Air Infiltration Review

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International Energy Agency – AIVC

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New Participating Country Italy

It is a pleasure to welcome Italy as the thirteenth participating country in the International Energy Agency's Air Infiltration and Ventilation Centre. Italy is actively involved in air flow related annexes within the IEA and we look forward to publishing details of the Italian infiltration and ventilation research programme shortly.

Italy's participation marks a further stage in the development of the AIVC as it approaches its tenth year of operation. We look forward to consolidating our links with those involved in air infiltration and ventilation studies in Italy, and to making the full bibliographic and technical services offered by the Centre available to organisations and research bodies in the country.

The Steering Group Representative is Mr Marco Masoero of the Dipartimento di Energetica, Politecnico di Torino, Italy.

Inside this issue:

Ten Years of Constant Concentration Tracer Gas Measurements

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Introduction

Ten years ago the automated constant concentration tracer gas (CCTG) method was conceived at the Technological Institute, Tastrup, Denmark. This technique is now used by researchers to examine a wide variety of air infiltration and ventilation related problems. At this juncture it would seem appropriate to summarise the development of the CCTG system and examine its use in present day research.

Development

The impetus behind the development of the CCTG system was provided by the need to determine the cause of moisture problems in the roofs of dwellings and swimming pools. Part of this work involved studying the infiltration of humid air into the roof space from moisture producing areas below. In the mid 1970's a simple manual CCTG system was developed and put to use in houses and swimming pools.

In order to evaluate the energy consumption associated with air infiltration and ventilation it is necessary to continuously measure these parameters and ascertain the effect of occupancy and building usage upon them. At that time there was no appropriate technique available for the long term evaluation of occupied multi-cell buildings. Hence the need for an automated CCTG system became apparent.

Further development work was performed at the Institute and the result of this work was a computerised constant concentration system capable of making measurements in buildings with up to ten individual cells and air changes ranging between zero and 500,000 m^3h^{-1}. Continuous measurements can be made over a period of one to two weeks.

The evaluation of this sytem first took place in 1978–81 and the initial development and testing was funded by the EEC and the Danish Ministry of Energy. After this early reseach CCTG systems were developed in several countries including England (British Gas), USA (Princeton University) and Switzerland (Federal Institute of Technology). Over recent years the system has been refined to improve accuracy and the Technological Institute has built four separate CCTG systems. It is estimated that beween five and ten systems of various origin and design are now in use world wide.

Measurement Principle

The principle of the constant concentration tracer gas technique has been described by Kvisgaard (1985) and only a brief summary is presented here. A computerised system injects tracer gas into each of the rooms under test, and the information fed back from a gas analyser enables the tracer concentration to be maintained at a constant level in each room throughout the test.

The flow of outside air into each room (zone) can be evaluated from Equation [1].

$$V = \frac{Q}{c}\ m^3h^{-1} \qquad [1]$$

where V = air flow m^3h^{-1}
q = dosing rate of tracer m^3h^{-1}
c = tracer concentration m^3h^{-1}

Application

The CCTG system enables the user to examine a wide variety of ventilation related problems.

- Occupant influence on air infiltration and natural ventilation.
- Approximate assessment of air flow patterns in factories, dwellings and office buildings.
- Control of new ventilation systems.
- Control of new control methods such as demand control systems.
- Assessing potential building damage due to moisture migration and air movement.
- Indoor air quality studies.
- Measurement of ventilation efficiency.

The design of efficient natural and mechanical ventilation systems is reliant upon an accurate understanding of the influence of occupancy and air flow patterns upon air infiltration and ventilation efficiency. The CCTG system is ideally suited to the task of examining buildings under conditions of normal usage and occupancy.

Using the CCTG can be both difficult and expensive. However contract work has shown use of the CCTG system to be both efficient and cost effective. It has been found that several clients can expect a payback of at least ten times the initial outlay by following the course indicated by the CCTG tests.

Case Studies

This section contains several case studies which illustrate how the CCTG system has been used to examine a variety of air infiltration and ventilation related problems.

Dwelling: Energy Loss

In Denmark the users' influence on the airing of buildings is considerable (see figure 1). This influence should certainly be taken into account when designing natural or mechanical ventilation systems.

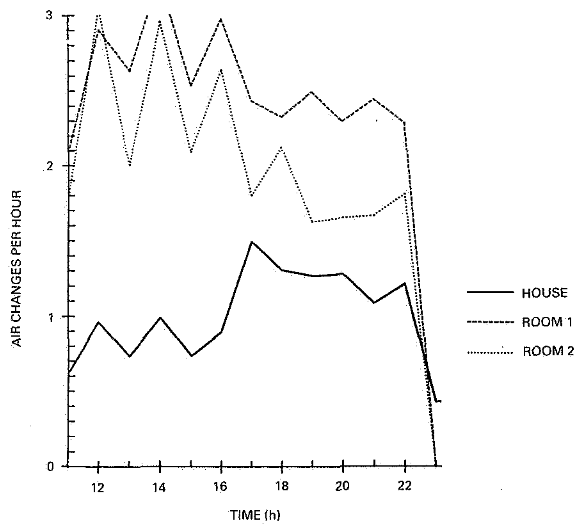

Figure 1: Variation of air change rate with time as measured by CCTG (occupant influence)

Brewery: Dust Problem

Figure 2 shows a plan of a three hall brewery. The central clean area had a dust problem and the CCTG system was used to assess the situation. Tracer gas was injected to a constant concentration in all three areas simultaneously and in only one hall at a time (see figure 3). This showed that only 17% of the air entering the clean room was due to the designed mechanical ventilation system. 67% was due to air flowing from the two adjoining 'dirty' rooms and 16% was due to infiltration of outside air.

