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An overview of the evaluation activities of IEA ECBCS Annex 23

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Abstract

A summary of the evaluation of an air flow and contaminant model as part of the IEA-ECBCS Annex 23 'Multizone Airflow Modelling' is presented. Evaluation, rather validation, is the goal. The most important points of the cases analyzed during this project are presented and commented from the point of view of analytical evaluation, comparison with experimental data and user sensitivity. The conclusion addresses the need for user-friendly tools and guidelines for the analysis of simulation output.

Keywords: Sensitivity analysis; Model validation; Network air flow model; Monte-Carlo simulation; Factorial design

1. Introduction

The work undertaken under the auspices of Subtask 3 of the IEA-ECBCS Annex 23 'Multizone air flow modeling' is reported here. This paper is a synthesis of the evaluation work done on COMVEN within Annex 23 [1].

COMVEN developed by COMIS (Conjunction of Multizone Infiltration Specialists) is a multizone air flow and contaminant model which was started in 1989 during a one-year international workshop [2]. The program, consisting of up-to-date models and numerical methods, as well as integrating some of the original work of the group, is aimed at allowing users to simulate air flow and pollutant distributions in a multizone structure. Following the first year and initial development, an international research project was organized under the IEA-ECBCS: The Annex 23 Multizone Air Infiltration Modeling. A considerable part of the work has concentrated on the validation of such models.

Validation is a word that is somewhat overused since a model can never be completely validated, even though it may be invalidated. The use of simulation in practice requires some warranty of the results and this is possible only by comprehensive evaluation and sensitivity analysis. For the assessment of simulation results, several tools have been developed, tested and improved. The whole methodology of 'validation' has been reviewed, reanalyzed and adapted to this field [3].

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2. COMVEN structure

COMVEN is a nodal model based on pressure boundary conditions incorporating cracks, duct systems, fans, volumes, stratification layers, vertical large openings, source and sink of pollutants and pressure coefficients of facades. The program makes use of the Newton–Raphson method to integrate the system of differential equations that comprises the model. The flow is modeled by a power law:

$$q_{ij} = C_{ij}(\Delta P_{ij})n_{ij} \quad (1)$$

The scientific basis of the program is described in the COMIS fundamentals [4]. The scheme of the ventilation drivers (wind, buoyancy and fans) is shown in Fig. 1.

3. Inter-model comparison

When a computer program is used to solve a mathematical model of a physical phenomenon, many different tests can be performed to evaluate its behavior. Program results may be compared with an analytical solution, the solution of another program or measured values. In the framework of the Annex 23 evaluation task, the comparison of the

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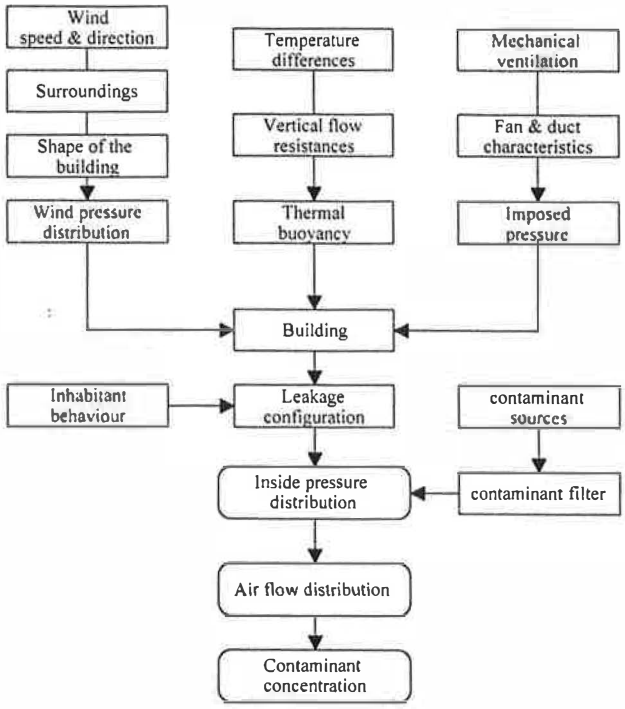

Fig. 1. Ventilation drivers.

COMVEN results with analytical solutions or with those obtained using specialized mathematical software, has been called *analytical evaluation* and the relative comparison of different models has been called *inter-model comparison*.

The analytical evaluation tests have been largely performed at EMPA, [1] with contributions also provided by LESO [2] and by the POLITECNICO. [3] Some cases are dedicated to checking the modeling of the physical effects and the algorithms in the code, while others are set up to check the proper functioning of the program with respect to input data processing, error handling, etc.

Most cases are set up to test one specific topic, for example the correct interpolation between the C_p values for any wind direction. Even when covering only one topic, a case can cover one specific situation only or can cover the full application range for the code. Cases covering several topics are in general more complex and the interpretation of the results is more difficult.

At EMPA a database of test cases has been established, ranging from simple cases for testing specific physical models or routines in the code to complex problems combining different physical effects and topics. These test cases can be organized into categories of tests checking the functionality of the code and tests used for the evaluation of algorithms, and checking of the numerical results.

The four test cases provided by the LESO consist of crack networks in very simple situations with relatively few indoor nodes. In the first test the aim is to check whether COMVEN manages the rotation between C_p's correctly, both for wind and building direction. The second test is used to check wind consequences for a case without stack effect. The third tests used to check stack effect. The fourth test wind and stack effects are both taken into account.

The first set of tests developed at the Politecnico involves only simple networks and was used for studying the effects in COMVEN of the link height. For all tests, inside and outside conditions are chosen in order to have stack effects and wind pressure equal to zero; therefore zero air flow should be determined by COMVEN. For this reason the tests are named 'zero-cases'. The influence of the link heights of the vertical and horizontal nodes and of the reference height was checked.

In the second set of tests the results of COMVEN are compared with the solution obtained using mathematical software. These tests concern thermal gradients and wind influence (e.g., wind velocity and wind exponent).

The large amount of cases and information is not easy to summarize. In Table 1 an attempt is made to roughly summarize the available test cases by defining some topics related to modeling and calculation element. The rows represent elements of the input data, while the columns refer to the computational element checked by the test. The table is not complete and shows only the most important elements. More complex cases cannot be shown since the matrix is only two-dimensional.

In the following paragraphs an attempt is made to summarize the results of the comparative tests.

Meteorological data: The physical properties of the air and the temperature and pressure boundary conditions were checked by several tests, and found to be correctly calculated by COMVEN.

Wind pressures: Tests were performed to verify that the interpolation among given C_p data according to the actual wind direction and building axis was correct. Wind speed corrections due to the different wind profiles at meteorological station and at site were also verified to be correct.

Stack effects: Stack effects were checked for the links in a zone and also in cases where density gradients were defined. Gradients per layer are averaged over the room height in COMVEN, which may lead to discrepancies with the analytical results. Convergence problems with non horizontal links have been solved.

