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Comparison of Multizone Air Flow Measurements and Simulations of the LESO Building Including Sensitivity Analysis

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Synopsis

The LESO building is a three storey, medium-sized office building on the campus of the Swiss Institute of Technology in Lausanne. In this building component leakages have been carefully determined followed by extensive measurements of the boundary conditions as well as the air flows.

This paper first gives some basic concepts of the evaluation and the sensitivity analysis. Then, the measured data are compared with results from simulations performed with the COMIS multizone air flow program. The simulations include a sensitivity analysis which shows the influence of input errors on the calculated air flows. Leakage distribution, outdoor temperature, wind and wind pressure coefficient data are considered in this analysis.

The comparison shows good agreement for some cases. For other cases, the respective error bars of measured and calculated flows do not overlap and the agreement is poor.

The crucial part in such a comparison exercise is the modelling of the building. Especially for real buildings it is mostly very difficult to model the wind pressure accurately enough to be able to perform a conclusive comparison.

Future work aims at the development of flexible sensitivity analysis tools, which would be included in the simulation package and would be adaptable in a problem-oriented way to the actual case.

1 Introduction

The goal of any computer code evaluation is to check that the program runs as specified, to assess its limits of application, to check its usability and, by a feedback effect, improve its performance.

The work presented in this paper deals with the evaluation of the multizone air flow model COMIS [1], in particular with the simulation code COMVEN. One step in this process is the comparison of measured and calculated data. Such a task requires sensitivity analysis and error propagation studies. The paper summarises the results for the application case "LESO building". The work presented has been performed within the Swiss project "ERL" [2] and now continues within the IEA-ECB Annex 23 "Multizone Air Flow Modelling", subtask 3, which also deals with the evaluation of COMIS [3].

The results of the Swiss project are comprehensively documented in [4]. Within Annex 23, comparisons between measured and calculated data are also made with data sets from other buildings, such as the ITALGAS-building [5] or the OPTIBAT test flat at INSA [6].

2 Comparison of simulations and experiments

Comparing results from simulations and measurements must be understood as the comparison of two images of the reality, established on one side on the basis of algorithms and on the other side by using a specific measuring set up.

For many reasons, the calculated as well as the measured values contain errors. This has to be considered when comparing the two data sets. Agreement between results of measurements and simulations is concluded if there is a sufficient overlap of the respective error bars. More details on the methodology for experimental comparison can be found in [7].

Confidence intervals for the simulation results have to be established using sensitivity and error propagation techniques on the basis of known or assumed errors in the input data. The techniques used for the present comparison are described below.

3 Sensitivity analysis

The sensitivity analysis of a system is a statistical procedure necessary to determine the effect of specific input parameters on the output parameters. It highlights the parameters that affect the output results at the most. In other words, it shows which input parameters have to be determined with high accuracy and which parameters can be treated more generously.

For a specific case, sensitivity analysis is essential for the calculation of the propagation of errors in the input data and thus the confidence interval of the output data. A comprehensive description of sensitivity analysis techniques for the evaluation of air flow simulation can be found in [8].

In general, a sensitivity analysis would include in a first step all input parameters describing the system, and a set of output parameters which covers all aspects of the problem. Nevertheless, for a multizone air flow problem, the number of input parameters is excessive for such a general approach. A reasonable set of relevant parameters has to be selected. At the initiation of this work it was thought that such a set could be defined once for a specific building. In the progress of the project it became clear that this selection is not only dependant on the building, but also on the specific case and also on which output parameters are of interest.

The next step in studying the effects of these relevant parameters is the determination of their ranges, hence defining the experimental domain. Here, the word "experimental" refers to the numerical experience that constitutes a run of the code.

Full factorial design would consider all possible combinations considering the two values within the range for each relevant parameter, thus leading to 2^R simulations (R: number of relevant parameters). The effects are estimated by fitting a polynomial function F(X) to a response Y which has been procured by running the set of experiments with the corresponding input vectors X. The polynomial F(X) can be more or less complicated depending on the level of interactions taken into account. The form used for this study is :

$$F(X) = a_0 + \sum_{i=1}^{N} a_i X_i + \sum_{j\neq i=1}^{N} a_{ij} X_i X_j \qquad (1)$$

where N is the number of inputs used for each run of the experiment.

