAIRS =11 m^3/h
FLOW STAIRS TO BED =36 m^3/h
BEDROOM ACH =0.8ach
STAIRWELL ACH =0.5ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
6.5	0.3	3.3	7.9	6.7	0.2			
9.1	0.3	3.3	10.0	6.5	0.4			
11.0	0.4	3.3	12.0	6.3	0.5			
13.0	0.3	3.0	14.2	6.0	0.8			
15.2	0.3	3.0	16.2	5.9	0.9			
18.4	0.3	2.8	19.4	5.5	1.0			
20.5	0.3	2.7	21.6	5.6	0.9			
22.9	0.3	2.7	24.0	5.3	1.0			
25.2	0.3	2.6	26.4	4.9	1.0			
27.4	0.3	2.5	28.8	4.6	0.9			
30.3	0.3	2.4	31.3	4.1	0.9			
33.5	0.3	2.2	34.8	3.4	0.9			
36.0	0.2	2.1	37.1	3.3	1.0			
40.5	0.2	1.9	41.6	2.6	1.0			

Bedroom door =pos 2a
Bedroom window =unsealed

Mean bedroom temp. =23 C
Mean stairwell temp. =21 C
Mean interzonal temperature difference. =2 C
Outside temperature. =10 C
Mean wind pressure predominance. =-8 Pa

FLOW BED TO STAIRS =57 m^3/h
FLOW STAIRS TO BED =8 m^3/h
BEDROOM ACH =1 ach
STAIRWELL ACH =1.3ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
7.4	0.4	5.8	8.6	7.6	0			
9.6	0.5	5.7	10.7	7.3	0			
11.8	0.6	5.7	12.8	7.3	0			
13.8	0.7	5.6	14.0	7.1	0			
15.9	0.8	5.5	17.0	7.0	0			
18.0	0.9	5.5	19.3	7.1	0			
20.3	0.9	5.3	21.3	6.7	0			
22.3	0.9	5.3	23.5	6.7	0			
24.5	1.0	5.4	27.0	6.6	0			
28.4	1.2	5.3	31.5	5.9	0			
30.5	1.2	5.3	31.4	5.9	0			
32.5	1.3	5.2	33.5	5.9	0			
34.5	1.2	5.1	35.5	5.8	0			

Bedroom door =pos 2a
Bedroom window =sealed

Mean bedroom temp. =18 C
Mean stairwell temp. =22 C
Mean interzonal temperature difference.=4 C
Outside temperature. =10 C
Mean wind pressure predominance. =+1 Pa

FLOW BED TO STAIRS =0 m^3/h
FLOW STAIRS TO BED =23 m^3/h
BEDROOM ACH =0.3ach
STAIRWELL ACH =0.5ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
9.4	0.3	7.7	10.5	7.9	0.5			
11.5	0.3	7.5	12.4	7.9	0.3			
13.5	0.4	7.3	14.4	7.7	0.3			
15.5	0.4	7.3	16.6	7.7	0.4			
17.5	0.4	7.3	18.5	7.6	0.4			
19.6	0.4	7.2	20.5	7.2	0.5			
21.5	0.4	7.1	22.4	7.1	0.4			
24.3	0.5	7.2	25.3	7.1	0.4			
26.3	0.5	7.0	27.3	7.1	0.4			
28.3	0.5	6.9	29.3	7.0	0.5			
30.3	0.5	6.9	31.3	6.8	0.4			
32.3	0.6	7.0	33.3	6.6	0.5			
34.3	0.6	7.0	35.4	6.6	0.5			
36.4	0.7	7.1	37.4	6.5	0.5			

Bedroom door =pos 2a
Bedroom window =sealed

Mean bedroom temp. =19 C
Mean stairwell temp. =21 C
Mean interzonal temperature difference.=2 C
Outside temperature. =10 C
Mean wind pressure predominance. =-5 Pa

FLOW BED TO STAIRS =12 m^3/h
FLOW STAIRS TO BED =11 m^3/h
BEDROOM ACH =0.3ach
STAIRWELL ACH =0.6ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
7.7	0.3	7.3	8.7	8.5	0			
9.6	0.3	7.1	10.5	8.5	0			
11.5	0.5	7.1	12.7	8.4	0			
13.6	0.6	6.8	14.7	8.2	0			
15.6	0.6	6.8	16.7	8.2	0			
17.8	0.8	6.8	18.8	8.2	0			
19.7	0.7	6.7	20.7	8.0	0			
21.6	0.8	6.5	22.6	8.0	0			
23.6	1.0	6.6	27.9	7.6	0			
25.7	1.0	6.6	30.2	7.5	0			
29.2	1.1	6.3	32.3	7.1	0			
31.3	1.2	6.3	32.3	7.1	0			
33.2	1.3	6.3	34.1	7.0	0			
35.2	1.3	6.2	36.2	6.8	0			

Bedroom door =pos 2a
Bedroom window =sealed

Mean bedroom temp. =19 C
Mean stairwell temp. =22 C
Mean interzonal temperature difference.=3 C
Outside temperature. =11 C
Mean wind pressure predominance. =+1 Pa

FLOW BED TO STAIRS =0 m^3/h
FLOW STAIRS TO BED =19 m^3/h
BEDROOM ACH =0.4ach
STAIRWELL ACH =0.4ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
8.5	0.3	2.7	9.9	5.3	0.4			
11.3	0.3	2.7	12.5	4.9	0.4	13.7	4.3	0
15.0	0.4	2.6	16.3	4.8	0.5			
17.5	0.4	2.6	18.8	4.4	0.4			
20.0	0.4	2.5	21.3	4.0	0.5			
22.5	0.4	2.5	23.7	4.0	0.7			
25.0	0.5	2.5	26.3	3.6	0.5			
27.5	0.5	2.4	28.9	3.6	0.6			
30.2	0.5	2.3	31.4	3.1	0.7	34	1.8	0
35.5	0.5	2.3	36.8	2.7	0.6			
38.2	0.5	2.3	39.6	2.5	0.6			
40.6	0.5	2.3	41.9	2.4	0.5			
43.4	0.5	2.3	44.7	2.3	0.5			

Bedroom door =pos 2a
Bedroom window =sealed

Mean bedroom temp. =28 C
Mean stairwell temp. =24 C
Mean interzonal temperature difference. =4 C
Outside temperature. =10 C
Mean wind pressure predominance. =+25Pa N.B. very windy day.Winter gales

FLOW BED TO STAIRS =44 m^3/h
FLOW STAIRS TO BED =14 m^3/h
BEDROOM ACH =0.4ach
STAIRWELL ACH =1.5ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	BCF		R12	BCF		R12	BCF
1.2	5.3	0	2.6	0.1	2.2	3.8	0.1	2.5
5.3	5.3	0.1	8.4	0.1	2.2	9.8	0.1	2.3
13.0	5.2	0.3	14.7	0.1	1.9	18.0	0.1	1.5
20.3	5.4	0.5	21.8	0.1	1.8	23.2	0.1	1.3
24.6	5.3	0.6	26.0	0.1	1.5	27.5	0	1.1
29.2	5.2	0.6	31.8	0	1.2	33.4	0	0.7
35.5	4.9	0.6	37.0	0	1.0	38.6	0	0.6
39.8	4.7	0.7	41.3	0	0.9	43.7	0	0.5
44.6	4.6	0.7	46.4	0	0.7	48.0	0	0.4
50.3	4.6	0.7	52.0	0	0.6	53.6	0	0.3
57.0	4.4	0.7	59.3	0	0.4	62.9	0	0.2

Bedroom door =pos 2a
Bedroom window =sealed

Mean bedroom temp. =26 C
Mean stairwell temp. =21 C
Mean interzonal temperature difference.=5 C
Outside temperature. =7 C
Mean wind pressure predominance. =+.4Pa

FLOW BED TO STAIRS =1 m^3/h
FLOW STAIRS TO BED =28 m^3/h
BEDROOM ACH =0.1ach
STAIRWELL ACH =1.3ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	BCF		R12	BCF		R12	BCF
2.1	5.8	0	4.2	0.1	2.5	6.0	0	3.5
7.5	5.6	0.1	9.3	0.6	2.5	10.5	0	3.1
12.3	5.5	0.2	13.7	0.6	2.3	15.0	0	2.5
16.5	5.4	0.3	17.7	0.8	2.1	19.0	0	2.2
20.6	5.3	0.3	22.0	0.9	1.9	23.3	0	1.7
24.4	5.2	0.4	25.7	0.8	1.7	28.2	0	1.4
29.6	5.1	0.4	31.2	1.0	1.5	32.4	0	1.2
34.2	5.0	0.5	35.6	0.8	1.4	37.0	0	1.1
39.4	4.8	0.5	40.6	0.9	1.1	42.5	0	0.9
44.2	4.7	0.6	45.5	0.8	0.9	47.3	0	0.6
49.3	4.4	0.6	55.3	0.8	0.7	57.6	0	0.4

Bedroom door =pos 2a
Bedroom window =sealed

Mean bedroom temp. =35 C
Mean stairwell temp. =20 C
Mean interzonal temperature difference.=15 C
Outside temperature. =9 C
Mean wind pressure predominance. =+.2Pa

FLOW BED TO STAIRS =24 m^3/h
FLOW STAIRS TO BED =22 m^3/h
BEDROOM ACH =0.3ach
STAIRWELL ACH =1.2ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	BCF		R12	BCF		R12	BCF
1.4	6.5	0.1	2.9	0				
4.5	6.3	0.2	5.8	0	3.7			
7.8	6.2	0.4	9.0	0	3.8	11.3	0	3.8
13.0	6.2	0.5	14.3	0	3.0	15.8	0	2.8
17.4	6.0	0.6	18.7	0	2.5	21.0	0	1.8
22.8	6.0	0.7	24.5	0	1.8	25.6	0	1.5
28.5	5.9	0.7	30.0	0	1.3	32.4	0	0.9
34.1	5.7	0.7	36.3	0	1.0	38.2	0	0.8
39.5	5.4	0.8	41.6	0	0.8	43.5	0	0.5
45.9	5.3	0.8	47.8	0	0.7	49.5	0	0.4
51.0	5.1	0.8	52.5	0	0.6	54.2	0	0.4

Bedroom door =pos 2a
Bedroom window =sealed

Mean bedroom temp. =26 C
Mean stairwell temp. =21 C
Mean interzonal temperature difference.=5 C
Outside temperature. =7 C
Mean wind pressure predominance. =-.5Pa

