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An example of model evaluation by experimental comparison: pollutant spread in an apartment

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Abstract

Within Annex 23 ('Multizone Air Flow Modelling') of the IEA (International Energy Agency), a large part of the effort went to the evaluation of the developed simulation tool COMIS [J.-M. Fürbringer, C.-A. Roulet, R. Borchiellini, Evaluation of COMIS, IEA Annex 23: Multizone Air Flow Modelling, LESO-EPFL, Lausanne, 1996; J.-M. Fürbringer, C.-A. Roulet, R. Borchiellini, Evaluation of COMIS —appendices, IEA Annex 23: Multizone Air Flow Modelling, LESO-EPFL, Lausanne, 1996]. The purpose of this work was to examine the reliability of the output of the program and also the impact of the input parameters on the simulation result. Therefore, the program was tested in different ways, for several cases with sometimes strongly different input parameters. Two cases were examined in detail by the BBRI (Belgian Building Research Institute):

- Spread of contaminants in an apartment with natural ventilation: this case will be discussed in this text.
- Single-sided ventilation in a PASSYS-test cell.

Thanks to all these different simulations, one can have an increased confidence in the simulation tool COMIS. More exactly, it gives an idea of the possibilities and limitations of the tool. © 1999 Elsevier Science S.A. All rights reserved.

Keywords: Pollutant spread; Apartment; Air flow; Fractional factorial analysis

1. Experimental comparison

A simulation code can be evaluated in the following ways.

1.1. Analytical evaluation

Comparison between the simulation result obtained with the code and the result of a simple analytical calculation.

1.2. Intermodel comparison

Comparison between the results obtained with different simulation tools. This is only appropriate if the other tools have already proved their reliability.

1.3. Experimental comparison

This is the most complete way to evaluate a tool. It consists of the comparison between measurement results and the simulation results obtained with the investigated tool. To take into account the influence of the input parameters' uncertainties (in this paper 'uncertainty' stands for '95% confidence interval') on the simulation result, a lot of simulations are performed. For each simulation the input parameters get random values from a normal distribution defined by the measured value and its uncertainty. Each run will give a different result: as a consequence it will be easy to determine the average value and the 95% confidence interval of the final result of the simulation. This technique is called the Monte Carlo analysis. One can conclude that the considered part of the model is reliable if there is an overlap between the confidence interval of the simulation and the confidence interval of the measurement.

If one wants to determine the influence of the different input parameters on the final result of the simulation, a Monte Carlo analysis will not be appropriate. There exists another technique called the 'Fractional Factorial Analysis' which makes it possible to determine the influence of the

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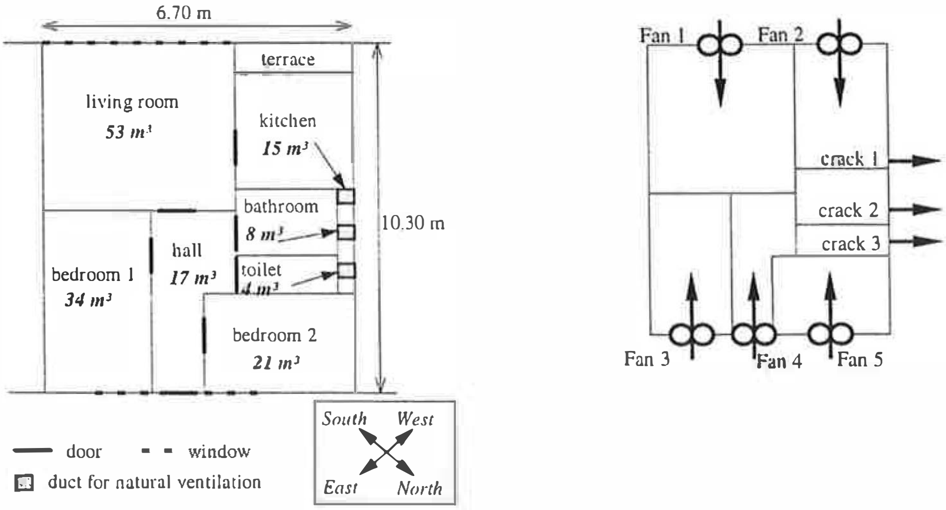

Fig. 1. Sketch of the apartment/sketch of the principle of using fans to simulate the fresh air supply.

input parameters on the simulation result (main effects) and also the influence of the interaction of two parameters (effects of the first order) (see also Refs. [1,2]).

