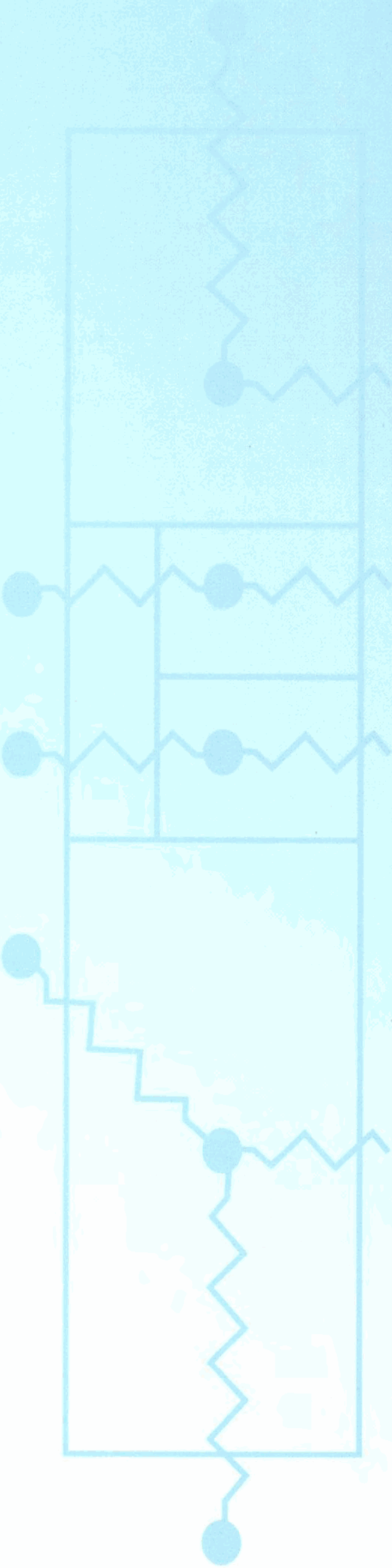
International Energy Agency

Multizone Air Flow Modelling (COMIS)

Technical Synthesis Report
IEA ECBCS Annex 23



Energy Conservation in Buildings
and Community Systems

Multizone Air Flow Modelling (COMIS)

Summary of IEA Annex 23
Multizone Airflow Modelling (COMIS)
Within the Energy Conservation in Buildings and Community Systems Programme
(Duration 1992 - 1996)

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About the Author

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Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty four IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research development and demonstration (RD&D).

Energy Conservation in Buildings and Community Systems (ECBCS)

The IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy.

The Executive Committee

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. To date, the following projects have been initiated by the Executive Committee (completed projects are identified by *):

1. Load Energy Determination of Buildings *
2. Ekistics and Advanced Community Energy Systems *
3. Energy Conservation in Residential Buildings *
4. Glasgow Commercial Building Monitoring *
5. Air Infiltration and Ventilation Centre
6. Energy Systems and Design of Communities *
7. Local Government Energy Planning *
8. Inhabitant Behaviour with Regard to Ventilation *
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11. Energy Auditing *
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13. Energy Management in Hospitals *
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16. BEMS - 1: Energy Management Procedures
17. BEMS - 2: Evaluation and Emulation Techniques *
18. Demand Controlled Ventilating Systems *
19. Low Slope Roof Systems *
20. Air Flow Patterns within Buildings *
21. Calculation of Energy and Environmental Performance of Buildings*
22. Energy Efficient Communities *
23. Multizone Air Flow Modelling (COMIS) *
24. Heat Air and Moisture Transfer in Envelopes *
25. Real Time HEVAC Simulation *
26. Energy Efficient Ventilation of Large Enclosures *
27. Evaluation and Demonstration of Domestic Ventilation Systems
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29. Daylight in Buildings
30. Bringing Simulation to Application
31. Energy Related Environmental Impact of Buildings
32. Integral Building Envelope Performance Assessment
33. Advanced Local Energy Planning
34. Computer-aided Evaluation of HVAC System Performance
35. Design of Energy Efficient Hybrid Ventilation (HYBVENT)
36. Retrofitting in Educational Buildings - Energy Concept Adviser for Technical Retrofit Measures
37. Low Exergy Systems for Heating and Cooling of Buildings
38. Solar Sustainable Housing.

Annex 23 Multizone Air Flow Modelling (COMIS)

Annex 23 was established within the ECBCS Implementing Agreement. The objective of this annex was to study physical phenomena causing air flow and pollutant transport (e.g. moisture) in multizone buildings and to develop modules to be integrated in a multizone air flow modelling system. The system itself shall be user-friendly and structured to be incorporable in thermal building simulation models. Furthermore, special emphasis was to be given to providing data necessary to use the system (e.g. wind pressure distribution, default values for leakage of building components, material properties like absorption and desorption). The comparison between results from the model and from in-situ tests was to be an important part of this annex.

To reach these objectives the project was structured in three parallel subtasks:

- Subtask 1: Implementation of new features in COMIS, including new models and user-friendly interface;
- Subtask 2: Collection of both input data and data for comparison with experiment;
- Subtask 3: Evaluation of the code and its User Guide

It was intended that the results of these subtasks would be addressed to researchers and consultants in order to promote energy efficient design.

The participants were to undertake a task sharing project involving model development, data acquisition and analytical studies.

Expected results were:

- Hardware-independent multizone air flow modelling system;
- User Guide for the modelling system;
- Database of reference cases for evaluation purposes;
- Database of default input values for use of air flow models;
- Document on evaluation exercise;
- Report on sensitivity analysis

Countries participating in Annex 23 were: *Belgium, Canada, France, Greece, Italy, Japan, the Netherlands, Switzerland and USA. The work was carried out in collaboration with Annex 5 (Air Infiltration and Ventilation Centre).*

The Annex 23 Operating Agent was Dr Helmut Feustel, Lawrence Berkeley National Laboratory, Berkeley, California.

Scope

This report contains a summary of the work of Annex 23, the formal duration of which was from 1992 to 1996. It also includes some information on the subsequent development and application of the work. It is intended to provide an introduction to the multizone airflow model COMIS, a review of the extensive work on the validation of COMIS and an indication of its potential for application to the design of building systems. The report is mainly based upon the principal Annex 23 project reports listed in Appendix 2.

CONTENTS

1 Background

1.1 Introduction

The ability to simulate the performance of a building is necessary for many aspects of its design and operation including, in particular, energy conservation. In recent years advances in building physics, improved understanding of the requirements and behaviour of occupants, access to meteorological data and the increased speed and power of computers have been combined to form the basis for powerful simulation tools for use by designers.

However, one of the weakest elements of simulation has been the ability to take into account the natural movement of air into and through a building. Together with air supplied by mechanical means, this air may serve useful purposes such as the dilution and removal of internally generated pollutants and the provision of cooling. Ventilation over and above these requirements can result in excessive consumption of energy for heating or air conditioning. Early simulation models dealt only with whole building infiltration and ventilation and could not provide designers with information on key factors such as heating and cooling loads for particular zones or the movement of pollutants from one zone to another. This report deals with a multizone model, COMIS, which has been developed in response to this need. In particular, it sets out the results of work under IEA Energy Conservation in Buildings and Community Systems Annex 23 to evaluate and to develop this model sufficiently for it to be readily used with confidence as part of the overall building design process.

1.2 Origins of COMIS

From October 1988 to September 1989, the Energy Performance of Buildings Group, Lawrence Berkeley National Laboratory, hosted a multinational group of experts for an extended workshop which was given the name Conjunction of Multizone Infiltration Specialists (COMIS). The purpose of this workshop was to develop a multizone infiltration program based upon the best available algorithms covering the principal mechanisms of air movement, including crack flow, interchange across large openings, HVAC systems etc. The intention was that the program (which subsequently took the name COMIS from the Workshop) should not be limited to one computer platform and should be modular in form, both to allow incorporation of improved algorithms as these became available and to allow its use in conjunction with other software for predicting building performance. The workshop was coordinated by Dr Helmut Feustel and included representatives of France, Italy, Japan, the Netherlands, Peoples' Republic of China, Spain, Switzerland and the United States of America. The work was continued under the auspices of the International Energy Agency, initially within Annex 20 'Air Flow Patterns within Buildings' and subsequently, from 1992, as Annex 23. Appendix 1 contains details of the organisations which have participated in the work of Annex 23.

The work under Annex 23 had a number of specific aims:

(a) To continue development of the modules of the COMIS code, including improved algorithms, extended coverage of factors which could influence inter-zonal flows;
(b) To improve the user-friendliness of COMIS;
(c) To evaluate COMIS against other models and the results of experimental studies.

This Report summarises the results of the work carried out under Annex 23. A brief description is given of the principal components of COMIS. This is followed by a review of the extensive work to evaluate and improve COMIS, including a number of experimental studies undertaken in real and test buildings to provide data for comparison with COMIS predictions. A brief description is given of several interfaces developed to make COMIS easier to use, particularly in relation to input data entry. Finally, a case study is outlined which illustrates the potential use of COMIS in building design. Appendix 1 gives the national organisations that participated in Annex 23. Appendices 2 and 3 list, respectively, the principal published outputs and other COMIS related publications.

In strict terms the acronym COMIS is an overall title for the project, the principal component of which is the core calculation code COMVEN. There are other components, related particularly to the means of entering input data. Here, unless it is especially necessary to identify individual components the general term COMIS will be used. COMIS has been subject to continuous development from its inception in 1989 as COMIS 1.0. The current version is COMIS 3.0 and further developments continue to take place. Appendix 4 contains a list of web-sites from which up-to-date information may be obtained, including software for downloading and user manuals.

2 Multizone air flow modelling

The modelling of air flow through mechanical ventilation and HVAC systems is a relatively straightforward problem since the air is contained within ducts or similar components, whose flow characteristics are well understood, and it is driven by fans with known pressure-flow characteristics. Techniques and calculation methods have been developed for the design and sizing of such systems. Much more difficult is the prediction of the general movement of air both within and between the principal spaces or 'zones' which make up a building and the exchange of air across the external envelope. Air movement within zones has been studied, initially with full-scale experiments and scaled physical models and, more recently, using computational fluid dynamics. Determination of the movement of air across between zones, and between zones and outside air, has presented many difficulties particularly because of the influence of highly variable external conditions, especially wind speed and direction, and the need to identify and characterise the flow paths between zones.

Early approaches considered the building as a single zone, within which the air was well-mixed, i.e. internal flows between spaces were ignored. Prediction methods, of varying degrees of sophistication, have been developed for this case, the more complex allowing the effect of wind speed, wind direction, internal/external temperature difference, multiple flow paths through the building envelope and background leakage to be taken into account. These single-zone models are relatively easy to use and are valuable in assessing quantities such as the overall energy consumption, particularly for relatively simple buildings such a single family houses. However, if the requirement is to determine likely individual heating or cooling loads for zones, or, to predict the distribution of a contaminant within a building from a given source, then more sophisticated inter-zonal models are required. Figure 1.1 shows in simple schematic terms the characteristics of single and multizone models.