FLOW BED TO STAIRS =0 m^3/h
FLOW STAIRS TO BED =25 m^3/h
BEDROOM ACH =0.2ach
STAIRWELL ACH =1.9ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	BCF		R12	BCF		R12	BCF
2.7	6.4	0.3	4.2	0.1	3.1	5.8	0.1	3.7
7.4	6.3	0.3	8.7	0.2	3.2	9.9	0.1	3.2
11.5	6.2	0.4	13.2	0.2	2.7	15.0	0.1	2.5
16.4	6.1	0.5	17.7	0.3	2.2	19.5	0	1.8
21.4	5.9	0.6	23.0	0.3	1.9	24.2	0	1.4
26.0	5.8	0.7	27.4	0.3	1.6	28.6	0	1.1
29.9	5.7	0.7	31.2	0.3	1.5	32.6	0	1.1
37.0	5.5	0.7	38.3	0.4	1.1	39.6	0	0.8
41.0	5.5	0.8	42.4	0.4	1.0	43.5	0	0.7
44.9	5.4	0.7	46.2	0.3	0.9	47.6	0	0.6
49.4	5.3	0.8	51.0	0.3	0.7	52.4	0	0.4
58.3	5.0	0.7	59.7	0.3	0.5	61.7	0	0.4

Bedroom door =pos 2a
Bedroom window =sealed

Mean bedroom temp. =27 C
Mean stairwell temp. =21 C
Mean interzonal temperature difference. =6 C
Outside temperature. =7 C
Mean wind pressure predominance. =+1 Pa

FLOW BED TO STAIRS =9 m^3/h
FLOW STAIRS TO BED =29 m^3/h
BEDROOM ACH =0.3ach
STAIRWELL ACH =1.8ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	BCF		R12	BCF		R12	BCF
5.9	4.7	0.2	7.2	2.8	1.3	9.9	0.3	3.9
11.5	4.3	0.3	12.8	3.2	1.3	15.5	0.9	3.1
16.8	3.9	0.3	18.2	3.3	1.2			
20.7	3.7	0.3	22.0	3.2	1.0	27.4	0.7	1.8
28.7	3.0	0.2	30.0	3.0	0.7	31.3	1.0	1.6
32.6	2.9	0.3	33.9	2.8	0.7	35.3	1.2	1.5
36.5	2.7	0.2	37.8	2.7	0.7	39.2	1.0	1.3
40.4	2.5	0.2	41.7	2.4	0.6	43.1	0.9	1.1
44.4	2.2	0.1	46.5	2.2	0.5	47.8	0.9	0.9
49.2	2.0	0.1	50.5	2.0	0.4	51.7	1.0	0.8
53.0	1.8	0.1	54.4	1.9	0.4	55.7	0.9	0.6
57.0	1.8	0.1	58.4	1.7	0.4	59.7	0.9	0.6

Bedroom door =pos 4a
Bedroom window =unsealed

Mean bedroom temp. =20 C
Mean stairwell temp. =20 C
Mean interzonal temperature difference.=0 C
Outside temperature. =10 C
Mean wind pressure predominance. =-4 Pa

FLOW BED TO STAIRS =128m^3/h
FLOW STAIRS TO BED =26 m^3/h
BEDROOM ACH =1.2ach
STAIRWELL ACH =1.7ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	BCF		R12	BCF		R12	BCF
1.5	6.5	1.2	3.4	0.7	5.6	4.9	1.3	5.8
6.7	5.9	1.8	8.5	1.3	5.6	10.4	1.3	5.3
12.2	5.7	2.6	13.6	1.2	5.1	15.4	1.4	4.7
17.0	5.3	2.9	18.6	1.3	4.5	20.4	1.5	5.0
22.3	5.1	3.2	23.6	1.7	3.8	27.2	1.5	3.5
28.8	4.6	3.2	30.7	1.4	3.1	32.5	1.4	2.8
33.9	4.4	3.3	35.6	1.6	2.8	37.7	1.4	2.6
39.6	3.9	3.1	41.2	1.6	2.5	42.9	1.3	2.2
44.7	3.7	3.1	46.5	1.7	2.3	48.5	1.3	2.0

Bedroom door =pos 4a
Bedroom window =unsealed

Mean bedroom temp. =14 C
Mean stairwell temp. =18 C
Mean interzonal temperature difference.=4 C
Outside temperature. =7 C
Mean wind pressure predominance. =+.4Pa

FLOW BED TO STAIRS =53 m^3/h
FLOW STAIRS TO BED =89 m^3/h
BEDROOM ACH =0.7ach
STAIRWELL ACH =1.3ach

TIME mins	BEDROOM conc arb units R12	R114	TIME mins	STAIRWELL TOP conc arb units R12	R114	TIME mins	STAIRWELL BOTTOM conc arb units R12	R114
4.9	0.4	7.5	5.9	8.5	1.4			
6.8	0.5	7.0	7.8	8.2	1.4			
8.7	0.4	6.2	10.3	8.4	1.2			
11.4	0.7	5.9	12.3	7.5	1.2			
13.4	0.7	5.6	14.3	7.3	1.2			
15.3	0.8	4.8	18.3	6.3	1.3			
17.3	0.8	4.8	18.3	6.3	1.3			
21.0	0.7	4.0	22.2	5.4	1.2	20.0	6.5	0.8
23.5	0.8	3.6	24.2	5.5	1.1			
25.4	0.7	3.0	26.3	4.6	1.2			
27.4	0.8	2.7	28.3	5.0	1.0			
29.3	0.8	2.3	32.4	3.3	1.0			

Bedroom door =pos 4a
Bedroom window =unsealed

Mean bedroom temp. =16 C
Mean stairwell temp. =21 C
Mean interzonal temperature difference.=5 C
Outside temperature. =9 C
Mean wind pressure predominance. =-25Pa Windy day.Winter gales

FLOW BED TO STAIRS =56 m^3/h
FLOW STAIRS TO BED =26 m^3/h
BEDROOM ACH =2.4ach
STAIRWELL ACH =1.6ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
8.2	0.7	6.6	9.1	8.6	1.4			
10.0	0.4	6.4	11.0	8.1	1.5			
12.0	0.7	6.0	13.0	7.7	1.8			
17.5	1.0	5.0	18.5	7.1	1.6	15.7	7.6	1.3
19.5	1.1	4.8	20.5	7.0	1.6			
21.5	1.2	4.6	22.4	6.9	1.5			
23.5	1.4	4.4	24.5	6.1	1.8			
25.5	1.2	4.1	26.4	6.6	1.6			
27.7	1.2	3.8	30.7	5.8	1.6			
29.5	1.2	3.3	30.7	5.8	1.6			
33.5	1.5	3.1	34.6	5.0	1.7	31.7	6.0	1.5

Bedroom door =pos 4a
Bedroom window =unsealed

Mean bedroom temp. =21 C
Mean stairwell temp. =17 C
Mean interzonal temperature difference. =4 C
Outside temperature. =12 C
Mean wind pressure predominance. =-3 Pa

FLOW BED TO STAIRS =60 m^3/h
FLOW STAIRS TO BED =31 m^3/h
BEDROOM ACH =1.9ach
STAIRWELL ACH =1.2ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
1.4	0	5.9	3.7	8.2	0.4			
7.5	0.2	4.7	6.6	7.5	0.7			
9.5	0.4	4.3	8.5	6.6	1.3			
11.7	0.8	4.0	10.6	5.7	1.5			
14.9	0.8	3.5	12.2	5.5	1.6			
16.7	0.8	3.4	15.7	4.3	1.7			
19.0	1.0	2.9	17.8	3.4	1.8			
22.5	1.0	2.5	20.0	3.2	1.7			
24.6	1.0	2.1	23.6	2.5	1.6			
26.8	1.0	2.0	25.7	2.5	1.6			
28.0	1.0	1.8	27.9	2.0	1.4			
31.0	1.0	1.8	30.0	2.0	1.4			
33.3	0.9	1.6	32.1	1.9	1.4			

Bedroom door =pos 4a
Bedroom window =unsealed

Mean bedroom temp. =19 C
Mean stairwell temp. =31 C
Mean interzonal temperature difference. =12 C
Outside temperature. =10 C
Mean wind pressure predominance. =+2 Pa

FLOW BED TO STAIRS =111m^3/h
FLOW STAIRS TO BED =31 m^3/h
BEDROOM ACH =2.4ach
STAIRWELL ACH =3.2ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
3.5	0.5	4.0	4.7	4.9	1.5			
6.0	0.5	3.9	7.3	4.0	1.8			
8.5	0.5	3.1	9.7	3.8	2.0			
10.9	0.5	2.9	14.6	4.3	1.8			
15.8	0.5	2.7	17.0	4.3	1.7			
18.2	0.6	2.5	19.5	4.1	1.8			
20.7	0.6	2.3	22.0	3.8	1.7			
24.5	0.6	2.1	25.8	3.5	1.6			
27.0	0.6	2.0	28.3	3.3	1.6			
29.7	0.6	1.9	31.0	3.4	1.3			

Bedroom door =pos 4a
Bedroom window =unsealed

Mean bedroom temp. =26 C
Mean stairwell temp. =24 C
Mean interzonal temperature difference.=2 C
Outside temperature. =10 C
Mean wind pressure predominance. =-5 Pa

FLOW BED TO STAIRS =127m^3/h
FLOW STAIRS TO BED =35 m^3/h
BEDROOM ACH =1.9ach
STAIRWELL ACH =0.4ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	BCF		R12	BCF		R12	BCF
8.0	1.4	2.2	9.1	5.1	0.7	4.8	5.7	0
10.2	1.7	2.1	11.4	4.8	0.8			
12.5	2.2	1.9	13.7	4.9	0.7			
15.1	2.4	1.9	16.4	4.4	0.7			
17.6	2.6	1.7	18.7	4.1	0.7	19.8	4.0	0
20.9	2.9	1.6	22.0	3.6	0.7			
23.3	3.0	1.6	24.4	3.5	0.7			
25.6	3.0	1.2	31.8	2.4	0.5			
33.0	3.0	1.2	34.3	2.1	0.5			
35.5	2.9	1.1	36.7	1.9	0.5			
38.0	2.8	1.1	39.0	1.8	0.5	40.2	0.9	0
41.6	2.8	1.0	42.8	1.6	0.3			

Bedroom door =pos 4a
Bedroom window =unsealed

Mean bedroom temp. =30 C
Mean stairwell temp. =22 C
Mean interzonal temperature difference.=8 C
Outside temperature. =5 C
Mean wind pressure predominance. =+1 Pa

FLOW BED TO STAIRS =72 m^3/h
FLOW STAIRS TO BED =107m^3/h
BEDROOM ACH =1.6ach
STAIRWELL ACH =1.9ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	BCF		R12	BCF		R12	BCF
12.4	2.8	1.6	11.2	0.6	5.7			
14.9	2.6	1.9	13.6	0.6	5.6			
17.3	2.4	2.2	16.1	0.6	5.4			
19.6	2.2	2.5	18.3	0.6	5.2			
21.9	2.0	2.8	20.6	0.6	4.9			
24.3	1.9	3.0	23.0	0.6	4.6			
26.6	1.8	3.1	25.4	0.6	4.2			
29.0	1.7	3.0	27.8	0.5	4.0			
31.5	1.6	3.2	30.3	0.5	3.6			
34.0	1.5	3.2	35.3	0.4	2.7			
39.0	1.4	3.1	37.8	0.4	2.4			

