# EVALUATING MULTI-ZONE AIR FLOWS USING A RANDOM SEARCH TECHNIQUE

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**ABSTRACT**

This paper deals with the determination of air exchanges between rooms. Emphasis is put on the parameter assessment procedure using a random search technique.
Among the relevant topics we discuss the required accuracy of the measurements and to what extent the procedure is applicable.
They are of particular importance when models concerning air flow through windows are to be validated.
Computer simulations and laboratory experiments using the tracer gas $SF_6$ were carried out to meet the afore mentioned goals.

**INTRODUCTION**

The use of tracer gases to determine air change rates and interzonal air flow rates has become common practice (1,2) nowadays.
Several measuring systems were developed in the past.
In this paper dealing with the investigation into interzonal air flows, a main emphasis is put on the parameter assessment procedure by means of a random search technique according to Schwefel and using the tracer gas $SF_6$.
Relevant items are the required accuracy of the measurements and to what extent the assessment procedure is applicable.
This is of particular importance when reliable air exchange rate data has to be used in temperature and energy calculations.
In the case of air flows through windows induced by wind and temperature (3) one is interested in the total net flow through the opening integrated over an appropriate time step.
In energy calculation programs which typically use hourly time steps and hourly climatic data, averaged air flow rate values over periods on the order of one or two hours are of importance.
Our procedure for determining the averaged net flows (the unknown parameters in our procedure) starts from the well-known equation for multi-zone flows:

$$V_i \cdot \dot{c}_i = \sum_{j=1}^{n} R_{ij} \cdot c_j + F_i \quad \text{wherein:} \qquad (1)$$

$V_i$ = volume of room i
$R_{ij}$ = air flow rate from room j to room i
$F_i$ = tracer gas source in room i
$c_i$ = tracer gas concentration in room i

$$R_{ii} = -\sum_{j=1}^{n} R_{ij} \qquad i \neq j$$

In this model the air in the rooms is assumed to be well-mixed, although perfect mixing seldom occurs.

To account for this imperfect mixing phenomenon, we regard $V_i$ in 1 as additional unknowns (reflecting the so called "effective" volumes) rather than geometrically determined.
This implies that the right hand side of equation 1, being the tracer gas source, should be significantly different from zero in order to supply us with sufficient independent output data to warrant the resolution of all unknowns.
Provided we have established an initial condition, we can now solve equation 1 numerically to find:

$c_i(\underline{\alpha};t)$ = concentration in room i, calculated by the model
$\underline{\alpha}$ = parameter vector, containing all unknown $V_i$, $R_{ij}$.

Having measured

$c_i^p(t_j)$ = measured concentration in the proces at discrete times $t_j$,

we can proceed to find an optimal estimate of the parameters $\hat{\underline{\alpha}}$ by minimizing the difference between $\underline{c}^p$ and $\underline{c}^m$:

$$\mathrm{Min}(\hat{\underline{\alpha}}) \quad \int_0^T (\underline{c}^p - \underline{c}^m)^T \cdot (\underline{c}^p - \underline{c}^m)dt \qquad 2$$

where the integration over the measurement interval T must effectively be accomplished by numerical integration over discrete time intervals bounded by $t_j$.
The actual establishment of $\hat{\underline{\alpha}}$ can be accomplished by a variety of algorithms. In our research we used a random search technique.

**COMPUTER SIMULATIONS**

Prior to the laboratory experiments computer simulations were carried out to gain insight into the required measuring accuracy.
Both systematic and random errors in the concentration and in the tracer gas sources were taken into account.
In case of a single zone, error analysis is rather simple.
The solution of the mass balance takes the form:

$$c(t) = F/R + \exp(-Rt/V)(c_o - F/R) \qquad 3$$

Assuming uncertainties in F and c error analysis can be carried out by differentiating equation 2.
Taking this approach for two or more spaces rapidly tends to become too laborious, so the use of computer simulations seems to be more appropriate here.

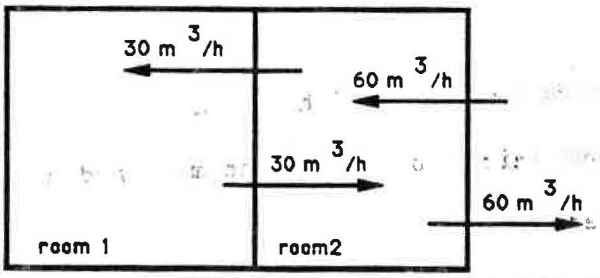


Fig. 1. Air flow rates

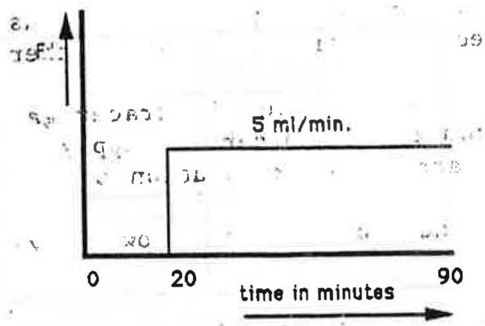


Fig. 2a. Tracer gas input in room 1

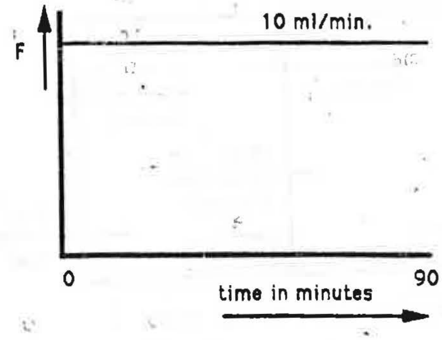


Fig. 2b. Tracer gas input in room 2

Table 1. Error analysis in a two-zone model.