2. An example of experimental comparison: pollutant spread in an apartment

2.1. Description of the apartment

The measurements were performed in an unoccupied flat in Namur, Belgium, on the ground floor of a building with nine storeys. The inside air is extracted by natural ventilation from bathroom, kitchen and toilet through vertical ventilation ducts, which are connected to the main duct by a shunt-system. In Fig. 1 a sketch is given of the apartment.

2.2. Performed measurements

The air flow through the ducts and the fresh air supply into the different rooms were determined by means of tracer gas techniques. CO_2 and water vapour were injected as pollutants in one room during certain periods of time. The concentration of CO_2 and water vapour was measured continuously in 50 points situated all over the apartment,

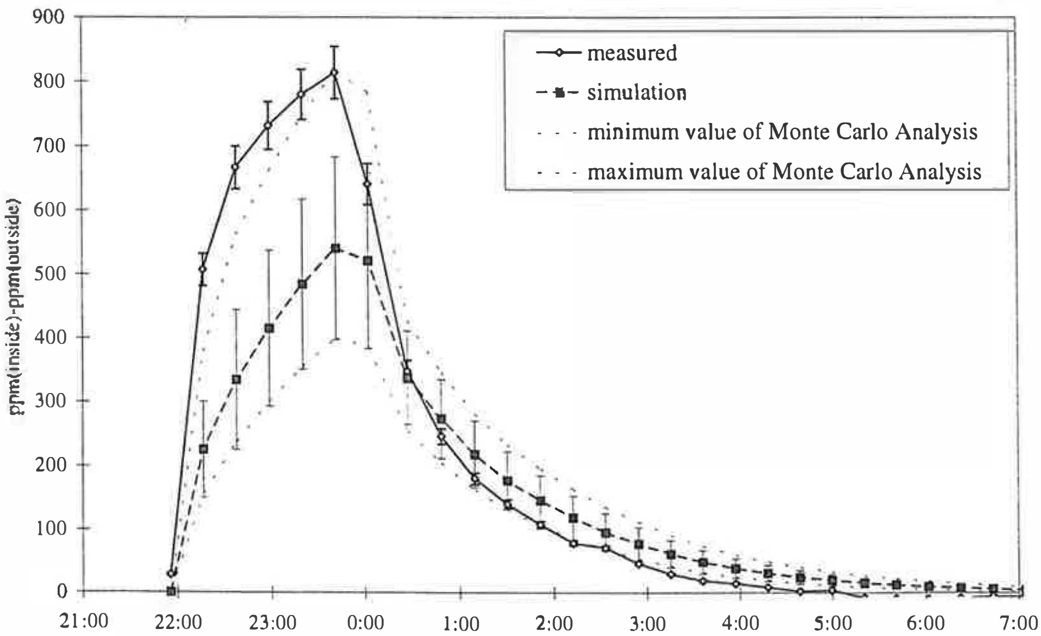

Fig. 2. CO_2 concentration in the injection room (bedroom 2): doors open.