Bedroom door =pos 4a
Bedroom window =unsealed

Mean bedroom temp. =29 C
Mean stairwell temp. =22 C
Mean interzonal temperature difference.=7 C
Outside temperature. =5 C
Mean wind pressure predominance. =+.4Pa

FLOW BED TO STAIRS =42 m^3/h
FLOW STAIRS TO BED =109m^3/h
BEDROOM ACH =2.3ach
STAIRWELL ACH =1.5ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	BCF		R12	BCF		R12	BCF
9.5	1.6	3.0	10.7	5.1	0.9			
12.0	1.8	2.8	13.3	5.0	1.0			
14.5	2.2	2.6	15.8	4.8	1.0			
17	2.4	2.4	18.3	4.7	1.0			
19.5	2.5	2.2	20.8	4.0	0.9			
23.4	2.8	2.1	24.6	3.4	0.8			
25.8	2.8	1.9	27.3	3.2	0.8			
28.3	2.9	1.8	29.5	3.0	0.8			
30.8	2.9	1.7	32.1	2.5	0.8			
33.2	2.8	1.5	34.4	2.4	0.8			
35.5	2.8	1.5	37	2.2	0.7			
38.2	2.8	1.4	39.3	1.9	0.6			
40.6	2.7	1.4	41.7	1.9	0.6			
43.0	2.6	1.3	44.0	1.8	0.6			

Bedroom door =pos 4a
Bedroom window =unsealed

Mean bedroom temp. =33 C
Mean stairwell temp. =23 C
Mean interzonal temperature difference.=10 C
Outside temperature. =5 C
Mean wind pressure predominance. =+.4Pa

FLOW BED TO STAIRS =69 m^3/h
FLOW STAIRS TO BED =98 m^3/h
BEDROOM ACH =1.8ach
STAIRWELL ACH =2.1ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	BCF		R12	BCF		R12	BCF
3.6	4.9	0.5	5.3	0.6	3.0	2.3	0.2	3.3
9.4	4.7	0.8	10.6	0.7	2.5	13.3	1.0	2.5
14.6	4.6	1.0	15.6	0.8	2.3	18.0	1.1	2.2
20.8	4.3	1.2	22.1	1.1	2.0	24.5	1.2	2.0
25.6	4.1	1.3	27.0	1.2	1.8	29.3	1.3	1.8
30.7	3.9	1.3	32.0	1.1	1.6	41.6	1.4	1.5
43.0	3.4	1.3	44.2	1.2	1.4	46.8	1.2	1.3
48.0	3.3	1.3	49.3	1.3	1.4	51.9	1.2	1.3
57.0	3.0	1.3	58.3	1.1	1.1	60.7	1.2	1.2
62.0	2.8	1.3	63.2	1.1	1.1	65.5	1.1	1.2

Bedroom door =pos 4a
Bedroom window =unsealed

Mean bedroom temp. =15 C
Mean stairwell temp. =18 C
Mean interzonal temperature difference.=3 C
Outside temperature. =7 C
Mean wind pressure predominance. =0 Pa No wind at all

FLOW BED TO STAIRS =39 m^3/h
FLOW STAIRS TO BED =57 m^3/h
BEDROOM ACH =0.5ach
STAIRWELL ACH =1.2ach

TIME mins	BEDROOM conc arb units R12	R114	TIME mins	STAIRWELL TOP conc arb units R12	R114	TIME mins	STAIRWELL BOTTOM conc arb units R12	R114
6.0	0.3	7.6	7.0	7.7	1.1			
8.0	0.6	7.4	9.0	7.4	1.1			
10.1	0.9	7.2	11.0	7.3	1.2			
12.0	1.0	7.0	13.0	7.0	1.4			
14.1	1.3	7.0	15.3	6.8	1.4			
16.3	1.2	6.8	17.2	6.6	1.3			
18.2	1.3	6.6	20.8	6.9	1.4			
21.8	1.5	6.7	22.8	6.3	1.3			
23.9	1.6	6.5	24.8	5.6	1.3			
26.0	1.9	6.5	27.0	5.4	1.4			
28.0	1.8	6.2	29.8	5.0	1.4			
30.7	1.9	6.1	31.7	4.8	1.4			
32.6	2.0	6.0	34.8	5.3	1.6			
36.0	2.5	5.9	37.0	4.5	1.4			

Bedroom door =pos 4a
Bedroom window =sealed

Mean bedroom temp. =20 C
Mean stairwell temp. =22 C
Mean interzonal temperature difference.=2 C
Outside temperature. =9 C
Mean wind pressure predominance. =+1 Pa

FLOW BED TO STAIRS =43 m^3/h
FLOW STAIRS TO BED =38 m^3/h
BEDROOM ACH =0.6ach
STAIRWELL ACH =1 ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
7.8	0.6	7.3	8.6	7.5	0.8			
9.4	0.8	6.9	10.5	7.4	0.8			
11.5	1.0	6.8	12.4	7.3	0.8			
13.5	1.1	6.7	14.4	7.1	0.7			
14.7	1.1	6.1	16.0	7.3	1.0			
17.0	2.1	6.4	18.0	7.0	1.1			
19.0	2.1	6.4	20.0	7.0	1.0			
25.3	3.1	6.0	26.4	6.5	1.3			
27.4	3.1	5.9	28.6	6.5	1.3			
29.7	3.4	5.7	30.9	6.3	1.3			
32.0	3.6	5.5	32.9	5.9	1.3			
34.0	3.4	5.5	37.0	5.8	1.0			

Bedroom door =pos 4a
Bedroom window =sealed

Mean bedroom temp. =18 C
Mean stairwell temp. =21 C
Mean interzonal temperature difference. =3 C
Outside temperature. =9 C
Mean wind pressure predominance. =-2 Pa

FLOW BED TO STAIRS =32 m^3/h
FLOW STAIRS TO BED =64 m^3/h
BEDROOM ACH =0.9ach
STAIRWELL ACH =0.5ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
6.0	0.3	7.3	7.0	7.7	0.1			
8.0	0.7	6.8	9.0	7.5	0.5			
10.0	0.9	6.8	11.0	6.9	0.8			
11.8	1.1	6.7	12.7	6.8	0.9			
16.4	1.6	6.3	17.3	6.0	1.1			
18.3	1.8	6.3	19.3	6.2	1.2			
20.2	2.0	6.2	21.2	6.0	1.2			
22.2	2.1	6.3	23.3	6.1	1.1			
25.1	2.5	6.0	26.0	5.1	1.4			
28.2	3.0	6.1	29.5	5.0	1.5			
30.4	3.1	5.8	31.5	4.7	1.5			
32.4	3.2	5.7	33.6	4.6	1.4			
34.5	3.4	5.7	35.6	4.2	1.4			
36.5	3.4	5.5	38	4.4	1.4			

Bedroom door =pos 4a
Bedroom window =sealed

Mean bedroom temp. =18 C
Mean stairwell temp. =22 C
Mean interzonal temperature difference.=4 C
Outside temperature. =9 C
Mean wind pressure predominance. =-4 Pa

FLOW BED TO STAIRS =39 m^3/h
FLOW STAIRS TO BED =56 m^3/h
BEDROOM ACH =0.6ach
STAIRWELL ACH =1.3ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
6.0	0	6.7	6.8	6.6	0.8			
8.0	0.4	6.4	9.0	6.5	0.7			
10.0	0.5	6.1	11.0	6.5	0.9			
12.0	0.8	5.8	13.3	6.6	1.0			
14.3	1.0	6.2	15.5	6.6	1.0			
16.4	1.1	5.9	17.7	6.3	1.3			
18.5	1.4	5.6	19.4	6.1	1.1			
20.5	1.5	5.4	23.4	5.8	1.5	24.4	5.3	0.3
22.4	1.9	5.4	21.4	5.8	1.3			
25.5	2.5	5.3	27.0	5.8	1.5			
29.0	2.6	5.0	30.1	5.2	1.6			
31.2	2.7	4.8	32.5	5.0	1.6			
34.5	3.0	4.7	35.5	4.5	1.5			
36.4	2.7	4.4	37.4	4.3	1.5			
38.6	3.2	4.4	39.7	4.2	1.6			

Bedroom door =pos 4a
Bedroom window =sealed

Mean bedroom temp. =18 C
Mean stairwell temp. =22 C
Mean interzonal temperature difference. =4 C
Outside temperature. =11 C
Mean wind pressure predominance. =-2 Pa

FLOW BED TO STAIRS =40 m^3/h
FLOW STAIRS TO BED =48 m^3/h
BEDROOM ACH =0.7ach
STAIRWELL ACH =0.5ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
7.7	0.5	2.2	9.0	4.2	0.7			
10.3	0.7	2.3	11.5	4.2	0.8			
12.7	0.9	2.1	14	4.3	0.8			
15.3	1.1	2.0	16.5	4.1	0.9			
17.7	1.2	1.9	19.8	4.0	0.8			
21.0	1.5	1.8	22.4	3.7	0.9			
23.9	1.6	1.8	25.3	3.5	0.8			
26.6	1.7	1.8	27.9	3.2	0.8			
29.4	1.8	1.7	30.7	2.9	0.8			
32.0	1.8	1.6	33.3	2.8	0.8			
34.6	1.9	1.5	36.0	2.5	0.8			
37.4	1.9	1.5	38.7	2.4	0.8			

Bedroom door =pos 4a
Bedroom window =sealed

Mean bedroom temp. =32 C
Mean stairwell temp. =25 C
Mean interzonal temperature difference. =8 C
Outside temperature. =5 C
Mean wind pressure predominance. =-.3Pa

FLOW BED TO STAIRS =80 m^3/h
FLOW STAIRS TO BED =66 m^3/h
BEDROOM ACH =1.1ach
STAIRWELL ACH =0.9ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
11.2	1.0	3.3	12.4	5.4	1.4			
13.5	1.4	3.1	15.0	5.2	1.6			
16.6	1.6	3.0	19.3	5.2	1.5			
20.8	1.8	2.7	22.0	4.7	1.6			
23.9	2.0	2.5	25.4	4.3	1.4			
26.6	2.0	2.4	27.7	3.9	1.4			
29.0	2.2	2.3	30.2	3.7	1.3			
31.5	2.2	2.2	32.6	3.4	1.2			
33.8	2.2	2.1	35.0	3.2	1.3			
37.3	2.2	2.1	38.7	2.8	1.2			
42.5	2.2	1.9	43.7	2.6	1.2			
45.0	2.2	1.8	46.3	2.3	1.0			

Bedroom door =pos 4a
Bedroom window =sealed

Mean bedroom temp. =32 C
Mean stairwell temp. =25 C
Mean interzonal temperature difference. =7 C
Outside temperature. =9 C
Mean wind pressure predominance. =-30Pa Very windy. Winter gales

FLOW BED TO STAIRS =87 m^3/h
FLOW STAIRS TO BED =63 m^3/h
BEDROOM ACH =1.4ach
STAIRWELL ACH =1.5ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	R114		R12	R114		R12	R114
1.6	0.5	4.7	3.0	6.6	0.8			
5.0	1.1	4.3	6.4	6.4	1.1	7.7	7.9	0
9.0	1.6	3.9	10.5	6.3	1.5			
12.5	2.0	3.6	14.0	6.3	1.4			
15.3	2.3	3.3	16.7	5.9	1.6			
18.1	2.6	2.7	19.5	5.6	1.7	20.6	6.0	0
22.7	2.9	2.6	24.4	5.0	1.4			
25.9	3.0	2.2	30.7	4.3	1.3			
29.1	3.0	2.0	35.2	3.7	1.2			
36.0	2.8	1.9	37.8	3.4	1.2			
39.0	2.8	1.8	40.4	3.0	1.1	41.2	1.7	0

Bedroom door =pos 4a
Bedroom window =sealed

Mean bedroom temp. =34 C
Mean stairwell temp. =25 C
Mean interzonal temperature difference.=9 C
Outside temperature. =9 C
Mean wind pressure predominance. =-80Pa Very windy.Winter gales.