The coefficients a_i are called the main effects of the parameter X_i and a_{ij} the conjugate effects of X_i and X_j. The relative effects a_i/a_o (a_{ij}/a_o) are usually presented as the results, indicating in percentage the change of the selected output when varying X_i from its lowest to its highest level. The half effect $a_i/2$ indicates the change from the centre to a limit of the range.

The values of the a_i and a_{ij} coefficients are determined by running the code for a set of parameters selected in such a way that a well conditioned system of equations is obtained with a minimum number of runs. The methods for creating good experimental designs can be found in [9].

4 The LESO building

The LESO building is a medium-sized administrative building constituted by nine south oriented cells with solar façades, a few differently oriented rooms, and a staircase as shown in figure 1. Building related measurements, including aeraulic data, have been measured for many years. The data concerning the leakage characteristics and the air flows have been compiled in a set referred to as the "LESO data set" [10].

From this data set, the following periods have been selected for the comparison:

Period	Series 1-87	Series 6-87	Series 1-88
Date	26 Dec 1987	3 Jan 1988	24 Dec 1988
Number of data points	9	6	18
Time interval	0.5 h	0.5 h	0.5 h
Wind sector	NE-SE	W	N
Mean wind speed	1.7 m/s	5 m/s	3 m/s
Outdoor temperature	4 °C	5 °C	3 °C
Indoor temperature	21 °C	21 °C	21 °C
Wind situation	Low wind speed Unsteady direction	High wind speed Steady direction	Low wind speed Steady direction
Building condition	With sunspaces	with sunspaces	no sunspaces
Tracer gas measurements	zero concentration in staircase	zero concentration in staircase	constant concentration in staircase

Air leakage data have been measured using a guarding zone technique with two fans [11].

Air flows have been determined by the single constant concentration tracer gas technique and by interpreting the measurements using mass conservation equations [12]. For each zone i the global incoming air flow Q_{Ai} can be determined as the weighted sum of the individual air flows coming from outside (Q_{oi}) or from adjacent zones j (Q_{ji}), :

$$Q_{Ai} = Q_{oi} + \sum_{j=1}^{N} \eta_{ji} Q_{ji} \qquad \text{(N= total number of zones)} \qquad (2)$$

The weighting coefficients η_{ij} are functions of the tracer gas concentration levels in each zone and are determined from the tracer gas concentrations during the measurements. They had to be considered especially in the 1987 periods, where there was no tracer gas supply in the staircase.

