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THE MAN-MACHINE-INTERFACE FOR THE AIR EXCHANGE MEASUREMENT SYSTEM MULTI-CAT

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ABSTRACT

The use of computers for data acquisition and analysis in air exchange measurements with tracer gases has become state of the art for the researcher.

However, for air exchange measurements in the field, reliable operation of the equipment and the proper reporting of the results are still points of concern. Here, the computer can assist the user in the correct handling of the tracer gas equipment, in dealing with unfavourable measurement conditions, and in the production of a readable report. These features are of special importance if the measurements have to be conducted by non-expert personnel.

This contribution describes the control and evaluation programs of the air exchange measurement system MULTI-CAT[1]. They provide a man-machine-interface, which achieves the mentioned goals by software driven guidance of the user through the whole measurement procedure. Its features include the input of building and measurement data, setup and performance of the measurement, data evaluation, report generation, error messages and help screens on demand.

1. INTRODUCTION

The use of computers for data acquisition and analysis in air exchange measurements with tracer gases has become state of the art for the researcher [1]. In many laboratories exist sophisticated computer controlled tracer gas systems for the measurement of the external infiltration rate of a building, the air change rate of single zones or the interzonal air flows in a multi cell building (see [8] and the literature cited there). A variety of different tracer gas methods is in use or under current development using one or more tracer gasses and various control and evaluation algorithms. Measurements are usually carried out under the supervision of the principal researcher and by staff, who was involved in the construction of the tracer gas system. The persons who conduct the measurements are often directly interested in the results, in order to include them into their own thesis, research report, etc. We can therefore expect reliable results from these often complicated measurement systems, since they are operated by persons who have expertise and motivation alike.

The situation is different for field measurements. Typically, the owner of a building needs some information on the air exchange. Sometimes, he may not even know exactly what he needs to know to answer his questions. He calls a consulting engineer in order to get the desired information at the lowest cost possible. The consulting engineer in turn asks a technician to perform quickly some tracer gas measurements. The technician responds to the best of his abilities and available equipment. The results are included in a report to the owner of the building, who has no other choice than to take these results for granted. A compilation of the problems usually encountered in field measurements is given in [4].

In some countries exist national standards for tracer gas measurements [5,6]. However it is not their intention to be detailed enough to protect the untrained operator from the pitfalls of his measurement device or the building under investigation. Due to this unpleasant situation, practioners in architecture and HVAC equipment often consider tracer gas measurements as an unreliable and uncorrect measurement method. This is a main obstacle to a wide application of air exchange measurements with tracer gas methods.

[1] MULTI-CAT: Multichannel Concentration Analysis of Tracers

A proven way to obtain reliable measurements is to support the operator of a tracer gas equipment with a computer controlled measurement and instrumentation system with integrated user guidance [4]. It is the experience of the authors, that also non-expert operators can conduct successful tracer gas measurements after a moderate training period (e.g. one day).

This contribution describes the control and evaluation programs for the air exchange measurement system MULTI-CAT. They provide a man-machine-interface, which assists the user in

- the preparation of the measurement,
- the correct handling of the tracer gas equipment,
- dealing with unfavourable measurement conditions,
- the evaluation of the collected concentrations profiles and
- the generation of a readable report

by software driven guidance through the whole measurement procedure.

2. GENERAL DESCRIPTION OF THE MULTI-CAT MEASURING SYSTEM

At the University of Siegen a mobile air exchange measuring system MULTI-CAT has been built and carefully examined [2]. It uses N_2O and SF_6 as tracer gasses for initial concentration decay as well as for constant emission measurement methods. This section describes its main components.

2.1 Equipment and Components

The experimental equipment consists of the following main subsystems:

- two gas analyzers (N_2O, SF_6)
- PC with keyboard, screen, printer and data acquisition interfaces
- tracer gas supply
- injection and sampling control unit
- operation mode control unit.

Additional necessary and important components of the system are electric power supplies, interface-adapters between PC and electronic devices, electronic control system, pumps and magnetic valves.

