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**A New Method For Linking Results of Detailed Air
Flow Pattern Calculation With Multizone Models.**

A. Schälin^{*}, V. Dorer^{}, J. Van der Maas^{***}, A.
Moser^{*}**

*** Energy Systems Laboratory (LESO), Swiss
Federal Institute of Technology of Zurich
(ETHZ), ETH-Zentrum, CH-8092 Zurich,
Switzerland**

**** EMPA, Section 175, CH-8600 Dübendorf,
Switzerland**

***** LESO-PB, Ecole Polytechnique Fédérale de
Lausanne, CH-1015 Lausanne, Switzerland**

Synopsis

Multi-zone models are a common tool for calculating air and contaminant exchange within rooms of a building and between building and outdoors. Usually a whole room is then modelled by one calculation node with the assumption of homogeneously mixed conditions within this room whereas in real cases temperature and contaminant concentrations vary in space. The exchange to the neighbouring nodes via the flow paths is then a function of the local values of these variables. Detailed knowledge can be obtained from the solution of the transport equations for the air flow pattern within the room at the expense of far higher computation cost.

This work shows a new approach called "method of detailed node values" to include results from detailed calculations in multi-zone models to give a better description of the real cases. Parameter transfer between a multi-zone program and a detailed air flow simulation program is discussed for different flow paths of practical importance.

The method is demonstrated in an example case with air in/exfiltration, ventilation and contaminant propagation, and discussed in a second example with large openings. This new method promises to improve the multizone model predictions with few additional CFD computations.

1. Introduction

Multizone models are computer tools for calculating air and contaminant exchange between rooms of a building and between the building and outdoors. Usually a whole room is modeled by one calculation node (a zone) under the assumption of homogeneous conditions within this room.

In real cases, however, temperature and contaminant concentrations vary in space. The exchange to the neighbouring nodes is then a function of the local values of these variables near the flow paths within each zone. Examples where detailed results are important for the multizone problem include:

- detailed multizone indoor air quality and detailed multizone ventilation efficiency simulations
- pollutant spread from a zone with a non-homogeneous concentration (i.e. a local source) into other rooms and therefore a complex room concentration pattern
- rooms with thermal stratification (e.g. displacement ventilation, open doors and windows)

Detailed knowledge can be obtained from the field solution of the transport equations for the air flow pattern within the room, at the expense of relatively high computation cost. Methods to include detailed results in multizone pro-

grams are therefore desirable to improve the predictions of the whole building transport behaviour.

On the other hand, it can quite generally be useful to calculate the boundary conditions for a specific ventilation problem and for desired climatic conditions with the multizone program. This holds especially for cases with a combined mechanical/natural ventilation system, i.e. small mechanical exhaust systems with inlets and infiltration paths considerably influenced by stack and wind pressures.

This work shows a new approach to include results from detailed single-room calculations in multizone models to give a better description of the real cases. Parameter transfer between a multizone program and a detailed air flow simulation program is discussed. The method is then applied to an example case with air infiltration and exfiltration, ventilation and contaminant propagation. For the case of an open door or window, detailed information on the risk for cold draughts and uncomfortable temperature gradients can be obtained.

The presented method may thus be very helpful in the conceptual and the design stages of advanced ventilation systems for residential and small office buildings.

2. Method for linking results of detailed air flow pattern calculation with multizone models

2.1. Brief description of multizone models

In a multizone model a building is represented by a network of nodes and links (flow paths) between nodes. Usually a whole room is modeled by one calculation node (a zone) with the assumption of homogeneous conditions within this room. Different connections (flow paths) between zones are described by functional relationships between mass flow and pressure difference. Figure 1a shows a simple example of a house, and Figure 1b its network representation for the multizone modeler.

A system of algebraic equations derived from mass continuity is then set up. The equations are explicitly solved for pressure, and mass flow; humidity and concentrations of contaminants are then derived from the calculated mass flow rates. Temperature is used as a known input for the calculation of the mass flow between two nodes; even stratification profiles can be provided as input to the presently used program COMIS [Feustel et al. 1990, 1992].

In the example of Figure 1b the node values 1 and 2 are calculated; the other nodes serve as boundary conditions. The results are in general time-dependent in accordance to the climatic data used in the input.