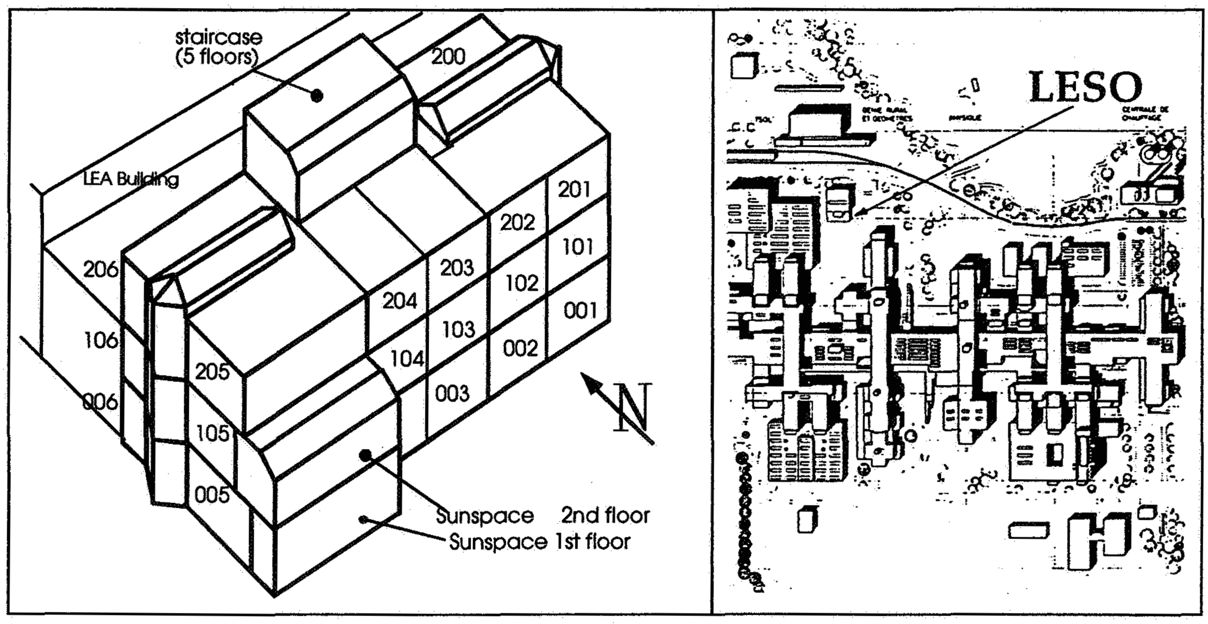


Figure 1: The LESO building (with the attached LEA building, left) and its surroundings (right)

From the per zone values Q_{Ai}, a global value for the whole building is formed as given below, weighting the Q_{Ai}- values per zone with the respective zone volume V_i:

$$Q_{A\text{-Building}} = \frac{1}{\sum\limits_{i=1,N} V_i} \cdot \sum_{i=1,N} Q_{Ai} V_i \qquad (3)$$

In fact, this value does not differ significantly from the simple sum of all Q_{Ai}- values.

Aeraulic model: For the sensitivity analysis as well as for the simulation of the measured periods, the building is represented by a network which consists of 11 zones and a total of 28 air flow links. These air flow links represent the measured leakages and are modelled by the well-known power law model for crack flow. Some measured coefficients have been split up arbitrarily between two or more conductance elements, especially in the staircase zone. The effect of the regrouped conductances is evaluated here. The consequences of the applied partition has been investigated in [13].

A typical section of such a network is given in figure 2 for the second floor of the building.

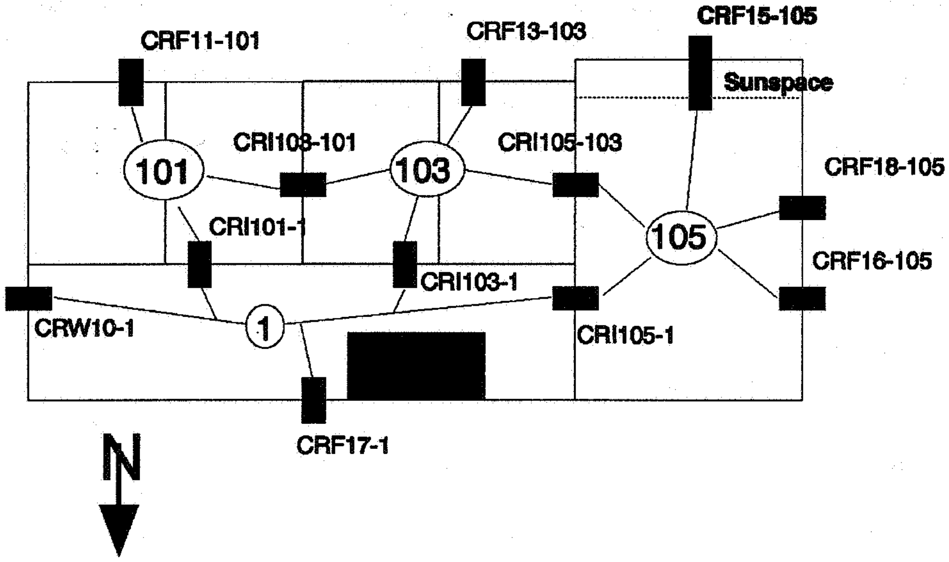


Figure 2: Typical section of the flow network (Floor 2 for situation 1987).

5 Sensitivity analysis for the LESO building

Experimental domain and observed output parameters

The experimental domain, that means the sets of relevant input parameters considered in this study are separated into two groups:

1. All the individual envelope leakage coefficients, the outdoor temperature and the wind speed, forming 12 sets of variables.
2. The wind pressure coefficients, forming 6 sets of variables per wind sector.

