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PAPER S.2

EVALUATION THROUGH FIELD MEASUREMENTS OF BNL/AIMS, A MULTIPLE TRACER GAS TECHNIQUE FOR DETERMINING AIR INFILTRATION RATES.

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Synopsis

Brookhaven National Laboratory (BNL) in the USA has developed a multiple tracergas technique called BNL/AIMS (Air Infiltration Measurement System) for determination of air infiltration rates. The technique is applicable in occupied dwellings and might be promising for wide-scale measurements. This paper discusses the main results of field measurements made by the Danish Building Research Institute with use of BNL/AIMS. The results obtained are compared with the results of parallel measurements made in the laboratory and by using computer controlled field measuring equipment.

The aim of the measurements was to gain experience in the use of the BNL/AIMS equipment, and to obtain a basis for evaluation of the application and applicability of the method.

With regard to whole-house air infiltration rates, the results prove to be in good agreement with results from known methods. However, there seems to be some inconsistency regarding zonal air infiltration rates and air exchange rates between zones.

Introduction

Since the beginning of the 1970'ies focus has been on efficient sealing of new buildings and on developing better insulating materials and techniques for use in existing and new buildings.

The aim was not to reduce the ventilation rate in the buildings, but merely to reduce the air infiltration through random cracks in the building envelope. This allows for improved possibilities for controlling ventilation and air distribution within the building.

To gain full profit from these improved possibilities thorough knowledge about air infiltration and internal air transport within buildings is essential, taking the principle of ventilation and the behavior of the occupants into consideration.

The Brookhaven National Laboratory/Air Infiltration Measurement System (BNL/AIMS) is a tracergas technique, developed by Brookhaven National Laboratory (BNL) in the USA, based on the use of multiple tracers and passive sampling (ref 1). BNL/AIMS determines the average air infiltration rate. By zone-dividing a building and by simultaneous use of several different tracergases, the average zonal air infiltration rate and the air exchange rate between different zones can be determined as well.

With the object of obtaining better knowledge of the mechanisms of air infiltration, air movements and distribution of gaseous contaminants in multizoned occupied dwellings, The Indoor Climate Division at The Danish Building Research Institute and the Tracer Technology Center of Brookhaven National Laboratory have entered an agreement upon collaboration on testing the BNL/AIMS through field and laboratory measurements.

BNL/AIMS (outline of features)

Reference 1 gives a detailed describtion of the method and the measuring equipment, therefore only the outlines of the equipment, the application, and the performance will be given here.

Equipment

The equipment consists of passive tracer emitters (PFT's - Perfluorocarbon Tracers), glasstubes for passive adsorption of the tracergases (CATS - Capillary Adsorption Tracer Sampler), and, as a possibility for active collection of tracergases, a programmable sampler (BATS - Brookhaven Atmospheric Tracer Sampler). The CATS and the adsorptiontubes in a BATS are analyzed in the laboratory by means of gaschromatography.

Application

Prior to a measurement the building is divided into zones. A different type of tracergas is used in each zone. The sources are usually distributed with one per every 50 m^2 of living area.

Dependent on the expected air infiltration rate in the building and the duration of the measurement the CATS and/or BATS are placed 2-24 hours after the distribution of the sources. Also the CATS are distributed one per every 50 m^2 of living area.

The measuring period can be from a few hours to several months.

Performance

Reference 1 describes a series of laboratory tests of the performance of the equipment. The results show that the equipment generally is reliable with a satisfactory reproducibility, though caution to the temperature sensitivity of the source rate must be observed, about 4 per cent change per 1 ^oC at room-temperature.

The BNL/AIMS is based on the assumption that a constant emission of tracergas, after some time, depending on the ventilation rate in the building, will establish an almost constant concentration. However, the ventilation rate normally varies in time, and therefore the concentration of tracergas will vary as well.

The adsorption tubes performe a long term registration, and analyses of the tubes gives the average tracergas concentration in the measuring period. As it can be mathematically proved, calculation of the air change rate on the basis of the average concentration, using the equilibrium equation, will invoke an error. The reciprocal of the average concentration is less than the average of reciprocal concentrations, hence the BNL/AIMS has a negative bias.

Measurements

This paper describes measurements made in a two-storey flat, a kindergarten and a non occupied testflat set up in a laboratory (ref 3).

The Brookhaven National Laboratory (BNL) placed the BNL/AIMS measuring equipment at our disposal and they also carried out the gaschromatographic analyses of the adsorption tubes.