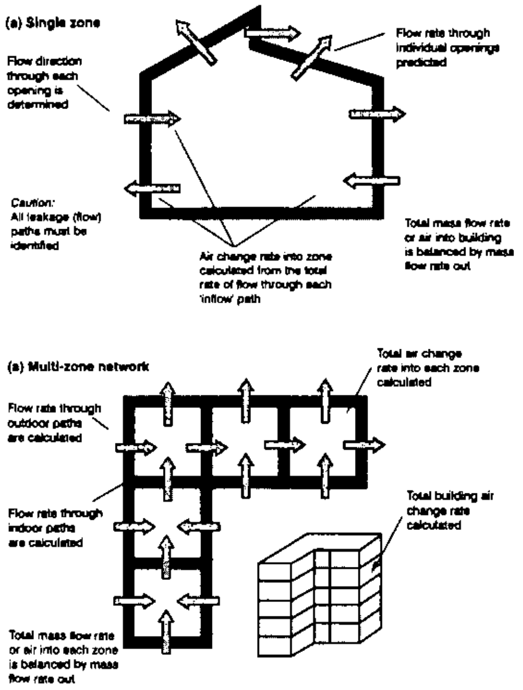


Figure 1.1 Single and multizone flow path networks (from Liddament [1])

A number of inter-zonal models have been developed, some of which are mentioned later in Section 6. While they differ from each other in detail they have a number of characteristics in common. The building is represented by a number of nodes representing building zones linked by paths representing flows between these zones. The resulting network resembles an electrical circuit with the links acting as resistances to flow generated by applied pressure differences. These pressure differences are generated naturally by the action of wind on the building surface and buoyancy due to differences in density, or mechanically by the action of fans. Unfortunately, unlike the electrical analogy, the relationship between the applied pressure and the flow through a link is non-linear and has to be carefully defined in relation to the type of flow path. This can lead to special considerations in obtaining solutions to the set of equations that govern the network.

3 Outline of COMIS

3.1 Introduction

COMIS has a greater capability to simulate buildings than earlier models. It is designed in a modular format so that it can be used either on a 'stand-alone' basis or incorporated into programs simulating the overall thermal performance of buildings.

The principal modules used in COMIS deal with the following:

(a) Applied pressure distribution;
(b) Air flow components;
(c) HVAC systems;
(d) Schedules;
(e) Contaminant transport.

3.2 Applied pressure distribution

Movement of air through any opening is driven by a pressure difference. This can occur naturally due to the action of wind or differences in temperature or mechanically due to the action of a fan. The latter is dealt with in Section 3.4.

3.2.1 Wind pressure

It is conventional to describe the pressure generated by the wind at the surface of a building in terms of a dimensionless pressure coefficient, C_p, defined as:

$$C_p = (p - p_o)/0.5\rho V_{ref}^2 ,$$

where ρ is the density of air, p is the surface pressure, p_o is the reference static pressure, and V_{ref} is the reference wind speed.

Within COMIS, wind pressure coefficients are generated by algorithms which take into account the following variables:

a)	Climate parameters:	Wind velocity profile Wind incident angle
b)	Environment parameters	Plan area density Relative building height
c)	Building parameters	Frontal aspect ratio Side aspect ratio Relative vertical position Relative horizontal position

The algorithms were developed by the systematic analysis of data sets obtained from published wind tunnel studies. They allow wind pressures to be calculated at any point on the surface of a rectangular building in a given environment for any given wind conditions (direction and speed).

3.2.2 Thermal buoyancy

Any differences in density of air either side of a boundary between two zones of a building, or between inside and outside, will generate hydrostatic pressure differences across the boundary, causing flow if openings are present. COMIS includes both the effects on density of temperature and moisture content. The importance of hydrostatic pressure is reflected in COMIS by the careful attention to defining reference heights.

3.3 Air flow paths

3.3.1 Air flow through cracks

The flow through small openings such as those around closed doors and windows, or at joins and penetrations of the fabric is both complex and ill-defined. However, a simple power law has been found to cover most situations that occur in practice:

$$Q = C\,(\Delta p)^n\,,$$

C and n are constants usually derived from regression fit to experimental measurements. COMIS includes correction factors to allow for differences in the conditions of the air, particularly temperature, from those which applied in deriving the power law. Also included are algorithms to compute the change in temperature of the air as it flows through small openings between zones at different temperatures.

3.3.2 Air flow through large openings

Air flow through large openings can be complex, with simultaneous flows in both directions being possible. The algorithms within COMIS assume:

d) Steady, inviscid and incompressible flow;
e) Linear density stratification on both sides of the opening;
f) Turbulence effects represented by an equivalent pressure difference profile;
g) Reduction of the effective area of an opening represented by a single coefficient.

3.4 HVAC systems

3.4.1 Duct components

Flow through duct networks is relatively well understood and a substantial body of theoreticaly and empirical knowledge exists. Following an extensive literature survey, COMIS includes data and algorithms to cover flow through a range of duct configurations and fittings, including entry and exit terminals, transitions, bends and junctions.

3.4.2 Fans

Fans are represented by polynomial curves relating pressure gain across the fan and volume flow rate. These curves are either provided by the user or fitted by COMIS to data entered from known fan characteristic curves.

3.4.3 Special components

COMIS is also equipped to deal with a number of special components including:

a) Flow controllers;
b) Kitchen hoods;
c) Passive ventilation ducts.

Also, non-standard, user-defined components can be included, provided that their pressure flow characteristics are known.

3.5 Schedules

Factors which affect air flow may vary with time. Such changes can be represented by schedules. A schedule includes an event (e.g. a window opened) and the time at which that event occurs. COMIS has the facility to include schedules for the following:

a) Weather data (wind speed and direction, air temperature etc.);
b) Window opening;
c) Fan use;
d) Zone temperature and humidity;
e) Contaminant source or sink.

3.6 Contaminant transport

As well as calculating air flow between zones, COMIS can also calculate the transport and distribution of up to five different contaminants, assuming that within a zone the concentration is uniform due to good mixing. Sources and sinks, including filter effects can be included. It should be noted that contaminant transport is a transient process and the time step for calculating changes is important. COMIS checks for the zone in which changes take place most rapidly and takes into account when setting this time step.

3.7 Solution of equations

The set of non-linear equations which describe the network are solved numerically using a Newton-Raphson algorithm with some modifications. This is described in detail in reference [2].

4 Evaluation

4.1 Strategy

Central to the work of Annex 23 was the evaluation of COMIS as a reliable, practical and user-friendly code for multizone airflow modelling. This task was split into the following components:

a) Analytical evaluation

This consisted of a comparison of the results obtained COMIS with known analytical solutions, where these existed;

b) Inter-model comparison

Other models for predicting whole building ventilation rates and inter-zonal flows are available. While these were not generally as comprehensive as COMIS, a comparison of results, using identical input data, was designed as a useful basis for confirming the validity of the output from COMIS;

c) Experimental comparison

A major test of the validity of any building performance simulation tool is comparison with measurements made on real buildings. For COMIS, an ideal programme of measurements would have covered the following categories of parameter:

- Building form and layout (including arrangement and linking of zones);
- Climatic conditions and surroundings (including wind-dominated, stack-dominated and mixed conditions);
- Typology of zones (including presence of thermal gradients, large openings etc.);
- Type of ventilation (including natural, mechanical, combined etc.);
- Steady and non-steady conditions.

In practice, it was not possible to apply these ideal criteria fully for reasons of cost and availability, and the choice of buildings was influenced by pragmatic factors such as the existing presence of instrumentation, dedication to experimental use etc. However, measurements were made in 10 buildings and covered a wide range of factors. These results were compared with predictions made using COMIS.

d) User tests

An important feature of the evaluation procedure was to check on the 'usability' of COMIS with three specific aims:

- To determine the errors made by users in interpreting multizone input data;
- To assess difficulties experienced by users in applying the input data;
- To use the results to improve input routines and data specification.

The outcome of these various components of the evaluation process are set out in Sections 5, 6, 7 and 8.

4.2 Sensitivity Analysis

A key aspect in carrying out the evaluation studies, was the need to understand the effect on the output from COMIS, of any errors or uncertainty in the input data. This was particularly important in relation to comparisons with experimental data, since the latter would also include measurement errors. The resulting combination of the uncertainty in both predicted and measured results could substantially reduce the usefulness of any comparison.

A systematic approach, applying advanced techniques of experimental design, was made to assessing the sensitivity of COMIS to input uncertainty. Because of the complexity of both the underlying algorithms and input data, special software tools were developed to assist this process:

MISA (Multirun Interface for Sensitivity Analysis) - This prepares a series of input files for COMIS, using experimental design techniques and then runs COMIS as many times as necessary and collects the resulting outputs.

SAM (Sensitivity Analysis Module) - A user-friendly program designed to work in conjunction with MISA and to assist in the design of the simulation and the processing of the output files.

Full details of these are given in Fürbringer et al [3] and in some of the references listed in Appendix 3.

5 Analytical Evaluation

5.1 Introduction

A major reason for developing a program such as COMIS is to solve complex multizone air flow problems, which cannot generally be dealt with by direct analytical solutions. However, where such solutions do exist, it is valuable to check the output of the more complex program against these. This was done as part of Annex 23. Sets of test cases were set up by (a) EMPA, (b) LESO and (c) Politecnico di Torino. These test cases were carefully designed to check the functionality of the code and to evaluate the algorithms in COMIS. The fully documented test cases, including COMIS input files, analytically calculated results and COMIS output files, were held on a central, accessible database. They were used both for the first version of COMIS and to check subsequent revisions.

5.2 EMPA Test Cases

This comprehensive set of test cases was designed to cover the topics set out in Table 5.1

Table 5.1 The test cases and the topics which they are designed to test

Test case category	Topics tested
Input data processing	Barometric pressure Extrapolation of wind pressure coefficient data Wind speed at reference height
Single or two zone models with cracks	Wind effects Stack effects Non-horizontal cracks
Two zone models with different types of air flow Components	Large vertical openings (including updated routines) HVAC components
Cases for contaminant spreading	Pollutant Humidity
Cases for checking zone layers	Layers in combination with (i) large vertical openings (ii) LVO's and pollutant transport
Cases for checking schedule processing routines	Schedule processing

5.3 LESO and Politecnico di Torino Test Cases

These test cases used very simple arrangements, designed to test the following features of COMIS:

a) The ability to predict the effect of changing wind direction on a simple four room symmetrical building model;
b) The ability to predict wind, stack and combined effects on a simple single-celled building model;
c) The ability to deal with different locations of links between zones under a range of wind and buoyancy conditions, using simple one or two zone building models.

The full details of the test cases are given in Fürbringer et al [3].

5.4 Outcome

These tests, against known analytical results, proved valuable in eliminating software errors. In general, COMIS results showed good agreement with the analytical results, except in the calculation of mass flows through large openings between zones, where there are layers in one or both of the zones. It was also demonstrated that the choice of time-step, when calculating time dependent changes in concentration of a contaminant, can have a significant effect on values of final concentration.

6 Intermodel Comparison

6.1 Introduction

As part of Annex 23, COMIS was compared with fourteen other computer models. Brief characteristics of these models are listed in Table 6.1. Further details may be obtained from the references given in Appendix 5, from Fürbringer et al [3] or, for some models, from Orme [4].