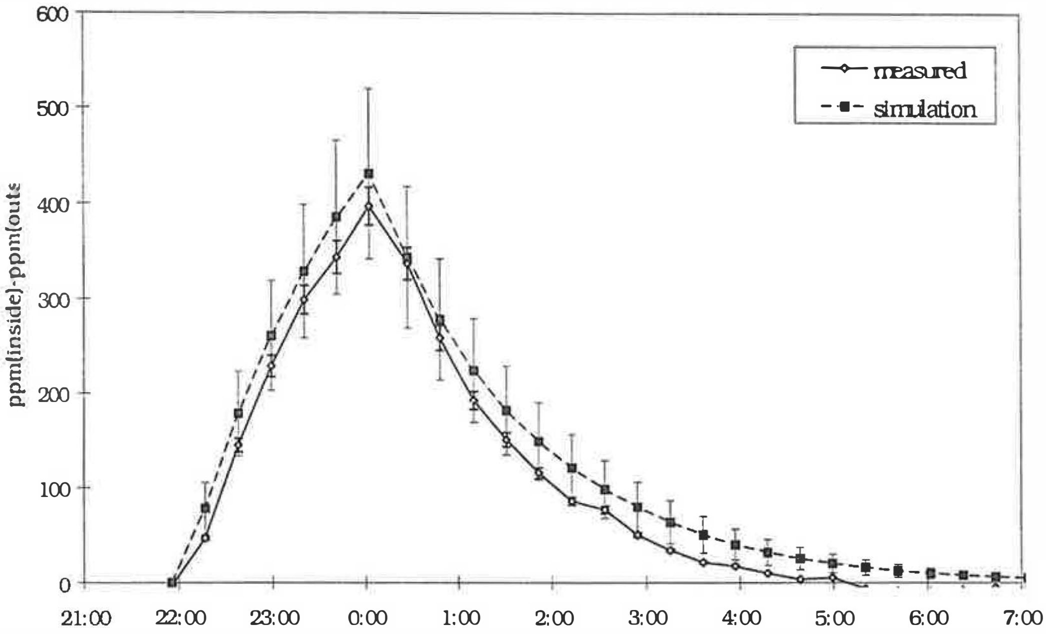

Fig. 3. CO_2 concentration in bedroom 1: doors open.

as well as the temperature. On the roof the wind speed and direction were also measured continuously.

2.3. Simulation

The purpose of the simulations is to test the reliability of COMIS in the field of internal air flows and pollutant spread. As there is a high uncertainty on the determination of pressures on the facades starting from wind speed and wind direction, the fresh air supplies in the rooms (which were determined with tracer gas) are entered as known parameters. This is done by putting a fan in each external wall, providing the fresh air supply. The ducts for natural ventilation are described as cracks in the input data. The principle is shown in Fig. 1.

Two cases are examined:

- Inside doors open
- Inside doors closed

In both cases the pollutants (CO_2 and water vapour) were injected into bedroom 2 for 2 h. The water vapour concentration is entered as a known parameter. The CO_2 concentration is the simulated parameter. For both cases the agreement between simulation and measurement is examined by means of a Monte Carlo analysis, as well as the influence of the input parameters on the simulation result (= CO_2-concentration) by means of a fractional factorial analysis.

3. Results and discussion

3.1. Situation with inside doors open

In Figs. 2 and 3 the results are shown of the simulation of the CO_2-concentration in two rooms: bedroom 2 (= injection room) and bedroom 1.

One can see that the agreement between simulation and measurement is rather good for bedroom 1. This is the case for all the rooms different from the injection room. However, for bedroom 2 (where the pollutant is injected), the agreement is far from good: during a long time there is no overlap between the confidence interval of the measure-

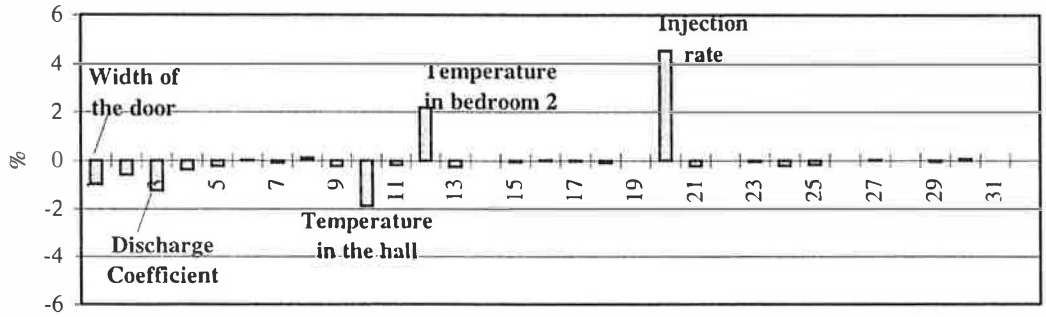

Fig. 4. Main effects of the input parameters on the simulated CO_2 concentration in bedroom 2 at 2300 hours: doors open.

