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Comparison of the Accuracy of Detailed and Simple Model of Air Infiltration

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SYNOPSIS

Simulation is proving more and more important in building physics. Programs of different levels of complexity are today available for researchers and designers to model and plan buildings. But the accuracy of the output is not usually provided as a common result.

This paper is a short summary of a dissertation [1] focused on the accuracy of the simulation outputs as a function of the accuracy of the input parameters. This is a point which requires particular attention, so that the simulation outputs can be used with their confidence intervals; without these intervals, the use of the simulation output is risky. The following question is discussed in the paper : is the prediction of detailed models more accurate than that of simple models if the accuracy of their respective input parameters is taken into account ? There is a risk that inaccurate input data can invalidate attempts at exact simulation. For the studied case, the answer is that the detailed model has larger confidence intervals than the simple models in wind as well as stack dominated situations.

The result has been obtained by investigating models and measurement processes and determining their confidence intervals. Fractional factorial design has been used to estimate the partial derivatives of the models by the input parameters with an optimum number of simulations for the detailed multizone model COMIS and 4 simple models BREVENT, LBL, AIDA and TURBUL. A 6-zone family house was chosen as case of study because it allowed the comparison of the sensitivity of simple and detailed models.

SYMBOLS

a_o	constant effect
a_i	main effect
a_{ij}	interaction effect
x_i	input parameter (standardised)
y	output parameter
$minX_i$	input parameter minima
$maxX_i$	input parameter maxima
C_i	airtightness coefficient, [$m^3/s\ Pa^n$]
n_i	exponent, [-]
Q_i	flow through the element i [m^3/s]
ΔP_i	pres. diff. through the element i, [Pa]
N	number of tested parameters

1. INTRODUCTION

For researchers, the simulation saves time and money. But a simulation procedure which is not validated and whose sensitivity is unknown is risky. It is imperative to know the influence of the uncertainty of the input parameter on the output. It is important to know which are the critical parameters to be determined with the smallest possible confidence interval and the one which can be roughly estimated. Each year new models with each time more sophisticated features are settled without any tools, and few study was available to assess their uncertainty level. At the age of the data base, data are used without handling of confidence intervals and the large majority of programs (for not saying all of them) has no tool to help the user to deal with the uncertainty of the input parameters.

From this standing point, we have tried with our study to make progress to solve this problem. We propose a method to analyse the sensitivity of simulation programs which is illustrated here. A tool was also set up to perform the analysis. This work was under taken in the frame of the IEA-ECB - Annex 23 "Multizone air flow modelling" [2, 3].

The questions which have motivated our work are :

1) Which are the confidence intervals of the output data of a simulation program taking into account the uncertainty on the input data and inversely which are the acceptable uncertainty on the input data to simulate the ventilation of a building within a given accuracy ?
2) Are the nodal and semi-empirical models, as COMVEN, more accurate than simple empirical models when the uncertainty of the input data is taken into account ?

We have also dealed a lot with the problem of discrepancies between measurements and simulations, but this work will not be reported here [1].

The usual tool systematically quoted when talking about sensitivity analysis is the Monte-Carlo Method. This random method allows with less than 100 runs the estimation of the global sensitivity of a program without having the possibility to determine which are the influent parameters. The other commonly quoted and used method is the "one factor at a time" method. This method is heavy to use and requests a considerable amount of simulations. More, it does not take into account the interaction effects which can occur between factors. After these depreciative comments, the reader has guessed that we want to make the apology of an alternative method : this is the factorial design method. Our study has also resulted to a comparison of factorial and Monte-Carlo design which can be synergetically combined [4].

Factorial design is a method settled in the 50's by chemists in the experimental domain. The main feature consists on extracting with a minimum number of experiments (runs) the maximum information. The method is also known as surface response method.

The aim of comparing simple against detailed model is not to eliminate the less accurates. Both types of models do not simulate exactly the same objects and the need in both of them is not in question. But from our point of view it appears risky to ignore, as it is done commonly, the problem of the confidence intervals of simulation results. This has ended in a despising regard of professionals to simulation and models to which it is reproached to give any desired answer. Under the deliberately polemic aspect of the comparison between two types of models which have convinced defenders, it lays the motivation of finding appropriate tools for given tasks.

2. FACTORIAL DESIGN METHOD

Factorial design has been used to calculate the confidence interval of the outputs and to evaluate their sensitivity to input inaccuracies. A comprehensive presentation of the factorial design can be found in [5], a short apology in [6,7]. The method consists on fitting an output y on a linear model corresponding to a Taylor series and which variables are the input parameters x_i :

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

where N is the number of tested inputs.