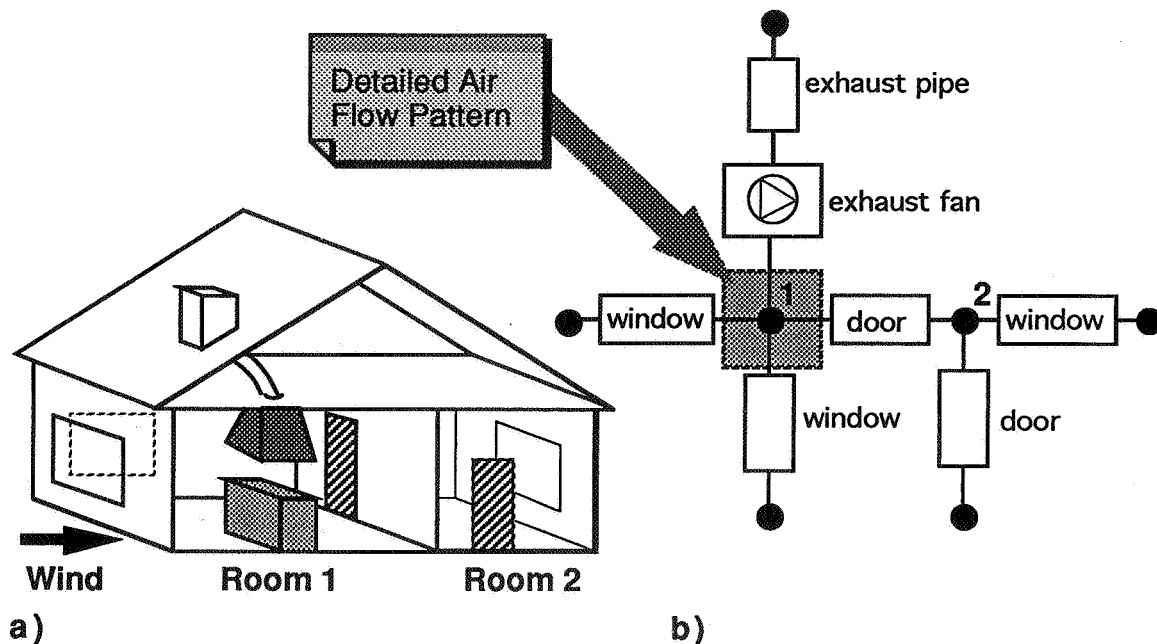


Figure 1: a) Example house with two rooms. The left room with internal details shown is the one chosen for the CFD calculation. b) Multizone network of the whole building.

The case of an open door or window is traditionally treated by keeping the inside temperature fixed. New modules under development for COMIS provide estimates for the time dependence of temperature and temperature gradients, and CFD can give a detailed picture of the velocity and temperature field.

2.2. Brief description of a CFD program

In a CFD (Computational Fluid Dynamics) program for the calculation of a single-room air flow pattern, the room is divided into a large number of cells (typically 10'000) and for each cell transport equations for mass, momentum, energy, turbulence quantities and concentrations of contaminants are solved. Variables solved for and under discussion for this application are: pressure, velocity components, temperature and contaminant concentrations. Turbulence variables depend on the turbulence model used and are not of concern for the present application.

In the present example the commercial code PHOENICS was used [Rosten and Spalding 1987, Chen et al. 1990]. The calculations have been performed in steady state, but could also be solved for time-varying boundary conditions. In most cases it is usually preferred to calculate stationary solutions for three or four different boundary conditions rather than the dynamical behaviour of the room air flow.

2.3. Evaluation of a method

A new method had to be worked out for combining detailed air flow pattern results with multizone programs, because no previous work is known for such an application.

At first an approach was considered to enhance the resolution of the multizone program itself by including several horizontally and vertically divided subzones with appropriate flow paths between them. The subdivision of a room in subzones should be done depending on the characteristic flow patterns. Figure 2a shows an example of a room with a radiator (after Inard et al. 1991) with 5 subzones and a predominant flow pattern in each subzone. The detailed air flow pattern calculation should then give details for each subzone.