Key components of the measuring system are two IR gas analysers for N_2O and SF_6, which detect low concentrations (1 - 100 ppm) of both gasses with low cross-sensitivities to water vapor. The PC is able to control all activities needed to perform measurements and data acquisition. Even tracer gas injection and air sampling can be operated and controlled by PC. Because preparation phase and performance of measurements require different flow schemes, an operation mode control is necessary which alters gas flows and tubings according to the required conditions.

The system addresses up to eight different zones or rooms. For common measurements with single zone theory, the eight channels for sampling and injection are interconnected with main headers. Additional sensors for temperatures, indoor-outdoor pressure differences, wind speed and wind direction are available for further analysis and interpretation of air exchange measurements.

2.2 Measuring- and Evaluation Programs

Various programs enable the user to carry out measurements, evaluate and report their results and display them graphically. A detailed description is given in [3].

- The control program MEASURE is the interface between the operator and the hardware of the measurement system. It controls the measurement procedure, records measured data and performs preliminary data analysis with graphic visualization of data and results.

- The evaluation program EVALUATE is intended and suited to perform a detailed analysis of already measured data at any time after measurements. By this way, erroneous measurement data can be omitted or the evaluation procedure can be restricted to a certain time interval without invalid measuring points.

- The program REPORT compiles the input data and the results into a readable report and formats the measurement values (concentration, temperature, pressure difference, wind data) for the output to spread-sheet, statistical and graphic presentation programs.

- The program PLOT uses a commercially available graphic package (NAG PC Graphics Library) to display the recorded time series graphically on various output devices.

Especially the first two programs are characterized by a strong user support via screen driven guidance either directly or by help screens on demand. This guidance is available for all parts of the measurement and evaluation procedure, including control of tracer gas equipment, data acquisition, data analysis and report generation.

MULTI-CAT allows to produce standardized and comparable air exchange measurements under varying conditions. It has been used since the end of 1988 for air exchange measurements in houses with natural ventilation as well as with uncontrolled and demand controlled mechanical ventilation systems [7].

3. MULTI-CAT USER INTERFACE

Although MULTI-CAT has been designed to serve mainly for research purposes, it was our intention to provide a user interface which allows also the operation by non-expert users. Some general concepts for PC-controlled air exchange measurements are outlined in [4]. In this section, we will describe the MULTI-CAT man machine-interface following these guidelines.

The general rule is to restrict the required operator action to a minimum, leaving the rest to a thoroughly tested control program. Thus, a high degree of standardization is automatically achieved, since all measurements follow the same control flow as dictated from the software. It is, of course, not possible to exclude any possible error just by a smart control program. But the restriction of the operator to his actual duties prevents the detrimental effect of unnecessary actions. It also minimizes the required time for the user training.

3.1 Control Program MEASURE

3.1.1 Structure

The control program possesses a linear structure, leading the operator from the beginning to the end of the measurement in a logical step by step procedure. On the software side, the control program is coupled with a data base which provides as much a priori available information as possible and with a set of numerical routines including data evaluation, control algorithms and error analysis. On the hardware side, the control program interfaces to a injection and sampling unit for the control of the air and tracer gas flows and to sensors for tracer gas concentration and environmental data. These relations of the control program to the components of the tracer gas system are shown in Figure 1. Optional help screens are available at each program step. They are self explainatory, so that no manual is required during the measurement.

3.1.2 Data Base

The data base contains four sets of data:

1. data describing the tracer gas system,
2. data describing the building under investigation,
3. data describing the measurement setup on site,
4. results of the measurement and evaluation.

Data, which describe the tracer gas system are the number of available data channels, measurement ranges of the gas analyzer, flow meters, and other sensors, maximum tracer gas injection rates, etc. These informations are write-protected from the operator.

Data, which describe the building under investigation are room designations and volumes according to the building plan, etc. An input menue prompts the user for all necessary inputs. This insures that all required information for the operator is available. This information can be input prior to the measurement and stored in a parameter file. On site, the data of the building under investigation are read from the corresponding parameter file. Figure 3 shows the screen after the input of eight rooms with the designations G-4xx and their respective volumes. Each room is assigned to one of the eight channels of the injection and sampling system.

Data, which describe the measurement setup are the numbering of the sampling and injection channels, date, start time and duration of the measurement, etc. Date and time information are read from the internal clock of the PC, so that the operator is prompted only for a minimal amount of information.