Table 6.1 Brief description of the models used for comparison with COMIS

Model	Description
AIDA	Single zone network model, designed only for crack flow
AIRNET	Multizone air flow model; includes cracks and large openings
ASCOS	Multizone air flow model; includes cracks, large openings and HVAC systems. Designed principally for the use in predicting performance of smoke control systems
BREEZE	Multizone air flow model; includes cracks, large openings and limited ability to deal with HVAC systems
BREVENT	Single zone model with simple representation of leakage characteristics
CBSAIR	Multizone air flow model
CONTAM	Multizone air flow model; includes cracks, large openings and simple representation of forced air flow. Designed principally for predicting contaminant distribution, it uses same solution procedure as AIRNET
ESP	Designed to predict overall environmental performance of a building, it includes an airflow module 'bfs' which allows interzonal flows to be calculated
LBL model	Single zone model with simple representation of leakage characteristics
MZAP	Multizone air flow model; includes cracks and large openings
NORMA	Single zone model. Designed to investigate thermal performance in relation to solar control, natural ventilation, thermal mass etc
PASSPORT-AIR	A thermal model which includes module for determining natural ventilation flow rates
TURBUL	Single zone model including the effects of compressibility and wind turbulence on air exchange through openings
VENCON	Multizone air flow model; includes cracks, large openings and limited ability to deal with HVAC systems

The comparison was undertaken to evaluate particular aspects of use and operation of the models and the models, were grouped accordingly. The six principal areas of comparison and the models used for comparison with COMIS are shown in Table 6.2.

Table 6.2 The characteristics compared for particular models

Model	**Characteristic compared with COMIS**					
	Interzonal flows (same input data)	**Large opening flows**	**Interzonal flows (User Test 1)**	**Mass flow equations**	**Sensitivity to input data uncertainty**	**Smoke propagation**
	(AIVC)	(University of Athens)	(BBRI)	(Concordia University)	(LESO)	(Politecnico di Torino)
AIDA					■	
AIRNET		■		■		
ASCOS						■
BREEZE	■	■				
BREVENT					■	
CBSAIR				■		
CONTAM 93/94	■			■		
ESP		■	■			
LBL					■	
MZAP	■					
NORMA		■				
PASSPORT		■				
TURBUL					■	
VENCON			■			

6.2 Comparisons

6.2.1 Comparison of results using the same sets of data

In order to compare COMIS with other similar models, a common data set based upon that developed for User Test 1 (see Section 7.2) was used. It refers to a three storey building with a stairwell, consisting of four zones. Figure 6.1 shows both the layout and the data considered.

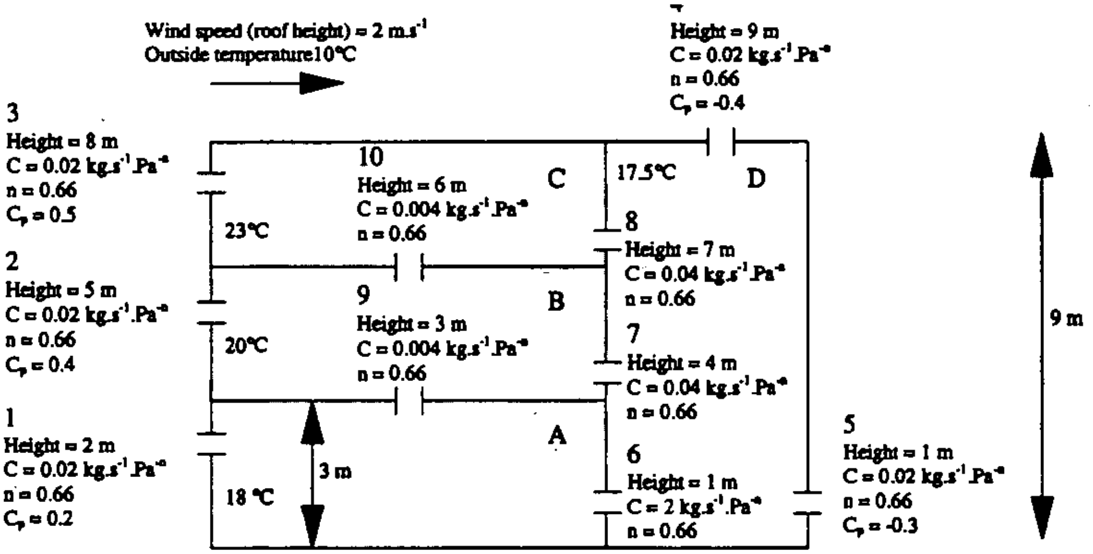


Figure 6.1 Schematic of simulated building

The models compared were COMIS 1.3, CONTAM93, MZAP and BREEZE 6.0f. The main emphasis of this study was to ensure that the same input data was used. Since the method of assigning input data differs between models and the ways that the models deal with some physical aspects (such as openings in horizontal surfaces between zones) vary, this required care and an understanding of the algorithms incorporated in each core code. The results showed a high degree of agreement, as illustrated by Table 6.3, which summarises the total outgoing flow rate for each zone, as well as that for the whole building.

Table 6.3 Total outgoing air flow rates calculated using a standards set of input data

Model	Zone A (kg/h)	Zone B (kg/h)	Zone C (kg/h)	Zone D (kg/h)	Total Building (kg/h)
COMIS	79.42	46.85	21.62	144.25	154.20
BREEZE	79.20	46.80	21.60	144.32	154.40
CONTAM93	80.45	47.11	22.01	145.41	155.40
MZAP	79.43	46.87	21.64	144.27	154.20

6.3 Large openings

The air exchange across a single opening in a zone, generally referred to as single-sided ventilation, is one of the more difficult situations to model since the physical mechanisms, other than buoyancy, giving rise to air exchange are less well understood. For this reason, a comparison was made between COMIS and five other models AIRNET, BREEZE, ESP, NORMA and PASSPORT, using the prevailing climatic conditions which applied during the measurements reported in Section 6.9.

These consisted of 19 sets of measurements in a closed, internally sealed room in the upper floor of a two storey building with a single variable opening, supplemented by 4 further sets made in the Greek PASSYS cell.

In general, the results were in good agreement, with correlation coefficients above 0.95. The one exception was the NORMA model which is simpler in concept to the others.

6.3.1 Interzonal flows with the same data but different users

This comparison is similar to that described in 6.2.1 above, except that the models were operated by different users. COMIS 1.1 was compared with VENCON and ESP 6.28. Table 6.4 illustrates the results, which are in close agreement, both with each other and the results given earlier in Table 6.3.

Table 6.4 Total outgoing air flow rates obtained by different users with same data

Model	Zone A (kg/h)	Zone B (kg/h)	Zone C (kg/h)	Zone D (kg/h)	Total Building (kg/h)
COMIS	78.94	45.72	24.19	145.52	155.16
ESP	78.73	46.48	21.49	143.03	152.93
VENCON	80.50	44.24	22.10	145.55	155.56

6.3.2 Comparison of mass flow equations

While all models use a general power law equation for predicting flow through cracks and small openings, there are differences in the way that they deal with the temperature of the air. The air temperature may change, due to heat transfer with the building fabric, as the air moves through the opening. This is important since it affects both density and viscosity and, in consequence, the magnitude of the flow and the calculated mass flow rates. Since there may be substantial differences in temperature across openings, particularly those linking to outside air, the direction of flow can be important and may lead to convergence problems where the applied pressure difference is small.

Using a simple four zone, two storey model building with a standard set of applied wind pressures and temperatures, a comparison was made of the predicted pressure differences and flow rate through air flow links. In addition to COMIS, three models were used AIRNET, CBSAIR and CONTAM94. In general, the results were in very good agreement, the only major differences occurring at a link where the calculated pressure difference was small.

6.3.3 Test of sensitivity to input data uncertainty

All models require input data. Uncertainty attaches to these data both in relation to any assumptions made in their choice and, where they are determined experimentally, measurement inaccuracy. To determine the sensitivity of output predictions to uncertainty in input data, COMIS was compared to four simpler, single zone models, AIDA, BREVENT, the LBL model and TURBUL. A six zone building based upon the Italgas Building (see Section 7.10) was used for the comparison, together with a number of sets of defined climatic conditions. A detailed discussion of the results is given by Fürbringer et al [2].

To illustrate the type of results obtained, Table 6.5 shows the uncertainty in the calculated global mean age of the air, expressed as an inaccuracy ratio (defined as the ratio between the inaccuracy of the output to the global inaccuracy of the input parameters), for three different wind regimes. Table 6.6 gives the estimated inaccuracy of each type of input parameter for each model.

Table 6.5 Uncertainty of global mean age of air for detailed and simple models when input data uncertainties are taken into account.

Wind speed (m/s)	**COMIS**	**AIDA**	**BREVENT**	**LBL**	**TURBUL**
0.3 (stack dominance)	51%	16%	34%	26%	15%
1.0 (balanced)	38%	24%	22%	29%	19%
3.0 (wind dominance)	32%	24%	24%	37%	24%

With input data uncertainty based upon the estimated experimental inaccuracy of the input data relevant to each model, Table 6.5 above, the output uncertainty associated with the more detailed model, COMIS, is larger than for the simpler models, although the difference tends to reduce as wind becomes the dominating influence. However, it is important to note that the simpler models deliver less information (for instance, inter-zonal flows) and can take into account fewer phenomena.

Table 6.6 Confidence limits for each parameter for each model

Parameters	**COMIS**	**AIDA**	**BREVENT**	**LBL**	**TURBUL**
Air tightness	± 24%	±24%	±5%	±20%	±24%
Exponents	±10%	±10%	±8%	±8%	±10%
Volumes	±10%	±10%	±10%	±10%	±10%
Temperatures	±0.5 °C	±0.5 °C	±0.5 °C	±0.5 °C	±0.5 °C
Atmospheric pressure	±0.5%	-	-	-	-
Pressure coefficients	±50%	±50%	-	-	±50%
Wind speed	±5%	±5%	±5%	±5%	±5%
Heights	±1%	±1%	±1%	±1%	±1%
Terrain	-	-	±1	-	-
Wind exposure	-	-	±1	-	-

6.3.4 Test for smoke control

Smoke generated by an accidental fire in a building may be regarded as a contaminant, distributed under the action of its own buoyancy and, as it cools, by the general inter-zonal flows within a building. Smoke differs from most contaminants considered in the context of ventilation due to its high initial temperature near the originating fire. To determine whether the use of COMIS could be extended to this application, a comparison was made with ASCOS. A multizone flow model intended specifically to study smoke movement.

A set of simple test cases was set up and the global mass flow rate calculated for each model. The test cases ranged from very simple 1, 2 and 3-celled building arrangements to a case representing a tall building with 15 zones representing storeys and an attached vertical shaft. Calculations were made in each case for two conditions:

a) Range of differences between internal and external temperature; no wind;
b) Range of wind speeds and profiles; no internal external temperature difference.

For the simplest test cases, the differences between the models was less than 1%. Larger differences were found for the more complex, tall building case but did not exceed 10%. This provides some indication that the use of COMIS could be extended to the analysis of smoke control problems.

6.4 Outcome

In general, good agreement was found between the results obtained using COMIS and those obtained by other, mainly less comprehensive, models. However, sensitivity tests showed that the range of uncertainty in the output increased with the complexity of the input data. Thus, there is some trade-off between uncertainty and the detail of the information provided by a program. The benefits of the increased information (e.g. flows between zones compared with whole building ventilation rates) will outweigh the lack of precision.

7 Experimental Comparison

7.1 Introduction

Comparisons between experimental measurements and the output from COMIS were made for nine buildings. The results are summarised in the following sections. Full details and the philosophical basis for making the comparisons are given more fully in Fürbringer et al [3]. Table 7.1 shows the principal features of COMIS investigated in each case.