FLOW BED TO STAIRS =74 m^3/h
FLOW STAIRS TO BED =83 m^3/h
BEDROOM ACH =1.7ach
STAIRWELL ACH =0.8ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	BCF		R12	BCF		R12	BCF
4.3	5.5	0.1	5.6	1.3	0.7	7.0	0	1.4
8.4	5.4	0.1	9.7	1.3	0.8	11.5	0	1.2
13.3	5.2	0.1	14.5	1.9	0.7	16.2	0	1.0
17.8	5.0	0.2	20.4	1.9	0.7	21.8	0	0.6
23.8	4.8	0.2	25.8	1.9	0.6	27.2	0	0.5
29.0	4.8	0.2	32.5	1.7	0.5	33.8	0	0.4
35.4	4.5	0.3	36.7	1.6	0.4	38.5	0	0.3
40.2	4.4	0.3	41.5	1.4	0.3	42.7	0	0.2
45.0	4.1	0.2	46.6	1.4	0.3	48.1	0	0.2
50.0	3.9	0.2	52.0	1.5	0.2	53.7	0	0.1

Bedroom door =pos 4a
Bedroom window =sealed

Mean bedroom temp. =25 C
Mean stairwell temp. =21 C
Mean interzonal temperature difference.=4 C
Outside temperature. =9 C
Mean wind pressure predominance. =-3 Pa

FLOW BED TO STAIRS =50 m^3/h
FLOW STAIRS TO BED =35 m^3/h
BEDROOM ACH =0.4ach
STAIRWELL ACH =1.1ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	BCF		R12	BCF		R12	BCF
0.8	5.8	0	2.1	0.7	0.9	3.8	0	1.5
5.5	5.5	0.1	7.5	1.5	0.8	8.9	0	1.1
12.0	5.0	0.2	13.4	1.8	0.7	14.6	0	0.7
16.6	4.7	0.3	18.0	1.5	0.6	19.3	0	0.4
20.8	4.5	0.3	22.3	1.4	0.5	23.5	0	0.3
25.8	4.1	0.4	27.2	1.4	0.4	28.5	0	0.3
29.7	3.9	0.4	31.2	1.4	0.4	32.5	0	0.2
34.6	3.6	0.35	36.5	1.3	0.3	37.9	0	0.2
40.5	3.4	0.35	41.9	1.2	0.3	43.5	0	0.1
45.5	3.0	0.3	47.4	1.1	0.2	48.8	0	0.1

Bedroom door =pos 4a
Bedroom window =sealed

Mean bedroom temp. =28 C
Mean stairwell temp. =21 C
Mean interzonal temperature difference.=7 C
Outside temperature. =5 C
Mean wind pressure predominance. =+1 Pa

FLOW BED TO STAIRS =64 m^3/h
FLOW STAIRS TO BED =65 m^3/h
BEDROOM ACH =0.8ach
STAIRWELL ACH =1.8ach

TIME	BEDROOM		TIME	STAIRWELL TOP		TIME	STAIRWELL BOTTOM	
	conc			conc			conc	
mins	arb units		mins	arb units		mins	arb units	
	R12	BCF		R12	BCF		R12	BCF
1.7	5.9	0.2	4.4	0.3	5.5	6.7	0.9	4.7
8.3	5.6	1.5	9.8	0.9	4.1	11.3	1.2	4.0
13.1	5.4	2.0	14.5	1.2	3.5	16.2	1.6	3.4
18.3	5.0	2.1	20.0	1.4	2.8	21.4	1.4	2.8
23.0	4.8	2.2	24.8	1.5	2.6	26.4	1.6	2.5
28.0	4.6	2.2	29.7	1.6	2.0	31.2	1.8	2.0
32.5	4.4	2.2	34.0	1.6	2.0	35.7	1.8	2.0
37.4	4.1	2.0	39.4	1.6	1.7	40.8	1.6	1.6
42.0	3.9	2.1	43.9	1.6	1.7	46.0	1.5	1.5

Bedroom door =pos 4a
Bedroom window =sealed

Mean bedroom temp. =14 C
Mean stairwell temp. =18 C
Mean interzonal temperature difference.=4 C
Outside temperature. =7 C
Mean wind pressure predominance. =0

FLOW BED TO STAIRS =62 m^3/h
FLOW STAIRS TO BED =76 m^3/h
BEDROOM ACH =0.6ach
STAIRWELL ACH =2 ach

APPENDIX G DATA FOR COMBINED TEMPERATURE AND PRESSURE DIFFERENCE; LABORATORY

Schedules of tests

Table 8.1 (Page 161); Results for Combined Pressure and Temperature difference; Lab

Time	Design side concentration		Time	Environ. side concentration	
mins	R12	R114	mins	R12	R114
1.4	0.8	6.8	2.5	7.2	0.8
3.7	1.1	6.2	4.6	6.0	3.5
5.7	1.7	5.2	6.8	4.9	4.1
7.9	1.3	4.55	8.9	4.05	4.4
10.3	1.25	4.2	11.4	3.0	4.2
13.3	0.9	3.0	14.6	2.0	3.6
15.5	0.7	2.4	16.5	1.8	3.2
17.6	0.6	2.0	18.7	1.5	2.9
19.6	0.5	1.6	21.0	1.0	2.3
22.0	0.3	1.15	23.4	0.8	1.9

Pressure diff. design/environmental=0.45 Pa

Mean temperature difference =28C

Backflow rate =39m^3/h

Time	Design side concentration		Time	Environ. side concentration	
mins	R12	R114	mins	R12	R114
0.8	0.35	7.0	3.3	6.15	1.2
4.3	0.6	6.6	5.4	4.8	4.4
6.5	0.8	6.0	7.5	3.5	5.1
8.5	0.8	5.6	9.7	2.8	5.3
10.8	0.9	5.0	11.8	2.4	5.1
13.2	0.7	4.25	14.3	1.9	4.9
15.3	0.6	3.6	16.3	1.5	4.6
17.2	0.55	3.0	18.4	1.2	4.2
19.5	0.6	2.5	20.8	1.1	3.9
21.8	0.4	1.9	23.0	0.8	3.1

Pressure diff. design/environmental=0.45 Pa

Mean temperature difference =26C

Backflow rate =26.8m^3/h

Time	Design side concentration		Time	Environ. side concentration	
mins	R12	R114	mins	R12	R114
2.5	0.6	6.6	3.4	7.4	0.5
4.5	0.9	6.2	5.5	6.7	3.8
6.5	1.4	5.7	7.8	5.6	4.4
9.2	1.3	4.7	10.0	4.5	4.4
11.1	1.2	3.8	12.4	3.6	4.15
13.5	1.0	3.4	14.5	3.0	4.0
16.2	0.8	2.6	17.6	2.0	3.0
18.6	0.7	2.2	19.8	1.9	3.0

Pressure diff. design/environmental=0.55 Pa

Mean temperature difference =27C

Backflow rate =36.1m^3/h

Time	Design side concentration		Time	Environ. side concentration	
mins	R12	R114	mins	R12	R114
2.0	0.7	6.9	3.0	6.0	4.0
4.0	0.7	6.8	5.0	5.3	5.0
6.0	0.6	6.2	7.3	4.3	4.4
8.3	0.5	5.7	9.4	3.5	4.5
10.4	0.4	5.3	12.1	2.9	4.5
13.1	0.35	3.85	14.7	2.0	4.2
15.8	0.25	3.4	17.5	1.6	3.8
18.5	0.15	2.4	19.7	1.2	3.25
20.7	0.1	2.0	21.7	0.9	3.0

Pressure diff. design/environmental=0.4 Pa

Mean temperature difference =10C

Backflow rate =17.9m^3/h

Time	Design side concentration		Time	Environ. side concentration	
mins	R12	R114	mins	R12	R114
2.0	0.2	7.0	3.0	6.1	2.4
4.1	0.3	6.5	5.2	5.0	3.9
6.3	0.15	5.8	7.3	3.8	4.55
8.5	0.1	5.2	9.7	2.7	4.7
10.7	0.05	3.8	11.8	1.95	4.3
12.8	0.05	2.75	13.8	1.3	3.9
15.0	0	2.2	16.1	0.9	3.45
17.2	0	1.7	18.2	0.7	2.9

Pressure diff. design/environmental=0.75 Pa

Mean temperature difference =11C

Backflow rate =6.1m^3/h

Time	Design side concentration		Time	Environ. side concentration	
mins	R12	R114	mins	R12	R114
2.6	0.2	6.9	3.6	6.2	2.8
4.7	0.3	6.6	5.7	5.5	4.1
6.8	0.35	6.2	8.0	4.6	4.7
9.3	0.4	5.7	10.4	3.5	5.1
11.4	0.4	5.1	12.5	2.5	5.0
13.5	0.35	4.5	14.6	1.9	4.8
15.5	0.35	3.7	16.8	1.65	4.6
17.8	0.3	3.1	19.0	1.3	4.15

Pressure diff. design/environmental=0.2 Pa

Mean temperature difference =16C

Backflow rate =12.3m^3/h

Time	Design side concentration		Time	Environ. side concentration	
mins	R12	R114	mins	R12	R114
3.8	0.4	5.8	2.7	6.5	0.15
4.9	0.4	5.65	6.0	4.7	3.1
7.0	0.25	4.8	8.1	3.8	3.4
9.2	0.2	4.2	10.4	3.0	3.4
11.3	0.2	3.45	12.4	2.3	3.25
13.5	0.15	3.0	14.6	1.8	3.0
15.7	0.1	2.3	17.0	1.3	2.7
18.2	0.1	1.7	19.3	1.1	2.35