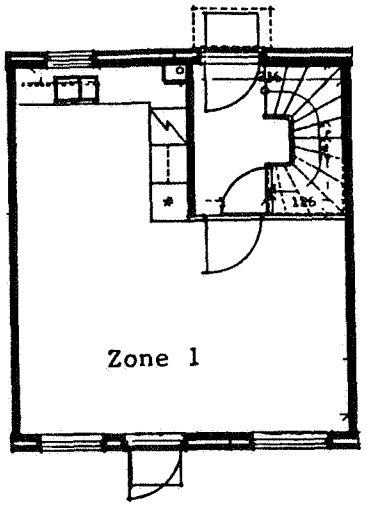
The field tests (two-storey flat, kindergarten) were made in collaboration with the Technological Institute of Denmark (TI), who carried out parallel measurements using their computer controlled measuring equipment (ref 2). This equipment performs a continuous measurement of the supply of outdoor air in up to ten different rooms simultaneously.

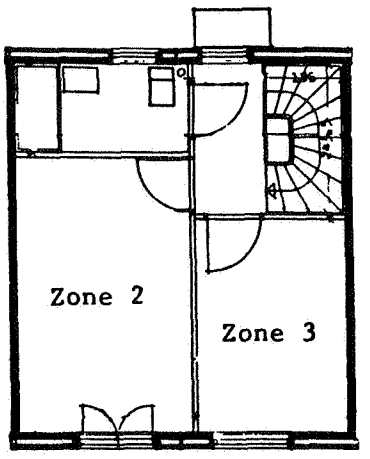
The tests in the laboratory flat were made in collaboration with The National Swedish Institute for Building Research (SIB).

Two-storey flat

The flat (fig 1) was divided into three zones. Zone 1 was first floor, zone 2 was master bedroom and zone 3 was small bedroom.

The measuring period lasted 94 hours. Active sampling by means of BATS were performed in 11 periods each lasting 8 hours (11 h - 19 h, 19 h - 3 h, and 3 h - 11 h). Table 1 shows the zone data, and table 2 the results of the measurements.





First floor Second floor

Figure 1. Two-storey flat. Floor plans.

Zone	Vol. (m^3)	Avg. temp.	Number of sources	Source type	Number of CATS	Number of BATS
1 First floor	90	21.0	2	PDCH	2	1
2 Master bedroom	35	21.0	1	PMCH	1	1
3 Small bedroom	23	21.0	1	PDCB	1	1

Table 1. Two-storey flat. Zonedata.

As seen from table 2 both the BNL/AIMS-measurement and the measurement made by TI showed that zone 1 had the greatest supply of outdoor air, subsequently zone 2 and 3. Zone 3 was, according to BNL/AIMS, an almost isolated zone. The standard deviations (SD's) stated in the table result from estimated standard deviations in the source strength (10 pct.) and zonevolume measurements (5 pct.) in the computer calculations and furthermore from differences in tracergas registrations in a zone.

Table 3 shows the air flow between the three zones. The largest air flow is from first floor to the master bedroom and vice versa and very small airflow to and from zone 3.

Figure 2 shows the measuring period divided into 9 8-hour periods corresponding to the working periods of the BATS (2 periods were cancelled due to malfunctioning of the BATS). In each period the concentration measured by BNL/AIMS, respectively TI, is shown.

Zone	Vol. (m^3)	BNL/AIMS (CATS) BNL +/- SD	BNL/AIMS (BATS) BNL +/- SD	TI
1 First floor	90	0.82 +/- 0.10	2.28 +/- 1.38	1.40
2 Master bedroom	35	0.43 +/- 0.21	-1.72 +/- 0.76	0.48
3 Small bedroom	23	0.02 +/- 0.07	0.03 +/- 0.25	0.22
Total	148	0.60 +/- 0.06	0.99 +/- 0.86	1.00

Table 2. Two-storey flat. Measured air infiltration rates (m^3/h per m^3). SD: Standard deviation, see text.

Zone to zone	Air flow (m^3/h)	Zone to zone	Air flow (m^3/h)
1 - 2	68.0 +/- 16.7	2 - 3	9.3 +/- 2.9
1 - 3	8.9 +/- 3.5	3 - 1	2.5 +/- 1.4
2 - 1	41.9 +/- 10.2	3 - 2	7.2 +/- 2.1
1 - outside	41.2 +/- 15.3	2 - outside	39.1 +/- 12.0
outside - 1	73.7 +/- 8.3	outside - 2	15.1 +/- 7.4
3 - outside	8.9 +/- 2.4		
outside - 3	0.4 +/- 1.7		

Table 3. Two-storey flat. Air flow (m^3/h) between zones.