Results of the measurement and evaluation are concentration values, air exchange rates, error bounds, etc. They are stored in the data base by the control program with no user action required.

The advantages of this structured data base are

- all relevant information is available for the measurement itself as well as for the measurement report,
- it is possible at all stages of the input to check the data for the feasability of the experiment.

The last point is extremly important. According to the tracer gas balance there is a close relationship between the room volume, the tracer gas injection rate and the concentration level. A meaningful measurement is only possible if the possible injection rates, the analyzer range and the room volume match. A simple data check after the input of data set 2 (building data) with data set 1 (tracer gas system data) reveals whether the injection rates are sufficient to yield a reasonable concentration in the rooms to investigate. It is thus possible to detect mismatches before the operator goes to the site. It is one of the tasks of the control program to perform such checks.

3.1.3 Injection and Sampling

Gas handling for injection and sampling is especially critical for measurement performance and, at the same time, it usually requires special skillness of the operator.

For the tracer decay method, certain quantities of tracer gas have to be released into different rooms at the beginning of the measurement. The actual values depend on the corresponding volumes and the desired concentration. The control program calculates the required masses of tracer gas for each room or zone if volumes and projected concentrations are given.

Figure 2 illustrates the injection system which is able to supply tracer gas by PC-control. It consists of a supply container, hand valve, pressure vessel with pressure gage and magnetic valves at the interface to various rooms.

For a given volume of the pressure vessel corresponds the amount of tracer gas to the gas pressure. Thus the pressure gage at the vessel indicates the amount of gas which is contained in the vessel. It is the task of the operator to fill the pressure vessel to the pressure calculated by the control program and to hit a key when the required pressure is reached. Then the control program opens the corresponding magnetic valve to the room and the specified mass of tracer gas is released. This procedure is repeated for all rooms.

A similar structure and procedure has been developed for the sampling system, which draws samples from the different rooms under investigation with the aid of PC-controlled pumps and magnetic valves. The sampling system is fully automated with no user action required.

The advantage of this kind of PC-controlled injection and sampling is that only a minimal amount of operator action is necessary. He can read the required information (pressure) from the PC-screen and does not have to perform mind calculations or organization tasks. Thus, sources for errors are minimized, as the operator cannot confuse room number, tube number, injection and sampling tube, required amount of tracer gas and so on.

Figure 4 shows the PC-screen during the injection into room G-406 (channel 7). The operator is about to input the desired inital concentration. The control program proposes a default value of 100 ppm. Once this value is accepted (or overridden), the required pressure in the vessel will be calculated and shown on the screen (see channels 1-6). If the operator is not shure at this point about the necessary actions on his part, he can obtain support from the help screen shown in Figure 5. Similar help screens exist for all stages of the control program where user action is required.

3.1.4 Data Acquisition

Measuring air exchange means measurement of tracer gas concentration in the course of time. After the injections have been accomplished, the important problems for any operator are:

- When to start with data acquisition of concentration measurements?
- How long data acquisition should continue?

The decision for starting concentration measurements with data acquisition is up to the operator and should be guided by two aspects: One is to meet the measuring range of tracer gas analyzer at its upper part, the second is to achieve uniform mixing in the room under investigation. The control program pauses at this point. The operator watches the analog concentration display at the gas analyzer and starts the data acquisition from keyboard, when the concentration shows a steady decay.

During the data acquisition, the operator can switch arbitrarily between two different screen outputs. A graphic screen shows the development of the concentration profile in real time. A numeric screen gives the current measurement values for concentration, temperature (9 channels), pressure difference (8 channels) and wind speed and direction.

The duration of data acquisition can be influenced by different ways and depends on measurement conditions:

- a priori input by the user/operator (This may be appropriate if a certain measuring plan has to be followed.),
- user/operator decision on site (May be caused by unforeseen events during measurements, requires graphic visualization of the measured values.),
- automatic (PC-controlled) termination of measurements, when concentration has dropped below a certain level.

3.1.5 Evaluation

After the data acquisition has been completed, a preliminary data evaluation is performed in order to inform the operator immediately about the outcomings of his measurement. The control program compiles on a single screen information on the performed parameter estimation, on the resulting air exchange rate including error bounds and on the average values of the measured environmental parameters. For constant injection measurements, the effective room volume is also calculated.