Pressure diff. design/environmental=0.2 Pa

Mean temperature difference =15C

Backflow rate =11.1m^3/h

Time	Design side concentration		Time	Environ. side concentration	
mins	R12	R114	mins	R12	R114
3.7	0.4	4.2	4.8	5.6	2.0
5.9	0.35	3.7	7.0	4.65	2.2
8.1	0.25	3.1	9.3	3.6	2.2
8.1	0.25	3.1	9.3	3.6	2.2
10.5	0.2	2.6	11.5	2.9	2.2
12.7	0.15	2.1	13.9	2.1	2.0
15.0	0.1	1.65	16.3	1.65	1.9
17.3	0.1	1.25	18.8	1.0	1.6
20.0	0.1	1.05	23.1	0.6	1.15

Pressure diff. design/environmental=0.5 Pa

Mean temperature difference =9C

Backflow rate =9.9m^3/h

Time	Design side concentration		Time	Environ. side concentration	
mins	R12	R114	mins	R12	R114
1.6	0.2	6.1	2.8	5.8	2.0
3.0	0.05	4.8	5.0	4.0	3.1
6.4	0	3.6	7.8	2.7	3.2
8.8	0	2.3	10.3	1.5	2.7
11.6	0	1.4	13.0	1.0	2.1
15.4	0	0.8	17.4	0.3	1.2

Pressure diff. design/environmental=1.3 Pa

Mean temperature difference =11C

Backflow rate =3.4m^3/h

Time	Design side concentration		Time	Environ. side concentration	
mins	R12	R114	mins	R12	R114
2.8	0.75	5.65	3.8	7.0	2.25
4.7	0.5	4.6	5.8	6.0	2.75
6.7	0.35	3.5	7.6	4.6	2.8
8.7	0.2	2.5	9.7	2.9	2.5
10.7	0.1	1.65	11.7	1.3	1.75
12.7	0.05	1.15	13.6	1.05	1.6
14.6	0.05	0.9	15.8	0.6	1.2
16.7	0	0.6	18.0	0.4	0.9

Pressure diff. design/environmental=1.15 Pa

Mean temperature difference =20C

Backflow rate =14.1m^3/h

Time	Design side concentration		Time	Environ. side concentration	
mins	R12	R114	mins	R12	R114
1.8	0.3	6.0	3.5	6.4	1.8
4.5	0.4	5.1	5.5	4.9	3.2
6.5	0.3	4.0	7.0	3.5	3.4
8.6	0.2	3.1	9.6	2.3	2.9
10.8	0.15	2.3	12.0	1.5	2.3
13.0	0.05	1.4	14.1	1.0	2.0
15.3	0.05	1.1	16.3	0.7	1.5
17.3	0	0.75	18.2	0.4	1.2
19.3	0	0.65	20.5	0.25	0.9

Pressure diff. design/environmental=0.95 Pa

Mean temperature difference =21C

Backflow rate =10.6m^3/h

Time	Design side concentration		Time	Environ. side concentration	
mins	R12	R114	mins	R12	R114
3.5	0.35	6.0	4.6	6.4	3.6
5.6	0.25	4.9	6.6	4.7	4.2
7.6	0.15	4.1	8.6	3.3	4.0
9.8	0.15	2.7	10.8	2.2	3.6
11.8	0.15	2.1	13.0	1.5	2.8
14.0	0.1	1.5	15.2	1.1	2.3
16.4	0.1	1.2	18.0	0.9	1.95
19.4	0.1	0.75	20.5	0.7	1.6

Pressure diff. design/environmental=0.85 Pa

Mean temperature difference =23C

Backflow rate =10.0m^3/h

Time	Design side concentration		Time	Environ. side concentration	
mins	R12	R114	mins	R12	R114
2.5	0.3	6.6	3.5	6.8	2.25
4.4	0.4	5.8	5.4	5.7	3.6
6.4	0.3	4.35	7.5	4.5	3.9
8.5	0.25	3.6	9.4	3.0	3.7
10.3	0.15	2.8	11.4	2.5	3.6
12.5	0.1	1.9	13.5	1.75	3.1
14.7	0.1	1.6	16.8	1.0	2.05
18.0	0.1	1.0	19.0	0.7	1.7

Pressure diff. design/environmental=0.75 Pa

Mean temperature difference =16C

Backflow rate =11.9m^3/h

Time	Design side concentration		Time	Environ. side concentration	
mins	R12	R114	mins	R12	R114
2.4	0.6	7.4	3.5	7.95	1.0
4.5	0.7	7.15	5.7	7.3	3.5
6.6	0.6	6.6	7.8	6.6	4.5
8.9	0.5	6.1	9.9	5.9	4.9
11.1	0.5	5.5	12.3	4.65	5.0
13.5	0.4	4.7	14.7	4.1	5.0
16.3	0.4	3.8	17.3	2.2	4.5
18.4	0.3	2.9	20.5	1.35	3.9
21.5	0.2	1.85	22.6	0.9	2.85

Pressure diff. design/environmental=0.5 Pa

Mean temperature difference =22C

Backflow rate =12.8m^3/h

Time	Design side concentration		Time	Environ. side concentration	
mins	R12	R114	mins	R12	R114
0.4	0.1	6.5	1.4	7.5	0.2
2.6	0.2	6.2	4.3	6.6	2.15
5.3	0.2	5.2	6.4	6.1	3.0
7.4	0.2	4.3	8.6	5.0	3.7
10.5	0.1	3.3	11.5	3.9	3.8
12.6	0.1	2.3	13.6	3.2	3.8
14.7	0.1	1.7	15.7	1.85	3.35
16.9	0.1	1.5	18.0	1.4	3.0

Pressure diff. design/environmental=0.2 Pa

Mean temperature difference =14C

Backflow rate =6.2m^3/h

APPENDIX H DATA FOR COMBINED TEMPERATURE AND PRESSURE DIFFERENCE; SITE

Table 9.1 (Page 170); Results for Combined Pressure and Temperature difference; Site

Time	Hall concentration		Time	Living room concentration	
mins	R12	R114	mins	R12	R114
6.4	6.2	0.6	7.4	3.9	3.7
8.4	5.5	0.6	9.3	3.9	3.3
10.3	5.7	0.7	11.3	3.8	3.2
12.3	4.3	0.5	14.7	3.8	2.5
15.8	3.7	0.4	16.8	3.4	2.0
17.7	3.2	0.4	18.6	3.3	1.9
19.5	3.0	0.4	20.5	3.0	1.6
21.5	2.3	0.3	22.5	2.8	1.3
23.5	2.0	0.2	24.5	2.7	1.2

Pressure diff. Hall/Living room =1.1 Pa

Mean temperature difference =4C

Backflow rate =51m^3/h

Time	Hall concentration		Time	Living room concentration	
mins	R12	R114	mins	R12	R114
2.5	7.0	0.7	4.5	2.0	4.4
6.5	6.8	0.9	8.5	3.7	4.7
10.4	5.6	1.1	12.3	3.8	3.2
14.2	4.3	1.0	16.0	3.6	2.6
18.0	3.2	0.7	20.2	3.4	2.1
21.1	2.8	0.7	22.0	3.1	1.8
23.5	2.3	0.6	24.4	2.8	1.5
26.5	2.1	0.5	26.5	2.7	1.4

Pressure diff. Hall/Living room =0.9 Pa

Mean temperature difference =5C

Backflow rate =74m^3/h

Time	Hall concentration		Time	Living room concentration	
mins	R12	R114	mins	R12	R114
1.9	8.2	1.3	4.0	1.7	3.8
5.0	7.8	0.5	6.0	2.8	4.4
7.2	7.6	1.4	8.5	3.6	4.3
9.8	7.2	1.3	10.9	3.4	3.6
11.8	7.3	1.4	13.0	4.0	3.4
14.0	6.3	1.5	14.8	4.2	3.0
15.8	5.6	1.4	16.8	4.1	2.7
17.7	5.1	1.3	18.7	4.3	2.6
19.7	4.9	1.4	20.6	4.2	2.4
25.6	3.9	1.0	27.5	4.0	1.8

Pressure diff. Hall/Living room =0.4 Pa

Mean temperature difference =4C

Backflow rate =101m^3/h

Time	Hall concentration		Time	Living room concentration	
mins	R12	R114	mins	R12	R114
1.7	8.2	0	3.8	2.3	5.6
5.8	7.4	0.7	7.8	3.7	5.0
9.7	6.6	0.8	10.6	4.2	4.0
12.0	5.6	0.6	13.0	4.5	3.4
14.0	5.0	0.6	15.0	4.3	2.9
16.0	4.8	0.7	17.0	4.2	2.5
17.9	4.7	0.6	18.9	4.0	2.3
20.8	4.3	0.7	20.8	3.8	2.0
21.8	3.2	0.5	22.8	3.5	1.7
23.6	2.9	0.5	24.7	3.4	1.6

Pressure diff. Hall/Living room =0.5 Pa

Mean temperature difference =4C

Backflow rate =45m^3/h

Time	Hall concentration		Time	Living room concentration	
mins	R12	R114	mins	R12	R114
2.0	8.6	0	4.0	4.5	4.9
5.0	7.3	0	6.0	5.1	4.2
6.8	5.7	0	7.8	5.5	3.3
9.8	3.1	0	10.7	5.4	2.7
11.7	2.7	0	12.5	5.1	2.4
16.5	1.4	0	17.8	4.0	1.3
19.4	0.8	0	20.9	3.4	1.1
21.8	0.6	0	22.8	2.8	0.8
25.6	0.5	0	27.0	2.2	0.6

Pressure diff. Hall/Living room =1.3 Pa

Mean temperature difference =4C

Backflow rate =0

Time	Hall concentration		Time	Living room concentration	
mins	R12	R114	mins	R12	R114
3.8	5.7	0	6.0	1.5	7.7
7.0	5.8	0	9.3	3.4	6.1
10.3	7.6	0	12.4	4.1	5.4
13.5	7.0	0	16.6	4.9	3.9
19.0	7.5	0	21.2	5.8	2.6
22.3	7.8	0	24.3	6.2	1.8
25.3	7.3	0	28.5	6.3	1.4