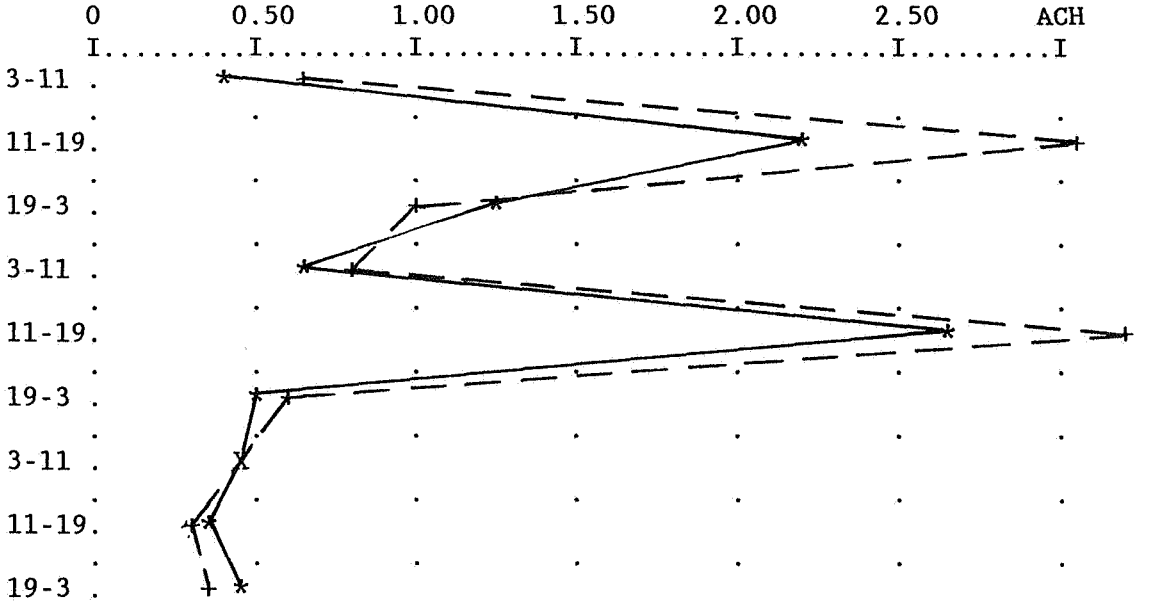


Figure 2. Two-storey flat. Whole-house average air infiltration rates (m^3/h per m^3), measuring period divided into BATS periods.
Continuous line: BNL/AIMS-BATS measurement.
Broken line : TI measurement.

Figure 3 shows the BNL/AIMS-CATS measurement vs. the TI measurement. The bars indicate the SD's of the BNL measurement. As previously discussed the BNL/AIMS has a negative bias. As appears from figure 2, significant variations in the air change rates did occur. This might explain the BNL/AIMS measurement using CATS being generally lower than the TI results (as seen from table 2 and figure 3) and the average of the measurement using BATS being closer to TI results.

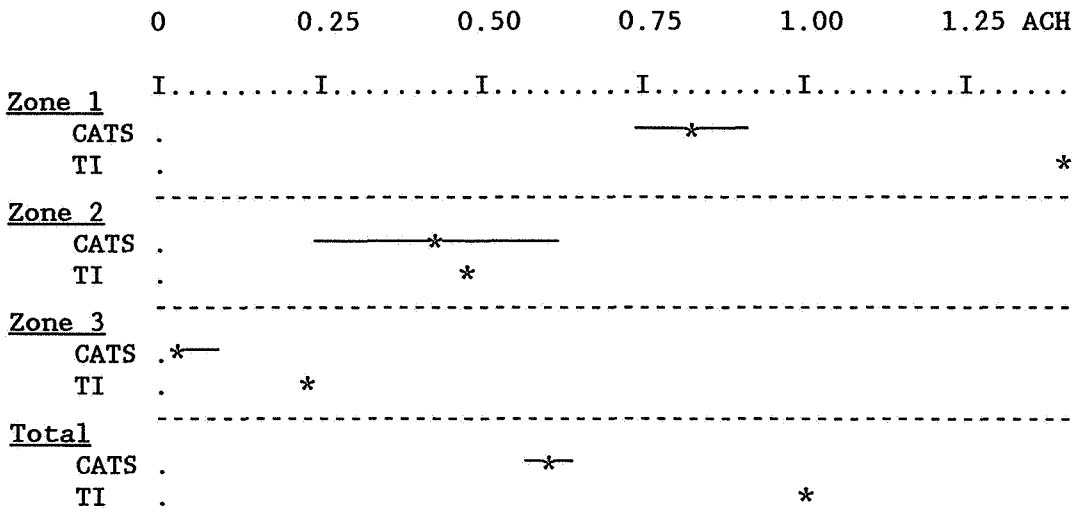


Figure 3. Two-storey flat. Measured air infiltration rates (m^3/h per m^3). BNL/AIMS-CATS measurement vs. the TI measurement.