The screen output of a concentration decay measurement is shown in figure 6. The deviation of the measured concentration data from the fitted curve was so small (0.9 ppm) that the parameters of the fitted curve and the air change rate were calulated with very high precision (±1%). The temperatures varied from 4.7 °C (outside) to 20.2 °C (inside). Pressure differences were rather low with one pressure transducer (nr. 8) not connected.

3.2 Evaluation Program EVALUATE

The Control Program MEASURE performs a first stage of data evaluation. It is important to show any errors which may have been happened during the measurements. It gives an indication whether the measurement should be repeated or even omitted.

The second stage of evaluation possibilities is performed by the evaluation programm EVALUATE. It aims at investigations which have to performed any time after the data acquisition. It has access to the existing data bases from previous mesurements. EVALUATE uses the same numerical procedures as the evaluation part of the control program MEASURE. Furthermore it allows to screen the concentration profiles for any events that could make the measurement unreliable, e.g poor mixing or accidental opening of doors and windows. Faulty sections can be excluded from the data analysis. The results of the evaluation program are added to the data base.

3.3 Programs REPORT and PLOT

Generation of a report must be a part of the whole measurement procedure. REPORT uses a standardized reporting format presenting a summary of the measured data. This summary should be given not only as a collection of numbers but as a readable text. Furthermore interfaces the reporting program to a word processor for special editing and report generation purposes. REPORT has access to all data stored in the data base. Data not suitable for being printed in a report (e.g. concentration samples) are stored in separate data files for further processing, like graphical representation with the program PLOT. It is able to display time series data (tracer concentration, environmental parameters) on various output devices.

Figure 7 shows the skeleton of an output of the program REPORT (same measurement as figure 6). It can be used in any word processor to produce a complete report on the measurement. The graphical result of some features of the program EVALUTE are shown in figure 8. Here, a window was opened in the course of a concentration decay measurement. A separate evaluation of the concentration curve before and after the opening reveals the different air change rates.

4. CONCLUSIONS

The contents of this contribution can be summarized in four points:

- Measurements of air change rate are not that easy as methods may suggest, because boundary conditions and information transfer can be a problem.
- There exist general concepts for measurement procedures which avoid or at least reduce the encountered problems by using PC-assistance.
- A measuring system MULTI-CAT for air exchange measurements and belonging environmental data following most of these concepts has been operating since two years.
- Experiences in practice collected from measurements in real houses with trained student helpers and technicians are very positive. Sufficient expertise for performing measurements and evaluation is acquired by the operating personnel after a one day training period only.

Therefore, air exchange measuring systems with PC-controlled instrumentation, measurements and evaluation are strongly recommended. They allow to conduct measurements easier and could lead to more widespread application, thus creating and increasing data bases for air infiltration and exchange research. Moreover, better evaluation techniques including the calculation of error bounds and standardized methods for better comparison of results can be introduced.

5. ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Fig. 1: Control Program for Air Exchange Measurements and its Interfaces.

Fig. 2: Scheme of PC-controlled Injection System.