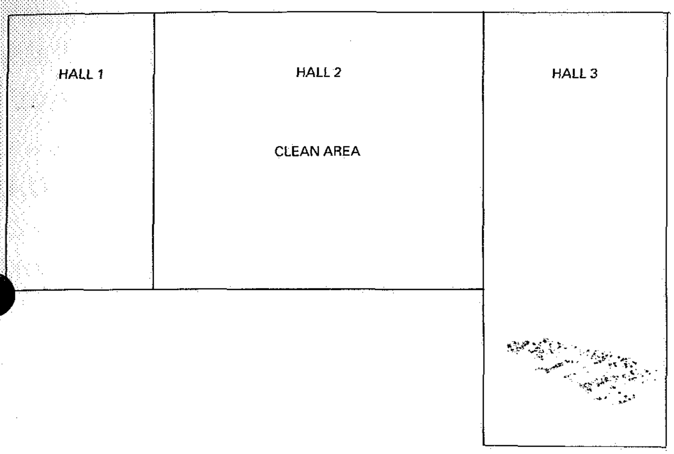

Figure 2: Plan of three hall production area with central clean room. Total area 10,000 m^3, volume 50,000 m^3

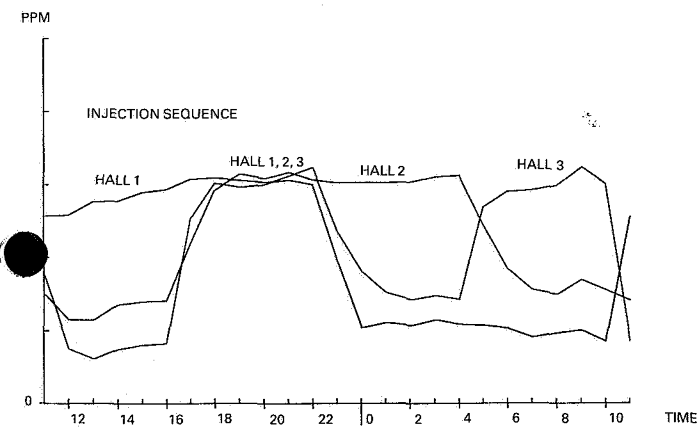

Figure 3: Dosing of tracer gas in different production halls and variation of tracer concentration

Office Building: Indoor Air Quality

The office building consisted of three floors with a total volume of 15,000 m^3. Measurements were made at a symmetrical cross-section containing 22 offices with a floor area of 400 m^3 and a volume of 1000 m^3. Using the CCTG system showed a natural ventilation rate of 2–8 m^3h^{-1} per person and a significantly increased infiltration rate when the staircase was used to promote the stack effect.

Semi-Detached House: Moisture Problem

The semi-detached house had moisture problems on two floors. The CCTG system was used to examine the building. The evaluated air flow patterns showed that refitting the second floor bathroom with exhaust ventilation had served to increase the infiltration rate of the first floor, but had done nothing to alleviate the moisture problems of the second floor bedrooms.

Kindergarten (School): CO_2 Concentration

Measurements were made in 25 kindergartens (see Figure 4). These showed a natural ventilation rate of 0.5 – 1.0 h^{-1} which is equivalent to 2–8 m^3h^{-1} per person. It was also found that the CO_2 concentration exceeded 1500 – 2000 ppm for much of the day in most kindergartens (see Figure 5).

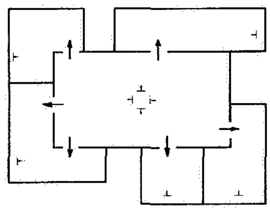

Figure 4: Plan of kindergarten typical of test area 3–400 m^2, volume 700–1000 m^3, 60–80 pupils natural ventilation

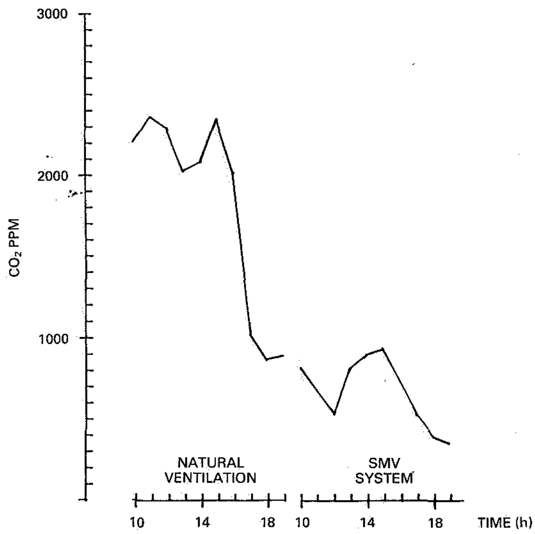

Figure 5: CO_2 concentration in kindergarten with and without SMV system

A new simplified mechanical ventilation (SMV) system was developed at the Institute and this system costs about 30% of conventional installations. Evaluation of the new system showed that air flow patterns were created which increased the efficiency of CO_2 removal. The nominal flow rate can be reduced to 50% of that of traditional designs and still keep the CO_2 level below 1000 ppm.

When the SMV system is equipped with demand control the exhaust from the CO_2 concentration is kept well below 1500 ppm during the day with a ventilation rate of only 4 – 8 m^3h^{-1} per person. The range is due to variation in the number of children present and their behavioural influence on the natural ventilation.

References

Kvisgaard (1985)
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The User's Influence on Air Infiltration,
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Determination of Flows and Volumes in Multiple Cell Systems

By Lars Jensen

1. Introduction

A new method to determine flows and volumes in multiple cell systems with a single tracer gas in one active experiment is described. The tracer gas concentration is measured in each cell. The same tracer gas is released in each cell in a certain pattern in time. The pattern is chosen so that the influence of different tracer gas inputs can be separated.

Ideal mixing is assumed in each cell. The interconnecting flows between the cells are constant and without time delays.

The time derivatives of the tracer gas concentrations are calculated. A large equation system can be formulated based on the multiple cell model structure and its parameters, the measured tracer gas concentrations and their time derivatives, and the tracer gas inputs. The equation system is linear in the model parameters which are flows and volumes. The linear programming method is used to determine the model parameters. All model parameters can be restricted to a given interval or even be given a fixed value.

A simulated three cell system is used as a test example. A comparison is also made with a decay experiment using the same amount of tracer gas.

An alternative method, which uses integrated mass balance equations, is also presented and tested.

This paper is a short version of an improved paper, based on a paper presented at ROOMVENT-87 in Stockholm, Sweden.

2. Model for Multiple Cell System

This model is well known and it is based on the following assumptions

1. The model consists of several cells with constant volumes interconnected with constant flows.
2. The concentration of any matter in a cell is the same (ideal mixing).
3. The flows between the cells have no time delays.

The following notations are made

n	number of cells
V_i	volume of cell number i
q_{ij}	interflow from cell number j to cell number i
q_{iu}	inflow from outside to cell number i
q_{ui}	outflow from cell number i to outside
q_{it}	total inflow from cell number i
q_{ti}	total outflow from cell number i
$c_i(t)$	tracer gas concentration in cell number i
$p_i(t)$	tracer gas inlet in cell number i

The total inflow and outflow for cell number i can be written

$$q_{it} = \sum_{j \neq i}^{n} q_{ij} + q_{iu} \quad (i = 1,n) \tag{2.1}$$

and

$$q_{ti} = \sum_{j \neq i}^{n} q_{ji} + q_{ui} \quad (i = 1,n) \tag{2.2}$$

respectively.