Air flow components: Flows through cracks are correctly determined in most test cases. The air flow and the contaminant spread through a large opening were compared with independently derived analytical results, also in combination with layers. Cases with HVAC systems were

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Table 1
Input and calculation topics covered by the available test cases

Topic related to input	Topic related to calculation							
	Meteo	Wind pressure	Stack pressure	Flow Crack	Window	HVAC	Pollutant transport	Schedules
Meteo data								
Building orientation								
One zone								
Several zones								
Zone layers								
Crack								
Window								
HVAC								
Pollutants, Sources, Sink, Filters								
Schedules								
Occupants								

created and run for single and multizone networks. Convergence problems may arise when T-junctions are connected to short ducts with small flow resistance.

Density gradients: The individual gradients defined for the zone layers are averaged over the zone height in COMVEN. For cases with layers having different gradients this may lead to quite substantial deviations from analytical solutions, especially for large opening flows.

Pollutant transport: Pollutant transport cases are available for single and multizone networks, including combined cases with zones having layers and large openings. Especially for stack driven flow (and thus also flow through large openings) the final concentration values depend significantly on the time step chosen. A short enough time step should be used in such cases.

Schedules: Schedules are defined in many cases and the proper processing of the scheduling inputs was verified.

In the *inter-model comparison* work performed under Annex 23, the COMVEN results were compared with those of 14 different models: AIDA, AIRNET, ASCOS, BREEZE, BREVENT, CSBAIR, CONTAM93–94, ESP, the LBL model, MZAP, NORMA, PASSPORT AIR, TURBUL and VENCON. For each of these models a brief summary can be found in Ref. [1].

Each phase of the evaluation work corresponds to comparison work focused on a defined topic: comparison of the results using the same sets of input data for AIVC, large opening for Athens University, User Test 1 for BBRI, mass flow equation for Concordia University, sensitivity to uncertainty in input data for LESO, and smoke control for Politecnico of Torino. Table 2 summarizes the models used for the comparison for each topic tested.

Overall good agreement was found between COMVEN results and the results of the other models. COMVEN is able to predict the air flow behavior as well as other models developed for more specific topics (e.g., smoke control). No differences are found among the results of the models if the same data are correctly applied to each model.

The prediction of the flow for a large vertical opening, in the single-side natural ventilation case, was performed using six different air flow models, and the agreement among the results obtained was very good (correlation coefficients greater than 0.95 except for the results obtained using NORMA).

Two special investigations were also performed. The first was devoted to sensitivity to uncertainty in input data. It was shown that increasing the complexity of the input data led to an increased uncertainty in the range of the results. The second was devoted to understanding smoke control in a building. The results obtained showed that COMVEN can be used for this purpose as well as ASCOS, a

Table 2
Summary of the used models in the intermodel comparison

models	result comparison	large opening	User Test 1	mass flow equation	sensitivity to uncertainty in input data	smoke propagation
	AIVC	Athens University	BBRI	Concordia University	LESO-PB	Politecnico di Torino
AIDA						
AIRNET						
ASCOS						
BREEZE						
BREVENT						
CBSAIR						
CONTAM93/94						
ESP						
LBL model						
MZAP						
NORMA						
PASSPORT						
TURBUL						
VENCON						

computer program developed especially for the smoke control simulation.

4. Empirical evaluation

The experimental comparison is the key aspect of the model evaluation demonstrating that COMVEN works well, in fact that it works coherently with some measured data.

The experimental data is not free of errors and consequently confidence regions or other forms of uncertainty must be considered. The result of a simulation or a measurement should not be thought of as a single number or a line in a graph but should be thought of as comporting uncertainty range. Moreover, in the case of significant disagreement between experimental data and corresponding simulated data, different possibilities must be investigated before it can be declared the numerical model or the measurement is wrong. For many reasons, data coming from both calculation and measurement can contain errors, and comparisons should take account of these uncertainties. In this paper, we make reference to visual comparison of confidence curves, considering a large, or fair degree of overlap to constitute reasonable, or encouraging, agreement between model and data. While it may be difficult to precisely quantify the degree of agreement directly from such graphics, this is a fairly standard approach to making model/data comparison and has the virtue of conveying insight over the entire range(s) of the parameter(s) considered and being statistical model assumption-free.

It should be noted that the purpose of a comparison between measured data and simulation can be to find and explore possible discrepancies, and not necessarily to prove any agreement. Two images of reality are compared (Fig. 2): an experimental model and a numerical one, and the question is when and where do they differ and why.

4.1. Data specifications

To be usable for an experimental validation, data should fulfill the following specifications:

- *compatibility*: the data should be measured on a building or a case which can be modeled with COMVEN,
- *completeness*: all the data necessary to run the code for the specified case and to compare results should be provided,

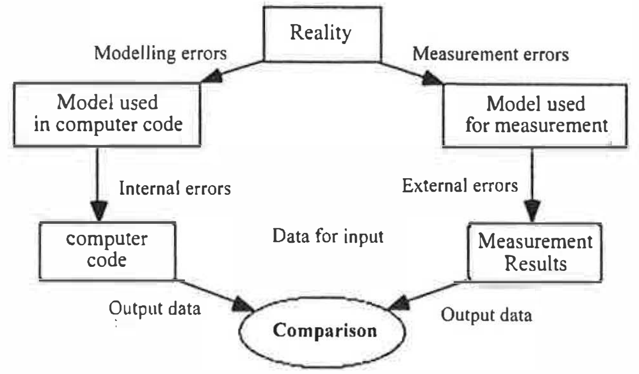


Fig. 2. Experimental validation is comparing the results of two models of reality.

- *known accuracy*: all the data should be provided with some meaningful estimate of error,
- *good accuracy*: the error should be commensurate with the state of the art,
- *synchronism*: all variable parameters should be measured at the same time.

4.2. Cases evaluated under Annex 23

Nine buildings were investigated under the framework of Annex 23. The full study appear in the final report [1]. A short presentation of interesting points from the nine cases is given below. Table 3 indicates the features of COMVEN used in the test cases.

OPTIBAT is an experimental one-floor flat, comprising six zones. It is built in a large experimental hall at the CETHIL laboratory of INSA near Lyon. The outdoor environment is controlled: it is not a field case. The main

Table 3
Features of COMVEN used in the reported test cases

Individual models	Optibat (F)	Solar house (J)	Family house (J)	LESO (CH)	Passys (B)	Namur flat (B)	Passys (G)	Large Opening (G)	Italgas (I)
Air flow components									
Crack									
Fan									
Straight ducts									
Duct fitting									
Flow controller									
Large vertical opening									
Test data component									
Zone layer									
Pollutant									
Schedules									
Links									
Large vertical openings									
Fan									
Zone temperature									
Zone humidity									
Pollutant source or sink									
Building orientation, terrain and wind profile data									
Cp values									
Weather data									