The coefficients a_i are called main effects of the parameter X_i, and a_{ij} the conjugate effects of X_i and X_j. The values of the a_i and a_{ij} coefficients are determined by running the program with values of parameters selected to lead to a well conditioned system of equations with a minimum number of runs.

The fit is done on a given domain D of IR^N which is determined by the lowest and the highest values, $minX_i$ and $maxX_i$ that the tested input parameter X_i can take. Being given the linear model of equation 1, the best choice for optimising the number of runs and the condition of the system is a factorial design. This design is constituted by the points at the vertex of the domain D. The maximum number of points of simulation is then 2^N (full factorial design). If some coefficients $a_i\, a_{ij}$ are of interest only a fraction of this full design can be selected (fractional design 2^{N-m}).

The choice of the linear model can be argued. Evidently physical phenomenon as complex as the air movements in a multizone building are seldom linear. But in one hand it is a suitable first step and in the other hand, it is possible to use non-linear metrics to linearize known non-linear input or output parameters.

The effects, corresponding to the first derivatives of the model are related to the local standard deviation $S_y(X_1,\ldots, X_i,\ldots)$ by the following equation :

$$(Sy(X_1,\ldots, X_i,\ldots))^2 = \sum a_i^2 + \sum a_{ij}^2 + \ldots \qquad (2)$$

demonstrating that the effects are an interpretation of the standard deviation with the variation of the input. Equation (2) is also the point of comparison with Monte-Carlo Method usable to perform a rough sensitivity analysis.

The response which has been analysed is the mean age of air. The age of air τ is a matrix computed from the flow matrix Q as follows:

$$\tau = Q^{-1}\, V \qquad (3)$$

where V is a diagonal matrix with the volume of the zones as elements. The mean age τ_j of air of a zone j is then :

$$\tau_j = \sum_j \tau_{ij} \qquad (4)$$

3. Programs

One detailed model and 4 simple models have been investigated. The detailed model is COMVEN of COMIS [8, 9]. It is a nodal multizone model using a Newton-Raphson algorithm with 2 fixed relaxation coefficients to solve by iteration the system based on the mass conservation. The flow equation used to define cracks is the power law :

$$Q_j = C_j\ (\Delta P_j)^{nj} \qquad (5)$$

The 4 simple models chosen for this study, BREVENT, LBL-model AIDA and TURBUL are of different types. The first two are used for the prediction of air renewal from pressurisation data [10, 11, 12]. Their simplicity makes their interest : both of them can be calculated by hand. AIDA is a nodal model for one zone [13]. It runs with an iterative algorithm simple enough to be implemented on a programmable pocket calculator. TURBUL is a monozone dynamic model settled to study wind turbulence effect on air renewal and test various algorithms of resolution in a dynamic process [14, 15]. Table 1 summarises they characteristics.

Table 1 : Caracteristics of the simple programs used in this study

Program	Comments
AIDA	Nodal monozone, iterative algorithm, implicit calculation of neutral level.
BREVENT	No calculation of neutral level. Air tightness uniformly distributed.
LBL	Calculation of neutral level. Air tightness uniformly distributed modelled by an equivalent leakage area. Wind, stack and mecanical induced ventilation calculated separatly.
TURBUL	implicit calculation of neutral level.

4. The case study

In the perspective of comparing detailed and simple models, a building suitable for both has been chosen. It is a test building of an Italian gas company. The plan is shown in figure 1 and the air flow network simulated with the detailed model COMVEN in figure 2. In table 2 are presented some data [16,17].