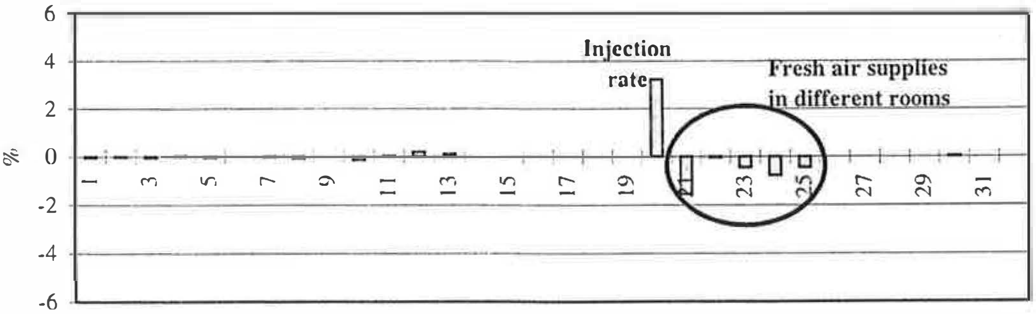

Fig. 5. Main effects of the input parameters on the simulated CO_2 concentration in bedroom 2 at 0100 hours: doors open.

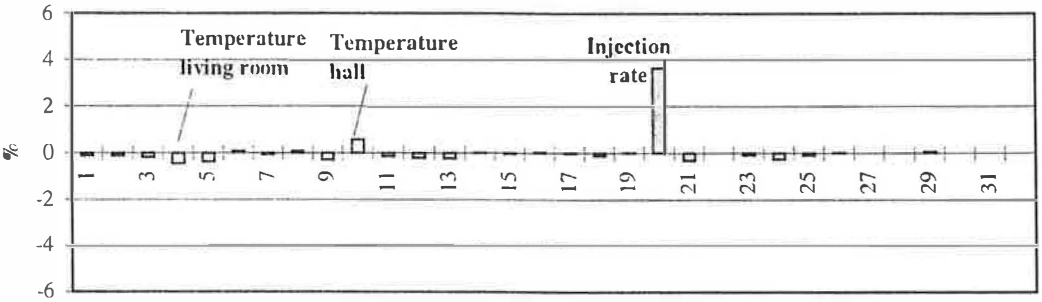

Fig. 6. Main effects of the input parameters on the simulated CO_2 concentration in the hall at 2300 hours: doors open.

ment and the confidence interval of the simulation. One can wonder if this is due to an error in the algorithm or if it is caused by a wrong value of one of the input parameters.

Performing a fractional factorial analysis will help to explain this problem. In Figs. 4–6 one can see the influence of different input parameters on the concentration.

This type of figure has to be evaluated in the following way. Each number represents a parameter, the height of the bar is an indication of the parameter's influence on the final result. For example, in Fig. 4 one can see that the influence of the injection rate is about 4.5%. The standard deviation of the injection rate was taken 10%. This means that a change of the injection rate with 10% will have an