Pressure diff. Hall/Living room =1.3 Pa

Mean temperature difference =5C

Backflow rate =0

APPENDIX I DATA FOR 3 ZONE WORK

Schedules of tests

Table 10.1 (Page 182); Results for 3 Zone; Site

TIME mins	STAIRWELL conc arb units 12	114	BCF	TIME mins	BEDROOM conc arb units 12	114	BCF	TIME mins	LIVING ROOM conc arb units 12	114	BCF
1.7	7.4	0	0.2	3.4	1.0	0	5.1	4.5	0.6	4.5	0
6.1	6.9	1.0	0.5	7.8	1.5	0	5.0	8.9	1.9	3.7	0.1
10.5	6.2	1.5	0.6	12.2	2.0	0	4.7	13.3	2.8	3.3	0.1
14.9	5.7	1.8	0.5	16.5	2.3	0.1	4.5	17.5	3.1	2.9	0.1
19.4	5.2	1.9	0.4	21.0	2.4	0.2	4.3	22.0	3.1	2.5	0.1
23.6	4.7	2.0	0.4	25.3	2.6	0.3	4.1	26.3	3.2	2.3	0.1
27.9	4.2	1.9	0.4	29.5	2.7	0.3	4.0	30.6	3.2	2.1	0.1
32.8	4.1	2.0	0.4	34.3	2.7	0.4	3.8	35.5	3.1	1.9	0.1
37.0	3.6	1.9	0.3	38.5	2.8	0.5	3.6	39.4	3.0	1.8	0.1

MEAN TEMP STAIRWELL =20C

MEAN TEMP BEDROOM =21C

MEAN TEMP LIVING ROOM =37C

MEAN TEMP OUTSIDE =9C

TEMP DIFF STAIRS/BED =1C

TEMP DIFF STAIRS/LIVING =17C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =-.4Pa

FLOW STAIRS TO BED =68m^3/h

FLOW BED TO STAIRS =21m^3/h

FLOW STAIRS TO LIVING =103m^3/h

FLOW LIVING TO STAIRS =121m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= UP

BEDROOM ACH =0.8

STAIRWELL ACH =1.4

LIVING ROOM ACH =1.7

TIME	STAIRWELL			TIME	BEDROOM			TIME	LIVING ROOM		
	conc				conc				conc		
mins	arb units			mins	arb units			mins	arb units		
	12	114	BCF		12	114	BCF		12	114	BCF
1.6	8.3	1.6	0.3	3.2	4.9	0	5.9	4.3	0.4	7.4	0
6.0	7.6	2.3	1.2	7.6	5.9	0.2	5.4	8.7	0.7	7.4	0
10.5	6.7	2.7	1.6	12.3	6.0	0.4	5.0	13.3	1.0	7.1	0
14.8	5.9	3.3	1.5	16.3	6.4	0.9	4.4	17.3	1.7	6.7	0.1
18.9	5.2	3.3	1.5	20.5	6.4	1.2	4.1	21.7	1.8	6.3	0.1
23.1	4.7	3.5	1.5	24.6	6.3	1.5	3.6	25.8	1.9	6.2	0.2
27.3	3.9	3.5	1.3	34.0	5.9	2.2	2.8	35.0	1.9	5.6	0.2

MEAN TEMP STAIRWELL =32C

MEAN TEMP BEDROOM =15C

MEAN TEMP LIVING ROOM =27C

MEAN TEMP OUTSIDE =8C

TEMP DIFF STAIRS/BED =17C

TEMP DIFF STAIRS/LIVING =12C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =-.1Pa

FLOW STAIRS TO BED =190m^3/h

FLOW BED TO STAIRS =64 m^3/h

FLOW STAIRS TO LIVING =41 m^3/h

FLOW LIVING TO STAIRS =107m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= UP

BEDROOM ACH =1.4

STAIRWELL ACH =1.5

LIVING ROOM ACH =0.6

TIME mins	STAIRWELL conc arb units			TIME mins	BEDROOM conc arb units			TIME mins	LIVING ROOM conc arb units		
	12	114	BCF		12	114	BCF		12	114	BCF
1.9	7.7	0	1.4	3.4	1.0	0	7.0	4.5	0.4	5.2	0.3
6.0	6.2	0.6	2.0	7.7	1.5	0	6.9	8.8	1.7	4.6	0.5
10.5	6.7	1.1	2.2	12.2	2.1	0.1	6.9	13.4	1.9	4.3	0.6
14.9	6.2	1.4	2.5	16.6	2.4	0.1	6.7	17.5	2.2	3.9	0.6
19.2	5.7	1.7	2.1	20.8	2.6	0.2	6.5	21.8	2.0	3.7	0.6
23.4	5.3	1.9	2.3	25.1	2.6	0.3	6.4	26.3	2.1	3.4	0.6
27.8	4.6	1.9	2.4	29.4	2.8	0.4	6.2	30.4	2.2	3.3	0.6
32.0	4.3	1.9	2.2	33.7	2.9	0.5	6.1	34.8	2.1	3.2	0.7
36.3	4.0	2.0	2.0	38.0	3.0	0.6	6.0	39.0	2.2	2.9	0.8

MEAN TEMP STAIRWELL =17C

MEAN TEMP BEDROOM =16C

MEAN TEMP LIVING ROOM =22C

MEAN TEMP OUTSIDE =8C

TEMP DIFF STAIRS/BED =1C

TEMP DIFF STAIRS/LIVING =5C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW)=+.02Pa

FLOW STAIRS TO BED =65 m^3/h

FLOW BED TO STAIRS =73 m^3/h

FLOW STAIRS TO LIVING =61 m^3/h

FLOW LIVING TO STAIRS =97 m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= DOWN

BEDROOM ACH =0.4

STAIRWELL ACH =1.2

LIVING ROOM ACH =1.1

TIME mins	STAIRWELL conc arb units 12	114	BCF	TIME mins	BEDROOM conc arb units 12	114	BCF	TIME mins	LIVING ROOM conc arb units 12	114	BCF
1.7	7.5	0	0.1	3.4	2.2	0	6.8	4.8	1.1	5.8	0
6.5	6.5	1.4	0.4	7.9	2.7	0	6.6	9.0	2.2	4.8	0.1
10.6	5.8	2.2	0.7	12.5	3.1	0.2	6.5	13.6	2.6	4.3	0.2
15.4	5.1	2.5	1.1	17.3	3.4	0.6	6.2	18.3	2.7	3.8	0.2
19.8	4.4	2.4	1.1	21.3	3.2	0.5	6.0	22.3	2.5	3.0	0.2
23.8	3.9	2.3	1.0	25.5	3.3	0.6	5.8	26.5	2.5	2.8	0.3
28.3	3.6	2.3	1.2	30.0	3.4	0.7	5.6	31.3	2.4	2.4	0.3
32.9	3.3	2.2	1.3	34.4	3.3	1.0	5.3	35.4	2.4	2.3	0.4
37.0	2.9	2.1	1.1	38.7	3.3	1.2	4.9	39.7	2.3	2.1	0.5

MEAN TEMP STAIRWELL =19C

MEAN TEMP BEDROOM =17C

MEAN TEMP LIVING ROOM =38C

MEAN TEMP OUTSIDE =8C

TEMP DIFF STAIRS/BED =2C

TEMP DIFF STAIRS/LIVING =19C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =-.2Pa

FLOW STAIRS TO BED =96m^3/h

FLOW BED TO STAIRS =36m^3/h

FLOW STAIRS TO LIVING =98m^3/h

FLOW LIVING TO STAIRS =124m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= UP

BEDROOM ACH =0.7

STAIRWELL ACH =1.7

LIVING ROOM ACH =2.1

TIME mins	STAIRWELL conc arb units 12	114	BCF	TIME mins	BEDROOM conc arb units 12	114	BCF	TIME mins	LIVING ROOM conc arb units 12	114	BCF
1.6	7.3	0	0.2	3.4	0.6	0	4.5	4.5	1.6	4.6	0.1
6.1	6.5	1.4	0.3	7.7	1.7	0.1	4.2	8.7	2.7	3.8	0.1
10.3	5.8	2.1	0.4	11.7	2.0	0.3	4.0	12.6	2.9	3.6	0.1
14.2	5.3	2.3	0.4	15.7	2.3	0.4	3.8	16.8	3.2	2.9	0.1
18.6	4.6	2.3	0.5	20.4	2.4	0.5	3.6	21.4	3.2	2.7	0.2
22.9	4.2	2.2	0.5	24.3	2.7	0.8	3.3	25.5	3.0	2.3	0.2
27.5	3.8	2.3	0.6	29.0	2.6	0.9	3.1	30.0	2.9	2.2	0.2
31.5	3.6	2.1	0.6	33.3	2.9	1.0	3.1	34.2	2.9	2.0	0.2

MEAN TEMP STAIRWELL =22C

MEAN TEMP BEDROOM =20C

MEAN TEMP LIVING ROOM =38C

MEAN TEMP OUTSIDE =8C

TEMP DIFF STAIRS/BED =2C

TEMP DIFF STAIRS/KITCHEN=16C

WIND PRESSURE PREDOMINANCE
ACROSS BEDROOM WINDOW =-0.05Pa

FLOW STAIRS TO BED =88m^3/h

FLOW BED TO STAIRS =32m^3/h

FLOW STAIRS TO LIVING =124m^3/h

FLOW LIVING TO STAIRS =158m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= UP

BEDROOM ACH =1.0

STAIRWELL ACH =1.6

LIVING ROOM ACH =1.9

TIME mins	STAIRWELL conc arb units			TIME mins	BEDROOM conc arb units			TIME mins	LIVING ROOM conc arb units		
	12	114	BCF		12	114	BCF		12	114	BCF
1.7	7.4	0	0.2	3.4	1.0	0	5.1	4.4	0.6	4.5	0.1
6.1	6.9	1.0	0.6	7.8	1.5	0	5.0	9.0	1.9	3.7	0.1
10.5	6.2	1.6	0.6	12.2	2.0	0	4.7	13.3	2.8	3.3	0.1
14.9	5.7	1.8	0.4	16.5	2.3	0.1	4.5	17.5	3.0	2.9	0.1
19.5	5.2	1.9	0.4	21.0	2.5	0.2	4.3	22.0	3.1	2.5	0.1
23.6	4.7	2.0	0.4	25.3	2.7	0.4	4.2	26.3	3.2	2.3	0.2
27.9	4.2	2.0	0.5	29.5	2.7	0.4	4.0	30.6	3.2	2.1	0.2
32.8	4.1	2.0	0.4	34.4	2.7	0.5	3.7	35.5	3.1	2.0	0.2
37.0	3.6	1.9	0.3	38.4	2.8	0.5	3.6	39.4	3.0	1.8	0.2

MEAN TEMP STAIRWELL =20C

MEAN TEMP BEDROOM =21C

MEAN TEMP LIVING ROOM =37C

MEAN TEMP OUTSIDE =9C

TEMP DIFF STAIRS/BED =1C

TEMP DIFF STAIRS/LIVING =17C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =-.5Pa

FLOW STAIRS TO BED =68m^3/h

FLOW BED TO STAIRS =22m^3/h

FLOW STAIRS TO LIVING =102m^3/h

FLOW LIVING TO STAIRS =122m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= UP

