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MOVECOMP: A Static-Multicell-Airflow-Model

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ABSTRACT

This paper deals with a new computer program, MOVECOMP, which calculates the in and exfiltration and the airflows between the rooms of a multicell building. The calculations are made due to wind and thermal forces and the characteristics of the leakage openings.

MOVECOMP is intended to be incorporated in a more complex model, AIRCOMP. This latter model will be used also to calculate the airflows in a ventilating system.

MOVECOMP was developed to be "user friendly;" input data are limited and output data are very flexible. The user chooses which output he wants from a menu. The building is described with a system of pressure nodes, connected to each other through flow - pressure difference functions. The program is able to handle an almost general building. A modified Newton-Raphson method was chosen to solve the nonlinear system of equations. AIRCOMP was started to be developed because no complex model was found to be available.

INTRODUCTION

AIRCOMP will be a program that calculates the airflow rates between rooms, between rooms and the atmosphere, and within the ventilating system. Such a program can be useful when a problem associated with the movements of air is to be studied and should give qualified support for the dimensioning of installations.

AIRCOMP has been split-up into two separate parts during its development. MOVECOMP calculates the air movements in the building, while FLOWCOMP calculates the flow rates in the ventilating system. The advantages to this division are obvious. Results are available during the period of development and it is also easier to control the problem. MOVECOMP was developed and programmed in FORTRAN 77 during 1984, while FLOWCOMP will be developed during 1985. Both input and output data are simple to handle. Only relevant input data are needed and output data are chosen from a menu.

Leakage openings are simulated as power functions. For each room there must be a balance between incoming and outgoing mass flow. Therefore, a node model is used. The number of equations is equal to the number of rooms in the building. A modified Newton-Raphson method is used to solve this system of equation. This method takes the specific problem into consideration more effectively than the conventional Newton-Raphson method. Problems associated with the convergence are

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effective avoided.

But why develop one more program? During the past 20 years, several computer programs have been developed in this field. In the beginning the models were simple but had serious limitations. A recent survey, including a study of the litterature dealing with the causes of, the calculation of, and the effects of air movements (Herrlin 1983, 1984) showed that these complex programs are not available. The reasons may be either that they are still being developed or that they are not public for commercial reasons. A validation and comparison of these programs have been made at the Air Infiltration Centre (Liddament and Allen 1983).

AIRCOMP

MOVECOMP calculates the airflows between the rooms, between the rooms and the atmosphere, and, finally, the ventilation flow rates. This is done with the assumption of constant conditions in the ventilating system. The ventilation flows are either given as constants or they are calculated from the starting point of constant pressures behind the air terminal devices. MOVECOMP can be used separately but is planned to be a part of a more complex program, AIRCOMP (Figure 1). FLOWCOMP, the other part of AIRCOMP, will calculate the airflow rates in the ventilating system. The assumption is that there are constant conditions in the building, that is, constant pressures in front of the air terminal devices.This program is going to be developed during 1985. When these two programs are running as a unit, the complete balance of all airflows is computed.

MOVECOMP has several applications. The only limitation is that the airflows in the ventilating system are not calculated correctly. If, however, we have for example a high-pressure-loss duct system, this approximation of a constant condition in the ventilating system is quite good. The model is mainly intended to be used to study the following:

-- air movements in the building with reference to fan, wind, and thermal forces

-- energy and power demand in different parts of the building with reference to the air movements ·

-- distribution of contamination throughout the building

FLOWCOMP as a separate program can be used to analyze the principal difference between varying ways of designing the ventilating system with reference to its flow balance. AIRCOMP takes both the building and the ventilating system into consideration and is therefore able to calculate all flows in a more accurate way.

MOVECOMP

General

MOVECOMP is developed as a node model; all unknown pressures are assigned to nodes. These nodes are connected to each other and with other constant nodes by power functions. If we assume that there must be a mass flow balance in every node, we can put up a system of nonlinear equations. This system is solvable with an iterative method.