Kindergarten

The kindergarten is a one floor building and it was treated as a 4-zone case. Each of the zones 1, 2, and 3 consists mainly of two play rooms. Zone 4 is a large room for common use with kitchen, staff quarters and toilet (fig 4).

The building is mechanically ventilated. Air is supplied to zones 1, 2, and 3 and air is exhausted from zone 4. There was no recirculation of air. The air passes from zone 1, 2, and 3 to zone 4 through doors and grilles placed above the doors. Exhaustion from toilets was deactivated during the measuring period.

Duration of the measurement was 10 days and nights, and BATS registered in two periods, each of 4 x 12 hours.

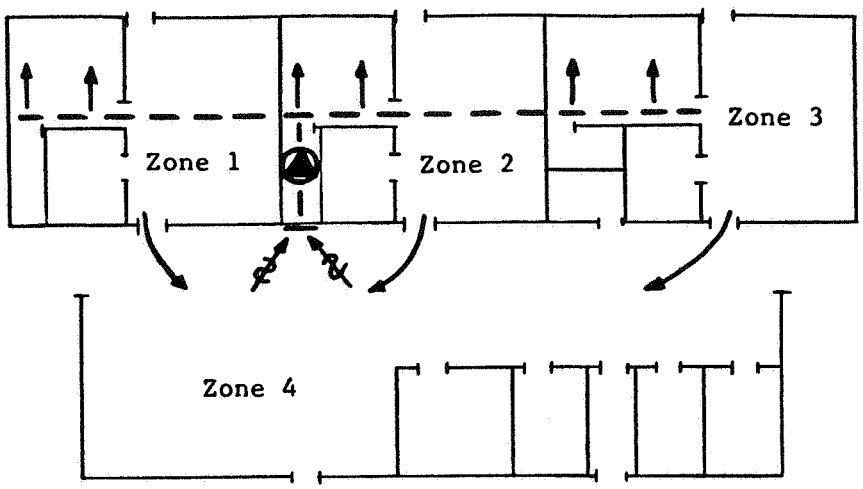


Figure 4. Kindergarten. Floor plan.

Zone	Vol. (m^3)	Avg. temp.	Number of sources	Source type	Number of CATS	Number of BATS
1 Rooms 101/2	175	22.0	2	PDCB	2	1
2 Rooms 103/4	175	21.0	2	PMCH	2	1
3 Rooms 105/6	230	21.0	2	PMCP	2	1
4 Room 118	850	21.5	4	PDCH	4	1

Table 5. Kindergarten. Zonedata.

As can be seen from table 6 and figure 5, the two measuring methods show the same tendency: largest air infiltration rate to zone 2, less to zone 1, 3, and 4.

Zone	Vol. (m^3)	BNL/AIMS (CATS) BNL +/- SD	BNL/AIMS (BATS) BNL +/- SD	TI
1 Rooms 101/2	175	0.95 +/- 0.26	0.80 +/- 0.18	1.04
2 Rooms 103/4	175	1.47 +/- 0.52	1.15 +/- 0.12	1.07
3 Rooms 105/6	230	0.58 +/- 0.14	0.51 +/- 0.08	0.86
4 Room 118	850	0.30 +/- 0.13	0.50 +/- 0.18	0.26
Total	1430	0.57 +/- 0.06	0.62 +/- 0.12	0.55

Table 6. Kindergarten. Measured air infiltration rates, (m^3/h per m^3). SD: Standard deviation, see text two-storey flat.