BEDROOM ACH =0.6

STAIRWELL ACH =1.2

LIVING ROOM ACH =1.8

TIME	STAIRWELL conc arb units			TIME	BEDROOM conc arb units			TIME	LIVING ROOM conc arb units		
mins	12	114	BCF	mins	12	114	BCF	mins	12	114	BCF
1.7	7.6	0	0.8	3.6	2.1	0	6.5	4.8	1.4	5.5	0.1
6.3	6.5	1.8	2.0	8.0	3.5	0.1	6.2	9.0	2.4	4.9	0.3
10.7	5.7	2.4	2.1	12.4	3.4	0.3	5.8	13.4	3.1	4.1	0.5
15.1	4.8	2.4	2.5	16.7	3.8	0.7	5.5	17.8	3.2	3.5	0.5
20.1	4.3	2.5	2.2	21.6	3.6	0.8	5.2	22.8	3.1	3.0	0.5
24.5	3.9	2.4	2.0	26.2	3.5	1.0	4.8	27.3	3.0	2.8	0.6
28.9	3.5	2.4	1.8	30.7	3.5	1.1	4.6	31.6	2.9	2.5	0.6
33.2	3.3	2.2	1.8	34.8	3.3	1.2	3.8	35.9	2.8	2.3	0.7
37.5	3.1	2.1	1.7	39.0	3.3	1.3	4.0	40.2	2.7	2.2	0.7

MEAN TEMP STAIRWELL =22C

MEAN TEMP BEDROOM =30C

MEAN TEMP LIVING ROOM =37C

MEAN TEMP OUTSIDE =8C

TEMP DIFF STAIRS/BED =8C

TEMP DIFF STAIRS/LIVING =15C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =-.6Pa

FLOW STAIRS TO BED =111m^3/h

FLOW BED TO STAIRS =84m^3/h

FLOW STAIRS TO LIVING =108m^3/h

FLOW LIVING TO STAIRS =117m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= DOWN

BEDROOM ACH =0.9

STAIRWELL ACH =1.6

LIVING ROOM ACH =1.9

TIME mins	STAIRWELL conc arb units 12	114	BCF	TIME mins	BEDROOM conc arb units 12	114	BCF	TIME mins	LIVING ROOM conc arb units 12	114	BCF
2.0	7.3	0.6	0.6	3.5	1.7	0	5.0	4.5	1.4	5.6	0
6.9	6.0	1.8	1.1	8.5	3.9	0	4.3	9.5	2.5	4.9	0
11.2	5.0	2.2	1.3	13.3	3.9	0.3	3.5	14.4	2.9	4.1	0.1
16.0	4.2	2.4	1.3	17.6	3.8	0.5	3.4	18.6	3.0	3.8	0.1
20.3	3.8	2.5	1.3	21.9	3.6	0.7	3.2	23.0	3.0	3.5	0.1
24.7	3.5	2.4	1.3	26.4	3.6	1.1	2.7	27.5	2.9	3.2	0.1
29.1	3.4	2.3	1.1	30.8	3.4	1.2	2.6	32.0	2.8	3.1	0.2
33.6	3.3	2.4	1.1	35.2	3.4	1.2	2.3	36.4	2.7	2.8	0.2

MEAN TEMP STAIRWELL =21C

MEAN TEMP BEDROOM =30C

MEAN TEMP LIVING ROOM =31C

MEAN TEMP OUTSIDE =12C

TEMP DIFF STAIRS/BED =9C

TEMP DIFF STAIRS/LIVING =10C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =0 Pa

FLOW STAIRS TO BED =145m^3/h

FLOW BED TO STAIRS =78 m^3/h

FLOW STAIRS TO LIVING =111m^3/h

FLOW LIVING TO STAIRS =123m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= UP

BEDROOM ACH =1.5

STAIRWELL ACH =1.8

LIVING ROOM ACH =1.3

TIME mins	STAIRWELL conc arb units			TIME mins	BEDROOM conc arb units			TIME mins	LIVING ROOM conc arb units		
	12	114	BCF		12	114	BCF		12	114	BCF
3.2	7.5	0	1.2	6.0	3.8	0	6.0	7.0	0.1	5.6	0
8.8	6.8	0.3	2.1	10.3	4.5	0	5.5	11.3	0.2	5.4	0
13.4	6.1	0.5	2.5	15.5	4.7	0	4.9	16.5	0.2	5.0	0
18.5	5.6	0.6	2.5	20.2	4.7	0.1	4.7	21.4	0.2	4.9	0.1
25.4	5.1	0.9	2.3	27.0	4.8	0.2	4.3	28.0	0.2	4.5	0.1
29.7	4.7	0.8	2.2	31.3	4.7	0.3	4.1	32.5	0.2	4.5	0.1
34.7	4.4	0.9	2.0	36.3	4.5	0.3	3.7	37.4	0.2	4.3	0
38.7	4.0	0.9	1.8	41.0	4.4	0.3	3.5	42.0	0.2	4.1	0

MEAN TEMP STAIRWELL =18C

MEAN TEMP BEDROOM =35C

MEAN TEMP LIVING ROOM =18C

MEAN TEMP OUTSIDE =12C

TEMP DIFF STAIRS/BED =17C

TEMP DIFF STAIRS/LIVING =0C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =+.5Pa

FLOW STAIRS TO BED =131m^3/h

FLOW BED TO STAIRS =86m^3/h

FLOW STAIRS TO LIVING =5m^3/h

FLOW LIVING TO STAIRS =29m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= UP

BEDROOM ACH =1.0

STAIRWELL ACH =1.1

LIVING ROOM ACH =0.6

TIME	STAIRWELL conc			TIME	BEDROOM conc			TIME	LIVING ROOM conc		
mins	arb units			mins	arb units			mins	arb units		
	12	114	BCF		12	114	BCF		12	114	BCF
2.2	8.1	0.1	0.4	4.4	3.9	0	5.9	5.5	0.6	5.1	0.1
7.4	7.2	0.8	1.5	9.5	5.2	0	5.1	11.8	1.3	4.6	0.1
13.5	5.9	1.4	2.0	15.2	5.4	0.3	4.5	16.9	2.0	3.9	0.1
18.8	5.1	1.6	1.9	20.7	5.3	0.5	3.9	22.4	2.0	3.7	0.1
24.3	4.6	1.6	1.8	26.0	5.1	0.7	3.5	27.2	2.2	3.3	0.1
28.9	4.3	1.7	1.7	30.5	5.1	0.9	3.3	31.7	2.2	2.8	0.2
33.4	3.9	1.8	1.5	35.2	4.9	1.0	3.0	36.5	2.1	2.8	0.2
38.9	3.6	1.7	1.4	41.0	4.6	1.1	2.6	42.0	2.1	2.5	0.2
43.7	3.1	1.7	1.3	45.4	4.3	1.2	2.3	4.7.0	2.0	2.4	0.2

MEAN TEMP STAIRWELL =20C

MEAN TEMP BEDROOM =37C

MEAN TEMP LIVING ROOM =25C

MEAN TEMP OUTSIDE =8C

TEMP DIFF STAIRS/BED =17C

TEMP DIFF STAIRS/LIVING =5C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =+.5Pa

FLOW STAIRS TO BED =146m^3/h

FLOW BED TO STAIRS =69m^3/h

FLOW STAIRS TO LIVING =54m^3/h

FLOW LIVING TO STAIRS =69m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= UP

BEDROOM ACH =1.5

STAIRWELL ACH =1.4

LIVING ROOM ACH =1.3

TIME	STAIRWELL conc arb units			TIME	BEDROOM conc arb units			TIME	LIVING ROOM conc arb units		
mins	12	114	BCF	mins	12	114	BCF	mins	12	114	BCF
1.5	7.7	0	0.4	3.3	2.2	0	5.6	4.4	0.2	5.9	0
6.2	6.8	0.8	0.9	8.0	5.0	0.1	4.4	9.2	0.7	5.6	0
11.0	6.1	1.5	1.2	12.5	4.5	0.2	4.4	13.7	1.0	5.0	0
15.4	5.2	1.8	1.2	17.3	4.7	0.5	3.7	18.5	1.1	4.7	0.1
20.3	4.5	1.9	1.2	22.0	4.6	0.6	3.6	23.3	1.3	4.5	0.1
25.0	3.9	2.0	1.1	27.0	4.4	0.7	3.2	28.3	1.3	4.2	0.1
30.1	3.5	2.2	1.1	31.7	4.3	1.0	2.8	33.0	1.3	3.9	0.1
34.6	3.1	2.2	0.9	41.0	3.9	1.2	2.3	43.2	1.2	3.3	0.1
39.3	2.7	2.2	0.9	41.0	3.9	1.2	2.3	43.2	1.2	3.3	0.1
44.8	2.4	2.0	0.8	46.4	3.6	1.2	2.0	47.5	1.2	3.0	0.1

MEAN TEMP STAIRWELL =19C

MEAN TEMP BEDROOM =30C

MEAN TEMP LIVING ROOM =24C

MEAN TEMP OUTSIDE =7C

TEMP DIFF STAIRS/BED =11C

TEMP DIFF STAIRS/LIVING =5C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =-1 Pa

FLOW STAIRS TO BED =133m^3/h

FLOW BED TO STAIRS =53m^3/h

FLOW STAIRS TO LIVING =34m^3/h

FLOW LIVING TO STAIRS =81m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= UP

BEDROOM ACH =1.3

STAIRWELL ACH =1.6

LIVING ROOM ACH =1.1

TIME mins	STAIRWELL conc arb units 12	114	BCF	TIME mins	BEDROOM conc arb units 12	114	BCF	TIME mins	LIVING ROOM conc arb units 12	114	BCF
3.1	8.4	0.3	0.6	5.8	1.6	0	7.1	7.0	1.4	5.8	0
8.6	7.7	1.1	1.5	10.4	2.4	0	6.5	11.5	2.1	5.4	0
13.3	6.8	1.5	2.5	15.0	2.6	0	6.1	16.2	3.0	4.6	0.1
17.8	6.0	1.8	2.3	19.5	2.9	0.1	5.8	21.0	3.4	4.0	0.1
22.8	5.6	1.9	2.0	24.6	2.8	0.2	5.3	26.0	3.4	3.6	0.1
27.7	4.8	1.7	2.1	29.5	2.7	0.4	4.9	30.6	3.4	3.4	0.2
32.2	4.2	1.8	2.0	34.0	2.5	0.4	4.4	35.0	3.2	2.9	0.3

MEAN TEMP STAIRWELL =19C

MEAN TEMP BEDROOM =25C

MEAN TEMP LIVING ROOM =26C

MEAN TEMP OUTSIDE =10C

TEMP DIFF STAIRS/BED =6C

TEMP DIFF STAIRS/LIVING =7C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =+6 Pa