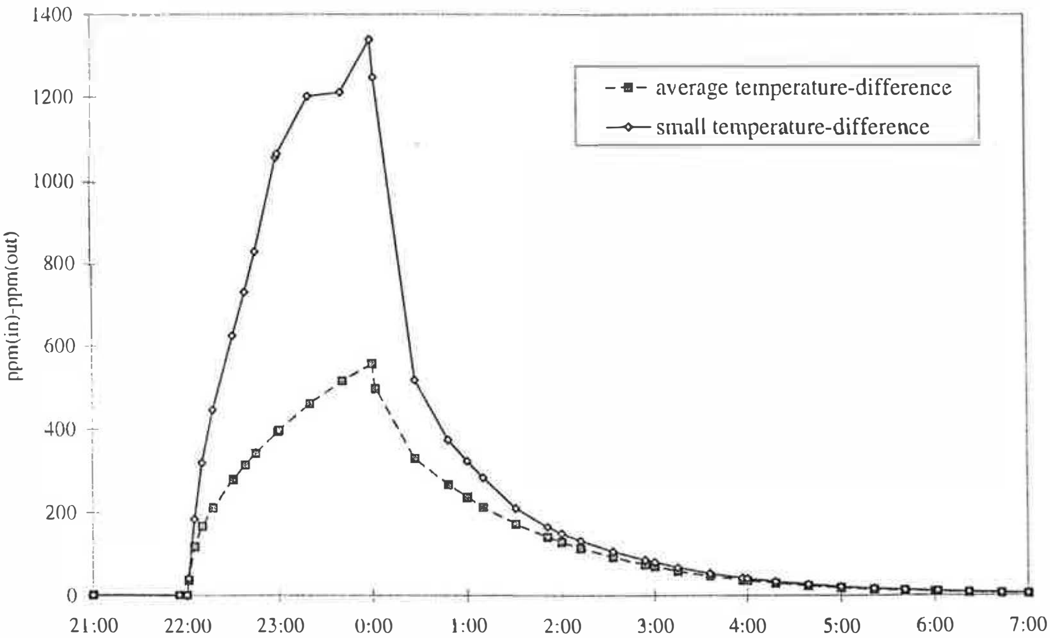

Fig. 7. Concentration in the injection room for two different values of the temperature difference.

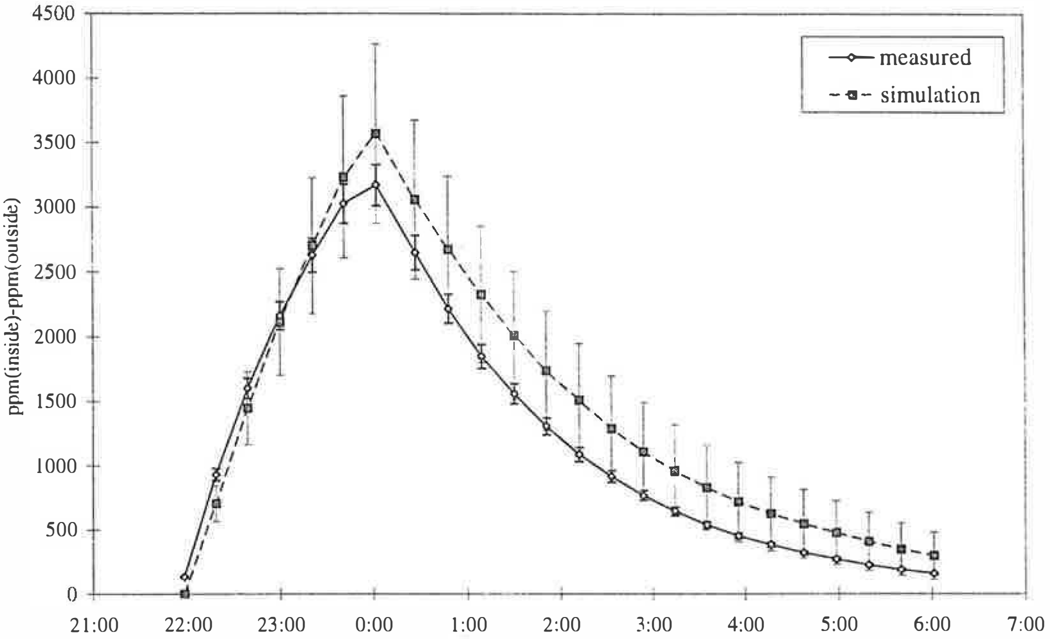

Fig. 8. CO_2 concentration in the injection room (= bedroom 2): doors closed.

influence on the concentration of 4.5% *at that moment* (2300 hours) *in that room* (bedroom 2). At 0100 hours, this influence decreased to about 3%. A negative bar means that an increase of the input parameter will result in a decrease of the final result.

Figs. 4 and 5 show the main effects for the concentration in bedroom 2 at two different moments. In Fig. 4 one can see that during the injection (2300 hours) the temperature difference between the bedroom and the hall has a high influence on the concentration in bedroom 2. When injection has stopped (0100 hours: see Fig. 5) the temperature difference has nearly no influence anymore: as one can see in Fig. 2 the agreement between simulation and measurement is much better when injection has stopped. For all the rooms different from the injection room the temperatures will have no important influence on the CO_2-concentration: see Fig. 6.