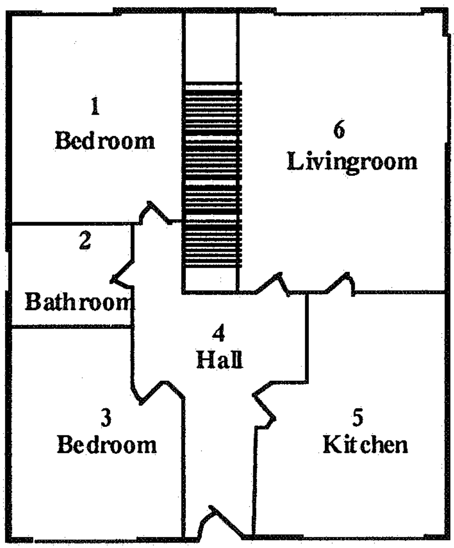

Figure 1 : Plan of the test building

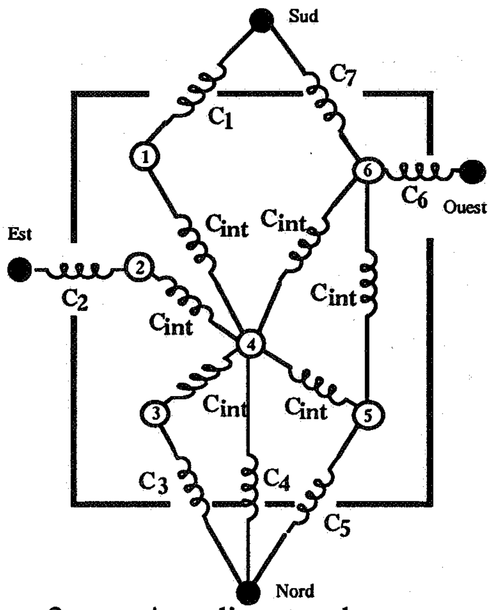

Figure 2 : Aeraulic network

Table 2 : Airtightness coefficients and related inaccuracies.

air tightness	[kg s^{-1} Pa^{-n}]	S(C)/C	Exponent	[-]	S(n)/n
C_1	0.018	24%	n_1	0.65	8%
C_2	0.0276	23%	n_2	0.39	13%
C_3	0.0048	24%	n_3	0.86	6%
C_4	0.0784	23%	n_4	0.54	10%
C_5	0.0252	23%	n_5	0.60	9%
C_6+C_7	0.0288	23%	$n_6 = n_7$	0.50	10%
C_{int}	0.0784	23%	n_{int}	0.54	10%

5. TEST AND RESULTS

The number of parameters being different for each model, different design have been used. Table 3 presents the features of the tests for each program. The comprehensive study includes analysis of the effect of each group of factors [1,16]. Here, for safe of concision, only general results are given. Detailed results and analysis will be published within the frame of Annex 23 of the IEA ECB&C. The results of two types of test are given here.

Table 3 : Detail of program tests.

Parameters	COMVEN	BREVENT	LBL	AIDA	TURBUL
Tested parameters	32	9	12	24	24
Design	$2^{(32-24)}$	$2^{(9-3)}$	$2^{(12-6)}$	$2^{(24-16)}$	$2^{(24-16)}$
Runs	64	64	64	256	256
Level of uncertainty :					
• air tightness(es)	±24%	±5%	±20%	±24%	±24%
• exponent(s)	±10%	±8%	±8%	±10%	±10%
• volume(s)	±10%	±10%	±10%	±10%	±10%
• temperatures	±0.5[°C]	±0.5[°C]	±0.5[°C]	±0.5[°C]	±0.5[°C]
• atmospheric pressure	±0.5%	-	-	-	-
• pressure coefficient	±50%	-	-	±50%	±50%
• wind speed	±5%	±5%	±5%	±5%	±5%
• heights	±1%	±5%	±5%	±1%	±1%
• terrain	-	±1	-	-	-
• wind exposure	-	±1	-	-	-

In a first step, the input parameters have been varied uniformly, with the same range of variation for each ones without relation with their actual and usual uncertainty. As example, all the parameter ranges have been fixed to 1% of their central value. The comparison is then done for the ratio between the standard deviation $S(\tau)$ of the mean age of air and the uniform standard deviation $S(X_i)$ of the input parameters. The results is shown in figure 3.

In a second step, the actual level of uncertainty has been used (cf table 3). This time the test has been performed for three different Archimede number. (The Archimède number is the ratio between wind and stack forces). The results are given in figure 4.

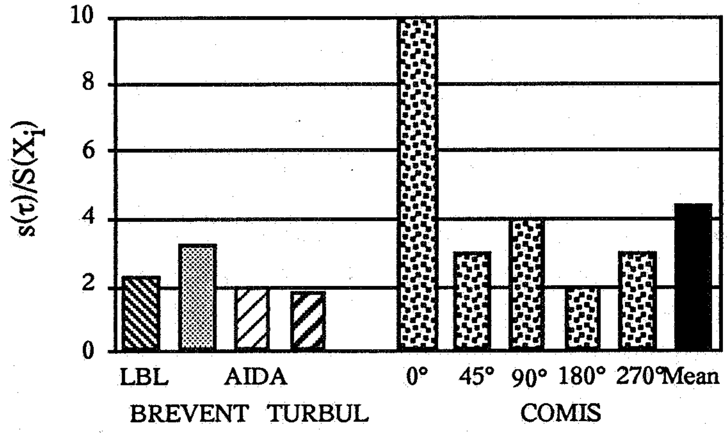

Figure 3 : Ratio between the standard deviation $S(\tau)$ of the mean age of air and the standard deviation $S(X_i)$ of the input parameters. Results obtained using different factorial designs for four simple models and COMVEN.

