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The BRESIM technique for measuring air infiltration rates in large buildings

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BRESIM is a simplified technique to determine approximately the infiltration and ventilation rates of large and complex buildings. It is a complete and easy-to-use package comprised of robust, inexpensive equipment together with a protocol for its use, designed to help non-specialists carry out assessments of the ventilation performance of buildings. This paper describes briefly the underlying basis of BRESIM and illustrates its application in two quite dissimilar buildings.

Results from such measurements can be used to assess the need for, or the benefits of, remedial measures. BRE provides a BRESIM measurement service for building service engineers, architects, builders, surveyors and others concerned with the provision and control of ventilation in buildings.

INTRODUCTION

Adequate ventilation is essential for the health, safety and comfort of the occupants of buildings but excessive ventilation may lead to energy waste or discomfort. To provide guidance on achieving ventilation requirements, data on ventilation rates in existing buildings are needed for assessing remedial measures and for improving methods of predicting ventilation rates.

Air enters a naturally-ventilated building either through purpose-built openings like windows or as uncontrolled leakage (infiltration) through cracks and gaps. The majority of UK buildings, whether for commercial, public or domestic use, are naturally ventilated, yet there have been very few measurements in the larger, more complex buildings like offices.

Conventional techniques measure the concentration of a tracer gas as it is diluted by outside air. The tracer is forcibly well-mixed with the air and an even concentration maintained through out the building during measurement. However, there are problems in applying this technique to large and complex buildings, of which the most significant are:

- local variations in filtration,
- imperfect mixing of air and tracer gas, and
- practical difficulties in distributing the tracer gas and subsequently obtaining air samples.

Research work carried out at BRE has led to a relatively simple technique[1,2,3,4] which overcomes these difficulties. BRESIM is a simplified technique for

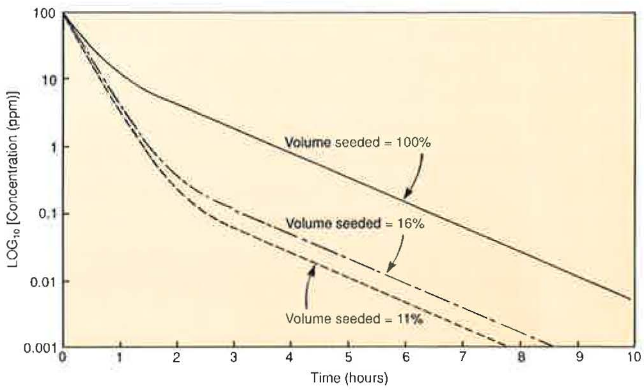

Figure 1 Concentration profiles in an office for various whole-building seeding patterns

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determining approximately the overall air change rate (ie total volumetric air inflow rate divided by the building volume) in large and complex buildings using a single tracer gas. It comprises equipment and an easily-implemented procedure designed to help non-specialists carry out assessments of the ventilation performance of buildings.

BRESIM TECHNIQUE

Theory

In a multi-celled building with n-cells (rooms, corridors, etc) the concentration, C(t), of tracer gas in any one cell will vary with time, t, according to:

$$C(t) = a_1 e^{-\lambda_1 t} + a_2 e^{-\lambda_2 t} + \ldots\ldots\ldots + a_n e^{-\lambda_n t}$$

where λ_1, λ_2 and λ_n are constants depending only upon the internal airflows. The coefficients a_1, a_2 and, a_n depend on the initial tracer gas distribution.

In a conventional ventilation measurement using tracer gas dilution, the tracer is introduced at the start of the test and is forcibly maintained well-mixed with the internal air. This reduces the above expression to only one term as follows:

$$C(t) = C_0 e^{-(Q/V)t}$$

Where C(t) is the concentration of tracer gas at time t (hours), C_0 is the initial seeded concentration at t = 0, Q (m^3/h) is the ventilation rate, and V (m^3) is the volume of the building. Plotting the logarithm of concentration as it falls with time produces approximately a straight line and the building's air change rate (Q/V) is determined by measuring the slope of this line. In large or multi-celled buildings it is generally not possible to ensure perfect mixing and the approach is invalid since the slopes of the semi-log plots of concentration profiles are influenced by air exchanges between spaces.

