The COMIS Infiltration Model

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ABSTRACT

The task is for COMIS to develop a reliable and well running multizone infiltration model on a modular base. This model does not only take crack flow into account, but also covers flow through large openings, single sided ventilation, cross ventilation and HVAC-systems. The model contains a large number of modules, which are peripheral to a steering program. COMIS can be used as a basis for future expansions in order to increase the capabilities of simulating buildings or their type of construction, in the field of ventilation, heat flow and spread of pollutants. To develop the different modules, small task groups were formed to work on particular problems. Each COMIS team member works on several task groups and might be responsible for one or more of them.

Almost three years ago, the first announcement was send to colleagues to inform them about the joint research project planned to develop a multizone infiltration model at LBL. Even though this kind of co-operation is well known in other fields of research, e.g., high energy physics; for the field of building physics, it seems to be a new approach to be engaged in a research project, one individual or country otherwise would not be able to do. From the beginning, COMIS was well taken by the research society. Due to the internationality of the group, several national and international research programmes are co-ordinated with the COMIS workshop. This paper describes the COMIS workshop as well as the outline of the COMIS model.

THE COMIS PROJECT

As part of its infiltration modelling effort Lawrence Berkeley Laboratory (LBL) is currently hosting the COMIS workshop (Conjunction Of Multizone Infiltrations Specialists). This workshop is an international co-operative research effort to develop a multizone infiltration model, which, due to its widespread distribution, might become a standard program.

This project has attracted a great deal of international interest and support. Researchers have come to LBL from France, Italy, Japan, The Netherlands, Peoples Republic of China, Spain, Sweden, and Switzerland to work together for some time.

After members of the group settled in their new working environment, planning on the structure of the modular program started. The workload was devided into eight task groups dealing with the different parts of the program development.

The modules for the "Minimum Requirement", as defined in March 1988 at the second COMIS meeting in Copenhagen, and a simplified version of the steering program were finished by April, 1989.

After all modules for the minimum requirement are integrated into the COMIS model, the existing routines will be checked for further improvements. Leakage characteristics measurements as well as air flow rate measurements will be performed in the Radon Test House in the Richmond Field Station. More work is needed to describe the pressure field around buildings. The algorithm which will be used for simple building designs is expected to be finished by the end of the workshop. A review on existing pollutant transport models is under way. We hope to include one of the existing transport models in our infiltration model. As water vapor is the number one pollutant in residences, we will try to include the transport of water vapor and its storage mechănism in the pollutant transport model.

THE COMIS MODEL

Ventilation, heat flow and pollutants are strongly coupled in a building. In studies about ventilation processes, it is generally not allowed to ignore heat flows and pollutants. Nowadays most of the problems in buildings deal more with indoor air quality, energy and ventilation rather than ventilation only. Even a connection with sound, lighting and comfort occurs. As occupants of the building can have a major influence on all of these processes, the effect of occupant behaviour cannot be ignored either. This all pointed at the need to simulate all processes in a building physically as precise as possible, in order not to exclude the possibility of coupling the different phenomena.

To supply the routines in the program with all necessary data of the building, the building data storage should be flexible in containing information about the building in almost any level of detail and about a variety of physical properties. As this includes a full geometrical description of the building, a CAD system would be preferable. As the code should be free of proprietary software, the possibilities for including a CAD were referred to "later add-on's by the user".

The COMIS Structure we use now includes schematic drawings of 87 modules and shows the relations between those modules and the major data flows. It is helpful to prevent flow chart errors in the program and to locate missing functions or routines. Besides this structure a list of parameters used in the main programs and a list of the prepared and finished modules is frequently updated.

Interactive Input Program

The first general concept of the interactive input program for the COMIS infiltration program has been finished. The interactive input program will contain a tree structure, which allows the user to either input new data, change already available data or delete stored data.

The input is given using seven different blocks, namely:

1) Problem Description
2) 3D-Building Description
3) Direct Network Description
4) Operating Schedules Input
5) Cp - Value Input
6) Environment Description
7) Meteo Description

Flow Equations

Crack Flow Equation

Data obtained from measurements on crack models show, that for turbulent crack flow the mathematical description of the friction factor is identical with the one found for conduit flow with smooth walls. Therefore, crack flow can be seen as duct flow with a more complicated form of the flow path.

From the crack flow equation research, we found that the flow performance is strongly temperature dependend. In order to arrange the results into the common form, we have introduced correction factors which account for the temperature influence. The correction factor depends on the type of the leakage. We have developed three different equations for the different correction factors.

In most cases, the temperature of the air in a crack is quite different from the temperatures of the the zones on either side of the crack. Furthermore, air leakage performance measurements are usually performed at certain temperature condition, but the results are used later at different temperatures. The temperature variation, however, has a big influence on the air leakage flow due to changes in the air viscosity and air density. Unfortunately, almost all of the models dealing with air leakage characteristics ignore this phenomenon.