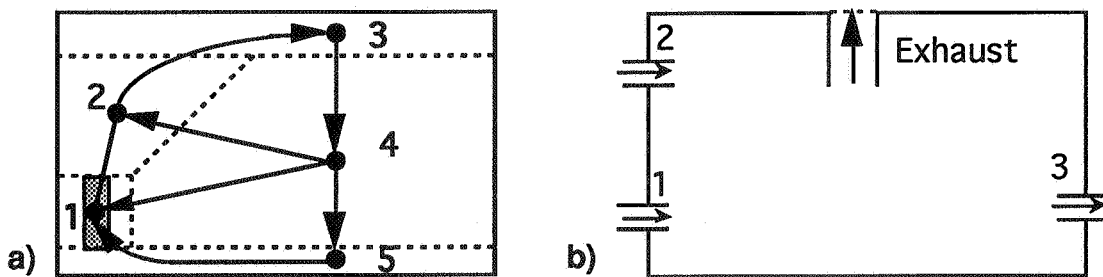


Figure 2: a) Substructuring in subzone model for a room with radiator (after C. Inard, 1991). b) Interface of new method for example room 1 of Figure 1: 1,2 window infiltration paths, 3 door exfiltration path, and kitchen exhaust.

For this situation Inard et al. (1991) obtained good agreement with measured data, but the flow pattern had to be known in advance. In a general case it is difficult to divide a room in such subzones. Even if it is possible in one case, a moderate parameter variation can change the flow pattern of the whole room and the division in ordered subzones has to be modified. As a further problem the available COMIS code cannot handle the desired subzones.

So another approach deferring all the detailed calculation to the CFD code was chosen. The complete room air flow pattern of one zone or node is calculated by CFD with appropriate boundary conditions at the connections to the other nodes. The remaining problem is then basically a discussion of the interface values at the connections to other nodes between the multizone program and the CFD program.

A suggested preliminary name of the whole method is "method of detailed node values". Instead of one average variable value (C_1 and C_2 for the nodes 1 and 2 in the example of Figure 1b and 2b), a different variable value is provided for each flow path connected to the considered node(s) (as indicated in Figure 2b).

3. Interface parameters

3.1. Flow paths considered

Multizone programs like COMIS provide many flow paths which the user can choose for his particular needs. We discuss here only those of practical importance for the present connection to air flow calculations:

- Fans (ventilation supply, exhaust), flow controller
- Leakage flow paths with infiltration or exfiltration
- Large openings (open doors, open windows)

In the example case the method is applied to some of these flow paths. An application to cases with large openings is shortly outlined in principle.

3.2. Input and output parameters

All the variables mentioned in Sections 2.1 and 2.2 can be transferred from one program to the other but will be handled differently. For each of the two programs they can be either input value (i.e. boundary condition) or output value (i.e. a result) or irrelevant, depending on the flow direction and the type of flow path.

- Pressure: The node pressure as a result of the multizone program can be given to the CFD code, but is irrelevant in the case of a single-room calculation as discussed here. In a case where a flow path like an exhaust pipe would be included in the calculation domain it could be used. However it is generally preferred to use velocity boundary conditions rather than pressure boundary conditions for numerical reasons. However it is possible to transfer local pressure differences due to temperature or air velocity differences to the multizone program allowing for higher accuracy (Figure 6c gives an impression of the local pressure field in a room).
- Velocities or mass flow belong to the main variables of concern here. Usually the multizone model will calculate first the whole network and therefore the resulting mass flows provide the boundary conditions for the CFD code. In some cases however (e.g. in a room with several large openings) it can also depend on the local air flow pattern and therefore be an unknown.
- Temperature and gradients as a result of the CFD calculation can in some cases be given back to the multizone program and be used as input for a calculation with higher accuracy.
- Concentrations are the other main variables of concern. They will be input or output variable depending on the flow direction.

	Velocity	Temperature	Concentrations
Ventilation inlet	i	i	i
Ventilation outlet	i	o	o
Leakage infiltration	i	i	i
Leakage exfiltration	i	o	o
Large opening	i/o	i/o	i/o

Table 1: Input(i) and output(o) parameters for CFD program for different flow paths.

Table 1 shows an overview of input and output parameters for different flow paths, as seen from the CFD program. The role of the different variables depends mainly on the flow direction. The case of the large opening must be treated specially because bi-directional flow is possible and often occurs.

All the output parameters which are results from CFD calculations will then be fed back to the multizone program. In some cases it is even possible that the mass flow depends strongly on the local conditions (e.g. in a room with two large openings). In such cases the whole procedure can be repeated two or three times, i.e. the CFD results are fed back into the multizone program which is run another time, and the new results put again into the CFD program and so on. This procedure could be called an external iteration.