Table 7.1 Features of COMIS used in each of the experimental comparisons

Feature	**Building Number**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Air flow component									
Crack	■	■	■	■		■	■	■	■
Fan						■			
Straight ducts									■
Duct fitting									■
Flow controller									
Large vertical Opening					■	■	■	■	
Test data Component		■	■						
Zone layer					■				
Pollutant						■			
Schedules									
Links									
Large vertical Openings									
Fan						■			
Zone Temperature				■	■				■
Zone humidity						■			■
Pollutant Source or sink			■						
Building									
Orientation		■	■	■			■	■	■
Terrain		■	■	■			■	■	■
Wind profile Data		■	■	■			■	■	■
Pressure coefficient		■	■	■					■
Meteorological data	■	■	■	■	■		■	■	■

7.2 Building 1 - OPTIBAT experimental flat (France)

OPTIBAT is an experimental, single floor flat, consisting of 6 principal zones, built in a large experimental hall. The external environment was, therefore, controlled and independent of wind conditions. The air leakage characteristics of all openings were obtained by measurement. A set of eight climatic conditions was investigated. Measurements were made using multiple tracer gas techniques.

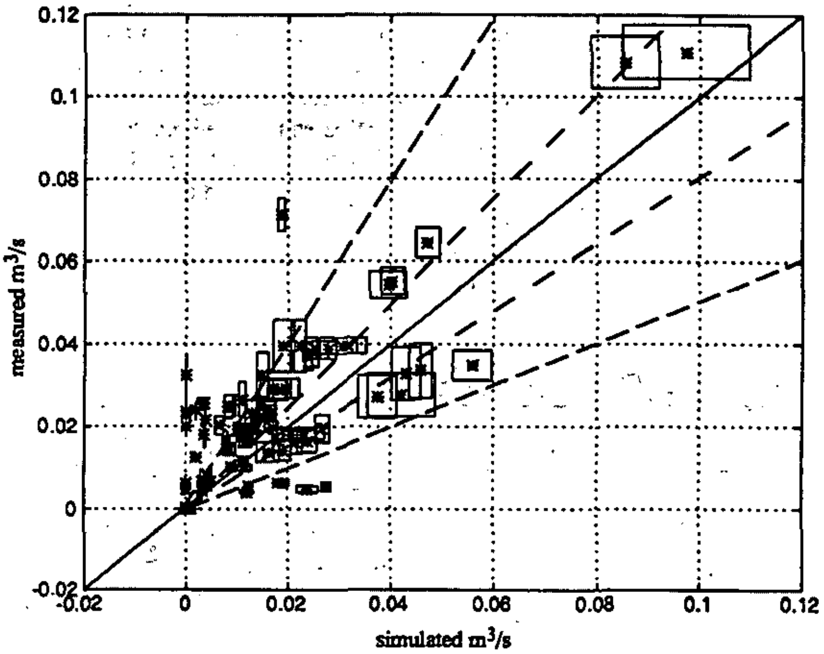


Figure 7.1 Comparison of simulated and measured air flow rates for all zones and scenarios. Rectangles correspond to confidence intervals

A summary of the results is shown by Figure 7.1. Although there is a broad agreement between measured and calculated airflow rates, there are many cases where significant differences occur, even for total air flow rates in the zones. Possible reasons for this discrepancy included:

a) Underestimation of the confidence intervals for the measured values, and
b) In some cases, lack of uniformity of the applied pressure over a façade due to the location of the pressurisation fans.

7.3 Building 2 - Solar House (Japan)

This single-storey building, shown in Figure 7.2, was constructed on the campus of Tohoku University, Japan, to investigate passive solar systems. Three zones were established and pressurisation tests were used to establish both background and component leakage characteristics. Three sets of measurements were made using the multiple tracer gas, constant and decay methods. Meteorological conditions were monitored over the test periods.

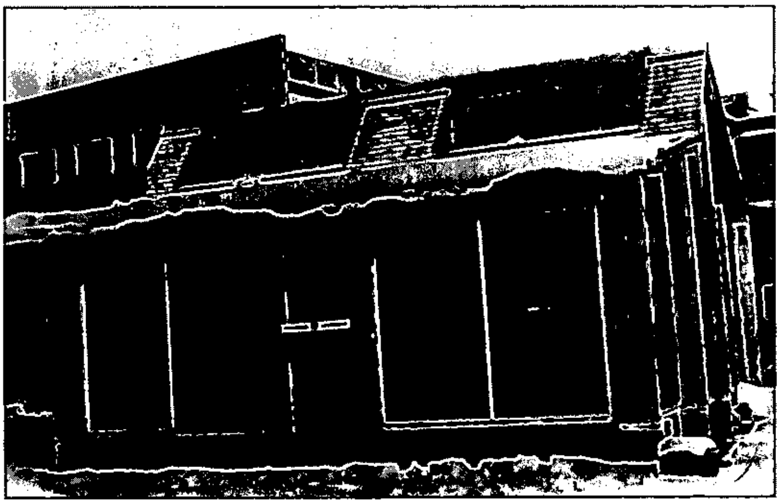


Figure 7.2 Building 2 - Passive solar test building, Japan.

A comparison showed that the relative error of air changes rates was within ±25%. A sensitivity analysis of the calculated data and estimated confidence limits on measurements indicated that the overall difference could be accounted for by these uncertainties.

7.4 Building 3 - Family house (Japan)

The building was a two-storey family house, consisting of nine zones. The connecting space between the two storeys, consisting of a lower and upper hall linked by a staircase was considered as two zones. The effective leakage rates of windows, walls, doors and other components were measured by the fan pressurisation method.

Figure 7.3 Building 3 - Two storey test house, Japan

External temperature and wind speed and direction were measured at the site. Wind pressure taps were located on the external walls and roof. Air temperature and tracer gas measurements were made at the centre of each zone. Measurements were made over a 10 hour period of air flows in each zone, using a pulsed injection technique with SF_6 tracer gas. A second set of measurements over a 16 hour period was made of contaminant concentrations in each zone, following initial liberation of SF_6 over a one hour period in one of the principal zones.

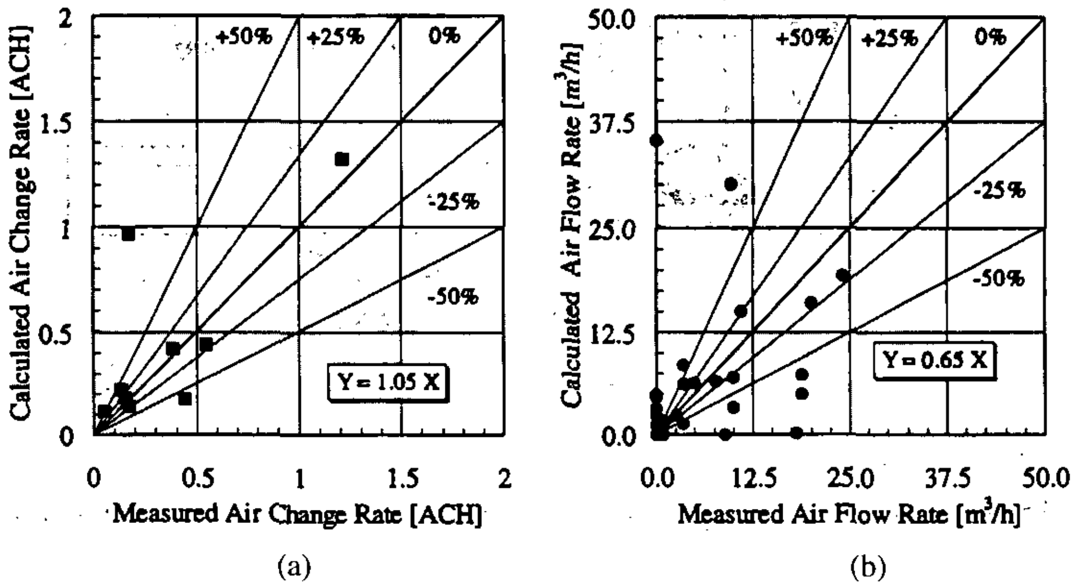


Figure 7.4 Comparison of measured and calculated air flows for Building 3

Figure 7.4 shows a comparison between the COMIS predictions and measured values of (a) mean air change rate and (b) air flow rates between zones. The correlation coefficient between measured and calculated air change rates is 0.7 but the agreement in the case of flow rates through individual air flow paths is poor. Possible contributory factors were identified as:

a) Inherent error in the tracer gas measurement technique;
b) Less than perfect mixing of the tracer gas in each zone;
c) Measured results were averaged over a three hour period, during which time climatic conditions were not constant.

Better agreement with COMIS predictions was obtained with the second set of measurements of contaminant concentrations, yielding a correlation coefficient of 0.94.

7.5 Building 4 - Three-storey office building (Switzerland)

This building has three storeys and, for the purposes of this investigation, was considered to consist of 11 zones with a total of 28 air flow links. Figure 7.3 shows, schematically, the second floor zones and their related links. The leakage characteristics were determined using a two-fan, guarded zone technique.

Figure 7.5 Building 4 - 3-storey office building, Switzerland

Climatic data was measured as both instantaneous and average values over 15 minutes. Air flows were measured with a multi-gas, constant concentration technique. The results were used to calculate a global air exchange rate for the whole building, $Q_{a\text{-building}}$. Measurements were made over three separate periods, varying from 3 to 9 hours in length.

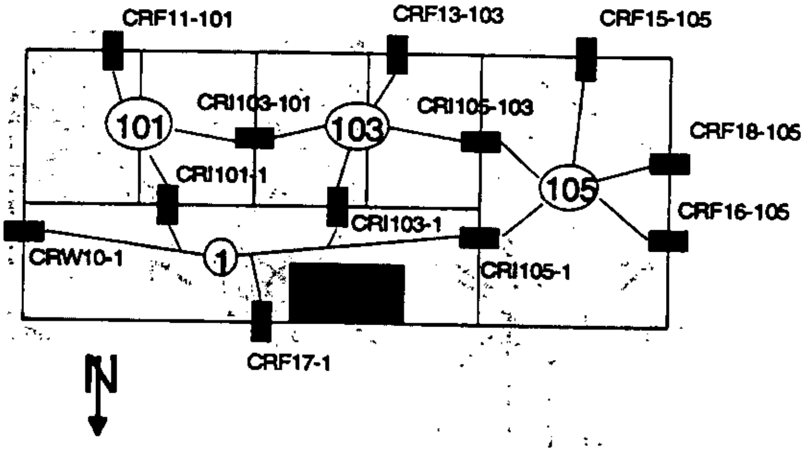


Figure 7.6 Typical network arrangement for Building 4 (Floor 2)

There was good agreement for periods 1 and 2 during which wind speed was close to zero. In period 3 the wind speed was initially 1.0 m/s but fell to 0.2 m/s during the course of the measurements. However, for the building and climatic periods analysed, it was not expected that wind speed would have a significant effect below 2.0 m/s. It was concluded that the difference is probably attributable to some unidentified change in the test conditions, such as sudden change in building leakage characteristics due, for instance, to door being opened.

7.6 Building 5 PASSYS Test Cell (Belgium)

The standard PASSYS test cell consists of two rooms, a test room and a service room. For the purpose of this investigation, which was concerned with single-sided ventilation, the service room and test room were connected by a large, 1m x 1m opening and an 0.5m by 0.5m opening connected the test room to outside air.