Fig. 3: PC-screen: interactive input of building data

Fig. 4: PC-screen: interactive tracer gas injection

Fig. 5: PC-screen: help screen for tracer gas injection

Fig. 6: PC-screen: results of data evaluation

Fig. 7: Reporting format

Fig. 8: Example of advanced data evaluation and graphical representation

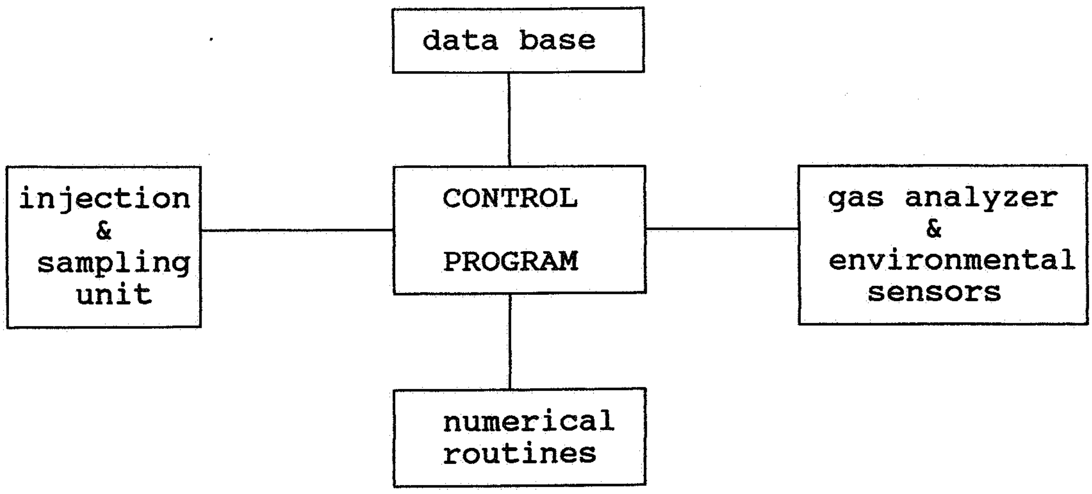

Figure 1: MULTI-CAT Control Program and its Interfaces

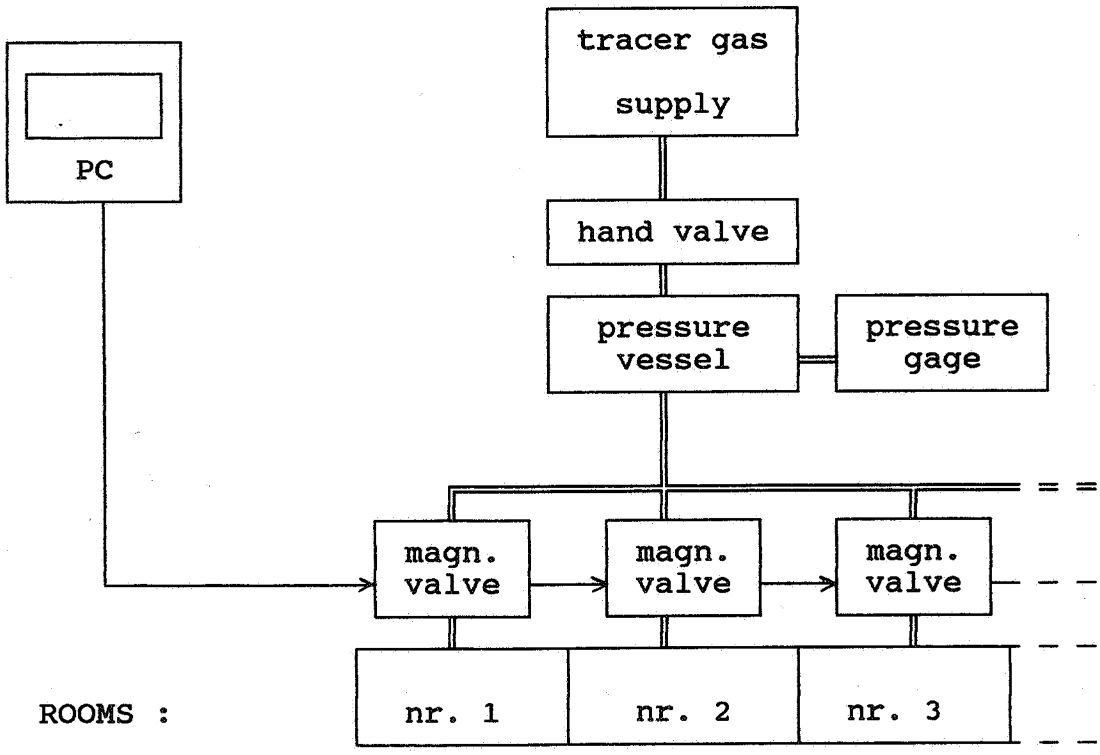

Figure 2: PC-Controlled Injection System

M U L T I - C A T (C) Prof. Heidt 1988

Specification of the rooms to be measured:

name of room	number	volume (cubic meters)
G-409	1	101.00
G-411	2	83.00
G-401	3	64.00
G-402	4	65.00
G-403	5	51.00
G-404	6	88.00
G-406	7	47.00
G-407	8	105.00