The total inflow is equal to the total outflow due to mass balance reasons for the flows. This means that

$$q_{it} = q_{ti} \quad (i = 1,n) \tag{2.3}$$

or

$$\sum_{j \neq i}^{n} q_{ij} + q_{iu} = \sum_{j \neq i}^{n} q_{ji} + q_{ui} \quad (i = 1,n) \tag{2.4}$$

A mass balance equation for the tracer gas in cell number i can be stated

$$V_i\dot{c}_i(t) = \sum_{j \neq i}^{n} q_{ij}c_j(t) - q_{ti}c_i(t) + p_i(t) \tag{2.5}$$

accumulation inflow outflow production

The tracer gas concentration outside the model is assumed to be zero. The time derivative is denoted with a ·. The whole multiple cell model can be stated using the following matrix notation

$$V\dot{c}(t) = Qc(t) + p(t) \tag{2.6}$$

where

$c(t)$	tracer gas concentration vector
$p(t)$	tracer gas inlet vector
V	diagonal volume matrix
Q	flow matrix

All non-diagonal elements in the flow matrix Q are defined earlier as the interflows q_{ij}. The diagonal elements q_{ii} are given by

$$q_{ii} = -q_{it} = -q_{ti} \quad (i = 1,n) \tag{2.7}$$

which can be seen from equations (2.1) – (2.5). The flow matrix Q has the following properties

1. The summation of all row elements in row i is equal to or less than zero, if zero then $q_{iu} = 0$ (no inflow from outside to cell i).
2. The summation of all column elements in column i is equal to or less than zero, if zero then $q_{ui} = 0$ (no outside from cell i).
3. All non-diagonal elements are non-negative.
4. All diagonal elements are negative.

The number of model parameters in a multiple cell model of order n is n(n + 2), consisting of n volumes, n(n – 1) interflows, n inflows and n outflows.

However, n parameters are linear dependent on the others which follows from equation (2.4). The number of model parameters becomes n(n + 1).

3. Model Parameter Identification

A general question is how to determine the model parameters in a multiple cell model from measurements of tracer gas concentration and tracer gas inlet in each cell.

The model (2.6) can be re-written on a more common form

$$\dot{c}(t) = V^{-1}Q\, c(t) + V^{-1}p(t) \quad (3.1)$$

This continuous time model is then transformed into a discrete time model as follows

$$c(t+1) = Fc(t) + Gp(t) \quad (3.2)$$

This is done on the assumption that the tracer gas production p(t) is constant during the time interval (t,t + 1).

The matrices F and G are given by

$$F = e^{V^{-1}Q} \quad (3.3)$$

$$G = \int_0^1 e^{V^{-1}Qs}\, ds V^{-1} \quad (3.4)$$

The matrices F and G can now be determined from the measurements. The volume matrix V and the flow matrix Q can be determined from equations (3.3) – (3.4). However, there is no guarantee that a solution exists.

Another method is to use the continuous time model. The only problem is that the time derivatives of the tracer gas concentration are unknown. Then, the idea is to calculate the derivatives directly from the measurements.

Now, a large linear equation system can be formulated containing m x n equations, describing the tracer gas mass balances for n cells and for m measurements. The major advantage of this method is that the equations are linear in the model parameters.

Linear programming is a method that can be used to solve this problem. One advantage of this method is that it works only with non-negative free parameters. Another advantage is that all free parameters can be restricted to given intervals. A third advantage is that linear relations between free parameters can be introduced into the equation system.

The problem has been solved with volumes, interflows, inflows and outflows as free parameters. All are non-negative. The model parameter vector x_m can also be given a lower bound b_1 and/or an upper bound b_u. The model parameter vector x_m can now be given as $x_m = b_1 + x_v$, where x_v is the variable part. If a model parameter is fixed, then the corresponding element in x_v is left out. The upper bounds are defined by the equation system

$$x_v + x_s = b_u - b_1 \quad (3.5)$$

where x_s is a slack variable.

All mass balance equations given by (2.5) can now be stated as a normally overdetermined equation system given as

$$A_m x_v = b_m - A_m b_1 \quad (3.6)$$

The dimensions are with q = mn and p = n(n + 2) as follows, A_m (q x p) and b_m (p x 1). The elements in the matrix A_m are given by $c_i(t)$, $c_i(t)$ and the differences $c_i(t)$–$c_j(t)$. The elements in the vector b_m are given by the tracer gas inlets $p_i(t)$.

the overdetermined equation system (3.6) can be fulfilled by introducing two non-negative error vectors x^p and x_n for positive and negative equation errors respectively, both with the dimension q. This gives

$$A_m x_v + x_p - x_n = b_m - A_m b_1 \quad (3.7)$$

The model parameter relations given by (2.4) can be stated as follows

$$A_r x_v = -A_r b_1 \quad (3.8)$$

The dimensions of the matrix A_r are (n x p). The elements in the matrix A_r are – 1, 0 or + 1. Each row contains n times – 1 and n times +1 if all flow parameters are free.

The loss function to be minimized is a summation of the errors in the mass balance equations given by the vectors x_p and a_n. Of course, there should be no penalty on the variable part of the model parameter vector x_v and the slack variable x_s used for the upper bound. The minimization is done under the constraints given by (3.5), (3.7) and (3.8).

Four simple interpolation methods have been tested to calculate the time derivatives. The first order forward difference turned out to be the best method, but the determined model parameters were not close to the actual values.

In a fifth model based method the time derivatives are calculated from earlier estimated or guessed model parameters and only different tracer gas concentrations in time. The tracer gas inlet p(t) is eliminated in (3.1) by using (3.2) which gives

$$dc(t) = A(e^{A}-I)^{-1}(c(t+1) - c(t)) \quad (3.9)$$

where the matrix A is given by $A = V^{-1}Q$. This method can be used iteratively. The formula (3.9) turns into a simple forward difference if the matrix A is small and diagonal (no interflows Q diagonal).