In such situations the slopes of the logarithmic plots of concentration (at any location) vary with time. However, studies[1,2,3,4] have shown that, in the long term, all of these slopes become nearly constant and approximately equal to the building's air change rate. This is illustrated in Figure 1, which shows the results of a computer simulation of a test in an office building with an air change rate of 1.0 per hour. The concentration in a single office is plotted on a logarithmic scale against time for both partial and uniform initial tracer distributions (seeding) within the building. It can be seen that in all cases the slopes are the same (0.84 per hour) after several hours and approximate to the air change rate. Note that by this time the concentrations have fallen by several orders of magnitude.

This approximate measure of the air change rate improves with better mixing of the air within the building and is influenced by the extent of unrestricted communication which exists between spaces. The long term (ie dominant) slope is independent of the initial tracer gas distribution and it is this feature which enables the BRESIM technique to be tolerant of a non-uniform dispersal of tracer gas within the building.

PROCEDURE

The procedure involves initially dispersing a tracer gas, usually sulphur hexafluoride (SF_6), within the building without paying particular attention as to how completely or uniformly this is acheived or maintained during the test. This is a significant departure from conventional techniques and makes artificial mixing unnecessary. The tracer is released from a commercially available portable aluminium cylinder (Figure 2) containing the liquefied gas, SF_6. The outlet valve is set to release the gas at a rate appropriate to achieve a set target concentration, say in approximately ten seconds, in an office.

Once the gas has been dispersed, a suitable period of time is allowed to elapse. The first of two averaged air samples is then collected in sample bags at one or more representative locations and the second at the same locations is taken after a further, but shorter, period of time. One of the BRE designed sampler units is shown in Figure 2. The user sets the time at which the first bag will be filled (several hours after dispersal), and a preset sequence fills each bag for ten minutes, with the second bag filled one-and-a-half hours after the first. Several sampler units are deployed in the building to give a check on the consistency of the results.

Figure 2 BRESIM equipment — gas bottle, sampler unit and bags

Tracer concentrations in the samples are subsequently analysed in the laboratory and the hourly air change rate (ach) is determined as follows:

ach = (1/T) × $\log_e$ [concentration (Bag1)/concentration (Bag 2)]

where T is the time (in hours) between the two samples. Concentrations are typically in the high parts per billion to low parts per million range and analysis is available at commercial laboratories or at BRE.

FIELD MEASUREMENTS

Buildings

As examples, two field measurements are described, one in a medium sized office building and the other in a large hangar building. The office building was naturally ventilated (Figure 3) and measurements were carried out in one section which was connected at one end to further interlinking sections. Offices were located on either side of central corridors which ran

Figure 3 Southwest elevation of office building

the full length of each of three storeys. The corridors were vertically linked at each end, through fire doors, via a common stairwell. The internal volume was estimated to be 5000 m^3. Room ventilation was provided by openable single glazed aluminium vertical sash windows.

The second, a hangar-type building sometimes referred to as a 'Marston' shed (Figure 4), was joined to a similar building at its southern end. A brick partition separated the two buildings, with access between them being via a steel horizontally-sliding, folding shutter door. Access with the outside was provided by two similar sliding doors, one in the eastern side at the southern end and one in the north face. The volume of the shed was estimated to be 4690 m^3.

Figure 4 North elevation (door) of hangar building

Test conditions

For the office building, the SF_6 tracer gas cylinder was preset in the laboratory to a pre-determined delivery rate and checked on the site with a simple flowmeter.. A target concentration was achieved in each room (and diffused) by slowly walking around for a set time (approximately ten seconds in a typical office), which was varied roughly in proportion to the room volume. This ensured that sufficient tracer gas was delivered to guarantee a detectable concentration of about 40 parts per billion (ppb) by volume in the second bag sample, allowing for an estimated upper limit (1.0 per hour from experience) for the air change rate in office buildings.

Each sampler unit was set to fill the first bag four hours after the tracer gas was dispersed (seeding).The timing sequence was initiated by switching on the mains power immediately after seeding was completed. Two units were placed along the corridor on each storey and one additional unit was placed on the stairwell on the second storey. All windows and external doors were closed since only the background ventilation (infiltration) was to be measured. All internal doors were wedged open to encourage dispersion of the tracer gas.