Type F1 for help, Bild to proceed

Figure 3: PC-screen: interactive input of building data

M U L T I - C A T (C) Prof. Heidt 1988

Initial tracer gas injection into the specified rooms:

name of room	number	init. concentration	required pressure
G-409	1	100	3.4
G-411	2	100	2.8
G-401	3	100	2.1
G-402	4	100	2.2
G-403	5	100	1.7
G-404	6	100	2.9
G-406	7	100	

Type F1 for help, Bild to proceed

Figure 4: PC-screen: interactive tracer gas injection

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M U L T I - C A T          (C) Prof. Heidt 1988

Initial Tracer Gas Injection:

Follow these steps for each room:

1. Type in the desired initial concentration (in ppm).
2. Type Bild
3. The program shows you the required pressure (in bar) for the vessel
   and opens the valve into the current room.
4. Close the hand valve at the pressure vessel.
5. Fill the vessel with tracer gas up to the required pressure.
6. Close the valve at the tracer gas container.
7. Open the valve at the vessel to release the tracer gas into the room.
8. Wait a few seconds.
9. Close hand valve at the vessel and type Bild  to proceed.

Type F1 to return
```

Figure 5: PC-screen: help screen for tracer gas injection

M U L T I - C A T   (C) Prof. Heidt 1988

CALCULATION OF THE RESULTS:

curve fitting for concentration data c(t) = A * exp (B*t) + C A = 47.5 ± 0.0 ppm B = -1.0 ± 0.0 1/h C = 0.0 ppm std. deviation of data = 0.9 ppm				air change rate: dyn.: n = 1.0 ± 0.0 1/h (± 1%)					
sensor nr.	0	1	2	3	4	5	6	7	8
temperature (°C) pressure diff. (Pa)	4.7	20.2 -0.6	19.7 0.5	18.0 0.6	19.1 1.2	19.0 0.8	18.9 -0.4	18.3 1.1	17.9 -50.0
wind data: (average values) speed = 1.0 m/s					direction = 34°				

Type Bild↓ to proceed

Figure 6: PC-screen: results of data evaluation

```
------------------------------------------------------------------------
                              M U L T I - C A T
------------------------------------------------------------------------
date : 1-9-1990            begin 11:8:17 h                 file: 090190il
------------------------------------------------------------------------
user input:

measurement procedure:

method                 : initial injection
duration               : 1200 s
sample spacing         : 1 s
minimal concentration : 2 ppm

 room nr.          room name             volume/m**3

     1               G-409                  101.00
     2               G-411                   83.00
     3               G-401                   64.00
     4               G-402                   65.00
     5               G-403                   51.00
     6               G-404                   88.00
     7               G-406                   47.00
     8               G-407                  105.00

total number :   8           total volume : 604.00 m**3
------------------------------------------------------------------------
description of measurement :

date : 1-9-1990         begin  11:8:17 h         actual duration : 1200 s

                      number of values        min.              max.

concentration [ppm]         1201              34.40             48.60
------------------------------------------------------------------------
results:

parameter estimation  c(t) = A * exp(B*t) + C        range:     0 to 1200 s
                        A =  47.51 ±  0.00 ppm
                        B =  -0.99 ±  0.01 1/h
                        C =   0.00 ±  0.01 ppm

standard deviation: data from fitted curve 0.92 ppm
                    gas analyser            1.00 ppm
                    flow meter              2.00 1/h

air change rate     dynamic 1.0 ±  0.0 1/h (± 1.0 %)

total volume        nominal  604.00 ±  0.00 m**3

----------------------------------------------------------------------
                 temperature (°C)                  pressure (Pa)
room          min.      ϕ       max.           min.      ϕ        max.