The building is represented by describing which nodes have connections with each other and which power functions are relevant at every connection. The program assumes the height between floors to be constant. This does not, however, mean that the height of each room must be constant. The height of each room may be an integral multiple of the height between the floors. For instance, shafts usually have a height equal to the height of the building. Besides this limitation, the program allows the rooms to be located arbitrarily.

Several roof levels as well as several ground levels are allowed. Further, an arbitrary number of leakage openings and/or air terminal devices can be specified in each room. These may also be placed at any levels as desired. The capacity of the computer is the limitation with reference to the size of problem that is solvable.

The mass flow through each leakage opening or air terminal device can either be specified as a constant or can be calculated. The external pressures at the faces and roof can either be specified at every leakage opening, if that is desired, or the program calculates the pressures with consideration to the height of the leakage opening above the ground level and current windspeed. The pressure coefficients are mean-values across each external surface; but, if local values are prefered at one or several leakage openings, these values can be specified.

Input and output

The values considered as constants are very few. Most values are calculated within the program.

The input data are devided into three logical parts. GENERAL INPUT deals with data concerning general conditions of the building and its surroundings. NODE INPUT consists of data that can be related to the nodes, for instance, their temperatures and pressures. LEAK INPUT consists of data that can be related to the leakage openings and air terminal devices, for instance, their characteristics.

The output data are designed to give as much information as the user wants. Therefore, the user chooses output data from a so-called output menu. This menu consists of the flow rates and the pressures but also information that can help the user to find errors. Lists of several different results are also included.

The physics

When the conditions are stationary, the sum of all incoming flow rates have to be equal to the sum of all outgoing flow rates for each room,

$$\dot{m}_{IN} = \dot{m}_{OUT} \qquad (1)$$

The mass flow through every leakage opening and air terminal device can be expressed as a function of the pressure difference across the opening. The most common (however, not most exact) function is a power function of the form:

$$\dot{m} = w\ K_0(\Delta p)^N \qquad (2)$$

where

w = a correction factor which takes the current density and viscosity into consideration

K_0 = constant

Δp = pressure difference

N = exponent

The correction factor w can be approximated with the following expression (Tamura and Wilson 1967):

$$w = \left(\frac{\rho}{\rho_0}\right)^N \left(\frac{\mu}{\mu_0}\right)^{1-2N} \qquad (3)$$

where

ρ = density
ρ_0 = reference density
μ = viscosity
μ_0 = reference viscosity

The constant K_0 is a measure of the size of the opening, while the exponent N is a measure of the kind of flow and must have a value between 0.5 and 1.0.

The outer pressures around the building are calculated with reference to wind and thermal forces. The pressures can be expressed with the following equation:

$$p = p_{ref} - \rho gh + C_p \frac{1}{2} \rho v^2 \qquad (4)$$

where

p_{ref} = pressure at ground level (reference)
ρ = density of the outside air
g = gravity
h = distance from leak to ground level
C_p = pressure coefficient
v = wind speed at roof level

C_p expresses the relation between the actual pressure caused by the wind at the leakage opening and the dynamic pressure of the wind at roof level. This is often a figure between -1.0 and 1.0 where a negative value indicates a pressure below atmospheric pressure.

The wind speed at roof level either can be given or can be calculated from meterological data. If the wind speed measured at standard conditions is available and the terrain around the building is known, the wind speed at roof level can be evaluated using the equation ("Recommendations" 1978):

$$v = v_{ref} \beta (h/10)^{\alpha} \qquad (5)$$

where

v_{ref} = wind speed at a height of 10 m in a standard terrain
h = height of the building
α, β = terrain dependent coefficients

MOVECOMP does not take the fan forces into concideration. As has been mentioned earlier, the program assumes constant conditions in the ventilating system.

The iternal pressures, which are the unknown pressures, are calculated at floor levels.