An alternative model based method is to integrate the mass balance equations (2.6) one or several sampling intervals. The integral of c(t) an p(t) becomes c(t + 1) – c(t) and p(t) for one sampling interval. The integral of c(t) can be computed as

$$\int_t^{t+1} c(s)ds = (I + AH)c(t) + HV^{-1}p(t) \quad (3.10)$$

where the matrix A is given as before $V^{-1}Q$ and where

$$H = I/2 + A/3! + A^2/4! + \ldots \quad (3.11)$$

4. Simulated Experiments

A three cell model is simulated with normally distributed measurement noise with zero mean and standard deviation 0.02. The model parameters are given in Table 4.1. Measurements were made at t = 1(1)15 time units. The tracer gas inlets $p_i(t)$ (i = 1,3) and the tracer gas concentrations $c_i(t)$ (i = 1,3) are given in Figure 4.1. without measurement noise for an active experiment. The tracer gas inlet patterns consist of three 5 time unit long parts. The three inlet patterns can then be described by the not linear dependent sequences 110, 011 and 101.

A decay experiment is also used as a comparison with the same number of measurements and with the same measurement noise. The initial values are 10.0, 5.0 and 6.7, which corresponds to an impulse of tracer gas with the same amount as used in the active experiment. Higher initial values will give better signal to noise ratio and thereby better parameter estimation. Lower intitial values will result in the opposite. Increased tracer gas injection in an active experiment will also improve the parameter estimation.

One important restriction when using a decay experiment is that the initial condition must not be equal to an eigenvector to the system matrix $A = {}^{-1}Q$.

Both mass balance equations and integrated mass balance equations are used. The calculations are iterated ten times for both methods. The volumes are both free and fixed, except for the decay experiment where the volumes have to be fixed. All flow parameters are free, even the interflows q_{13} and q_{31} which are zero in the model. All free model parameters are unbounded, except the basic physical bound (> 0).

The determined interflows, inflows, outflows, volumes and loss functions are given in Table 4.1. as follows

case	*experiment*	*method*	*volumes*
1	active	direct	free
2	active	direct	fixed
3	active	integrated	free
4	active	integrated	fixed
5	decay	direct	fixed
6	decay	integrated	fixed

The numbers in Table 4.1. show that determined model parameters differ only slightly from the real ones for the active experiments (cases 1–4) but the decay experiments (cases 5–6) result in several bad model parameters. The volumes seem to be most sensitive to noise.

Other simulations show that the model parameters are estimated correctly without any error when no measurement noise is added and that the model parameter error increases with increasing measurement noise.

The used standard deviation value of 0.02 should be compared with the tracer gas concentration levels around 1 unit. Assume that 1 unit corresponds to 500 ppm NO_2, then the standard deviation becomes 10 ppm NO_2.

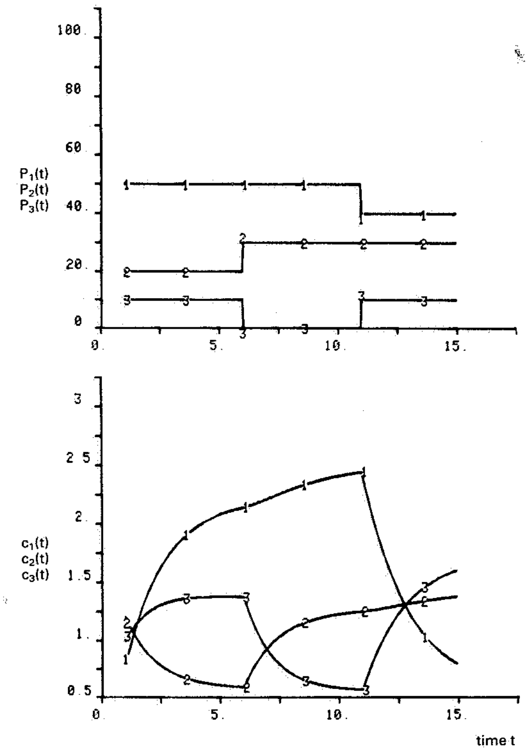

Figure 4.1: Tracer gas inlets $p_i(t)$ ($i = 1,3$) with shifted levels and tracer gas concentration $c_i(t)$ ($i = 1,3$) as a function of time t.

Table 4.1. Real and determined interflows q_{ij}, inflows q_{iu}, outflows q_{ui}, volumes V_i and loss function y for cases 1–6.

Para-meters	Real model	Case 1	2	3	4	5	6
q_{11}	−5.00	−4.78	−4.80	−4.73	−4.88	−9.70	−9.78
q_{12}	2.00	1.72	1.50	1.64	1.91	0.40	0.37
q_{13}	0.00	0.01	0.00	0.00	0.00	8.20	8.34
q_{21}	1.00	0.49	0.86	0.39	0.88	1.35	1.99
q_{22}	−11.00	−11.13	−11.15	−10.91	−11.17	−10.05	−9.83
q_{23}	3.00	3.77	3.50	3.56	3.49	1.57	0.44
q_{31}	0.00	0.03	0.00	0.10	0.00	0.55	0.00
q_{32}	4.00	4.07	4.05	3.96	4.03	4.02	3.81
q_{33}	−9.00	−9.07	−9.01	−9.15	−9.01	−9.77	−8.78
q_{1u}	3.00	3.05	3.30	3.08	2.96	1.11	1.07
q_{2u}	7.00	6.86	6.79	6.97	6.80	7.12	7.40
q_{3u}	5.00	4.96	4.96	5.09	4.97	5.20	4.98
q_{u1}	4.00	4.26	3.94	4.23	4.00	7.80	7.79
q_{u2}	5.00	5.33	5.60	5.31	5.22	5.63	5.65
q_{u3}	6.00	5.29	5.51	5.60	5.51	0.00	0.00
V_1	10.00	10.68	10.00	10.75	10.00	10.00	10.00
V_2	20.00	17.16	20.00	15.56	20.00	20.00	20.00
V_3	15.00	14.39	15.00	14.50	15.00	15.00	15.00
y		12.92	12.35	10.03	11.34	12.33	10.40

5. Further Research

The method presented is still more an idea than a method. It remains to investigate noise sensitivity further, to test different filtering methods, to use real measurements, to use other combined inlet and measurement patterns and to use other model parameter identification methods.

9th AIVC-Conference 'Effective Ventilation'

12–15 September 1988
Novotel Hotel, Gent, Belgium

Preliminary Notice

This conference will provide an opportunity to exchange ideas on both new developments and the operational performance of recently implemented ventilation techniques. The following key areas will be covered:

- New developments
- Airflow in buildings
- Demand control
- Air quality and energy implications
- Occupant perception
- Definitions
- Comfort
- Optimum airtightness
- Case studies
- Future trends
- Standards

Full programme and registration details will be published in the May edition of AIR, or can be obtained from your Steering Group Representative.