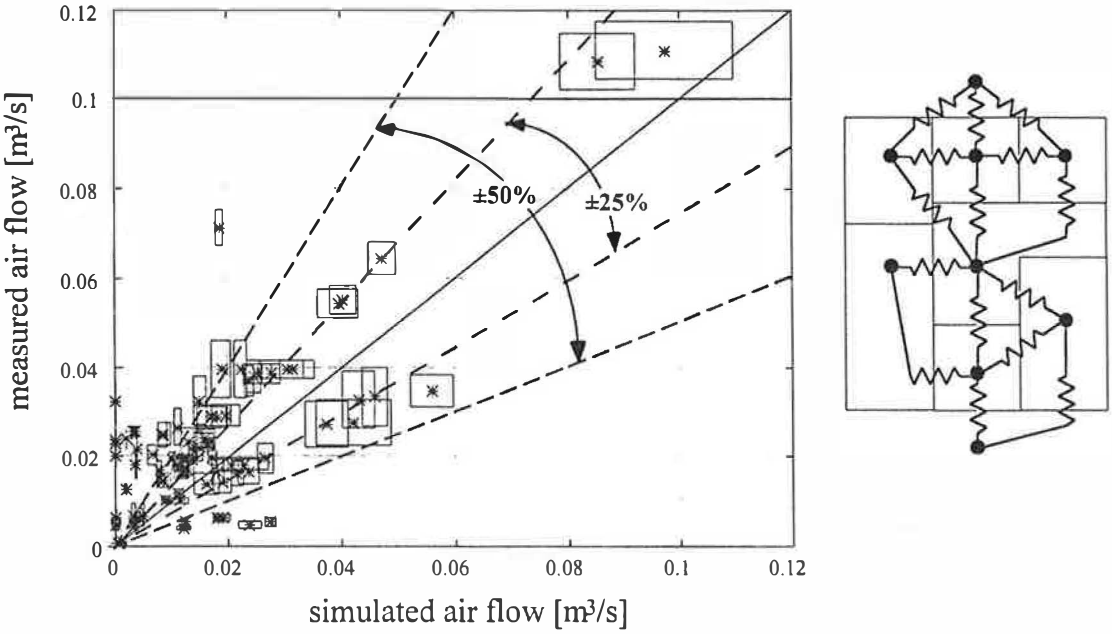


Fig. 3. Comparison of simulated and measured air flow rates for all zones and eight scenarios. Rectangles correspond to approximate 67% (one σ) confidence intervals on both simulated and measured air flow. The simulated data uncertainty is calculated with a Monte-Carlo technique. The simulated air flow network is shown to the right.

goal of the controlled environment was to by-pass the problem of pressure coefficients. Another interesting point was the possibility of imposing the outdoor pressure and temperature conditions. Calculations were performed for various climatic conditions.

Global sensitivity analysis was performed using the Monte-Carlo technique: 100 runs were performed, varying all parameters at random before each run [3]. The random changes of the parameters were made following a uniform distribution, with maximum and minimum values taken to be the estimates of the experimental inaccuracies. For these calculations COMVEN 1.3 was used, together with the MISA tool. Comparisons of measured and calculated interzonal air flow rates are given in detail in the final report [1]. A summary of these comparisons is shown with the simulated network in Fig. 3. Each flow is represented by a central star surrounded by its confidence rectangle.

It can be seen that very few confidence rectangles touch the 45° line corresponding to perfect agreement. This means that there are significant differences, as far as confidence intervals are properly estimated. In nearly half of the cases, simulated results are larger than measured air

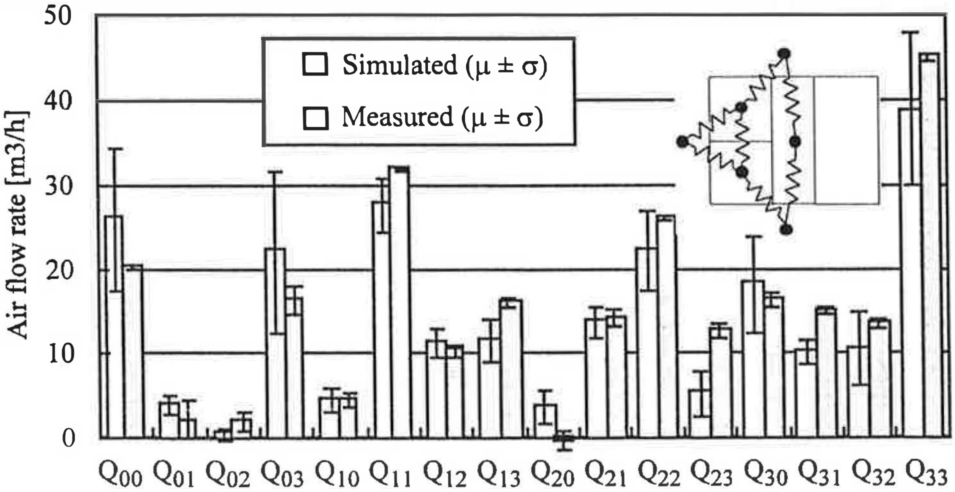


Fig. 4. Comparison of measured and simulated air flow rates. The confidence intervals are calculated by sensitivity analysis for the simulated data. The simulated air flow network is shown to the right.

Table 4
Measured and simulated flow matrix for the three cases of the Japanese SOLAR HOUSE

				Measured flows ($m^3\ h^{-1}$)				Simulated flows ($m^3\ h^{-1}$)			
	Q_{01}	Q_{02}	Q_{03}		2.08	1.99	16.2		3.9	0	19.1
Q_{10}	Q_{11}	Q_{12}	Q_{13}	4.5	31.08	10.6	16	4.4	***27.4*** ***27.5***	11.3	11.8
Q_{20}	Q_{21}	Q_{22}	Q_{23}	0.3	14.1	***27*** ***26.4***	12.6	3.4	13.3	***22.1*** ***22.3***	5.41
Q_{30}	Q_{31}	Q_{32}	Q_{33}	16.1	14.9	13.8	44.8	15	10.2	11	***36.3*** ***36.2***

The double elements in the diagonal indicates the inconsistency of the flow matrices when the entering flow does not equals the out going flow.

flow rates, while the contrary is true in the other cases. There are also several air flows which were significantly different from zero when measured, but these were not when simulated. These are represented by stars with error bars on the vertical axis. In most cases, there are significant differences between calculated and measured air flow rates, even for total air flow rates in zones. There could be several reasons for this.

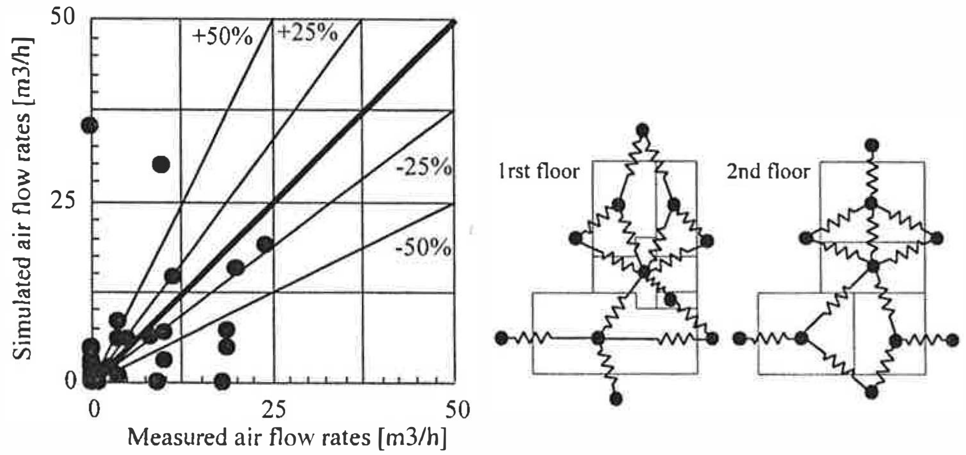
- Are there programming error in COMVEN? This does not seem to be the case since inter-model comparisons show results very close to those of other programs. The other possibility would be that all compared programs contain the same programming error.
- The nodal network model prepared by the user to simulate a real building may not replicate correctly the air pathways (in particular missing links).
- Confidence intervals on measurements are underestimated.