For the evaluation of a code, the performance with respect to all possible output options (e.g. energy losses, comfort, pollutant concentrations) should be considered. Thus, a well defined response set should have these completeness characteristics. In this study, for the purpose of comparison with measured values, only the incoming air flows QAi per zone have been chosen as the relevant output parameters. In addition, for the selection of the most relevant parameters, the mean age of air in the zone, calculated from the flow matrix has been considered.

MISA

In order to speed up and automate the sensitivity analysis process, MISA, a multirun interface to COMVEN has been developed. This tool uses the basic input file, a file with the range for each input parameter included in the sensitivity analysis and a design file which contains the experimental matrix.

Experimental matrix

A fractional factorial design as described in chapter 3 has been used to define the experiments for this sensitivity analysis. The used design considers all main effects a_i between the relevant parameters as well as some second order interaction effects a_{ij}, but neglects any higher order interactions [8]. Both groups of relevant parameters have been studied using this factorial design method. Up to now, sensitivity analysis studies have been performed only for one case (corresponding to one time step) for each period.

6 Simulations with COMVEN and comparison of measured and calculated airflows

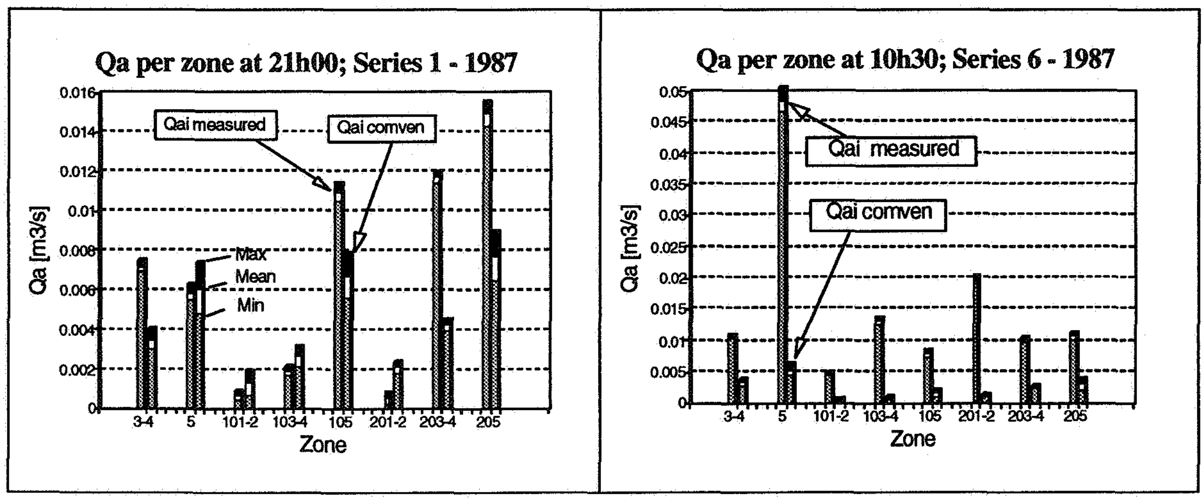
Simulations have been performed on the basis of the same aeraulic network as used for the sensitivity analysis. Similarly to a good empirical evaluation, as many input parameters as possible should be taken from the measured data set for the simulation. On the other hand the observed output should be determined independently from the measurements. In this study, most of the input parameters are taken from the LESO data set. Nevertheless the resulting air flows Q_{Ai} are determined according to eq. (2) from the calculated individual Q_{oi} and Q_{ji} flows, but with the η_{ij} based on the measurements. Thus the calculated Q_{Ai} values are not pure simulation results.

The confidence intervals for the air flow results have been determined on the basis of the sensitivity analysis results by calculating the propagation of the errors in the relevant input data. These errors in the relevant input data are:

1. For group 1 (all the individual envelope leakage coefficients, the outdoor temperature and the wind speed): The actual confidence intervals from the measurements [11].
2. For group 2 (the wind pressure coefficients): A fixed value of 25% error is assumed in this study. The cp-values have been determined from wind tunnel measurements on a scale model of the LESO. For the roof and the building condition without sunspaces, values from the literature were used in addition. The confidence intervals for all these values are not known.