For the contaminant transport the new concentrations (the above-mentioned output parameters) can be fed directly into the contaminant modules of the multizone program without a second run. The Swiss version of COMIS (called COMERL) which was actually used for this application was adapted for this special type of input. With such local values, also time-dependent contaminant concentrations can be calculated under the assumption that the room air flow pattern remains unchanged.

4. Example cases

The first example (sections 4.1 to 4.4) shows how the air flow pattern in a room in a simple building is calculated with a CFD program while most boundary conditions are given from the output of a multizone program. From the CFD results temperature and concentrations at those locations where outflow occurs can be fed back to the multizone program. The contaminant transport can be calculated with the new input values.

The second example (in section 4.5) gives a short discussion on cases with large openings.

4.1. Case description

We consider the typical residential building from Figure 1. The situation represents a living room and kitchen combination, as seen in more details in Figure 3. The kitchen ventilation is mechanically forced by an exhaust system above the cooking plate running at $200 \text{ m}^3/\text{h}$. The cooking plates are assumed to have a convective heat transfer of 500 W to the air. For the cooking process a unit contaminant source of $S=0.01 \text{ ml/s}$ is assumed (For a weight factor of 1.0, it corresponds to an olfactory source of 1 olf [Fanger 1989]). For higher source strengths, the concentration results (given in ppm) can be scaled up by the same factor. The walls are treated as adiabatic.

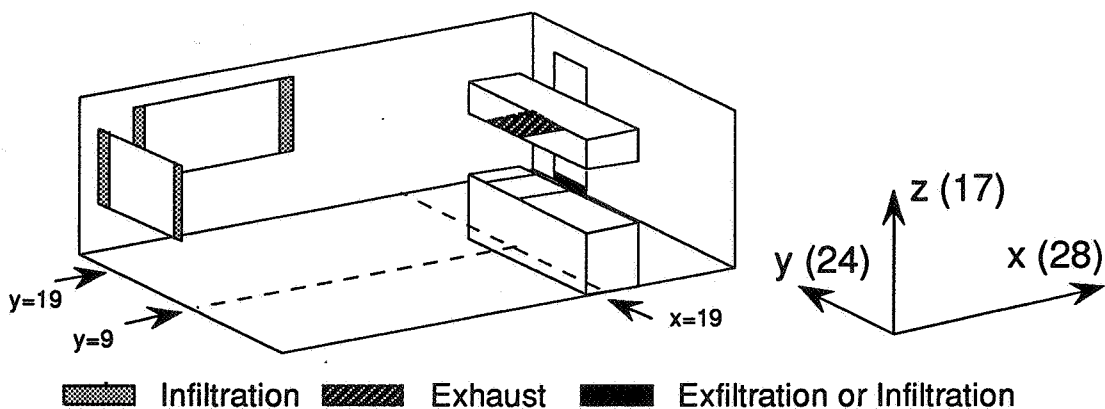


Figure 3: Sketch of the living room & kitchen, with two windows and infiltration area, kitchen combination and exhaust, and door and exfiltration area. To the right the number of cells in each direction are given, with a total of 11424 cells for the CFD program.

4.2. Input from multizone program

The values for the crack flow through the windows and the internal door into the adjacent room have been calculated with the multizone program for two meteorological wind conditions assuming typical building wind pressure and leakage data, and exhaust fan characteristics. The cracks have been modeled by rather large areas because of the coarse grid resolution chosen; a finer grid would only change the resulting air flow pattern in the near-crack region, and is not needed in the present example.

In the first situation (case K4) without wind, half of the exhaust volume flow is infiltrated from the windows, the other half from the adjacent room (through the door). In the second situation (case K5) a strong wind (10 m/s) has been assumed from the left which leads to a total infiltration through the window cracks of $240 \text{ m}^3/\text{h}$, and therefore to an exfiltration of $40 \text{ m}^3/\text{h}$ through the door crack to the adjacent room.

The temperature of the outside air was assumed to be 20°C, and of the air from the second room 22°C; contaminant concentration of inflowing air is 0. A list of these parameters is contained in Table 2.