In the Japanese SOLAR HOUSE, the air exchanges among three zones on one floor are precisely investigated. The air tightness is well known. The main interest of this case resides in the simplicity of the structure.

Fig. 4 shows a comparison of simulated and measured air flow rates with their respective confidence intervals. For the simulation data, the intervals have been calculated using the sum of squares of the effects of 16 main input parameters. For most of the cases, the confidence intervals overlap, but there are also some significant differences between the simulated and measured data which cannot be explained solely by imprecision.

The comparison of the flow matrices is instructive. In Table 4, it is possible to observe the difference between the measured and the simulated data both in the values and in the flow structure. The total flow rates through the zones are different as can be seen by observing the diagonal elements. The inconsistency of the flow matrix is indicated by double elements in the diagonal. The air flow rates entering the zones from outside are different as shown by the diverging values of the first columns. Typically, the flow entering Zone 2 is small in the measurement (0.3 $m^3\ h^{-1}$) while it is large in the simulation (3.4 $m^3\ h^{-1}$).

The next case is the Japanese FAMILY HOUSE with nine zones distributed over two floors. The simulated network



Japanese family house

Fig. 5. Comparison of measured and calculated air flows and simulated network of the Japanese FAMILY HOUSE.

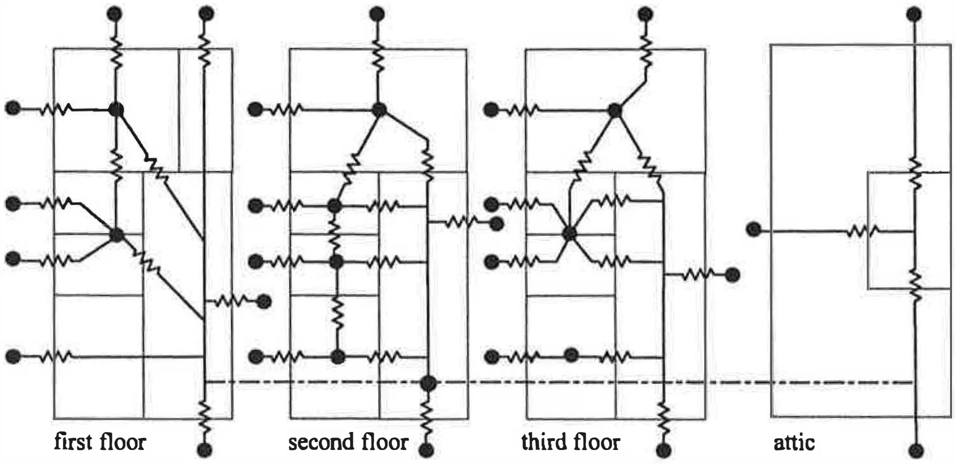


Fig. 6. Simulated network of the LESO building.

is shown in Fig. 5. This case is representative of an important part of the building set. The presence of two floors is of great interest for observing the interaction between wind and stack effect. The tracer gas measurement is made by a pulse injection of SF_6 in the living room which is the only room to be heated in this building during the measurement. As was the case for OPTIBAT, it can be seen in Fig. 5 that some flows are large in the measured data while they are almost nonexistent in the simulated data and vice versa, which means that the measured network again does not correspond to the simulated one.

The LESO Building is a three-story administrative building. It houses a building physics laboratory. Its thermal, as well as its ventilation, characteristics have been investigated for many years [5]. This building is especially well instrumented. The simulated network is presented in Fig. 6. The structure of the building is quite complicated. For the measurements, the 19 rooms are grouped in 11 zones. This case can be taken as a good representative of a small office building. Its three floors also allows the interaction of wind and stack effects to be studied. In the comparison, measured and simulated data for main flows

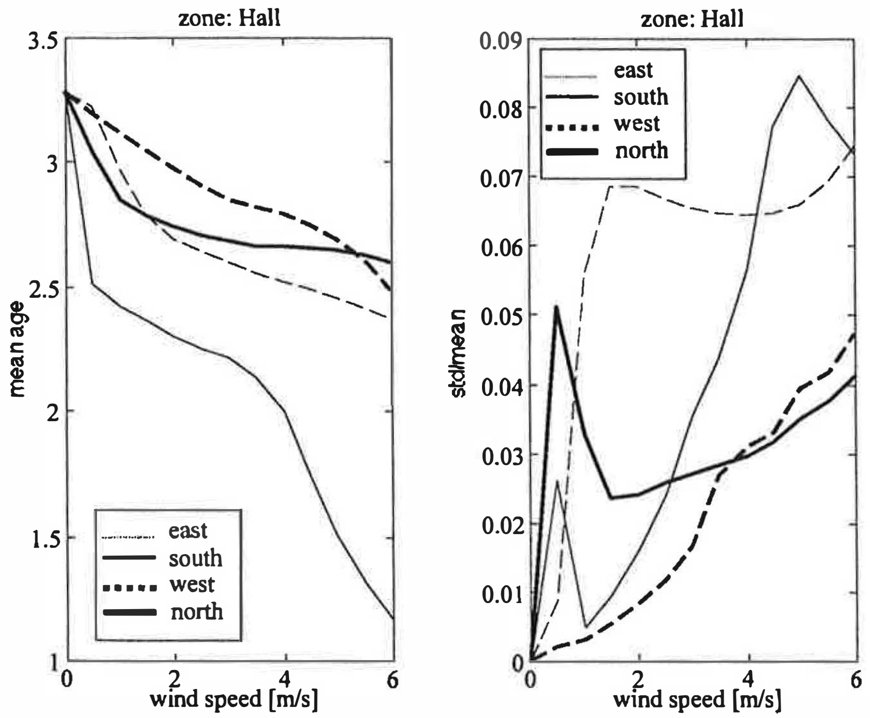


Fig. 7. Mean age of air and its standard deviation calculated by the Monte-Carlo method for the hall of the LESO Building.