| imposed errors in % | | | | resulting errors in % | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| room 1 | | room 2 | | $R_{11}$ | $R_{12}$ | $R_{21}$ | $R_{22}$ | $V_1$ | $V_2$ |
| c | F | c | F | | | | | | |
| +5 | +4 | +5 | 0 | -3 | -3 | -3 | -4 | -7 | -5 |
| +5 | +2 | +5 | -2 | -6 | -6 | -9 | -5 | -6 | -1 |
| +5 | -2 | +5 | +2 | -2 | -2 | -2 | -5 | -3 | -7 |
| +5 | 0 | +5 | +4 | -4 | -4 | -7 | -8 | -5 | -9 |
| -5 | 4 | -5 | 0 | -1 | -4 | -1 | -4 | -1 | -6 |
| -5 | +2 | -5 | -2 | 1 | 0 | 1 | 7 | 3 | 8 |
| -5 | -2 | -5 | +2 | 3 | -3 | 1 | 3 | 3 | 3 |
| -5 | 0 | -5 | +4 | 3 | 0 | -1 | 1 | 3 | 1 |
| in c also a random error of 3% occurs | | | | | | | | | |

Parameter estimations were thus carried out for the air exchanges between two spaces based on simulated (i.e. "true") concentration data $\underline{c}^P(t)$, contaminated by systematic and random errors.
Fig. 1 and 2 give the air flow rates and the tracer gas inputs.
Table 1 shows the accuracy in the air flow rate and in the effective volume when systematic errors in the concentration and in the tracer gas sources are assumed.
Additionally a random error with a variancy of 3% is imposed on the concentration.
The total proces time is 90 minutes with a sampling time of 4 minutes,

Inspection of the results reveil that maximum errors occur on the order of 10% in the interzonal air flow rates and effective volumes are induced.

**EXPERIMENTS**

Measurements were carried out in two adjacent rooms with volumes of 51 $m^3$ and 39 $m^3$ respectively.
Air supply to the rooms and interzonal air flows were accomplished by means of fans, see fig. 3.
The tests were performed with $SF_6$ tracer gas.

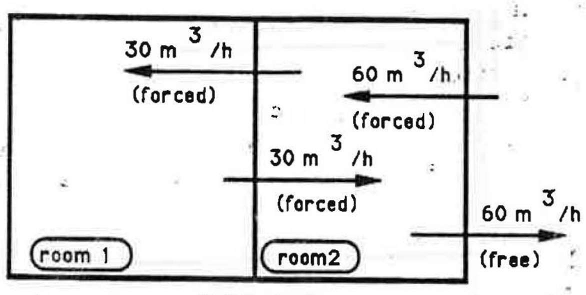


Fig. 3a. Air flows in case 1

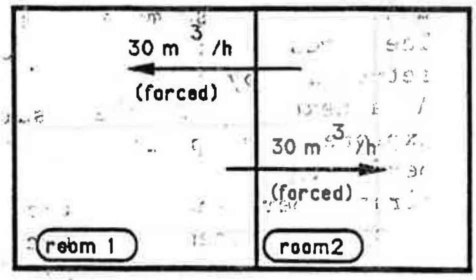


Fig. 3b. Air flows in case 2

Table 2. Estimated air flow rates and effective volumes for case 1.

| | $R_{11}$ $m^3/h$ | $R_{12}$ $m^3/h$ | $R_{21}$ $m^3/h$ | $R_{22}$ $m^3/h$ | $V_1$ $m^3/h$ | $V_2$ $m^3/h$ |
|---|---|---|---|---|---|---|
| estimated values | -52,4 | 51,6 | 37,2 | -113,7 | 50,1 | 37,5 |
| imposed values | -30 | 30 | 30 | -90 | 52 (geom) | 39 (geom) |

Table 3. Estimated air flow rates and effective volumes for case 2

| | $R_{11}$ | $R_{12}$ | $R_{21}$ | $R_{22}$ | $V_1$ | $V_2$ |
|---|---|---|---|---|---|---|
| estimated values | -36 | 36 | 36 | -40 | 51 | 38 |
| imposed values | -30 | 30 | 30 | -30 | 52 (geom) | 39 (geom) |

Concentrations were measured by a infra-red detector which receives air from the sampling points through a multiplexer. Sampling times were on the order of 4 minutes.
Although regularly distributed measuring points in a room showed only slight concentration differences small fans were installed in the rooms to approach a perfect mixing.
Also by gathering the air of these distributed measuring points a spatial average is achieved.
Tables 2 and 3 show the obtained results.

## CONCLUSIONS

From table 2 and 3 it can be concluded that there is a good agreement between the estimated and the geometrically determined volume, which was expected because of the imposed mixing, but the assessed air flow rates show a distinctly biased result.
The measured tracer gas concentrations however meet the simulated results derived from the estimated air flow rates and the effective volumes within an accuracy of one percent (not shown). This demonstrates that no better result for the parameter assessment is possible.
This seems to support Sherman's statement (4) that only multi-trace gas techniques are capable to determine the entire matrix of air flows uniquely.

Although the earlier mentioned computer simulations, including error analysis, arouse more promising expectations.
The investigation will be continued by carefully checking the experimental set-up and by further examining means of statistical accuracy.
As a next step in the ensuing research a multi-tracer gas approach will be explored by performing two dual experiments sequentially, i.e. by performing:
first experiment : source in room 1
second experiment : source in room 2
and performing a parameter estimation based on the outputs of both experiments.

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## References


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(2) [illegible] and Buildings (19[illegible]), pp. [illegible].

(3) [illegible]

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