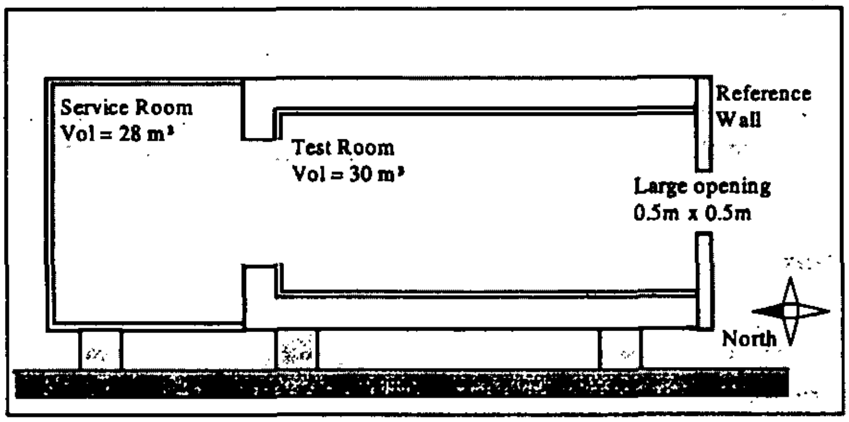


Figure 7.7 Schematic cross-section through the PASSYS test cell

The remainder of the envelope of each room was sealed. The general layout is shown in Figure 7.7. Both rooms could be artificially heated or cooled to obtain a range of operating conditions

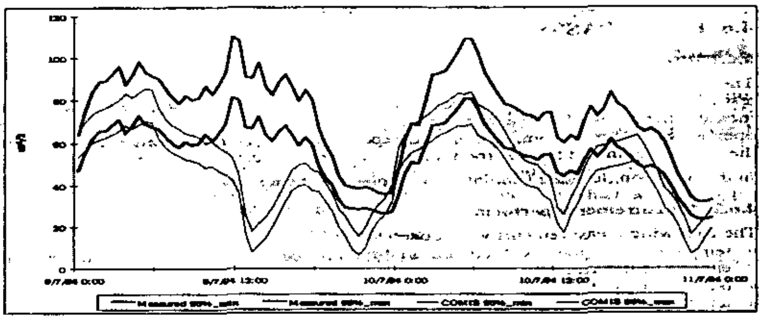


Figure 7.8(a) Measured and simulated airflow through the opening

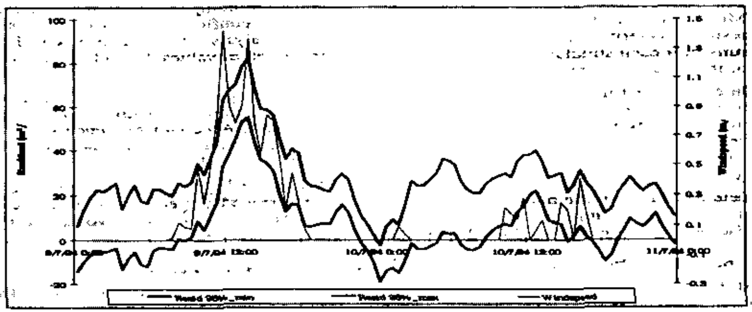


Figure 7.8(b) Wind speed and confidence band of the residual (i.e. measurement minus simulation) of the airflow through the opening

Measurements were made over two periods of four and five days in length. Repeated 24 hour heating/cooling cycles were used. Climatic conditions were monitored at the site and temperatures were measured at different heights in each zone to determine temperature gradient. Air flow rates through both openings were measured continuously using a dual tracer gas technique.

The results are illustrated by Figure 7.8(a) which shows the variation of measured air flow rate with that calculated by COMIS 1.2. There is good agreement, shown by the overlap of the 95% confidence bands, for some parts of the period but not for others. However, when the residual (i.e. difference between experiment and prediction) values are shown together with wind speed, Figure 7.8(b) it is apparent that the differences are larger during periods of higher wind speed.

It was concluded that a major contribution to the lack of agreement was the failure of COMIS 1.2 to include an algorithm for determining the effect of wind on the air flow rate through large openings. This has been remedied, subsequently, in COMIS 3.0. The results also showed the importance of modelling the effect of turbulent exchange at low wind speeds and temperature differences.

7.7 Building 6 - Single floor flat (Belgium)

This test site consisted of a flat, with seven zones, situated at ground level in a nine-storey block. Apart from natural air leakage at the two external walls, the toilet, bathroom and kitchen were separately naturally ventilated by shunt connections to vertical ducts running the full height of the main building.

Temperatures were measured at 50 locations within the flat. Air flow rate through the shunt ducts was measured by tracer gas (N_2O) and fresh air supply rate to each room, using a constant concentration tracer gas method, employing SF_6. The principal aim of the investigation was to compare measured pollutant concentrations with those predicted by COMIS. This was done by injecting carbon dioxide and water vapour, at a measured rate, into one zone (a bedroom) for two hours, and monitoring the resulting concentrations in each zone over this period and the subsequent 8 hours. Two situations were examined (a) all internal doors open and (b) all doors closed.

Because of the difficulty of estimating the likely values of pressure coefficient, due to the location of the flat, the external air flows to the flat were simulated artificially in COMIS by notional 'fans' providing a flow rate equal to the measured rate in the relevant zone. In general, with internal doors open, the agreement between measured and predicted concentrations was good, except for the room in which the contaminant was released. The latter was ascribed to the relative sensitivity of the predicted air exchange between room to temperature difference. For the situation with internal doors closed, the comparison showed good agreement for the injection room but less so in other rooms. This was ascribed to the occurrence in reality of some cross ventilation, which was not included in the way that COMIS was set up using the notional 'fan' arrangement.

In general, it was concluded that COMIS provided a good means for predicting pollutant distribution. Such differences as were found were ascribed to problems associated with the experimental set up (measurement of small temperature differences, cross ventilation etc.)

7.8 Building 7 - PASSYS test cell (Greece)

The arrangement of the test cell, shown in Figure 7.9, is similar to that described in Section 7.6, except that in this case the experimental work was undertaken in the service room and the opening to the test room was sealed. The service room had a 2.0m high, 1.0m wide opening to the external air. Climatic conditions were monitored locally. Temperature sensors were placed at a number of locations in the space to allow the temperature gradient to be measured. Air velocities, measured by hot wire anemometers, and temperatures, were measured at a range of heights in the plane of the vertical opening. Four sets of ventilation measurements were made using a N_2O tracer gas decay technique. For the purposes of analysis, the results were amalgamated and a more extensive set of measurements described in the following section.

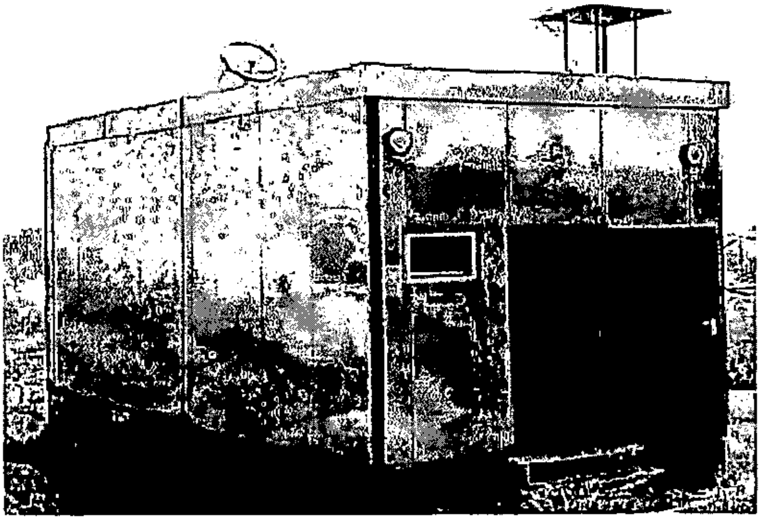


Figure 7.9 Building 7 - Passys test cell, Greece.

7.9 Building 8 - Isolated test room (Greece)

In order to investigate the air exchange between a space and outside air through a single opening, a room in the central storey of a three-storey office building was sealed from the remainder of the building. The outer wall contained a rectangular opening whose size and configuration could be altered to give a range of areas from 0.66 to 2.54 m^2 and heights from 0.62 to 2.40 m. Ambient air temperatures were measured locally and air speeds were measured at two heights near to the window. Internal temperatures were measured at several heights in the room to establish the temperature gradient. Ventilation rates were measured with a N_2O tracer gas decay technique, with several injection and sampling points to ensure good distribution and more accurate averaged concentrations.

Fourteen sets of measurements were made. In general, it was found that COMIS underpredicted the air exchange rate. Further analysis indicated that the discrepancy tended to increase with wind speed. COMIS, at the stage of this investigation, had no mechanism for including the effect of wind on single-sided ventilation. The main mechanism was assumed to be buoyancy resulting from internal-external temperature differences. The results were used to derive an empirical correction factor, CF, for future incorporation in COMIS. This correction factor is given by the following equation:

$$CF = 0.08\,(Ar_D)^{-0.38}$$

Where Ar_D is the Archimedes Number, a dimensionless number which is effectively a ratio of bouyancy to inertial forces.

7.10 Building 9 - Italgas test house (Italy)

This building was an experimental test house (constructed by the Italian utility, Italgas) consisting of a basement containing measuring equipment, a principal floor containing six zones, and a heatable roof space. Pressurisation tests were undertaken to establish leakage characteristics. The main floor was instrumented to measure temperature and to allow tracer gas measurements. Climatic conditions were monitored locally. Two series of tests were carried out. In the first, only a single zone was used and ventilation rates were measured by a single tracer gas technique. Nine sets of results, for various combinations of external ventilator and chimney opening, were reported and these are shown in Figure 7.10.

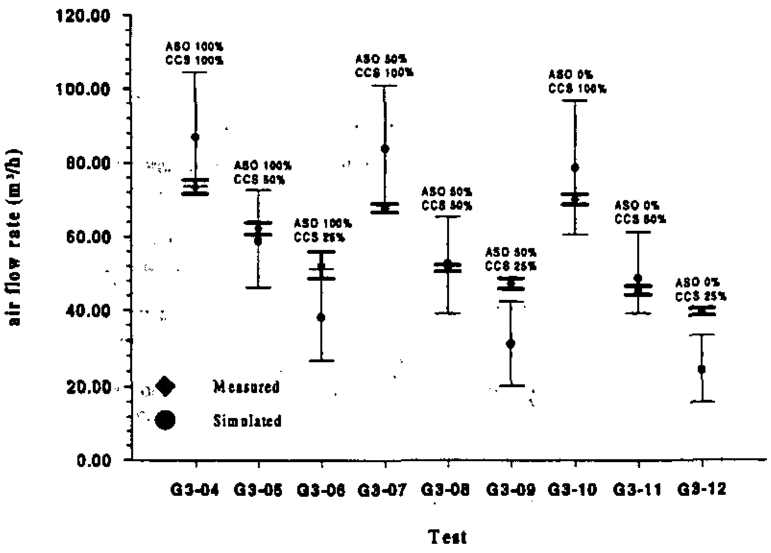


Figure 7.10 Simulated and measured air flow rates for various combinations of air supply and chimney opening (ASO - air supply opening; CCS chimney area)

In general, the agreement, as indicated by the overlapping confidence limits, was reasonably good. The second set of measurements was made using the test floor divided into two zones and the openings used in the first series closed. A two-tracer gas method was used to measure the flows between the zones and between each zone and outside. Four sets of measurements were reported. In the first two of these, the measured results were substantially higher than those predicted by COMIS. However, inspection indicated the presence of leakage paths not included in the results from the pressurisation tests. These were eliminated and two subsequent tests showed good agreement.

The results of this investigation pointed to the need for correct definition of loss coefficients in ductwork components and, for accurate identification of all relevant leakage paths when using COMIS.