New AIVC Publications

AIVC-TN-23-88 IEA Annex VIII – Inhabitant Behaviour with Respect to Ventilation – a Summary Report

Reviewed by Martin Liddament

The results of IEA Annex VIII on Inhabitants Behaviour with Respect to Ventilation are now available and a comprehensive summary of this study has been published as an AIVC Technical Note.

The main objectives of this study were to:

- determine the behaviour of inhabitants and to correlate it to the outdoor and indoor climate.
- estimate the amount of energy lost due to such behaviour.
- study the motivation behind inhabitants' behaviour.
- study whether such behaviour can be modified and, if so, to estimate the resulting energy savings.

Figure 1 summarises the structure of the study.

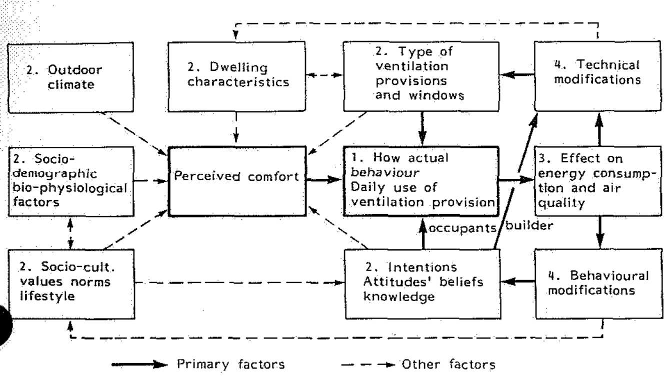

Figure 1

Central to this approach is the actual behaviour of occupants of dwellings with respect to airing and ventilation, known as 'HOW'. Chapter 1 of the report refers to this block and is concerned with how people behave. As such, information on 'HOW' people behave is meaningless without some insight into the reasons 'WHY' they behave as they say, do, or intend to do. The figure shows the main clusters of variables explaining behaviour and Chapter 2 relates these variables to actual behaviour. It can be assumed that behavioural intention and actual behaviour are strongly related to the sensory perception of comfort with respect to the micro-climate in dwellings. In other words comfort can be viewed as one of the main reasons for airing or ventilating dwellings or rooms. The use of windows affects ventilation rates in dwellings and consequently influences the amount of energy required for heating. Chapter 3 uses the ventilation patterns described in Chapter 1 to estimate ventilation rates due to window opening and the resulting energy consumption. Chapter 4 considers the possibility of modifying ventilation behaviour either directly by means of information campaigns or indirectly by technical improvements to ventilation equipment or window design.

Three methods were used to assess the actual behaviour of inhabitants. These were:

- survey techniques (interviews, postal questionnaires)
- self observation (diaries, log books)
- direct measurement (independent observations of open windows, photography, use of microswitches).

Each participating country undertook several projects concerned with inhabitants behaviour with respect to ventilation based on these measurement techniques.

Measurements included an analysis of window use throughout the year, including variation due to type of room and according to outside conditions. The diurnal use of windows was also investigated. Temperature relationships are shown in Figure 2 and clearly depict a declining yet significant use of windows as the outdoor temperature falls. Figure 3 illustrates window opening patterns over a 48 hour winter period. Typically, maximum window opening occurs in the morning, peaking at lunch time, after cooking and then declining until about 5pm, coincident with returning from work. Window opening decreases again during the evening and remains fairly constant during the night. In addition to the number of and period of window opening, the amount by which windows were opened was also analysed.

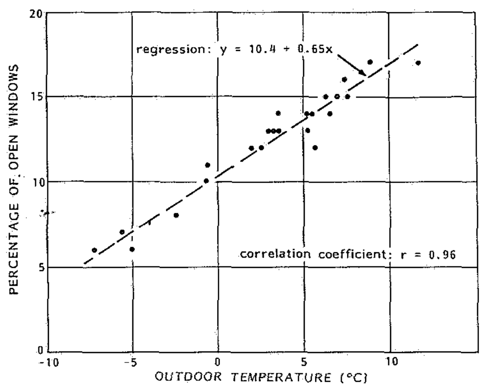

Figure 2: Temperature relationship

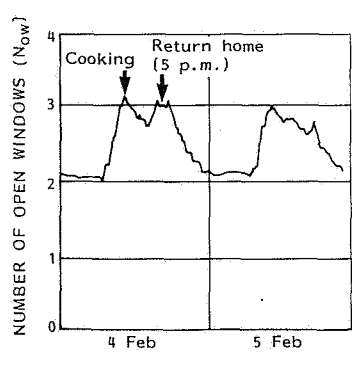

Figure 3: Window opening patterns over a 48 hour winter period

In relation to why windows were opened, perceived comfort was regarded as the most significant. Other factors included:

- temporal:
  biorythmic patterns during the day, season of the year, day of the week, previous thermal experience of the inhabitants;
- spatial:
  room characteristics (eg volume, contact with the outside, lightening level, chromatism, furniture type, position and type of windows and doors);

- environmental:
  perceived indoor air quality acoustic and odour characteristics, occupancy of the dwelling or room (number and characteristics of people), appropriation of dwelling or room, freedom to control the micro-climate;

- human:
  general sense of well being, socio-cultural factors, level of technical development;

- external:
  outdoor climate.

Other factors taken into consideration included the type and age of building, orientation of rooms, window design, level of insulation, method of heating and method of ventilation. In relation to the occupants themselves the study took in to account smoking behaviour, household activities, attitude to energy, moisture production and indoor climate preferences.

Chapter 3 of the report provides an overview of measured and estimated ventilation rates in houses, from which a simplified approach is derived that takes into account both the airtightness of the building and behaviour. The second part of this chapter deals with heat losses and seasonal heating demand due to window use. The effect of house type and insulation level is also analysed since the effect of variations in window use on energy consumption can be very important in relation to these aspects.

The results are used to present a simple nomogram to estimate ventilation rate due to occupancy combined with that due to the natural porosity of the building (Figure 4). This is based on the following:

(a) The 'basic' air change, or infiltration, rate of a dwelling, in the absence of window opening, may be derived from the air leakage at 50 Pa using the simple 'rule of thumb' below.

qv (inf) = qv (50)/K

where qv (inf) = the basic air change rate (infiltration) (h^{-1})

qv (50) is the air leakage at 50 Pa

K is a constant which has a value between 10 and 30 (a value of 20 may be regarded as typical). A guide to the appropriate choice of K is given below:

10 < K < 20: if a combination of at least two of the following characteristics is found:

- high rise building
- exposed situation
- averaged winter meteorological wind speed greater than 4 m/s.