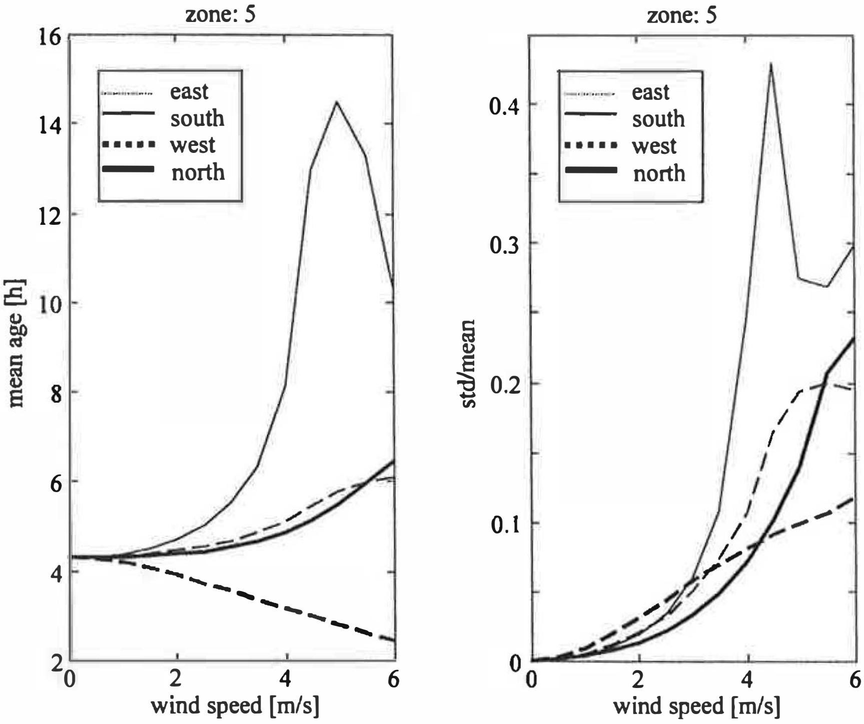


Fig. 8. Mean age of air and its standard deviation calculated by the Monte Carlo method for Zone 005 of the LESO building.

overlap most of the time. The sensitivity analysis was especially focused on the problem of the pressure coefficients. It is that part of the study which is shown here for illustrating the nonlinearity aspect of multizone air flow simulation. An uncertainty of 50%, corresponding to the discrepancies found in the literature, has been considered.

The behavior of the mean age of air is presented in Figs. 7–10 for some zones presenting typical behavior.

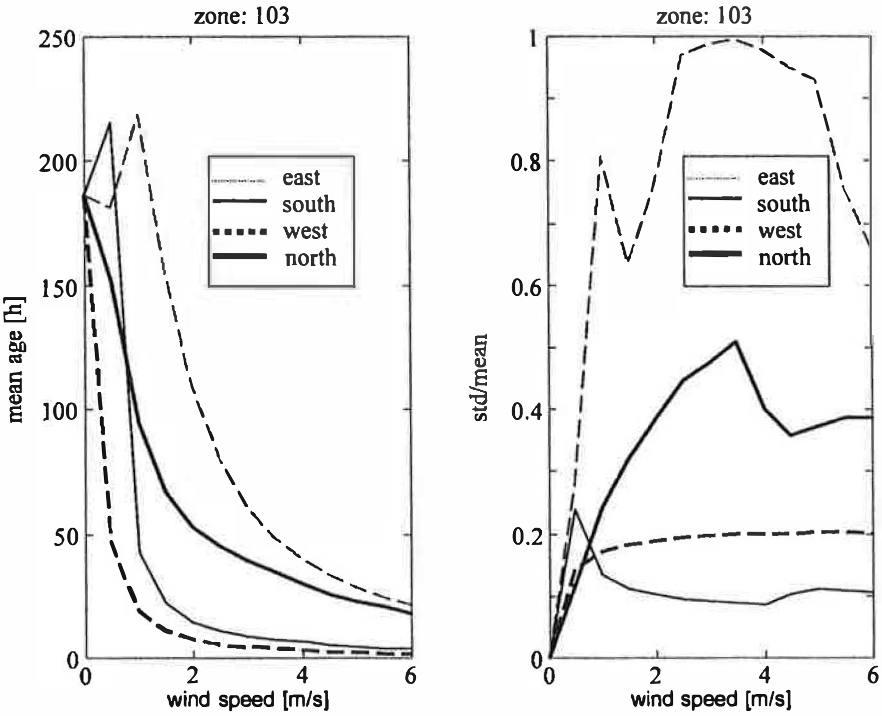


Fig. 9. Mean age of air and its standard deviation calculated by the Monte Carlo method for zone 103 of the LESO Building.

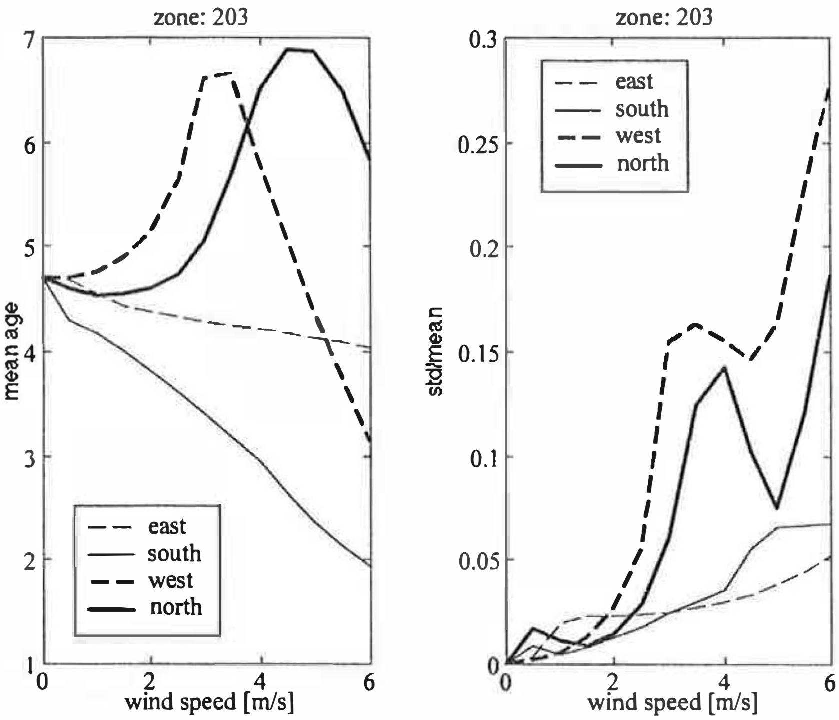


Fig. 10. Mean age of air and its standard deviation calculated by the Monte Carlo method for zone 205 of the LESO Building.

The average of the mean age of air τ in each zone and the corresponding relative standard deviation σ_τ/τ are shown for the four main wind directions θ and wind speeds ν between 0 m s − *1* and 6 m s^{-1}.

Fig. 7 presents the behavior of the mean age of air $\tau(\nu,\theta)$ in the hall. This zone corresponds to the entrance hall which has a very leaky door on the east side, a stair case through five floors (from the basement to the attic) and some additional spaces on each floor. The evolution of the mean air age is more or less inversely proportional to the wind speed. Note the stronger ventilation when the wind blows from the south. The behavior of the standard deviation σ_τ/τ (due to the uncertainty in the C_p's) is more complex. At low wind speed, when the wind blows from the south or north σ_τ/τ decreases when the wind speed increases, while the inverse behavior is observed at high wind speed. In the situation without wind, no error can come from the uncertainty in C_p.

When the wind blows from the west, which corresponds to the most airtight side of this zone, the inaccuracy of the simulation is proportional to the wind speed. When the wind blows from the east, the behavior is still different, showing a quick increase at low wind speed, followed by a cup shape.