The temperature of air flowing through a crack depends on the following factors:

- air flow rate
- air temperatures of the zones on both sides of the crack
- dimensions and form of crack

HVAC Systems

HVAC-Systems (The Heating, Ventilating and Air-Conditioning Systems) are composed of ducts, duct fittings, junctions, fans, air filters, heating and cooling coils, air-to-air heat exchanger, flow controllers, etc. So far, several of the program modules concerning the ventilating sytems have been developed, allowing to calculate the coefficients of the flow equation for duct works with fittings, the static pressure losses for T-junctions, the volume flow rate of a fan as well as for a flow controller as a function of the pressure difference.

As duct systems are described by a network in the air flow model, the junction is treated as a pressure node. Input data are the three volume flow rates through the three ducts which are connected at the junction as well as the static pressure at the point in a duct just before the junction. The output is the static pressures at the two points in two ducts just after the junction.

To our surprise, we found that the values given in the literature for pressure loss coefficients were significantly different between different sources. For example, in the case of the converging flow, the pressure loss coefficient through the main duct of the T-junction, obtained from one source is double the value of the loss coefficient given in other sources. We have to continue our literature survey to find original sources and the experimental conditions of the pressure loss tests.

On the bases of more than three data sets for the volume flow rate and the pressure difference, the fan performance curve can be expressed by a polynomial approximate formular, using the least square method. As the air density effects the fan performance, the correction of the fan performance due to the air density is included in the model.

Large Openings

Basically, a multizone infiltration model like COMIS is defined by a network description of the pressure field in a building. The pressure nodes or zones are linked together by nonlinear resistances, and the law of mass conservation in each zone leads to a nonlinear system of pressure equations.

To include the behavior of large openings in this description, two ways are obviously possible. Either we are able to describe the air flow rate through a large opening using a nonlinear equation of the pressure drop, or we have to separately solve this singular problem and to include the results as an unbalanced flow in the mass conservation equation of the described zone.

Both solutions are presently being investigated by COMIS.

Airflow rates through door ways, windows and other common large openings have been pointed out as significant effects by which air, pollutants and thermal energy are transferred from one zone of a building to another [1]. However, in a previous review of multizone infiltration models published in 1985, none of the described codes were able to solve this problem by any other way than to split the large opening into a series of small ones described by crack flow equations.

To connect the large openings to the general network, we have to define their behavior in terms of nonlinear equations of the pressure drop. The first idea is to describe the large opening as a conjunction of parallel small openings. Each small opening is then described by a crack flow equation taking into account the local pressure drop, and the whole system of nonlinear equations can be introduced directly in the pressure network [2,3]. Another approach consists in interpreting the flow equations given by the fluid mechanics approach in terms of pressure. This method leads to the definition of new flow equations in pressure characterizing the behavior of large openings.

All these elementary solutions have been developed by COMIS, they will now have to be tested and compared in order to clearly define the limits and the leading advantages of each one.

COMIS's contribution to this fundamental problem will be a description of the physical problem, a review of the various solutions developed in the literature, and a comparison of these solutions with both, a numerical and a physical points of view.

Wind Pressure Distribution

Compared to the static pressure associated with an undisturbed wind-velocity pattern, the pressure field around a building is generally characterized by regions of overpressure on the windward side and underpressure on the facades parallel to the air stream and on the leeward side of the building.

The pressure distribution around a building is usually described by a dimensionless pressure coefficient (Cp), which is the ratio of the surface pressure caused by the wind action and the dynamic pressure in the undisturbed flow pattern, measured at a reference height [4].

Wall averaged values of Cp usually do not match the accuracy required for air flow calculation models. Therefore, more detailed evaluations, taking the Cp distribution on the envelope of buildings into account, have to be made. This can be done in the following ways:

- performing full scale measurements,
- carrying out wind tunnel tests on building models
- generating Cp values by numerical models based on parametrical analysis

The first way is pratically impossible to follow, unless it is done within expensive and time-consuming experimental plans. The second one depends too much on the availability of test equipment and relevant assistance. The third method seems to be the only one assuring an easy and wide data access.

COMIS has been working on the bases of a parametrical study, in order to define a Cp calculation method, as input module for a multizone infiltration model. Several wind tunnel test reports have been considered, in order to find a set of data large enough to cover a wide range of parameters, affecting the variation of CP.

The center-line Cp vertical profile of the Hussein & Lee's test cube-shaped model [5] has been taken as reference - wind direction normal to the wall, windward position, no surrounding obstacles, model height the same as roughness, low density urban area. Then several Cp data sets from the tests have been analyzed and the relevant variations at different relative model heights normalized with respect to the reference profile.

Correction factors were determined for each of the parameters influencing the pressure distribution. The Cp-value for an abitrary point on the surface can be determinend by the reference value multiplied by the correction factors found for the given boundary conditions.