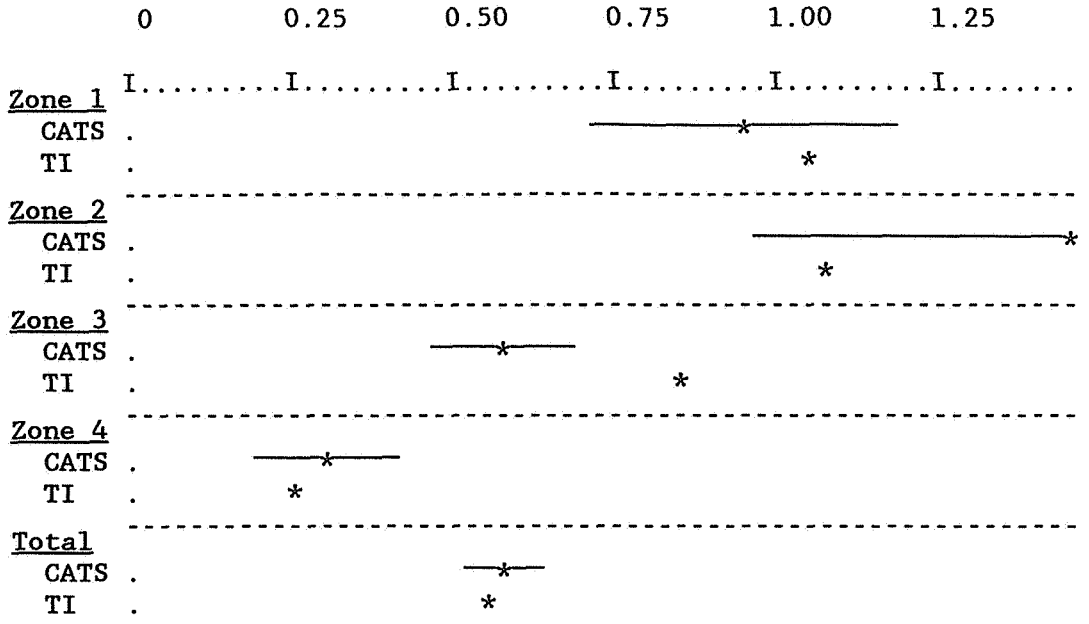


Figure 5. Kindergarten. Measured air infiltration rates (m^3/h per m^3). BNL/AIMS-CATS measurement vs. the TI measurement.

Results of measurements in zone 1 and 4 can be considered equal, and measurements of the whole-house air infiltration rate are almost identical.

The ventilation system can be characterized as well balanced (table 7), and as could be expected, air exchange rate between zone 1, 2, and 3 was low.

To be able to compare passive and active collection of tracergas, one of the two adsorption tubes in each of zone 1, 2, and 3 was placed near the BATS. Results (not shown in this paper) indicates that CATS and BATS register identical concentrations of tracergas.

Zone to zone	Air flow (m^3/h)	Zone to zone	Air flow (m^3/h)
1 - 2	8.6 +/- 8.4	3 - 1	-3.9 +/- 4.0
1 - 3	2.4 +/- 1.5	3 - 2	5.5 +/- 12.3
1 - 4	195.0 +/- 81.2	3 - 4	199.9 +/- 66.2
2 - 1	15.9 +/- 7.8	4 - 1	37.8 +/- 17.2
2 - 3	17.4 +/- 7.2	4 - 2	45.5 +/- 28.7
2 - 4	215.9 +/- 88.1	4 - 3	13.8 +/- 5.0
1 - outside	9.2 +/- 62.6	2 - outside	67.1 +/- 60.0
outside - 1	165.5 +/- 44.4	outside - 2	256.6 +/- 90.2
3 - outside	-35.2 +/- 49.3	4 - outside	770.0 +/-157.0
outside - 3	132.6 +/- 31.2	outside - 4	256.5 +/-106.1

Table 7. Kindergarten. Air flow (m^3/h) between zones.

In each of the play rooms in zone 1, 2, and 3 TI supplied tracergas and measured the concentration. In each zone a significant difference between air infiltration rates in the two play rooms could be observed, with considerable fluctuations in the air flow to the bigger room.

Figure 6 shows the whole-house air infiltration rate measured by means of BATS. As can be seen, steady state conditions prevailed during the first period, whereas conditions were more unstable during the second period.