Zone 5 (Fig. 8) is situated at the west side of the first floor. When the wind speed increases from 0 m s^{-1} to 6.5 m s^{-1} the age of air decreases when the wind blows from the west while it increases if the wind blows from the north or east. If the wind blows from the south, a maximum can be observed close to 5 m s^{-1}, indicating equilibrium among driving forces. beyond this point, some flows change direction. The relative standard deviation σ_τ/τ increases with wind speed. For low wind speeds, smaller than 2 m s^{-1} the σ_τ/τ does not exceed 3% although it can attain 20% for high wind speeds and even 40% for the equilibrium situation when the wind comes from the south. The values of the mean age of air, between 2 and 6 h is satisfactory.

Zone 103 (Fig. 9) is located on the second floor, at the centre of the south facade. If the wind blows from the north or west, the mean age of air decreases exponentially with the wind speed. The same behaviour occurs when the wind originates from the south or east except that the age of air begins to increase until it reaches a maximum. The

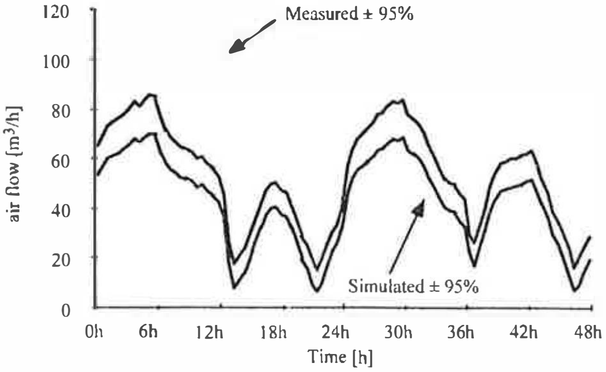


Fig. 11. 95%-intervals of measurement and simulation for the external opening. First period.

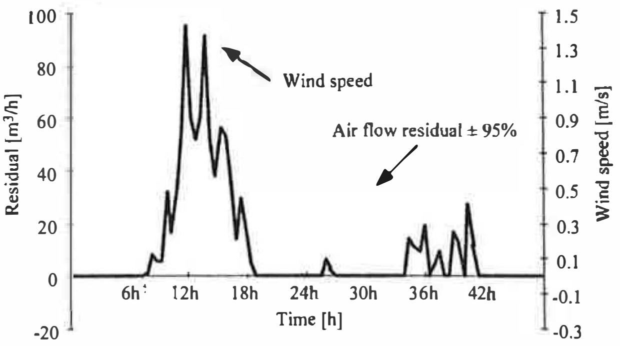


Fig. 12. Wind speed and 95%-interval of residual (= measurement − simulation) for air flow rate through external opening. First period.

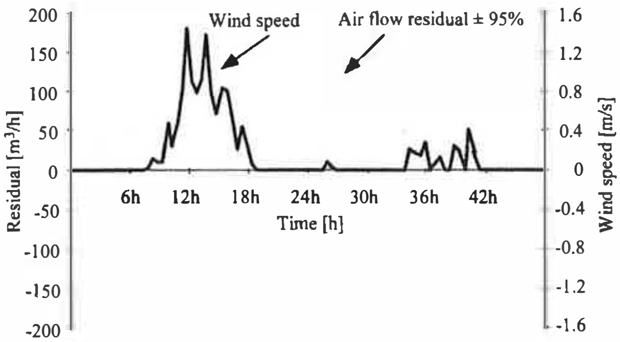


Fig. 14. Wind speed and 95%-interval of residual (= measurement − simulation) for air flow rate through internal opening. First period.

values are very high, attaining a satisfactory level at high wind speeds only. The standard deviation is also high, approaching 100% of the mean when the wind blows from the east. The behaviour changes from one wind direction to another indicating different flow patterns.

The behaviour of a zone on the third floor is also shown in Fig. 10. The evolution of the age of air through the wind velocity increase is still different. For two wind directions (north and west) the ventilation has equilibrium points around 3 m s^{-1} and 5 m s^{-1}. For the other directions there is a monotonic decrease. The value of the age of air is between 2 and 7 h. The standard deviation displays irregular behaviour for both wind directions.

The sensitivity to the pressure coefficient uncertainty depends on wind direction and also wind speed. This short study again shows the complexity of the air flow pattern behaviour and the necessity of having easy-to-use tools to perform online general and single-parameter sensitivity analyses when simulating. This study also shows that the pressure coefficient still is a critical parameter.

The Belgian and the Greek PASSYS cells have been investigated by the BBRI and the University of Athens, respectively. The influence of the wind on a large opening was investigated. The experiments were sufficiently simple to be well controlled. Comprehensive sensitivity analyses of the Belgian case were performed using Monte Carlo and factorial design techniques.

Fig. 11 compares 95% confidence intervals of the experimental with the simulation data. There is a considerable region of non-overlap. In Fig. 12, the residuals are compared to the wind speed signal. The apparent correlation suggests that wind speed may be responsible for the most visible discrepancies between data and simulation. This means that the wind speed effect is not sufficiently taken into account by the large opening model in COMVEN. This comparison also clearly shows the existence of a turbulence effect. The simulation result is nearly always dominated by the measurements, even without wind. The turbulence effect is a constant value corresponding to the minimal air flow through a large opening. Even without any temperature gradient and without wind there is some air flow through a large opening.

In Fig. 13, the same type of comparison is made for an internal opening. In this case simulated and measured air flow do not overlap most of the time either. A residual analysis (Fig. 14) did not provide any insight.

The NAMUR FLAT is used for the evaluation of contaminant spreading and also air exchange through large openings. The flat has seven rooms and is located on the ground floor of a nine-story building. Factorial and Monte carlo sensitivity analyses were run. The analysis of input uncertainties for this annex is exemplary.

While it is difficult to precisely quantify the overlap of confidence intervals or curves, the visual comparison of

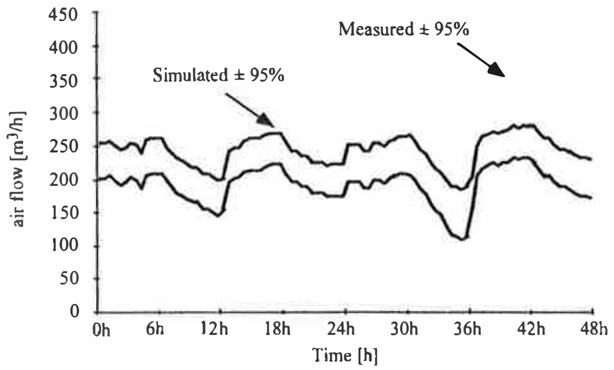


Fig. 13. 95%-intervals of measurement and simulation for the internal opening. First period.

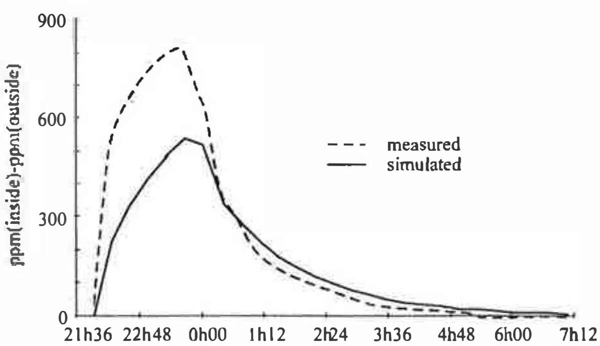


Fig. 15. Measured and simulated CO_2-concentration in bedroom 2; doors open.