The mathematical solution

The balance of the mass flow in every room can be written as:

$$\sum_{\text{TERMINAL}} +/- \left(\frac{\rho}{\rho_0}\right)^N \left(\frac{\mu}{\mu_0}\right)^{1-2N} K_0 \, |\Delta p|^N \; +$$

$$\sum_{\text{LEAK}} +/- \left(\frac{\rho}{\rho_0}\right)^N \left(\frac{\mu}{\mu_0}\right)^{1-2N} K_0 \, |\Delta p|^N = 0 \qquad (6)$$

The choice of sign, which indicates the direction of every flow is determined by the sign of the pressure difference across the opening.

The balance of the mass flows in all rooms together can be expressed with the following vector equation:

$$\bar{f}(\bar{p}) = 0 \qquad (7)$$

This is a system of nonlinear equations. There are as many equations as there are unknown pressures (rooms).

If we provide one approximate solution to this vector equation, it is possible to do a linear approximation of the flow equation around this solution with the form:

$$\bar{f}(\bar{p}) \approx \bar{f}(\bar{p}_a) + J(\bar{p}_a)\,(\overline{p-p_a}) \qquad (8)$$

where

$\bar{p}_a$ = approximative solution

$\bar{p}$ = "new" approximative solution

$J(\bar{p}_a)$ = the Jacobian-Matrix containing all partial derivates of the flow equations with reference to the pressures.

The pressures $\bar{p}$ can be determined using the relation,

$$\bar{f}(\bar{p}_a) + J(\bar{p}_a)\,(\overline{p-p_a}) = 0 \qquad (9)$$

if the linear system of equations,

$$J(\bar{p}_a)\,(\overline{p-p_a}) = -\bar{f}(\bar{p}_a) \qquad (10)$$

is solved. Then the next approximation is:

$$\bar{p} = \bar{p}_a + (\overline{p-p_a}) \qquad (11)$$

If the first approximation $\bar{p}_a$ is sufficiently close to the solution, the calculations converge. To get the first approximation, all exponents set equal to unity and linear system of equations is solved.

During every iteration, all elements in the Jacobian-Matrix have to be calculated. The partial derivates in the matrix,

$$\frac{\delta f_1}{\delta p_1} \qquad (12)$$

where

$$f_1(p_1) = w\,K_0(\Delta p)^N \qquad (13)$$

is calculated as:

$$\frac{wNK_0(\Delta p)^N}{\Delta p} \qquad (14)$$

To avoid division by numbers near zero, the flows corresponding to small pressure differences are neglected.

To prevent long calculation times, the conventional Newton-Raphson method described above is replaced by a modified Newton-Raphson method (Gill et al. 1982; Lindberg 1985) if the system has not converged after five iterations.

This modified method calculates the next approximation using the relations,

$$\bar{p} = \bar{p}_a + \lambda\,(\overline{p-p_a}) \qquad (15)$$

$$J(\bar{p}_a)\,(\overline{p-p_a}) = -\bar{f}(\bar{p}_a) \qquad (16)$$

where λ is chosen such that a scalar merit function,

$$\phi = \Phi(\bar{p}_a + \lambda\,(\overline{p-p_a})) \qquad (17)$$

is minimized with respect to λ. Then the next approximation becomes:

$$\bar{p} = \bar{p}_a + \lambda_{min}\,(\overline{p-p_a}) \qquad (18)$$

The function Φ is determined using the condition that its derivate with respect to p shall be equal to the function f.

The iterations are interrupted when the maximum norm of the mass flow balance vector is below a certain level. A simple flow chart, shown in Figure 2 further explains the numerical method of solution.