It seems very probable that there is a problem with the values entered for the temperatures. The mass flow through a large opening (= open door) is proportional to the square

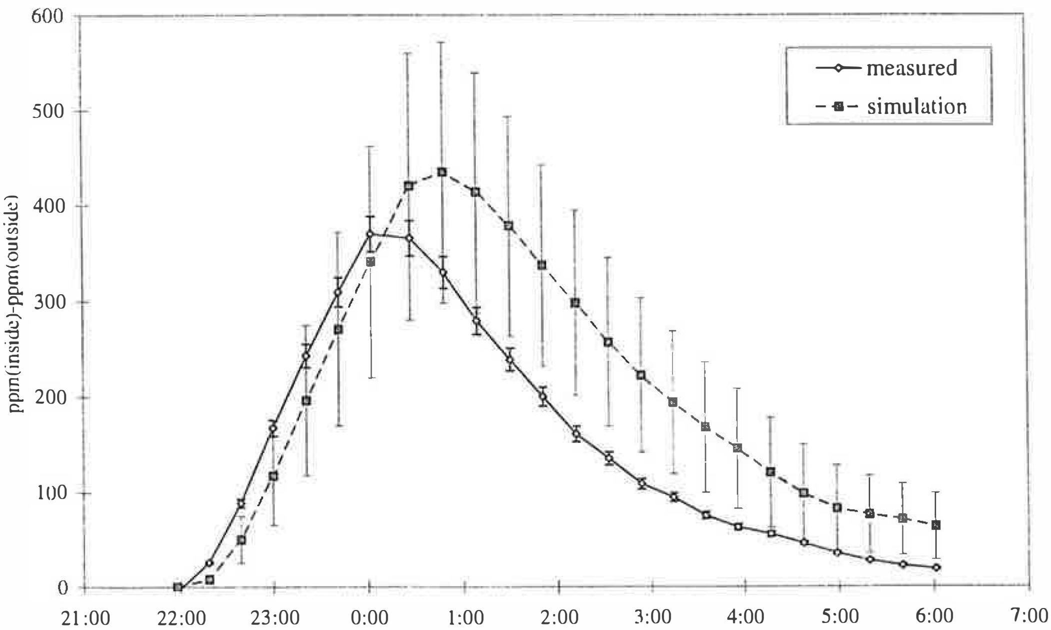

Fig. 9. CO_2 concentration in the bathroom: doors closed.

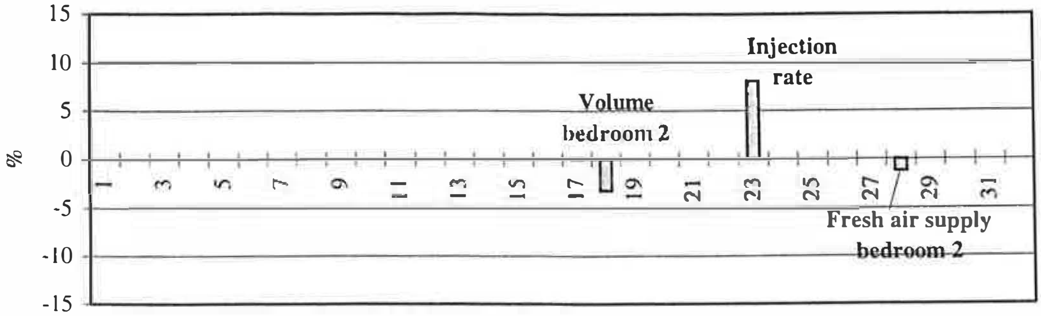

Fig. 10. Main effects of the input parameters on the simulated CO_2 concentration in bedroom 2 at 2300 hours: doors closed.

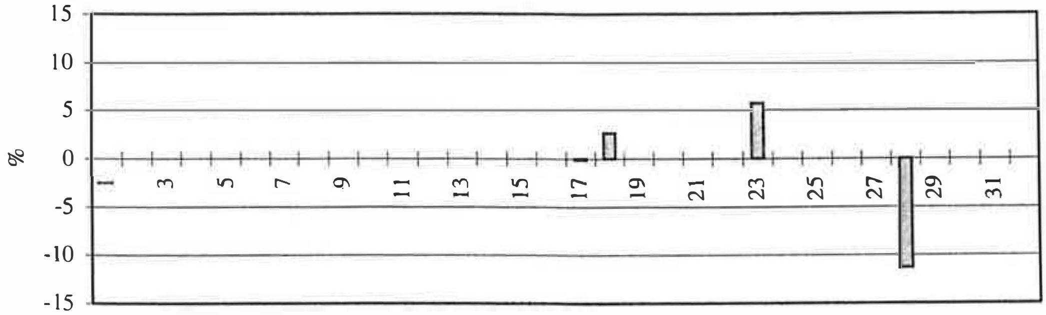

Fig. 11. Main effects of the input parameters on the simulated CO_2 concentration in bedroom 2 at 0400 hours: doors closed.

root of the temperature difference. As a consequence the concentration in the injection room will be *inversely* proportional to the square root of the temperature difference. This means that when the temperature difference is small, the concentration in the injection room will be more sensitive to changes of the temperature than when the temperature difference is high.