8 User Tests

8.1 Introduction

An important feature of any software intended for general application is that the opportunity for the user to introduce errors should be minimised. The objectives of the user tests on COMIS were as follows:

a) To assess the difficulties experienced by users when applying the data;
b) To use the results to improve the specification of data sets and the input routines;
c) To determine the errors made by users in interpreting multizone input data.

Two tests were prepared by LESO and AIVC. The first was a simple benchmark analysis in which the flow network and input data were provided. No interpretation of factors such as building leakage or climatic data was required. The second was a more open test in which the user was required to devise a network and set up input data based upon a more general description of the problem. In addition, a short questionnaire was distributed to obtain feedback on usability.

8.2 User Test 1

The simple four zone building used for this test has been previously described in Section 6.2.1. Input data was provided and is that shown in Figure 6.1. Users were asked to evaluate the ventilation rate in each zone and the air flow rate in each path. The first run of this test took place in November 1992 with eight organisations participating. The results showed differences with considerable variation in some items of the output data, as summarised in Table 8.1 which shows the total air flow rates for the four zones.

Table 8.1 Summary of the variation between zone total air flow rates, as calculated by participants in the first run of User Test 1.

	Total air flows in zones (kg/h)			
Zone	**1**	**2**	**3**	**4**
Average	72.1	55.4	21.9	142.6
Standard Deviation	23.8	14.8	15.2	19.0
Minimum	16.6	24.6	9.9	95.2
Maximum	109.5	64.5	48.4	162.3

The causes of the variation were not analysed in detail, as it was apparent that serious bugs in COMIS 1.1 had contributed to some of the differences. Useful feedback was, however, obtained from the questionnaire, including identification of inconsistencies between the User Guide and the code, software bugs and the lack of in-built routines for calculating output in terms of commonly needed quantities (total air change rate, fresh air change rate etc.). These were used to make improvements to the code.

A second run was instituted in which ten organisations participated. To eliminate variations due to different versions of COMIS, all participants used COMIS 1.2, an updated version taking into account the lessons learned in the first run. Apart from one participant that made an obvious networking error, the results were much more consistent, as indicated by Figure 8.1.

The reasons for differences were analysed. It was clear that even with much of the problem being well defined a complex program such as COMIS, requiring the entry of substantial quantities of data, is open to user error.

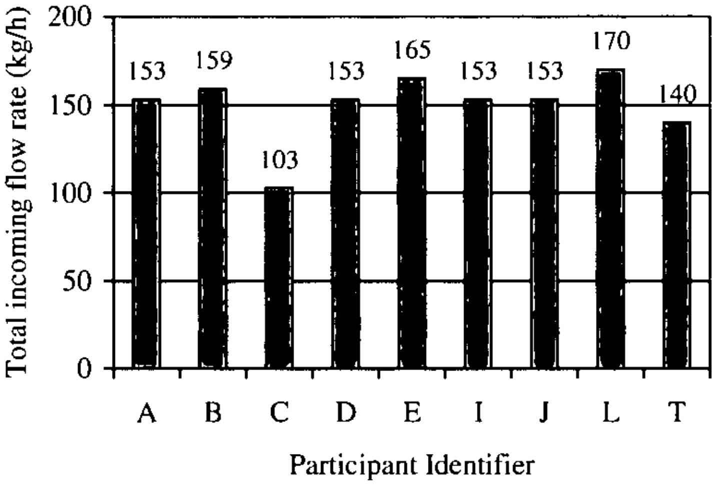


Figure 8.1 Variation in predictions of total incoming flow rate from the second run of User Test 1.

8.3 User Test 2

The test case consisted of a fifth-floor apartment at the centre of a nine-storey apartment block located in mainland Europe. The following characteristics were defined in table 8.2.

Table 8.2 Characteristics for the test case for User Test 2.

Characteristic	**Definition**
Overall dimensions	9.5m x 9.0m x 2.7m (volume - 230m^3)
Surroundings	Urban, similar buildings at 40m spacing.
Background leakage	3 ach at 50Pa, distribution between zones defined with flow exponent of 0.6
Natural duct system:	
(a) Main duct	Section 0.23m x 0.18m, air leakage 6.9l/s at 1Pa with flow exponent of 0.5.
(b) WC duct	Section 0.10m x 0.10m, joining main duct, inlet height 2.6m
(c) Bathroom duct	Section 0.10m x 0.10m, joining main duct, inlet height 2.6m
(d) Kitchen duct	Section 0.23m x 0.10m, joining main duct, inlet height 2.6m
Other components:	
(a) External windows, doors	Included in background leakage
(b) Internal doors	1m x 2m, perimeter gap of 1.0mm with flow exponent of 0.5

The objective was to calculate the total air change rate of each zone, the air flow in each flow path and the proportion of fresh air into each zone for the following conditions:

Table 8.3 Set conditions for User Test 2

Variable	**Condition**
Configuration	External windows and doors closed; internal doors closed except for living room; ventilation ducts open
Internal temperature	20°C
External temperatures	0, 10 and 20°C
Wind direction	North West
Wind speed	0, 1, 2, 5 and 10 m/s

Seven organisations, using COMIS 1.2, participated. The initial results are typified by Figure 8.2 which shows the results for total air flow rate for three different conditions.

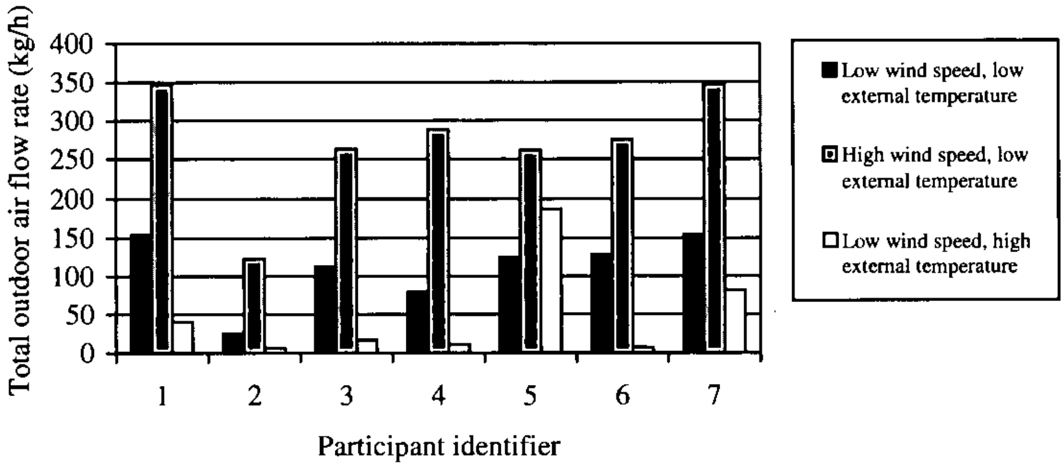


Figure 8.2 Total outdoor air flow rate for three different conditions as calculated by participants in User Test 2

The differences in the results produced by participants, as typified by those above, were substantial. A first review indicated large variations in modelling the network for the apartment, including a range of 10 to 12 nodes, 17 to 25 links and 2 to 13 pressure coefficients. A more detailed analysis of input files revealed a range of different interpretations and errors, some with the potential to result in large discrepancies.

8.4 Outcome

From these user tests it was found that:

a) Identical input files gave identical results on different computers or with codes issued by different compilers, if the same source version of COMIS is used. The code was not found to be too sensitive to numerical noise;

b) Large differences between results come from modelling errors or input entry errors. Some misunderstanding of the User Guide resulted in large changes in wind velocity at the façade level. The most common misunderstandings occurred when defining reference heights of buildings, zones and meteorological station, and when defining building orientation;

c) Slight differences may result from different options chosen by the user.

d) Both user tests revealed substantial quantity of useful information that was fed back into improvements to the code and the User Guide.

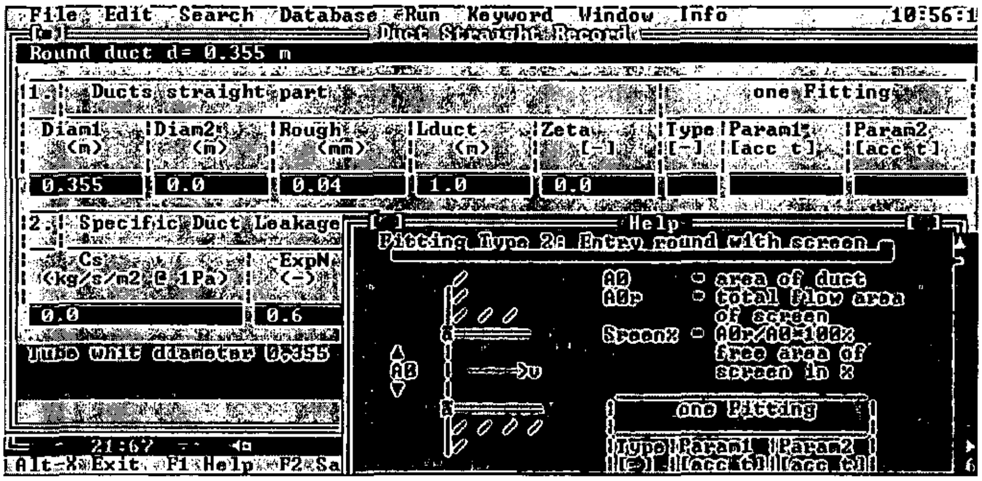
9 COMIS Interfaces

9.1 Introduction

As part of the modular design of COMIS, input/output modules are separate from the input/output interface. This has the benefit that COMIS can be used as a stand-alone model for predicting air flows or, can be incorporated in more complex building simulation programs. The first input module, COMIN, was designed to be hardware independent and to allow input data files to be set up and modified. However, it is no longer supported and has been supplanted by several more 'user-friendly' notably COMERL and IISiBat. These are described briefly below.

9.2 COMERL

COMERL is a DOS-based interface for COMIS, using Windows technology, developed by the Building Energy Simulation Group, EMPA. The input file can be established in the task specific editor. COMIS 3.0 can be run from within the shell and the output shown directly in a separate COMERL window. It includes several databases for input data, including leakage data for various types of flow path, as well as for ducts and fans. A separate routine, with on-screen checking, is available to assist in fitting a polynomial approximation to any chosen fan characteristic. A typical input window is shown in Figure 9.1.



Round duct d= 0.355 m

1. Ducts straight part | one Fitting

Diam1 (m)	Diam2 (m)	Rough (mm)	Lduct (m)	Zeta [-]	Type [-]	Param1 [acc t]	Param2 [acc t]
0.355	0.0	0.04	1.0	0.0			

2. Specific Duct Leakage

Cs (kg/s/m2 @ 1Pa)	ExpN (-)
0.0	0.6

Tube whit diameter 0.355

Fitting Type 2: Entry round with screen

A0 = area of duct
A0p = total flow area of screen
ScreenX = A0p/A0*100% free area of screen in %

one Fitting

Type [-]	Param1 [acc t]	Param2 [acc t]

Figure 9.1 COMERL input window for ducts, also showing on line help text.

9.3 IISiBat

The French acronym IISiBat can be translated as 'Intelligent Interface for the Simulation of Buildings'. IISiBat is a general simulation environment program that has been adapted to house the COMIS simulation software. It has a high degree of flexibility and can incorporate utility programs, including databases, spreadsheets and plotting software.