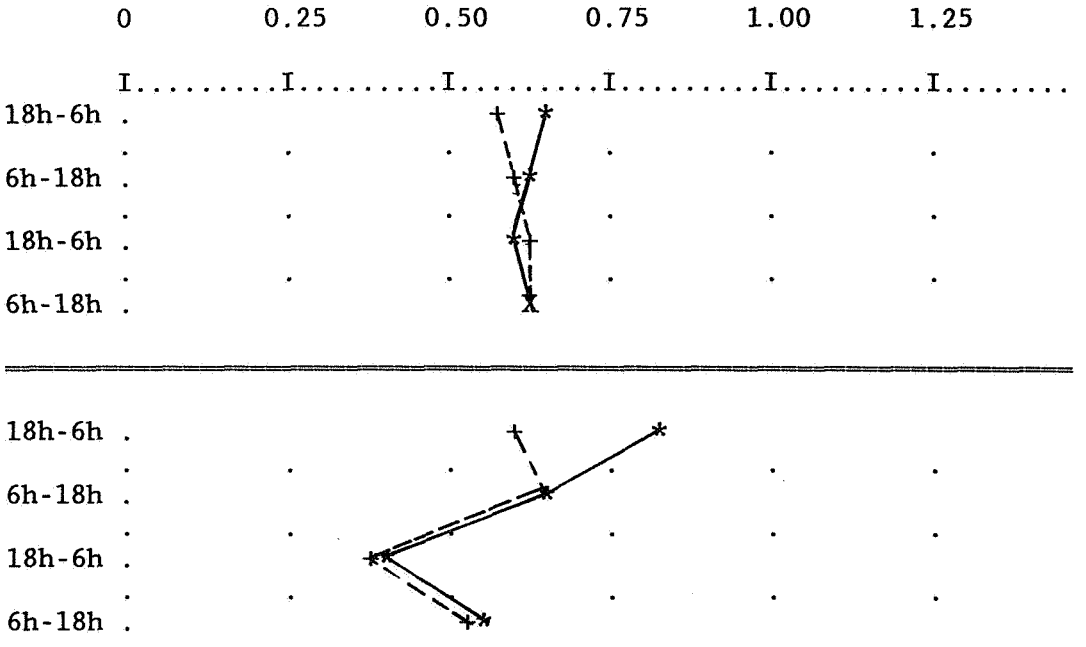


Figure 6. Kindergarten. Whole-house average air infiltration rates (m^3/h per m^3), measuring period divided into BATS periods.
Continuous line: BNL/AIMS-BATS measurement.
Broken line : TI measurement.

Test flat in Sweden

In the laboratory at the National Swedish Institute for Building Research (SIB) a full scale one floor test flat is built. The flat consists of living room, bedroom, kitchen, bath and hall. In the test flat it is possible - with great accuracy - to control and measure the supply of outdoor air to each room.

The aim of the measurements made in this flat was to test the performance of BNL/AIMS under controlled laboratory conditions.

Two sets of measurements were carried out: internal doors open

and internal doors shut. Each measurement lasted 3 days and nights. Only CATS were used, and the flat was treated as a four zone case. Zone 1: living room, zone 2: bedroom, zone 3: kitchen and zone 4: bath and hall.

Mechanical exhaustion from kitchen and bath (67 m^3/h and 28 m^3/h respectively) was active during both measurements. Outdoor air was supplied through openings in the ceiling in the living room and in the bedroom. Simultaneous measurements were carried out by the standard measuring equipment in the flat. Mixing fans were used during both measurements.

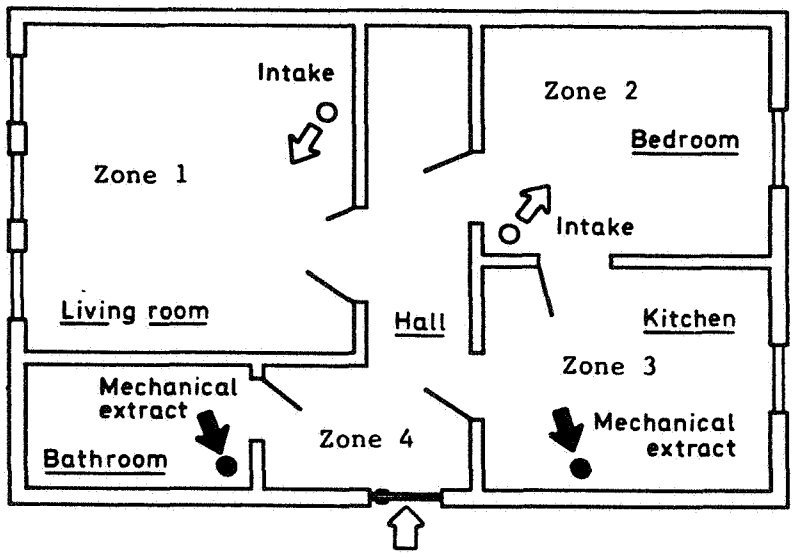


Figure 7. Laboratory flat. Floor plan.

Zone	Vol. (m^3)	Number of sources	Source type	Number of CATS	Number of BATS
1 Livingroom	56	1	PDCB	3	0
2 Bedroom	36	1	PMCH	2	0
3 Kitchen	35	1	PMCP	2	0
4 Bath/Hall	49	1	PDCH	3	0

Table 8. Laboratory flat. Zonedata.

Internal doors open

The measurements indicate a uniform distrution of tracergas in the whole flat. As could be expected: Air exchange rates between zones were comparatively high and directions of air movements diffuse, see table 9.

Zone to zone	Air flow (m^3/h)	Zone to zone	Air flow (m^3/h)
1 - 2	132.1 +/- 74.5	3 - 1	69.5 +/- 43.8
1 - 3	130.2 +/- 38.5	3 - 2	9.5 +/- 34.3
1 - 4	40.1 +/- 42.6	3 - 4	103.1 +/- 90.4
2 - 1	126.9 +/- 48.1	4 - 1	61.0 +/- 57.6
2 - 3	0.4 +/- 19.0	4 - 2	6.4 +/- 27.6
2 - 4	39.7 +/- 36.6	4 - 3	58.7 +/- 53.9
1 - outside	-3.0 +/- 37.7	2 - outside	10.3 +/- 24.9
outside - 1	41.9 +/- 11.5	outside - 2	29.3 +/- 12.1
3 - outside	17.1 +/- 37.0	4 - outside	60.9 +/- 55.1
outside - 3	9.9 +/- 4.4	outside - 4	4.2 +/- 5.0

Table 9. Laboratory flat. Air flow (m^3/h) between zones. Internal doors open.

