MOVECOMP
A Multizone Infiltration and Ventilation Simulation Program

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Introduction

A program calculating both the infiltration/inter-zonal air flows and the ventilation flow rates can be used for a wide range of applications. From simply studying the air change rate to the interaction between building and ventilation system. Using this tool, engineers and architects could gain valuable information of many different topics.

As long as no methods exist to accurately determine neither the leakage paths and their characteristics nor the pressure coefficients for external walls, an air infiltration program is most suitable for parametric studies. Here, the change of a parameter is more interesting than its absolute value.

An infiltration and ventilation simulation program should accurately determine the flow rates in a reasonable time. Furthermore, the model should have few limitations and be flexible enough to simulate different types of buildings and ventilation systems.

A 1984 survey showed that no such complex program was available. A long term project started shortly afterwards at the Royal Institute of Technology to develop Movecomp. This paper describes briefly the program, the model it is based on, and the solving algorithm.

Description of Building and Ventilation System

To get a complete picture of the air flows in a building, any model must take both the building and the ventilation system into consideration. Furthermore, if one expects to get an accurate result then these two parts have to be described in detail. The user should not be restricted in this sense by limitations in the model. Therefore, the possibilities to describe the building and the ventilation system must be flexible without any serious limitations. Ideally, any types should be possible to handle. The 1984 survey showed that most models could not meet that demand of flexibility.

When developing Movecomp efforts were done to make possible to describe most buildings without any significant limitations. Flow paths can therefore be specified wherever; the distribution and number of leaks are arbitrary. Furthermore, the rooms do not need to be in a specific configuration or height; corridors and shafts can be mixed with ordinary rooms as desired. The ventilation system may be described with a similar degree of flexibility. The system can be specified in detail with 10 well-defined components, arranged in almost any practical configuration. If it is not considered to be important to simulate the entire system then fixed outlet and inlet flow rates can be given.

Figure 1 shows, as an example, a description of a two-zone building and its exhaust/supply ventilation system. The thin bars represent the major flow paths in the structure.

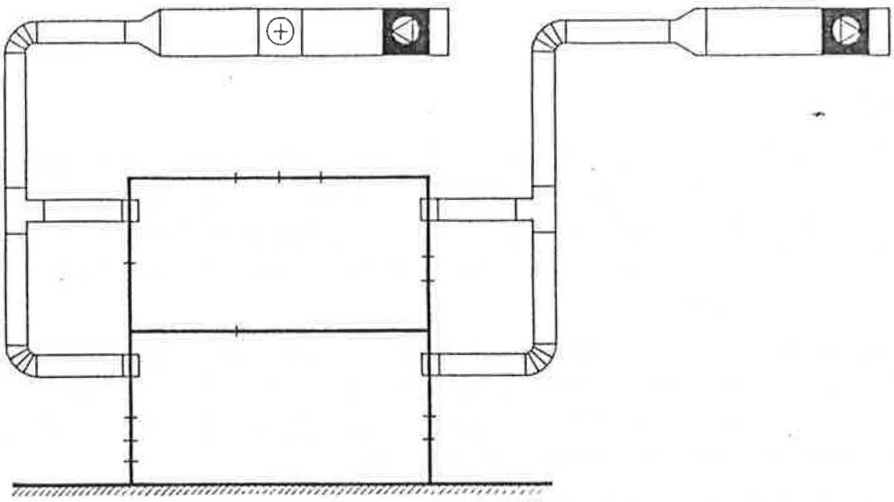

Figure 1: Description of a building and its ventilation system.

Simulation of Building and Ventilation System

It can be expected from a numerical point of view that a model simulating the building and ventilation system simultaneously is more time efficient than if the two parts are treated separately. Therefore, the building and the ventilation system is simulated as one common network of nodes and flow paths. Rooms and duct junctions are represented as nodes. In each node there has to be a mass flow balance under assumed steady-state conditions. Leaks and ducts are represented as flow paths. The mass flow versus pressure difference characteristic for each one of these paths has to be determined from measurements and/or experience.

Flow through leaks are simulated with a simple power function but extended with a correction for density and viscosity changes. A power function is in agreement with measurement although it does not reflect the change of flow regime. The added correction is important. The mass flow rate can change as much as 30%. Of this change, the contribution from the viscosity can be between 0 and 40% depending on the flow regime. Flow through large vertical openings where a two-way flow often exists is also possible to approximate. The opening is then considered to consist of several smaller openings.