From all the 100 Monte Carlo runs, the best agreement with the measurements seemed to be found for these runs which have a very small temperature difference between injection room and hall. This is illustrated in Fig. 2 where the maximum simulation result is represented by the upper dashed line: there seems to be a very good agreement with the measurement.

In each room the temperature was measured at different points. The value entered to perform the simulation was the mean temperature. One could see that there were sometimes important differences between two points in the same room. This probably explains the disagreement between measurement and simulation for the injection room.

In other words, the difference is probably not due to an error in the code, but it is a problem of introducing correct input parameters to perform a simulation. To illustrate this, the results of two single (no Monte Carlo) simulations are shown in Fig. 7. In one case the temperature difference between the hall and the injection room is the same as in the previous case (1.8 K); in the other case the temperature difference is very small (0.05 K).

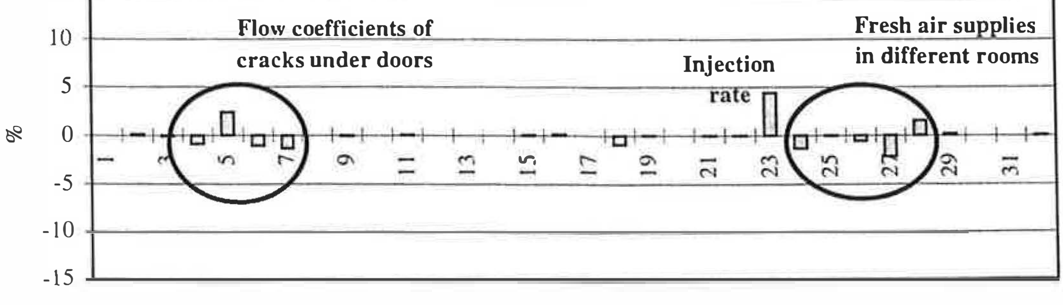

Fig. 12. Main effects of the input parameters on the simulated CO_2 concentration in the hall at 0100 hours: doors closed.

This shows that a very good knowledge of the temperature distribution is necessary to be able to make good predictions of the pollutant spread and the internal air flows.

3.2. Situation with inside doors closed

In Figs. 8 and 9 results are shown of the Monte Carlo Analysis. One can see that the agreement is quite good for the injection room. On the other hand there seems to be a significant difference between simulation and measurement for the other rooms as one can see for example in Fig. 9. This difference is probably caused by the fact that a part of the fresh air entering a room, does not leave the apartment via the ducts, but via the external walls. As the fresh air supply is only simulated by one fan per room and all the fans are supply fans, this part of the ventilation cannot be simulated. Due to this the CO_2-concentration will decrease faster in reality.

A fractional factorial analysis shows that the only parameters which have a significant influence on the concentration in the injection room are the volume, the injection rate and the fresh air supply in the room. Comparing Fig. 10 with Fig. 11 one can see that the fresh air supply becomes a lot more important when injection has stopped. For the rooms different from the injection room the flow coefficients of the cracks under the doors also have a significant influence on the concentration. This can be seen in Fig. 12.

4. Conclusions

Only a specific part of COMIS 1.2 has been evaluated in this example: the calculation of the air flow through large openings and the prediction of concentration levels of pollutants. The simulation of fresh air supplies starting from weather data and leakage data was not considered in this case. The reason is that it is easier to evaluate a tool if only a small part is tested.

The differences found between simulation and measurement were mainly caused by incorrect (temperature in the rooms in the case with the internal doors open) or incomplete (part of inside air leaving the rooms through the walls in the case with the inside doors closed) input data.

A fractional factorial analysis can give a lot of information on the importance of different input parameters. In that way it is possible for the user to determine which parameters have to be measured with greater care than other ones.

Acknowledgements

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