FLOW STAIRS TO BED =74m^3/h

FLOW BED TO STAIRS =76m^3/h

FLOW STAIRS TO LIVING =91m^3/h

FLOW LIVING TO STAIRS =72m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= UP

BEDROOM ACH =1.0

STAIRWELL ACH =1.4

LIVING ROOM ACH =1.1

TIME mins	STAIRWELL conc arb units 12	114	BCF	TIME mins	BEDROOM conc arb units 12	114	BCF	TIME mins	LIVING ROOM conc arb units 12	114	BCF
1.8	8.9	0	0.2	4.1	0.4	0	6.7	5.7	1.3	5.2	0
8.4	8.2	1.2	0.8	10.3	0.9	0	6.5	12.0	2.8	4.7	0
13.9	7.6	1.7	0.8	16.0	1.7	0.1	6.1	17.2	3.5	3.9	0.1
20.5	6.7	1.8	1.3	22.3	1.7	0.1	5.7	23.4	4.1	3.1	0.1
25.1	6.3	1.9	1.0	26.8	2.0	0.2	5.5	27.8	4.0	3.0	0.1
29.6	5.8	1.9	1.2	32.4	2.0	0.3	5.0	33.5	4.2	2.5	0.3
35.7	5.1	1.7	1.3	37.3	2.0	0.3	4.5	38.4	4.1	2.2	0.3
40.1	4.7	1.7	1.4	41.7	2.0	0.4	4.4	43.0	4.1	2.1	0.4
44.7	4.4	1.7	1.3	46.4	2.0	0.4	4.1	47.5	3.9	1.9	0.4
49.2	4.0	1.5	1.4	51.0	2.1	0.4	4.0	52.2	3.8	1.8	0.4

MEAN TEMP STAIRWELL =19C

MEAN TEMP BEDROOM =18C

MEAN TEMP LIVING ROOM =28C

MEAN TEMP OUTSIDE =10C

TEMP DIFF STAIRS/BED =1C

TEMP DIFF STAIRS/LIVING =9C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =+1 Pa

FLOW STAIRS TO BED =33m^3/h

FLOW BED TO STAIRS =32m^3/h

FLOW STAIRS TO LIVING =93m^3/h

FLOW LIVING TO STAIRS =71m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= UP

BEDROOM ACH =0.7

STAIRWELL ACH =1.0

LIVING ROOM ACH =1.8

TIME mins	STAIRWELL conc arb units			TIME mins	BEDROOM conc arb units			TIME mins	LIVING ROOM conc arb units		
	12	114	BCF		12	114	BCF		12	114	BCF
2.8	8.3	0.4	0.2	5.3	1.3	0	6.9	6.8	1.0	6.4	0
8.8	7.2	1.4	1.4	10.8	2.2	0	6.2	12.3	2.4	5.4	0
14.1	5.9	2.0	3.0	16.2	2.4	0.1	5.8	17.6	2.4	4.6	0.1
19.7	4.6	2.3	2.0	21.5	2.4	0.3	5.1	23.0	2.7	3.9	0.1
25.0	3.9	2.3	1.8	27.4	2.3	0.4	4.6	28.8	2.6	3.5	0.2
30.7	3.3	2.3	1.7	33.0	2.2	0.5	4.1	34.0	2.4	2.9	0.2

MEAN TEMP STAIRWELL =20C

MEAN TEMP BEDROOM =27C

MEAN TEMP LIVING ROOM =29C

MEAN TEMP OUTSIDE =8C

TEMP DIFF STAIRS/BED =7C

TEMP DIFF STAIRS/LIVING =9C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =+2 Pa

FLOW STAIRS TO BED =72m^3/h

FLOW BED TO STAIRS =80m^3/h

FLOW STAIRS TO LIVING =81m^3/h

FLOW LIVING TO STAIRS =91m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= UP

BEDROOM ACH =1.2

STAIRWELL ACH =1.9

LIVING ROOM ACH =1.2

TIME	STAIRWELL conc arb units			TIME	BEDROOM conc arb units			TIME	LIVING ROOM conc arb units		
mins	12	114	BCF	mins	12	114	BCF	mins	12	114	BCF
2.5	8.5	0	0.4	5.5	1.4	0	4.4	7.0	1.5	6.3	0.1
9.3	7.0	2.0	1.0	11.4	2.8	0	3.7	12.9	2.5	5.6	0.1
14.8	6.2	2.2	1.2	17.0	3.1	0.2	3.4	18.8	2.9	5.0	0.1
20.7	5.0	2.2	1.2	23.6	2.9	0.3	2.6	25.0	3.2	4.2	0.1
26.9	4.2	2.2	1.1	29.0	2.9	0.5	2.4	30.0	3.2	4.0	0.2
32.3	3.9	2.2	1.1	35.5	2.6	0.5	2.0	36.9	3.0	3.2	0.2
38.6	3.5	2.1	1.0	41.0	2.6	0.7	1.8	42.0	3.0	3.0	0.2

MEAN TEMP STAIRWELL =19C

MEAN TEMP BEDROOM =28C

MEAN TEMP LIVING ROOM =30C

MEAN TEMP OUTSIDE =10C

TEMP DIFF STAIRS/BED =9C

TEMP DIFF STAIRS/LIVING =11C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =+2 Pa

FLOW STAIRS TO BED =82m^3/h

FLOW BED TO STAIRS =65m^3/h

FLOW STAIRS TO LIVING =90m^3/h

FLOW LIVING TO STAIRS =87m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= UP

BEDROOM ACH =1.6

STAIRWELL ACH =1.5

LIVING ROOM ACH =1.6

TIME mins	STAIRWELL conc arb units 12	114	BCF	TIME mins	BEDROOM conc arb units 12	114	BCF	TIME mins	LIVING ROOM conc arb units 12	114	BCF
2.2	6.7	0	1.0	6.3	1.7	0	2.2	8.4	1.2	2.4	0.1
10.6	5.9	0.5	1.0	13.1	2.1	0.1	1.9	14.8	1.8	2.1	0.2
17.1	5.0	0.5	0.9	20.5	2.9	0.2	2.0	22.2	2.5	2.0	0.4
25.0	4.5	0.8	1.1	28.0	3.0	0.3	1.8	29.0	2.7	1.9	0.4
31.5	4.0	0.9	1.0	34.3	3.2	0.4	1.7	36.7	2.7	1.6	0.5
39.3	3.6	0.9	1.1	42.2	3.2	0.4	1.6	44.0	2.7	1.5	0.5
46.7	3.2	0.9	0.9	49.7	2.9	0.3	1.4	51.6	2.5	1.2	0.4

MEAN TEMP STAIRWELL =9C

MEAN TEMP BEDROOM =6C

MEAN TEMP LIVING ROOM =12C

MEAN TEMP OUTSIDE =3C

TEMP DIFF STAIRS/BED =3C

TEMP DIFF STAIRS/LIVING =3C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =-.5Pa

FLOW STAIRS TO BED =72m^3/h

FLOW BED TO STAIRS =95m^3/h

FLOW STAIRS TO LIVING =71m^3/h

FLOW LIVING TO STAIRS =61m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= UP

BEDROOM ACH =0.5

STAIRWELL ACH =0.9

LIVING ROOM ACH =1.1

TIME	STAIRWELL			TIME	BEDROOM			TIME	LIVING ROOM		
	conc				conc				conc		
mins	arb units			mins	arb units			mins	arb units		
	12	114	BCF		12	114	BCF		12	114	BCF
2.8	8.6	0.1	0.3	5.5	3.2	0	5.9	7.1	0.4	4.1	0
9.6	7.5	0.2	2.0	13.0	4.1	0	5.3	14.5	0.6	4.1	0.1
17.1	6.5	0.2	2.3	20.0	4.6	0	4.8	22.2	0.6	4.0	0.1
25.1	6.2	0.3	2.5	28.0	4.9	0.1	4.4	29.8	0.8	4.0	0.1
32.2	5.4	0.3	2.4	34.5	5.0	0.1	4.1	36.0	0.8	3.9	0.1
37.9	4.6	0.2	2.4	40.2	4.9	0.1	3.8	42.0	0.8	3.7	0.1
44.4	4.6	0.3	2.2	46.9	5.0	0.1	3.6	48.3	0.9	3.6	0.2

MEAN TEMP STAIRWELL =8C

MEAN TEMP BEDROOM =14C

MEAN TEMP LIVING ROOM =8C

MEAN TEMP OUTSIDE =3C

TEMP DIFF STAIRS/BED =6C

TEMP DIFF STAIRS/LIVING =0C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =+.5Pa

FLOW STAIRS TO BED =102m^3/h

FLOW BED TO STAIRS =75m^3/h

FLOW STAIRS TO LIVING =14m^3/h

FLOW LIVING TO STAIRS =11m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= UP

BEDROOM ACH =0.8

STAIRWELL ACH =0.9

LIVING ROOM ACH =0.2

TIME mins	STAIRWELL conc arb units			TIME mins	BEDROOM conc arb units			TIME mins	LIVING ROOM conc arb units		
	12	114	BCF		12	114	BCF		12	114	BCF
5.8	7.5	1.1	2.0	8.3	2.3	0	4.6	10.0	1.9	4.0	0.3
11.5	6.1	1.5	2.1	13.2	2.7	0.1	3.8	14.6	2.6	3.6	0.4
17.0	5.2	1.6	2.3	19.5	2.8	0.2	3.4	22.0	3.0	3.1	0.6
24.6	4.3	1.9	2.1	27.1	2.8	0.3	3.0	29.0	3.2	2.7	0.8
30.5	3.9	1.4	2.3	33.2	2.6	0.5	2.5	35.2	2.8	2.3	0.9
37.6	3.3	1.6	1.8	39.2	2.6	0.6	2.3	41.2	2.8	2.2	0.9
43.7	3.2	1.6	1.7	46.0	2.5	0.7	2.1	47.1	2.7	2.1	0.9
49.5	2.9	1.6	1.6	51.1	2.4	0.7	1.9	53.0	2.6	1.9	0.9

MEAN TEMP STAIRWELL =19C

MEAN TEMP BEDROOM =29C

MEAN TEMP LIVING ROOM =31C

MEAN TEMP OUTSIDE =3C

TEMP DIFF STAIRS/BED =10C

TEMP DIFF STAIRS/LIVING =12C

WIND PRESSURE PREDOMINANCE
(ACROSS BEDROOM WINDOW) =-2 Pa

FLOW STAIRS TO BED =75m^3/h

FLOW BED TO STAIRS =105m^3/h

FLOW STAIRS TO LIVING =76m^3/h

FLOW LIVING TO STAIRS =87m^3/h

DIRECTION OF FLOW BETWEEN
LIVING ROOM AND BEDROOM= DOWN

BEDROOM ACH =1.4

STAIRWELL ACH =1.4

LIVING ROOM ACH =1.2