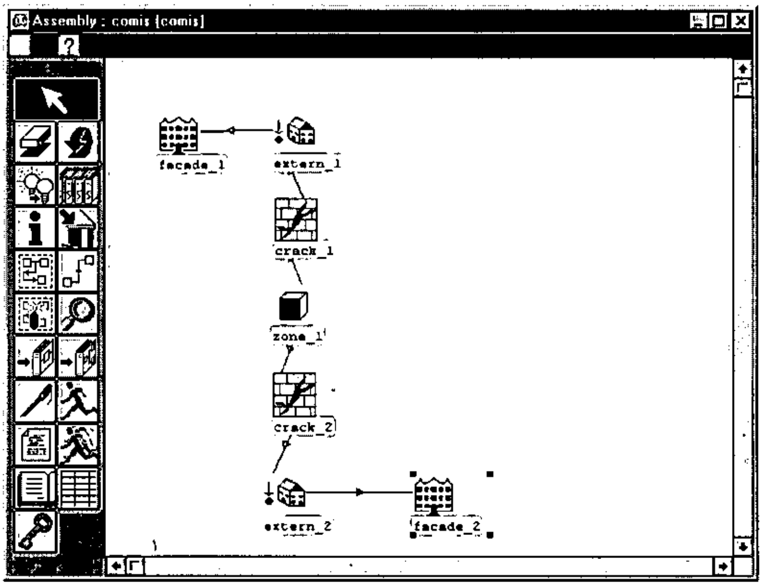


Figure 9.2 Assembly screen from IISiBat showing icons linked to simulate a simple single cell building

IISiBat has an integrated pre-processing utility that allows users to create COMIS Input Files graphically by connecting icons that represent COMIS components, as shown in the typical input screen in Figure 9.2.

Clicking on any icon opens another window which allows specific characteristics to be entered, for instance the pressure coefficients at a façade.

10 Continuing Work with COMIS

10.1 Further developments

The international co-operation on the development of COMIS has resulted in its widespread use and continued development. To facilitate this both COMIS and its utilities have been fully documented. Details of manuals and tutorials are included in Appendices 2 and 3. Two COMIS Workshops have been organised by the Department of Building, Civil and Environmental Engineering, Concordia University, Canada. In addition, several internet websites (see Appendix 4) are concerned with COMIS and provide information on current developments. COMIS has played a role in several recently completed and continuing IEA Annexes, notably Annex 27 'Evaluation of Domestic Ventilation Systems', Annex 30 'Bringing Simulation to Application' and Annex 35 'Design of Energy Efficient Hybrid Ventilation'.

COMIS is being incorporated into building energy simulation programs. Work is ongoing to develop a connection for COMIS within the second release of EnergyPlus, scheduled for 2001. EnergyPlus is a second generation energy simulation program, under development in the USA as a successor to BLAST and DOE-2.

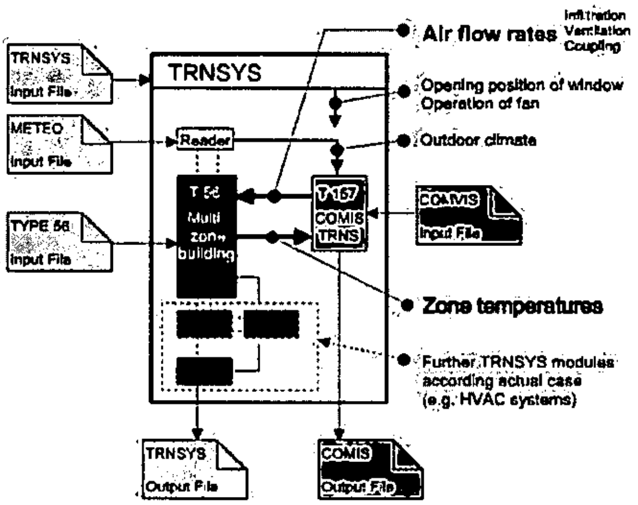


Figure 10.1 Diagram showing the integration of COMIS within TRNSYS

Work at EMPA has adapted COMIS to be a separate component of the building and systems application code TRNSYS. TRNSYS was originally developed by the Solar Energy Laboratory, University of Wisconsin as a general purpose modular transient systems simulation program. Using a common IISiBat based input module, the combined COMIS-TRNSYS provides a powerful thermal and airflow simulation tool, shown schematically in Figure 10.1. An example of its use is given in the next section.

10.2 Application of COMIS

The design of modifications to the ZTL Building, Lucerne, described fully in reference (5) illustrates the use of COMIS in conjunction with TRNSYS. It was planned to retrofit the existing four-storey building with a glazed double façade, with the aim of reducing heat loss in winter. Concern that the change might also result in summer overheating and inadequate ventilation, resulted in the need for a detailed design study to clarify the following:

a) Risk of overheating under summer conditions;
b) Potential for temperature using passive cooling by natural ventilation at night;
c) The control strategies for the ventilation openings to ensure thermal comfort;
d) Cross-contamination from one class room to another.

A representative four-storey section of the building was modelled. Figure 10.2 shows network for COMIS. Figure 10.3 illustrates the results obtained, showing the predicted temperatures and air flow rates during a warm period in summer at two times of day, 0600 when windows are closed, and 1600 (at peak outside temperature) when windows are open.

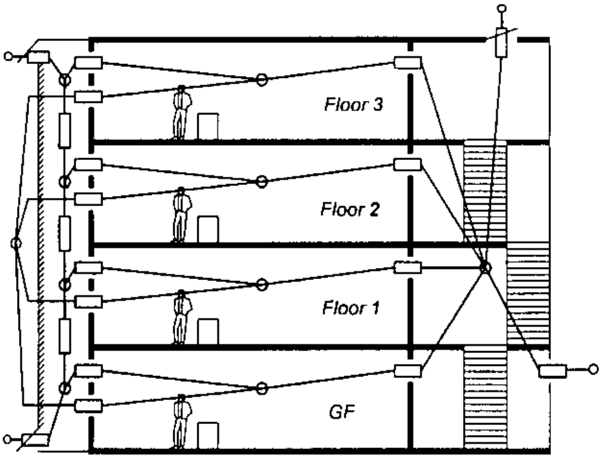
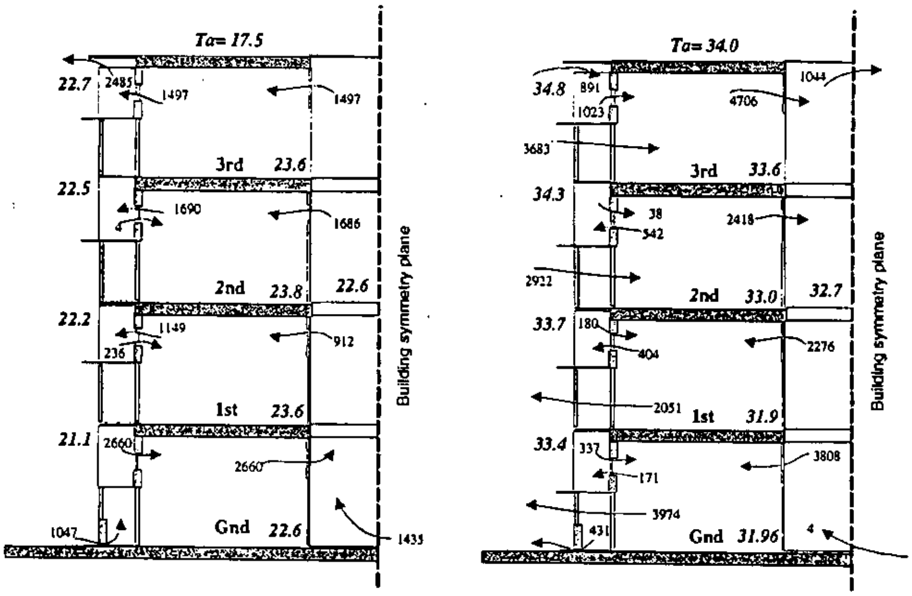


Figure 10.2 Airflow network for COMIS



(a) At 0600, windows closed

(b) At 16.00, windows open

Figure 10.3 Predicted classroom temperatures (^{0}C) and air flow rates (kg/h) at two times of day, 0600 and 1600, during a spell of warm weather.

11 Conclusions

The work of Annex 23 has resulted in the availability in the public domain of a robust and flexible computer code, COMIS, for the simulation of interzonal air flow in a multizone building. The international links established through Annex 23 have both contributed to the development of COMIS and stimulated its widespread use and availability.

Extensive testing, by comparison with analytical solutions and other simulation models, has ensured that the later versions of COMIS are free from errors in programming and the underlying algorithms.

The modular design of COMIS has allowed the algorithms to be improved and extended, for instance to deal with single-sided ventilation through large openings. It has also facilitated the development of improved user-friendly input tools, such as COMERL and IISiBaT and has allowed COMIS to be integrated with other building performance packages such as TRNSYS and EnergyPlus.

Direct comparisons of COMIS with the results of experimental studies carried out under Annex 23 gave very variable results, although the predictions were generally of the right magnitude. In practice, it was found very difficult to make adequate comparisons both because of the combined effect of the measuring errors associated with the direct measurements of air flow because of and those related to the input data required by COMIS, such as climatic conditions and component air leakage characteristics.

A major difficulty identified by the work of Annex 23 was the tendency of COMIS to user error. This is partly due to the complexity of the required input data but may also be due to the lack of understanding by users of the underlying mechanisms of air flow, resulting in an incorrect definition of the problem to be solved by COMIS. The new user-friendly input modules, the availability of data 'libraries' for key input requirements such as pressure coefficients and air leakage characteristics, and improved documentation will go some way to resolve this problem. However, there remains a need for potential users to be trained and the COMIS-related workshops and courses which have sprung up in the wake of Annex 23 make a valuable contribution to this.

12 References

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2. Feustel, H.E. and A. Raynor-Hoosen (Eds), 1990: Fundamentals of the Multizone Air Flow Model -COMIS. AIVC Technical Note 29, Air Infiltration and Ventilation Centre, Coventry, UK.
3. Fürbringer, J.-M., C.-A. Roulet, R. Borchiellini (Eds), 1996: Annex 23 Final Report - Evaluation of COMIS," Swiss Federal Institute of Technology, Lausanne.
4. Orme, M, 1999. Applicable Models for Air Infiltration and Ventilation Calculations. Air Infiltration and Ventilation Centre, Coventry, UK.
5. Dorer V and Weber A. Air, contaminant transport models: integration and application. Energy and Buildings, 30, pp97-104, 1999.

Appendix 1 Participating Organisations

Country	Organisation
Belgium	**Belgian Building Research Institute (BBRI)** A Bossaer, D Ducarne, B Geerinckx, P Wouters
Canada	**Center for Building Studies, University of Concordia, Montreal** F Haghihat
France	**Centre de Thermique, National Institute of Applied Sciences (INSA), Lyon** F Allard, F Amara
Greece	**Laboratory of Meteorology, University of Athens, Athens** E Dascalaki, M Santamouris
Italy	**Dipartimento di Energetica, Politecnico di Torino, Torino** R Borchiellini, M Grosso
Japan	**Tohuku University, Sendai** H Yoshino, Y Zhao **Department of Architecture, Miyagi National College of Technology, Miyagi** Y Utsumi
Netherlands	**TNO Building and Construction Research, Delft** H Phaff
Switzerland	**Institute of Building Technology, Federal Institute of Technology (LESO), Lausanne** J-M Fürbringer, C-A Roulet **Federal Laboratory for Materials, Dübendorf** V Dorer, F Huck, A Weber
USA	**Lawrence Berkeley National Laboratory (LBNL), Berkeley, California** H Feustel, B V Smith
IEA	**Air Infiltration and Ventilation Centre (AIVC), Coventry, UK** M Orme

Appendix 2 Principal Annex 23 Reports

1. Feustel, H.E. and A. Raynor-Hoosen (Eds), 1990: Fundamentals of the Multizone Air Flow Model -COMIS. AIVC Technical Note 29, Air Infiltration and Ventilation Centre, Coventry, UK.
2. Fürbringer, J.-M., C.-A. Roulet, R. Borchiellini (Eds), 1996: Annex 23 Final Report - Evaluation of COMIS," Swiss Federal Institute of Technology, Lausanne.
3. Fürbringer, J.-M., C.-A. Roulet, R. Borchiellini (Eds), 1996: Annex 23 Final Report - Evaluation of COMIS Appendices," Swiss Federal Institute of Technology, Lausanne.
4. Keilholz W., 1997: COMIS 3.0 with IISiBat™ - User Manual.CSTB, Sophia Antipolis.
5. Keilholz W., 1997: COMIS 3.0 with IISiBat™ - Tutorial. CSTB, Sophia Antipolis.
6. Feustel, H.E., and B.V. Smith (Editors), 1998. "COMIS 3.0 User's Guide,"Lawrence Berkeley National Laboratory, Berkeley, USA.