Table 10 and figure 8 show the result of the BNL/AIMS measurement compared with the SIB measurement. As can be seen, there is good agreement between the two, especially with respect to the whole-house air infiltration rate.

Zone	Vol. (m^3)	BNL/AIMS (CATS) BNL +/- SD	SIB
1 Livingroom	56	0.75 +/- 0.21	0.95
2 Bedroom	36	0.81 +/- 0.34	0.94
3 Kitchen	35	0.28 +/- 0.13	0.11
4 Bath/Hall	49	0.09 +/- 0.10	0.05
Total	176	0.49 +/- 0.03	0.53

Table 10. Laboratory flat. Measured air infiltration rates (m^3/h per m^3). Internal doors open. SD: Standard deviation, see text two-storey flat. SIB: The National Swedish Institute for Building Research.

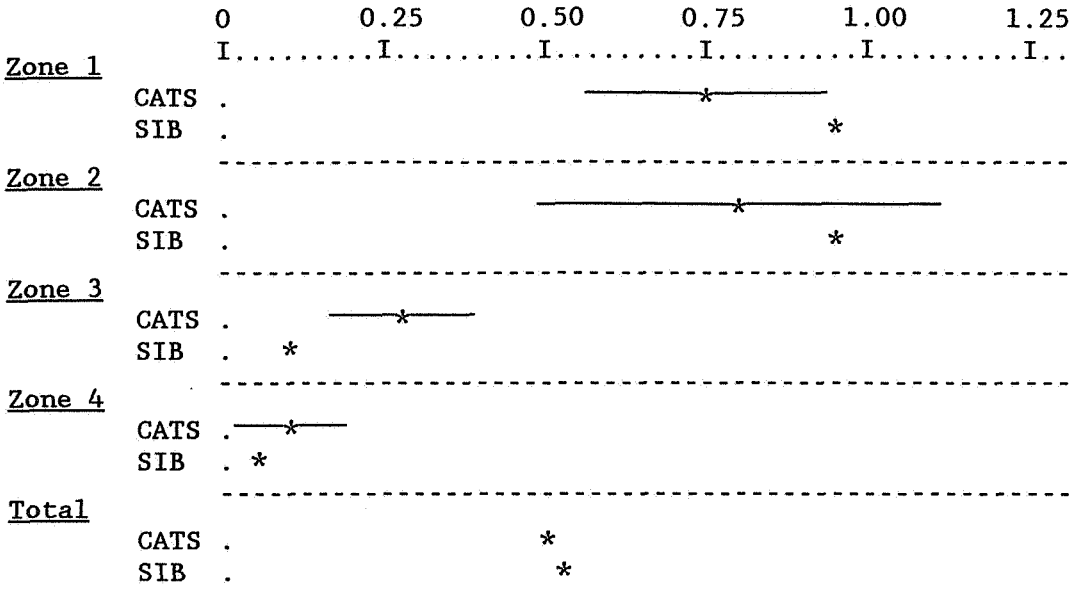


Figure 8. Laboratory flat. Measured air infiltration rates (m^3/h per m^3). Internal doors open. BNL/AIMS-CATS measurement vs. the SIB measurement. SIB: The National Swedish Institute for Building Research.

Internal doors closed

Internal doors were closed with a 10 mm fissure above doors.

Standard deviations of average concentrations measured of each tracer in each zone are below 10 per cent - not considering PMCP placed and measured in zone 3.

Zone to zone	Air flow (m^3/h)	Zone to zone	Air flow (m^3/h)
1 - 2	0.0 +/- 0.0	3 - 1	0.0 +/- 0.0
1 - 3	22.2 +/- 5.6	3 - 2	0.3 +/- 0.1
1 - 4	17.1 +/- 3.1	3 - 4	-0.1 +/- 0.0
2 - 1	0.1 +/- 0.0	4 - 1	0.1 +/- 0.0
2 - 3	27.6 +/- 6.9	4 - 2	0.2 +/- 0.0
2 - 4	9.8 +/- 1.7	4 - 3	0.1 +/- 0.0
1 - outside	-1.5 +/- 7.3	2 - outside	1.9 +/- 8.1
outside - 1	37.5 +/- 4.2	outside - 2	38.8 +/- 4.0
3 - outside	60.3 +/- 14.3	4 - outside	32.4 +/- 4.6
outside - 3	10.6 +/- 3.8	outside - 4	6.0 +/- 2.3

Table 11. Laboratory flat. Air flow between zones. Doors closed.