The total error E for the flow Q_{Ai} has been calculated from the effects according to eq. (1) as follows:

$$E = Q_{Ai} * \sqrt{\left(\Sigma a_i^2 + \Sigma a_{ij}^2\right)_{\text{group 1}} + \left(\Sigma a_i^2 + \Sigma a_{ij}^2\right)_{\text{group 2}}} \qquad (3)$$



Qa per zone at 21h00; Series 1 - 1987

Qa per zone at 10h30; Series 6 - 1987

Figure 2: Comparison of measured and calculated (COMVEN) flow values Q_A for all zones for one time step in series 1-87 and 6-87 respectively, including confidence intervals for both measured and calculated values.

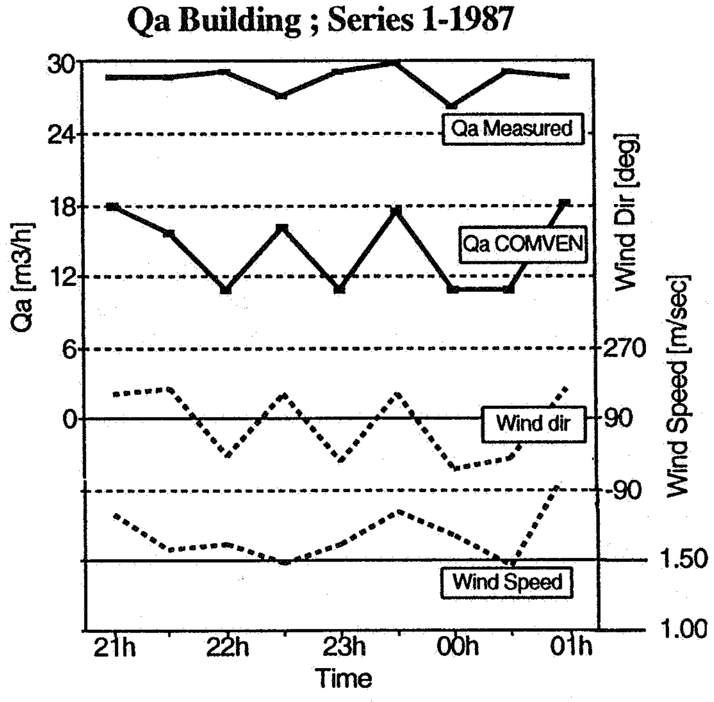


Figure 3: Comparison of measured and calculated (COMVEN) flow values Q_A for the whole building; period 1-87

Figure 2 shows the measured and calculated air flows of each individual zone Q_{Ai} with their respective error bars for one time step in series 1-87 and in series 6-87 respectively.

In figure 3, measured and calculated room volume weighted total flows Q_A for the building are compared for the first winter period. Data for wind speed and direction are also plotted. The strong influence of the wind direction on the calculated flow can be clearly seen, but this is not reflected in the measured data. This fact can already lead to the conclusion that there might be some differencies between the influence of the wind on the tracer gas measurements and its influence on the calculated air flows.

Also for the period with stronger wind (6-87), rather large discrepancies exist between measurement and simulation. Again, the influence of the wind seems to be important. Better agreement is achieved for the 1-88 period.