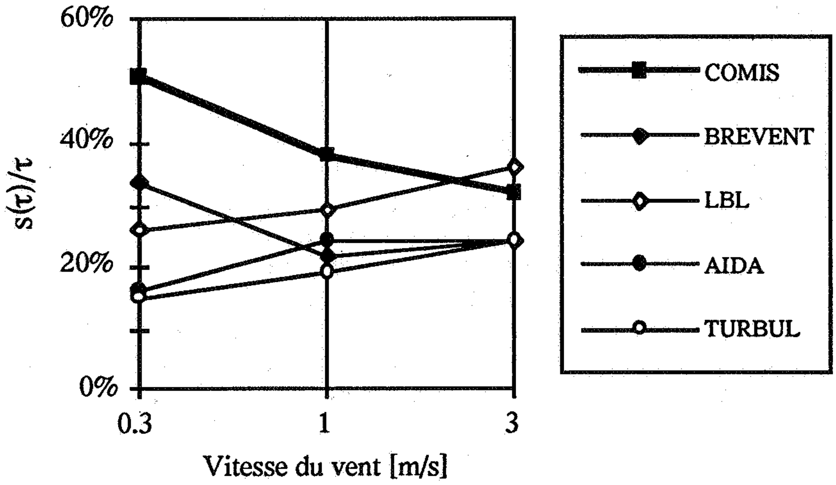

Figure 4 : Comparison of the variation of the mean age of air uncertainty as a function of the wind speed for considered models.

6. DISCUSSION

Comparing the uncertainty of simple model against the detailed model when using uniform ranges for the input (cf fig. 3), brings the following points :

- With same variation ranges for all the input parameters, the uncertainty ratio of simple or detailed model are of the same order of magnitude.
- For simple models, the confidence intervals of the nodal models (AIDA, TURBUL) are almost half the confidence intervals of the models of empirical conception (LBL, BREVENT).
- For the detailed model, there may be a large difference in sensitivity depending on the considered zone and the wind direction. There are critical situations for which the detailed

level of the model is not adapted to the accuracy of measurements. In these cases, the amplification of uncertainty between input and output data is about one order of magnitude. Except those critical situations, the uncertainty amplification ranges between 2 and 3.

The second step, when using actual uncertainty, drives to the following comments :

- The uncertainty got with the detailed model is greater than the uncertainty shown by the simple model. Remember that we are talking about the uncertainty coming from the input data and propagated trough the model. It is not question here of the accuracy of results, from the physical point of view, which must be determined by the validation process.
- The evolution of the uncertainty of the simple model with the wind speed is different from a model to another. This is attributed to the different options used to model wind effects.
- The model with a nodal conception have their uncertainty increasing with the wind speed.
- The model BREVENT has a maximal uncertainty when the wind dominates the thermal buoyancy. The LBL model has the inverse behaviour showing the smallest uncertainty at the equilibrium situation. For the latter, this is due to the use of indices for the terrain and the wind exposure. The minimal uncertainty for those indices, ±1, enlarge the output uncertainty of 10% each. Once these indices excepted, both models have the same behaviour with a light smaller uncertainty for the LBL model.
- A trend of homogeneity of uncertainty can be observed when the wind dominates ventilation process.

7. CONCLUSION

This study has shown the feasibility of a sensitivity analysis with a factorial design. The method has been illustrated for one building with five models. For these models, it has been shown that the amplification of the uncertainty between input and output data is almost two. Nevertheless there are considerable variations of sensitivity from a case to another. From one side, it has been shown for empirical model that the wind effect is more precise than the stack effect. For the detailed model COMVEN, those results are contradicted for some zones and some meteorological conditions. In those situations, the confidence intervals are so large that the numerical values can not be used. But those critical situations attest the existence of ventilation problems which must be detected and corrected. The possibility of simulating these situations, even inaccurately, is then interesting.

For simple models, it has been observed that the nodal ones (AIDA, TURBUL) present a smaller global sensitivity than the empirical ones (BREVENT, LBL) and this has been confirmed when taking into account the experimental uncertainties as variation ranges for the input data. The gap between the uncertainty of both model types is larger when stack effect dominates the ventilation process. This allows us to think that the localisation of leakages, which makes the difference between nodal model and others ends in more precise modelling.

More largely, take into account some features highlighted by our study but which have not been presented here, the following conclusions can be presented [1] :

- The enhancement of measurement techniques is imperative because of the dramatic amplification of the uncertainty during the simulation process.
- At the level of the empirical validation, it will not be possible to identify internal errors whose consequences are smaller than the model uncertainty (20% to 50%).

- The determination of the empirical model coefficients using a detailed model is not free of risk.
- Both types of models (simple or detailed) are interesting and related research must be continued. For global problems, as energy conservation, simple model are satisfactory.

8. REFERENCES

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