20 < K < 30: if a combination of at least two of the following characteristics is found:

- individual terraced houses
- sheltered situation
- averaged winter meteorological wind speed greater than 4 m/s
- leakage area mainly situated at high level

(b) Based on observations it is assumed that there is no significant association between window use and the leakage characteristics

(c) Similarly, it is assumed that there is no significant association between window use and dwelling volume.

(d) Finally it is assumed that ventilation rate due to window use can be categorised as follows:

Low window use	– 0.0 to 0.1 ach
Averaged window use	– 0.1 to 0.5 ach
High window use	– 0.5 to 0.8 ach

Hence for an average dwelling of volume 250 m^3, this leads to the following air flow rates:

Low window use	– 0 to 7 dm^3/s (0 to 25 m^3/h)
Average window use	– 7 to 35 dm^3/s (25 to 125 m^3/h)
High window use	35 to 55 dm^3/s (125 to 200 m^3/h)

The report states that the upper limit of high window use is not the absolute maximum value but it will rarely be exceeded in practice.

The following example illustrates the use of the nomograph given in Figure 4. If the values of air leakage at 50 Pa (qv (50)) and K are known (eq. qv (50) = 1000 dm^3/s and K = 20) the top part of the figure is used to obtain the infiltration rate. Thus qv (inf) is found to be dm^3/s. By extending the qv (inf) value down to the lower part of the figure, the appropriate total air flow can be read off according to the degree of window use. In the example shown, moderate window use was assumed and a qv (tot) value of 50 dm^3/s was found.

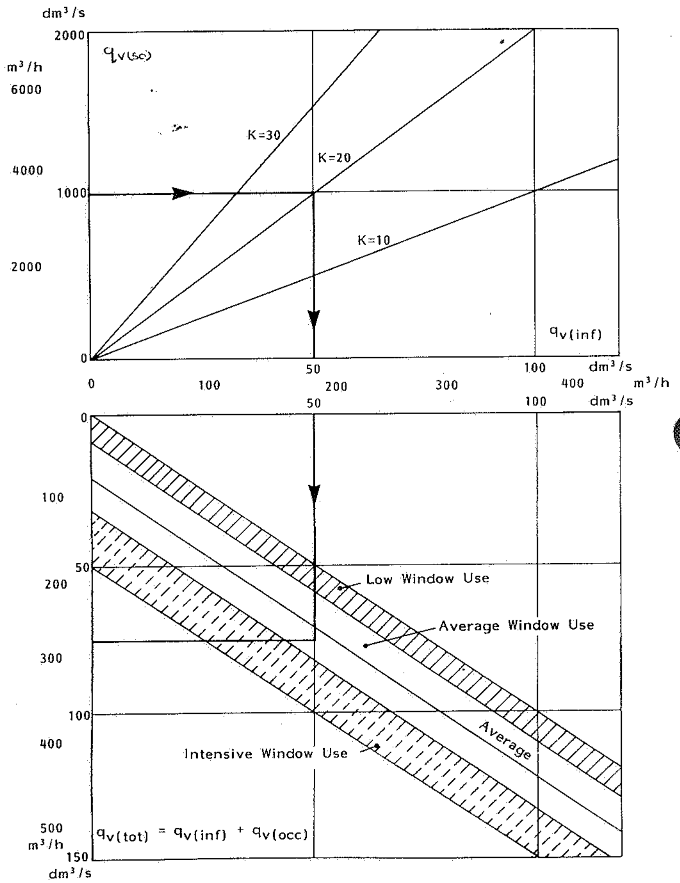

Figure 4: Nomograph for evaluating the influence of window opening

These data are then combined in the report to evaluate seasonal heating demand and the proportion of ventilation heat loss as a fraction of the total building heat loss. The results show that:

- in uninsulated dwellings, an average of 5 to 13% of the heating demand is due to window use. In uninsulated houses it is rarely more than 10%;

- in moderately insulated dwellings, an average of 15 to 33% of the heating demand is due to window use. It can reach 50% for high window use in apartments;

- in well insulated dwellings, an average of 25 to 50% of the heating demand is due to window use;

- in uninsulated dwellings, differences in window use cannot explain the large observed differences in heating demand.

- in well insulated dwellings, especially apartments, the ventilation rate due to behaviour has a large effect on heating demand. This means that a precise estimation of the heating in such dwellings is very difficult.

In the analysis on the modification of behaviour it is stated in the report that excessive window use could result in an additional 17,000 MJ being placed on the required heating load. Advice on controlling ventilation, which was shown to have an impact on reducing energy consumption included:

- in the living room:
  lower the thermostat one hour before airing;

- in bedrooms:
  air in the morning and before heating; 15 minutes airing is usually sufficient;

- in the kitchen:
  do not ventilate for long periods unnecessarily and do not heat before cooking.

Temperatures of 20°C in the living room and 15°C in the bedrooms were advised and it was suggested that internal doors were kept closed. Some of the findings following conservation advice to occupants were:

- energy conservation was more likely if occupants within a dwelling could agree on room temperature settings;

- the greater the subjects' interest in controlling energy use the more positive was the energy saving advice;

- the hypothesis that there is no significant relationship between consumers' knowledge of residential energy matters, their specific and general energy attitudes and their intentions to conserve energy, was rejected.

The overall conclusions of the study were:

- ventilation behaviour (its frequency and duration and its underlying motives) is related to the type of room in which it occurs;

- differences between households, in patterns of ventilation behaviour, appear to be expressed in the form of differences in the type of strategy used to control the indoor environment (eg. its temperature, air quality, and the presence of external noise) in relation to the outdoor environment;

- ventilation behaviour is highly weather dependent but this dependency varies by type of room. Also, considerable differences exist between households in their sensitivity to temperature variation;

- ventilation behaviour is influenced by the design characteristics of the dwellings and its heating system. This can occur by affecting the needs of occupants and by making ventilation easier to accomplish.

- the basic air change of a dwelling, in the absence of window opening, may be inferred from the air leakage at 50 Pa;

- there is no significant association between window use and air leakage characteristics;

- there is no significant association between window use and dwelling volume;

- analysis of data provided support for the simple categorisation of additional average seasonal ventilation rate due to window use;

- it is important to give information to inhabitants of dwellings so that they may be able to optimise their ventilation behaviour by balancing between low energy use and adequate indoor air quality. Since ventilation facilities must be available for inhabitants to use in an appropriate way, information campaigns need to be directed at builders and developers of dwellings and devices, as well as to government administrators;

- the adoption of energy conserving behaviour demands that the individual must perceive, favourably evaluate, understand and remember information given to him.