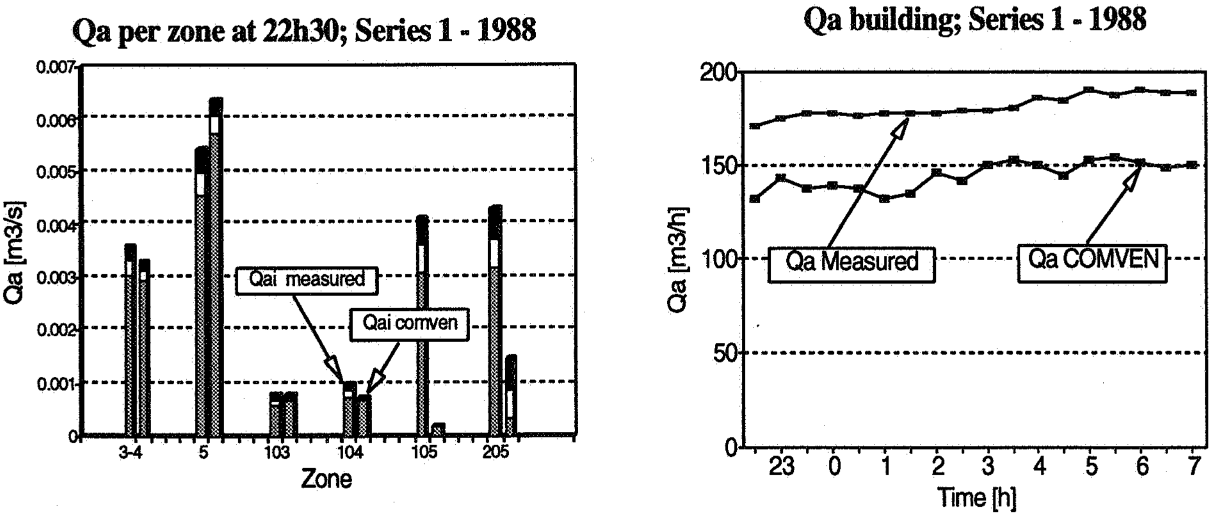


Figure 4: Comparison of measured and calculated flow values for period 1-88 Q_{Ai}-values per zone (left) and Q_A-value for the whole building (right).

7 Conclusions and future work

Comparison of measured and calculated flows for the LESO building

For all three periods investigated, the calculated air flows are smaller than the measured ones. Most significant discrepancies between measurement and simulation are not in situations with low wind, but rather in that with strong wind. The reasons for the partially unsatisfactory compliance of measured and calculated data are not yet fully understood and subject of the ongoing work in Annex 23. Compared to earlier work [4],[13], also the inclusion of the wind pressure coefficients into the set of relevant parameters (only with assumed errors though) did not lead to a significantly better agreement between the confidence intervals of measured and calculated air flows. Further investigations will include:

- The consideration of the influence of the building attached next to the LESO (the LEA building).
- The evaluation of the concept of wind pressure coefficients in general for this heavily shielded building, especially for the low wind speed cases.
- The determination of the confidence intervals in the wind pressure coefficients used and the measurement of wind pressures on the real building.
- The consideration of possible errors in the η_{ji} - values used.

Sensitivity Analysis

When this sensitivity analysis work was initiated, it was assumed that one single set of relevant parameters could be established for a specific building. This work has shown, that the sensitivity and error propagation analysis has to be performed as case dependent. Consecutively, error propagation calculations cannot be based on one singular sensitivity analysis, but sensitivity and error propagation have to be seen as one integral analysis. For air flow studies over a larger time period, this task cannot be performed without a high degree of automation. As a consequence, present and future work concentrates on the development of flexible and powerful routines which will be integrated into the simulation code. This will form a valuable tool for the user of the program and allow him to perform on-line sensitivity and error propagation studies for the actual case under investigation. Besides factorial design, also Monte Carlo techniques will be used.

Program evaluation by comparing measurements and simulation results

It is absolutely necessary to know the accuracy of the measured data and that of the input data as well as the confidence intervals of the simulation results. The sensitivity and error propagation analysis procedures shown have proved to be a valuable tool for this kind of evaluation work.

As mentioned, both measurements and simulations are images of the reality. Thus, in order to be able to evaluate the program, one has to be sure that the data of the measured validation set and 'reality' are as close as possible. This is especially valid for the measured data used as input for the simulations.

As is shown in [6] and [14], measured and calculated air flow results are within 10% for a multizone structure also, if the real leakages and the pressure distribution on the façades are accurately known.

A second, preliminary conclusion from the on-going evaluation work is that the measured building should not be too complex. In a complex building, there are many interactions between a large number of relevant parameters, making it very difficult to understand and explain the resulting air flow situation. Also, in a complex network, the pressure and thus the flow field can be in an unstable equilibrium condition and thus be very sensitive to small changes in the boundary conditions.

Application limits for multizone models

For most simulation tasks, the modelling and the definition of the boundary conditions is the crucial part of the work. For multizone air flow simulations of real buildings, uncertainties in the leakage distribution and the modelling of the wind pressures may substantially limit the accuracy of the results.

Nevertheless it is expected that air flow simulation tools will be used more and more for the design of energy efficient ventilation systems and control strategies which provide a comfortable and healthy indoor air environment.

Acknowledgements

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