Significant air movements from living room and bedroom to kitchen and bath were observed (table 11), whereas no other air movements were observed. Air flows were small compared to the case with internal doors open.

Zone	Vol. (m^3)	BNL/AIMS (CATS) BNL +/- SD	SIB
1 Livingroom	56	0.67 +/- 0.08	0.75
2 Bedroom	36	1.08 +/- 0.12	1.06
3 Kitchen	35	0.30 +/- 0.11	0.20
4 Bath/Hall	49	0.12 +/- 0.05	0.15
Total	176	0.53 +/- 0.04	0.54

Table 12. Laboratory flat. Measured air infiltration rates (m^3/h per m^3). Internal doors closed. SD: Standard deviation, see text two-storey flat. SIB: The National Swedish Institute for Building Research.

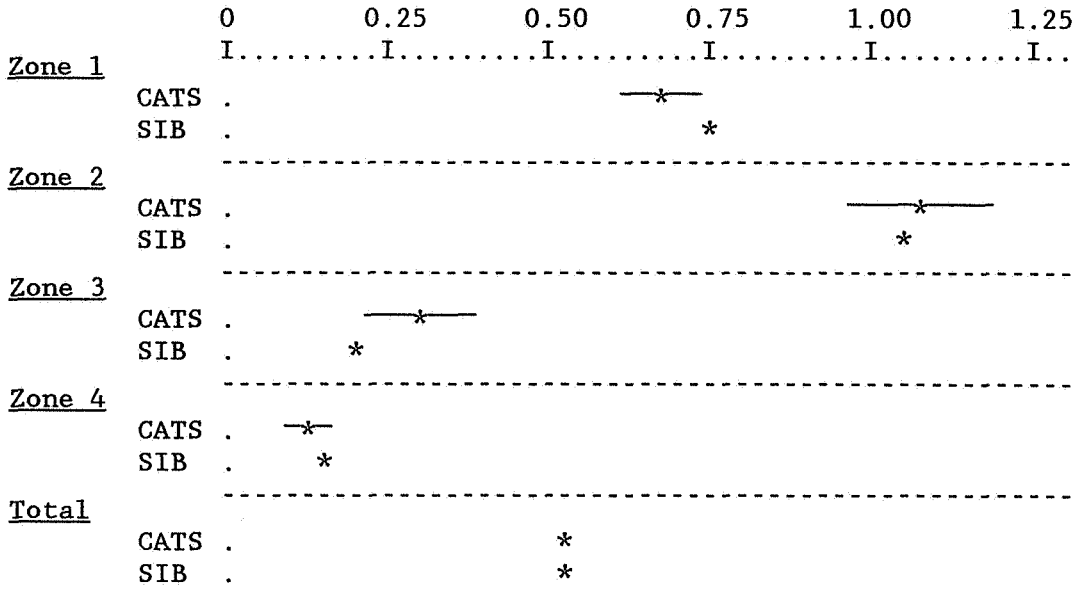


Figure 9. Laboratory flat. Measured air infiltration rates (m^3/h per m^3). Internal doors closed. BNL/AIMS-CATS measurement vs. the SIB measurement. SIB: The National Swedish Institute for Building Research.

Generally there is good agreement between measurements made with BNL/AIMS and by SIB. Exfiltration from zone 3 measured by BNL/AIMS was 60,3 m^3/h and from zone 4 32,4 m^3/h, which is close to SIB's preset exhaustion rates mentioned above.

Conclusion

Experience gained from field use of BNL/AIMS shows the measuring equipment to be easy and uncomplicated to handle. However, the importance of keeping the sources and the samplers well separated during storage and transportation (in order to aviod unintentional contamination of the samplers) is a minor irritant.

Placed in a dwelling the measuring equipment is practically invisible, thus interference with the occupants are not induced.

In spite of the very few measurements made, and even though the primary aim of this project was to gain experience with the practical use of the measuring equipment, the measurements do indicate the BNL/AIMS-method to be useful. Further investigations, theoretically as well as based on laboratory tests and field use, are however essential before the method can be widely accepted.

The mathematical multi-zone infiltration model used may be modified (in order to reduce the negative bias) through questionnaires to the inhabitants about their airing routines. Distribution of tracergases (single-zone and multi-zone) must be examined under laboratory conditions and comparisons to known methods must be made through extended field studies. In the future The Indoor Climate Division at The Danish Building Research Institute plans to carry out such investigations.

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