Flow through ducts and components in the system are simulated by the traditional concept of friction or loss factors and the dynamic pressure of the flow. There are built-in algorithms for 10 standard components. All flows are considered to be turbulent because laminar flow is not common in forced ventilation systems. Besides this, most loss factors are experimentally determined at high Re-number. To exclude laminar flow also means that we avoid the transition zone between laminar and turbulent flow which is less well known. Just because the flow is considered to be turbulent does *not* necessarily mean that the flow rate is proportional to the square root of the pressure difference. For straight ducts and most common combinations of air velocities and duct dimensions, the friction factors are functions of the flow rates. The loss factors for components as bends also show a strong Re-number dependence while other components are almost independent of Re-number.

The air density and, to some extend, the air viscosity are frequently used in air flow models. Systematic errors are introduced if these properties are considered to be a function of temperature only, that is if the pressure or relative humidity dependence is ignored. These errors have been investigated. The analyses show that the maximum errors in the main flow rates are of the magnitude of +/- 2% which is mainly due to moist air.

Driving Forces

The driving forces for the air flows are thermal forces resulting from differences in air densities both within the building and to the outside, wind forces, and fan forces. Describing the driving forces accurately is as important as describing the building and the ventilation system thoroughly. Again, the fewer limitations the model has the better. Any steady-state model do though have some fundamental restrictions on this point. These models can never strictly take into account phenomenon associated with dynamic driving forces. However, several approaches have been made to add corrections to steady-state models so that air flows caused by dynamic wind can be estimated. Such corrections, if acceptable, can easily be included in a flexible model.

Temperatures and temperature gradients may be specified in each room separately. The program does not include any thermal model, consequently, these variables have to be given as inputs. The different air temperatures throughout the duct system are automatically calculated according to the current air flow rates.

Figure 2 shows that an internal thermal gradient can be important for the flow pattern in a building. The building consists simply of a shaft with equally distributed leaks. The *average* indoor temperature is equal to the outdoor temperature but has a linear gradient. Thus, if the indoor temperature is simulated as one single temperature no flow will occur across the outer walls. However, if the temperature can be described more in detail, the result is according to the figure. The flow pattern here is owing to the internal gradient only, no other driving forces are present.

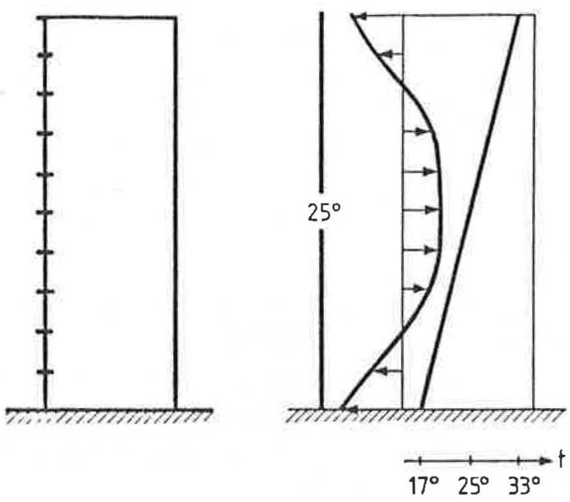

Figure 2: Example of influence of thermal gradient.

The wind pressures on the outer surfaces of the building depend on many variables and are hard to measure accurately. Average pressure coefficients for each surface are sometimes used. In other cases a more exact pattern has to be simulated. The input to Movecomp is made according to this, thus pressure coefficients can be given in any pattern over the facades of the building. In addition, both on and off-site wind can be specified.

Fan characteristics are often neglected. However, this can result in large errors. The flow rates delivered by many fans are sensitive to the pressure across them. Therefore, each fan can be given a separate fan characteristic of an almost arbitrary shape as long as the pressure rise across the fan is strictly decreasing with the flow rate. Since the ventilation system and fans can be simulated in detail, the behavior of different types of ventilation systems can be studied under various conditions.