Solver

A building is basically modeled by pressure nodes that are interconnected with air flow links. For one time step, the outside of the building is represented by a fixed boundary condition. The pressures of the internal nodes in the air flow network have to be solved to be able to determine the different air flow rates. To solve these infiltration and ventilation flow rates requires the solution of a non-linear system of flow equations. The main task is to find an efficient and stable solving method.

The starting point is the Newton-Raphson method with derivatives, operating on a node oriented network, which in most cases quickly converges the system of equations. The method will be modified to avoid occasional convergence problems when working with power functions. Fortunately, the origin of the convergence problems is well known. The solving method is working on the flow balance equations and not on the flow equations. If one or several of these balance equations have an exponent close to one-half, the Newton-Raphson method will not work very well due to the nature of the procedure to find the next approximation. The instance this happens is when a leakage opening with a flow exponent of one-half is predominant in one zone. In this case, the flow balance equation will also have an exponent close to one-half. An under-relaxation will increase the convergence velocity and bring us to the solution.

In each step of the iterative method, a linear system of equations has to be solved. The special characteristics of the linear system of equations have been studied. The most important characteristics, as long as the matrix is not singular, are the symmetry and positive definiteness of the Jacobian matrix.

Based on these studies, a direct method based on the Cholesky's method modified for band matrices has been developed, timed, and documented. The band feature is avoiding unnecessary calculations with elements which values are zero. The method consists basically of two parts. The first part is the decomposition of the matrix into two triangular matrices. The second part is the back and forward substitutions of these matrices. The method does not require pivoting and just the lower triangular matrix has to be calculated during the decomposition. The method has been modified in such a way that band matrices can be handled efficiently. If no unique solution exists, due to the modeling or round-off errors, the routine determines where the singularity is located in the matrix.

A direct method may run into calculation time problems for a not well structured matrix, i.e., large band width. It may be interesting to study methods which renumber the nodes in such a way that the band width decreases. If the matrix is large and has a bad structure an iterative method is probably the best choice. An iterative method is therefore planned to be integrated in the solver.

Experiments

The original goal of the experiments developed by COMIS is to provide data for comparing results from multizone infiltration models with results obtained from full-scale experiments. The first experiment was performed by the EPFL group in Lausanne using the LESO facility. The second building we use for measurements is located in the Bay Area.

In order to get a precise definition of the building's characteristics, a precise geometrical description of the house has been made. Some modifications were necessary to improve the representativity of the house, and elementary experiments such as calibration of the blower doors to be used have been carried out.

After these preleminary works, the experiment itself has been set up. The house has been divided into six zones, each zone corresponding to a room. The tubings and wirings have been put in place, and a weather tower has been installed on the roof.

For measurement definition, our minimum requirement was one temperature sensor located in the geometrical center of each room, one pressure tap on the central part of each facade at each floor level, tubings for injection and measurement of tracer gases in each room, and a pressure reference inside the house.

The first level of experiment consists of a general description of the whole leakage characteristics of the house. A multizone external leakages measurement has to be done. Various techniques using one or more blower doors have been discussed in the literature and are tested on our experimental setup.

In order to get this necessary air flow distribution, we use the EPB multi tracer gas facility. We use six different kinds of gases, each one injected in a different zone, and we run the experiment for a sufficient period of time to get the possibility to select various wind and thermal conditions.

During all these experiments, at least one pressure tap has been placed on the central part of each facade of both stories of the building. However, it is obviously not possible to get a precise description of the pressure field around the house using only few points.

The usual way to get this information is to reproduce in a wind tunnel a scale model of the building to be tested and of its surroundings. We plan to build a scale model of the test house, and to use the wind tunnel facility of the Departement of Architecture of the UC Berkeley.

With the conjunction of the real scale experiment developed in the test house, and the wind tunnel test of its scale model, we should be able to determine the limits of this method in a more realistic configuration, by measuring the pressure in well defined locations on one or various walls of both experimental setups.

OUTLOOK

During April 10 - 12, 1989, twenty-three experts on building physics from eleven countries formed the review panel for the COMIS mid-term review. The presentations by the members of the COMIS group were followed by a round-table discussion about the future of the COMIS program.

Additional features for the COMIS program which would increase the model's applications and usage beyond the original scope have been discovered by the COMIS group and the COMIS review panel. To obtain the additional features, the project has to be extended. Several colleagues showed interest to continue the project on a reduced scale. Specific tasks have been identified by Germany and Italy for co-operative work on back drafting and pressure distribution.

One of the major concerns among the review panel was the upkeep and further development of the COMIS program. The question was raised, how the COMIS project could be institutionalized as a international co-operative project. Voluntary contributions without formal commitments were not viewed favorably by the panel as a way to run a project of this scale effectively.

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