4.3. CFD results

Figure 4 shows as an illustration, for case K5, the resulting air flow pattern, temperature and contaminant concentration contour lines in the planes $y=9$ and 19, and $x=9$. The position of these planes (in units of cell numbers) is indicated in Figure 3. The air inflow at the window cracks and outflow at the exhaust and near the bottom of the door, temperature stratification in the room (21°C near the bottom, and +1K/m) and contaminant distribution can be nicely seen. The stratification would be important for the multizone problem specially in connection with large openings.

Table 2 gives also the results (bold face) of the variable values at the flow paths to the neighboured nodes (exhaust and door crack) for cases K4 and K5.

Case K4 (no wind)	Volume flow	Velocity	Temperature	Concentration
Window, Inf.	100 m ³ /h	0.03 m/s	20°C	0
Door, Inf.	100 m ³ /h	0.35 m/s	22°C	0
Exhaust	- 200 m ³ /h	0.09 m/s	24.5°C	0.18

Case K5 (wind)	Volume flow	Velocity	Temperature	Concentration
Window, Inf.	240 m ³ /h	0.07 m/s	20°C	0
Door, Exf.	- 40 m ³ /h	0.14 m/s	21°C	0.09
Exhaust	- 200 m ³ /h	0.09 m/s	24.5°C	0.185

Table 2: Input parameters and results (bold) for the two cases K4 and K5.

4.4. Results of the detailed node value method

In the present example, the most interesting results are those for the contaminant concentrations. Table 3 compares the results of the multizone program a) under the usual assumption of homogeneous mixing, and b) with the CFD result as additional input. Figure 5 illustrates the terminology of the following analytical discussion.