Copies of this Technical Note are available direct from the AIVC price £15.00 Sterling to organisations in Annex V and VIII, participating countries, and price £25,00 Sterling elsewhere.

The content was prepared by the task operating agent, Mrs Carine Dubrul of the University of Namur, Belgium. Countries participating in this task were Belgium, the Federal Republic of Germany, The Netheralnds, Switzerland and the United Kingdom.

Copies of the full report, comprising three volumes, are available from:

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University of Namur
Belgium

AIVC-TN-5.4-88
AIRGLOSS: Air Infiltration Glossary

(English-Dutch/Nederlands-Engels) Supplement

AIVC, January 1988

The fourth language supplement to the AIVC's glossary of 750 terms and their definitions related to air infiltration, its description, detection, measurement, modelling and prevention as well as to the environment and relevant physical processes. Previous supplements are available for German, French and Italian language terms.

New Literature List

No 10 Humidity- Carbon Dioxide- and Demand-Controlled Ventilation (32 References)

This updated Literature List contains a sample of records from the AIVC's bibliographic database, Airbase, on the subject of humidity-, CO2- and demand-controlled ventilation. Abstracts are reproduced in full, and copies of the relevant documents can be obtained from the AIVC on request.

Book Reviews

System Simulation in Buildings Proceedings of an International Conference

Hosted by University of Liège, Chateau Colonster, Liège, Belgium
1–3 December 1986

The Conference is organised in close cooperation with a project realized for the International Energy Agency: Energy Conservation in Buildings and Community Systems Programme, 'Annex 10: System Simulation'.

The main objective of this project is to fill in the gap which remains between the definition of a building 'net space heating or cooling demand', and the corresponding energy consumption of its HVAC equipment.

Papers are presented in ten sessions, comprising:

- Modelling principles
- Components modelling
- Building modelling for system simulation
- System simulation softwares
- System simulation applications (heating)
- System simulation applications (ventilation and air conditioning)
- Auditing, validation, future perspectives
- Optimal control
- Short communications and general discussion
- Forum and conclusions

The proceedings also include a forum of questions and answers about the presentations and a summary of conclusions for each session by Jean Lebrun, the conference organiser.

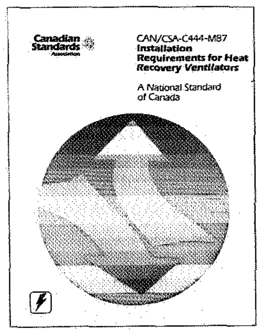
The proceedings are available, price 1,000 Belgian Francs (taxes and mailing fees included) from:

Prof Jean Lebrun
Laboratoire de Thermodynamique
Faculté des Sciences Appliquées
Université de Liège
Rue Ernest Solvay, 21
BAT C3
B-4000 Liège
Belgium

New Canadian Standard Installation Requirements for Heat Recovery Ventilators

CAN/CSA-C444-M87
Canadian Standards Association, June 1987

This is the second edition of CSA Standard C444, now CAN/CSA-C444, Installation Requirements for Heat Recovery Ventilators, and supercedes the Preliminary Standard published in 1985. The Standard applies to the installation requirements for self-contained ducted heat recovery ventilators that comprise factory assembled elements in which heat is transferred between two isolated air streams. The heat recovery ventilator will have a maximum rated capacity of not less than 25 L/s (50 cfm) and not more than 200 L/s (400 cfm), with a tolerance of +5% or +5 L/s 910 cfm), whichever is greater. It applies to heat recovery generators for installation in new and existing buildings and to equipment selection, minimum installation requirements, and information to be provided to the purchaser.



Forthcoming Conferences

1. 2nd International Workshop on 'Transparent Insulation Materials for Passive Energy Utilization'
(Organised by the German section of ISES)
24–25 March 1988
Freiburg
Federal Republic of Germany

Further details from:

Fraunhofer-Institut fur Solare Energiesysteme
Oltmannsstrasse 22
7800 Freiburg
Federal Republic of Germany

2. 9th AIVC Conference
'Effective Ventilation'
12–15 September 1988
Novotel Hotel, Gent, Belgium

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Air Infiltration and Ventilation Centre
Old Bracknell Lane West
Bracknell, Berkshire RG12 4AH
Great Britain
Tel: + 44 344 53123
Telex: 848288 BSRIAC G

3. Symposium on Air Change Rate and Air Tightness in Buildings
17–18 April 1989
Atlanta, Georgia
USA

Further details from:

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Recent Additions to *AIRBASE*
Quarterly bulletin of abstracts added to *AIRBASE,* AIVC's bibliographic database. Provides an effective means of keeping up-to-date with published material on air infiltration and associated subjects. Copies of papers abstracted in 'Recent Additions to *AIRBASE'* can be obtained from AIVC library. *Bulletin and copies of papers available free-of-charge to participating countries* only.*

GUIDES AND HANDBOOKS

AIC-AG-1-86 – Liddament, M.W.
'Air Infiltration Calculation Techniques – An Applications Guide'
A loose-leaf handbook divided into six chapters covering empirical and theoretical calculation techniques, algorithms, references and glossary of terms. *Available free-of-charge to participating countries* only, via your national Steering Group representative.*

HANDBOOK – Elmroth, A., Levin, P.
'Air infiltration control in housing. A guide to international practice'
An international guide to airtightness design solutions of great practical value to all those concerned with the design of pollution – free dwellings with low energy demands. *Unrestricted availability. Price £12.50 hard copy. Also available in microfiche £10.00.*

TECHNICAL NOTES

AIC-TN-5-81 – Allen, C.
AIRGLOSS: Air Infiltration Glossary (English edition)'
Contains approximately 750 terms and their definitions related to air infiltration, its description, detection, measurement, modelling and prevention as well as to the environment and relevant physical processes. *Available free-of-charge to participating countries.* Price: £10 to non-participating countries.*

AIC-TN-5.1-83, AIC-TN-5.2-84, AIC-TN-5.3-84, AIC-TN-5.4-88 – Allen, C.
'AIRGLOSS': Air Infiltration Glossaries (German, French, Italian and Dutch) Supplements.