Appendix 3 Other COMIS related publications

1. Allard F., and Y. Utsumi, 1992. "Air Flow through Large Openings ," Energy and Buildings, 18, 133-145
2. Borchiellini R., Fürbringer J., 1999: "An evaluation exercise of a multizone air flow model." Energy and Buildings, Vol 30, No 1, 35-51.
3. Dascalaki, E., Santamouris M., Bruant M., Balaras C. A., Bossaer A., Ducarme D., Wouters P., 1999: "Modeling Large Openings with COMIS. Energy and Buildings." Vol. 30, No 1, 105-115.
4. Dorer, V., F. Huck F., Weber A., 1995: "COMERL PC-based User Interface for the Multizone Air Flow and Contaminant Transport Model COMIS." EMPA Dübendorf
5. Dorer V, Weber A., 1997: "COMVEN 3.0 Programmer's Guide," EMPA Dübendorf,
6. Feustel H.E., F. Allard, V.B. Dorer, M. Grosso, M. Herrlin, M. Liu, J.C. Phaff, Y. Utsumi, and H. Yoshino 1989: The COMIS Infiltration Model, in Proceedings, "Building Simulation '89", International Building Performance Simulation Association, Vancouver.
7. Feustel H.E. and J. Dieris, 1992. "A Survey on Air Flow Models for Multizone Structures," Energy and Buildings, Vol. 18
8. Feustel H.E., 1996: "Annex 23 - An International Effort in Multizone Air Flow Modeling." Proceedings, ROOMVENT '96, Yokohama
9. Feustel, H. E., 1999: "COMIS - An international multizone air flow and contaminant model." Energy and Buildings, Vol 30, No 1, 3-18. [Also LBNL Report 42182. Lawrence Berkeley National Laboratory, Berkeley, USA.]
10. Fürbringer J-M., Dorer V., 1993. "Air flow simulation of the LESO building including comparison with measurements and sensitivity analysis." Proc. Indoor Air '93, Finland, 1993.
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12. Fürbringer J-M., 1994. "Comparison of the accuracy of detailed and simple models of air infiltration." Proc. 15th AIVC Conference, Buxton, England.
13. Fürbringer J-M., Roulet C-A., Borchiellini R., 1999: "An overview of the evaluation activities of IEA ECBCS Annex 23." Energy and Buildings, Vol 30, No 1, 19-33.
14. Fürbringer J-M., Roulet C-A., 1999: "Confidence in simulation results: put a sensitivity analysis module in your model." The IEA-ECBCS Annex 23 experience of model evaluation. Energy and Buildings, Vol 30, No 1, 61-71.
15. Geerinckx B., Wouters, P., 1992. "Empirical methodology to validate energy related simulation programs." Proc. International Symposium on air Flow in Multozone Buildings, Technical University of Budapest, Hungary, September 8, 1992.
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19. Liddament, M.W., 1996. "Two Air Flow Studies Completed," Air Infiltration Review, Vol. 17, No. 4, Air Infiltration and Ventilation Centre, Coventry, U.K.

20. Morgner, S., 1997. "XCOMIS -- Development of a Graphical User Interface for the Multizone Air Flow and Contaminant Transport Simulation Model COMIS," Masters Thesis, Georg-Simon-Ohm Fachhochschule, Nuremberg

21. Pelletret, R., 1996. "IISiBat - A User Interface for Multizone Modelling (Annex 23)," News, International Energy Agency, Energy Conservation in Buildings and Community Systems Programme

22. Pelletret, R., S. Soubra, W. Keilholz, A. Melouk, 1992. "Annex 23 - Multizone Air Flow and Pollutant Transport Modeling, Subtask 1: The Multizone Air Flow and Pollutant Transport Model developed in the Frame of the IEA Annex 23," in Proceedings International Symposium - Air Flow in Multizone Structures, Vol. 1, Budapest

23. Phaff, J.C., 1996. "Final Report Annex 23 - Multizone Ventilation Models: Participation of TNO Bouw. Examples," TNO Report 96-BBI-R1086

24. Roulet C-A., Fürbringer J-M., Cretton P., 1999: "The influence of the user on the results of multizone air flow simulations with COMIS." Energy and Buildings, Vol 30, No 1, 73-86.

25. van der Mass, K., 1992. "IEA-ECB Annex 20 Technical Report: Air Flow through Large Openings in Buildings," International Energy Agency

Appendix 4 COMIS related web sites

Lawrence Berkeley National Laboratory	http://www-epb.lbl.gov/comis/
	Contains sections on the background, historical development, capabilities of COMIS, together with links and addresses from which COMIS interfaces and publications may be obtained.
CSTB	http://evl.cstb.fr/francais/projets/IISiBaT/COMIS/comis1
	Contains details of COMIS with IISiBaT interface and coupling of COMIS with TRNSYS. IISiBaT/COMIS can be downloaded. Information is given on past and future IISiBaT events. *Hosts the COMIS users mailing list (366 subscribers at October 1999).*
EMPA	http://www.empa.ch/englisch/erg/comis/comis.htm
	Contains a brief summary of the history of Annex 23 and COMIS, together with information on interfaces, including COMERL, and the coupling of COMIS with the TRNSYS simulation code. Provides links from which COMIS may be downloaded or ordered. Also includes pages giving two examples of the application of COMIS to building simulation problems.
Swiss Federal Institute of Technology, Lausanne LESO-PB	http://lesowww.epfl.ch/anglais/Leso_a_frame_rec.htm
	Contains a brief summary of COMIS and IEA Annex 23 together with an introduction to the procedures for evaluating COMIS. Includes e-mail addresses of principal national representatives of IEA Annex 23 participants.
IEA Energy in Buildings and Community Systems	http://www.ecbcs.org/annex23.html
	Contains a brief summary of Annex 23.
Air Infiltration and Ventilation Centre	http://www.aivc.org
	Contains information on work of the AIVC and generally on all matters dealing with ventilation and air movement within buildings.

Appendix 5 Sources of information on models used for comparison

AIDA	**Contact organisation:Air Infiltration and Ventilation Centre, Coventry, UK. http://www.aivc.org**
	Liddament, M. 'AIDA - An Infiltration Development Algorithm' Air Infiltration Review, Vol 11, No 1, December 1989.
AIRNET	**Contact organisation: National Institute of Standards and Technology, Gaithersburg, USA.**
	Walton, G N. 'AIRNET - A Computer Program for Building Airflow Network Modelling.' U.S. Department of Commerce, National Institute of Standards and Technology, Report NISTIR 89-4072. 1989.
ASCOS	
	Klote, J H and Milke J A. 'Design of Smoke Management Systems.' American Society of Heating, Refrigerating and Air-Conditioning Engineers. 1992.
BREEZE	**Contact organisation:Building Research Establishment, Watford, UK.**
	'BREEZE 6.0f User Manual' Building Research Establishment, Watford, UK. 1994.
BREVENT	**Contact organisation:Building Research Establishment, Watford, UK.**
	Warren, P R and Webb, B C. 'The Relationship Between Tracer Gas and pressurisation Techniques in Dwellings.' Proceedings of First AIVC Conference, Bracknell, UK, 1980.
CBSAIR	**Contact organisation: Centre for Building Studies, University of Concordia, Montreal, Canada.**
	Haghihat, F and Rao, J. 'Computer-Aided Building Ventilation System Design - A System Theoretic Approach.' Energy and Buildings, Vol 1, pp147-155, 1991. *Rao, J and Haghihat, F. 'A Procedure for Sensitivity Analysis of Airflow in Multizone Buildings.' Building Environment, Vol 28, pp 53-62, 1993.*
CONTAM	**Contact organisation: National Institute of Standards and Technology, Gaithersburg, USA.**
	Walton, G N. 'CONTAM93 User Manual.' U.S. Department of Commerce, National Institute of Standards and Technology, Report NISTIR 94-5385, 1994. *Walton, G N. et al. 'Application of Multizone airflow and Contaminant Dispersal Model to Indoor Air Quality in Residential Buildings.' Proceedings of 15th AIVC Conference, Buxton, UK. 1994.*
ESP	
	Hensen, J L M. 'On the Thermal Interaction of Building Structure and Heating and Ventilating System.' Ph.D. Thesis, University of Eindhoven, 1991. *Clarke, J A. 'Energy Simulation in Building Design' Adam Hilger Ltd., Bristol and Boston. 1985.*
LBL Model	**Contact organisation: Lawrence Berkeley National Laboratory, Berkeley, California, USA.**
	Sherman, M and Grimsrud, D T. 'Infiltration-Pressurisation Correlation: Simplified Physical Modelling. ASHRAE Semi-Annual Meeting, Denver. June 1980.
MZAP	**Contact organisation: National Institute of Standards and Technology, Gaithersburg, USA.**

	Walton, G N. 'A Computer algorithm for Estimating Infiltration and Inter-Room Air Flows'. U.S. Department of Commerce, National Institute of Standards and Technology, Report NISTIR 83-2635, 1983.
NORMA	**Contact organisation: Laboratory of Meteorology, University of Athens, Greece.**
	Santamouris, M. 'Norma Manual.' *University of Athens, Greece.*
PASSPORT-AIR	**Contact organisation: Laboratory of Meteorology, University of Athens, Greece.**
	Descalaski, E and Santamouris, M. (eds.) 'PASSPORT-AIR Manual'. *PASCOOL Research Programme, CEC DGRD, 1994.*
TURBUL	**Contact organisation: LESO-PB, EPFL, Lausanne, Switzerland.**
	Fürbringer, J-M and Van der Maas, J. 'Suitable Algorithms for Calculating Air Renewal Rate by Pulsating Air Flow Through a Single Large Opening.' Building and Environment, 1995.
VENCON	**Contact organisation: TNO, Delft, Netherlands.**

The International Energy Agency (IEA) Energy Conservation in Buildings and Community Systems Programme (ECBCS)

The International Energy (IEA) was established as an autonomous body within the Organisation for Economic Co-operation and Development (OECD) in 1974, with the purpose of strengthening co-operation in the vital area of energy policy. As one element of this programme, member countries take part in various energy research, development and demonstration activities. The Energy Conservation in Buildings and Community Systems Programme has sponsored various research annexes associated with energy prediction, monitoring and energy efficiency measures in both new and existing buildings. The results have provided much valuable information about the state of the art of building analysis and have led to further IEA sponsored research.