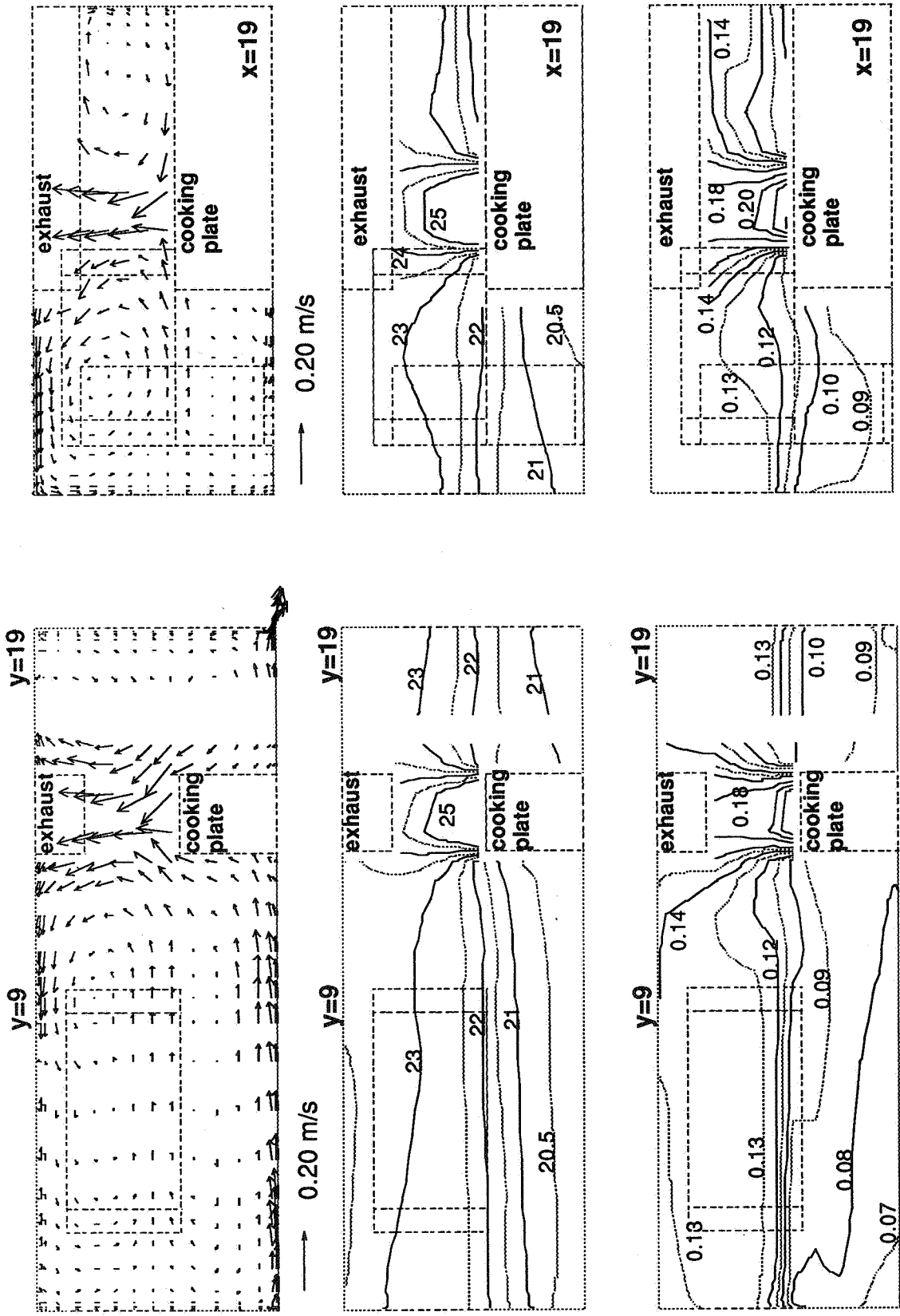


Figure 4: Case K5. Left column: y-planes y=9 and y=19 (see Figure 3). Right column: x-plane x=19. Top row: Air flow field. Medium row: Temperature contour lines. Bottom row: Contaminant concentration contour lines. The source is situated above the cooking plate.

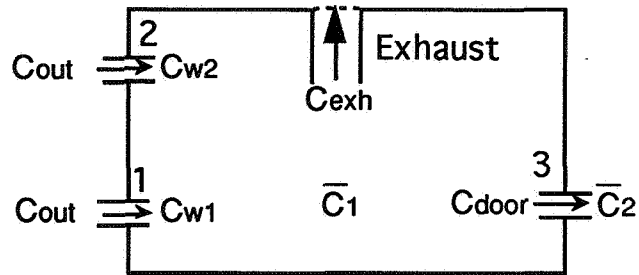


Figure 5: Terminology for case K5.

In the no-wind case (K4) also the door is an inflow path. The balance for node 1 (our example room) states then for the volume flow rates ($\dot{V} = \dot{m} / \rho$):

$$\dot{V}_{w1} + \dot{V}_{w2} + \dot{V}_{door} = \dot{V}_{exh} \quad (1)$$

For the contaminant concentration (we consider one contaminant species) we get for the multizone model:

$$\dot{V}_{w1} C_{outdoor} + \dot{V}_{w2} C_{outdoor} + \dot{V}_{door} C_2 + S = \dot{V}_{exh} C_1 \quad (2)$$

The outdoor concentration $C_{outdoor}$ and the concentration in the adjacent room C_2 are 0 because the contaminant source is inside of Room 1. C_1 is the average concentration in Room 1, which is in this simple case calculated by

$$C_1 = \frac{S}{\dot{V}_{exh}} = 0.18 \text{ ppm} \quad (3)$$

The detailed node value method leads to the same concentration result at the exhaust because there is only one outflow port. Note that in this case the concentration in the typical occupied area in Room 1 is 0.11 ppm, also lower than the calculated C_1 .

Case K4 (no wind)	Room 1	Room 2	Exhaust
a) Multizone only (perfect mixing)	0.18 ppm	0	0.18 ppm
b) Detailed node value method	0.11 ppm	0	0.18 ppm

Case K5 (wind)	Room 1	Room 2	Exhaust
a) Multizone only (perfect mixing)	0.15 ppm	0.15 ppm	0.15 ppm
b) Detailed node value method	0.12 ppm	0.09 ppm	0.185 ppm

Table 3: Node value concentrations for the nodes living room & kitchen (Room 1), adjacent room (Room 2) and exhaust, in the two cases K4 and K5. For Room 1 typical values in a height of 1.6 m have been taken.

In the wind-case (K5) Equation 2 for the multi-zone model, again with $C_{out} = 0$, is changed to:

$$S = \dot{V}_{exh} C_1 + \dot{V}_{door} C_1 \quad (4)$$

The multizone average value C_1 is then 0.15 ppm, whereas the detailed node value method equation reads as

$$S = \dot{V}_{exh} C_{exh} + \dot{V}_{door} C_{door} \quad (5)$$

The concentrations are $C_2 = C_{door} = 0.09$ ppm in the adjacent room near the door and $C_{exh} = 0.185$ ppm for the exhaust from the CFD results (the values can be read approximately from Figure 4).