  0           4.57    4.73     4.86
  1          20.10   20.18    20.25           -0.66    -0.58    -0.50
  2          19.62   19.67    19.72            0.43     0.54     0.62
  3          17.84   18.04    18.24            0.48     0.64     0.74
  4          18.91   19.06    19.22            1.15     1.22     1.34
  5          18.92   18.96    19.00            0.65     0.84     1.10
  6          18.89   18.93    18.99          -17.40    -0.35     0.83
  7          18.19   18.31    18.37            1.06     1.15     1.22
  8          17.87   17.90    17.92          ******    *****    *****
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Figure 7: Reporting Format

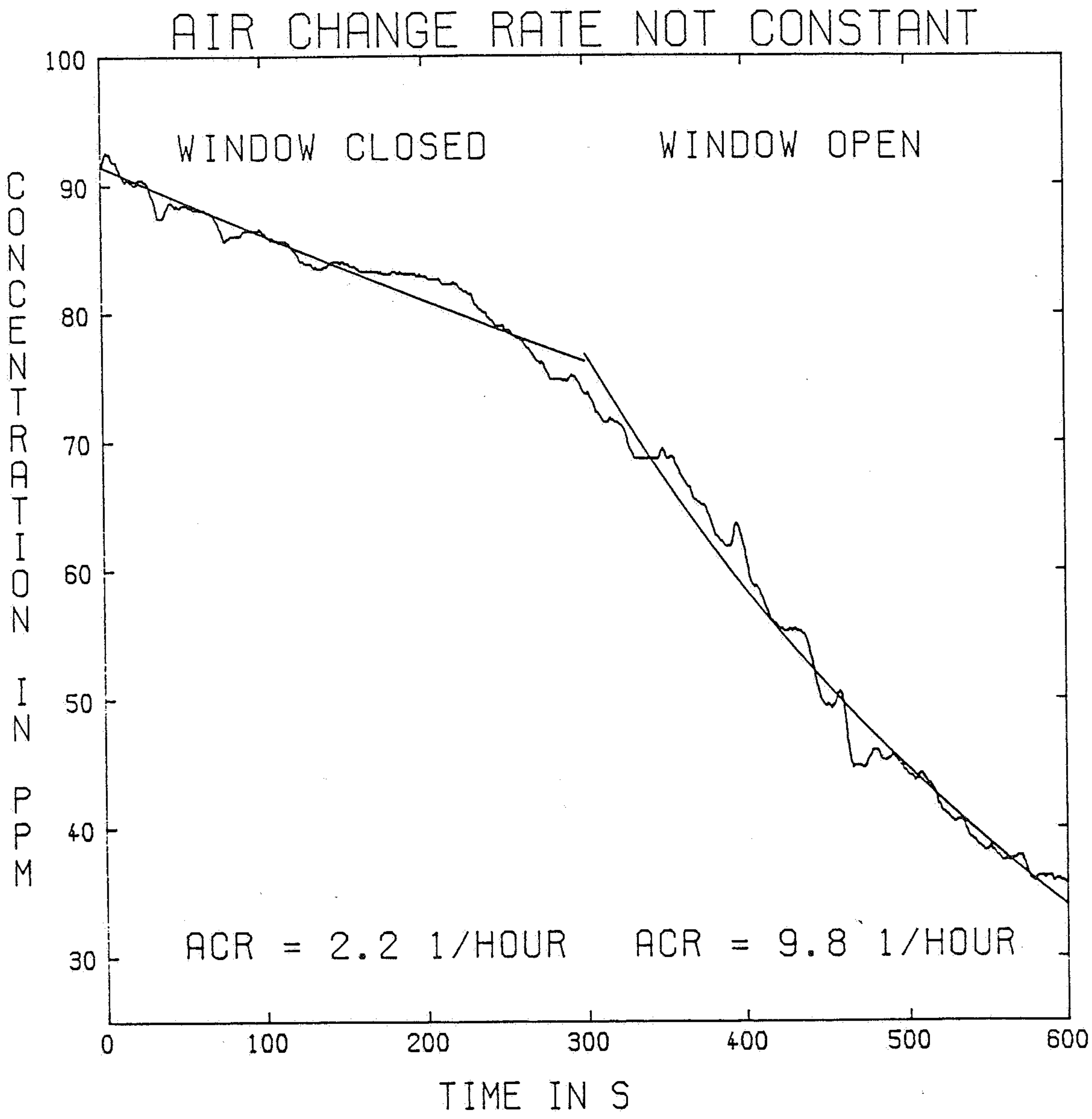

Figure 8: Example of advanced data evaluation and graphical representation