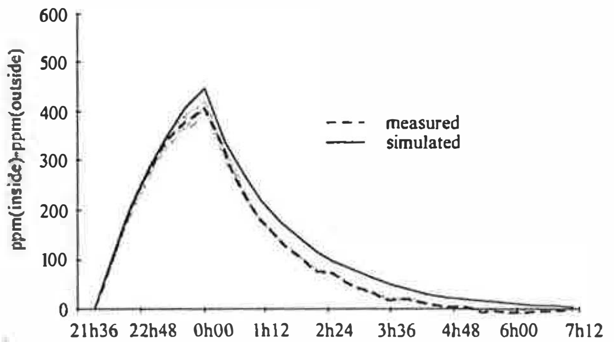


Fig. 16. Measured and simulated CO_2-concentration in the toilet; doors open.

such curves is a standard accepted device for assessing the agreement between sets of estimates or measured data and models.

In the NAMUR FLAT runs, the agreement between measurement and simulation is good for all rooms, except for the injection room (bedroom 2, Figs. 15 and 16). One wonders if this discrepancy is an indication of an error in the algorithm or if it is caused by an incorrect value of an input parameter. A possible explanation might be that the distribution of the final results appears not to be normal. This is caused by the value of the temperature difference. The air flow rate through a large opening is roughly proportional to the square root of pressure difference. The pressure difference resulting from stack effect is proportional to the indoor–outdoor temperature difference. Therefore, in the absence of wind, at constant injection rate and constant temperature differences, tracer concentration is inversely proportional to the square root of temperature difference. This means that for small temperature differences the air flow rate is more sensitive to changes in temperature than for higher temperature differences. This is probably the cause of the difference between simulation and measurement. The Monte Carlo analyses with smaller temperature differences seem to be in good agreement with the measurements.

The effect of the parameters on the final result changes over a period of time and also from room to room. In Fig. 17 the results from a fractional factorial analysis of the injection room are shown. It can be seen that the most important parameters are the injection rate and the temperature difference between both rooms. After injection, the influence of the fresh air flow rates becomes more important.

The ITALGAS Building, investigated by the Politecnico di Torino, is a one-level family house. Built by a gas company for the investigation of gas heaters, the building is well instrumented. It is sufficiently simple to be studied with accuracy, but also sufficiently complex to be representative of real buildings. A comprehensive data set was obtained from this facility.

Fig. 18 refers to the single zone tests (G3-04 to G3-12) when a gas-fire unit was operating in the zone. The simulated and measured air flow rates compared in the figure represent the total (net) flow of the zone which in these tests corresponds to the air flow from the outside to the zone. The analysis of these results emphasizes the strong influence of the chimney stack effect on room ventilation. Special attention must be given to the choice of the single loss coefficient representing the butterfly valves as many different values can be found in the literature [6]. There are only two tests in which the error ranges of the simulated value and the measured value do not overlap (G3-09 and G3-12). In both tests the chimney cross-section is 25%. That corresponds to the maximum value of the single loss coefficient representing the butterfly valve. Probably for such high single loss coefficient values a greater error range than the 25% of the Monte Carlo analysis should be used, since when a valve is near to the closed position, a high variation of the single loss

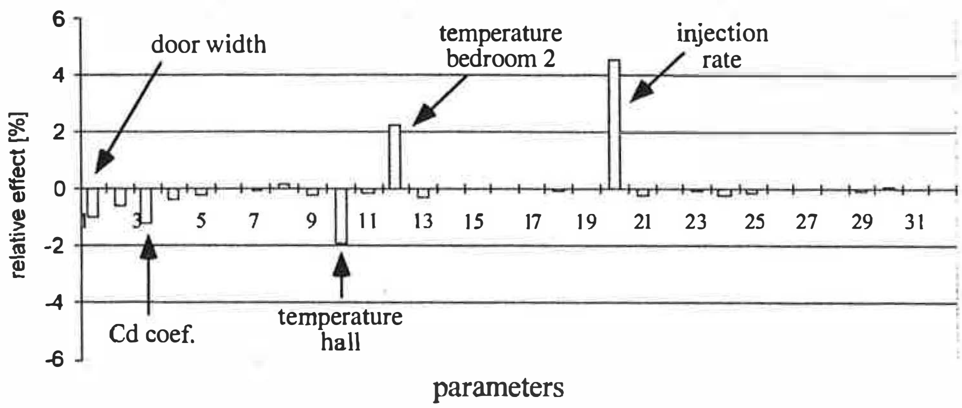


Fig. 17. Main effects for the CO_2-concentration in bedroom 2 at 2300 hours: doors open.

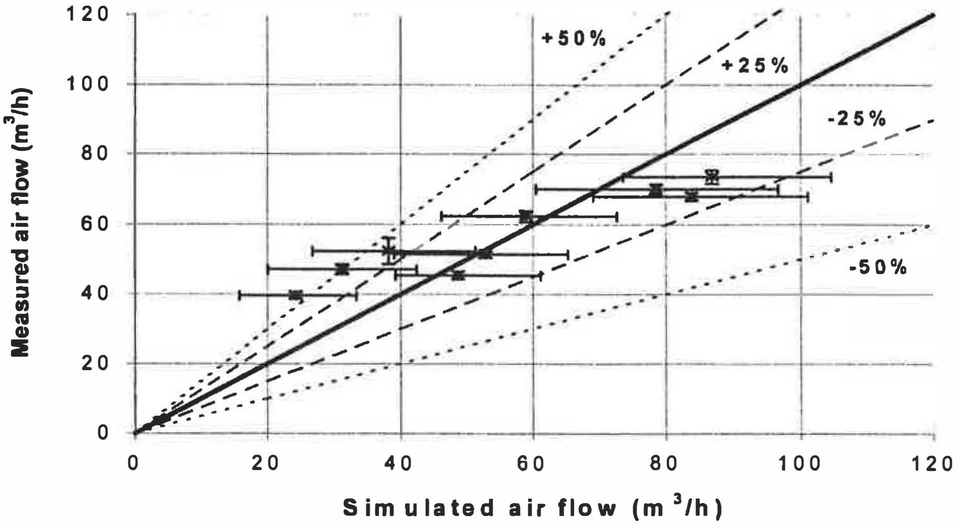


Fig. 18. Simulated and measured air flow rates for tests G3-04 to G3-12. The error bar correspond to $\pm 1\sigma$.

coefficient is associated with a small error in the valve position.

5. User sensitivity

The objectives of the user tests performed under the aegis of Annex 23 were:
1. to assess the difficulties experienced by COMVEN,
2. to improve the specification of data sets and the input routines of network models,
3. to determine the errors made by users in interpreting network input data.

Two tests were proposed. The first represents a simple benchmark analysis in which a network and input data are provided. No interpretation of building leakage and weather data is necessary. The second is an open test requiring network specification and interpretation of the data by the user.