AIC-TN-6-81 – Allen, C.
'Reporting format for the measurement of air infiltration in buildings'
Produced to provide a common method for research workers to set out experimental data, so assisting abstraction for subsequent analysis or mathematical model development. May be used directly for entering results and as a useful checklist for those initiating projects. Example of use of format is included as an appendix. *Available free-of-charge to participating countries.* Price: £6 to non-participating countries.* (Being reprinted.)

AIC-TN-10-83 – Liddament, M., Thompson, C.
'Techniques and instrumentation for the measurement of air infiltration in buildings – a brief review and annotated bibliography'
Four-section bibliography contains review papers, information on tracer gas techniques, pressurization methods and miscellaneous approaches. In addition the report contains a list of manufacturers of instrumentation currently being used in air infiltration investigations. *Available free-of-charge to participating countries.* Price: £15.00 to non-participating countries.*

AIC-TN-11-83 – Liddament, M., Allen, C.
The validation and comparison of mathematical models of air infiltration'
Contains analysis of ten models developed in five participating countries. These range in complexity from 'single-cell' to 'multi-cell' approaches. Also contains numerical and climatic data for fourteen dwellings compiled to produce three key datasets which were used in model validation study. *Available free-of-charge to participating countries.* Price: £15.00 to non-participating countries.*

AIC-TN-12-83 – Liddament, M.
Superseded by TN19 (see below).

AIC-TN-13-84 – Allen, C.
'Wind Pressure Data Requirements for Air Infiltration Calculations'
An up-to-date review of the problems associated with satisfying the wind pressure data requirements of air infiltration models. *Available free-of-charge to participating countries.* Price: £20.00 (price includes copy of TN-13.1) to non-participating countries.*

AIC-TN-13.1-84
'1984 Wind Pressure Workshop Proceedings'
Report of written contributions and discussion at Workshop held in March 1984, Brussels. *Available free-of-charge to participating countries.* Also available to non-participating countries (see note at TN-13 above).*

AIC-TN-14-84 – Thompson, C.
'A Review of Building Airtightness and Ventilation Standards'
Lists and summarises airtightness and related standards to achieve energy efficient ventilation. *Available free-of-charge to participating countries* only.*

AIC-TN-16-85 – Allen, C.
'Leakage Distribution in Buildings'
Examines those factors which can influence leakage distribution, including building style, construction quality, materials, ageing, pressure and variations in humidity. *Available free-of-charge to participating countries.* Price: £20.00 to non-participating countries.*

AIC-TN-17-85 – Parfitt, Y.
'Ventilation Strategy – A Selected Bibliography'
Review of literature on choice of ventilation strategy for residential, industrial and other buildings. *Available free-of-charge to participating countries.* Price: £20.00 to non-participating countries.*

AIC-TN-18-86 – Parfitt, Y.
Superseded by TN22 (see below).

AIC-TN-19-86 – Charlesworth, P.
'1986 Survey of current research into air infiltration and related air quality problems in buildings'
Fourth worldwide survey by AIVC containing over 200 replies from 19 countries. Produced in two sections: an analysis in tabular form of survey results, followed by reproduction in full of research summaries and list of names and addresses of principal researchers. *Available free-of-charge to particpating countries* only.*

AIC-TN-20-87
'Airborne moisture transfer: New Zealand workshop proceedings and bibliographic review'
Proceedings of AIVC's Moisture Workshop, held at BRANZ New Zealand in March 1987, with bibliographic review. *Available free-of-charge to participating countries* only.*

AIC-TN-21-87 – Liddament, M.W.
'A review and bibliography of ventilation effectiveness – definitions, measurement, design and calculation'
Reviews definitions of ventilation efficiency and outlines physical concepts, measurement methods and calculation techniques. Includes bibliographic and list of author affiliations. *Available free-of-charge to participating countries* only.*

AIC-TN-22-87 – Blacknell, J.
'A subject analysis of the AIVC's bibliographic database – AIRBASE', 5th edition
Comprehensive register of published information on air infiltration and associated subjects. The articles are indexed, and full bibliographic details of the 2,600 documents are given. Also includes the AIRBASE Thesaurus, as well as a list of principal authors.
Available free of charge to participating countries only.*

AIC-TN-23-88 – Dubrul, C.
'Inhabitants' behaviour with regard to ventilation'
This report summarises the IEA annex VIII study into the behaviour of occupants with regard to ventilation. It assesses the extent to which the actions of occupants can be modified in order to minimise energy use yet maintain adequate indoor air quality. Chapters cover observational techniques, energy loss due to window opening, reasons for window opening and the resultant energy savings from modified use of windows. *Price: £15.00 to participating countries, £25.00 to non-participating countries.*

LITERATURE LISTS – ***Listing of abstracts in AIRBASE on particular topics* related to air infiltration.**

- No. 1 Pressurization – Infiltration Correlation: 1. Models (17 references).
- No. 2 Pressurization – Infiltration Correlation: 2. Measurements (26 references).
- No. 3 Weatherstripping windows and doors (30 references) - updated.
- No. 4 Caulks and sealants (30 references) - updated.
- No. 5 Domestic air-to-air heat exchangers (25 references).
- No. 6 Air infiltration in industrial buildings (51 references) - updated.
- No. 7 Air flow through building entrances (22 references).
- No. 8 Air infiltration in commercial buildings (28 references).
- No. 9 Air infiltration in public buildings (10 references).
- No. 10 Humidity- Carbon Dioxide- and Demand Controlled-Ventilation (32 references).
- No. 11 Occupancy effects on air infiltration (15 references).
- No. 12 Windbreaks and shelter belts (30 references) - updated.
- No. 13 Air infiltration measurement techniques (27 references).
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- No. 15 Identification of air leakage paths (23 references).

Available free-of-charge to participating countries only.*

CONFERENCE PROCEEDINGS

- No. 1 'Instrumentation and measuring techniques'. Unrestricted availability. £35.00 sterling.
- No. 2 'Building design for minimum air infiltration'. Unrestricted availability. Price: £15.00 sterling.
- No. 3 'Energy efficient domestic ventilation systems for achieving acceptable indoor air quality'. Unrestricted availability. Price: £23.50 sterling.
- No. 4 'Air infiltration reduction in existing buildings'. Unrestricted availability. Price: £16.00 sterling.
- No. 5 'The implementation and effectiveness of air infiltration standards in buildings'. Unrestricted availability. Price: £22.00 sterling.
- No. 6 'Ventilation strategies and measurement techniques'. Unrestricted availability. Price: £16.00 sterling.
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