For the measurements in the hangar building a much higher concentration of tracer gas at parts per million (ppm) was used to enable on-site analysis using a portable infra-red analyser. A large gas cylinder was used to achieve a target concentration in ten minutes, seeding at a central location. This ensured the minimum detectable concentration (5 ppm) in the second bag sample, allowing for an estimated upper limit (again 1.0 per hour from experience) for the air change rate in a large modern factory-type shed.

Previous measurements in hangar type buildings have shown that internal air movements, which disperse the tracer gas, are sufficient to enable the first sample to be taken much earlier than for cellular office-type buildings. In this test, the sampler units were set to take the first sample only one hour after seeding with tracer. Four units were deployed, one in the centre of each quadrant of the floor area, between one and 1.5 m above the floor, with one unit (in the north east quadrant) placed at a height of approximately 3 m. All external doors and windows were closed.

Results and discussion

The decay rates measured at each location and the mean values (which are interpreted as the air-change rates), within both buildings, are shown in Tables 1 and 2 respectively. The measured air change rate is dependant on the prevailing wind and temperatures, and therefore these parameters are also summarised.

Table 1 Results for the office building

Storey/location	Concentration (ppb) Bag 1	Bag 2	Interval (mins)	Decay rate (≈ ach) (h^{-1})
3 (NW)	875	415	90.5	0.48
3 (SE)	1485	715	90.6	0.48
2 (stairs)	570	270	91.3	0.49
2 (NW)	505	170	93.7	0.70
2 (SE)	565	270	93.6	0.47
1 (NW)	745	410	93.1	0.38
1 (SE)	1075	575	90.9	0.41

Mean air change rate 0.49 per hour (standard deviation 0.10)
Wind 3.1 ms^{-1} from SW T_{int} = 22.5°C T_{ext} = 11.0°C

Table 2 Results for the hangar building

Location/height	Concentration (ppm) Bag 1	Bag 2	Interval (mins)	Decay rate (≈ ach) (h^{-1})
NE (3m)	157.5	57.8	93.6	0.64
SE (1m)	124.3	36.9	91.4	0.79
SW (1m)	84.4	26.7	90.9	0.76
NW (1m)	117.3	34.2	91.6	0.80

Mean air change rate 0.75 per hour (standard deviation 0.06)
Wind 1.3 ms^{-1} from N T_{int} = 29°C T_{ext} = 20.3°C

The results from both tests show that consistent air change rates can be measured for the two buildings, even though individual results may deviate from the general trend. This shows that it is desirable to take measurements in at least three locations to ensure confidence in the results. The results presented indicate a mean air change rate of 0.5 per hour for the office building and 0.75 per hour for the hangar building.

CONCLUSIONS

At present, there is very little information on infiltration rates in large and complex buildings. This is because no suitable procedure has been available other than for the specialist. Such information, however, is very important for many applications, including the assessment of remedial measures.

The BRESIM technique was designed and built to provide this knowledge. It is a robust, inexpensive and easy-to-use package comprising of both equipment and protocol. It will help the non-specialist to carry out measurements, for example, in any of the following ways:

— independantly; the user provides his own sampling equipment (which need not be automated) and tracer gas, carries out the measurements himself and arranges for sample analysis (eg by BRE or commercial laboratory) with advice from BRE where required,

— in collaboration with BRE; BRE provides the equipment and tracer gas but the user carries out the test (perhaps with BRE assistance) and BRE arranges (or itself performs) analysis,

— by BRE; BRE undertakes the measurements as part of its Technical Consultancy service.

The technique relies on 'long-term' decay rate measurements as an approximation to the overall air change rate of the building. Studies indicate that rates measured using the technique are typically within 30% of the true air change rate and that this approximation improves with increased internal mixing.

The two measurements described above are examples of a series of tests, carried out in four office and three hangar type buildings, which form part of an on-going research programme. BRE can advise, assist or undertake measurements for other organisations through its Technical Consultancy service.For information on this service, contact BRE Technical Consultancy, Building Research Establishment, Garston, Watford, WD2 7JR. Telephone (0923) 664800.

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