The results of these user tests are summarised below, but presented in more detail in another paper of the same issue [7].

5.1. First case

A vertical cut through the building is represented in Fig. 19, a three story building with a staircase. Temperatures are different on each floor, and there is a vertical thermal gradient in the staircase. All characteristics of cracks, pressure coefficients, meteorological conditions, etc. were specified.

The sensitivity analysis showed that the upper floor and the staircases performances are extremely sensitive to the input variation when the stack pressure compensates the wind pressure. The test case, with a wind speed of 2 m s^{-1} is very close to this critical situation. Small changes in air density(induced by change in temperature or air humidity), and wind speed induce large changes in the age of air.

Two runs were performed with this building. The first one involved eight institutions. It showed significant differences between results, which might have been caused by errors in introducing input data as well as by differences between various versions of COMVEN. User comments were used to improve both the code and the User Guide. In order to clearly separate the effects of COMVEN versions and of users, the second run was performed exclusively with COMVEN 1.2 (version 1.1 corrected for bugs detected by the first run). Eleven institutions participated in this test.

With two exceptions, the results are obviously closer to each other than in the first run. A careful analysis of input files shown that the main reasons for differences are input errors and options taken by participants.

In order to ensure that the COMVEN code does not provide different results on different computers, a reference input file was used by five laboratories with COMVEN

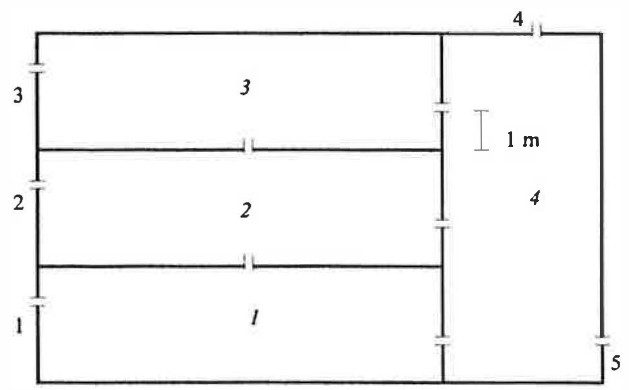


Fig. 19. The building USERTEST1. Number of zones are in italics, while envelope elements are numerated in normal numbers.

1.2. The results were all identical, except for one laboratory which showed tiny differences. For this laboratory, it appeared that the 1.2 version they had obtained from the LBL was slightly different than the 'official' one.

5.2. Second case

Test case 2 is a fifth floor apartment situated at the centre of a nine floors building located in mainland France. Ventilation is provided by natural stack effect and outdoor air enters through natural leakage. The initial data provided were those an engineer can usually obtain from an architect at the design phase. In particular, pressure coefficients were not given. The extract air flow rate was the output parameter selected for this study.

Large differences appeared among the eight participants to this test (see Fig. 20). In particular, there were as many ways of modeling the flat as participants. Therefore, and also because input errors and misinterpretation of the user guide, large differences were observed between simulation results.

In order to eliminate any possible difference resulting from different versions of COMVEN, all received input files were run with the same version, COMVEN 1.3. A reference input file was also carefully constructed. A sensitivity study shown that the meteorological reference height, the building orientation and pressure coefficients have the largest influence on the output. Whenever one door between extraction and the facades is closed, the other internal leaks do not have a large influence on global air change. If there is a short circuit between extraction and the facades, no solution can be found.

Discrepancy between the results of participants resulted from different ways of modeling the flat, differences in input data, and input errors or omissions. Since comparisons of files presenting strong differences because of unclear definitions are not easy, input files were corrected for input errors or omissions and made similar to the reference file for the following variables: reference heights, building orientation, wind direction and wind exponent. Despite these corrections, large differences between results still remain.

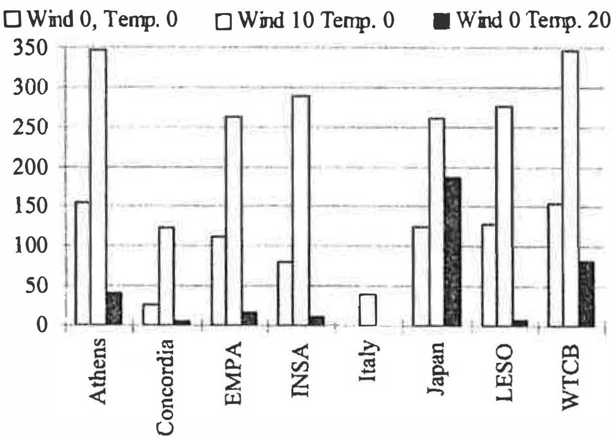


Fig. 20. Outdoor air flow rate as calculated by participants for three different meteorological conditions.

5.3. Conclusions from user tests

From the user tests, we can conclude the following.

Identical input files give identical results on different computers or with codes issued by different compilers, if the same source version of COMVEN is used.

Large differences between results come essentially from modeling options or input typing errors. Some misunderstandings of the User Guide resulted in large changes in wind velocity at the facade level.

In most cases, however, different options chosen by the user for a properly located network generally result in slight differences in airflow rates.

This test has revealed substantial useful information which was used for the improvement of both the code and the User Guide. It is also shows that the quality of the interface between the user and the code is of paramount importance. This interface can be a good User Guide, but may also be a carefully prepared user-friendly graphical interface.

6. Conclusions

This work could provide the basis for a careful treatment of uncertainty in simulations which is an absolute requirement for the confident use of simulation in practice. A basic challenge for developers is to distribute products which can not be misused too easily.

An up-to-date methodology with a robust background and efficient tools is taking form and the main conclusion of all this work is sensitivity analysis modules belong with simulations. This study highlights that a model must encourage the user to assess the influence of the accuracy of the input parameters to the model. The calculation of confidence intervals is a way to do this. This paper, together with another in the same issue, proposes solutions to this important problem. They show the tools needed for such a task and provide examples from the Annex 23 work.

There is an urgent need for tools and precise rules for air flow and contaminant simulation analysis. Users have the largest influence on the results of simulation. They therefore need a guide for the analysis, instructing them what to look for in the output. Until now, such simulation models were used mainly by their authors. But these types of models should be available as planning tools for building physics professionals. To make this work useful for professionals, simulation computer programs should also include analysis tools.

It is hopped that the continuation of this work will lead to an analysis procedure, which must include the following points:

- Sensitivity analysis in given situations (for example over a range of Archimedes numbers).
- Study of mean age of air, energy efficiency and exposure.
- Comparison of user cases with evaluated cases including comparison with experimental data.

7. Nomenclature

C_{ij} air tightness coefficient between node i and j of the network ($m^3\ h^{-1}\ Pa^{-n}$)
C_p pressure coefficient (–)
n_{ij} air tightness exponent between node i and j of the network (–)
q_{ij} air flow rate between node i and j of the network ($m^3\ h^{-1}$)
Q_{ij} element of the flow matrix which is the flow coming in node i from node j ($m^3\ h^{-1}$)
Q flow matrix ($m^3\ h^{-1}$)
ΔP_{ij} pressure difference between node i and j of the network (Pa)
σ_x standard deviation of x
τ mean age of air (h)

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