Solving Algorithm

The mass balances, the characteristics of the flow paths, and the driving forces make up a non-linear system of equations which has to be solved. For infiltration models, the most common solving algorithm for this non-linear system of equations is Newton-Raphson. However, the nature of Newton-Raphson creates problems when the dominant leak in the zone has an exponent close to one-half and/or the start approximation is not close enough to the solution. The results can either be diverging iterations or very slow convergence. These problems are usually solved with an under-relaxation chosen according to experience only. So far, no systematic method in choosing the relaxation has been introduced in this field. The algorithm used in Movecomp is based on Newton-Raphson but also takes advantage of the special properties of the system of non-linear equations to obtain an efficient algorithm based on ideas from non-linear optimization. This approach has been successfully used which will be shown below.

Figure 3 shows a comparison of the calculation time, in a relative scale, between Newton-Raphson (N-R) and Movecomp (M-N-R) for a two-zone building. The air forced through the building must pass two facades and one internal door. All three leakage openings have a flow exponent of one-half; the two facades have the same flow coefficient K_f.

The curve representing Newton-Raphson describes the characteristic problem with the method when the flow coefficient ratio K_f/K_d is well away from unity. Movecomp on the other hand does not show any significant change in calculation time for different ratios of the leakage openings. The absolute sizes of the openings do not have any significant influence on these results.

Even though, this is a simple network, numerically it can be a hard problem. It is therefore suggested that this network is adapted as a test case for multizone infiltration models.

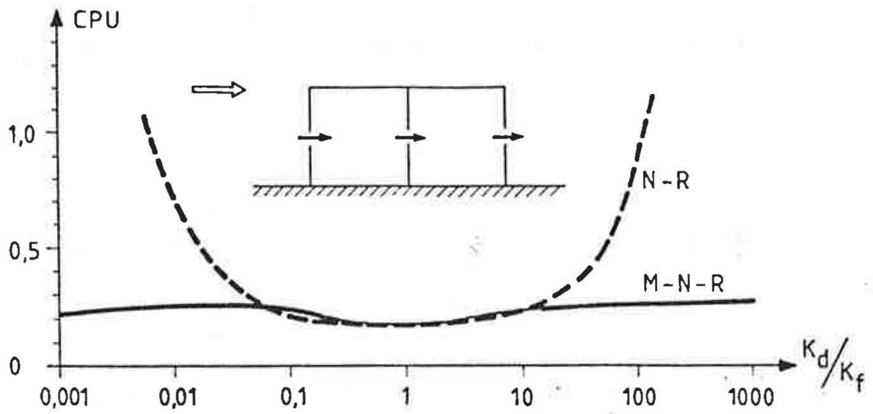

Figure 3: Calculation time for Newton-Raphson and Movecomp.

Parametric studies

The good convergency features make the program suitable for parametric studies. One or several parameters are changed systematically in steps to get knowledge about some special properties. Parametric studies thus require many measurements or calculations, maybe thousands. Measurements that would have taken unreasonable long time to do or even impossible to perform can be simulated fast and accurately.

To be able to use any infiltration program on a specific building, there must be accurate methods to determine the leakage paths and their characteristics. The most recent work made with the program has been to estimate the errors of measured path characteristics. This work has been conducted at the Lawrence Berkeley Laboratory, USA, and is a typical example of an extensive parametric study.

It is known that the technique to determine the coefficients of the flow equation from pressurization with blower doors is sensitive to wind fluctuations. Calculations were made to quantify this sensitivity for coefficients for internal walls. In general, the higher mean wind speed the higher turbulence can be expected. At each mean wind speed the wind can be considered to be log-normal distributed. Wind speeds are randomly taken from these distributions and the standard deviation for the coefficients of each mean wind speed is calculated. With the criteria of a maximum acceptable standard deviation, the highest mean wind speed has been determined for a typical 3-story building. These results are planned to be published at the 9th annual AIVC meeting in Belgium, September 1988.

Input/Output

The input to a multizone model can be extensive if the building is going to be simulated in detail, which often is the case. The input must therefore be structured and arranged in logical parts. The input is arranged in several tables and thus not of an interactive type. Tables give a good overview of the input compared to the interactive type of input for an experienced user. For a beginner, on the other hand, the interactive type of input probably have several advantages.

The output can be even more extensive than the input but is much dependent of the actual program. The output can include declarations of many other variables besides the air flow rates. Furthermore, these variables can be treated statistically or in any other way. Besides this, information about the progress of the calculation itself can be included. It is therefore desirable and often necessary to be able to select both type and amount of output in each individual case or simulation. Here, the amount of output can be chosen from a menu that contains several levels of each type of output to suit the user's needs.

References

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