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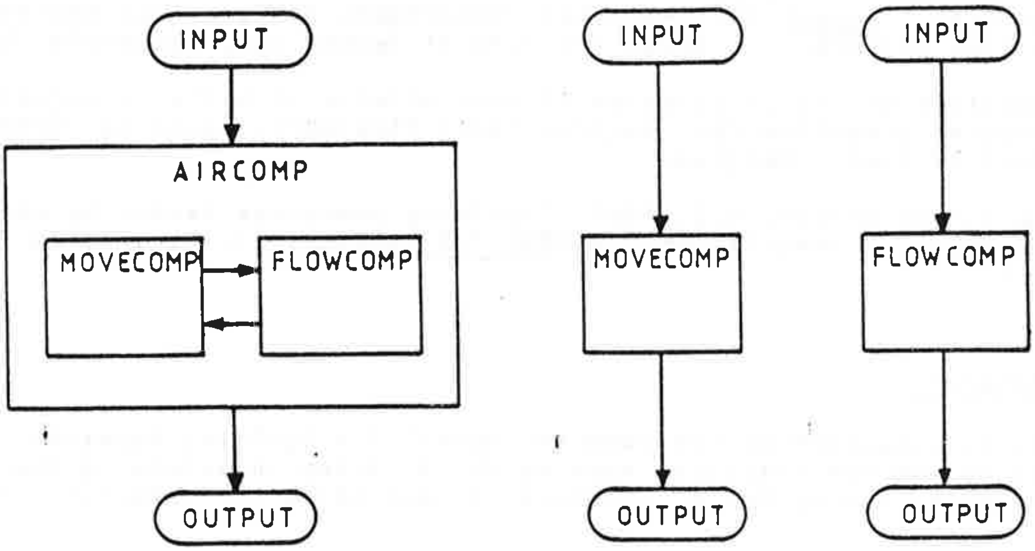
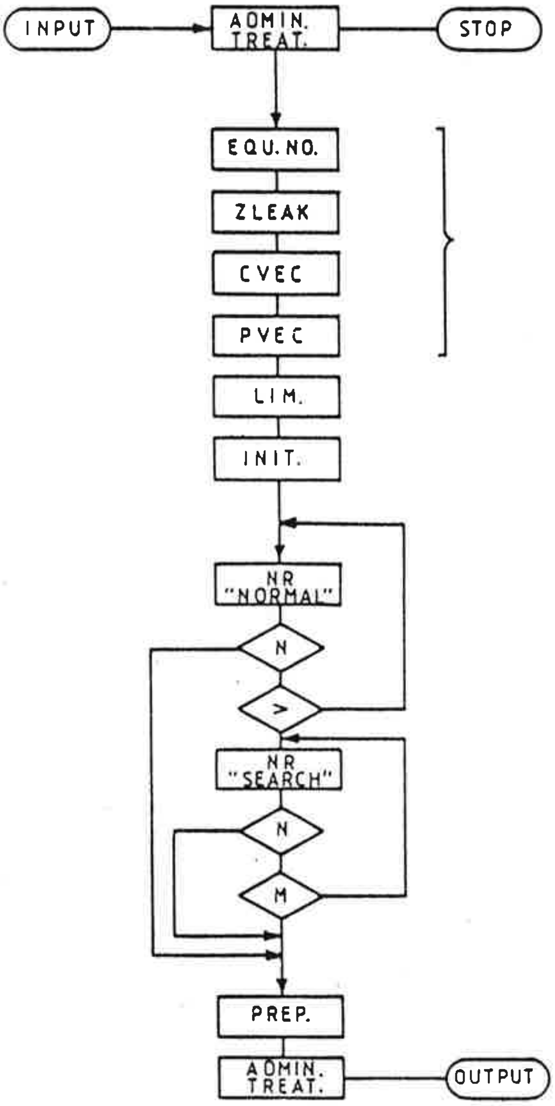


Figure 1. AIRCOMP and it's two independent parts



Input data are checked. If any errors - the run is interupped. Simple precalculations are also done.

All values needed for the system of equations are calculated within these blocks. These values are constant during the following iterations.

Some values are calculated concerning the accuracy of the following iterations.

The first approximation of the pressure-vector is calculated.

A conventional Newton-Raphson iteration is done.

The accuracy of the flow-balances are checked.

If more than four iterations are run - go further to the modified Newton-Raphson method.

A modified Newton-Raphson iteration is done.

The accuracy of the flow-balances are checked.

The number of iterations are checked with the maximum allowed number of iterations.

A matrix of results is calculated.

The matrix of results is prepared to suite the user's choice of output.

Figure 2. Flow chart for the program, MOWECOMP