In this simple example, which was chosen to illustrate the essential features, no additional multizone run was necessary to produce the desired results, but in a general case the procedure would go on as described in Section 3. For a time-dependent multizone calculation, e.g., of a time-dependent source $S(t) = S_0 f(t)$, the above results could also be applied, e.g., to the concentration in Room 2 being $C_2(t) = C_{door} f(t)$. This is based on the assumption that the room air flow pattern is still the same. This is fulfilled in the present example, but must be verified in a general case; otherwise more CFD runs are needed to give additional informations.

4.5. Open doors and windows

A multizone program calculates mass and heat flow through open doors and windows by using simplified algorithms based on the Bernoulli equation (Schaelin et al. 1992). The algorithm uses the average zone temperatures (both air and wall temperatures can be used) and an estimated linear zone temperature gradient. Also estimates for the velocities in the opening plane can be made available. However no information is available on the vertical and horizontal variation of the air temperature gradient as a function of the opening arrangement.

A link to a CFD program should be very helpful to predict the ventilation efficiency as a function of the position of the openings, and could indicate when cold draughts at floor level become a problem (CFD can help finding comfort problems with open doors and windows), e.g. as a function of the opening angle or when more than one window are opened.

Figure 6 shows air flow pattern, temperature and pressure contour lines of a twodimensional calculation of a room with an open door and a heater inside. The CFD computation domain includes the outdoor environment in this case. This example serves as an illustration how the temperature and pressure vary

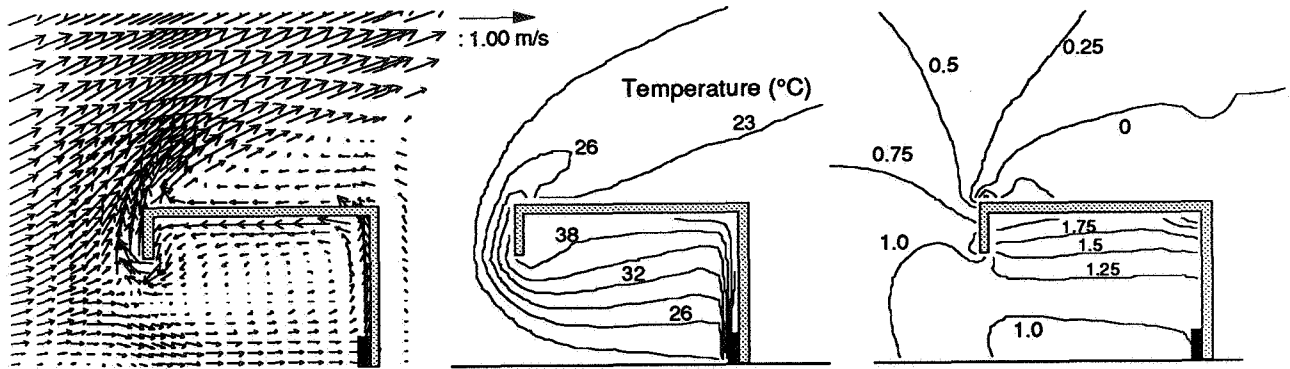


Figure 6: Air flow pattern, temperature and pressure contour lines of a room with an open door and a heater inside (calculation from Schaelin et al. 1992).

inside the room. The pressure varies in this example due to stagnation pressure of the wind, due to the temperature stratification and, in the corners, due to the deceleration of the air flow.

5. Conclusions

- A new method for linking CFD detailed air flow pattern results with multizone models has been presented. The accuracy of results of multizone simulations is limited by the assumption of homogeneously mixed conditions in each node. This condition is violated in many cases of practical importance. Therefore the accuracy can be considerably enhanced by the presented method.
- The proposed name of the method is "method of detailed node values". Instead of one variable value used for each node, a different value is provided for each flow path connected to that node.
- The method is demonstrated with a simple example and shows a more accurate prediction of the contaminant spread. The method can and will be expanded to more complicated cases. It can be used to determine detailed transfer values of all the variables solved in the multizone program like pressure, mass flows, temperature and contaminant concentrations.
- The method so far is suited for applications to cases where detailed air flow knowledge in a few rooms or only one room (in the important ones) is sufficient to give a better prediction of the overall air and contamination transport. In these cases, the method promises to improve the multizone model predictions with few additional CFD computations.

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